DECISION SUPPORT SYSTEM FOR FLOOD MANAGEMENT BY RETENTION BASINS

by

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Abstract

Retention basins, when properly selected and designed, can be a powerful tool for flood management. A decision support system has been designed helping optimize the process of retention basins selection and design, using multiple criteria (hydrologic, hydraulic, economic, ecologic, etc.). As a running example, results of the river Tisza case study are presented.

1. Introduction

The concept of retention basins is well known in hydraulic engineering, as it provides an efficient means for active flood protection [3]. The retention basins are predefined and prepared storage areas into which the excess flood water is controllably discharged in order to reduce water levels downstream.

There are two cases when retention basins are used. The first is when the capacity of a river channel, i.e. the flood plains within the existing levees, is insufficient to reduce the water levels and discharges to an acceptable degree. This would happen if an extreme flood event occurs, exceeding the "design flood", according to which the levees have been constructed. Retention basins ensure protection against such floods. For instance, levees designed for 100-year extreme flows, may prove adequate for 500-year flows, if retention basins of appropriate volume are provided.

The second case is connected with the safety of levees. Some rivers are characterized by flood events of very long duration. Under such circumstances, the existing levees may be severely damaged due to effluent seepage. Water level control by retention basins prevents potential levee failures and ensures the safety of levees during long lasting floods of relatively frequent occurrence.

The underlying decision process consists of several principal parts, and is intrinsically of iterative nature. Selection of locations for retention basins requires decisions that are made at various levels. The criteria involved come from domains as disparate as topography, economy and ecology, and are often conflicting. A location that is favorable for its topography may be of too high economic and/or ecologic value, and vice versa.

On the other hand, the number and the size of retention basins is determined by the intended degree to which selected area(s) are to be protected from flood. This assumes that for any given level of protection, an analysis is performed making sure that the potential cost of damage to the protected areas exceeds the total costs involved in retention basins design, construction and operation (including damage caused by temporary flooding of areas covered by retention basins). All this indicates that there are no general comprehensive criteria that can guarantee optimal decisions in the planning phase.

The next important issue deals with optimization of construction parameters. After decisions are made on location of basins, their number and size, optimal values for side weir bottom elevation and length can be hydraulically determined.

Finally, optimal operational strategy is needed for an existing flood management system in order to fully utilize its potential. Such a strategy would enable the existing levee system to withstand floods exceeding the design flood, or to protect levees against damage or failure during very long flood events.

2. Decision support system characterization

To take full advantage of retention basins, as a powerful means for flood management, a decision support system has been developed. It is a suite of comprehensive models and databases, for the purpose of setup and evaluation of different policy alternatives with respect to planning and flood management.

The idea motivating the design of the system was to make operational the available knowledge, data and models describing various aspects of river flow, retention basin site selection, and design [4]. Some of the previous experience in building decision support systems [7], [8] has been used to design the present system.

2.1 Type of support

A suite of models integrated within a decision support system presents a quality advantage over a set of individual models. It is important that a user is able to analyze a number of possible cases with ease and flexibility. The system's support is off-line. The scope of the present system would have made on-line support of little advantage, if any. It is conceivable, however, that adding new modules to the system, and thus broadening its scope would call for including on-line support.

2.1 Target groups

The decision support system is made available to the following target groups:

- Policy makers and flood management decision makers. They will use the system in order to analyze the impact of different scenarios. They access model data via the user interface and make selection from the list of available options. It is assumed, however, that they have basic knowledge on the subject, i.e. that they understand basic concepts of the hydraulic model employed by the system.
- Modelers. They may use the system for sensitivity analyses. They must be able to access all the relevant input data, but it is not necessary that the user interface supports that activity. A modeler has the additional option of directly editing various input files for a particular model, using standard editors.
- Civil engineers involved in flood protection-aimed river training and various infrastructure developments (roads, highways, or railways).

2.2 User interface

User interface enables the user to run models, select various combinations of input data and analyze outputs, while requiring no specific knowledge about how data files are organized, about their formats, and other artifacts. When designing user interface several considerations have been kept in mind:

- User interface should provide sufficient flexibility for interaction with the model data. Data input is supported by providing default values and range checking. Users should have an overview of the options that are available to them during a particular analysis, and they should be kept informed of their progress in the analysis procedure.
- Users should be able to easily switch from one case or sub-area to another. The system should allow for easy and smooth integration of new modules (models, interface types).

2.3 System's structure

2.3.1 Hydraulic computational model

The hearth of this decision support system is a reliable, validated numerical model for the unsteady flow simulation. Hydraulically based predictions of time and space distribution of maximal water stages and discharges are to be used in order to formulate the most efficient flood management strategy.

One and two-dimensional unsteady flow computational models provide a sound means for reliable flow predictions, even for such complex flow patterns, as the one resulting from levee failure (Fig. 1).

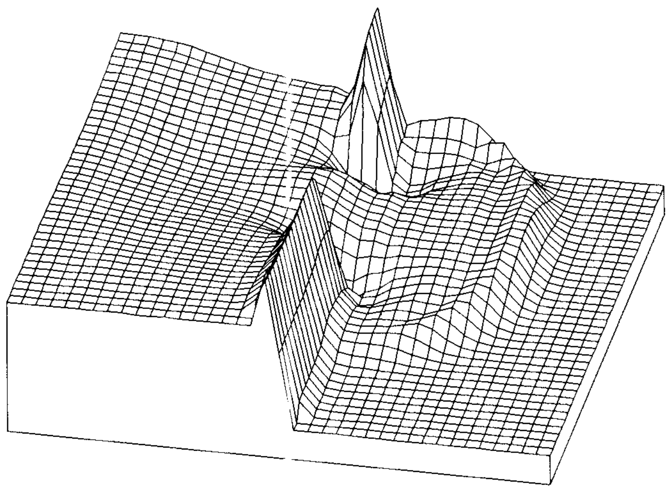

Fig. 1 Numerical simulation of two-dimensional breach flow, a few seconds after levee failure [4]

For calculation of flood waves propagation in river channel, one-dimensional flow models are usually used. These models are based on numerical integration of a system of partial differential equations describing the unsteady flow in non prismatic channels. After years of experience, the Preissman implicit method, the details of which can be found in numerous specialized literature (for instance, [2]), has become the standard method for this type of calculations.

The flow exchange between the river channel and a retention basin can be treated as broad-crested free weir overflow within the limits of 1D flow modelling. This flow is bidirectional, from the river channel to the basin, and vice versa, depending on the instantaneous water surface elevations. The water elevation in each basin is determined by iterative solution of the continuity equation, using the input elevation-volume relationship, and assuming that the water surface in the retention basin is horizontal.

2.3.2 Databases

There are several groups of data stored in system's databases. The first group comprise of input data and can be regarded as temporary. For the flow simulation model these data are hydrologic, hydraulic and topographic parameters of the model. Another set of input data are those describing various economic and/or environmental aspects of areas under consideration. These include cost of infrastructure, land use, associated ecological value, etc. and are used for evaluating alternate a candidate location for retention basin.

The next group of data are data on selected retention basins. The retention basins are either the already existing ones, or the prospective ones, that user have opted for in the course of consultation with the decision support system. These data are used for analyzing various scenarios for flood management.

Finally, data on user sessions are being recorded. Since in a typical session alternate solutions are considered and compared, choices made regarding input data, as well as sequence of steps taken during the session, are automatically recorded for future reference.

2.3.3 GIS interface

Incorporating interface modules to Geographic Information Systems (GIS) technology will broaden the possible applications of the decision support system. For instance, it will allow for automating some of the time consuming processes, as in suggesting optimal locations for retention basins. On the user interface part, GIS connection will further enhance the visual aspect of the system's support. Ability to represent visually, for instance, detailed areas under consideration, or depths of inundation, is a desirable property of the system. Moreover, for disciplines like hydroinformatics, as Abbott argues in [1], it has a deeper gnoseological value, serving as a vehicle for visual transfer of knowledge.

3. River Tisza case study

3.1 General layout

Several locations can be potentially used for water storage along the 80 km long reach of the river Tisza in Yugoslavia, between the town Bečej (km 76+150) and the Hungarian border (km 156+175, Fig.2). Using a database information on topographic characteristics, land usage, infrastructure, and other relevant data, three locations, labeled in Fig. 1 "1", "2", and "3" have been chosen for retention basins. Their individual capacities are between 105 and 140 million cubic meters, while the flooded areas are from 1560 to 2123 hectares.

The proposed retentions are to be activated only in the case when the water level exceeds the crest of the existing levees which have been designed for the 100-year flood, or in the case of emergency, when the stability of levees is endangered, regardless of the flood wave return period.

Each basin is to be provided with one side weir, used for filling and emptying. The bottom elevation and length of each weir is to be determined by hydraulic calculations in such a way that the retention capacity is maximal. The side weirs can be prepared in advance as emergency structures, or formed by blowing up a portion of the levee at the moment of emergency. In either case, their activation

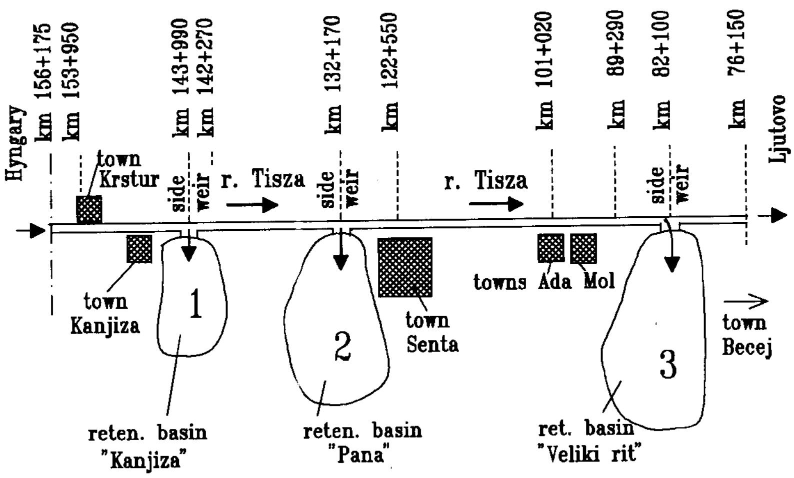

Fig. 2 Schematic layout of retention basins on the river Tisza

can be considered instantaneous in the time scale of the flood event.

3.2 Input data and design criteria

Several synthetic flood waves of return periods between 20 - 500 years, as well as real flood episodes recorded in the past, have been used in order to investigate the individual and combined effects of one, two, or all three retention basins.

The basic assumption is that activation of retention basins starts from the most upstream basin (No. "1" in Fig. 1), and proceeds downstream, as the water stages attain certain predetermined elevations. For instance, for 200 and 500-year floods, the critical elevation triggering the activation of retention basins is set to equal the design elevation of the levees (maximum water level of the 100-year flood).

The crucial locations for evaluation of effects of retention basins are towns Senta and Becej (Fig.1), where maximal water stages must be sufficiently lowered to ensure the safety of buildings and valuable property.

3.4 Results of the decision support system application

The decision support system was used to:

(a) design side weirs, i.e. to determine hydraulically optimal lengths and bottom elevations, which would ensure best effects – maximal storage volume and consequently, the maximal downstream attenuation of the flood wave;

(b) develop optimal flood management strategies for different floods, i.e. to determine the number and sequence of retention basins that need to be activated under given conditions.

The answer to the first question is given in Fig. 3. The result refers to the 500-year flood and the retention basin "No. 1". For a preset weir bottom elevation (in this case, corresponding to the 10-year water stage maximum), calculations were repeated for different weir lengths, from 30 to 250 m. The maximal reduction of water stage at town Senta was obtained for weir lengths between 50 and 80 m. Since the three considered retention basins are of similar characteristics, the value of 50 m has been chosen for all basins.

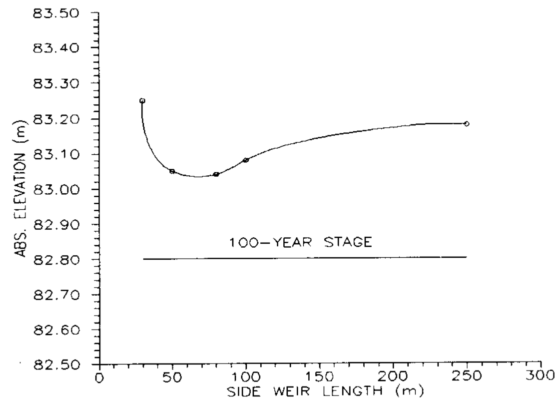

Fig. 3 Maximal stage for the 500-year flood at town Senta for different lengths of the side weir of the retention basin "1"

Optimal flood management strategy was determined for each considered flood wave. Unsteady flow calculations were performed for different sets of initial and boundary conditions, including different number of retentions basins and their different combinations, in accordance with the river flow dynamics.

The application of the decision-support system is demonstrated on the examples of the 500-year and 100-year flood waves, and only a few results are presented, for illustration purposes.

Fig. 4 depicts the combined effects of retentions "1" and "2", on this particular flood. The maximal discharge can be reduced from 4500 m^3/s to about 4100 m^3/s (Fig. 4-a), which roughly corresponds to the 100-year maximum. The step-like diagram of maximal discharges along the river channel (Fig. 4-b), shows the individual flow reduction effect of each retention basin. Fig. 4-c shows the dynamics of filling of the considered retentions.

4. Conclusions

The retention basins can be efficient means of active flood control and management. Activation of several basins, individually or in combination, gives the possibility of reduction of flood stages and discharges, according to specific, predefined goals. A decision support system is prerequisite in optimization of construction parameters (side weir bottom elevation and length), or an optimal operational strategy which would enable the existing levee system to withstand floods exceeding the design flood, or to protect levees against damage or failure during very long flood events.

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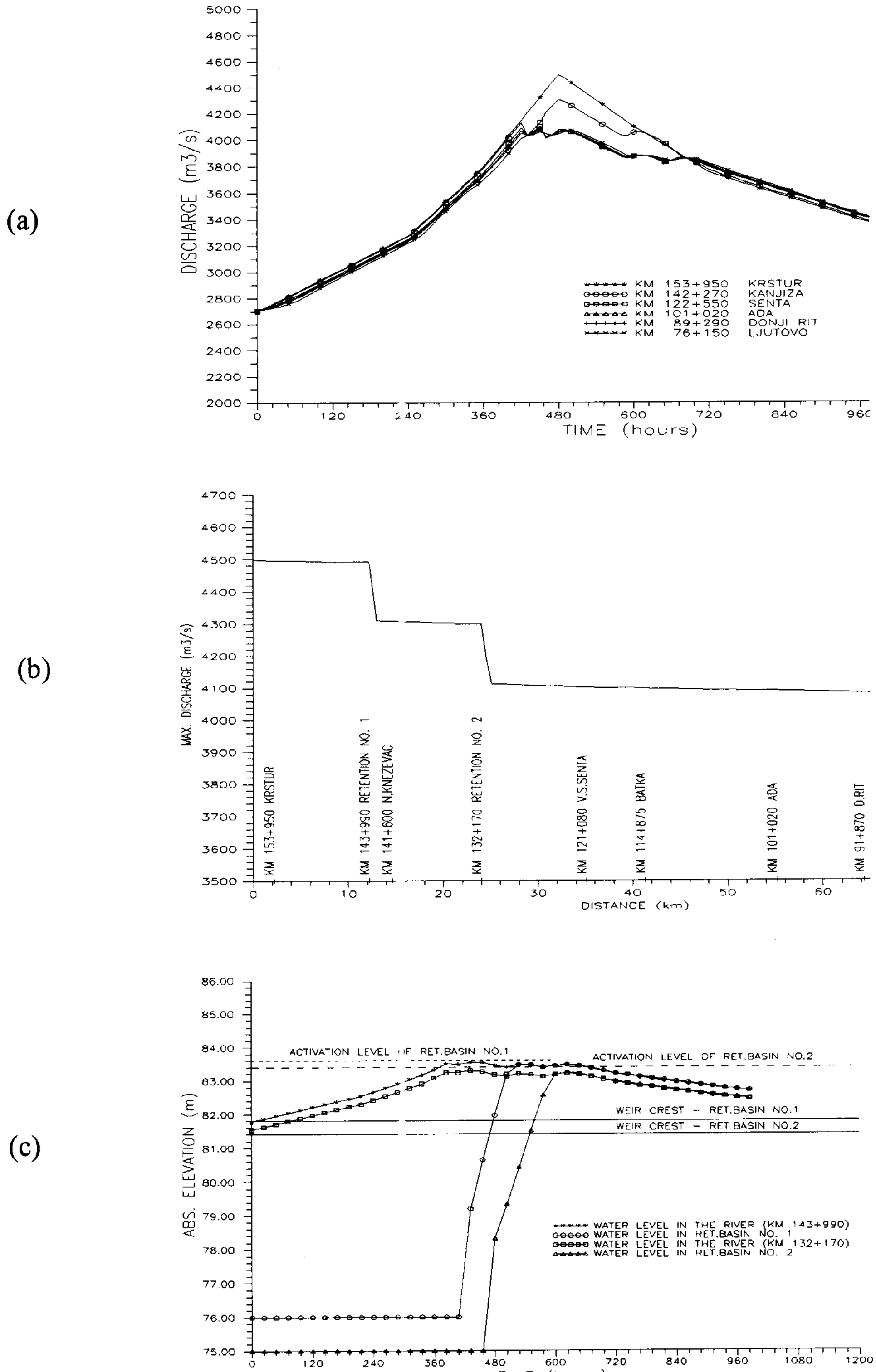

Fig. 4 The effects of retention basins "1" and "2" on the 500-year flood: (a) Discharge hydrographs (b) Maximal discharges along the analysed reach of the Tisza river (c) Stage hydrographs for retentions "1" and "2" [4], [5]