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Uncertainty in Dam Break Flow Simulation

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The flow caused by a dam breaking across its entire length can be approximated by a one-dimensional, unsteady flow model in form of the St. Venant equations. In this model, the flow is governed by the river geometry and the river roughness, which is quantified by Manning's coefficient. The roughness characteristics are generally difficult to estimate under natural conditions. Thus, the estimates of the Manning's coefficient will in general be subject to uncertainty. In this paper, the uncertainty in the discharge and depth hydrographs due to the uncertainty in estimating the roughness characteristics of a river, is investigated. A specific case of the Noppikoski dam in Sweden that failed in 1985 is used to illustrate the sensitivity of the flow simulation on the roughness coefficient. The analysis shows that the uncertainty in the dam break flow simulation due to the uncertainty in estimating Manning's coefficient, is significant. The uncertainty is larger at greater distances from the dam, and is greater for the discharge hydrograph than for the depth hydrograph.

Introduction

Dams are built for water supply, hydro-power, flood control, etc. However, dams may cause catatrophic disaster to human life and property if they collapse. In order to be able to assess the consequences of a dam failure, simulation of the flood caused by a dam break is required.

In current investigations, the unsteady flow caused by a dam breaking across its entire length is usually approximated as one-dimensional flow. This flow is commonly assumed to be described by the shallow water equations, where the vertical motion is neglected and the pressure distribution is assumed to be hydrostatic; these equations are also referred to as the St. Venant equations. It is reasonable to assume such hydrostatic pressure distribution in the vertical direction when the horizontal length scale is much larger in comparison to the vertical scale.

The governing equations describing the flow due to a dam breaking are non-linear quasi-hyperbolic systems of equations. In the general case, a numerical method must be applied for solving the St. Venant equations. Different numerical methods have been used for solving the dam break problem, such as the method of characteristics in combination with an algebraic shock fitting condition (Sakkas and Strelkoff 1973) and the Finite difference methods (Fread 1984; Fennema and Chaudhry 1987), etc.

In this paper, the St. Venant equations are solved using a finite difference scheme of the type presented in Kung (1988). A specific case of the Noppikoski dam that failed in 1985 is chosen for investigating the uncertainty in the depth and discharge hydrographs due to the uncertainty in estimating the roughness coefficient under natural conditions.

Governing Equations

The one dimensional St. Venant equations based on the conservation of mass and momentum can be used to describe the unsteady flow caused by a dam breaking in a prismatic channel having a small bottom slope. Furthermore, the rate of energy dissipation is assumed to be uniquely related to the bed shear stress and expressed in the same way as in steady uniform flow. This equation is written in form with no lateral inflow as (Cunge *et al.* 1980)

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

$$\frac{\partial Q}{\partial t} + \frac{\partial Q^2/A}{\partial x} + gA\,\frac{\partial h}{\partial x} \equiv gAS_B - gAS_0 \tag{2}$$

where

x – the distance along the river bottom measured positive in the downstream direction,

t – time,

Q – the discharge over the cross section,

A – the area of the cross section,

h – the water depth to the pressure center of the cross section,

g – the gravity constant

S_b – the river bed slope

S_0 – the energy slope.

The friction effect of the river bed is approximated by Manning's formula which is expressed in terms of the conservation variables as

$$S_0 = \frac{n^2 Q|Q|}{A^2 R^{4/3}} \tag{3}$$

where

n – Manning's coefficient,
R – the hydraulic radius of the cross section.

Eqs. (1) and (2) are nonlinear partial differential equations which are to be solved numerically by using a finite difference TVD type of scheme presented in Kung (1988).

Deterministic Simulation

In our present discussion, we shall use for illustrative purposes the dam at Noppikoski on the river Ore, in Sweden, that failed on September 25, 1985; this failure has been reported by Enfors and Eurenius (1988). Specifically, the dam failed by overtopping and eroded reaching the river bed within several minutes. The volume of the storage was approximately 1×10^6 m^3 and the dam height was 16.5 m. The reservoir was emptied within 45 minutes after the dam break. Neither the discharge, nor the stage hydrograph have been measured downstream of the dam during the flood. The flood caused by the Noppikoski dam failure was limited and did not cause significant damage.

The longtudinal profile of the river Ore, and the cross section geometry are shown in Fig. 1. Due to the characteristics of the river profile and the surrounding terrain, it seems most appropriate to approximate the river cross section as a prismatic channel. Furthermore, we shall hypothesize the breaching scenario as a sudden dam break. This is justified by the fact that the dam overtopped and eroded to the river bed within several minutes.

If the Manning coefficient of the river is estimated as $n=0.03$, we may calculate the passage flow at sections $x=5$ km and $x=10$ km downstream of the dam site. The resulting depth and discharge hydrograph at different sections are shown in Fig. 2. If the Manning coefficient, n, is estimated as 60% larger, *i.e.*, as $n=0.05$, the resulting depth and discharge hydrograph at sections $x=5$ km and $x=10$ km, are illustrated in Fig. 3. By comparing the curves in Figs. 2 and 3, it is shown that the depth and discharge hydrographs are significantly different for $n=0.03$ and $n=0.05$. This indicates a sensitivity of the dam break simulation to the value of the friction parameter, n. In the following section, we shall discuss more systematically the uncertainty in the depth and discharge hydrographs due to the uncertainty in the Manning coefficient n.

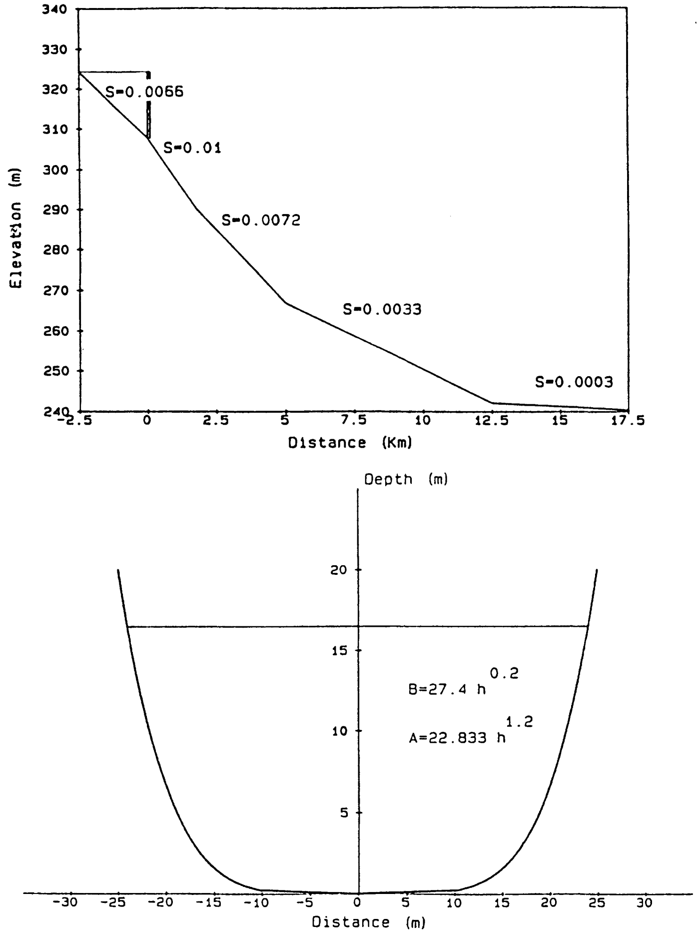

Fig. 1. Longitudinal profile and cross section geometry of the river Ore.

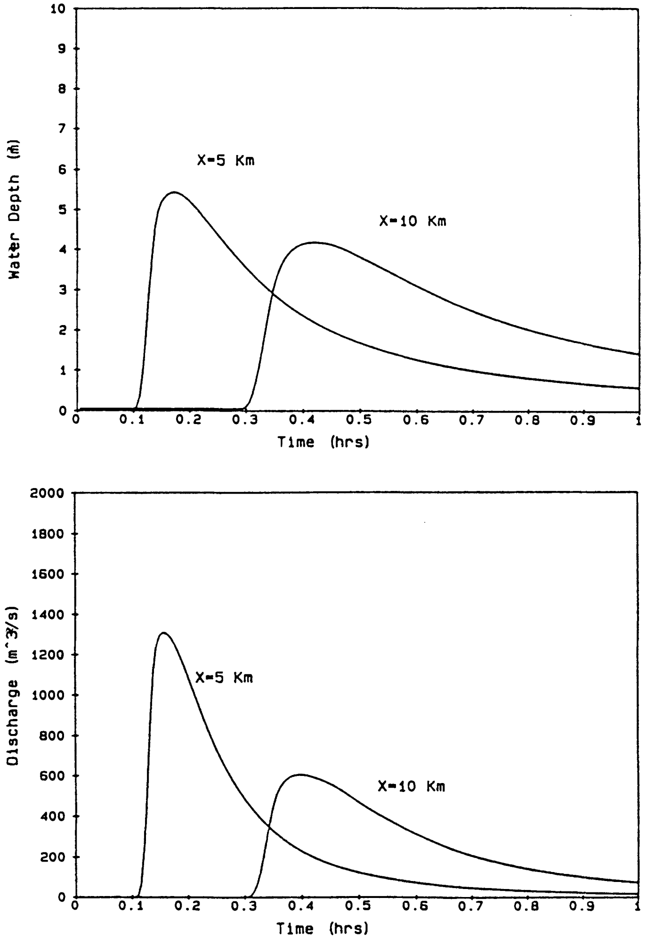

Fig. 2. Simulated hydrograph at different stations with roughness, $n=0.03$, a) water depth, b) discharge.

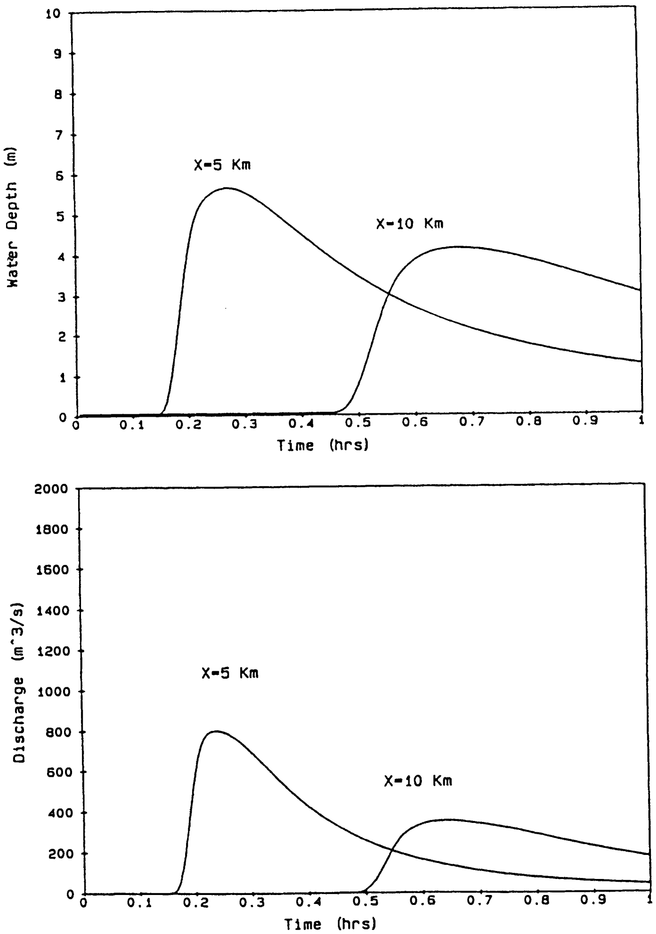

Fig. 3. Simulated hydrograph at different stations with roughness, n=0.05, a) water depth, b) discharge.

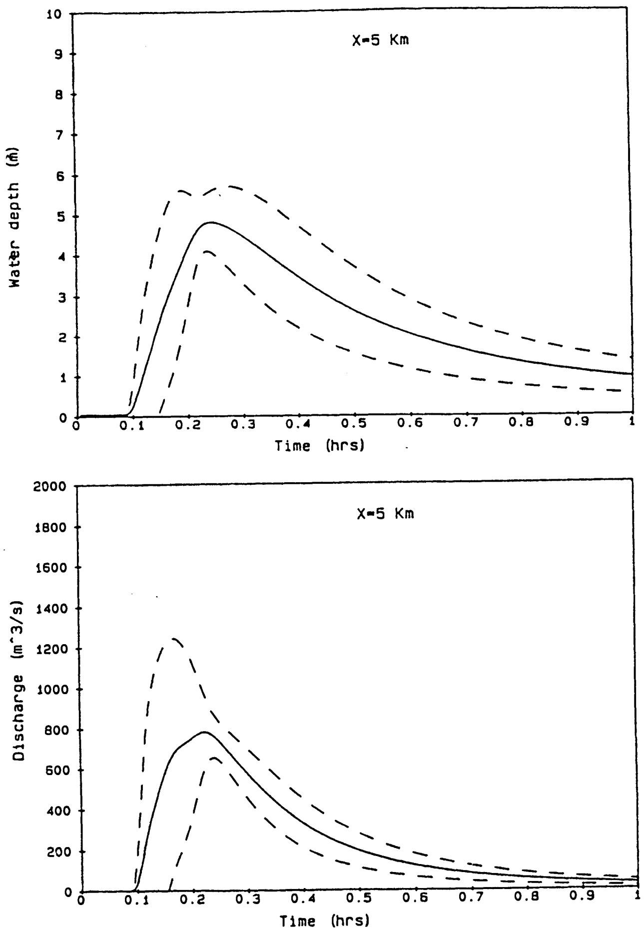

Fig. 4. The expected hydrograph within one standard deviation at X=5 km, a) water depth, b) discharge.

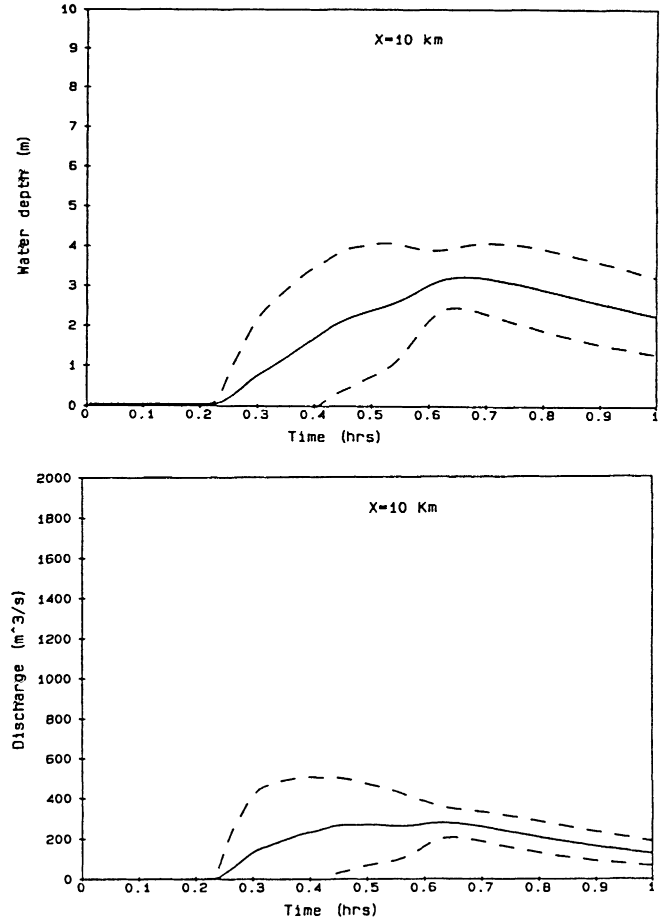

Fig. 5. The expected hydrograph within one standard deviation at X=10 km, a) water depth, b) discharge.

Stochastic Simulation

The uncertainty in the dam break flow simulation arises from three different sources. For instance, the uncertainty in the simulation will arise due to different possible breaching scenarios for the dam failure (see, *e.g.*, the discussion in Plate (1989)). Furthermore, the uncertainty in the dam break simulation arises from the fact that the assumed mathematical model is more or less appropriate for the physical system considered. Finally, uncertainty in the dam break simulation arises due to the uncertainty in our estimates of the hydraulic parameters. In this work, we shall restrict our discussion to the uncertainty arising due to parametric uncertainty.

In general, the Manning's coefficient, *n*, varies in space, and is a function of depth, discharge and other physical parameters. Because it is very difficult to estimate the distribution and the correlation properties of the roughness coefficient as a spatial random function, we shall assume that the dam break flow can be simulated with an effective *n*, that characterizes the roughness of a given river. The estimate of the effective Manning's coefficient, however, is also difficult and subject to uncertainty. In order to illustrate the effect of this uncertainty, *i.e.*, the sensitivity of the depth and discharge hydrographs on the roughness coefficient, *n*, the Monte Carlo approach is adopted.

Due to lack of information on the distribution of the roughness coefficient, we shall assume for simplicity that *n* is uniformly distributed, with the range from 0.02 to 0.06; however, other distributions, such as the normal, triangular, or lognormal, can readily be adopted for the analysis. The assumed limiting values for the roughness coefficient, *n*, represent possible values from a smooth river channel to the natural condition with trees in the river bank (French 1986). The expected depth and discharge hydrographs obtained from 50 realizations are illustrated in Figs. 4 and 5, at different cross sections, 5 km and 10 km, respectively. In addition to the expected value, one standard deviation limit is shown that illustrates the possible deviations from the expected values. The uncertainty is larger further from the dam since the arrival time of the flood wave is more dispersed due to the uncertainty in the friction coefficient (Figs. 4 and 5). Furthermore, the uncertainty is larger for the discharge than for the water depth, since the velocity is more sentitive to the value of the Manning coefficient in comparison to the water depth (comparing Figs. 4a and 5a, with Figs. 4b and 5b).

Conclusions

The uncertainty in the dam break flow simulation due to the uncertainty in the roughness coefficient, is significant. The uncertainty in the depth and discharge hydrographs is larger further downstream of the dam. Furthermore, the uncertainty is greater for the discharge hydrograph than for the depth hydrograph. Since it is difficult to estimate a single, effective value of the Manning's coefficient in engineering applications, the limits of the roughness coefficient should be estimated instead. Therefrom, using the analysis proposed in this work, the upper limit for the discharge and depth hydrographs can be evaluated.

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