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PRACTICAL 1-D AND 2-D COMPUTER MODELLING OF FLOW AND TRANSPORT PROCESSES IN RIVERS, ESTUARIES AND COASTAL WATERS

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SUMMARY

Modelling the hydrodynamic and plume transportation processes of rivers, estuaries and coastal waters requires professional expertise, and computer software for technical analysis and data processing. For the computer software to be of use in practice, it must be accurate, robust and supported by appropriate hardware and a comprehensive computer graphics system. These requirements are recognised and are an integral part of WBM's research and development programme. In recent years several new computer programs have been developed in-house. For each program a solution scheme was selected, computer coded and rigorously tested, followed by the formulation of additional algorithms and the writing of data processing and computer graphics software.

This paper briefly discusses key aspects of computer flow modelling followed by a review of the ESTRY, TUFLOW, WATQAL and TUQAL programs which are finding widespread application in the consulting field to help solve a range of complex problems. Illustrations from applications of the software to the Gold Coast Seaway and Moreton Bay are presented.

INTRODUCTION

Numerical models are a widely accepted tool for analysing the flood and tidal hydrodynamics and transport processes of rivers, estuaries and coastal waters. Their development and application requires both professional expertise and appropriate computer software.

The detail and complexity with which these models can be developed is continually improving with the increasing computational power of the computer. This has direct benefits in reducing the uncertainties inherent in mathematical models by providing for more accurate predictions and assessments of impacts.

However, to utilise these potential benefits an on-going research and development programme to develop new computer software is needed. This software must incorporate robust and accurate solution schemes and be supported by computer graphics and data processing systems for setting-up models and displaying results.

To further enhance these areas, WBM Pty Ltd has recently been involved in developing new computer software for modelling 2-D flows with dynamic links between 1-D and 2-D models, and for 2-D and 1-D plume advection/dispersion processes. Alongside these R&D programmes, comprehensive computer graphics systems have been developed for setting up models and displaying results.

PRACTICAL COMPUTER FLOW MODELLING

General

There are three essential elements required to efficiently and effectively complete a computer flow modelling investigation. They are, in order of importance, as follows:

1. Qualified engineers/scientists with appropriate expertise in numerical flow modelling.
2. Suitable computer programs for technical analyses.
3. Quick and efficient data input and output procedures, including good computer graphics.

In addition to the above, the acquisition of field data for model development and calibration is an important aspect of an investigation.

Data Collection

The level of data collection is dependent on the purpose and objectives of the investigation.

There are two main types of data to be collected, namely, (1) data for model calibration, and (2) geometric data defining the physical terrain/bathymetry of the area of interest.

For model calibration purposes, sufficient data should be collected to enable the engineer/scientist to be as confident as practicable in their analysis and conclusions. The experience and expertise of the modeller is vitally important in this regard. For a flood modelling investigation where calibration data is scarce or non-existent, appropriate caution should be exercised in the way in which the results are used.

The most important data are the geometric data and the boundary conditions. A numerical (or physical) model will be inadequate if it does not accurately represent the physical terrain/bathymetry being modelled. The acquisition of this data can be prohibitively expensive, especially for models which cover a large area. However, every effort should be made to obtain good data in areas of the model which are of special interest.

Of note is that the use of unrealistic friction coefficients to calibrate a model is unacceptable unless it can be shown that there is likely to be additional losses from eddy formations, etc. If model calibration can not be achieved from using typical friction coefficients, the cause will almost be due to poor geometric representation and/or incorrect boundary conditions. For flood models, the cause may also be due to uncertainties in the hydrologic modelling.

Professional Expertise

The quality of a numerical flow modelling investigation is highly dependent on the engineering/scientific expertise employed.

The requirements for suitable expertise won't be elaborated upon here, other than to emphasise that the engineer/scientist should have the following attributes.

- a clear understanding of the fundamental physical processes of free-surface fluid flow
- extensive experience in applying these models in practice, or for the inexperienced, be closely supervised by someone with that experience
- the ability to interpret the results in terms of the relative influence of the various factors and to act on the basis of those interpretations
- continually keeping "in touch" with recent developments presented in the literature
- where possible seek to work closely with fellow engineers/scientists in their own and other organisations
- know the limitations of their modelling and work within those limitations
- recognise that numerical modelling is an approximation of reality and that results are indicative only, not definitive
- know the limitations and uncertainties of the field data

Solution Schemes

For many studies of rivers and estuaries, solution schemes which solve the 1-D shallow water and transport equations are generally satisfactory. The flow is predominantly uni-directional, such as that which occurs in a river. Networking allows branching of flow paths to be represented. For floodplains, networking is used giving a quasi 2-D effect.

For coastal waters and where more complex flows occur in broad rivers and estuaries or near obstructions, a scheme which solves the 2-D equations can generally be used. These equations are significantly more complex than the 1-D equations and are used where a more detailed analysis of the flow patterns is required.

For tide models, it is essential that the inertia terms in the shallow water equations are included.

TECHNICAL COMPUTER SOFTWARE

General

There are two key components in the development of technical computer programs for use in practice. They are:

1. The solution scheme, which must be accurate, robust and versatile, and

2. the development of algorithms, and other aspects such as error coding and 'user-friendliness' which make the program economically and efficiently useable for consulting purposes.

As part of WBM's research and development programme, the continued development of technical computer programs along the above lines is of high priority. In recent years three new programs, codenamed TUFLOW, TUQAL and WATQAL have been developed and complement the established ESTRY program.

The following sections briefly address each of WBM's current technical programs in the field of flow and plume transportation modelling.

ESTRY - 1-D Network Flow Modelling

ESTRY has found widespread use along the eastern coast of Australia for modelling floods and tides and can be regarded as one of the leaders in its field of application. The development of ESTRY started in 1974 and is described in Morrison, 1980. Of note are several aspects of the solution scheme and algorithms which have made ESTRY such a versatile tool for practical applications. These are briefly discussed as follows:

- Where storage effects are important, such as on extensive floodplains or in tidal broadwaters, the storage compartment is defined separately as tables of surface area versus elevation rather than using information from the channel cross-section details which can lead to an erroneous representation.
- Algorithms have been developed for structures such as bridges, weirs and culverts based on standard formulae and manufacturer's specifications. The inclusion of the structures algorithms has been a key component and in some studies, essential.
- Wetting and drying can be accommodated readily. There is no need for overland channels to maintain water and flow with, for example, artificial and unrealistic 'slots'.
- Where a river section has several different conveyance characteristics, this is easily represented by any number of parallel channels.

TUFLOW - 2-D/1-D Flow Modelling

TUFLOW is used for modelling 2-D hydrodynamics of coastal waters and for complex flow patterns in rivers and estuaries. It also allows for any number of ESTRY models to be dynamically linked to the 2-D model giving greater flexibility and versatility. An example of 2-D/1-D link model schematisation is illustrated in Figure 1.

The program has been developed as part of a joint research project between WBM Pty Ltd and The University of Queensland (Syme, 1990). The 2-D solution scheme is based on that of Stelling, 1984

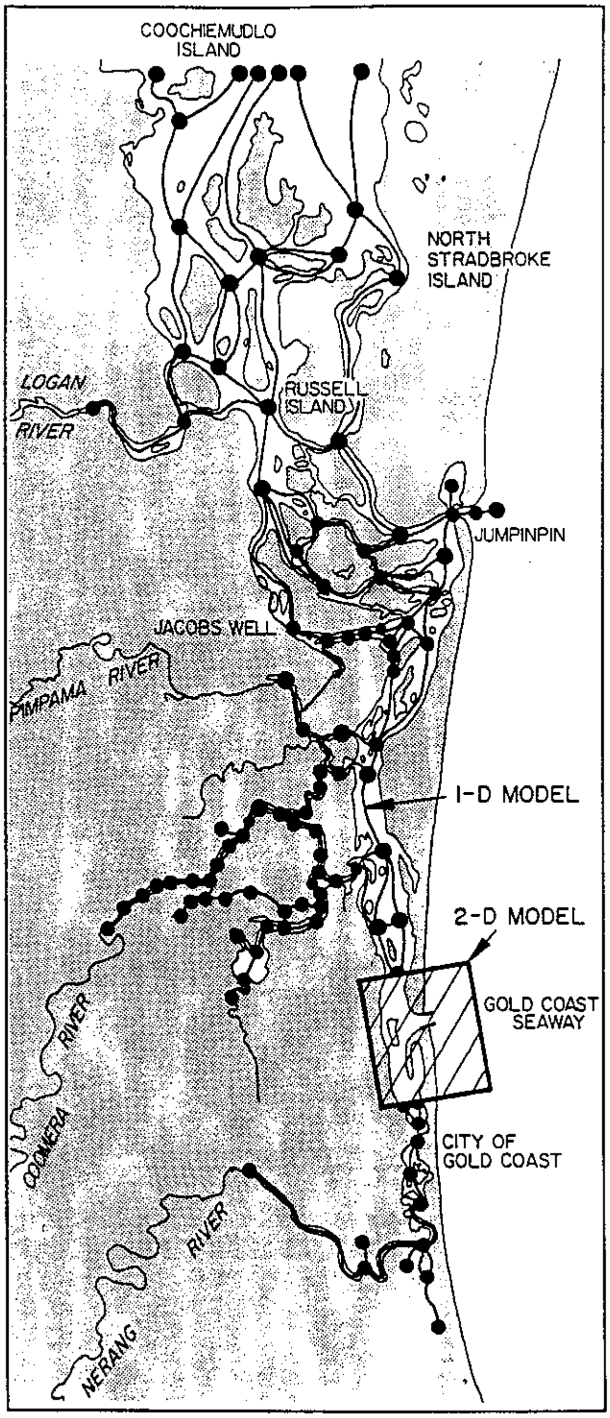

Figure 1 2-D/1-D Link Model Southern Moreton Bay/Gold Coast Broadwater

which is a major advancement on the Rand Corporation scheme (Leendertse, 1967) with respect to stability, robustness and accuracy. It does not require artificial viscosity for stability purposes.

Key algorithms which have been developed through use in practice are listed below.

- a robust wetting and drying algorithm for intertidal flats which allows draining of perched waters and a very small threshold depth.
- an algorithm for adjustment of water level boundary values at oblique boundaries to an orthogonal grid.
- adjustment of the friction coefficient with changing water depth which has been shown to be important, especially for models with significant areas of inter-tidal flats.

An example of a TUFLOW simulation of the Gold Coast Broadwater 2-D/1-D link model (Figure 1) is given in Figure 2 which illustrates ebb tide velocities through the Seaway during a calibration run. The 2-D/1-D link model is to be used for assessing management options for the Gold Coast Broadwater.

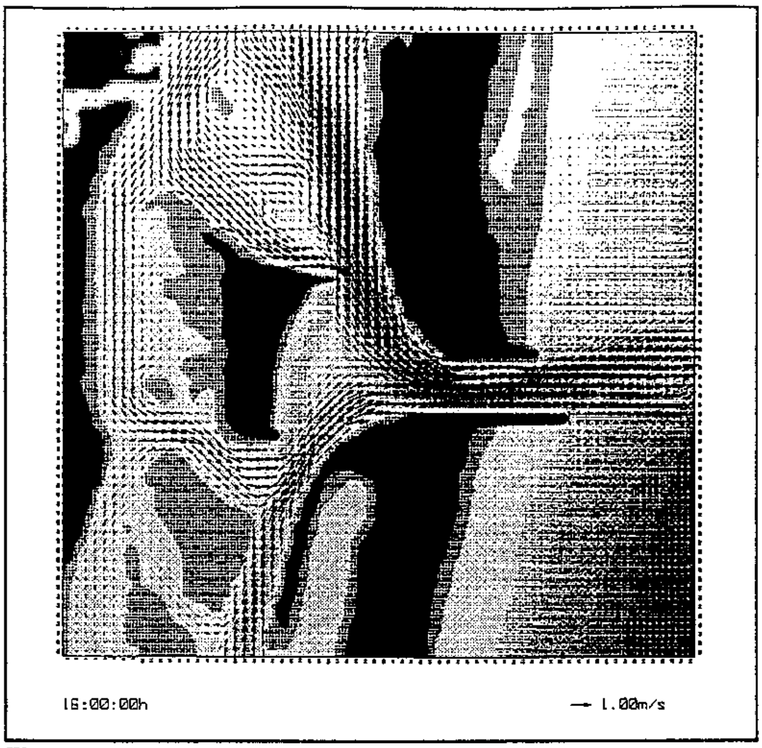

Figure 2 Ebb Tide, Gold Coast Seaway
Velocity Vectors on Shaded Bathymetry

WATQAL - 1-D Advection/Dispersion

WATQAL is a 1-D water quality modelling program (McAlister, 1989) which uses a Lagrangian frame of reference based on the approach of Fischer, 1972. The program has essentially replaced the previously used program, QALTY which used an Eulerian approach based on the FWQA method (Feigner, 1970).

The lagrangian approach has negligible numerical diffusion compared to that of the Eulerian approach.

TUQAL - 2-D Advection/Dispersion of Plumes

TUQAL has recently been developed by the author for modelling 2-D transportation of plumes. The solution scheme is based on that described by Nguyen, 1988.

A fractionary step approach is used to solve the 2-D transport equations. Firstly, the advection terms are solved using the method of characteristics combined with a bi-cubic interpolation technique. Secondly the diffusion terms are solved using a standard alternating direction implicit (ADI) method.

The scheme does not have the degree of numerical diffusion problems of the advection step inherent in other schemes, such as the well-known Leendertse, 1970 scheme. This is particularly important in coastal waters where advection dominates over diffusion, as this does not allow for the practical adjustment of the dispersion coefficients to minimise numerical diffusion. The TUQAL scheme is unconditionally stable allowing the use of large timesteps.

An example of the results from a TUQAL simulation is shown in Figure 3 which illustrates the extent and concentration of three hypothetical plumes in Moreton Bay after a time period of four days.

COMPUTER GRAPHICS

For the successful completion of investigations to a high standard and within budget limitations, it is essential to use a high level of computer graphics.

The main benefits of using good computer graphics software are:

- reduction of model development time
- detailed visual displays giving increased understanding and higher quality assessment of results
- faster and improved model calibration
- improved presentation of results leading to a better understanding by the lay-person
- user satisfaction and performance.

The comprehensive computer graphic systems which have been developed for 1-D models (Syme, 1989) and for 2-D models (Syme, 1990), are now an integral component of the modelling procedure.

The benefits of this software has, without doubt, far out-weighed the development costs.

CONCLUSIONS

The level of professional expertise is the most important element of practical computer modelling of flow and transport processes in rivers, estuaries and coastal waters.

However, as computers and computer graphics continue to become faster and more powerful, existing practises in this field can be greatly enhanced through the continued development and application of numerical methods and computer software.

This provides those with the professional expertise to use these programs with greater capacity, flexibility and efficiency to carry out investigations.

WBM Pty Ltd through its research and development programme has shown this to be the case. A number of new computer programs have been developed based on recent research which have already proven to be powerful modelling tools in practice. This particularly applies to the TUFLOW program with its facility to link 1-D and 2-D models dynamically.

The power of the graphic workstation should also not be underestimated for setting up models and displaying results.

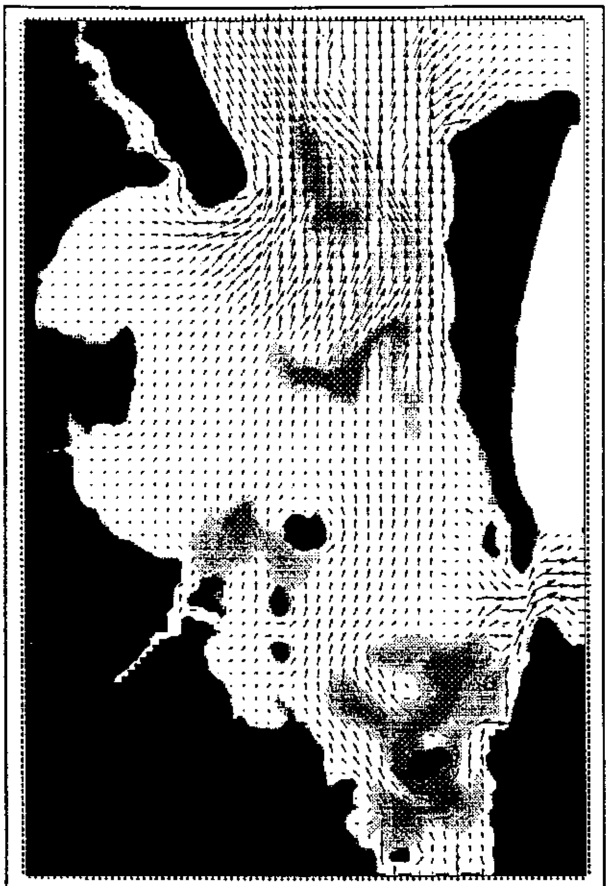

Figure 3 Transportation of Plumes Moreton Bay

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