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Full Length Research Paper

Flood forecasting based on geographical information system

Karim Solaimani

GIS and RS Centre, University of Agriculture and Natural Resources, P. O. Box 737 Sari, Iran.
E-mail: solaimani2001@yahoo.co.uk. Tel: (+98) 9111521858.

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Floodplain management is a recently new and applied method at the river engineering and is essential for prediction of flood hazards. On the other hand, for the purpose of managing and performing all river training practices, it is necessary to simulate complicated hydraulic behavior of the river in a more simple way. In this research, steady flow was simulated along ~4 km end of Zaremrood River (upstream of the Tajan River) and flood hazard extends derived using HEC-RAS/HEC-geoRAS. For simulating, first used HEC-geoRAS to define the river channel and extract cross sections from the TIN, then the results of pre-RAS within the steady flow data and the other required data imported to the HEC-RAS for process and ultimately provided 2-5-10-25-50-100-year inundation extends. The results indicate that hydraulic simulation by integrating HEC-RAS model GIS is effective for various kinds of floodplain managements and different scenarios of river training practices.

Key words: Hydraulic simulation, flood management, Zaremrood River.

INTRODUCTION

From the world's earliest records, water has played an integral role in civic development. Water is viewed both as an invaluable resource to be protected and a violent force to be respected. The evolution of water a precious resource continues today; we are also developing better practices for mitigating losses from water in its destruct-tive capacity-flooding. The continually-growing population of the world, it is certain that without proper guidance, a large number of homes will be built in areas that place them at the mercy of flood events. (Walker and Maidment, 2006) in addition natural disasters demon-strated that Flooding is a hazard with serious socioecono-mic consequences for all activities and infrastructure within an affected floodplain, then accurate delineation of flood extents and depths within the floodplain is essential for flood management officials to make sensible and fair decisions regarding construction, insurance and other regulated practices on land and property potentially affected by flooding (Noman et al., 2003). The intro-duction of computer technology to hydraulic modeling provided greater flexibility for engineers for the purpose of engineering tasks such as floodplain mapping. Recent advances with the use of digital elevation models (DEM) in the form of triangular irregular networks (TIN) have the potential to further that flexibility by affording engineers the ability to create geometric representations for use in hydraulic modeling in a far more cost-effective manner. Through a combination of the GIS extension, HEC-GeoRAS and HEC-RAS, engineers can use an available DEM to build the geometric file for a HEC-RAS model. Additionally, the GeoRAS extension has simple import and export capabilities to smooth the transition between creating the geometric file, running the model and displaying the results. The end result of the process is not only quicker floodplain delineation with greater accuracy than traditional methods, but also a flow depth grid indicating to the user the level of inundation of any area in the model (Werner, 2001). However, while these new techniques may represent the future of hydraulic modeling and a step in the right direction, a major obstacle exists in the limited amount of data sufficient for terrain modeling. Until adequately precise data becomes more readily accessible for the average user, these capabilities will remain the "future" of hydraulic modeling. Flood hazard studies on several regions using integration of HEC-RAS hydraulic model and GIS represent effective results. Abdalla et al. (2006) introduced hybrid approach for flood risk assessment through GIS. The developed approach was based on the integration of hydraulic simulation and GIS analysis, which allows spatial-based visualization and prediction of flood disaster. The developed approach was applied to a section of the

Qu'Appelle River in southern Saskatchewan. The results indicated that the developed methodology was efficient in modeling and visualizing the spatial extent of different flood scenarios and in determining flooded areas at risk. It was found that changes in water elevations of the Qu'Appelle River made the downstream areas more at risk. And Earles et al. (2004) demonstrated the utility of the HECgeoRAS model for floodplain delineation and determination of key hydraulic parameters and also, HEC-RAS capability of producing hydraulic results in Los Alamos, New Mexico, USA. Williams (2006) carried out a study on Santee River. In this study were outlined the advantages of integration to model the impact of the Santee River rediversion. In 1941 the US Army Corp of Engineers completed the Santee-Cooper hydroelectric project, diverting water from the Santee River into the Cooper River. This resulted in rapid silting of the Charleston Harbor and in 1984 flow was rediverted into the Santee valley about 30 km downstream of the dam. Flooding pattern within the Santee floodplain has been altered by rediversion and operation of the hydroelectric plant on the rediversion canal. HEC-RAS 3.2 and the HEC-geoRAS extension for ARC-VIEW were used to examine the flooding regime prior to and subsequent to rediversion operations. ARC-GIS 8.3 was used to reduce LIDAR elevation data and Real Time Kinematics surveys of the river bottom elevations into data usable by the program. Although the large amount of high precision data resulted in an easily calibrated model that was well validated, it strained the limitations of the GIS software. Yang et al. (2006) developed a direct-processing approach to river system floodplain delineation. Floodplain zones of part of the South Nation River system, located just east of Ottawa, Ontario, were mapped in two dimensions and three dimensions by integrating the hydraulic model of the choice with geographic information systems (GIS). The first objective was to construct and validate a Hydrologic Engineering Center's River Analysis System (HEC-RAS) river network model of the system using existing HEC-2 model-generated data. Next, HEC-RAS simulations were performed to generate water surface profiles throughout the system for six different design storm events. The in-channel spatial data of HEC-RAS were then geo-referenced and mapped in the GIS domain and integrated with digital elevation model (DEM) over-bank data to build a triangular irregular network (TIN) terrain model. In the final step, floodplain zones for the six design storms were reproduced in three dimensions by overlaying the integrated terrain model for the region with the corresponding water surface TIN.Chuan and Jing (2006) explored the methodology for compiling the torrent hazard and risk zonation map by means of GIS technique for the Red River Basin in Yunnan province of China, where was prone to torrent. Based on a 1:250,000 scale digital map, six factors including slope angle, rainstorm days, buffer of river channels, maximum runoff discharge of standard area, debris flow distribution density and flood disaster history were analyzed and superimposed to create the torrent risk evaluation map. The risk evaluation result in the upper Red River Basin showed that the extremely high risk area of 13,150 km^2 takes up 17.9% of the total inundated area, the high risk area of 33,783 km^2 is 45.9%, the moderate risk area of 18,563 km^2 was 25.2% and the low risk area of 8115 km^2 is 11.0%.

Alho et al. (2007) investigated Jökulhlaups that are the consequence of a sudden and significant release of melt-water from the edge of a glacier. Such floods are sourced commonly from ice-dammed lakes, but occasional volcanic eruptions beneath ice can produce intense jökulhlaups due to prodigious rates of meltwater release. in this study it was presented the results of one-dimensional hydraulic modeling of the inundation area of a massive, hypothetical jökulhlaup on the Jökulsá á Fjöllum River in northeast Iceland. Remotely sensed data were used to derive a digital elevation model and to assign surface-roughness parameters. Also it was used a HEC-RAS/HEC-geoRAS system to host the hydraulic model; to calculate the steady water-surface elevation; to visualize the flooded area; and to assess flood hazards. The purpose of this study is to create a geometric model using ArcView 3.2 and the HEC-geoRAS extension for export into HEC-RAS and to determine a floodplain given a predetermined peak flowrate for the Zaremrood River. By comparing traditional methods of floodplain mapping and those available through computer technology, a conclusion can be reached about how new methods improve the floodplain mapping process and what is still required in order to make this new method the standard. Presently, creation of a geometric model is a labor-intensive task that must be done by hand, costing the engineer valuable resources. The addition of computer technology to such tasks can reduce both time and money spent on the project, benefiting all parties involved. (Dhital et al, 2005)

MATERIALS AND METHODS

Study area

Zaremrood River lies in ~15 Km southeast of Sari, Mazandaran, Iran between 36˚ 26′15″to 36˚26′44″ N latitude and 53˚8′23″ to 53˚9′52″ E longitude. The length of river is approximately 95 km that it flows eastward to westward to join Tajan River and ultimately draining in to the Khazar (Casrian Sea) Lake. The area has a supper humid climate with a mean annual rainfall ~ 987.5 mm. the maximum precipitation occurs in autumn and minimum precipitation in summer. The maximum and minimum temperature in Zaremrood Catchment is 20.4 and 8.95C˚, respectively and the mean annual temperature is about 14.5 C˚. The length of river in this study is terminal ~3 Km of Zaremrood River. The village, Garmrood is located in the adjacent to this reach of river but with an elevation difference of about 10 m from the bed. According to a report from Mazandaran Jahad Agricultural organization the dangerous floods of this river caused lots of losses such as breaking down two bridge openings of river and destruction of Garmrood hydrometric station and some similar cases at recent years; in addition the river stream causes bank undercutting that may cause landsliding some parts of village in the long term.

Datasets

The analyses of this research relied on two types of data: annual peak discharge, river plan concluded surveyed elevation points and topographic map. Only one hydrometric station named Garmrood with 24 years annual peak flow data used in analyses of this research .after evaluation of annual peak flow data accuracy Import to the SMADA software for statistical analysis. then select the best statistical distribution and estimate 2, 5, 10, 25, 50, 100- years flood discharge using SMADA. Whereas the surveyed points of the Zaremrood River plan have relative elevation, GPS must be used for determining absolute and correct positioning of them.

GIS data and analysis

For the last two decades advancement in the field of geographic information system (GIS) has greatly facilitated the operation of flood mapping and flood risk assessment. It is evident that GIS has a great role to play in natural hazard management because natural hazards are multi dimensional and the spatial component is inherent (Coppock, 1995). The main advantage of using GIS for flood management is that it not only generates a visualization of flooding but also creates potential to further analyze this product to estimate probable damage due to flood (Hausmann et al., 1998; Clark, 1998). GIS is indeed a useful tool to integrate and manipulate information which is useful, not only for technical purposes but also to communicate more easily with the public. In order to take advantage of this tool it is important to integrate as much data and models as possible for the purposes being pursued. Progress being made in information technology shows a clear trend towards the integration of various tools in one single system. This improvement may result in better interfaces, richer databases and more realistic analyses provided by a Multimedia GIS.(Correia et al., 1998; Corria et al., 1999).

There are several methods for hydraulic modeling process for floodplain mapping. One of them is addition of the HEC-geoRAS extension for ArcView 3.x. This extension is available free of charge from the Hydrologic Engineering Center of the U.S. Army Corps of Engineers and works directly with the HEC-RAS to create a geometric data file for the desired hydraulic simulation.(Crampton and Fleming, 2005; Studley, 2003). The HEC-geoRAS extension is used in conjunction with 3D analyst for interpolation of digital terrain data and Spatial Analyst for proper display of the output flow depth grids and velocity grids that are the object of the application. After preparing the project file, a triangulated irregular network (TIN) theme is required in order for the data to be processed. The most important component of any hydraulic model is the use of accurate terrain data. (Machado and Ahmad, 2006; Hardmeyer and Spencer, 2007).

Topographic map of area with scale of 1:25000 and river plan with scale of 1:1000 is applied for TIN generation, using 3D analyst capability of ArcView. TIN is used for preparation of required data for hydraulic simulation in HEC-RAS.

The stream centerline and left and right channel banks, flowpath and cross section cut lines themes must be prepared using the preRAS drop-down menu and then generate RAS GIS import file for HEC-RAS modeling .

Hydraulic simulation

HEC-RAS is a numerical model that designed for hydraulic simulation. This software allows the user to perform one-dimensional steady flow, unsteady flow calculations (HEC-RAS manual) the system is comprised of graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphical and reporting facilities. The HEC-RAS system will ultimately contain three one-dimensional hydraulic components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation and movable boundary sediment transport computations. The steady-flow version of the model solves one-dimensional step-backwater calculations; however, the following assumptions are necessary when using this approach for natural channels: (1) flow is comparatively steady along the whole reach because time-dependent variables are not included in the energy equation; (2) flow varies gradually between cross-sections due to the energy equation having a postulated hydrostatic pressure distribution at each cross-section; (3) flow is one-dimensional and therefore the calculation is based on the premise that the total energy head is the same at every point in a cross section; (4) the bed-slope of the channel is less than 10% because the pressure head is represented by water depth, which is measured vertically in the energy equation and (5) the energy slope is constant over the cross-section (Hydrologic Engineering Center, 2005).

In this study, steady flow analysis is applied and calculating water surface profiles for steady gradually varied flow is performed. Additionally the steady flow component is capable of modeling sub critical, supercritical and mixed flow regime water surface profiles (Snead, 2000).

The basic computational procedure in HEC-RAS model is based on the solution of the one-dimensional energy equation. (Figure 1) energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head).

The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (that is, hydraulic jumps), hydraulics of bridges and evaluating profiles at river confluences (stream junctions). The steady flow system is designed for application in flood plain management and flood. Water surface profiles are computed from one cross section to the next by solving the energy equation with an interactive procedure called the standard step method. The energy equation is written as follows:

$$y_2 + z_2 + \frac{a_2 v_2^{2}}{2g} = y_1 + z_1 + \frac{a_1 v_1^{2}}{2g} + h_e$$

where: $y_1, y_2 =$ depth of water at cross sections

$z_1, z_2 =$ elevation of the main channel inverts

$v_1, v_2 =$ average velocities (total discharge/total flow area)

$a_1, a_2 =$ velocity weighting coefficients

$g =$ gravitational acceleration

$h_e =$ energy head loss

A diagram showing the terms of the energy equation is shown in Figure 1. Capability of modeling common types of hydraulic control structures with appropriate on and off features and having a GUI with pre- and post-processing are strengths of this model, but HEC-RAS have some limitations such as it cannot simulate water quality processes and relatively difficult to use in conjunction with other water quality models. Likewise another limitation is that it cannot simulate groundwater levels. The basic data requirements for simulation are included: geometric data, study limit determination, river system schematic, cross section geometry, ineffective flow areas, reach lengths, energy loss coefficients, Manning's n, Equivalent Roughness'k', contraction and expansion coefficients, steady flow data, boundary condition, flow regime. In this study the

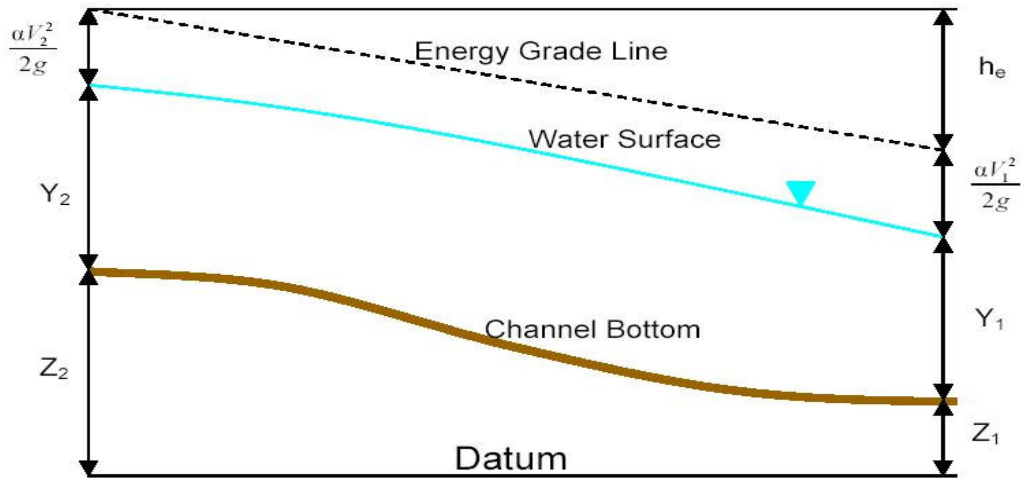

Figure 1. Representation of terms in the energy equation.

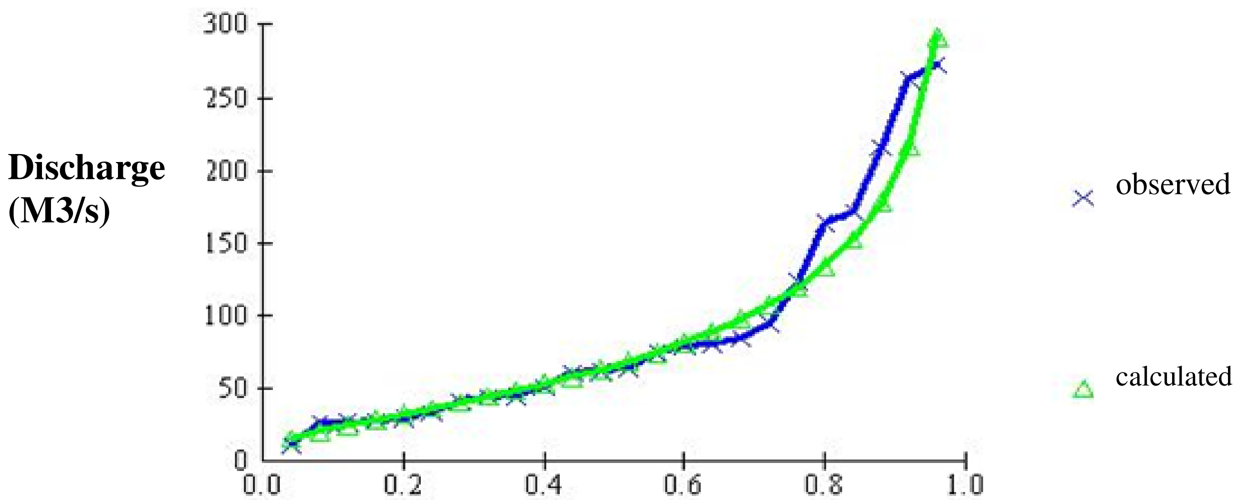

Figure 2. Estimation of flood discharge for 2,5,10,25,50,100-years flood using SMADA software and Pearson type III.

results that HEC-geoRAS extracted from TIN in ArcView, import to the HEC-RAS model for simulation. Then some additional required data that HEC-RAS needs for running, like steady flow data, boundary condition, Manning's n and contraction and expansion coefficients must be imported. Selection of a suitable value for Manning's n is very significant to the accuracy of the computed water surface profiles. There are several references that can access Manning's n value for typical channel. In this study applied slide source that agreed with Chow's tables. Boundary conditions are another part of model that must be completed. Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the program to begin the calculations. In a sub critical flow regime, boundary conditions are only required at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime calculation is going to be made, then boundary conditions must be entered at all open ends of the river system. One of the HEC-RAS capabilities is providing user cross section interpolation in some parts that is necessary that have been used in this modeling. Ultimately after completing of all essential data, model runned.

RESULTS AND DISCUSSION

24 years annual peak flow imported to the SMADA software and Pearson type III statistical distribution selected for estimating 2, 5, 10, 25, 50, 100-years flood discharges (Figure 2).

Area topographic map with scale of 1:25000 and river plan with scale of 1:1000 are applied for TIN generation, using 3D analyst capability of ArcView (Figure 3).

The stream centerline and left and right channel banks, flowpath and cross section cut lines themes prepared using the preRAS option in ArcView (Figure 4). The 3D cross section cut lines theme generated using preRAS that is shown in Figure 5.

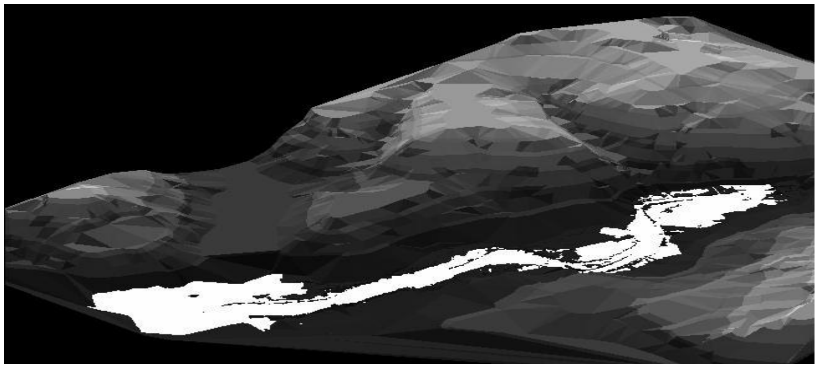

Figure 3. River plan at 1:1000 are applied for TIN generation, using ArcView.

Figure 4. Flow path and cross section cut lines themes prepared using the preRAS option in Arc View.

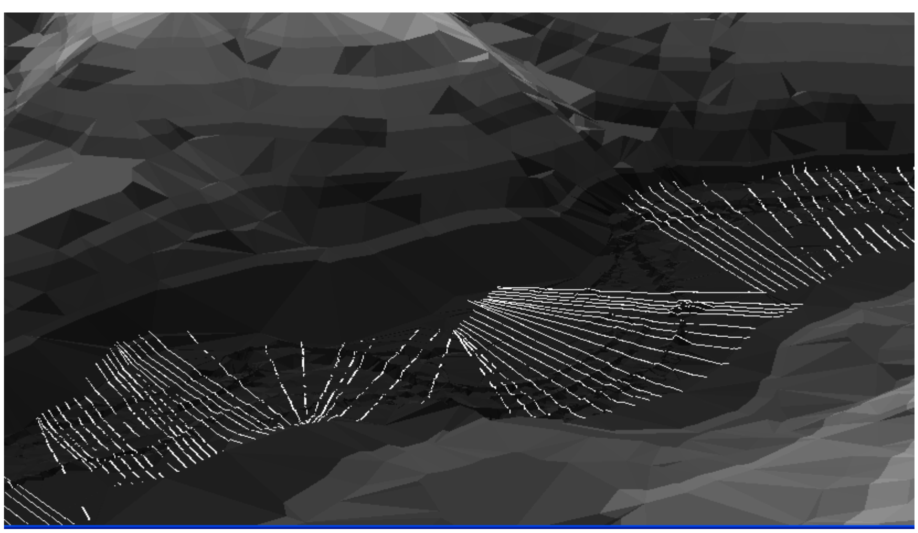

Figure 5. The cross section using preRAS.

The HEC-RAS essential data as a RAS GIS import file imported to the model and also for boundary conditions considered normal depth for upstream and critical depth for downstream. Other data such as steady flow data, Manning's n value, river system schematic, contraction and expansion coefficients, flow regime entered to model

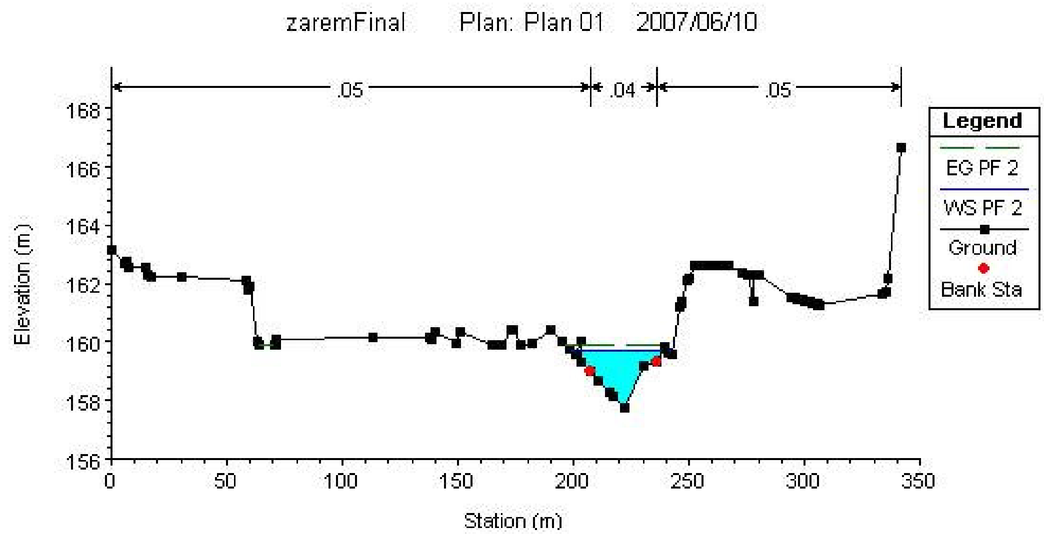

Figure 6. Differences between cross section plots of 2 and 100 year flood levels.

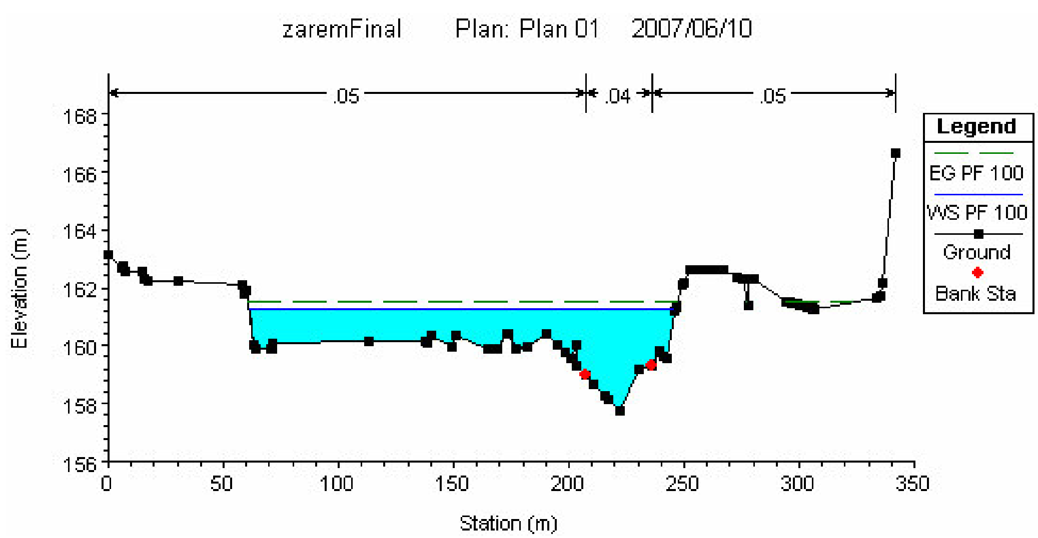

Figure 7. Differences between cross section plots of 2 and 100 year flood levels.

and ultimately runned HEC-RAS model for steady flow and mixed flow regime.

By comparing Figures 6 and 7 we can see differences between two cross section plots of 2 and 100 year flood levels in a sample of Zaremrood cross section.

One of the most important results of HEC-RAS simulation is preparing different water surface profiles of different T-year floods. The Figure 8 show 100-year water surface profile of Zaremrood River.

Conclusion

This paper focused on integrating GIS tools to Hydraulic analysis. These tools could reasonably separate high-hazard from low-hazard areas in the floodplain to minimize future flood losses. The important acquirement from this paper is that engineers could reduce time to prepare geometric data using GIS and it could be coupled with hydraulic models that are able to predict flooded areas for different scenarios of storm events and catchments land use. The linkage of the hydraulic models to the GIS may be quite complex task flexibility to the overall modeling system. Before using GIS, geometric data preparation is time-consuming and painful work. But GIS allows the engineer to concentrate on hydraulic principles rather than data. Also one of the most important conclusions made from this study is that use of GIS for

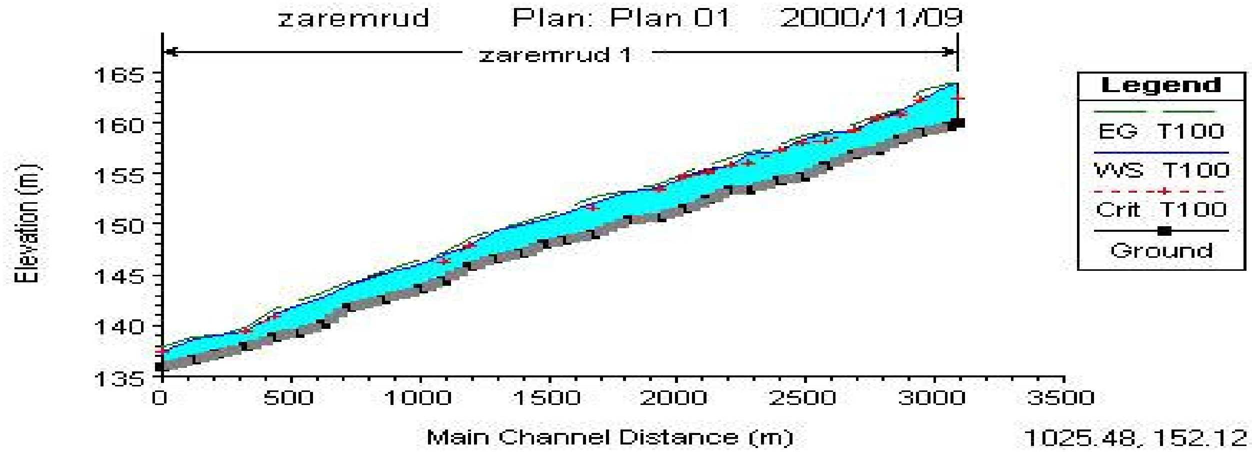

Figure 8. 100-year water surface profile of Zaremrood River.

the undertaking of a hydraulic analysis has the potential to be both an accuracy improving and cost-saving addition to the civil engineers available tools. It means that if detailed TIN data were given, more accurate results would be produced. Thus it is suggested that TIN could be improved with applying more numbers of surveyed points with an accurate elevation.

Results from hydraulic analysis are displayed in the GIS and it is easy to confirm results (Floodplain extent, flood depth, velocity).

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REFERENCES

Alho P, Roberts MJ, Käyhkö J (2007). Estimating the inundation area of a massive, hypothetical jökulhlaup from northwest Vatnajökull, Iceland. J. Nat. Hazards. 41(1): 21-42.

Chuan T, Jing Z (2006). Torrent risk zonation in the Upstream Red River Basin based on GIS, J. Geogr. Sci. 16(4): 479-486.

Clark MJ (1998). Putting water in its place: A perspective on GIS in hydrology and water management. J .Hydrol. Process. 12: 823-834.

Coppock JT (1995). GIS and natural hazard: an overview from a GIS perspective, In: Carrara A, Guzzetti F (eds), Geographical Information System in Assessing Natural Hazard, Kluwer Academic, Netherlands, pp. 21-34.

Correia FN, Saraiva MDG, Silva FUD, Ramos I (1998). Floodplain management in urban developing areas. Part II. GIS-Based flood Analysis and urban growth modeling. J. Water. Resour. Manage. 13: 23-37.

Correia FN, Rego FC, Saraiva MG, Ramos I (1999). Coupling GIS with hydrologic and hydraulic flood modelling, J. Water. Resour. Manage.12: 229–249.

Crampton S, Fleming S (2005). Practical applications of GIS for water resources Gwinnett county case study . Proceedings of the 2005 Georgia Water Resources Conference, University of Georgia, Athens, Georgia.

Studley SE (2003). Estimated flood-inundation maps for Cowskin Creek in Western Wichita, Kansas. Water-Resources Investigations Report.

Dhital MR, Shrestha R, Ghimire, Shrestha GB, Tripathi D (2005). Hydrological hazard mappingin Rupandehi district, west Nepal. J. Nepal. Geo.Soc. 31: 59-66.

Earles TA, Wright RK, Brown C, Langan TE (2004). Los alamos forest fire impact modeling. J. Am. Water. Resour. Assoc. (JAWRA) 40(2): 371-384.

Hardmeyer K, Spencer BA (2007). Using risk-based analysis and geographic information systems to assess flooding problems in an urban watershed in Rhode island. J. Environ. Manage. 39(4): 563-574.

Hausmann P, Weber M (1988). Possible contributions of hydroinformatics to risk analysis in insurance, In: Proc. 2nd International Conference on Hydroinformatics, Zurich, Switzerland, 9–13 September, Balkema, Rotterdam. Hydrologic Engineering Center., 2005. HEC-RAS river analysis system. Hydraulic Reference Manual ver. 3.1.3 U.S. Army Corps of Engineering., 262pp.

Machado M, Ahmad S (2006). Flood hazard assessment of Atrato River in Colombia. J. Water Resour. Manage. 21(3): 591-609.

Noman NS, Nelson EJ, Zundel AK (2003). Improved process for floodplain delineation from digital terrain models. J. Water Resour 129: 427-436.

Snead DB (2000). Development and Application of Unsteady Flood Models Using Geographic Information Systems. Departmental Report, Civil Engineering Department of the University of Texas at Austin., 195pp.

Walker WS, Maidment DR (2006). Geodatabase Design for FEMA Flood Hazard Studies, CRWR Online Report 06-10, Center for Research in Water Resources, University of Texas at Austin.

Werner MGF (2001). Impact of grid size in GIS based flood extent mapping using a 1D flow model. J. Phys. Chem. Earth, Part B: Hydrol. Oceans. Atmosphere. 26: 517-522.

Williams TM (2006). Incorporating GIS in river hydraulic modeling: assessing the ability to predict ecological consequences of river modification on floodplain forests. Hydrology and Management of Forested Wetlands Proceedings of the International Conference Published by the American Society of Agricultural and Biological Engineers.

Yang J, Townsend RD, Daneshfar B (2006). Applying the HEC-RAS model and GIS techniques in river network floodplain delineation. Canadian. J. Civil. Eng. 33(1): 19-28.