SURVEY OF MODEL PROVIDERS

To whom it may concern,

The Manly Hydraulics Laboratory (MHL) is conducting a survey of the providers of numerical models used in analysing hydrological and hydraulic phenomena in Floodplain Applications for the Department of Infrastructure, Planning and Natural Resources (DIPNR). The purpose of this survey is to define the characteristics of these models in a reasonably succinct manner and thus provide a simple matrix of the applicability of each model to particular floodplain modelling issues. A paper detailing the results will be presented to the Floodplain Management Conference in February, 2006.
Your firm is one of those chosen for this survey and MHL would appreciate your finding the time to respond.

The attachment shows the format in which MHL would prefer to receive information regarding your model. We suggest this format so that comparisons may be made among several models surveyed. If the format is really not appropriate for your model, then another format would be acceptable, provided it were similar to the one suggested.

The same survey has been sent to both hydrological and hydraulic model providers because of the overlap between some models. Please answer Not Applicable to questions that do not relate to you particular model.

Following the results of this survey, we intend to seek the views of users. After this, it is likely that we will come back with confirmation of any issues that appear to conflict.

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Suggested Response Format

1 General

1.1 Model Name

TUFLOW

1.2 Model Type (eg. 2D finite difference, etc.)

2D Scheme: ADI (Alternating Direction Implicit) finite difference

1D Scheme: Explicit second-order Runge-Kutta finite difference

1.3 A general description of the model in less than 2 pages (including model structure and schematisation)

General

TUFLOW is a computational engine for carrying out 2D/1D hydrodynamic calculations using the full 1D and 2D equations of continuity and momentum to predict the dynamic patterns of water movement. Its applicability extends from coastal bays and major rivers down to urban environments with extensive pipes networks.

TUFLOW itself is not a graphical user interface (GUI). As of the end of 2005, there will be two new GUI options in addition to the traditional GIS option:

1. Direct use of GIS and other industry standard software for the creation, manipulation and viewing of data. The software needed are:

- A GIS that can import/export .mif/.mid files (MapInfo Interchange Format files). MapInfo is the recommended GIS.
- 3D surface modelling software running inside the GIS (eg. Vertical Mapper) for the creation and interrogation of a DTM, and for importing from TUFLOW 3D surfaces of water levels, depths, hazard, etc.
- SMS (Surfacewater Modelling System) or WaterRIDE for the viewing of results and creation of flow animations.
- A text editor such as UltraEdit. UltraEdit has been colour customised especially for TUFLOW formatted files.
- Spreadsheet software such as Microsoft Excel.

- MIKE 11 and ISIS cross-section editors are sometimes used for managing and editing 1D cross-sections. TUFLOW and ESTRY read the processed cross-section data text formats of these software.

2. SMS TUFLOW Interface. This module of SMS (www.ems-i.com) allows TUFLOW models to be created, managed and viewed entirely within the SMS software.
3. XP-SWMM 2D Module. The new XP-SWMM interface (www.xpsoftware.com) offers a complete environment for developing 2D models based on the TUFLOW 2D engine. TUFLOW has been dynamically linked (codes merged) with the XP-SWMM 1D engine, allowing existing or new XP-SWMM models to have linked 2D domains.

The above combinations of software offer a range of solutions to suit a variety of users within alternative cost structures and working environments.

1D Schematisation

1D domains are created as a network of interconnecting flowpaths (channels). Types of channels offered are open channels, bridges, weirs, box culverts, pipes and gully traps (pits). Channels automatically switch between upstream and downstream controlled flow regimes.

Open channels, bridges and weirs require cross-sections (either one roughly mid-way along each channel or cross-sections at each end of the channel). Bed roughness or land-use categories can vary across the cross-section and in the vertical. Total and effective flow area formulations, and parallel channel analyses to prevent reducing conveyance with height are available. The storage width and effective flow width of a cross-section are both retained in the processed data so that any conveyance above the top of the cross-section is correctly calculated. Bed roughness is modelled using the Manning equation. Losses as a fraction of the dynamic head can be specified to model additional energy losses at, for example, sharp bends.

Structures can handle a wide range of upstream and downstream flow regimes. Contraction and expansion losses can be fixed or automatically adjusted according to the approach and departure velocities. Additional bend losses and pit losses can be included.

Nodes are automatically created at the channel ends or manually specified. The volume or storage of a node can be based on the connecting channels' storage widths, or manually specified as a surface area versus height table where additional storage is required or is to be more accurately defined (eg. from a DTM).

The 1D momentum equation or structure equation is applied to the channels and the continuity equation at the nodes. Flow and velocity over time are output at the channels and water levels at the nodes.

2D Schematisation

2D domains are a grid of square cells. The cells contain information on bed elevations and land-use categories (materials).

Cell elevations are specified not only at the cell centres, but also at the cells' mid-sides and corners, therefore, a 10m grid samples elevations on a 5m spacing. Elevations can be readily modified using 3D breaklines in GIS format to represent crests of levees, roads, railways, fences, etc.

Materials usually are derived from GIS layers of land-use. Each material is assigned a Manning's n or Chezy coefficient. Manning's n values can vary with depth.

The effective flow widths of 2D cells can be modified and "lids" placed on top to model large box culverts and bridge decks. Additional losses as a fraction of the dynamic head can be specified at any cell to model the effects of fine-scale features (eg. bridge piers), or unaccounted losses in the third dimension.

Cells and cell sides can wet and dry with cut off depths less than a millimetre.

Turbulence is approximated using either a constant eddy viscosity or the Smagorinsky formulation. Other terms include the effect of Coriolos, wind stresses, wave radiation stresses, pier forces, etc.

The X and Y 2D momentum equations are applied at the cell sides and the continuity equation at the cell centre. Therefore, flow velocities are computed at the cell mid-sides and water levels at the centre.

Boundaries

A range of flow and water level boundaries are avaiable for 1D and 2D domains. These include time-varying, tidal harmonics, pumps and stage-discharge boundaries.

1D/2D and 2D/2D Linking

Dynamic linking of 1D and 2D domains is highly flexible and effective. 1D open channels can be carved through 2D domains and large 1D pipe networks laid underneath. 2D domains can be nested against/within each other with no restriction on different orientations and cell sizes. There is no limit to the number of 1D and 2D domains within a model.

1.4 Terms of sale or hire

TUFLOW computational engine is available for sale from WBM Pty Ltd (contact tuflow@wbmpl.com.au). Licensees can also hire additional licenses on a monthly basis. For further details see www.tuflow.com.

The 1D TUFLOW engine (ESTRY) is provided free as a separate 1D only executable to TUFLOW licensees.

TUFLOW's 2D capabilities are available through XP-Software as their 2D computational hydraulics engine within a specially designed interface. TUFLOW has been dynamically linked with XP-SWMM allowing users to develop a model made up of XP-SWMM and TUFLOW domains. The new XP-Interface and XP 2D capability is available from the end of 2005. See www.xpsoftware.com.

The SMS (Surfacewater Modelling System) software has been upgraded to offer a specially customised interface for developing TUFLOW 1D/2D models. The SMS software is developed by EMRL (Environmental Modelling Research Laboratory) at Brigham Young University (http://emrl.byu.edu/home.htm) and sold by EMS-I (Environmental Modelling Systems Inc - http://www.ems-i.com). As of November 2005, the interface is currently being beta tested.

1.5 Arrangements for user support

In Australia, training is carried out in-house, usually involving setting up a real-world model by the trainee(s). General one-day workshops are offered during the year to bring TUFLOW users up-to-date on new features, etc. Our approach is to customise the training to best suit the user and meet the user's objectives.

In the UK, more formalised training courses are being conducted by Capita-Symonds using WBM staff, and these may also be offered here in Australia in the future.

On-going support/training is offered on a time and expenses basis. Technical support and minor queries are included in the annual software upgrade fee (see TUFLOW licence agreement on www.tuflow.com). Email queries are sent to tuflow@wbmpl.com.

Provided the annual software upgrade fee is paid, users can use new releases of TUFLOW at no additional cost.

2 Data Input/Output

2.1 Format required for data input. If not GIS compatible then are there third party products and what are their names.

Input data to the TUFLOW engine consists of:

- small free-form (similar to writing a macro) text files;
- GIS layers in the MapInfo open mif/mid format (ESRI .shp files will be offered in a future release);
- spreadsheet generated comma delimited files (.csv format) for tabular data.

The XP and SMS software interfaces also use these formats.

No unpublished or protected formats are used.

2.2 Third party tools to help automate model input creation

If the user does not wish to use text files, a GIS and spreadsheet software, the TUFLOW customised XP and SMS software interfaces offer a fully customised GUI (see previous sections).

2.3 Preferred survey accuracy in terms of some model parameters

Ground levels / Bathymetry:

Major Rivers (2D Domains): A DTM accuracy of ±0.2m is recommended in areas of interest or that are critical to the overall flood hydraulics. ±0.5m maybe acceptable in non-critical areas.

Minor Creeks and Urban Areas (2D Domains): A DTM accuracy of ±0.1m. Fine-scale modelling of urban areas may require less than ±0.1m.

The above specifications are appropriate for your typical Council funded Flood Study or for detailed flood impact assessments. For initial investigations (eg. highway route option assessment) or for strategic planning studies, lesser accuracy maybe acceptable.

1D Domains: 1D cross-sections should ideally be from field surveys and be spaced according to changes in flow area, grade and bed roughness to adequately approximate the conveyance along the flowpath.

It is noted that in nearly all DTMs considerably less accuracy is realistically achieved from aerial surveys in areas of dense vegetation. There is often a perception that an aerial survey will allow the extraction of accurate 1D cross-sections or 2D elevations within in-bank areas. This is rarely the case unless the in-bank areas are void of vegetation and are dry (eg. concrete lined channel). Budgeting for field surveys of in-bank areas is essential for producing a good model, especially as the larger percentage of the flood flow is usually within the in-bank areas.

Bed Roughness or Land-Use Categories (Materials)

Either aerial photography suitable for digitising land-use categories, or existing GIS layers. The Manning's n values associated with each category should follow industry standard values.

2.4 Boundary conditions required/acceptable (types and ranges)

Water Level Boundaries:

- Water Level versus Time
- Tidal harmonics
  (no limit on number of harmonic curves within the one boundary)
- Water Level versus Flow
  (ie. Stage Discharge Relationship)

Flow Boundaries:

- Flow versus Time
  (flow direction automatically determined or manually specified)
- Velocity versus Time
  (flow direction required)
- Flow as a Sink/Source versus Time
  (eg. catchment runoff onto the 2D domain; evaporation)
- Rainfall versus Time (directly onto 2D cells or to 1D nodes)
- Flow versus Water Level (eg. Pumps)

Water level and flow boundaries can be accumulated. For example, at an ocean boundary: tidal harmonic water levels, storm surge heights and wave setup heights over time can be specified as three separate boundaries all applied to the same 1D or 2D elements. TUFLOW will accumulate the boundaries together, the combined effect in this example giving an ocean storm tide. Similarly, there is no limit to the number of flow boundaries that can be applied to the same 1D or 2D element.

External Forces:

- Wind stresses
- Wave radiation stresses

- Pier forces

Others:

- Bathymetry versus time
- Range of morphological modelling parameters.

2D boundaries can be at any orientation to the 2D domain's XY axes, and placed anywhere within the domain.

2.5 Results output format (GIS compatible?)

Output from TUFLOW uses the following formats. The same output data are often repeated in different formats to offer the user flexibility in viewing/presenting results.

- Text files.
- SMS generic formats for map based data. 2D and 1D output are merged and output together as one data set.
- GIS layers in the MapInfo open mif/mid format including time-series data from 1D and 2D domains for graphing in MapInfo.
- Spreadsheet generated comma delimited files (.csv format) for tabular data.

Time Varying Map Output:

The following output data types are available in spatially and temporally varying SMS formatted map output. All of the below can be animated over time.

- Water Level
- Velocity (magnitude and vectors)
- Water Depth
- Unit Flow (magnitude and vectors)
- Energy Level
- Froude Number
- Flood hazard (product of depth and velocity) – same as Unit Flow Magnitude
- Flow Regime. Distinguishes between: Sub-critical flow; Upstream controlled friction flow (eg. supercritical flow); Upstream controlled broad-crested weir flow; and Submerged flow through a flow constriction.
- Sink/source inflows and outflows

- Manning’s n value
  (only changes in time if using depth varying Manning’s n option)
- Eddy viscosity coefficient (Smagorinsky formulation)
- Presently five (5) different Flood Hazard Outputs based on: Australian NSW Floodplain Management Manual; Herbert River Flood Study, Australia; Tweed River Flood Study, Australia; Australian Guidelines; and UK EA Guidelines.
- Ground/Bathymetry elevations (primarily used for morphological modelling or embankment breaching where bed elevations change over time)

The maximum and/or minimum values of the following map outputs are optionally tracked on a timestep by timestep basis:

- Water Level
- Simulation Time in hours of when the maximum and/or minimum water level occurred.
- Velocity
- Water Depth
- Unit Flow
- Energy Level
- Flood Hazard Categories

1D and 2D map output are merged and can be viewed/animated as one data set.

SMS formatted map output data is easily converted to GIS mif/mid and ESRI ASCII Grid formats using the free TUFLOW_to_GIS.exe utility.

WaterRIDE recognises TUFLOW generated SMS formatted map output.

Time-Series Output:

Time-series output for all 1D computational points is available in:

- .csv files for importing into Excel;
- .mif/.mid format for graphing interactively in MapInfo GIS; and
- TUFLOW .eof text file

Time-series output from the 2D domain(s) can be predefined using GIS layer(s) of points and polylines. Examples are water levels at a cell or total flow across a line. Output formats are:

- .csv files for importing into Excel; and

- in combination with the 1D .mif/.mid output for graphing interactively in MapInfo GIS.

Alternatively, time-series data in 1D and 2D domains can be post-processed using SMS or TUFLOW utilities.

2.6 Post processing capabilities

- Statistical
- Hazard analysis
- Difference mapping
- Flow distributions
- Internal hydrographs

Post processing utilities are provided free from www.tuflow.com for carrying out:

- Maximum/minimum spatial analyses across any number of simulations.
- Differences between simulations including categories for showing areas that were previously wet and are now dry and vice versa.
- Duration of inundation above a specified depth.
- Longitudinal profiles showing water levels (both 1D and 2D if applicable), bed, top of left and right banks, pipe obverts, etc. Calibration points within a specified distance of the longitudinal profile can optionally be included.
- Extraction of water levels at specified points in a GIS layer.
- Flow and flow area across line(s) in a GIS layer (the lines can be of any shape).
- Time series of any output data at points in a GIS layer.
- Flood hazard categories are an optional output from TUFLOW simulations. The categories are tracked over time and the maximum monitored on a timestep by timestep basis. Five different flood hazard relationships are available including the NSW and Australian standards.

2.7 Direct linkage to proprietary databases (input and output)

TUFLOW itself does not have direct linkages to proprietary databases. However, direct links between TUFLOW input and output data can be set up by the user if they wish.

The XP and SMS interfaces offer direct links to proprietary databases.

2.8 Access to internal model databases

All databases utilised by TUFLOW are open formats.

2.9 Linkages to other models eg links from hydrological to hydraulic models

Hydrology Models:

- XP-RAFTS .tot and .loc files
- XP-SWMM .int interface files
- WBNM output files

Hydraulic Models:

- MIKE 11 cross-section databases (.txt format)
- ISIS cross-section databases

1D/2D Dynamic Links (Source codes merged)

- ISIS (UK 1D modelling system)
- XP-SWMM

2.10 Documented data input/output formats

All data formats are documented in the TUFLOW manual or in the documentation of the format owner (eg. MapInfo .mif/mid format; SMS .dat format).

Source code is provided to collaborative users to read/write these formats.

3 Model Characteristics

3.1 Governing equations

TUFLOW 1D:

The 1D solution in TUFLOW uses an explicit finite difference, second-order, Runge-Kutta solution technique (Morrison and Smith, 1978) for the 1-D SWE of continuity and momentum as given by the equations below. An implicit scheme was also developed, however, testing and experience has shown the explicit scheme to be preferred. The equations contain the essential terms for modelling periodic long waves in estuaries and rivers, that is: wave propagation; advection of momentum (inertia terms) and bed friction (Manning's equation).

$$\frac{\partial (uA)}{\partial x} + B\frac{\partial \zeta}{\partial t} = 0 \qquad \text{(1D Continuity)}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} + k\,|u|\,u = 0 \qquad \text{(2D Momentum)}$$

where

$u = \text{depth and width averaged velocity}$

$\zeta = \text{water level}$

$t = \text{time}$

$x = \text{distance}$

$A = \text{cross sectional area}$

$B = \text{width of flow}$

$k = \text{energy loss coefficient} = \frac{gn^2}{R^{4/3}}$

$n = \text{M'annings } n$

$R = \text{Hydraulic Radius}$

$g = \text{acceleration due to gravity}$

TUFLOW 2D:

TUFLOW solves the depth averaged 2D shallow water equations (SWE). The SWE are the equations of fluid motion used for modelling long waves such as floods, ocean tides and storm surges. They are derived using the hypotheses of vertically uniform horizontal velocity and negligible vertical acceleration (ie. a hydrostatic pressure distribution). These assumptions are valid where the wave length is much greater than the depth of water. In the case of the ocean tide the SWE are applicable everywhere.

The 2-D SWE in the horizontal plane are described by the following partial differential equations of mass continuity and momentum conservation in the X and Y directions for an in-plan cartesian coordinate frame of reference.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0 \qquad \text{(2D Continuity)}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - c_f\, v + g\frac{\partial \zeta}{\partial x} + g\, u\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = F_x \quad \text{(2D X Momentum)}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + c_f\, u + g\frac{\partial \zeta}{\partial y} + g\, v\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = F_y \quad \text{(2D Y Momentum)}$$

where

ζ = *Water surface elevation*

u *and* v = *Depth averaged velocity components in X and Y directions*

H = *Depth of water*

t = *Time*

x *and* y = *Distance in X and Y directions*

c_f = *Coriolis force coefficient*

C = *ChÇzy coefficient*

μ = *Horizontal diffusion of momentum coefficient*

F_x *and* F_y = *Sum of components of external forces in X and Y directions*

The terms of the SWE can be attributed to different physical phenomena. These are propagation of the wave due to gravitational forces, the transport of momentum by advection, the horizontal diffusion of momentum, and external forces such as bed friction, rotation of the earth, wind, wave radiation stresses, and barometric pressure.

The computational procedure used is an alternating direction implicit (ADI) finite difference method based on the work of Stelling, 1984. The method involves two stages each having two steps, giving four steps overall. Each step involves solving a tri-diagonal matrix.

Stage 1, step 1 solves the momentum equation in the Y-direction for the Y-velocities. The equation is solved using a predictor/corrector method, which involves two sweeps. For the first sweep, the calculation proceeds column by column in the Y-direction. If the signs of all velocities in the X-direction are the same the second sweep is not necessary, otherwise the calculation is repeated sweeping in the opposite direction.

The second step of Stage 1 solves for the water levels and X-direction velocities by solving the equations of mass continuity and of momentum in the X-direction. A tri-diagonal equation is obtained by substituting the momentum equation into the mass equation and eliminating the X-velocity. The water levels are calculated and back substituted into the momentum equation to calculate the X-velocities. This process is repeated for a recommended two iterations. Testing on a number of models showed there to be little benefit in using more than two iterations.

Stage 2 proceeds in a similar manner to Stage 1 with the first step using the X-direction momentum equation and the second step using the mass equation and the Y-direction momentum equation.

The solution as formulated by Stelling has been enhanced and improved to provide much more robust wetting and drying of elements, upstream controlled flow regimes (eg. supercritical flow and upstream controlled weir flow), modifications to cells to model structure obverts (eg. bridge decks) and additional energy losses due to fine-scale features such as bridge piers.

3.2 Solution algorithms (descriptive)

Also include if applicable:

- How does information transfer between modules eg 1D to 2D
- Criteria for interface compatibility between 1D and 2D eg level, energy, momentum

See above.

Information on water levels and flows are interchanged between 1D and 2D schemes every half timestep using the smallest timestep of all 1D and 2D domains. There are no intermediate data files used in the process. The same approach is successfully used for the TUFLOW-ISIS and TUFLOW-XP-SWMM 1D/2D linkages which have been merged with the TUFLOW_LINK.dll executable code.

Water level compatibility criteria is preferred and recommended. Additional energy losses can be applied along the 2D interface if appropriate.

3.3 Stability criteria

- What are reasonable variable tolerances outside of which the model becomes unreliable? Are there in built methods for counteracting this (automatic or manual)

TUFLOW's stability is without doubt one of its strengths. It consistently demonstrates to be a stable platform for a wide range of hydraulic problems varying in range from:

- Fine grid urban models (1 to 10m cell size) of over a million cells with upwards of 5,000 pipes and gully traps.
- Major rivers and their floodplains extending for tens of kilometres consisting upwards of several hundred thousand active cells.
- Storm tide inundation models over and through breaches in flood defence walls. Numerous models of this type have been developed in the UK consisting of upwards of a million cells.
- Estuarine and coastal models.

Nevertheless, all numerical models can be unstable or produce unreliable results if not correctly set up or are used/pushed beyond their limits. For the TUFLOW software the following observations are noted:

- Based on research presented in Barton 2001, application of TUFLOW (and other schemes) where the flood depth significantly exceeds the cell size may produce poor results. It is recommended that results are closely reviewed in these situations, or CFD modelling be carried out.
- The 2D Courant No should be kept below 10. Most flood models use a Courant No between 2 (steep flow models) and 10 (predominantly sub-critical flow). Most well constructed models would use a Courant No of around 5. Courant Nos above 10 may produce unreliable results (Syme 1991).
- The 1D Courant number needs to remain below 1 (the 1D scheme is explicit). Use of too large a 1D timestep usually causes an instability rather than remain stable and produce erroneous results. 1D nodes that are unstable maybe stabilised with additional storage without loss of accuracy (this would only apply in conveyance dominated flow areas – sensitivity testing maybe required).
- Observation of experienced TUFLOW users has shown that little or no difficulty is experienced in developing your typical TUFLOW model. Difficulties can be experienced where the underlying data sets are of poor quality or when developing high-end models (eg. large models with many complex flow regimes). Within WBM, where many TUFLOW models have been developed, we have not yet failed to produce a reliable TUFLOW model.
- Ultimately, the stability and quality of a model very much depends on the experience of the user, quality of the data, quality control during model set up, amount of training, and mentoring level available to the user.

3.4 Convergence, convergence testing & criteria

The ADI approach does not require any convergence testing provided Courant Nos are within acceptable bounds. Options exist to increase the number of iterations, etc, however, most (all) modellers will tend to opt for a smaller timestep.

TUFLOW outputs mass balance parameters for both 1D and 2D schemes. If a high mass error occurs, this may be due to using a too high timestep, or for steep models, the wet-dry depth of the cell centres and sides need to be reduced to a mm or less.

The majority of TUFLOW models operate at less than 1% cumulative mass error (based on the cumulative volume error divided by the average flow in/out of the model.

3.5 Precision

The accuracy of any hydraulic model is very much a function of the input data (particularly the topography and bed roughness), and of the resolution of the 1D and 2D domains. Provided these are well defined, TUFLOW produces reliable and accurate results.

A double precision option has recently been built into TUFLOW that computes 2D water levels using 8-byte precision (ie. around 15 significant figures). This option maybe necessary for a satisfactory solution when flood levels are several hundred metres above sea level as there is a loss of precision due to the large numbers.

3.6 Run time for a typical model size (nominate)

For Pentium 4, 3 GHz computers:

- Small models of 10,000 to 20,000 flooded 2D cells of 5 to 20m size for a 6 to 24 hour duration flood would typically take half an hour to a couple of hours.
- Large river models of several hundred thousand flooded cells of 30 to 60m size for a flood of several days to a week duration would take 12 to 36 hours.

As a rule, the 1D component adds only a small percentage to the total run time. The exception would be models with several thousand 1D flowpaths (eg. large urban pipe network models).

If a 2D domain's cell size is halved this typically equates to an eight fold increase in the 2D run time, ie. four times as many cells and half the computational timestep.

3.7 Does the model allow hot starts

Yes.

3.8 Maximum practical size having regard among other factors to the size of machine used.

For Pentium 4 computers, models in excess of 1 million cells are practical, noting that these would be for storms of relatively short duration (eg. up to 6 hours). For major river models with flood durations in the order of days/weeks up to a few hundred thousand active cells will generally keep run times within a day.

3.9 Typical time step size (range and criteria for range)

A well constructed model will use a 2D timestep in seconds of around half the cell size in metres. For example, a 10m cell size should aim for a 5 second 2D timestep. If the model contains significant areas of steep flow or deep fast flowing water, the timestep in seconds maybe as low as roughly one quarter of the cell size in metres.

Different 1D and 2D domains can have different timesteps. As the 1D solution is explicit, 1D domains compute very quickly per timestep but will typically use smaller timesteps than the 2D domain(s). Different 2D domains of different cell size within a model can have different timesteps.

3.10 Model version compatibility

- Data format compatibility between versions
- Do the results change for the same set of inputs from one model version to the next?
- Is there a time limit on data set compatibility?

TUFLOW continues to support all previous formats including the old fixed field and binary formats (old WBM models only). The intention is to always support past file formats and maintain backward compatibility.

The TUFLOW manual has a section titled “Why Do I Get Different Results?”. The section details when default settings have changed due to new features/improvements, and lists new commands that allow the user to maintain backward compatibility. For example, when supercritical flow was introduced this became the default setting. To maintain backward compatibility, a new command was introduced to switch supercritical flow off if the user wishes to obtain the same results as before.

Occasionally, backward compatibility cannot be maintained, however, this is now rare and usually only applies to rarely used features. It is worth noting that even different source code compilers will cause different results (albeit slightly). Recent testing between Compaq Visual Fortran and the new Intel Fortran has shown this to be the case.

There are no time limits on any data set compatibility.

3.11 Does the model provide adequate direction relating to model instabilities for users to debug problems?

Yes. TUFLOW outputs a GIS layer that provides text messages pointing directly at problematic locations within the model. By reviewing these messages the original source of an instability, or problematic computational points that may one day cause an instability, can be identified. 95% of instabilities are ultimately identified as being due to poor topographic data (eg. a “cliff” in the DTM, or incorrectly entered cross-section), poor boundary definition, inappropriate roughness values, etc. Along with the GIS text messages, TUFLOW provides a wide range of check files, mostly GIS layers, that readily allows the user to review the final model configuration and locate problem areas.

A number of instability examples have been retained for inclusion in the TUFLOW manual to help guide users in identifying/fixing an instability.

3.12 Routing methods available for catchment, floodplain and channels (spatial variations possible)

TUFLOW applies the full momentum equations at all times (except at 1D structures where the relevant structure equation applies). It is planned to offer a purely bed friction based form of the equation for user specified areas of 2D domains – this is primarily for friction dominated upper areas of a catchment when the whole of the catchment is modelled.

3.13 How does the model allow for spatial and temporal rainfall distributions? How does the model estimate rainfall distributions from limited point rainfall data?

Direct rainfall onto 2D domains within a model is a new feature presently being applied to several catchments within Bankstown City Council and elsewhere. Results thus far indicate it offers a better alternative to using traditional rainfall-runoff models with the added benefit of having full integration with overland flowpaths and the underground pipe networks.

TUFLOW allows the following options:

- Any number of rain gauges (ie. rainfall versus time boundaries) maybe specified.
- Each 2D cell can receive rain from one or more of the rain gauges.

- The depth of rain applied can be adjusted on a cell by cell basis to allow for temporal and spatial variation in total rainfall.
- Initial and continuing loss rates are based on the GIS based material (land-use) categories. For example, roads would have different loss rates to gardens.

The spatial and temporal variation in rainfall is defined using one or more GIS layers. Either polygons can be used or alternatively, variation on a cell by cell basis can be easily set up using GIS layers and 3D surface modelling software (eg. Vertical Mapper, Spatial Analyst, 12D). The latter allows the user to apply (or develop) any number of spatial interpolation techniques offered by 3D surface modelling software.

3.14 Sinks/sources

- Temporal/spatial variability
- Ability to define rules

Sinks/sources can be applied anywhere to the 1D and 2D domains as flow versus time, flow versus water level (eg. pump) or depth versus time (ie. rainfall). There is no limit on the number of sink/sources that can be applied to a 2D cell; therefore, full temporal and spatial variability is available. As mentioned above for rainfall the temporal and spatial distributions can be pre-processed using 3D surface modelling software.

Sources can also be applied on a sub-catchment by sub-catchment basis as a source over area function. Local hydrographs from a hydrologic model falling directly onto a 2D domain are usually applied in this manner. TUFLOW uses a GIS layer of sub-catchment polygons and applies the inflow hydrograph as follows:

- if all cells within the polygon are dry, the flow is applied to the lowest cell;
- otherwise the flow is equally distributed to the wet cells only.

The sub-catchment polygon can extend beyond the 2D domain, but must contain at least one active 2D cell.

Pumps in various configurations including pumping between 1D and 2D, and different 2D domains are available.

3.15 Depth varying mannings ‘n’

Variable Manning’s n with depth was implemented in September 2005 and can be defined on a material by material (ie. roughness or land-use category) basis. This is particularly useful for modelling sheet flow in steeper areas where the depth of flow may only be a few centimetres, or where, for example, grass becomes flattened by floodwaters.

3.16 Is it possible to extend the model capabilities with user extensions

Yes, we are very open to joint R&D exercises. Two major ventures have been successfully completed, these being the dynamic linking of the ISIS and XP-SWMM 1D engines with TUFLOW's 2D solution scheme.

4 Physical characteristics required

4.1 Catchment area

Required if applying rainfall to 1D nodes.

4.2 Storage volumes in catchments, streams and overbanks

Only for 1D nodes where storage is to be defined using a surface area versus height table rather than using the connecting channel flow widths.

4.3 Stream length

Only for 1D flowpaths.

4.4 Model dimensions (*Eg sub catchment delineation, grid size etc*)

The extent and resolution (cell size) for each 2D domain is required. Extent of 1D domains are as digitised.

4.5 Others (please specify) (*Eg slope, landuse, soils, geology* etc)

Land-use categories (materials) are used to assign Manning's n, and optionally, rainfall loss values. Manning's n may optionally vary with depth for each material.

Numerous other physical characteristics are required as specified elsewhere in this document.

5 Parameters

Numerical models make use of a number of parameters in attempting to reproduce prototype flow conditions. These include:

5.1 Bed friction
5.2 Mixing coefficients
5.3 Stage/discharge rating
5.4 Catchment/Stream/Overbank roughness
5.5 Time of concentration
5.6 Rainfall (intensity, frequency, duration and spatial and temporal distribution).
5.7 Loss models and spatial/temporal distribution
5.8 Baseflow
5.9 Storage/discharge relationships
5.10 Other parameters

These parameters can be evaluated by:

- Direct calculation from survey
- Estimation from look-up tables (or other literature)
- Calibration against field measured events
- Internal default tables and databases eg bridge loss tables, pit databases
- User defined functions

For the model under consideration please indicate the parameters used and the method used for their evaluation. If it is considered that the model has useful functions to perform even without field calibration please indicate the basis for this conclusion and estimate the percentage of applications where this would have been the case.

The primary parameters required by TUFLOW are:

- Bed roughness, usually specified as Manning's n. Provided the model's ground elevations / bathymetry and boundary values are well defined, this is the single most important parameter.
    - Within 2D domains, the roughness values are usually applied on a material-by-material basis using a lookup table (alternatively the user can specify roughness values on a spatially varying grid).
    - For 1D cross-sections, roughness can vary across the section as a change in (a) material type, (b) relative roughness coefficient or (c) actual roughness value.
    - Roughness can also vary with height in both 1D and 2D domains.
    - Within WBM's applications, there have been many TUFLOW models calibrated to field data. Based on this knowledge and a general consistency in the derived Manning's n values, these values can be confidently applied to models where no calibration data exists.

- Turbulence effects in the 2D domain can be represented using a constant viscosity or Smagorinsky formulation. In flood studies, the viscosity term usually does not have a major influence (provided industry standard coefficients are used). TUFLOW does not require the use of artificially high viscosity coefficients to achieve model stability.
- Form (energy) losses can be applied as a fraction of the dynamic head to both 1D and 2D domains to model losses in addition to that from bed roughness. This is particularly useful for sharp bends in 1D open channels, pit losses in pipe networks, and where fine-scale features (eg. bridge piers) or significant 3D effects occur within the 2D domain (see Syme 2001b). To our knowledge, there is little in the literature that provides recommendations on suitable form loss coefficient values. In the absence of field calibration or other benchmark data (eg. pit loss databases), form loss coefficients should be sensitivity tested where possible. Form loss coefficients can vary with height for bridge structures.
- Weir calibration factor can be applied to 1D weirs and to 2D upstream controlled weir flow when it occurs. This parameter is rarely used, but is available for fine-tuning model performance where appropriate.
- Hydraulic computations for 1D flowpaths can use either Effective Flow Area or Total Flow Area. While either approach yields the same conveyance and similar water levels, Effective Area by nature of its formulation produces a velocity representative of the main channel. This can be important for correctly calculating the approach and departure velocities for structures, or for carrying out advection-dispersion calculations. Where there is no variation in bed roughness across a cross-section, there is no difference between Effective and Total Area approaches.
- For direct rainfall application, the user controls how the rainfall is applied both spatially and temporally using GIS and 3D surface modelling interpolation/extrapolation tools. The rainfall loss model is the commonly used Initial Loss / Continuing Loss model. Each material type has it’s own initial loss and continuing loss values.
- Baseflow is specified by the user as an additional inflow boundary.

TUFLOW parameters are derived from calibration to recorded flood levels, flows and observed flow patterns. Where no calibration data exists, parameters would be based on those derived from other studies and/or from the literature.

Uncalibrated TUFLOW models perform very useful functions and can be condifently used for flood investigations. Of note is that the uncertainty in the TUFLOW parameters is usually minor in comparison to the uncertainty in the input data sets. (Poor topographic resolution, hydrologic modelling uncertainties or inexperienced modelling are more often than not the cause for greater uncertainty in a 2D hydraulic model than the effects of the uncertainties associated with the parameters.)

The influence of TUFLOW parameters on model results can be readily ascertained through carrying out sensitivity tests.

Within WBM, most of the larger models, especially those for government clients, usually involve model calibration. Smaller models for development assessments on minor creeks and waterways often have no calibration data available, and are therefore uncalibrated. The majority of our modelling effort would be with models that are calibrated. However, this split could be very different for a user who, for example, predominantly works for mining clients where it is rare for calibration data to be available.

6 Calibration and Validation

6.1 Manual or automatic

Manual only. We don't recommend automatic calibration as this may lead to use of non-industry standard values. There is also a likelihood that the modeller "loses touch" with the model and fails to appreciate or understand the uncertainties, and therefore limitations, of the model.

6.2 Procedures (constraints and limitations)

Where the ground elevation / bathymetry data is well defined; the model discretisation (ie. 1D cross-section and 2D mesh resolution) is adequate; and boundary values (inflows, downstream water levels) are reliable, calibration of TUFLOW models essentially requires the fine-tuning of Manning's n values and any form loss coefficients. This is carried out using a simple look-up table of material type (ie. bed roughness or land-use category) versus Manning's n value. This approach is applied to both 1D and 2D domains.

1D channels can be further adjusted through an additional factor, or alternatively, by direct specification of a Manning's n value. Variation in roughness across a 1D cross-section can be applied by varying the material type across the section (relative resistance and direct specification of Manning's n values across the section are also available).

Considerable uncertainty in the model's boundaries can occur, especially in flow boundaries and stage-discharge boundaries. It is important that these uncertainties are understood and taken into account when evaluating a model's calibration. During calibration, it is not appropriate to use, for example, non-industry standard Manning's n values when there is considerable uncertainty in the estimated inflows to the model. A better approach is to adjust the inflow boundaries within the bounds of their uncertainty.

7 Applications

For the model under consideration, indicate the technique used to treat the phenomena listed below in a brief description of approximately 1 page or less.
Phenomena:

7.1 Subcritical/supercritical transitions

Both 1D and 2D solutions automatically switch between upstream (eg. supercritical) and downstream (sub-critical) controlled flow regimes. The switch is based on the Froude number and monitoring of the flow and depths. The automatic switching can be switched off to marginally reduce computational times, however, this is not recommended for models with steep flow.

7.2 Controls such as bridges, culverts, gates, pits, manholes, fences, buildings, etc.

Bridges are represented by a cross-section (the top of which is assumed to be the bridge soffit) and a form loss versus height table. Automatic generation of form loss versus height tables is available for simple bridges. Loss coefficients can be automatically adjusted down to near zero according to the approach and departure velocities.

Culverts can be circular or rectangular in shape and can represent 12 different flow regimes as documented in the TUFLOW manual. Height and width contraction coefficients are specified for inlet orifice flow conditions. Contraction (inlet) and expansion (outlet) loss coefficients are specified and can be automatically adjusted down to near zero based on the approach and departure velocities. An additional bend loss coefficient can be specified (this value is not adjusted according to approach and departure velocities). A percentage blockage can be applied to culverts. Irregular shaped culverts are planned for inclusion in a future release.

Fixed gate structures can be modelled using zero length rectangular culverts. Moveable gate structures are not available at present.

Pits/Manholes/Gully Traps are typically modelled using zero length small rectangular culverts or, occasionally weirs. These channels do not have to be manually entered, but are automatically generated from pit point objects that offer a variety of options including automatic connection to an overlying 2D domain. Future releases will include specification of a Q-h relationship to define the inlet flow and automatic allocation of pit losses to the outlet pipe (at present pit losses are assigned to the outlet pipe directly). Pit objects can back flow to simulate surcharging.

Solid fences are modelled in 2D domains as 3D breaklines representing the top (crest) of the fence. These breaklines raise the sides of the 2D cells (not the whole cell) to simulate a thin, impenetrable obstruction to flow (until it is overtopped). When it is overtopped, the flow can be either upstream controlled weir flow or downstream controlled flow if drowned out. For impermeable fences, options exist to reduce the cell side's flow width.

If the 2D mesh is fine enough, buildings can be modelled as inactive cells (ie. no flow, or storage). However, most commonly the buildings are represented as very high bed roughness. A building within a 1D cross-section would be represented through appropriate adjustment of the cross-section elevations and/or roughness. TUFLOW directly reads GIS layers of building polygons to set the appropriate parameters.

Weir structures are available for 1D channels and can be adjusted through an additional weir calibration factor. Automatic insertion of weir channels over culverts and bridges is also available that includes parameters to set the height and "porosity" of the handrail.

7.3 Multiple configurations of culverts/bridge openings with overtopping (including railway with many culverts and waterway opening design for irrigation earthworks and flood conveyance on floodplains remote from river channels (typical Australian rural setting)

There is no limit to the number of parallel 1D channels that can be set up to represent multiple culverts/bridges/weirs for overtopping. In the 2D domain, a combination of 1D and 2D can be utilised. For example, 2D flow through a bridge with 1D weir flow for overtopping, or multiple 1D structures with 2D flow for overtopping.

7.4 River flooding protected by levees (including levee protection located on floodplains remote from river channels (typical Australian rural setting for crop protection associated with broad-acre farming)

TUFLOW can process any number of 3D breaklines to modify ground elevations along 2D cell sides and/or cell centres to represent the crest of levees, road/rail embankments, etc.

7.5 Channel and over bank storage/ detention basins

2D domains accurately represent the storage of over bank areas and detention basins by nature of their much higher resolution. TUFLOW's 1D nodes are all assigned storage using a surface area versus height table. These tables are usually automatically generated using the storage widths of connected or user-selected 1D cross-sections multiplied by half the channel length. Additional storage can be added to the node or specified separately where the storage based on the cross-section widths is not representative, such as off-stream storage, detention basins, etc.

7.6 Flow at junctions in networks (including special interest in treating energy loss & momentum transfer for applications involving overbank flow junctions in rural floodway network design)

TUFLOW 1D junctions conserve mass and assume a common water level. Additional form (energy) losses can be applied to represent losses associated with the entry of water from a side channel causing a deformation of the streamlines, or due to bending of the streamlines as water flows overbank. Similarly, additional form losses can be added to any 2D cells to represent any fine-scale losses or 3D effects not adequately depicted by the 2D solution.

7.7 Floodplain wetting and drying

TUFLOW has a very reliable and robust wetting and drying algorithm. Wetting and drying rarely causes any difficulties in TUFLOW models. Both the whole cell and the individual cell sides can wet and dry. Cutoff depths for wetting and drying are now being specified down to 0.1 of a millimetre.

7.8 Erosion at beach/levee breakouts

A TUFLOW morphological module has been developed and successfully applied to several south coast NSW creek/river entrances (see Wainwright 2004). David Wainwright is presently extending the modules capabilities as part of his PhD. The module is presently only available for use through WBM.

7.9 Dam Break

Breaching of flood defence walls is a common task for TUFLOW models in the UK. TUFLOW can modify the geometry of the wall and breach over time.

We are unaware of any application of TUFLOW to simulate a dam failure, but it is considered viable. Studies have routed a hydrograph generate from, for example, DAMBREAK, through TUFLOW models (see Phillips 2004)

7.10 Momentum exchange between channel and floodplain

If the channel and floodplain are both modelled in 2D, then the momentum exchange between channel and floodplain will largely be taken into account (noting that if there are significant 3D influences and/or the cell resolution is too coarse, additional form losses maybe required – this would a great area of research if some good field data can be obtained).

If both are modelled in 1D, then the representation of any momentum exchange will be rough, non-existent or incorrect. Additional form losses can be applied to represent (albeit roughly) any energy losses, besides those from bed roughness, associated with the transition from channel to floodplain and vice versa. However, without good field data or other benchmark data, it is difficult for the user to be given sound guidance.

If the channel is modelled in 1D and the floodplain in 2D, the situation falls between the above two paragraphs. Once again, this would be an excellent area of research.

7.11 Reversing flow, as in tidal reaches

Fully accounted for in both 1D and 2D solutions.

7.12 Hydraulic roughness/ bed friction

1D solution utilises the Manning equation. Processing of 1D cross-sections can use either the total flow area or effective flow area methods. Where the bed roughness or materials vary across the cross-section, a parallel channel analysis is automatically invoked. There is also an option to perform a parallel channel analysis on all cross-section segments – this ensures there is no reducing conveyance with height (a common, yet not well known, problem if using the Manning equation).

2D solution offers the Manning and Chezy equations.

7.13 Overland flooding through urban streets and buildings

Fine grid 2D domains are well suited to this task. 1D pit/pipe networks can be easily integrated.

7.14 Pipe flow

Available. Long pipes can be split up into segments to better predict the hydraulic grade along the pipe.

7.15 Pipe subsurface surcharging

Available. Works well when connected to an overlying 2D domain.

7.16 Event oriented or continuous simulation model. Can it allow catchment to dry out in between rainfall events?

N/A

7.17 Ungauged catchments. What research has been conducted to define default parameters?

N/A

7.18 Mixed urban/rural catchments. Can it differentiate between rural and urban catchments? Which does the model best represent?

In the rainfall mode, the 2D domain can be divided up into any number of different land-uses on a cell by cell basis. Research and testing being presently carried out will further clarify the model’s performance in this area.

7.19 Backwater flooding

Automatic in both 1D and 2D solutions.

8 Projects

Indicate projects successfully completed using the model relating to application case studies in Section 7, with date of completion, client (if applicable), size and complexity. Please include any other examples that demonstrate another specific capability of your model along with the particular capability

A thousand plus TUFLOW models have probably now been constructed in Australia and the UK with great success. Below is a short list of WBM models that demonstrate the range of TUFLOW's capabilities.

Throsby Creek, Cottage Creek and CBD Flood Study for Newcastle City Council

- One of the largest and most complex urban flood studies carried out to-date. The catchment is predominantly urbanised and the waterways consist largely of concrete lined channels.
- The TUFLOW model consists of around 2,000 1D elements, including 900 cross-sections representing the in-bank flowpaths (eg. concrete lined channels), 700 culverts/pipes, and over 100 bridges. The 2D domain was setup as a 20m grid for preliminary calibration (to facilitate short simulation times) and 10m grid for final calibration. For final design flood simulations a finer 5m or 7.5m grid is planned to be used.
- The model calibrated well using standard parameters to two historical floods in 1988 and 1990. Up to six pluviographs, hundreds of flood marks, streamflow recordings and other observations were available.
- The TUFLOW model successfully reproduces observed historical flow patterns. These include high in-bank velocities in the concrete lined channels in excess of 6m/s. The ability to reproduce structure losses from zero (for example, flow under a clear-span bridge across a concrete lined channel where there is no effect on the flow until the flow touches the underside of the deck) was a key achievement as previously applied other software could not achieve this.

Little Salt Pan Creek Drainage Study for Bewsher Consulting and Bankstown City Council, Sydney

- The whole of the Little Salt Pan Creek catchment is modelled using a 5m 2D grid, alongwith all of the 3,000 underground pipes and gully traps as 1D elements. The lower section of the creek is modelled as 1D channels carved through the 2D domain.
- One of the first direct rainfall applications. Rainfall is directly applied to the 2D domain rather than utilising a hydrology model.
- Comparisons in upper areas were made with other models based on the DRAINS and MIKESTORM software to cross-check the new approach.

Port Adelaide Seawater Inundation Study for Tonkins and Enfield City Council

- A multiple 2D domain model was developed to cover Barker Inlet, the Port River, various stormwater detention basins and artificial wetlands. Six different domains of different orientation and cell size were dynamically linked.
- The model was calibrated to the June 1999 storm surge and successfully reproduced the tidal oscillations and amplification recorded at Inner Harbour in the Port River.
- The model was used to simulate flood inundation from storm tides and stormwater inundation from the local catchments.
- The TUFLOW model demonstrated the importance of the inertia terms in being able to reproduce tidal amplification and the ability to model a range of hydraulic features in 2D at different mesh resolutions.

Thames Embayments Inundation Study (Syme 2004)

- TUFLOW was benchmarked with three other software selected as options for a major emergency management study into the risks of storm tide inundation along the River Thames, including the low lying suburbs of London. The other software trialled were ISIS (1D), TELEMAC (2D Finite Element) and LISFLOOD (2D Raster Routing). Some of the results of the benchmarking are presented in Syme et al, 2004.
- TUFLOW in conjunction with ISIS was selected and are currently being applied to cover the entire 23 embayments along the River Thames. As part of the project, the ISIS and TUFLOW codes were merged and the ISIS 1D and TUFLOW 2D solutions dynamically linked. A long-term aim is to produce one huge model with the River Thames modelled using the existing ISIS model and the 23 embayments as 23 dynamically linked TUFLOW 2D domains to the ISIS domain.
- The modelling demontrates TUFLOW's superior ability to simulate storm-tide inundation via overtopping of major levees several metres in height and from breaching of flood defence walls.

Johnstone, Herbert, Tweed, Clarence, Richmond and Hunter River TUFLOW Flood Models Reviews for government clients.

- These major river models were developed to replace the traditional 1D models used in previous flood studies. The new 2D TUFLOW models provide greater accuracy and much better definition of the flood hazards and the flood risk. All models were extensively calibrated.
- These studies are good examples of TUFLOW's ability to model large rivers and their floodplains. Key features of the models are the deep fast flowing water in

the rivers, major levee systems that may or may not overtop, major cross-drainage structures along highways and railways and ocean tide – flood wave interaction.

Newman Road Development Assessment, Brisbane

- Although a relatively small TUFLOW model compared with others, this model has three 2D domains: two 5m cell size grids of different orientation to represent areas upstream, downstream and away from the development site, and one 2m grid covering the development site and neighbouring areas. The three 2D domains are dynamically nested. Nested 1D domains have also been carved through the two 5m grids to represent the in-bank sections of the creek as the 5m grid was considered too coarse to reproduce the in-bank topography. Embedded 1D elements were inserted into the 2m grid to represent the culverts at several road crossings.
- The model demonstrates TUFLOW's unique ability to link different 2D domains of different cell size and orientation as well as incorporate a 1D representation where appropriate. The conservation of momentum across the interfaces between different 2D domains, and between 1D and 2D domains, is well demonstrated by the preservation of the velocity fields and water surface slope from one domain to the other.

Lake Conjola and Burrill Lake Flood Studies

- These studies utilised TUFLOW's morphologic module to simulate the erosion and deposition of the sand entrance of these lakes under flood conditions. The modelling demonstrated the significant benefits in representing the morphological changes that occur at a creek or river entrance and the influence those changes have on flood levels (see Wainwright et al, 2004).

Eudlo Creek Hydraulic Investigations; Gold Coast Convention Centre Assessment; and Coomera and Nerang River Investigations

- The models from these studies are of interest as there was also other 2D models (MIKE 21, FESWMS and RMA2), and in the case of Eudlo Creek, a 1:30 scale physical model, from which results could be compared.
- In each case the other model results compared similarly with TUFLOW's (as one would hope!). Notable differences were TUFLOW's seemingly superior representation of hydraulic structures and the benefits from TUFLOW's 1D/2D dynamic link, and in recent work, the benefits of the 2D/2D nesting.

9 Useful information

The models chosen for this study are: MIKE Flood, Sobek, HEC-RAS, RMA2, Tu-Flow, RAFTS (XP), WBNM, RORB, Drains. Do you have any experience or knowledge of where your model has advantages over any of these models? Note, this information will remain confidential

Feedback from users has indicated that TUFLOW is very robust, reliable and accurate compared with other similar software; offers greater flexibility and features; and is better value for money. The availability of two Graphical User Interfaces via the SMS and XP-SWMM software platforms offers users a similar platform compared with other packages to develop, create, manage, simulate and view TUFLOW models.

Known advantages of TUFLOW are:

- 2D/1D linking robustness and flexibility.
- 2D wetting and drying under rapidly changing flow
- Automatic switching between upstream controlled flow regimes (eg. supercritical and weir flow) in both 1D and 2D solutions.
- Boundaries can occur anywhere at any orientation within a 2D domain.
- 2D representation of structures (eg. bridge decks, large box culverts).
- GIS based thereby offering all the power of GIS technology.
- Flexibility in data management. Model topography is built from a common base so that there is no duplication of data. This is a very powerful feature in large modelling studies.
- A dongle is only needed to carry out a simulation. No dongle is needed to create models or view results.
- Excellent error reporting with the bulk of messages GIS referenced so that they point exactly to the location in the model where the problem is.
- Numerous ”check” files in GIS and text formats so that the user can review their input data. For example, the topography maybe built from 20 different GIS layers (eg. DTM, 3D breaklines of levees, etc), but the elevation check file will represent the final elevations that resulted.
- Multiple 2D domains. Any number of 2D domains of different orientation and cell size can be linked 2D to 2D or 1D to 2D to form one overall model.
- Can carve any width of 1D channel through a 2D domain.
- Open formats – all formats are published.
- Dynamic links with other 1D schemes, namely ISIS and XP-SWMM.

In evaluating software and making comparisons, it is important to note that software is an ever-changing world, and what applied in the past may not apply in the present or the future.

10 Reference

List publications in journals or conferences considered appropriate to the evaluation of the model.

References:

Note, most of the below can be downloaded from http://www.tuflow.com/Downloads_Publications.htm.

Barton, C.L. (2001) *Flow Through an Abrupt Constriction – 2D Hydrodynamic Model Performance and Influence of Spatial Resolution* Thesis submitted as partial fulfilment for Master of Engineering Science, Environmental Engineering, Griffith University, July 2001.

Benham, S.A., Rogencamp, G.J. (2003) *Application of 2D Flood Models with 1D Drainage Elements* Flood Mitigation Conference, Forbes, 2003.

Charteris, A.B., Syme, W.J. (2001) *Urban Flood Modelling and Mapping – 2D or not 2D* Conference on Hydraulics in Civil Engineering, Hobart, November 2001.

Huxley, C.D. (2004) *TUFLOW Testing and Validation* Undergraduate Thesis for Bachelor of Engineering in Environmental Engineering, School of Environmental Engineering, Griffith University, June 2004.

Phillips B. (2004) *1-D and 2-D Hydraulic Modelling of Extreme Floods in a Steep Urban Stream* 8th National Conference on Hydraulics in Water Engineering, Gold Coast, July 2004.

Morrison W.R.B., Smith P.A. (1978) *A Practical Application of a Network Model Numerical Simulation of Fluid Motion* North Holland Publishing Company, Amsterdam, 1978.

Stelling G.S. (1984) *On the Construction of Computational Methods for Shallow Water Flow Problems* Rijkswaterstaat Communications, No 35/1984, The Hague, The Netherlands.

Syme W.J., Apelt C. (1990) *Linked 2-D/1-D Flow Modelling using the Shallow Water Equations* Conference on Hydraulics in Civil Engineering Sydney, Australia, 1990.

Syme W.J. (1990) *Practical 1-D and 2-D Computer Modelling of Flow in Coastal Waters and Estuaries* Technical Paper I.E. Aust. Qld Division, 1990.

Syme W.J. (1990) *Computer Modelling of Flow and Transport Processes. A Powerful Environmental Management Tool for Coastal Waters* Engineering in Coral Reef Regions Conference Townsville, Australia, 1990.

Syme, W.J. (1991) *Dynamically Linked Two-Dimensional / One-Dimensional Hydrodynamic Modelling Program for Rivers, Estuaries & Coastal Waters* William Syme, M.Eng.Sc (100% Research) Thesis, Dept of Civil Engineering, The University of Queensland, May 1991.

Syme, W.J., Nielsen, C.F., Charteris, A.B. (1998) *Comparison of Two-Dimensional Hydrodynamic Modelling Systems Part One - Flow Through a Constriction* International Conference on Hydraulics in Civil Engineering, Adelaide, September 1998.

Syme W.J., Rogencamp G.J., Nielsen C.F. (1999) *Two-Dimensional Modelling of Floodplains – A Powerful Floodplain Management Tool* NSW Flood Mitigation Conference, Tamworth, NSW, 1999.

Syme W.J. (2000) *Pros and Cons of One-dimensional and Two-Dimensional Modelling of Floodplains* Queensland Hydrology Symposium, Brisbane, Qld, 2000.

Syme W.J. (2001a) *TUFLOW – Two & one-dimensional Unsteady FLOW Software for Rivers, Estuaries and Coastal Waters* IEAust Water Panel Seminar and Workshop on 2D Flood Modelling, Guest Speaker, Sydney, February 2001.

Syme W.J. (2001b) *Modelling of Bends and Hydraulic Structures in a Two-Dimensional Scheme* Conference on Hydraulics in Civil Engineering, Hobart, November 2001.

Syme W.J., Pinnell M.G., Wicks J.M. (2004) *Modelling Flood Inundation of Urban Areas in the UK using 2D / 1D Hydraulic Models* 8th National Conference on Hydraulics in Water Engineering, Gold Coast, July 2004.

Wainwright D., Vienot P., Syme W.J. (2004) *Dynamic Modelling Of The Impact Of Entrance Scour On Flood - Behaviour In Coastal Lakes And Estuaries* NSW Flood Mitigation Conference, 2004