STREAM A

SESSION 5 (i)
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Applications of 2D Flood Models with 1D Drainage Elements

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Abstract

Two-dimensional (2D) flood modeling techniques have been used on floodplain management investigations for some years now. These techniques include fixed grid and finite element approaches. There have been some limitations with applications of fixed grid systems in simulating small drainage elements (eg. narrow creeks, open drains, pipes, culverts etc). If these elements are in the order of a few grid cells wide, then representation of the elements in 2D is somewhat coarse and can over-estimate flow capacity.

Advances in 2D modeling techniques have overcome this limitation through the representation of these small elements as 1-dimensional (1D) channels within a dynamically linked, large 2D model. This paper discusses these advances and applications of the modeling techniques on a number of 2D / 1D flood studies in New South Wales, Queensland and Victoria.

The primary consequence of this advance is that floodplains that were once considered unsuitable for 2D modeling are now able to be modeled in 2D using 1D elements for smaller drainage features. A specific application of this technique is the modelling of urban flowpaths in which underground drainage features are modeled in 1D in conjunction with complex overland flowpaths in 2D.

Keywords

Flood modelling, 2D/1D hydraulic modelling

1 INTRODUCTION

Recent advances in (2D) hydraulic modelling technology and computer power have led to increased usage of 2D models in floodplain management throughout New South Wales. Merging with this is the demand for application to new and increasingly complex flooding regimes. In particular, there has been an increased focus in urban drainage in floodplain management within NSW, bringing with it challenges of modelling complex overland flows in parallel with underground drainage. The extent of study areas has also expanded in response to increased computer power, raising the issue of how to best represent smaller, although significant, drainage paths.

These challenges have been met within the TUFLOW 2D modelling package by inserting dynamically linked 1D elements representing smaller drainage elements within the broader floodplain.

2 DEVELOPMENT OF THE 2D/1D MODELLING REGIME

The TUFLOW hydraulic modelling package was first developed in the early 1990's for application to specific areas of complex flow behaviour within a 1D model (refer schematic in Figure 1a).

Innovation in floodplain management in NSW saw the need for broadscale 2D modelling to accurately represent complex floodplain flow. Increases in computer speed facilitated significant development of the software in response to these changes. This allowed the models to change from 2D models within larger 1D models to large 2D models with small inserts of 1D elements to represent hydraulic structures such as culverts and bridges as shown in Figure 1b.

Application of the model continued to expand to larger floodplains and urban areas. These two scenarios (illustrated in Figure 1c) have presented the most recent challenge in ensuring the applicability of the TUFLOW hydraulic model to the requirements of floodplain management.

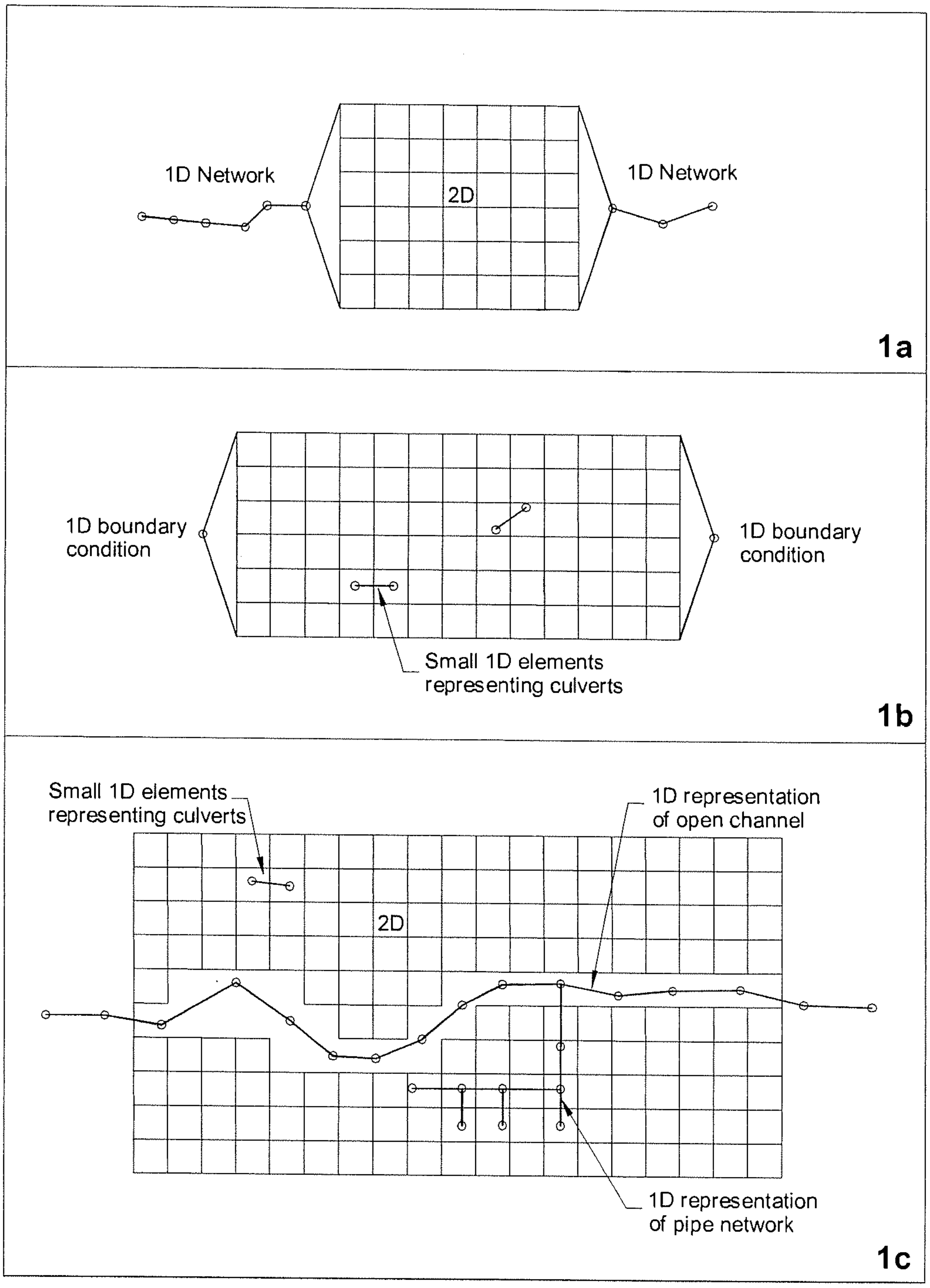

Figure 1 - TUFLOW Model Development

3 OPEN CHANNEL REPRESENTATION WITHIN LARGE FLOODPLAINS

3.1 The Need for Dynamically Linking 1D Elements to the 2D Model

Modelling a floodplain in 2D allows detailed analysis of complex flow regimes such as unconfined flow over uneven terrain where flow paths are difficult to define and multi-directional. This level of complexity is beyond that of 1D models that allow only for pre-determined flowpaths.

However, modelling large floodplains using a fixed grid system such as in TUFLOW sometimes requires a grid cell size that is not able to accurately represent smaller, though not less significant, flow paths such as rivers and creeks.

For example, the Laidley Creek floodplain model covers an area of almost 4,000 ha. The most important element of the floodplain is Laidley Creek, which is approximately 45m wide.

The 2D model of the Laidley Creek floodplain was developed using a grid cell size of 20m and a computational timestep of 5 seconds. This results in the 100 year average recurrence interval (ARI) flood event taking approximately 5 hours to run. Halving the grid size would quadruple the number of computations for any given timestep, increasing the run-time substantially.

It is generally considered that at least four cells are required to provide adequate definition of a channel. Hence, it was not possible to accurately represent a 45m wide creek using a 20m grid of 2D cells (refer Figure 2).

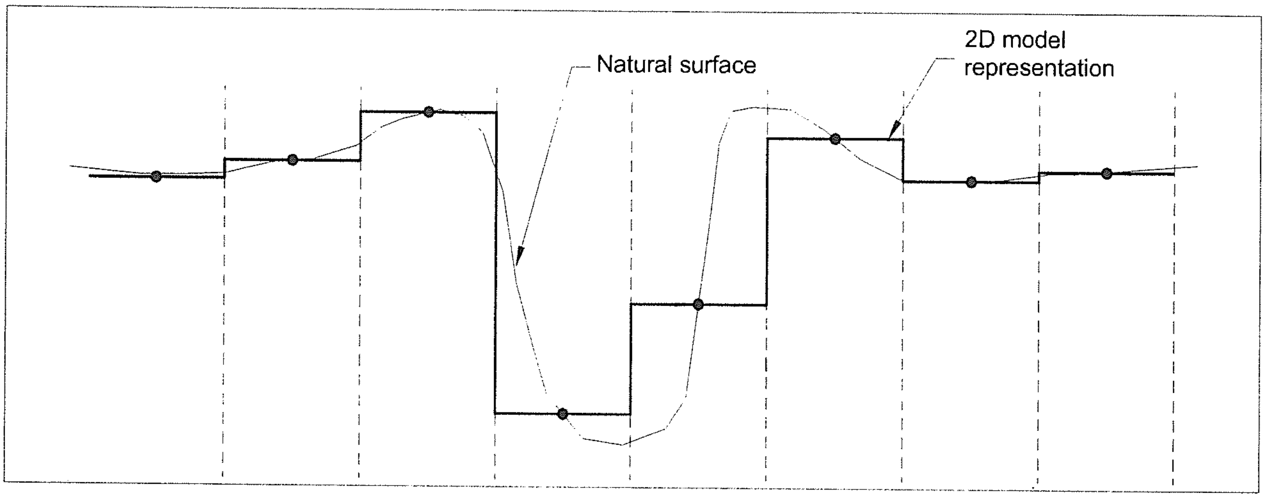

Figure 2 – Poor Representation of a Narrow Channel in 2D

Dynamically linking the 2D model cells with 1D elements representing the creek allows water to flow between the creek and floodplain *at each time step*, dramatically improving the simulation of the flood behaviour of the creek / floodplain interaction.

3.2 How the Linkage Works

The 1D channel representation within a 2D model is different to previous forms of linkage (such as for culverts and bridges) because flow transfer between 2D model and 1D elements occurs over the length of the river / creek banks with varying water levels.

Applying the head gradient along the channel to the 2D model is an important consideration in this innovation. This type of 2D/1D linkage is illustrated in Figures 3 and 4 and is described below:

1. A 1D network representing the channel and a 2D model representing the floodplain are defined using GIS. 1D channel storage and conveyance characteristics are defined by cross-sections.
2. The channel area is removed from the 2D model (the cells representing the channel are made "null").
3. A line of boundary cells each side of the channel defines the location of the 2D/1D link within the 2D model.
4. The 1D nodes (ie. h-points) are dynamically linked to the 2D cells along this line of cells.
5. During the simulation:
    a. The water level along this line of 2D cells is defined by linearly interpolating the water level of the 1D nodes;
    b. The resulting flow into or out of the 2D model to maintain the resulting flood gradient is drawn from the 1D model nodes (ie. h-points) to preserve continuity.

The result of the above approach is a 2D model of a floodplain with a dynamic linkage to a 1D model of the creek / river.

3.3 Applications of 2D/1D Linkages to Channel Representation Within a Large Floodplain

The method of linking 1D channel components to 2D models was initially developed for use in a study of Hexam Swamp, Newcastle. This application involved the development of a 2D model of the swamp area and a 1D model of Ironbark Creek. The combined 2D / 1D model was used to predict the effects of opening tidal gates to re-inundate the swamp with saltwater from the Hunter River. The accurate simulation of the interaction between the tidal flow in Ironbark Creek and the inundation of the swamp was critical to this modelling application.

This method was then used in a major study investigating the impact of the Western Sydney Orbital road on Cabramatta Creek and its floodplain. This model has a 2D extent of 15 km^2 with 17 km of channel within this represented by 1D network. A further 11 km of 1D network is modelled upstream and downstream of the 2D model area.

Since this time, linkages between 1D channels and 2D models have been successfully used for studies of the Richmond River near Kyogle, Laidley Creek at Laidley in Queensland, Fairy Creek in Wollongong, Mullet Creek at Dapto and Cudgera Creek in the northern NSW coast hinterland.

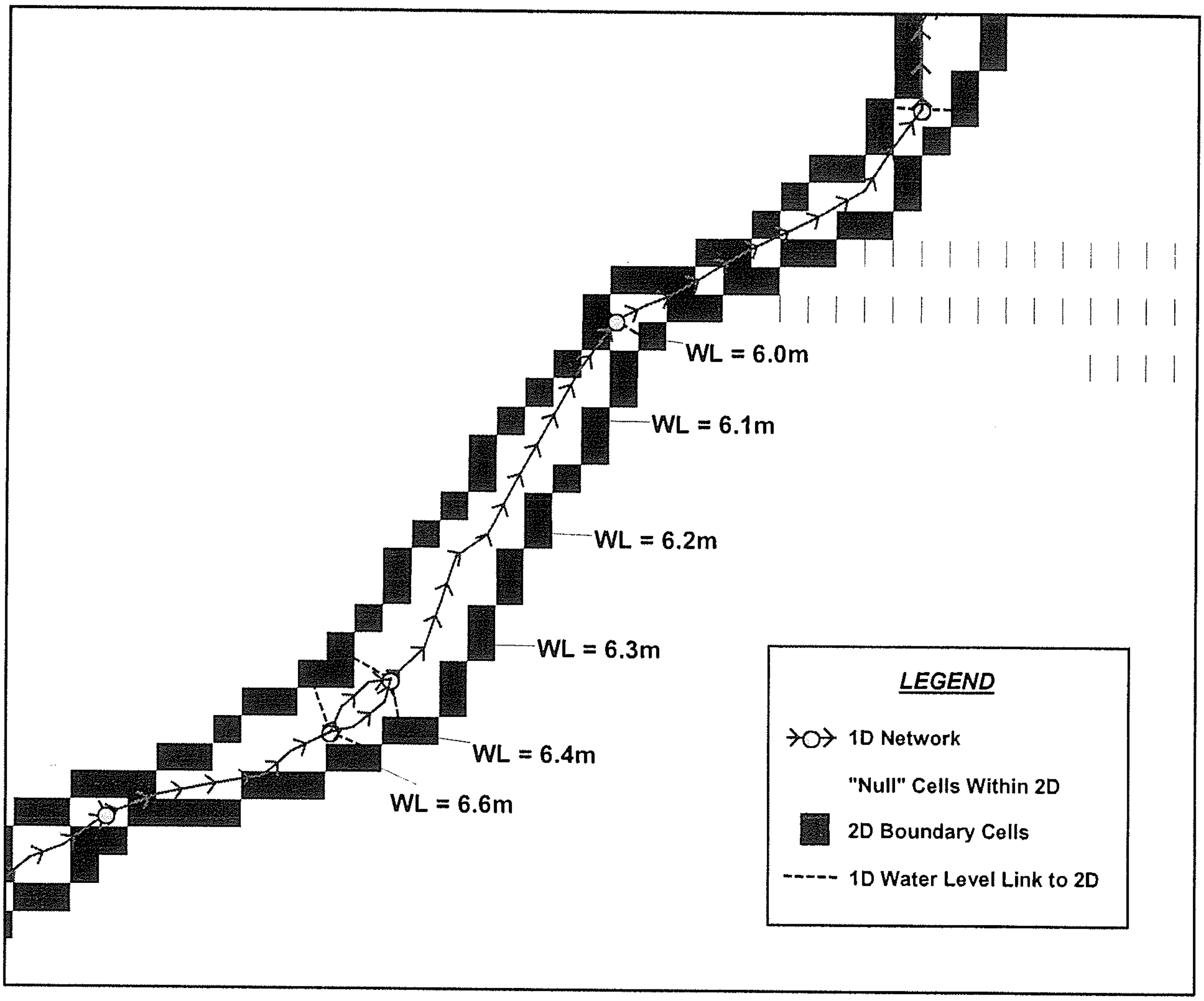

Figure 3 - 2D/1D Linkages In A Large Floodplain

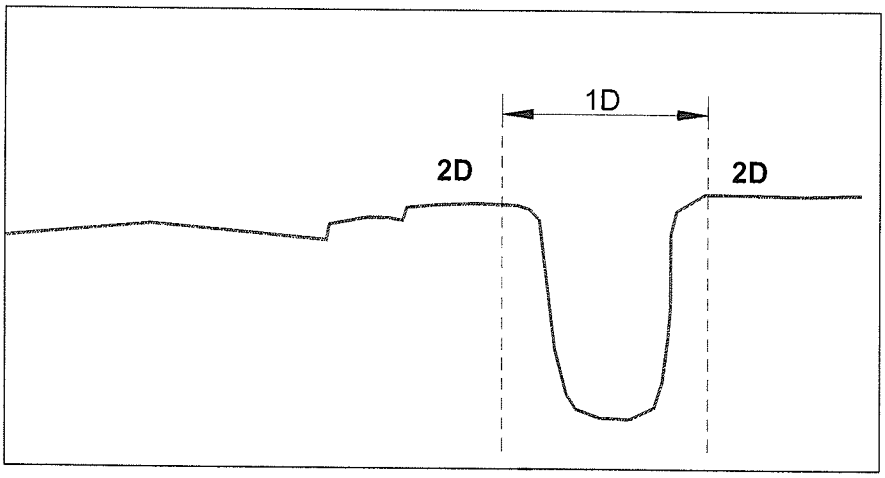

Figure 4 - 2D/1D linkages in Cross-Section between Creek and Floodplain

4 UNDERGROUND PIPE NETWORK WITHIN URBAN FLOODPLAINS

4.1 The Need for Dynamically Linking 1D Elements to the 2D Model

Urban floodplains have many components including open channels, underground piped drainage, open areas (eg. yards) and roadways. The interaction of these is difficult to simulate in either 1D or 2D models individually.

As an example, flowpaths may change from being entirely contained within the roadway to shortcutting between residences as the water level increases. Behaviour such as this, along with barriers to flow such as fences and houses, is difficult to represent in 1D models.

Conversely, 2D models are unable to accurately model the piped drainage network, which may commonly be designed for flow up to a 10 year average recurrence interval (ARI) and convey up to 40% of the flow in larger flood events such as the 100 year ARI.

By dynamically linking the 2D overland flow model to a 1D piped network, the interaction between the two systems is simulated with each timestep. The result is a model that is able to represent all facets of urban floodplain flow and their interconnection.

4.2 How the Linkage Works

Diagrams of an urban 2D / 1D linkage is shown in Figure 4 and Figure 5 and described below:

1. A 1D network representing the piped drainage system and 2D model representing the floodplain are defined within GIS. The 1D channels can be specified as circular or box culverts. Upstream and downstream invert levels and inlet/outlet/bend losses are also defined;
2. The 1D model nodes (ie. h-points) representing gully pits are linked to 2D model cells;
3. During the simulation:
    a. The 1D pipe network model operates similar to any other 1D pipe network dynamic flow model with water levels defined at pits and flows and velocities defined in the pipes.
    b. The water level in the 2D model and a weir relationship representing the flow into / out of the gully pits is used define the flow into / out of the 1D pipe network;
    c. The resulting flow into or out of the 1D model to maintain the resulting pipe gradient is drawn from the 2D model to preserve continuity.

4.3 Applications of 2D/1D Linkages to Urban Drainage Systems

An example of a 2D/1D linkage for urban drainage is Tatura in Victoria. This model contained over 500 pipes with diameters ranging from 150mm to 1650mm and 20 rectangular box culverts ranging from 150 x 450mm to 2000 x 1500mm.

The development of the 1D component was greatly simplified through the use of GIS. A program was developed to extract the required information from the GIS database received from the client into a format suitable for use by the 1D model. This process also allowed the network to be modelled in much finer detail.

Additional studies that have utilised pipe network linkages include Cottage Creek in Newcastle, Brooks Creek at Dapto, and three urban catchments in Melbourne.

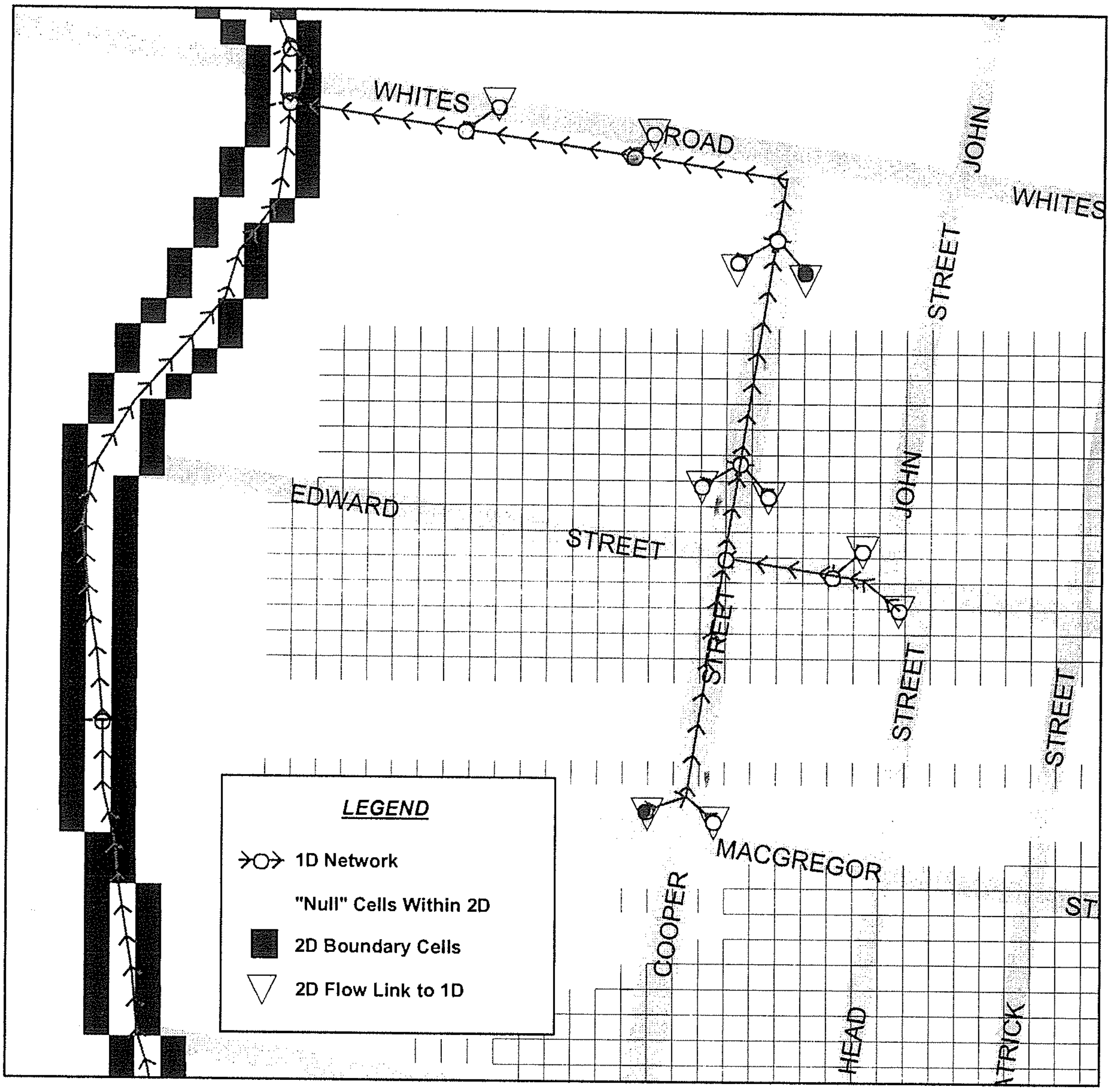

Figure 5 - 2D/1D Linkages In An Urban Floodplain

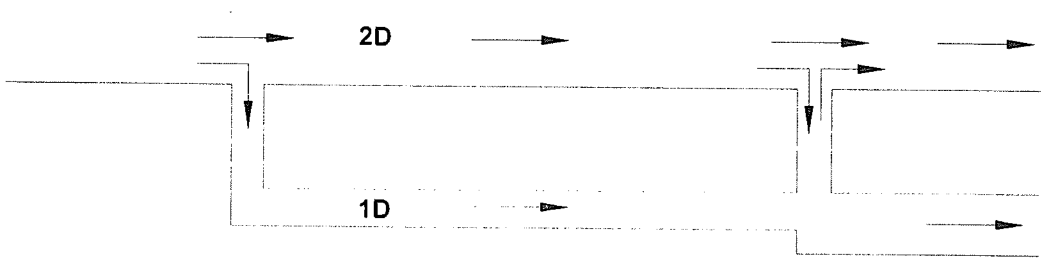

Figure 6 - 2D/1D linkages in Long Section between Pipe and Urban Floodplain

5 SUMMARY AND CONCLUSIONS

The TUFLOW modelling package is able to meet the specific requirements of NSW floodplain management through developments tailored to this application. Most recently, innovation in 2D/1D linkages has allowed representation of relatively small open channels within large floodplains and modelling of the interaction between underground pipe networks and surface flow in urban floodplains.

Since its inception, this methodology has been proven in a number of studies throughout New South Wales, Queensland and Victoria.

The specific demands of floodplain management modelling in NSW and throughout Australia will continue to drive development of new technologies and applications of existing techniques. The Australian based development of TUFLOW allows the modelling package to be continually and promptly upgraded to meet the emerging demands of local clients such as NSW Councils.

6 REFERENCES

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