A MODULAR MODELING SYSTEM FOR HYDRODYNAMIC AND SOLUTE TRANSPORT MODELING

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Abstract. In this paper, a Modular Modeling System for simulation of flow and contaminant fate and transport in open-channel networks, called *RiverNet*, was introduced. The governing equations and algorithm used in this system, and the design and functionality of the software are described. By integrating flow simulation module and solute transport module into same environment and platform, it can simulate flows and contaminant fate and transport process in open-channels separately and conjunctively with user-friendly Graphic User Interface (GUI). It can solve various complex flow regimes including shock wave propagation and contaminant transport under both steady and unsteady flow regimes.

INTRODUCTION

Simulation of flow in open-channels and contaminant transport and fate in streams are important topics in river mechanics and environmental engineering. Many research works have been done for the solutions of these problems and significant progress has been made in this area (Schaffranek et al. 1981, Bencala et al. 1983, Alcrudo et al. 1992, Bhallamudi et al. 1992, Navarro Garcia et al. 1992, Choi et al. 1993, Jha et al. 1994, Aral et al. 1998). Although some industrial codes and software have been developed for practical applications, they have some deficiencies and usually lack of user-friendly interface. For instance, software for flow simulation can usually not solve shock wave propagation or discontinuous flows. Software for solute transport is usually only suitable for steady flow case or just solve simplified flow equation. Therefore, the general software with user-friendly interfaces for both continuous and discontinuous flows and for solute transport under both steady and unsteady flow regimes is necessary.

RiverNet, a Modular Modeling System for hydrodynamic and contaminant transport modeling in open-channel networks for this purpose, was developed by the author when he did research in Multimedia Environmental Simulation Lab at Georgia Institute of Technology[1]. In this paper, the details of this system will be described, which includes governing equations and algorithm used in the software, the design and functionality of the systems.

GOVERNING EQUATIONS

Hydrodynamics

The governing equations for unsteady one-dimensional flow in the channel segments, called St. Venant equations, can be written in conservative form as [Liggett and Cunge,1975]:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left[\frac{P}{r}+\frac{Q^2}{A}\right]=gA\left(S_0-S_f\right) \tag{2}$$

Where, A is the cross-sectional area of the channel; Q is the discharge; S_0 is the channel bed slope; S_f is the friction slope defined by

$$S_f=\frac{Q\,|Q|}{K^2} \tag{3}$$

Where K is the conveyance, defined as

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$$K = \frac{Co}{n_0} AR^{2/3} \qquad (4)$$

In which n_0 is Manning's roughness coefficient; R is the hydraulic radius; Co is dimensional constant (Co = 1 for SI units and Co = 1.49 for the British units); P is the pressure force; is the density of the fluid ,and P/ is defined as

$$\frac{P}{r} = g \int_0^h (h - z) b(z) dz = gI \qquad (5)$$

Where, z is the vertical coordinate; h is the water depth; b(z) is the channel width at elevation z above the channel bottom , i.e.,

$$b(z) = \frac{\partial A}{\partial z} \qquad (6)$$

Solute Transport

A solute transport model in a stream which takes into account transient storage consists of a system of two equations (Bacala et al. 1983; Aral et al. 1998): one for the solute concentration in the main channel and the other for the solute concentration in the storage zone. The exchange of solute between the main channel and the storage zone is based on the first-order mass transfer relationship, i.e., it is proportional to the difference in concentration between the stream and the storage zone. The governing equations are derived from the conservation of mass for the stream and storage zone segments and can be written in following conservative form [Dawes and Short, 1994]:

$$\frac{\partial (AC)}{\partial t} + \frac{\partial (QC)}{\partial x} = \frac{\partial}{\partial x}\left(AD \frac{\partial C}{\partial x} \right) + q_L (C_L - C) + a_s A(C_S - C) - kAC \qquad (7)$$

$$\frac{\partial (A_S C_S)}{\partial t} = a_s A(C - C_S) - k_S A_S C_S \qquad (8)$$

Where A is the stream channel cross-sectional area (L^2); A_S is the storage zone cross-sectional area (L^2); C is the in-stream solute concentration (M/L^3); C_L is the solute concentration in lateral inflow (M/L^3); C_S is the storage zone solute concentration (M/L^3); D is the dispersion coefficient ($L^2\ T^{-1}$); Q is the flow discharge ($L^3\ T^{-1}$); q_L is the lateral inflow rate ($L^2 T^{-1}$); $_s$ is the storage zone exchange coefficient (T^{-1}); k is the in-stream first-order decay coefficient (T^{-1}); k_S is the storage zone first-order decay coefficient (T^{-1}).

Above governing equations combined with initial and boundary conditions consist of mathematical models solved in *RiverNet*.

ALGORITHM

A relaxation scheme (Jin and Xin, 1995) was used to solve flow equations in open-channels and solute transport equations. Various complex flow regimes and shock waves in open-channels can be solved using this algorithm (Aral, Zhang and Jin, 1998). Solute transport equations were also successfully solved even for pure advection equation for which most tradition algorithms fail to solve (Aral and Zhang, 1998).

RIVERNET - A MODULAR MODELING SYSTEM

General Description

RiverNet is a modular modeling system developed using Visual Basic 6.0 and DBGrid database tool. It includes two modules which are flow simulation module and contaminant transport module. Each module can be run independently or conjunctively with other module.

In *RiverNet*, each module includes a Tabular Form Interface and Graphical Interface for data input and output depending on the user's preference, and can be executed independently. This modeling system with user-friendly GUI interface allows a user to generate input and output data much more easily and provides an efficient and convenient way for a user to simulate flows and contaminant transport and fate in open-channel networks. In addition, the main system window also provides file management, editing, on-line help, and other related functions.

Conceptual Design

The conceptual model is shown in Figure 1.

System Components

There are three main system components, which collaborate to provide the required functionality. Each component has specific responsibilities as listed bellow.

1. Flow simulation Module

This component includes two parts: Flow Simulation Model and GUI Interface. GUI interface

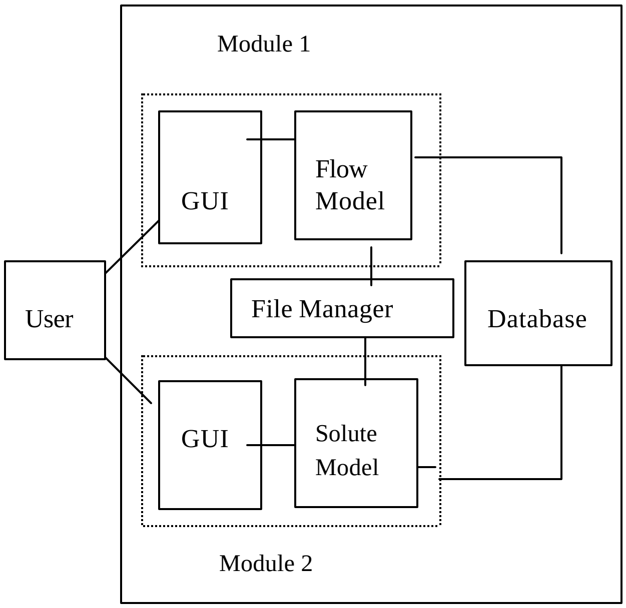

Figure 1. Concept design.

provides a user a platform to input data into the model, output results and display those results easily and efficiently as shown in later part. The flow simulation model computes the flow regimes based on the input data.

Input data are input into data files or database through GUI interface for use by flow simulation model. Then simulation model is run and the results are store in data files or database. The results then can be displayed in graphics or table through post processing GUI interface. The functionality of flow module will be shown later.

2. Contaminant Transport simulation Module

This component also includes two parts: Contaminant Transport Simulation Model and GUI Interface. Similarly, GUI interface provides a user an environment to input data into the model, output results and display the result easily. The contaminant Transport simulation model computes the contaminant transport and fate process based on the input data.

The design and functionality of GUI interface for this module are very much like those in Flow Simulation module above. But in this module, we have more pages and functionality in GUI interface for inputting data related to contaminant transport and fate.

3. File Manager and Database

File manager consists of various files that are needed by the model. These files include initial condition file, boundary condition file, input, output, and temp files. The initial file holds initial conditions, boundary file holds boundary conditions, the input file holds all input data, the output file holds all output data and temp files hold some intermediate results. DBgrid database tool is also used to store and display various data.

GUI Interface

The user interface is a windows-based, graphical user interface (GUI) developed by Visual Basic. All forms are MDI (Multiple Document Interfaces) forms except the Welcome form. This MDI technique provides users easier access to the functions and menus, and makes the system easier to maintain and update. It is operated in Windows 98/NT environment. The interface is user-friendly and easy to use without causing frequent errors.

The GUI interface includes Graphic Input interface and Tabular Input interface. For the graphic Input interface, a user can draw any river network that he wants to simulate for on the screen using the mouse. A user can also erase the drawing using the mouse.

The river network consists of channels and junctions. By clicking the channel or a junction, a user can input river parameters, initial conditions, boundary conditions and other input data into the model through dialogue boxes. All input data will also appear in the tabular input interface.

The Tabular Input interface consists of various textboxes and true grids. The true grid allows a user to input any size of river network and the parameter value can be edited.

Post processing interface allows a user to display the simulation results in graphic or table format.

Several examples of GUI interface are shown in following Figure 2, 3 and 4.

System Functionality

The following functions are provided by this system:

1 The system can simulate various complex flow regimes including subcritical, supercritical, hydraulic jump or bole etc. in complicated river networks. It can also simulate contaminant transport process in river system under both steady and unsteady flow regimes. The system can run both Modules independently or in conjunction.

2 The system provides a user-friendly GUI interface

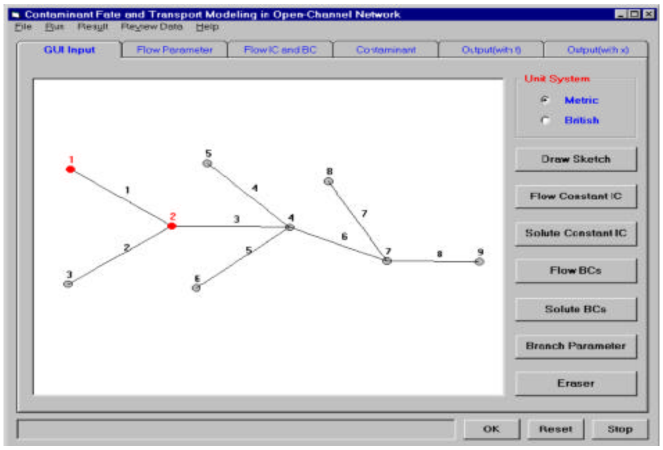

Figure 2. GUI Interface.

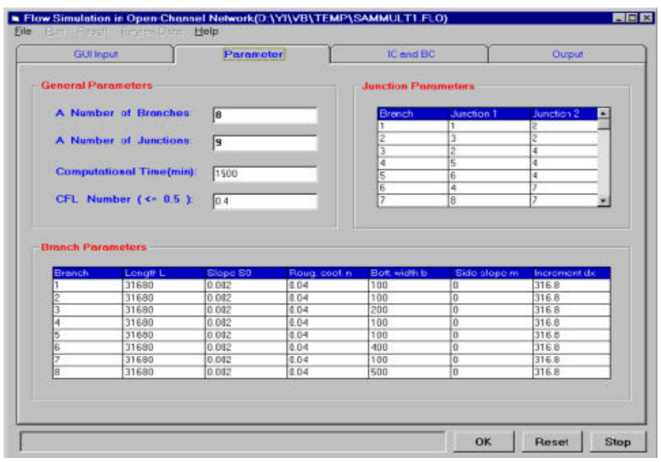

Figure 3. Tabular Form Interface.

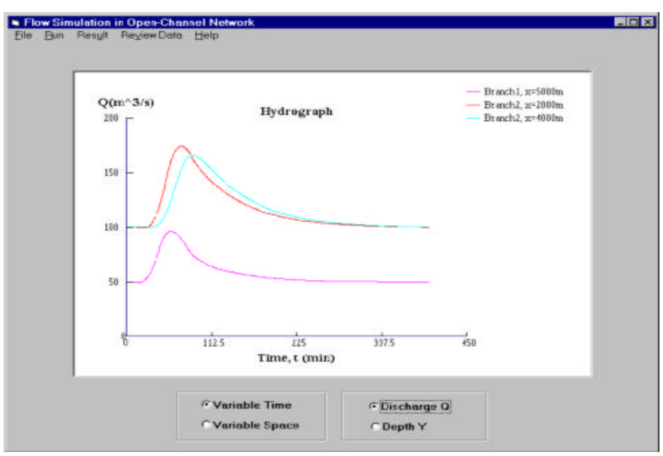

Figure 4. Post Process and Result Display Form.

so that a user can easily generate data input and output, run the model and do post processing and analysis conveniently and effectively.

3 The GUI interface has both tabular input interface and graphic input interface so that a user can use either of them to generate data input. Both formats can allow different type and structure of channel networks without special limitation on size of channels. A user can easily edit and modify the input data through both interface formats and save the input data into the file and database. Later, the user can easily load the data into interfaces to view and modify them or directly open the file and database to view and modify them. The GUI allow different types of initial and boundary conditions, i.e., both constant and variant conditions. The user can set up output at any place and any time point thought GUI.

4 The user can display output in a graphic and tabular format.

5 The system provides graphic display functionality for display various output results graphically and can print out the result and graphics.

6 The system provides database and file system for data storage so that a user can view and manipulate the data easily.

7 The system can automatically check data input and give error information if input is wrong or absent. The system provides strong error handling. The run time error is below 0.1%.

8 System provides on-line help system.

SUMMAY

RiverNet integrates hydrodynamic model and contaminant transport model into same platform with a very user-friendly GUI interface for input, output, simulation, error checking, result display and post processing. Two modules for flow simulation and contaminant transport can be run independently or conjunctively. It can simulate various complicated flow regimes with discontinuities or shocks in flow regimes in open-channel networks. It can also simulate contaminant fate and transport under unsteady flow regime. *RiverNet* provides a convenient tool for modeling flow and contaminant fate and transport in open-channel networks.

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