The application of MIKE 11 river modelling package to modelling the middle reaches of an estuary
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Abstract

The understanding and prediction of effects of engineering schemes on estuaries can be facilitated by using mathematical models. One such mathematical model, MIKE 11, that models the transport of solute and suspended solids was recently introduced into the market by the Danish Hydraulic Institute, Denmark. MIKE 11 has been tested with recent field measurements of solute concentration, tide level and flow in the middle reaches of the Tamar Estuary. The Tamar is located in the South West of England and is partially mixed in its middle reaches. The time varying dispersion coefficient for solute transport has been estimated from vertical profile data from mid-channel. The results from the modelling exercise suggest that MIKE 11 is suitable for practical modelling of a partially mixed tidal river. There is a drawback with editing. Other qualities of the software were tested and the view of the author was given on each of these qualities.

Introduction

Estuaries are of economic importance as they are used for, amongst other things, navigation and disposal of solid and liquid pollutants. The understanding and prediction of effects of engineering schemes on estuaries are therefore important in order to optimise the use of estuaries. This understanding can be facilitated by using mathematical models. One such mathematical model, MIKE 11, that models the dynamic transport of solute and suspended solids was recently introduced into the market by the Danish Hydraulic Institute, Denmark.

An estuary constantly experiences the interaction of fresh water, saline water, and turbid water. The mixing and flushing actions of tides, together with the irregularity in the channel structure, the variation in the bed material and the presence of a longitudinal density gradient lead to complexity in the structure of estuarine
flows. The interaction of these phenomena leads to transverse and / or vertical density gradients which may be very small or may occur as interfaces.

The experience to date with the application of MIKE 11 to non-tidal rivers is that the software performs adequately well\(^3,4\). However, the application of MIKE 11 to rivers for modelling river impacts can be extended to partially-mixed estuaries with small vertical density gradients, provided the vertical density gradients are small enough not to invalidate the one-dimensional assumption implied in the MIKE 11 software. To the author’s knowledge, a case study on such application has not been discussed previously.

This paper describes the testing of MIKE 11 software with recent field measurements of solute concentration, tide level and flow in a 4.2Km reach the Tamar estuary (Fig. 1). Discussion of the testing is centred on the modelling performance of MIKE 11 software when applied to a partially-mixed tidal river.

**Modelling Strategy and Field Work**

The testing programme was designed to give an overall assessment of the performance of the software and an indication of likely errors.

The tests adopted checked the stability of the hydraulic and pollutant transport modules and the software capability of modelling winding channel. All these were checked using the field data obtained during a measurement campaign in 1985 in the Tamar.

The data used for testing the MIKE 11 software are described below:

The vertical distribution of the horizontal mean velocity of water was measured over 100sec. intervals using an array of Braystoke current meters mounted at 0.25m intervals on a 2m mast, with the current meter closest to the bed placed at 0.25m above the bed. Salinity and temperature readings were obtained by using MC5 salinometers, the calibration of which was checked before and after the surveys\(^5,6\). Vertical gradients of temperature are approximately zero for the data collected.
As part of the data collection a survey of the 4.2Km reach of the estuary was undertaken.

Computing Requirements

The program is written in a modular form and is developed to run on hardware that is widely used in the educational establishments and in the water industry. These are IBM compatible personal computers and UNIX workstations. The hardware used for the study described in this report is the former.

Data Analysis and Discussion of Results

Hydrodynamic Module

The Hydrodynamic module (HD) is the most essential of the MIKE 11 package. In this module, the channel, time varying flow and any instream structure configurations within the channel are defined and modelled. The module is used as a basis for all other modules within MIKE 11. In this study, instream structures were not present within the channel modelled. The absence of instream structures was necessary in order not to complicate the objective of this study - that of evaluating the effect of vertical density gradients on the performance of MIKE 11 software.

Stability

The testing was aimed at identifying the situations which caused instability. The esuarine channel reach shown in Fig. 1 was used in testing the HD module.

It was found that instability was a problem when large time steps were used. The instability was removed by a reduction in timestep. From the author’s experience, it is better to operate the model with time steps of approximately 1 minute when slope of channel is $10^{-3}$ or less. Spatial steps of between 350m and 650m were used successfully in this study.

Examples of outputs from the hydrodynamic modelling are shown in Figs. 2 and 3, together with the field data. Chainage 0.000Km is the extreme upstream location (Calstock) in the reach while chainage 4.200Km is the...
extreme downstream location (Halton Quay). The trends in the hydrodynamic parameters are satisfactorily predicted. Errors in water level range between 0 and 0.5m. The errors are a combination of numerical errors and other potential errors within the modelling exercise (e.g. data collection error, modelling assumption error etc.). These levels of errors are however thought to be acceptable in view of modelling the partially-mixed estuary with a one-dimensional approach. Furthermore, the errors are acceptable for an approximate solution to a similar engineering problem to the one described in this report – that of an estuary with vertical salinity gradient of up to 5 Kg/m$^4$.

**Transport - Dispersion Module**

The Transport - Dispersion (TD) module is based upon the one dimensional equation of the conservation of mass. It is used to simulate the advection and dispersion of dissolved and fine suspended matter. The module requires the results file from a relevant HD module for the flows, water levels and channel geometry. In this study, the TD module was used to model the advection and dispersion of salt.

**Dispersion**

The estuarine channel reach used in this study was assumed to be well-mixed transversely. This allowed for the calculation of the time varying dispersion coefficient for solute transport from the vertical profiles of salinity and longitudinal velocity. The basic relationship used is given below:

\[
D = \langle -S'U' \rangle \cdot \frac{dX}{dS}
\]  

(1)

where

- $D$ = dispersion coefficient
- $U$ = cross-sectional average longitudinal velocity
- $S$ = cross-sectional average salinity
- $U'$ = local deviation of longitudinal velocity from $U$
- $S'$ = local deviation of salinity from $S$
- $X$ = longitudinal co-ordinate direction
- $\langle \rangle$ indicates cross-sectional average value
The dispersion coefficient calculated using equation (1) was expressed in the form acceptable to MIKE 11. This form is written below:

\[ D = f \cdot V^{ex} \]  

where \( f \) = dispersion factor  
\( V \) = flow velocity  
\( ex \) = dimensionless exponent

The results of the simulation of salt transport in the estuarine reach are shown in Fig. 4, together with measured field data. The trend in the salt concentration is adequately predicted. The differences between these two sets of data have a maximum of 3Kg/m^2. These values, when compared with the corresponding vertical gradients of salt concentration ranging between 0 and 5 Kg/m^4, are remarkably low for a two-dimensional problem of this nature.

Overview on Data Entry and Ease of Use

Data entry is menu-driven and clear instructions are usually given. Most inputs are checked for range compliance and an error message is displayed for inappropriate values. However editing was found to be tedious.

Presentation of results is of reasonably good quality and graphics are easy to use, but some errors throw users out of the software completely without prior warning.

Conclusions

A version of the MIKE 11 software package was tested and it adequately models a partially-mixed tidal river.

The HD module models successfully the winding channel used in this study. However, it was noted that instability could set in when large values of time step are used. The range of values of time and spatial steps used successfully for this case study are provided.
The TD module models successfully the salt concentrations in the estuarine reach. Other qualities of the software were tested and the view of the author was given on each of these qualities.

References

1. Danish Hydraulic Institute, MIKE 11 Manual, Denmark.


Fig 2
WATER LEVELS AND DISCHARGE IN THE TAMAR
K. ODUYEMI, DUNDEE INSTITUTE OF TECHNOLOGY

field data

DATA FILE : TAMAR.RDF
RESULT FILE : TAMAR.RRF
BOUNDARY FILE : TAMAR.BSF
CALCULATED : 2 - JUN - 1993, 10:58

MIKE 11
Dwg no:
Fig 3  WATER LEVELS AND DISCHARGE IN THE TAMAR
K. ODUYEMI, DUNDEE INSTITUTE OF TECHNOLOGY

FIELD DATA

DATA FILE : TAMAR.RDF
BOUNDARY FILE : TAMAR.BSF
RESULT FILE : TAMAR.RRF
CALCULATED : 2 - JUN - 1993, 10:58

MIKE 11
Fig 4

SALINITY IN THE TAMAR
K. ODUYEMI, DUNDEE INSTITUTE OF TECHNOLOGY

DATA FILE : TAMAR.RDF
RESULT FILE : TAMAR.TRF
BOUNDARY FILE : TAMAR1.BSF
CALCULATED : 2 - JUN - 1993, 11:03

MIKE 11