

Review of Software for Gold Coast City Council's Stormwater Flood Mapping Projects

This document is from a review in 2008 of modelling systems to meet Gold Coast City Council's stormwater flood mapping needs. For further information, please contact Paul Ollett at POLLETT@goldcoast.qld.gov.au.

Summary

The following report summarises the results of the Stormwater Floodmapping Pilot Study. As discussed it is recommended that the TUFLOW software is purchased for the purposes of 2-dimensional stormwater floodmapping for the catchment-wide Part 1 Stormwater Drainage Studies.

Generally, TUFLOW was found to be more stable, faster, much less expensive, and had many more useful modelling features than Mike Flood. The main interface to TUFLOW is Mapinfo which makes it easier to build models (utilising the power of GIS), and staff will also feel more comfortable with the software as they are already familiar with Mapinfo. TUFLOW also has some advantages over Mike 11 (for example, much more flexibility in assigning structure losses), and for some open channel and floodplain design projects (for example, bridge and cross-road drainage design) we also see benefits in using TUFLOW.

Brisbane City Council interestingly also carried out an evaluation of TUFLOW and Mike Flood at the time of this Pilot Study, and came to the same conclusions. They have now adopted TUFLOW for their large scale 2-dimensional study of the Brisbane River.

An implementation plan is included in the following document. It is proposed to use TUFLOW for catchment-wide floodmapping studies to identify hot spots and problem areas (SDS Part 1), then Mike Urban for assessment of options and design-based modelling (SDS Parts 2 – 3). The implementation plan was proven in the Pilot Study to be efficient and trouble free.

Approval to purchase TUFLOW against EAP Part 1 Stormwater Drainage Studies has been given. PET has also given positive feedback on the TUFLOW results and floodmaps, confirming that this information is much more suitable to them than that produced by the previous MDS studies.

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ABBREVIATIONS

1D	1 Dimensional
2D	2 Dimensional
ALS	Airborne Laser Survey
DEM	Digital Elevation Model (also referred to as a grid or DTM)
GCCC	Gold Coast City Council
GIS	Geographic Information System (for example, Easymaps is based on GIS)
MDS	Master Drainage Scheme
M21	Mike 21
MF	Mike Flood
MU	Mike Urban
PET	Planning, Environment and Transport Directorate, GCCC
SDS Part 1	Stormwater Drainage Study. Part 1: Needs Assessment
SIS	Spatial Information Services Group, GCCC
TIN	Triangular Irregular Network

1 SCOPE OF STUDY

Previous MDS investigations have not produced the information needed by Planning, Environment and Transport (PET) to assist with Development Applications. Furthermore, previous MDS investigations using either Mike Storm or Mike Urban required the manual delineation and assessment of physical parameters of hundreds of sub-catchments per study, and also the delineation of the 1D overland flowpath network. This is an extremely laborious and expensive process, and a more efficient technique was sought to reduce cost of producing the studies (now referred to as the Stormwater Drainage Study (SDS) Part 1).

The purpose of the following Pilot Study is to evaluate the floodmapping ability of some mainstream software packages (see Section 2). The packages were evaluated in terms of accuracy of overland flowpath mapping, ability to simulate underground pipe network, quality of results and output, integration with existing systems in Council, and time required to setup models.

Testing and comparisons between the technologies was carried out on an urban subcatchment in Palm Beach (see Section 3). The comparative results between the selected packages are discussed (see Section 4), and a more detailed discussion on the differences between Mike Flood and TUFLOW is made (see Section 5).

The Pilot Study was carried out in conjunction with PET (Implementation & Assessment group) to ensure the best technology was selected to provide the most suitable type of output. An implementation plan (see Section 6) has been produced which outlines how the software packages would be implemented within Technical Services;

2 SOFTWARE SELECTION

2.1 *1D Technology*

In a 1D package such as Mike Urban, the underground pipe network is established from the stormwater asset GIS database. The overland flow network is defined manually by the user. 1D means that the direction of flow is controlled purely by the direction of the link or branch, and flow velocity is uniform at a given point both in the vertical and horizontal. In order to produce floodmaps, a flood surface is created by interpolating between flood levels at stormwater result nodes throughout the model.

2.2 *1D Software Selection*

As Technical Services already uses the Mike Urban software, this package was used as the choice for the 1D technology. In terms of producing floodmaps from the Mike Urban results, two options were initially considered:

- Vertical Mapper is the 3D spatial analyst module for Mapinfo GIS. In order to produce flood maps showing overland flow paths, maximum flood levels are taken from the Mike Urban result file, then Vertical Mapper is used to create a flood surface. The ground surface (DEM) is then subtracted from the flood surface in order to create a flood depth inundation map.
- Mike11 GIS is a product by DHI which has now been used for some 10 years to produce floodmaps from the 1D Mike11 (open channel) and Mike Urban (pipe network) softwares. Using Mike11 GIS to produce floodmaps is a very similar process to using Vertical Mapper, however it does have additional features for creating breaklines between river branches or pipelines, masking out pockets of erroneous flooding, and general floodmap cleaning.

DHI however no longer supports the Mike Urban extension to Mike 11 GIS, and therefore it can not be used to produce overland inundation maps. The selected combination for the 1D technology was Mike Urban and Vertical Mapper.

2.3 *Coupled 1D-2D Technology*

In a Coupled 1D-2D model the above ground overland network is represented by a 2D grid of land values. Flood routing equations are then applied at each cell in order to rout flow in both the X (Easting) and Y (Northing) directions. The overland flow network does not require manual delineation as with the 1D technology, but is inherent in the 2D DEM. Floodmaps and overland flow paths are produced as a direct output from the 2D model, and no post processing is required to produce floodmaps.

2.4 Coupled 1D-2D Software Selection

Four packages were initially considered. These were Mike Flood (by the Danish Hydraulic Institute in Denmark), TUFLOW (by WBM Oceanics in Brisbane), SOBEK (by Delft Hydraulics Software in the Netherlands), and Infoworks 2D (by Wallingford Software in the UK).

In 2D modelling the scale of the 2D grid cells can be such that they may not adequately simulate sub-scale turbulence, which is usually evident around channel flow, around structures, and in and water bodies such as estuaries. Sub-scale turbulence is accounted for by a subscale turbulence model. These models have an eddy viscosity term typically utilising a Velocity based or Smagorinsky formulation. As this sub-scale model is considered important, and as the SOBEK and Infoworks 2D softwares do not apply a sub-scale turbulence model, only the TUFLOW and Mike Flood softwares were considered.

2.5 Raster Routing Technology

Raster routing does not directly produce floodmaps, but shows the location of potential overland flow paths. A DEM is produced of the study area, and a series of start points are selected on the DEM. The algorithm then searches the adjacent cells to the start point, finds the lowest adjacent cell, then draws a line segment between the cell centres. The process is iterated until a final line is produced showing the steepest path from the initial start point to the lowest point in the catchment, and it is presumed that water would flow along this path.

2.6 Raster Routing Software Selection

Mike Basin is produced by DHI, and has already been used to try to determine flow paths across the entire Gold Coast City. Mike Basin is based on the ArcGIS software package. Catchment SIM is a local Australian package, and is available on the Catchment Modelling Toolkit website (www.toolkit.net.au). The software is already owned by Technical Services.

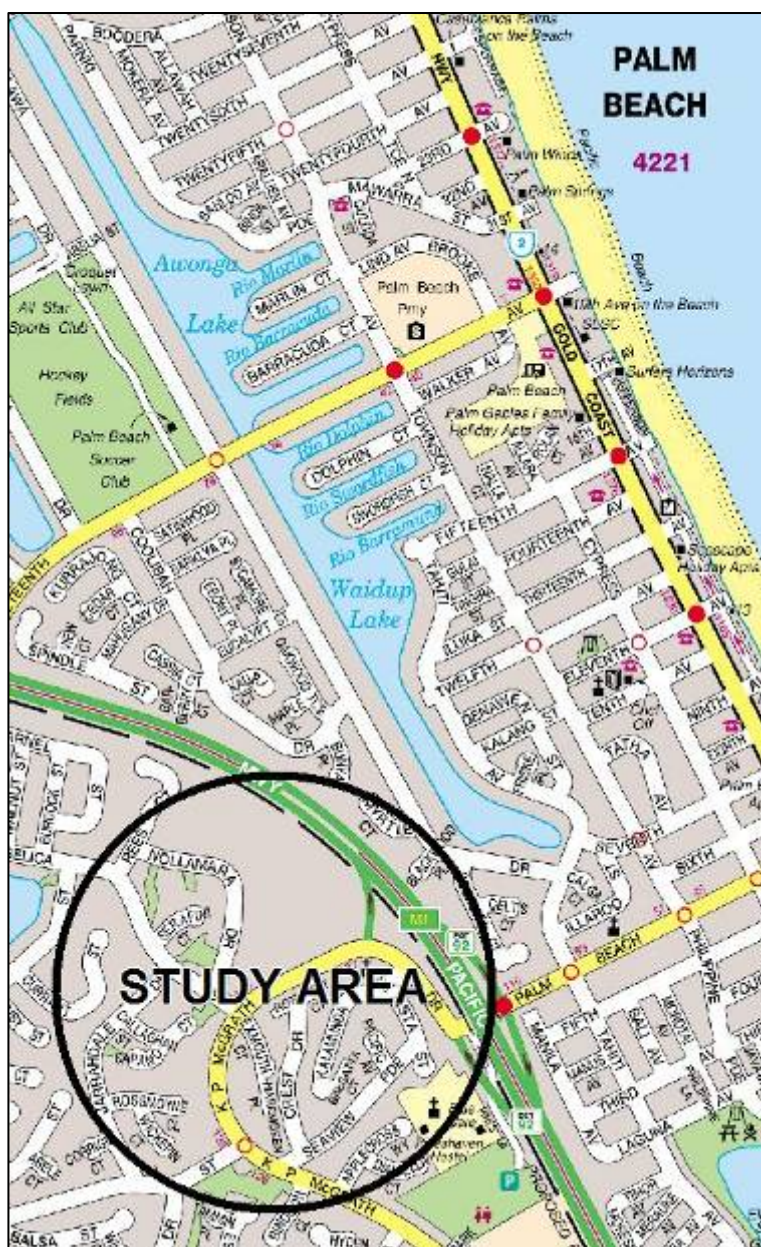
2.7 Summary of Software Selection

The following technologies and software packages were evaluated:

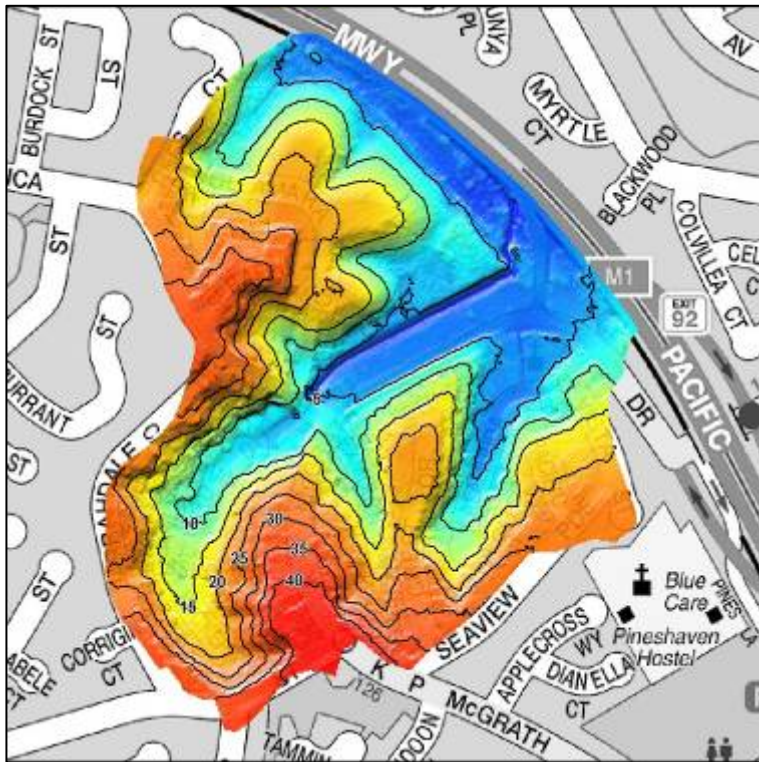
Technology	1D	Coupled 1D/2D	Raster Routing
Software	Mike Urban (& Vertical Mapper)	Mike Flood	Mike Basin
		TUFLOW	

3 STUDY AREA

In order to test the ability and versatility of the softwares, an urban catchment which comprises piped network, open channel, and a large fraction of impervious cover was chosen in Palm Beach. The study area was 0.75 km², the highest point in the catchment was 40m AHD, and the lowest point was 0.5m AHD.



LOCATION MAP



DEM (2007)



Aerial Photo (2005)

4 COMPARISON OF RESULTS

4.1 *1D Technology*

1D models have the advantage that they run quickly. However the main disadvantages are the quality of flood hazard output, and also the accuracy of the model is based purely on the experience and judgement of the modeller in defining catchments and overland flow paths.

There are also inherent errors in producing floodmaps based on 1D results. In order to generate a flood map, points must be extracted from the model results which contain the maximum elevation of flooding. A flood surface is then generated by interpolation between these points. The primary problem here is that the interpolation routine interpolates a surface between all points, even though groups of points are hydraulically independent.

For example, a flood surface will be generated between two stormwater network branches which are completely independent and unrelated, therefore the flood surface will not be correct.

Also, where there are low points in the DEM between independent branches, a flood surface will be created where there is not necessarily any flooding.

Flood mapping based on 1D model results has long been a problematic practice experienced in the water industry. Only about 50% to 70% of the actual floodmap has reasonable accuracy. Utilising floodmaps based on this approach has a large amount of risk and therefore should not be practised.

4.2 *Coupled 1D-2D Technology*

The main disadvantages are that model runtimes are quite long (often 2 to 6 hours), and 2D models generally can not include hydraulic structures in the scheme, for example, a culvert passing under a road. However, the results of the 1D-2D coupled technology is far superior to that of just 1D models. Also, as rainfall is applied directly to a DEM, the time to build a model is drastically reduced, as manual delineation of sub-catchment boundaries, sub-catchment slope area & length, and overland flow path routes, is no longer required. In the course of the study 1D-2D coupled models were built in TUFLOW and Mike Flood. TUFLOW was found to be the better package for many reasons.

4.3 Raster Routing Technology

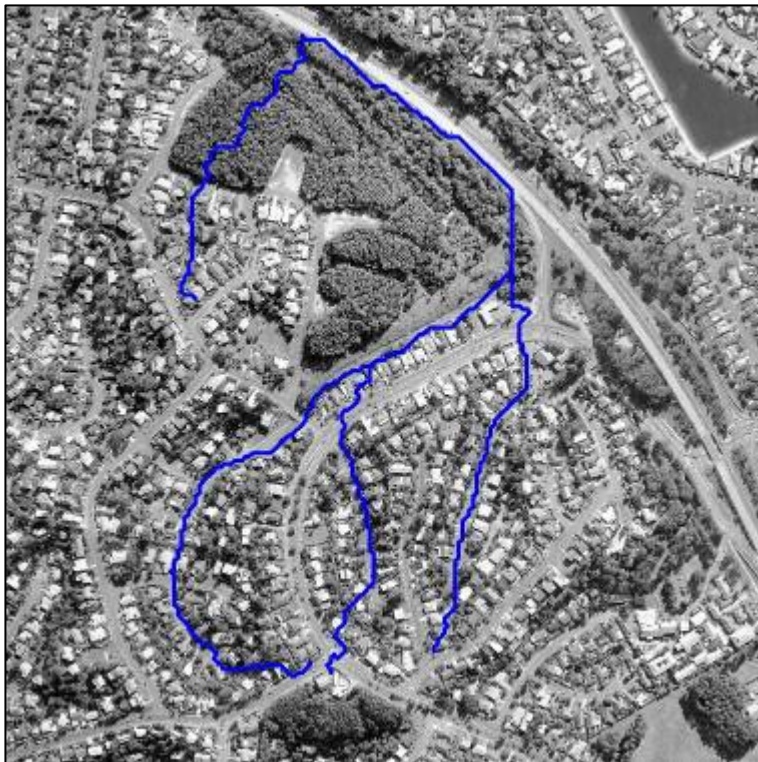
Raster Routing is a useful application for determining channel flow paths in relatively steep terrain. However no information such as flood depth, velocity or hazard is produced, and the application is therefore limited. Raster routing also has inherent problems, for example:

- Inability to simulate flow diversion of waterways;
- Inability to simulate the affect of the underground pipe network;
- Very inaccurate in flat terrain;
- Flow paths are derived by the DEM surface, however in hydraulics it is the flood surface which governs routing;
- Flow paths can terminate early of trapped in local depressions in the DEM.

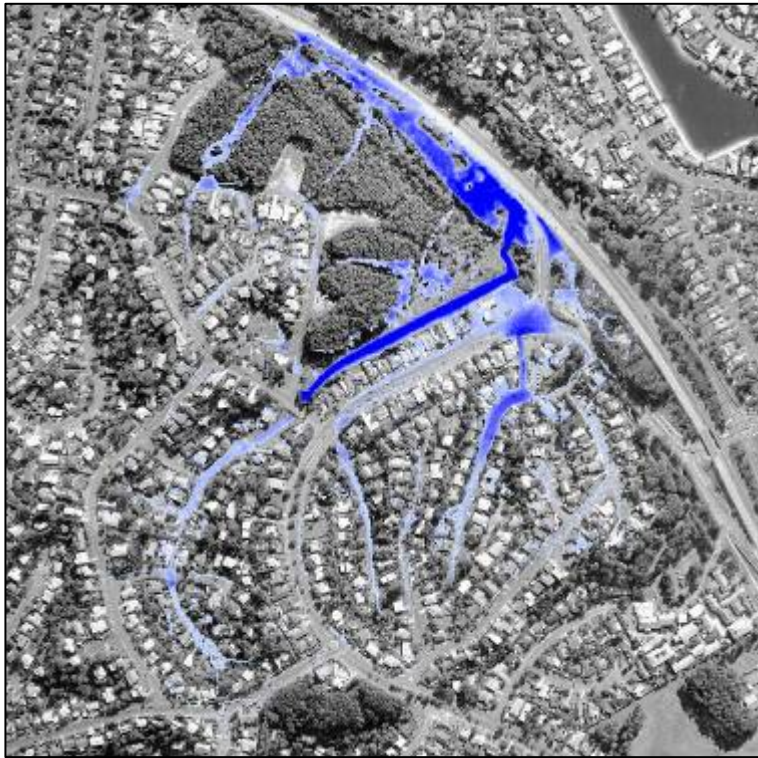
While raster-routing does have its place, it is not suitable as a stormwater flood mapping application. Incidentally, raster routing was carried out for the Gold Coast in 2006 using the Mike Basin software. There were many identified mistakes and inaccuracies in the output, which led to the results being discarded.



1D Technology: Mike Urban & Vertical Mapper



Raster Routing Technology: Mike Basin



Coupled 1D-2D Technology: TUFLOW



Coupled 1D-2D Technology: Mike Flood

5 TUFLOW AND MIKE FLOOD COMPARISON

5.1 **Cost**

TUFLOW presently costs \$9,900 to purchase, and additional licenses are heavily discounted. Mike Flood presently costs \$60,000 for linkage between Mike Urban (pipe network) and Mike 21, and \$90,000 for additional linkage with Mike11 (open channels). PET Waterways & Flood Management already owns Mike Flood, therefore an additional license for Technical Services would be half price at \$45,000. If additional TUFLOW licenses are needed (it is anticipated that Technical Services may eventually need to acquire 2 to 3 licenses), TUFLOW will be the least expensive option.

Developers and consultants involved in stormwater development can potentially make use of stormwater models developed by Technical Services. However, at \$60,000 to \$90,000 a license it is highly unlikely consultants or developers will be able to make use of Mike Flood stormwater models. Developing models in TUFLOW will make them more widely available outside Council, thus preventing model duplication and also reducing costs for others.

5.2 **Software Keys**

Both TUFLOW and Mike Flood require software keys. Mike Flood requires the software key to be used at all times. However TUFLOW only requires the software key to run a simulation. This means that several users can be in the process of developing TUFLOW models without taking up valuable simulation runtime. This feature is so convenient it can not be emphasised enough – it is almost equivalent to having a second licensed copy of the software.

5.3 **Hydrology**

The models will be used by applying rainfall directly to the 2 dimensional grid in order to generate runoff. Manning's 'n' varies with stage, depending on whether flow is overland sheet flow (typically high Manning's values), or channel flow (typically low Manning's values). TUFLOW has the ability to vary Manning's values with depth during simulation, which is an excellent feature for correct simulation of runoff. Mike Flood only uses a fixed Manning's value. TUFLOW can also subtract initial losses and continuing losses from rainfall data. In Mike Flood, these losses must be subtracted manually from the rainfall time series.

Mike 21 requires a grid of Manning's values to vary roughness at different locations on the DEM. TUFLOW can directly use a MapInfo layer of landuse to assign roughness values, which makes the process of setting up the model much easier. Council already has MapInfo GIS layers of land use for the Gold Coast.

5.4 Flow Regimes And Form Losses

Both the 1D and 2D components of TUFLOW can handle subcritical flow and super critical flow regimes. This is particularly important for some of the concrete lined canals in the Gold Coast (for example, Harbour Town Canal) where flow can approach critical flow. Mike Flood's 1D open channel component Mike11 is based on the St Venant equations, and can not accurately solve flows approaching critical.

TUFLOW is able to vary energy loss factors with stage. For example, where a channel passes through a culvert and the transition is smooth (clear span), no form loss will be experienced. However, when the water surface reaches the culvert obvert or bridge soffit, a form loss is generated, elevating flood levels upstream. TUFLOW can apply an energy loss factor from the soffit or obvert of a structure, however Mike11 will apply this energy loss factor over the entire depth of the structure.

TUFLOW is a better design package particularly for open channels and structures, and is more akin to packages such as HEC-RAS than Mike11. Mike11 definitely has its strengths, however a package that is more tailored for the design of open channels and structures is also needed in Technical Services.

TUFLOW can output 2D plots of energy level on the floodplain. With road and culvert crossing design, the modeller can check to make sure energy levels are maintained as per existing conditions, and that energy is not shifted downstream or reconcentrated potentially leading to erosion and channel migration. Being able to plot energy in the 2D is another useful feature for the design engineer.

TUFLOW may also introduce cell side walls and cell lids in the 2D domain, with associated energy loss factors. This is a particularly useful feature to simulate fine scale structures in the 2D domain, for example, flow blockages at buildings, fences, stopbanks, culverts and bridges. Setting up equivalent structures in Mike Flood is very time consuming.

5.5 Boundaries & Linkages

Mike Flood boundaries are quite difficult to set up, and usually require digging out of cells and much manipulation. Boundaries may only be set up in limited orientations and locations. TUFLOW boundaries can be set up anywhere and any orientation with no manipulation of cells. Boundaries are simply established through drawing in the location in MapInfo.

TUFLOW can utilise the power of MapInfo SQL queries for sorting and applying changes to sets of linkages. In Mike Flood, there is no sorting functionality for linkages, and any changes must be made manually.

5.6 DEM Editing

TUFLOW can adjust its DEM by using simple GIS functionality. For example, if an embankment is desired across the DEM, then one just needs to draw the embankment in GIS and enter the node elevations. New DEM updates can be stacked in TUFLOW, so that the last entry is stamped on to the previous, thus building up the DEM. The DEM can be easily re-adjusted by altering or adding new DEM layers. TUFLOW can read a number of DEM and TIN formats including 12D format. This feature is also very good from a quality assurance point of view, as DEM edits are clearly visible, and notes may be written in the GIS tables as a record.

Mike 21 DEM edits are a very tedious and manual process. Essentially the grid is opened and cells are selected manually for editing. Once saved, there is no record of edits carried out. The user must therefore save a series of grids, however the editing documentation process is poor.

5.7 Simulations

TUFLOW is commonly reported in the modelling industry to be much more stable and robust than Mike Flood.

Stability problems were experienced with Mike Flood during this Pilot Study. DHI suggested saving the result file at every time step to see where instabilities start to occur, then try manually smoothing or digging out the bathymetry at this location. Saving at every time step produced result files some 70 GB in size, and scanning through hundreds of individual time steps was exceptionally tedious. This advice was impracticable and many hours were wasted trying to resolve Mike Flood instabilities. Mike Flood initially crashed a lot at the 0.25s time step, and the author had to deepen and smoothen quite a few grid cells (and surrounding cells) which were coupled to Mike Urban outlets. Often the Mike Flood model would start producing blank output part way through the run (supposedly because of an instability crash), however the model would run until the end of the simulation and no error messages were produced.

The TUFLOW model ran in 81.5 minutes, and Mike Flood in 135.2 minutes. The real flood duration was 1.1 hrs, with 126,078 2m wet cells. The TUFLOW time step was 0.5 seconds, and the Mike Flood time step was 0.25s which is typical for a 2m grid. Mike Flood would crash at the 0.5s time step. The runs were carried out on a laptop with the following specs: Brand HP; CPU Intel Core T7200 @ 2.00 GHz; Ram 2GB. TUFLOW has excellent error reporting, and writes error messages out to a GIS table which may be viewed spatially. Mike Flood error messages are generally quite poor and uninformative – usually all that is given is the approximate location of a blow up.

5.8 Model Outputs

TUFLOW has a very wide range of output options compared with Mike Flood. For example, *animated* and maximum value map output includes flood level, flood level difference (useful for directly evaluating improvements), velocity (& vectors), depth, unit flow, energy level, Froude number, flood hazard (5 methods), flow regime, Manning's 'n', and eddy viscosity.

Mike Flood does have a flood hazard post processing tool which can be adequate. Generally the option for output are far less than TUFLOW, for example, all that is available is water depth and surface, x-velocity, y-velocity, x-shear stress and y-shear stress. Velocity vectors can be produced through Mike Flood's Plot Composer, however this information is not available in a GIS environment and could not be used easily by other groups in Council.

Mike Flood df2s result files are very large in nature and are difficult to work with. They require constant zipping and unzipping. TUFLOW 2D results are stored in a binary file which is much more compact, but also very accessible using post processing tools).

5.9 Software Support And Training

Currently in Queensland no DHI staff have reasonable experience in the Mike 21 Mike Urban coupling. This is very frustrating, and most enquiries to date have had to go to the Denmark office for feedback. WBM's experience in urban flood modelling is far more extensive than DHI, and this kind of technical support is very important. WBM are also a multi-disciplined engineering firm and can offer engineering, planning and management advice. This broader experience base at WBM will enhance the support and application of the TUFLOW software at Council.

In the past, Technical Services has had to pay DHI to improve the Mike Storm and Mike Urban packages to give them better stormwater functionality. Given Technical Services has provided all this stormwater conceptual input into DHI software over the years, it is disappointing to see that Mike Flood is so far behind TUFLOW in regards to stormwater simulation, especially considering the premium cost of Mike Flood.

WBM currently has three senior TUFLOW developers, and three intermediate developers. Therefore there is a solid core of developers available should one of the senior developers leave WBM for example. DHI is a large organisation and has been producing hydraulic software for many years, and it is likely they will always be able to do so. From the author's experience working at DHI in Australia, and general contacts in the modelling industry, it seems quite clear that TUFLOW has a larger user base for 2D stormwater modelling.

The 1D-2D Mike Urban coupling was only released in the Mike Flood interface in the 2008 version of DHI software. Looking at how Mike Flood (Mike11 1D coupling) and Mike Urban have developed over the years, it generally takes DHI about 3 to 4 years before a package becomes highly viable, user friendly and bug free. Given this track record, and that Mike Flood (Urban coupling) is so far behind TUFLOW, the author believes it will take DHI up to 5 years to catch up, provided DHI puts in a determined effort to improve Mike Flood.

TUFLOW has a dedicated user group and discussion forum managed through the TUFLOW website. Regular TUFLOW workshops are held to discuss future software releases and issues. The TUFLOW tutorials are very thorough and easy to follow, allowing existing Mapinfo users to learn the software with minimal training from WBM. Mike products are typically more difficult to use, and the tutorials and user manuals are sparse and not well written. Users of DHI software typically need to attend at least one full training course (preferably a basic and advanced course for each DHI product) to become proficient modellers.

5.10 Software Improvements

When commencing the Pilot Study Mike Flood 2008 Service Pack 1 was initially used. However it soon became evident that several bugs or acute shortcomings were present in the Mike Urban to Mike 21 linkages. As a result the study was delayed until DHI could remediate these errors for the Service Pack 2 release.

Some new linkages were also suggested, and DHI's response was that they wanted to put more work into making the current linkages stable rather than develop new ones. Furthermore, Council was advised verbally that it was unlikely any new feature releases could be requested for 2009, as these had already been decided.

As the study progressed, it became evident that the existing linkages in Mike Flood were inadequate for stormwater applications.

WBM are extremely attentive to software users, especially as it is a locally produced package. Many of the features detailed in TUFLOW above have been the direct result of feedback from users.

The United States Federal Highway Administration (US FHWA) recently released a new methodology for estimating energy losses for different manhole configurations. This method is referred to as the Kilgore method and is detailed in the US FHWA Urban Drainage Manual (2008). This method is based on state-of-the-art laboratory testing, including full-scale and scaled physical modelling, and also Computational Fluid Dynamics modelling. Most other manhole loss methods (for example, QUDM 2007 and DHI's method based on Engelund & Pedersen, 1978) are generally 30 to 50 years old. WBM would look at implementing the Kilgore manhole loss method into TUFLOW as it would be seen to benefit other users.

6 TUFLOW IMPLEMENTATION STRATEGY

6.1 **Technical Services Staff Training**

Initially TUFLOW modelling will be carried out on two SDS Part 1 studies for a period of 6 months, in order to learn the intricacies of the software, and establish modelling procedures, as was carried out with the successful implementation of the Mike Urban software in Technical Services earlier this year.

The amount of TUFLOW modelling in the office for a given year will be limited, and it is not warranted training all stormwater staff in the use of the software. A core team of three people will be trained at 6 month intervals. Then, if one person leaves, a new staff member can be trained.

6.2 **TUFLOW AND MIKE URBAN**

Only catchment-wide SDS Part 1 studies will be carried out in TUFLOW. SDS Studies which are more design orientated and small in area should be carried out in Mike Urban. Essentially TUFLOW will be the choice of software for fine scale high quality floodmapping, and Mike Urban will be the choice of software for assessment of stormwater design and improvements options to specific problem areas.

Stormwater pipe network will initially be imported into Mike Urban for cleaning and fixing, as staff are used to using Mike Urban for this process. Once the pipe network is scrubbed, it can be exported to mid/mif format and read into TUFLOW directly. *The author has already validated that this process works, as it was used for this Pilot Study.*

Once TUFLOW has run and problem areas or hotspots are identified, then the relevant section of pipe network still in Mike Urban format can then be used for the design work.

As TUFLOW is a 2D model and run times are long, the package is not suitable for pipe network design work where dozens of improvement iterations are required. 1D models are much more suitable to design work due to their very fast run times. There will be a slight double up in areas between the 2D floodmapping and 1D design, however the overall process will be much faster than that previously carried out there the entire above ground overland flow network and catchment delineation was carried out manually in 1D.

6.3 *PET – Implementation & Assessment*

PET has no policy to enforce a certain software package. They have already reviewed many applications using TUFLOW, and is confident that it is a robust package. PET (Implementation & Assessment) would have no problems with TUFLOW being adopted by Technical Services, if it were to influence more development applications using TUFLOW. PET has review the results of this Pilot Study and provided very positive feedback.

6.4 *PET – Waterways & Flood Management*

Usually it is vary rare that Waterways & Flood Management will need to use a model produced by Technical Services, as Technical Services usually model smaller waterways and stormwater networks, and not the larger Council floodplains and rivers. Technical Services generally only use Waterways & Flood Management models to determine tailwater conditions for its stormwater models. The stormwater floodmapping models are for areas above the floodplain, and there is a comfortable separation from the work carried out by Waterways & Flood Management.

6.5 *SIS and City Wide Flood Data*

The City Wide Flood Data is purely a GIS Layer of flood surface and is relatively straight forward to produce. Flood surfaces of the stormwater network above the floodplain can easily be reproduced in the same format as the City Wide Flood Data, and if desired merged together to form one overall maximum layer. Once the first formal TUFLOW study is near its conclusion, consultation will be held with SIS to discuss the incorporation of the stormwater floodmaps with the City Wide Flood Data.

6.6 *GCCC GIS PLATFORM*

TUFLOW's main interface is Mapinfo with the Vertical Mapper module. This is very convenient as Mapinfo is currently GCCC's GIS platform and also Council has a corporate licence to the Vertical Mapper module – that is, all staff can access it. One external Mapinfo and TUFLOW user (WRM Pty) said that they find TUFLOW is an easier package to build models with (compared to Mike Flood) because they were already familiar with Mapinfo GIS. Less work would be involved in IT setting up desk top items, as Mapinfo is already integrated into Council's IT systems.

