Bruce Highway Eudlo Creek Hydraulic Investigations—A Turning Point

Bill Syme
WBM Pty, Ltd.

Introduction

Eudlo Creek is a small, relatively insignificant waterway flowing out of the Sunshine Coast hinterland some 100 km north of Brisbane, Australia. During 1989 and 1990 the Bruce Highway crossing (part of Australia's No. 1 Route) of Eudlo Creek was duplicated. The existing banks of large box culverts were removed and the main bridge lengthened, significantly changing the configuration of the cross-drainage flood structures. In 1992, as fate would have it, a major flood overtopped the new carriageway, and inundated surrounding properties. As a consequence, Eudlo Creek is not an insignificant waterway within the flood modeling and legal fields.

In addition to the road works, on-going works involving gravel extraction, bunds (levees), and filling of the floodplain have been a major feature of the floodplain upstream and downstream of the Eudlo Creek crossing during the 1980s and 1990s. The perceived effect on flood behaviour of these works was, in part, the reason for reconfiguring the cross-drainage flood structures.

After the 1992 flood, the landowner upstream of the highway initiated several claims for damages and losses. This resulted in legal proceedings throughout the 1990s that culminated in a final appeal by the landowner to the High Court of Australia. This appeal was upheld, and the case was set down for a re-hearing in the early 2000s. Up until this point the various hydraulic analyses conducted had been of the traditional one-dimensional (1D) modeling approach.

In the late 1990s, Queensland Transport sought Expressions of Interest from consultants to carry out detailed hydraulic investigations of the Bruce Highway crossing of Eudlo Creek. The study was to comprehensively evaluate the benefits of two-dimensional (2D) modeling as an alternative to traditional 1D approaches, and to benchmark both 1D and 2D approaches against a physical (scale) model. There was also recorded data available from the 1983 and 1992 floods to be used for the models'calibrations. Three consultants were short-listed with WBM Pty, Ltd. being awarded the tender. The selection of the preferred consultant was purely on technical grounds.

Thus, in 1998, commenced one of the most exhaustive road-related flood investigations in Australia. The main objectives were to (1) comprehensively establish the flood effect of the Bruce Highway duplication and other works, and (2) to evaluate the pros and cons of different modeling approaches, particularly the emerging 2D option. A 1:30 scale physical model was constructed (see Figure 1), calibrated and reconfigured to represent five different snapshots in time. Two of these were the pre-and post-highway duplication scenarios, the other snapshots representing changes to the floodplain from the gravel extraction works and floodplain filling. A 1D ESTRY (Morrison, 1978) model was created to complement the previous

Figure 1. Eudlo Creek Physical Model Showing Four Span Bridge

RUBICON and MIKE 11 models. A 2D finite difference TUFLOW (WBM 2006) model, and a 2D finite element FESWMS (Froehlich, 1996) model were developed. To add spice to the study, a flood occurred in February 1999 that all but validated modeling predictions to date. This flood was used to further strengthen the models' calibrations and fine-tune the flood effect predictions.

The findings from the study were comprehensively reported on (WBM, 1999) and retained for the rehearing of the legal proceedings when the outcome of the High Court appeal was known. The legal rehearing was carried out over 2002 in three separate periods taking seven weeks. During this time the landowner's consultant developed a RMA2 model. Also, a MIKE 21 model based on the TUFLOW model was independently created as a crosscheck, fortunately producing very similar results. In all, over a period of 15 years, eight different models have been used at the site (three 1D, four 2D, and a physical model), offering a rare opportunity to make comparisons.

Comparison of Different Modeling Approaches

Comparisons between the TUFLOW, FESWMS and physical models are presented in WBM 1999. They primarily focus on comparing the head level difference (or head drop) across the highway at the bridge, and across the locations of the original Southern Culverts and Northern Culverts (see Figures 2 and 3). The comparisons were presented in a variety of formats including that presented in Table 1.

Examination of the results generally shows good agreement, although some significant differences exist. Of interest is that it is difficult to draw any definite conclusions. In interpreting the results, it is noted that some of the gauges are located in high gradient areas (making it difficult to measure in the physical model), and the downstream water level boundary of the physical model has some influence on the results at the Northern and Southern Culverts.

What can be concluded is that different modeling approaches using the same topographic data and same flow data can, in some locations, produce similar results, and in other locations, differences of 10 cm or more. On this basis, any notion that results should be presented to less than a 1-cm accuracy is likely to give a false impression of model accuracy.

1D model results are not included in the comparison, partly because the 1D models were not simulated for all the scenarios, but also, due to their much coarser resolution, it is difficult to have common comparison points. However, during the calibration of the 1D models, typical or default bridge and culvert loss coefficients fell way short of reproducing the recorded head

Table 1. Comparison of Head Drops Across Highway

Flood Size	Head Drop (m) Across: Bridge			Southern Culverts			Northern Culverts		
	TU	FE	PM	TU	FE	PM	TU	FE	PM
1972 Topography – Single Carriageway									
Q83	0.38	0.59	n/a	0.53	0.66	n/a	0.47	0.64	n/a
Q92	0.51	0.76	n/a	0.65	0.78	n/a	0.60	0.78	n/a
Q100	0.75	0.90	n/a	0.83	0.90	n/a	0.81	0.91	n/a
1983 Topography - Single Carriageway									
Q83	0.44	0.61	0.55	0.39	0.44	0.43	0.34	0.38	0.37
Q92	0.60	0.72	0.71	0.51	0.52	0.56	0.44	0.46	0.72
Q100	0.77	0.80	n/a	0.68	0.64	n/a	0.67	0.60	n/a
1992 Topography – Single Carriageway									
Q83	0.48	0.70	0.53	0.32	0.48	0.39	0.10	0.27	0.20
Q92	0.67	0.88	0.68	0.48	0.66	0.60	0.16	0.32	0.32
Q100	0.79	0.95	0.77	0.66	0.72	0.67	0.26	0.33	0.48
1992 Topography - Dual Carriageway									
Q83	0.45	0.56	0.34	0.76	1.05	1.07	0.85	1.13	1.08
Q92	0.72	0.62	0.54	1.26	1.22	1.32	1.26	1.20	1.41
Q100	0.92	0.76	0.73	1.28	1.28	1.34	1.28	1.28	1.35
1997 Topography - Dual Carriageway									
Q83	0.45	0.40	0.40	0.58	0.69	0.91	0.71	0.67	0.90
Q92	0.65	0.52	0.59	1.01	0.81	1.20	0.99	0.82	1.12
Q100	0.88	0.65	0.85	1.19	1.14	1.37	1.26	1.30	1.45

Notes:
TU: TUFLOW / FE: FESWMS / PM: Physical Model
Q83: 1983 flood / Q92: 1992 flood / Q100: 100 year flood.
Single carriageway: Four span bridge with northern and southern banks of culverts (Figure 2).
Dual carriageway: Dual seven span bridges with twin 1.8m pipes in place of the northern and southern banks of culverts (Figure 3).
The different topographies are due to the gravel extraction works and bunding/filling of the floodplain.

drop recorded across the Bruce Highway for the 1983, 1992 and 1999 floods. For unsubmerged bridge conditions, 2½ to 3½ dynamic head losses are required to achieve calibration. This seemingly high number, especially given that only the 1992 flood surcharged against the bridge deck, is believed to be in part a consequence of significant additional form losses downstream of the bridge where the flow is forced to veer northwards and southwards due to the dense vegetation immediately downstream of the bridge (see flow pattern

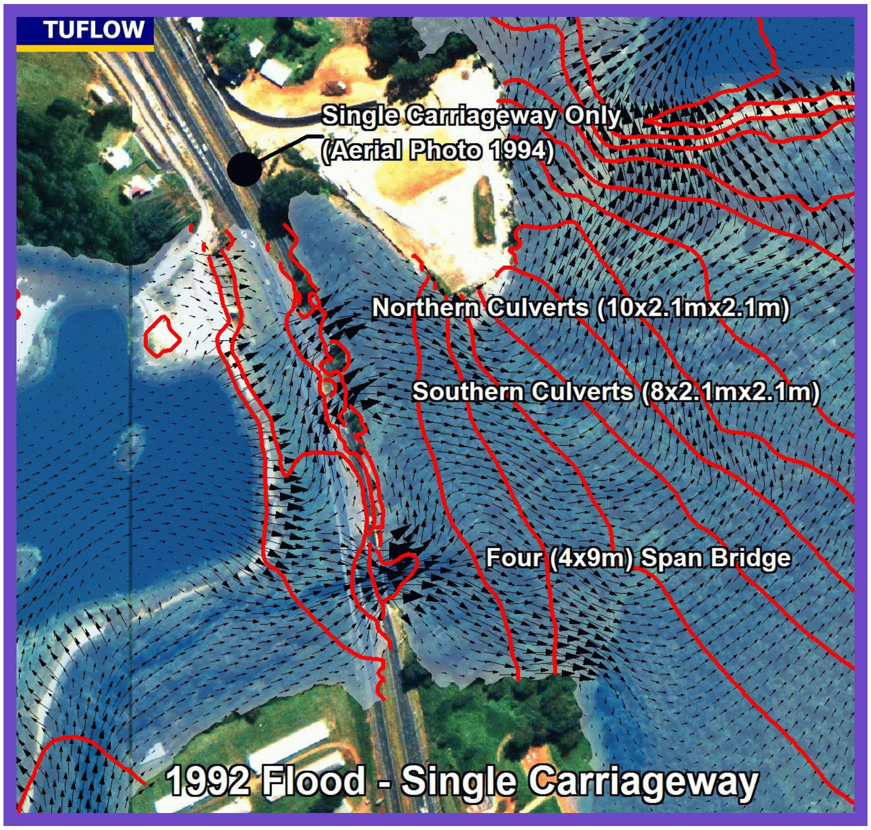

Figure 2. 2D Modeling of Single Carriageway Scenario

arrows and red water level contours at 0.2m intervals in Figures 2 and 3). In the absence of calibration data, the 1D models would very likely have used significantly lower loss coefficients and would have under-predicted the head drop.

In comparison, the 2D models (TUFLOW, FESWMS) and the physical model had little difficulty reproducing the recorded head drops across the highway for these events. The flow patterns in these models show the rapid change in flow direction and speed downstream of the crossing that is believed to contribute to the significant loss of energy that occurs as the flow expands and redistributes downstream of the highway. This is in accordance with the findings in Syme et al., 1998 and Syme, 2001, which examine the performance of 2D modeling at bends and structures.

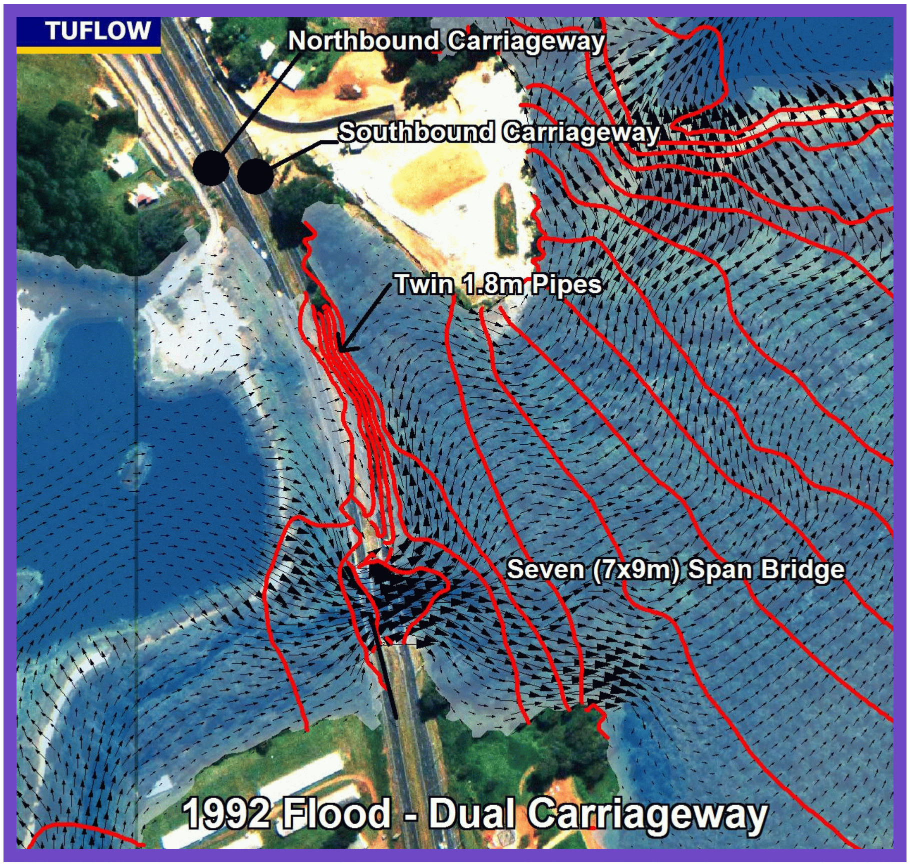

Figure 3. 2D Modeling of Dual Carriageway Scenario

Pros and Cons of Different Modeling Approaches

The pros and cons of the various modeling approaches noted during the study and from other investigations are

- 1D solutions have no computing limitations, whereas 2D solutions, being much more computationally intensive, can be slow to simulate.
- 1D modeling is more of an "art," requiring substantially more modeler judgement whilst designing and constructing the model. 2D modeling is more precise and has considerably less uncertainties (provided the underlying data sets are adequate).

- 2D model graphics and animations offer substantial benefits over 1D models in terms of communicating with and informing stakeholders.
- 2D modeling provides a substantially more accurate representation of the flow patterns and flood level variations compared with 1D solutions.
- The 2D FESWMS software (and also RMA2) has been found to be limited in its ability to model complex flood flows dynamically (i.e., over time) and are largely constrained to steady-state simulations.
- Considerable difficulty was experienced in modeling large banks of culverts, such as the Northern and Southern Culverts, using FESWMS. Insertion of these structures using the culvert routines in FESWMS could not be stabilised and, after consultation with FESWMS software support, no practical solution could be achieved. The culverts were eventually modeled as openings (similar to a bridge) with satisfactory results.
- Physical models have benefits in that they are a closer representation of the full 3D hydraulic processes, and provide an independent check of computer modeling.
- The ability for stakeholders to view and “touch” the model is of considerable benefit for demonstrating hydraulic flow patterns and focussing discussions on key issues.
- Physical scale models are not “perfect” in that they all suffer scale effects to some extent. Scales must be selected to minimise scale effects, often requiring large and expensive models.
- Physical models need to be calibrated to achieve appropriate bed resistance representation. For the Eudlo Creek model, this was a complex and time-consuming exercise requiring knowledge and experience for an appropriate outcome.
- Physical models are dependent on being provided boundary conditions (inflows and downstream water levels) from other sources (typically a computer model). There is considerable merit in carrying out preliminary 2D modeling to assist in more accurately defining the boundaries of a physical model.
- Physical models for flood modeling are limited in their extent (realistically confined to small prototype areas), are expensive, difficult to modify or reinstate and constrained to steady-state conditions.
- Computer (mathematical) modeling has several forms (1D, 2D FD, 2D FE, etc.). Each form has its pros and cons and should be selected based on the objectives of the study. The quality of a computer model is controlled by the experience and quality of the modeler (not the

software). It is paramount that the modeler understands the software's limitations and applies it appropriately.

- Physical modeling is warranted if the hydraulic processes are highly complex (significant 3D flow effects) and/or there is a need to use it as a forum for discussions with stakeholders. With the success of 2D models, the need for physical models for flood studies has become substantially less.
- Both computer models and physical models need to be validated to historical flood data if at all possible. Other forms of validation should be performed in the absence of calibration data.

After Eudlo Creek

The exhaustive and testing nature of the Eudlo Creek investigations in the late 1990s had a significant influence on the escalation of 2D flood modeling in Australia. The Eudlo Creek investigations were the driver behind substantial research and development into adapting TUFLOW from relatively unused estuarine/coastal modeling software, to software that could handle and accurately predict the 2D flood flow patterns associated with the complex and high velocity flow patterns found in levee/embankment overtopping, and through bridges and banks of culverts and flood flows in general. The 1D/2D dynamic linking capabilities in TUFLOW (Syme 1991) were fundamental to TUFLOW's adaptation to flood modeling, and have since been extended to new levels of sophistication. These developments have seen 2D replacing 1D in nearly all studies carried out by WBM since the late 1990s.

The late 1990s and early 2000s have been, in Australia, a period of healthy competition in 2D software application and development, with TUFLOW and other similar computational engines such as DELFT-FLS/SOBEK, MIKE21/MIKEFLOOD, and also the RMA2 finite element code being proactively applied and enhanced.

Geographic information systems (GIS) have also played an important role, as have modeling interfaces such as SMS. TUFLOW uses GIS data layers as the primary data inputs, and demonstrates well the power and cost effectiveness of using GIS as the work environment for flood modeling.

TUFLOW (http://www.tuflow.com) is today widely used throughout Australia and has become the predominant 2D flood modeling software in the United Kingdom. It has also been dynamically linked with ISIS (http://www.halcrow.com/software/media/media_isistuflow.asp), and the XP-SWMM 1D schemes. EMRL (Environmental Modeling Research Laboratory) through its SMS product (http://www.ems-i.com), and

XP-Software through the XP-SWMM2D platform (http://www.xpsoftware.com/products/xp2d.htm), now offer as of 2006 customised GUI environments for the TUFLOW engine.

Conclusion

The WBM study of the Bruce Highway crossing of Eudlo Creek was a crossroads in many ways. It provided an insight into the ability of 1D, 2D, and physical models to reproduce the complex flood behaviour at road crossings. The study was the impetus for developing advanced features into the TUFLOW software to the extent that it is now one of the leading 2D flood modeling softwares in Australia and the United Kingdom. The study was a turning point in many respects.

There is a saying, “No one believes a computer model (except the modeler), and everyone believes a physical model (except the modeler).” With the success of 2D computer flood modeling, this may be changing!

References

Froehlich D.C., 1996. “Finite Element Surface-Water Modelling System: Two-Dimensional Flow in a Horizontal Plane, Version 2 Users Manual.” Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Morrison W.R.B. and P.A. Smith. 1978. *A Practical Application of a Network Model: Numerical Simulation of Fluid Motion.* Amsterdam: North Holland Publishing Co.

Syme, W.J., C.F. Nielsen, and A.B. Charteris. 1998. “Comparison of Two-Dimensional Hydrodynamic Modelling Systems Part One, Flow through a Constriction.” Presented at the International Conference on Hydraulics in Civil Engineering, Adelaide, September 1998.

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

Syme, W.J. 2001. “Modelling of Bends and Hydraulic Structures in a Two-Dimensional Scheme.” Presented at the Conference on Hydraulics in Civil Engineering, Hobart, November 2001.

WBM. 1999. “Bruce Highway Crossing—Eudlo Creek—Hydraulic Analysis Final Report.” Document 11329.R1.2 WBM Pty, Ltd.

WBM. 2006. “TUFLOW User Manual.” WBM Pty, Ltd.