AN APPLICATION OF GIS TECHNOLOGY TO FLOOD CONTROL

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ABSTRACT: GIS technology and methods of river engineering are integrated within a system supporting decisions in flood control by means of retention basins. The two provide for a powerful tool for selecting locations for retention basins, evaluating various scenarios for flood events, etc. The results of the Tisza river case study are used as a running example.

KEY WORDS: flood control, GIS, retention basins, decision support, river engineering

1. Introduction

The emergence of geographic information systems (GIS) has marked, most vividly, the diffusion of the present information revolution into a number of disciplines. One of the disciplines GIS has revolutionized is hydroinformatics. Here GIS does not only help manage geographic information, but it is a user interface within which hydraulic processes and the effects of human interventions can be visualized in the most natural way.

Retention basins has been long known in river engineering as an efficient means for active flood protection. The retention basins are predefined and prepared storage areas into which the excess flood water is controllably discharged to reduce water levels downstream.

Typically, there are two kinds of situations when retention basins are used. The first is if 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 kind of situation has to do 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 decision process involved consists of several principle parts, and is intrinsically of iterative nature. Selection of locations for retention basins requires decisions 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, given approximate location(s) for retention basins, their number and size is determined by the intended degree to which selected area(s) are to be protected from the flood. This assumes that for any given level of protection, a cost-benefit analysis is performed making sure the total costs involved in retention basins' design, construction and operation (including damage caused by temporary flooding of areas covered by retention basins) do not exceed the potential cost of damage to the protected areas. 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 the locations of retention basins, their number and size, optimal values for side weir bottom elevation and length can be 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. The system overview

A system has been developed, aimed to support decisions involved in flood control by means of retention basins [4]. 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 [3]. The system is a suite of comprehensive models and databases, where a GIS (in this case, MapInfo) is used as a mapping and analytical tool. The system is used for setup and evaluation of various policy alternatives with respect to environmental planning and flood control.

2.1. *User Interface*

Users have an overview of the options that are available to them during a particular analysis, and they are kept informed of their progress in the analysis procedure. They can easily switch from one case or sub-area to another. The system is designed to provide decision support at various levels. Accordingly, its user interface is adapted to address the needs and expectations different user groups may have.

Policy makers, and flood control decision makers use the system to analyze the impact of different scenarios. They access topographic data via GIS, which is also used for visualizing the effects of various scenarios. Cost-benefit analysis is also available, once the relevant data are supplied. It is assumed, however, that they have basic knowledge about the domain, e.g., that they understand basic concepts of the hydraulic model employed by the system.

User interface provides sufficient flexibility for interaction with the model data. Data input is supported by providing default values and range checking. Civil engineers involved in the flood protection-aimed river training and various infrastructure developments (roads, highways, or railways) can select various combinations of input data and analyze outputs, while not being required to have any specific knowledge about how data files are organized, about their formats, and other artifacts. Modelers may also 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.

2.2. *Hydraulic computational model*

One important module of the decision support system is a validated numerical model for the unsteady flow simulation. Hydraulically based predictions of time and space distribution of maximal water stages and discharges are used to formulate the most efficient flood control strategy.

For calculation of flood waves propagation in a river channel, one-dimensional flow models are usually used, based on numerical integration of a system of partial differential equations describing the unsteady flow in non prismatic channels. 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 modeling. This flow is bi-directional, from the river channel to the retention basin, and vice versa, depending on the instantaneous water surface elevations. The water surface elevations in retention basins are calculated by means of volume elevation relationships included in the topographic database.

2.3. *GIS interface*

Interfacing the computational model with GIS within the decision support system provides for a powerful tool, as exemplified by the systems comprehensive decision support for flood management in general, presented in [5], and [6]. It also provides a natural environment where various groups of data can be managed, analyzed and displayed. Hydrologic, hydraulic and topographic parameters of the flow simulation model make for one such group. Another group of data is the one 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 locations for retention basins.

The next group of data consists of data on selected retention basins. The retention basins are either the already existing ones, or the prospective ones, that user has opted for in the course of consultation with the decision support system. These data are used for analyzing various scenarios for flood management. All these data are related to geographic objects and are stored in GIS databases.

On the user interface part, GIS connection further enhances the visual aspect of the system's support. However, for disciplines like hydroinformatics, as Abbott argues in [1], it has a deeper epistemological value, serving as a vehicle for visual transfer of knowledge.

Interface to GIS has also extended the possible applications of the decision support system. A spacial reasoning module has been under development for suggesting candidate locations for retention basins. Initial studies show that, subject to available data, it will allow for automating portions of this time consuming process.

3. Selecting Locations for Retention Basins: The Tisza River Case Study

3.1. *General layout*

The Tisza is a river in Central Europe which belongs to the Danube catchment, and has a total drainage area of more than 150 thousand square kilometers. The stream flow originates in upstream catchments in Slovakia, Ukraine, and Romania. Some of these regions have annual precipitation of up to 2,000mm, while most of the river's midstream and downstream regions in Hungary and Yugoslavia, respectively, have less than 1,000mm, of which roughly half over the period from April through September. It is in these latter regions that Tisza is known for relatively frequent occurrence of flood events of long duration. The regions in question are part of the Panonian valley where the land surrounding the river's last stretch of over hundred kilometers before its confluence with Danube is under the 10m contour. Consequently, the search for candidate locations for retention basins involves primarily the two-dimensional, rather than three-dimensional space.

Figure 1. shows the general disposition of retention basins on the Yougoslav part of the river Tisza with main roads, railways, towns and levees.

Several locations can be potentially used for water storage along the 80 km long reach of the Tisza river in Yugoslavia, between the town Bečej (km 76+150) and the Hungarian border (km 156+175, Figure 1.). Using a database information on topographic characteristics, land usage, infrastructure, and other relevant data, five potential locations for retention basins were originally considered. Their individual capacities are between 21 and 140 million cubic meters, while the flooded areas are from 235 to 2829 hectares.

The proposed retentions are to be activated only in the case when the water level exceeds the crest of the existing levees that have been designed for the 100-year flood, or in case of an 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 so 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 can be considered instantaneous in the time scale of the flood event.

Retention basin databases comprise of topographic, infrastructural, economic, environmental, and other data. For instance, Figure 2. shows the enlarged map of a retention basin ("Pana"), with information relevant for land usage aspects of this basin. Evaluation of economic and/or environmental consequences of basin filling is possible in terms of areas, classified as "farms", "forest", "meadows", "orchards", etc.

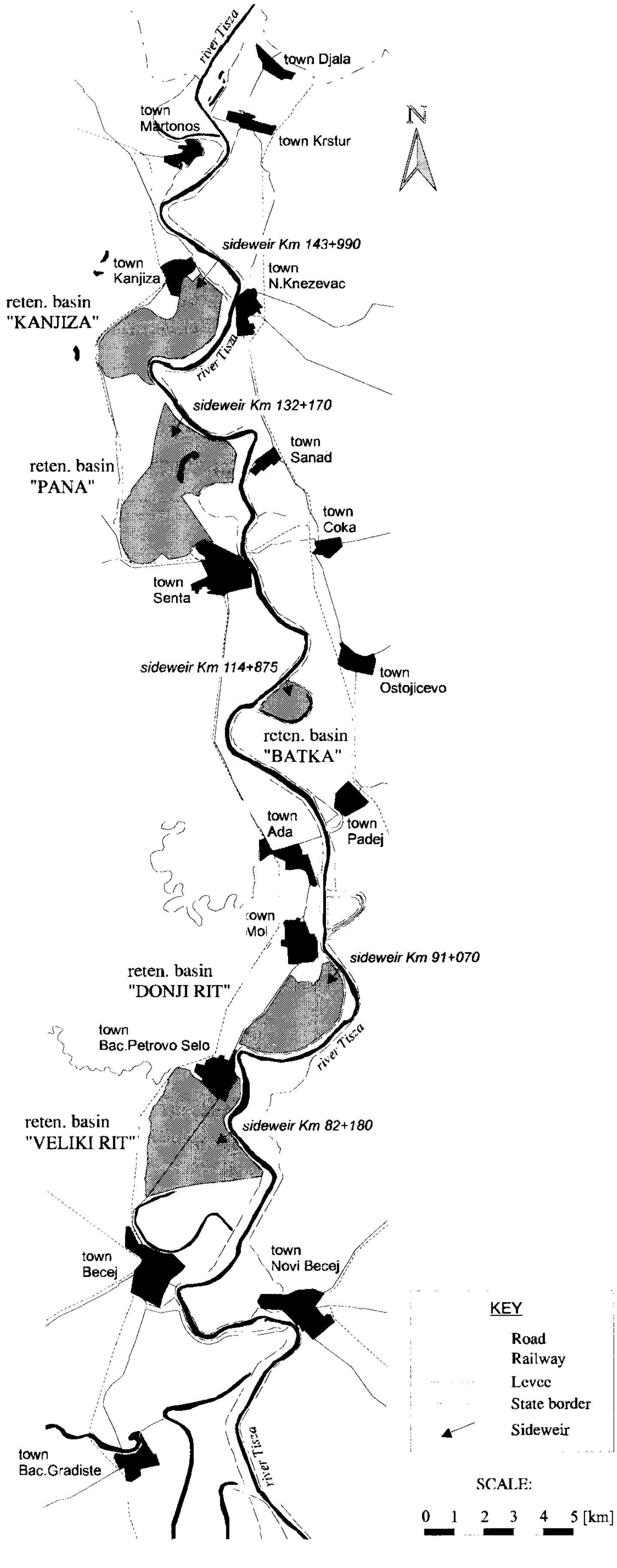

Figure 1. *General layout of retention basins on the river Tisza*

This information helps user to select economically acceptable basin locations from a set of potentially available ones. This can be considered as the first phase in retention basin selection.

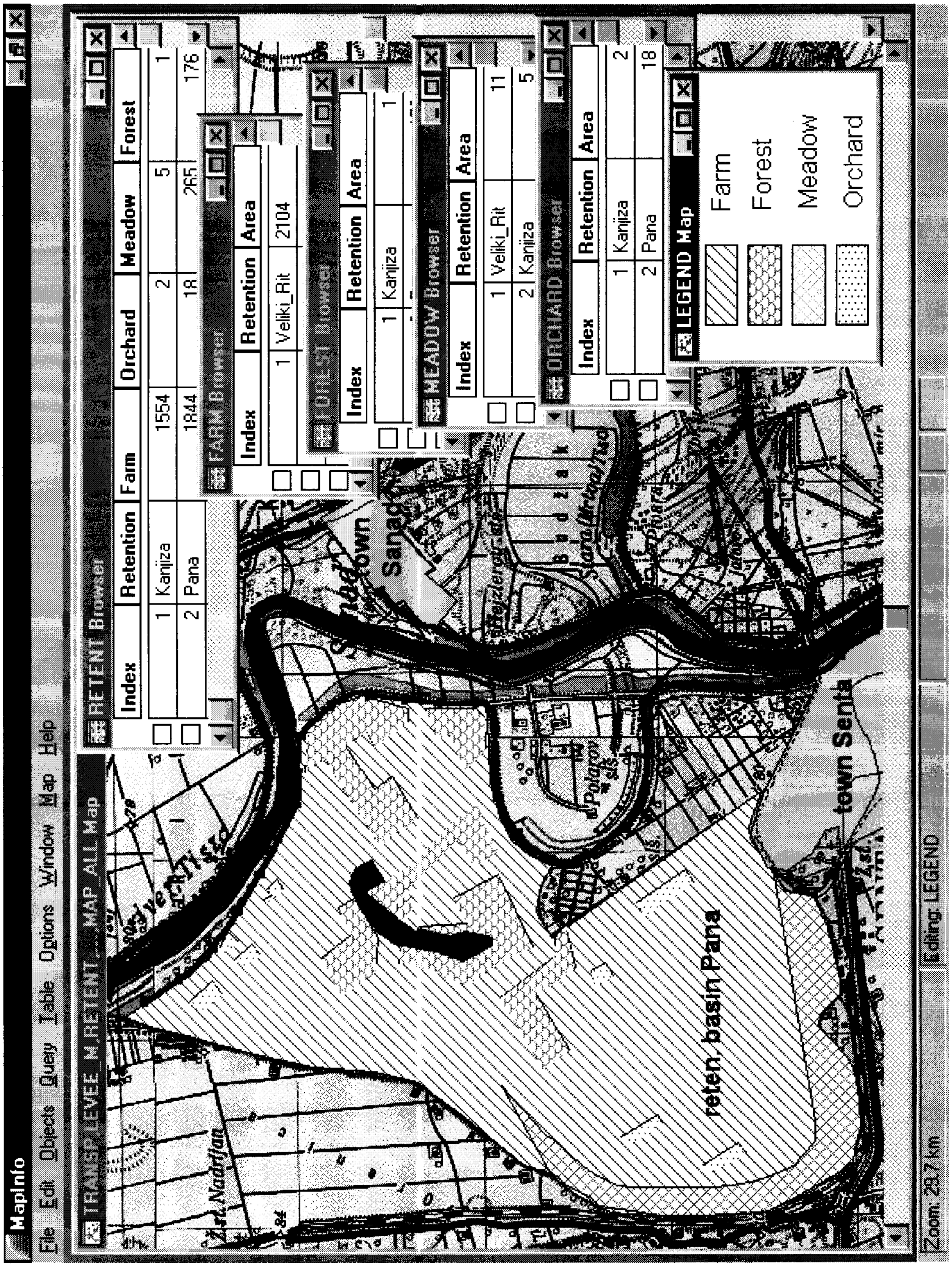

Figure 2. *Retention basin "Pana" with land usage information*

Table 1. displays data relevant for economic analyses of the proposed locations for Tisza river retention basins. First two rows of data display retention basins' water capacity (**volume**), and **area** they cover, respectively. **Current land value** is computed from the available data on the current land use, using average values for different categories of land use as defaults. These values may also be user defined. **Estimated damage** refers to the cost of damage to the land and infrastructure in the area "covered" by a particular retention basin which will result from the planned use of the basin as a water storage during the flood event considered. (Note that estimated damage is not necessarily a linear function of the current land value.) **Investment required** refers to the costs involved in making a selected area ready for use as a retention basin. That includes strengthening of the existing levees, or where necessary, design and construction of the new levees, side weir formation, etc. **Operating costs** refer to the costs of operating a retention basin before, during and after a flood event. They reflect the maintenance costs of keeping a basin operational between the two successive uses in flood events, operating it during the flood event, and finally, after the flood event is over, the costs of pumping the residual water back into the river, and the costs of land reclamation. **Total Cost** is the sum of the estimated damage, investment required, and operating costs.

RETENTION	1 Kanjiža km143+990	2 Pana km132+170	3 Batka km114+875	4 Donji Rit km91+070	5 Veliki Rit km82+180
Volume [m^3] (millions)	105	140	21	74	110
Area [km^2]	15.63	28.29	2.35	13.73	21.25
Current land value (mil.$)	1.87	4.56	0.35	3.42	3.57
Estimated damage (mil.$)	0.78	1.82	0.14	1.40	1.82
Investment required (mil.$)	0.32	0.87	0.12	0.26	0.31
Operating costs (mil.$)	0.20	0.35	0.03	0.17	0.25
TOTAL COST (mil.$)	1.30	3.04	0.29	1.83	2.38

Table 1. *Comparative analysis of the proposed locations for Tisza river retention basins.*

The second phase consists of verifying the hydraulic efficiency of the selected basins. The hydraulic module of the decision support system is used:

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

b) to develop the optimal flood management strategy for a particular flood, i.e. to determine the number and sequence of retention basins to be activated under given conditions.

These tasks are based on information contained in the levee database. Figure 3. shows an enlarged map of a retention basin ("Kanjiža") with hydraulically relevant data.

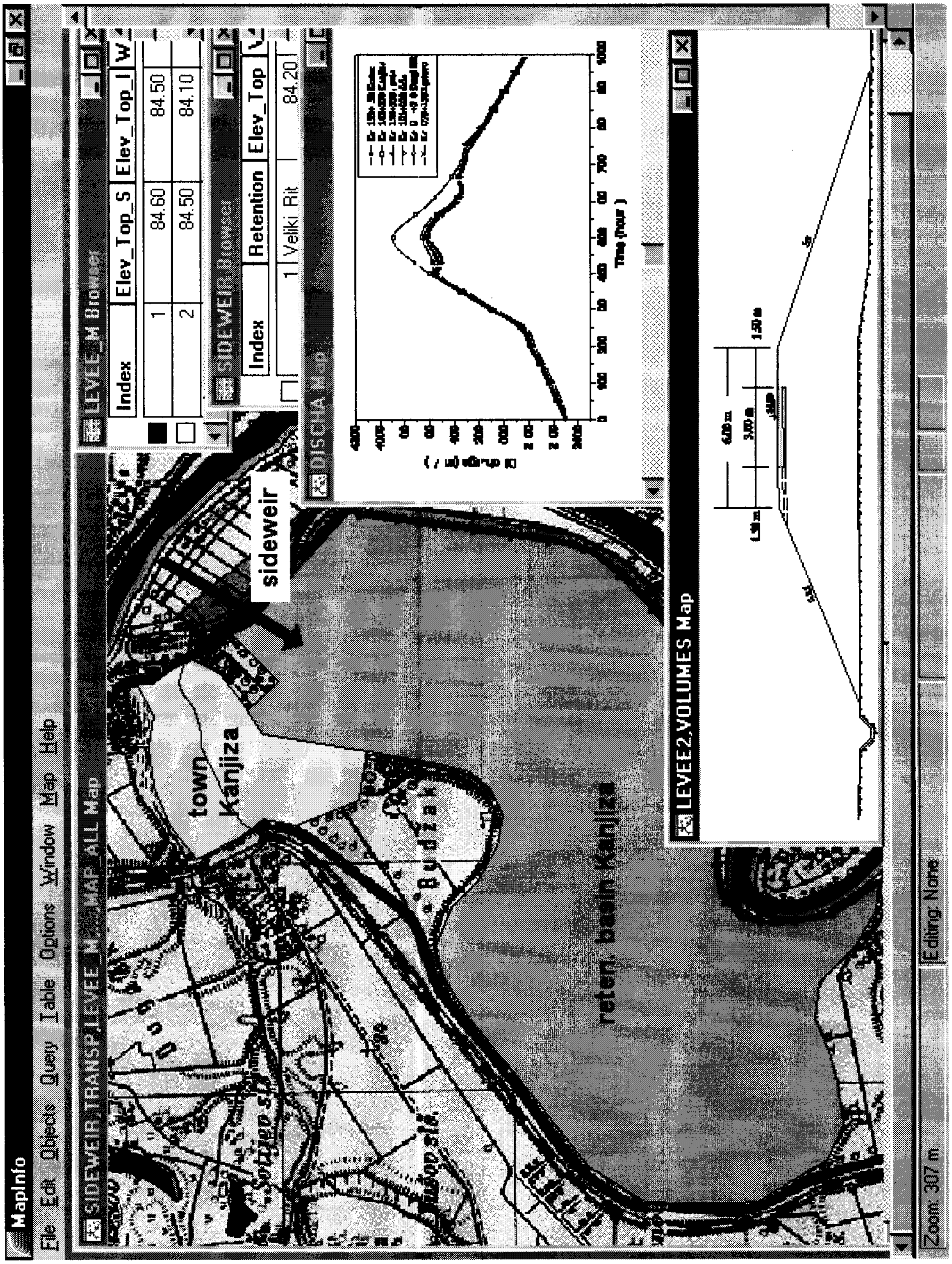

Figure 3. *Retention basin with hydraulically relevant information*

The construction characteristics of levees (top width, side slopes, volumes, building materials, etc.) for a sector of the basin are available in either tabular or graphical form. Geometric characteristics of side weirs (top width, length, bottom elevations) are also available in tabular form. The levee database is updated as the levees may be reconstructed, and side weir characteristics may change accordingly.

This database also contains volume-elevation relationships for all retention basins, which are required in hydraulic computations. The flood attenuation capacity of each basin can be displayed by discharge hydrographs, such as the one on Figure 3. The difference in peak values reflects the efficiency of the basin, while the area between the two curves represent the effective storage volume.

The levee database plays a key role not only in hydraulic analysis and determination of the best flood control strategies, but also in various economic evaluations - determination of investment and maintenance costs of levees and retention basins, including costs of pumping residual water from the basin back into the river after the flood event.

3.2. *Testing various scenarios*

The optimal flood control strategy is determined for each flood event. Unsteady flow calculations are performed for different initial and boundary conditions. Predictive simulations are based on either synthetic flood hydrographs obtained from statistical analysis, or real hydrographs - recorded flood events. In order to determine the optimal flood control strategy, the number of retention basins is varied, as well as their combination, according to the river flow dynamics. It is at this point that retentions 3 and 4 (in Table 1.) were eliminated from further consideration. Retention 3 for its low capacity, while retention 4, despite its size, for contributing relatively little to the downstream attenuation of the flood wave in the compound model.

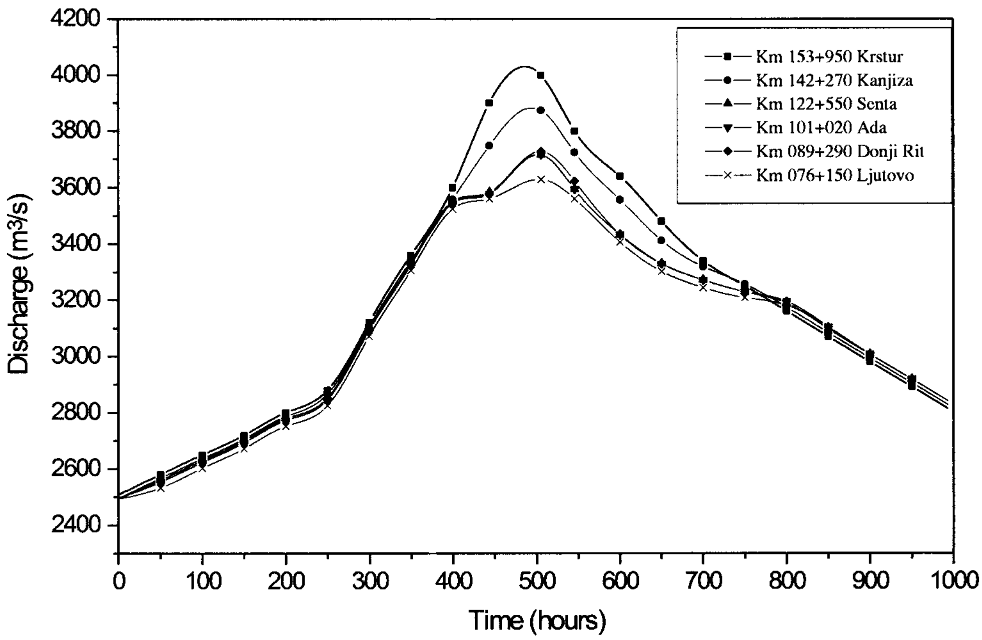

Figure 4. Combined effect of three selected storages on the 500-year flood

Figure 4. shows the combined effect of three storages - "Kanjiža", "Pana", and "Veliki Rit" on the 500-year flood. The maximal discharge is reduced from about 4.000m^3/s in natural conditions to 3.600m^3/s, which roughly corresponds to the 100-year flood, or the design flood of the levee system. This means that the existing levees can provide protection even for floods exceeding their design capacity if adequate storage facilities are provided along the river. The areas between the curves in Figure 4. represent the individual storage impact of each retention basin.

The sequence in which chosen basins start with operation can be left free to the river flow dynamics, i.e. to the characteristics of the flood wave, or can be preset by some design time schedule, according to the particular goals to be accomplished ("safe" water elevations, time delays, tolerated flooded areas, etc.).

4. Conclusions

The system supporting decisions involved in flood control by means of retention basins is presented. The system interfaces the flow simulation model with GIS to provide for a powerful tool for managing, analyzing, and displaying relevant data. It also has a potential for automating some of the time consuming processes involved in selecting locations for retention basins. The system provides support to various groups of decision makers throughout various phases of retention basins' planning, design, and operation.

In the planning phase, multiple criteria are used by policy makers and flood management decision makers to determine retention basins' locations, number and size. These criteria are determined by hydrologic, hydraulic, economic and ecologic considerations.

In the design phase the decision support system is used for optimizing the retention basins' construction parameters such as side weir bottom elevation and length.

The system provides support for flood control and management by optimizing the retention basins' operational strategy. It can be used at the present stage to run simulations of various events and scenarios, helping select the optimal operational strategy that 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.

The Tisza river case study has shown how activation of several basins, individually or in combination, gives the possibility of reduction of flood stages and discharges, according to specific, predefined goals.

References

[1] M.B. Abbott, Hydroinformatics: A Copernican revolution in hydraulics, *Journal of Hydraulic Research*, 32 (3) (1994) pp. 3-14.

[2] M. Jovanović, S. Varga, Flood Forecasting and Management by Retention Basins, *XVII Conference of the Danubian Countries*, Budapest (1994).

[3] M. Jovanović, V. Srdanović, Decision Support System for Flood Management by Retention Basins, In *Critical Review of the Application of Advanced Technologies*, Proceedings of the Fifth EuropIA International Conference, Europia, Paris, (1995) 343-352.

[4] G.N. Pandyal, M.J. Syme, Profiling a flood management system for Bangladesh: The strategy of the generic model - GIS connection, *Journal of Hydraulic Research*, 32 (3) (1994) 21-34.

[5] H. J. Van Zuylen, et al., Hydroinformatics at Delft Hydraulics, *Journal of Hydraulic Research*, 32 (3) (1994) 83-136.