Engineering in Coral Reef Regions Conference
Magnetic Island, Townsville
5-7 November 1990

Computer Modelling of Flow and Transport Processes

A Powerful Management Tool for Coastal Waters

W J Syme, BE, Grad IE Aust
Senior Engineer WBM Pty Ltd
Postgraduate Student, The University of Queensland

SUMMARY

Coral is known to deteriorate when adverse changes to water quality occur, particularly with respect to water clarity, salinity, nutrient content and suspended sediment load. The future viability of coral reef regions is thus dependent on maintaining the water quality surrounding reefs. It is therefore important to be able to predict the consequences of proposed works adjacent to reefs and develop appropriate environmental management strategies.

Through the use of numerical models and professional expertise, the hydrodynamic behaviour, and the transportation of plumes in coastal waters can be quantified with confidence. Once these models are developed they can be used for predicting the impacts on water quality of works and natural events.

To broaden its existing base of expertise and computer software in this area, WBM/Oceanics has recently developed the program TUFLOW for modelling 2-D hydrodynamics, and TUQAL for modelling 2-D transportation of plumes. These programs have been rigorously tested and successfully applied to a number of investigations. A comprehensive computer graphics system has also been developed for setting up models and displaying results.

1.0 INTRODUCTION

Corals form the backbone of coral reefs and are vital to the reef ecology and environment. The protection of these coral reefs from deterioration under man's activities is strongly acknowledged and considered by some to be paramount.

Coral reefs have evolved in a dynamic regime of tidal currents, water quality, and long-term climatic and sea level changes. The degradation of a coral reef can be caused by a number of factors relating to the water quality, such as:

- reduction in water clarity
- low salinity from periods of freshwater intrusion
- increased nutrients causing greater algal growth
- higher rates of suspended sediment deposition

If a <u>working</u> relationship between man's activities and the protection of coral reef regions is to occur, management strategies and impact assessments are essential. To achieve this, it is necessary to understand the current patterns and water quality processes, and in particular, the impacts of works and developments.

2.0 COMPUTER MODELLING AS A PREDICTIVE TOOL

Research is necessary to understand the physical and biological processes and responses of corals. However, a difficulty arises when there is a need to predict the impacts of proposed works or a natural event. To establish these impacts, a quantitative assessment of the likely changes to the current patterns and water quality would be required.

Computer modelling is developing as a most useful tool for this purpose. Advances in recent times have been substantial due to a greater knowledge in modelling the physical processes, and the increasing computational power and graphics capabilities of the computer.

WBM Pty Ltd through a joint project with The University of Queensland, and its own in-house research and development programme has been actively involved in developing expertise and computer software in this area. The TUFLOW and TUQAL computer programs have recently been developed for modelling currents and transportation of plumes in coastal waters. These programs, their solution schemes and area of application are discussed in the following sections.

3.0 TUFLOW & TUQAL COMPUTER PROGRAMS

3.1 Coastal Hydrodynamics

The hydrodynamics of coastal waters can be described by the 2-D shallow water equations (SWE). These equations are applicable where the wave length is far greater than the water depth, as is the case for the ocean tide and storm surge. They are based on the assumption of negligible vertical acceleration and a hydrostatic pressure distribution.

The SWE solved by the TUFLOW program are given below. Equation 1 represents the conservation of mass, while Equations 2 and 3 are the conservation of momentum in the X and Y directions. These equations describe the essential physical processes for the movement of a long wave, namely, wave propagation, advection of momentum, diffusion of momentum, bed friction and other external forces.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv + g\frac{\partial \zeta}{\partial x} + gu\frac{\sqrt{u^2 + v^2}}{C^2 H} - \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = F_x \qquad (2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + fu + g\frac{\partial \zeta}{\partial y} + gv\frac{\sqrt{u^2 + v^2}}{C^2 H} - \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = F_y \qquad (3)$$

where
ζ = Water surface elevation
u = depth averaged velocity in x-direction
v = depth averaged velocity in y-direction
h = depth of water relative to a datum
H = ζ + h = total water depth
f = Coriolis parameter
C = Chezy bed friction coefficient
ν = Viscosity coefficient
F_x and F_y = External forces (Wind stress, Wave radiation stress, and Barometric pressure)

The solution scheme used for the 2-D component of TUFLOW is based on that described in Stelling, 1984. This is an alternating direction implicit (ADI) finite difference scheme, similar to that of the well known Leendertse or RAND scheme, but uses a higher order of accuracy and is computationally more robust and stable. The development of TUFLOW (Syme, 1990) was carried out as part of a joint project between WBM and The University of Queensland.

Special features allowing use of the program particularly in coastal and reef regions, include algorithms which have been developed for:

- wetting and drying of intertidal flats including the ability for draining of perched waters
- incorporation of external forces due to wind, wave induced radiation stresses and barometric pressure variations
- defining boundary conditions along oblique boundaries to an orthogonal grid
- any number of 1-D network models based on the ESTRY program can be dynamically linked to a 2-D model

3.2 Plume Transportation

The transport or the advection/dispersion of plumes in coastal waters is described by the 2-D scalar transport equation as given below.

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_x\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} \quad (4)$$

where
C = Scalar value (eg. Concentration)
u = Velocity component in X-direction
v = Velocity component in Y-direction
D_x = Diffusion coefficient in X-direction
D_y = Diffusion coefficient in Y-direction

The solution of these equations by some schemes produces excessive numerical dispersion when solving the advection terms. This problem of numerical dispersion is particularly important in coastal waters where advection typically dominates over diffusion processes.

The solution scheme adopted for the program TUQAL, was based on that described by Nguyen, 1988. It overcomes the problem of excessive numerical dispersion through utilisation of a fractionary step approach. This involves separate steps for solving the advection and diffusion terms. The advection step uses the method of characteristics and a fourth-order bi-cubic interpolation procedure, while the diffusion terms are solved using a standard ADI method. Rigorous testing has confirmed that this method is characterised by its very small numerical dispersion, accuracy, and excellent stability properties.

4.0 APPLICATION OF TUFLOW & TUQAL

Computer programs such as TUFLOW and TUQAL, when used by suitably qualified engineers/scientists, are excellent tools for helping to solve a range of water quality problems for coastal and reef regions. Typically they are used for:

- quantifying changes in water quality to assist marine biologists
- siting sewerage outfall sites
- pollutant discharging strategies
- movement and settling of spoil plumes from dredging activities
- strategies for dredge and waste spoil disposal

Moreton Bay is an example of a coastal bay with areas of coral reef which have undergone significant changes in growth and deterioration caused by variations in tidal flushing, salinity (freshwater intrusion from flooding) and deposition of sediment. These changes in water quality have been caused by events such as the opening of the Jumpinpin bar, and major floods such as that of 1974.

To illustrate the capabilities of the TUFLOW and TUQAL programs a model of Moreton Bay was set-up and calibrated to spring tide ranges. The model consists of 137 by 89 elements, each element being a 500 m square. The model bathymetry and current velocities during a flood tide are illustrated in Figure 1.

Moreton Bay is characterised by a range of complex flow patterns and tidal amplifications and can, therefore, be regarded as a rigorous test for a 2-D flow modelling program. Its interaction with the Gold Coast Broadwater which has entrances to the ocean at Jumpinpin and the Nerang Seaway is also complex. To account for this, the Gold Coast Broadwater, along with the Brisbane River, were represented by 1-D network models.

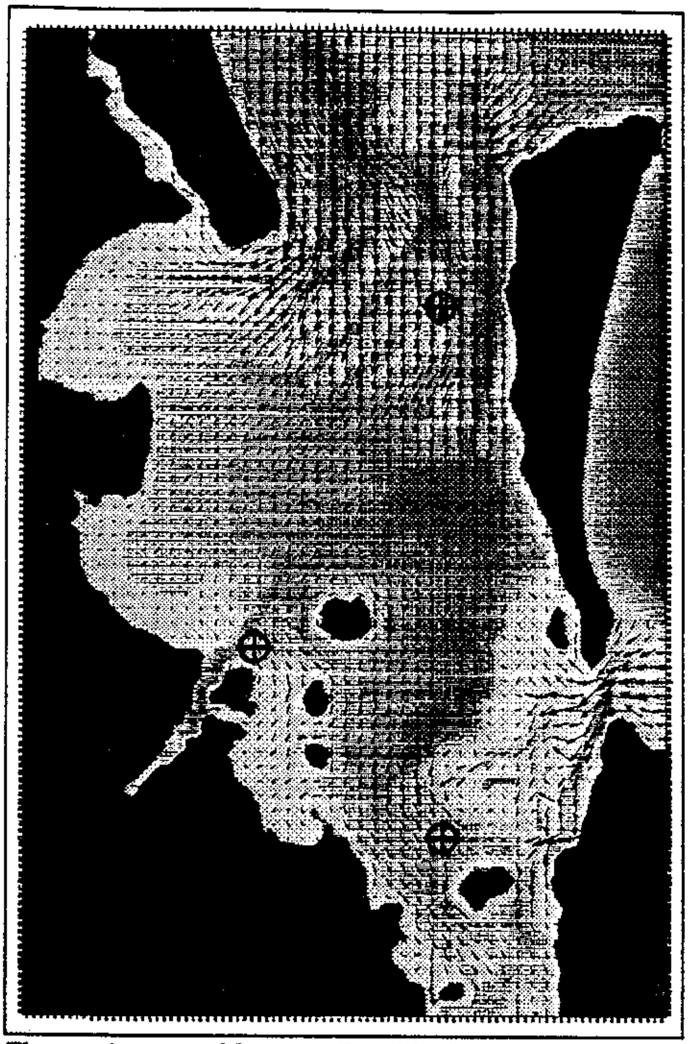

Figure 1 ***Moreton Bay Model***
Flood Tide Velocities on Bathymetry
[⊕ - Discharge Site]

Once the hydrodynamics of the Bay were calculated, the transportation of plumes can be modelled. Three discharge sites were specified as shown in Figure 1. The simulation extended from 12 to 100 hours with a constant discharge of material starting at 12 hours and ceasing at 48 hours. Figures 2a to d show the location and extent of the plumes at times 25, 45, 65 and 85 hours.

5.0 CONCLUSIONS

Computer models combined with professional expertise allow complex flow and plume transportation processes of coastal waters to be modelled with confidence. These models can be used as excellent tools for predicting changes to water quality from proposed works and the development of environmental management strategies. The graphics workstation provides the necessary link between the model results and the lay-person.

To develop the professional expertise and computer software in this area, it is essential for on-going research and development to be carried out by both academic institutions and industry, preferably in conjunction with each other. This has shown to be the case for the development of the TUFLOW and TUQAL programs for modelling the hydrodynamics and plume transportation processes of coastal waters, which has been the result of a joint project between WBM Pty Ltd and The University of Queensland.

REFERENCES

Nguyen K D and Martin J (1988) A Fourth-Order Simulation for Scalar Transport in Estuaries and Coastal Seas Estuarine, Coastal and Shelf Science, 1988, v27 pp 263-281

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 and Apelt C J (1990) Linked Two-Dimensional/One-Dimensional Flow Modelling Using the Shallow Water Equations Hydraulics in Civil Engineering 1990, Sydney

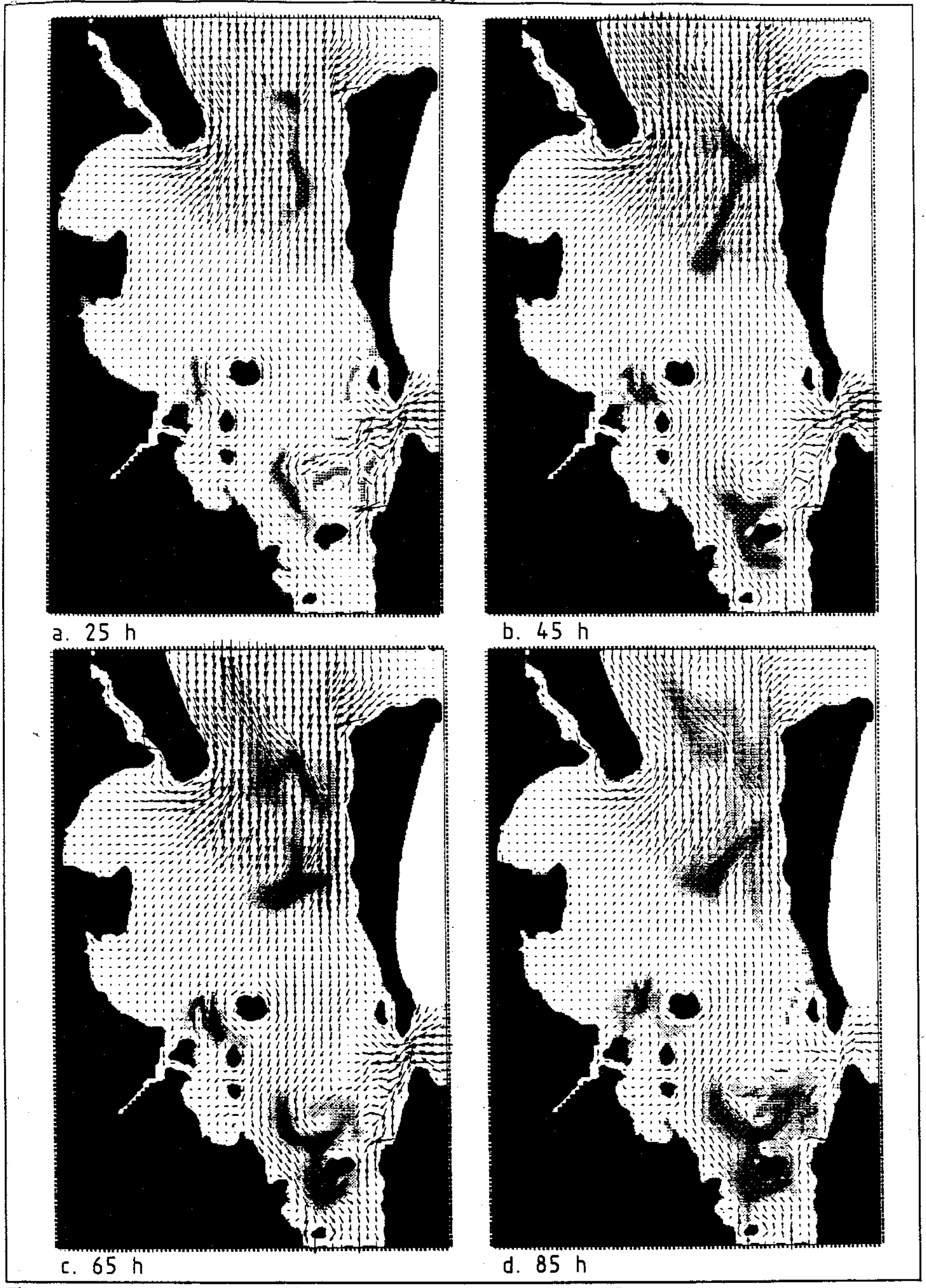

Figure 2 *Transportation of Plumes in Moreton Bay*
Current Patterns and Plume Concentrations at times 25, 45, 65 and 85 hours