Numerical Simulation of Flood Routing in Complex Hydraulic Schemes. The "Routing System" Computer Program

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ABSTRACT

Dams are often connected to hydraulic structures devoted to water collecting, conveying or control. Therefore, flow of water is strongly modified in such catchment areas influenced by hydraulic structures. The computer program, "Routing System", was developed in order to simulate flood formation and propagation in complex schemes constituted of multiple watersheds, water intakes, reservoirs, galleries and control structures.

"Routing System" is based on LabVIEW® from National Instruments, a standard data acquisition software. All the structures are described by their hydraulic function in the simulated network, like diversion, storage in reservoirs or routing in channels. These functions, represented by module icons, can be composed on a window. The connections between modules allowing the flow of data are made simply by wiring the different icons with the mouse. Very large and complex networks can be modelled with this system, which enables analysis at different scales by grouping of sub systems.

KEYWORDS

Fluvial system, flood storage, flood routing, hydraulic structures, flood, hydraulic function, network, hydrology, watershed, data acquisition, graphical programming, numerical simulation

INTRODUCTION

The software RS, for "Routing System", was developed in 1996 at the Laboratory of Hydraulic Constructions of the Swiss Federal Institute of Technology in Lausanne. It offers a library of hydraulic functions which permits the simulation of flood routing in complex hydraulic schemes connected to natural watersheds [1].

Routing System is based on a functional description of the flowing system. In fact, only 6 functions are needed to simulate it, which are the flow generation, the water routing, the flow diversion and addition, the storage and the regulation. Since all hydraulic structures generally have a proper and original design, the simplest way to classify them is by means of their hydraulic function in the fluvial network.

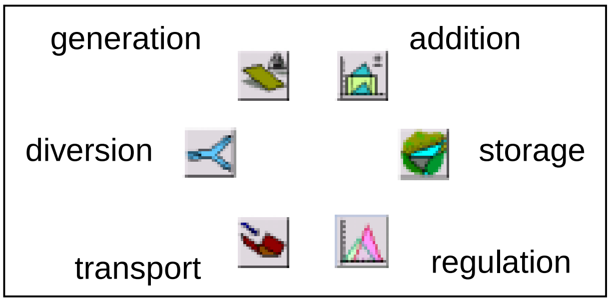

Figure 1 : The basic hydraulic functions to model the entire fluvial system.

In fact, all is function! Watersheds are generation functions, intakes are diversion ones, rivers transport, lakes and basins store, confluences add (Figure 1). The data flowing through the network are functions too : hydrographs, height – discharge relations, upstream discharge – derived discharge relations and so on. This concept greatly simplifies the modelling of a scheme. It also allows to aggregate a part or a complete network in a single macro-function which can be incorporated again as a simple one in a larger scale model. With Routing System, it is possible to build these macro-functions which simulate the behaviour of a complex entity related to a little watershed, a geographic area or to the entire scheme.

“Routing System” is based on the commercial software LabVIEW from National Instrument [2]. LabVIEW is a program development application, much like various commercial C or BASIC development systems. However, it differs in one important aspect. While other programming systems use text based languages to create code lines, LabVIEW is based on a graphical language, G, to create programs in block diagram form. The principle that governs the “Routing System” program execution is called data flow. Stated simply, a node or a function executes instructions only when the data arrive at all its input terminals. The function supplies data to all of its output terminals when the execution is finished, and the data passes immediately from source to sink terminals. Data flow contrasts with the control flow method of a conventional program, in which instructions are executed in the sequence they are written in. Control flow execution is instruction driven when the data flow is data driven or data dependent.

“Routing System” is a library of sub routines, called VI for “Virtual Instrument” in the LabVIEW terminology. All the 6 hydraulic functions presented in figure 1 have been implemented and are ready for assembly. The user of RS can easily model his hydraulic network by dropping the needed functions in the block diagram and wiring them to transfer the information from one to another. Any error made during the development of the model is immediately detected, described and localised by the programming environment. Graphically developed routing models are compiled in real time without any intervention of the user. This guarantees a user friendly environment and optimised performance.

BASIC HYDRAULIC FUNCTIONS

GENERATION OF FLOOD

In the Routing System terminology, the flood generation is to be understood as a hydrologic model. The one implemented here is oriented towards the estimation of extreme floods in alpine watersheds. It solves the kinematic wave equations over a plane [3]. These equations look like :

$$\frac{\partial h}{\partial t} + \frac{\partial (Vh)}{\partial x} = i \qquad (1) \qquad\qquad J_0 = J_f \qquad (2)$$

where h is the flow depth, V the mean velocity, i the intensity of the rain, J_0 the slope of the plane and J_f the slope of the energy line. With a relation between mean velocity and flow depth of the form

$$V = \alpha h^{m-1} \qquad (3)$$

a partial differential equation with one variable is obtained :

$$\frac{\partial h}{\partial t} + \alpha \frac{\partial h^m}{\partial x} = i \qquad (4)$$

Transforming this equation by means of the method of characteristics leads to the following system :

$$\frac{dh}{dt} = i \qquad (5) \qquad\qquad \frac{dx}{dt} = \alpha m h^{m-1} \qquad (6)$$

The integration of equation (5) gives the evolution of the flow depth in time and space. It is only valid on the characteristic described by equation (6). If the rain is constant over a time step, it is possible to solve these equations analytically and to obtain the hydrograph at the downstream end of the plane.

Input parameters of this function are the upstream hydrograph (optional), the relation between time and intensity of the rain, the runoff coefficient, the length of the plane, its slope and its roughness coefficient. The result is the downstream hydrograph.

ROUTING IN A RIVER

This function performs the routing of flood in a river or a channel. The routing phenomena is modelled through the Muskingum-Cunge method [4]. Cunge demonstrated that this solution corresponds to the approximation of the diffusive wave of the full St-Venant equations. By means of finite difference approximation, one can obtain :

$$Q_j^{t+1} = C_0 Q_j^{t+1} + C_1 Q_j^t + C_2 Q_{j+1}^t \qquad (7)$$

with

$$C_0 = \frac{\Delta t - 2Kx}{2K(1-x) + \Delta t} \quad (8) \qquad C_1 = \frac{\Delta t + 2Kx}{2K(1-x) + \Delta t} \quad (9) \qquad C_2 = 1 - C_0 - C_1 \quad (10)$$

and

$$K = \frac{\Delta x}{dQ/dA} \quad (11) \qquad x = \frac{1}{2}\left[1 - \frac{Q}{BJ_0 \Delta x \, dQ/dA}\right] \quad (12)$$

where Q_j^t is the discharge at time t in the distance x of the reach, A is the wetted cross section, B the width of the cross section at the free surface, Δt the time increment and Δx the space increment. The input parameters are upstream hydrograph, slope, length, shape and roughness coefficient of the river. The result is the downstream hydrograph.

FLOOD DETENTION

This function perform the whole computation of storage and flood detention effect in a reservoir. This effect is described by the continuity equation:

$$\frac{d\forall}{dt} = Q_e - Q_s \quad (13)$$

where $\forall$ is the volume of water in the reservoir, Q_e is the input discharge and Q_s the output discharge. This differential equation is numerically integrated with the fourth order accurate algorithm of Runge-Kutta [5]. The inputs are the entering hydrograph, the level – volume relation of the reservoir and the height – discharge relation of the outlet structure. In order to initialise the integration, the initial water level in the reservoir is also needed.

This function produces two results, namely the downstream hydrograph and the time dependant water level evolution in the reservoir.

DIVERSION OF FLOOD

A water intake can also be modelled by a function. It requires a relation between the upstream and the derived discharges. This relation can easily be established in a spreadsheet and then imported into “Routing System”.

CONFLUENCE

A confluence of two rivers is a hydraulic function of summation of hydrographs. The hydrographs flowing in a Routing System network have not to be described by synchronised points. This function manages interpolations to obtain correct results.

In order to put this conceptual development into concrete form, an application example will be presented below.

APPLICATION EXAMPLE

It is well known that expanding urbanisation amplifies flooding in river areas. One original and efficient method to fight flooding in such cases is to divert flood peaks into appropriate storage reservoirs. Once the first outline of a possible scenario including the protection objective, the associated flood and the protection measures, has been chosen, the analyst can proceed to the optimisation of the overall project. This may, if it concerns a large area, involve several combinations of storage basins.

In order to simplify the optimisation procedure of such a project significantly, “Routing System” will be used. The modelling can thus be executed in a user-friendly way. As an example, a scheme of seven consecutive basins parallel to the river is proposed in figure 2. The icons either represent elements of the river network such as derivation works, storage basins, confluences, etc., or they characterise, if connected to file addresses which themselves contain the functions, the previously mentioned elements.

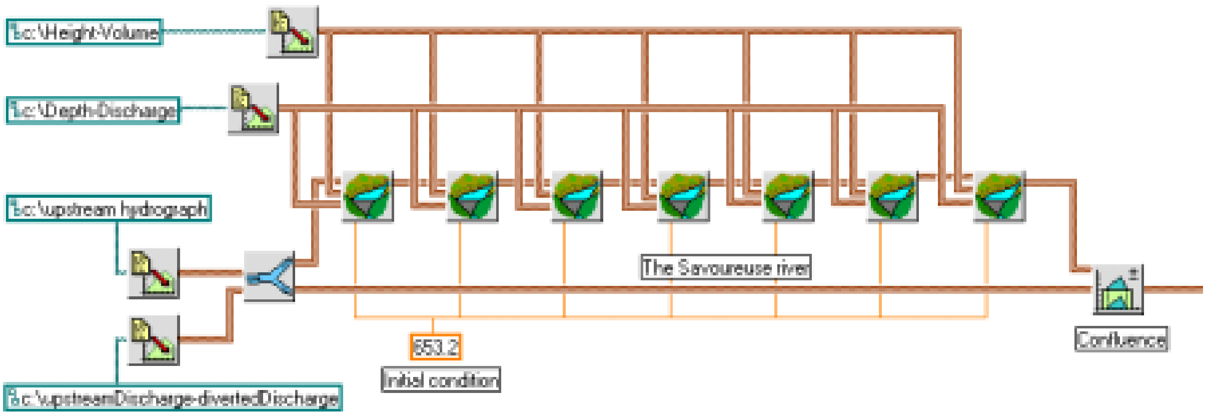

Figure 2: Project modelling using “Routing System” (RS).

The results of the RS-simulation can be represented either graphically or in text-file form. A graphical output calculated in order to optimise the mentioned sequence of seven storage basins is shown in figure 3. The upstream hydrograph represents the flow evolution just upstream of the derivation work. Note that part of the flow is derived as soon as the discharge reaches the sill value. The derived hydrograph represents the time variation of the inflow in the successive stages of storage basins, each of which is able to stock a certain amount of water and thereby reduces the resulting outflow.

The result of figure 3 shows in an impressive manner how efficient storage may be with a sequence of seven storage reservoirs. In that specific case, the peak discharge corresponding to the return period T = 50 years could be reduced by as much as 17 [m^3/s] to 51 [m^3/s] which corresponds to a return period of T=10 years. Without RS, the optimisation of this system would be annoyingly time-consuming.

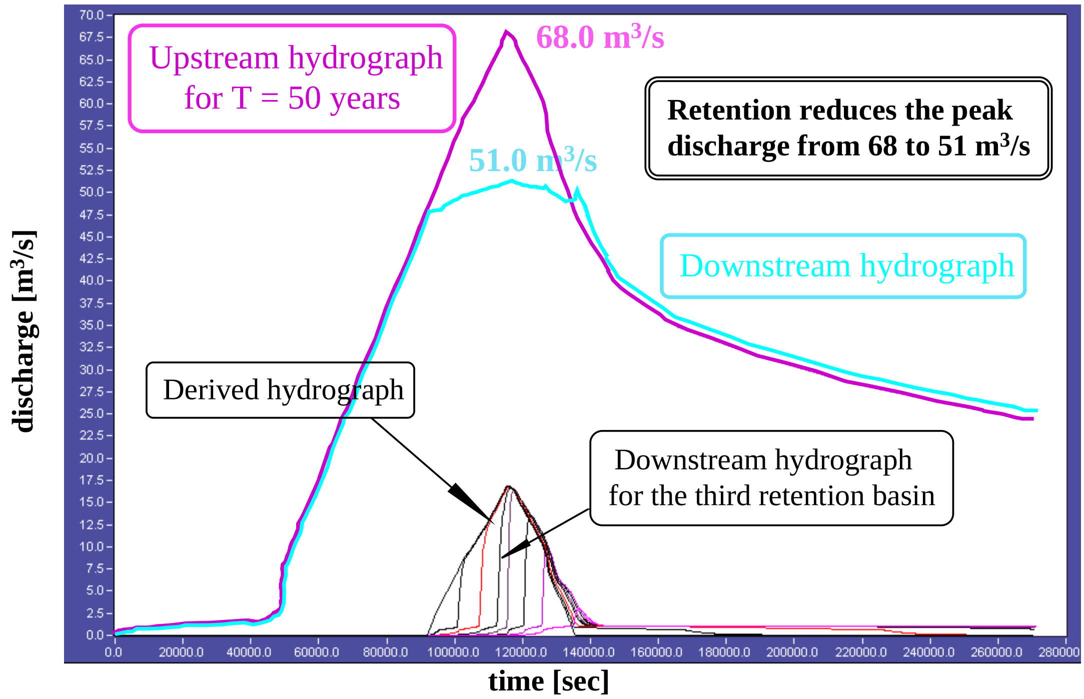

Figure 3: Routing-System-calculated results.

CONCLUSIONS

The numerical simulation of flood routing in complex hydraulic schemes can be considerably simplified when describing each element of the network by its hydraulic function. Fundamentally, six different functions can achieve the model building. The programming of this concept is performed by the "Routing System" software. It is supported by the LabVIEW program and developed with its graphical language. One of the most important advantages of "Routing System" is the fact that it allows the aggregation of partial or complete schemes within macro-functions which are useful for the analysis of large fluvial systems on different scales.

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