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Rainfall-runoff Simulation and Modeling of Karun River Using HEC-RAS and HEC-HMS Models, Izeh District, Iran

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Abstract: This study developed a framework for regional scale flood modeling that integrates GIS and two hydrological models. Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) and Hydrologic Engineering Center-River Analysis System (HEC-RAS) models are used to simulate and model relations between rainfall and runoff in Karun River, SW Iran. The Karun River is the domain of the study because it is a region subject to frequent occurrences of severe flash flooding. The model consists of a rainfall-runoff model (HEC-HMS) that converts precipitation excess to overland flow and channel runoff, as well as a hydraulic model (HEC-RAS) that models unsteady state flow through the river channel network based on the HEC-HMS derived hydrographs. For model calibration, the simulated results were compared with the observed water storage data for several storm events. The same rainfall event in Izeh district generates almost twice as much of the surface water runoff generated in each of other downstream. This is mainly attributed to the large catchment area of Izeh basin as compared to the other two basins. The modeling framework presented in this study incorporates a portion of the recently developed GIS tool named Map to Map that has been created on a local scale and extends it to a regional scale. The results of this research will benefit future modeling efforts by providing a tool for hydrological forecasts of flooding on a regional scale. While designed for the Karun River, this regional scale model may be used as a prototype for model applications in other areas.

Key words: River analysis system, hydrologic modeling system, map to map tools, Karun river, Iran

INTRODUCTION

Flood events are defined as the occurrence of severe storms. With increasing average global temperature trend to exacerbate climate events has been increased (Behbahani *et al*., 2006; Bates, 2004; Borga, 2002). So with regard to climate change, the need to provide reliable models in flood modeling is high. Increasingly, for environmental planning, due to the development of regulatory and planning tools, such as the river basin masterplan, there is need to such models for flood forecasting and river management. Usually, morphologic analyses are used for the delineation of river floodplain, but for the computing of the flood return period there is need to using computational hydraulic-hydrologic models (Clark, 1945; Anderson *et al*., 2002; Ahrens and Maidment, 1999; Bedient *et al*., 2003).

Similarly, there is a need to establish rules for the use of water resources, for instance when authorizing the maximum rate of abstraction for irrigation taking into account the water budget for the whole basin (Freeze and Harlan, 1969; Gasim *et al*., 2012).

Planning a river basin master plan has a need for planning the procedures of basin and its design, that both of them are based on shared databases and computational procedures (Becker and Grunewald, 2003; Beven, 2002; Garrote and Bras, 1995). The evaluation of areas at risk and the implementation of measures of risk mitigation delineate a dynamic context in which an upgraded representation of the river network and its hydrologic parameters play a relevant role in supporting environmental as well as urban planning.

Recent researches conducted in the field of flood modeling have focused mainly on using ArcGIS utilities. This modeling extension allows coping with quasi-2D aspects of flow through connecting the river geometry with a digital terrain model in the form of a Triangulated Irregular Network (TIN) (Gholami *et al*., 2009;

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Alireza and Nabavi, 2007; Razi *et al*., 2010). In this way, the distributed output provided by HEC-RAS for each cross section is interpolated between cross sections and results in a water depth and a water velocity surface. When compared with a fully-2D flow model, the only limitation is in giving a flow velocity which disregards transversal components of the flow field vectors, on their side usually deemed negligible in stream hydraulics (HEC, 1996a, b, 2000, 2002).

Based on the above sketched model, it is possible to map with appreciable realism the morphology of river and floodplain and to detect the flooded areas for a discharge and flood hydrograph with given return period.

Robayo *et al*. (2004) had presented a method using the MAP to MAP, time series of rainfall from weather radar and hydrological models for flood modeling. The model HEC-RAS delineates a fully functional modeling environment which allows coping with virtually all types of problems concerning river networks. In the application case described below, the advanced capabilities of the software for modeling hydraulic singularities such as bridges and weirs was exploited to derive theoretical rating curves based on steady non uniform flow. The purpose of this study is to understand hydrologic behavior of the Karun River in Northern Izeh district and planning for development of rural in vicinity of river bank.

MATERIALS AND METHODS

Study area: Karun River is located in Southernwest of Iran between 49°54'48’’to 49°54’58’’E and 31°59’12’’ to 32°N. Six catchments of the Karun River, Northern Izeh, Iran, are selected for this study (Table 1) in a 2.5 Km length of Karun River. These catchments have different physiographic specifications (Table 2). Figure 1 shows study area location in Iran. Runoff measurements of six hydrometry stations are collected in a 3 year period from 2008 to 2011. Topographic and climatic conditions of these sub-catchments are mostly the same. Rainfall-snowy regime are dominant in all sub-catchments. Average rainfall of the study area is about 650 mm/year (WMO, 2003). Dry season starts at June and ends at November.

In this research, steady flow was simulated along 2.5 km of Karun River, SW of Iran. HEC-RAS simulation model in combination with GIS capabilities was used for this purpose (Fig. 2). After preparing the project file, a TIN theme was extracted based on georeferenced field cross sections and topographical data in order to prepare required data to be processed. Topographic map with scale of 1:25000 and river plan with scale of 1:1000 were applied for TIN generation using 3D analyst capability of ArcGIS. 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 cross sections. The stream centerline and left and right channel banks, flowpath and cross section cut lines themes have prepared and then generate RAS GIS import file for hydraulic simulation in HEC-RAS model (Salimi *et al*., 2008).

Rainfall-runoff model HEC-HMS: The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) uses ArcGIS and Spatial Analyst to develop a number of hydrologic modeling inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. Rainfall-Runoff modeling was performed using the Hydrologic Engineering Center’s Hydrologic

Table 1: Details of studied sub-catchments

Sub-catchment	Area (km^2)	Average annual runoff (m^3 sec^{-1})	Hydrometry station elevation (m)
Betari	885	16.6	1560
Barez	8999	126.8	815
Shalu Bridge	24141	341.9	800
Dehkadeh	200	5.3	2220
Shah Mokhtar	1187	22.2	1730
Morghak	2146	74.3	860

Table 2: Calibrated parameters for studied sub-catchments

	Concentration time (h)		Reservation coefficient (h)		Initial Discharge (m^3 sec^{-1})	
Sub-catchment	Real	Calibrated	Real	Calibrated	Real	Calibrated
Betari	87	12	139	94	15	13
Barez	54	17	77	52	109	107
Shalu Bridge	69	15	79	37	227	216
Dehkadeh	82	19	48	26	4	3
Shah Mokhtar	76	24	113	83	16	14
Morghak	79	21	93	56	42	37

Fig. 1: Location of study area in Iran

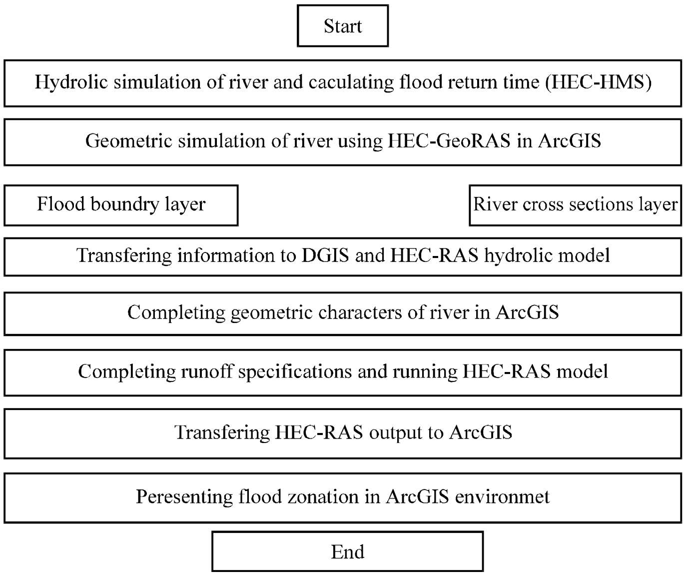

Fig. 2: Flowchart that shows how models are running

Modeling System (HEC-HMS version 3.0.1) importing results from HEC-Geo-HMS (Feldman, 2000). This model developed by the US Army Corps of Engineers, is designed to simulate the precipitation-runoff processes of dendritic watershed systems (HEC, 2002; Brunner, 2001). The physical representation of the watershed is accomplished with a basin model. Various hydrologic elements are connected in a dendritic network to simulate runoff processes (Jayakrishnan *et al.*, 2004; Horritt and Bates, 2002; Lamidi *et al.*, 2008).

Hydro-dynamic model HEC-RAS: HEC-RAS, developed by the United States Army Corps of Engineers Hydrologic Engineering Center, is intended for performing one-dimensional hydraulic calculations for a full network of natural and constructed channels. The system can calculate water surface profiles for both steady and unsteady gradually varied flow. The steady flow system is designed for application in flood plain management studies (Reed and Maidment, 1995; Rinaldi *et al*., 2012; Azar *et al*., 2012). Also, capabilities are available for assessing the change in water surface profiles due to channel improvements and levees. HEC-GeoRAS, an ArcGIS extension, creates a HEC-RAS import file containing geometric attribute data from a Digital Terrain Model (DTM) and performs post processing of results exported from HEC-RAS.

Statistical analysis: Topographic map and detailed thematic map of the Izeh district are feed in HEC-RAS and HEC-HMS models. Digital Elevation Model of the study area is base map for outputs. Main parameters needed are cross-sections for river and flood plain including left and right bank locations and flow paths, roughness coefficients (Manning's n) and contraction and expansion coefficients (Giannoni *et al*., 2003; Hudson and Colditz, 2003; Grassotti *et al*., 2003; Dastorani *et al*., 2010). A variety of methods are available for simulating infiltration losses, transforming excess precipitation into surface runoff, computing base-flow contributions to subbasin out flow, flow routing etc. Outflow from a sub-basin is computed from rainfall data by subtracting losses, transforming excess precipitation and adding base flow.

RESULTS AND DISCUSSION

Frequency analysis of peak flow data was conducted to select the most accurate input for the hydraulic simulation of the river reach. It has shown that Log-Pearson III is the best distribution to estimate peak flow in different return periods, regarding to the least differences between observed and estimated peak flow (Dastorani *et al*., 2011; Wadsworth, 1999; Townsend and Walsh, 1998). Table 3 has shown magnitude of peak flow in 2-100 years return periods. Peak flow estimated using flood frequency analysis was used as the steady flow data for simulation. In this table, first column is river name that is same for all parts of the study area. Second column is station name. Profile column shows return period of floods. Q-total is total discharge (m^3 sec^{-1}), max. channel elevation is elevation of each station. W.S. elevation is elevation of water surface and Crit. W.S. is critical water surface (in meter). Flow area is area that flood covers. Top width is maximum of elevation of flood surface and Froude Chl. is Froud number that can be critical, sub-critical of hyper-critical. Normal depth for upstream and critical depth for downstream was considered as boundary conditions for this analysis. Other inputs such as Manning`s n value, river system schematic, contraction and expansion coefficients, flow regime entered to model and HEC-RAS model has run for steady flow and mixed flow regime (Shokoohi, 2007; Vieux and Bedient, 1994).

Flood levels in one of the analyzed cross sections can be shown in Fig. 3 and 4. There is more than 1.5 m difference between flood levels in two mentioned return periods. One of the most important results of HEC-RAS simulation is preparing different water surface profiles of different T-year floods. In the next step, the results of hydraulic simulation within HEC-RAS model were exported to GIS for floodplain delineation and further analysis. Delineation of flood extents and depths within the floodplain of Karun River was conducted in different return periods based on the integration of hydraulic simulation results and GIS analysis using the HEC-geoRAS extension of ArcGIS. Figure 3 and 4 have shown

Table 3: Outputs of HEC-RAS model in Karun river

River station	Profile (year)	Q total (m^3 sec^{-1})	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m m^{-1})	Flow Area (m^2)	Top Width (m)	Froude Chl.
2351.82	2	1725	561.57	565.46	569.98	608.04	0.400693	59.67	28.37	6.36
2351.82	5	2972	561.57	566.43	572.11	620.98	0.400080	90.83	35.88	6.56
2351.82	10	4014	561.57	567.05	573.53	629.90	0.400211	114.28	40.63	6.69
2351.82	20	5177	561.57	567.60	574.93	639.24	0.400204	138.06	44.48	6.79
2351.82	50	6927	561.57	568.29	576.90	652.72	0.400419	170.16	48.39	6.93
2351.82	100	8431	561.57	568.82	578.06	662.93	0.400356	196.15	51.33	7.02
2309.313	2	1725	558.99	563.98	568.07	591.19	0.220732	74.65	31.24	4.77
2309.313	5	2972	558.99	564.96	570.14	602.97	0.247265	108.81	38.73	5.20
2309.313	10	4014	558.99	565.57	571.48	611.28	0.261847	134.00	43.44	5.44
2309.313	20	5177	558.99	566.13	572.68	620.01	0.277317	159.18	47.69	5.68
2309.313	50	6927	558.99	566.79	574.25	632.62	0.300297	192.70	52.81	6.01
2309.313	100	8431	558.99	567.29	575.49	642.32	0.314870	219.69	56.60	6.22

Profile: Return period of floods, Q-total: Total discharge, Min. channel elevation is elevation of each station. W.S. Elev: Elevation of water surface, Crit. W.S.: Critical water surface, Flow area: Area that flood covers, Top width: Maximum of elevation of flood surface, Froude Chl.: Froud number that can be critical, sub-critical of hyper-critical

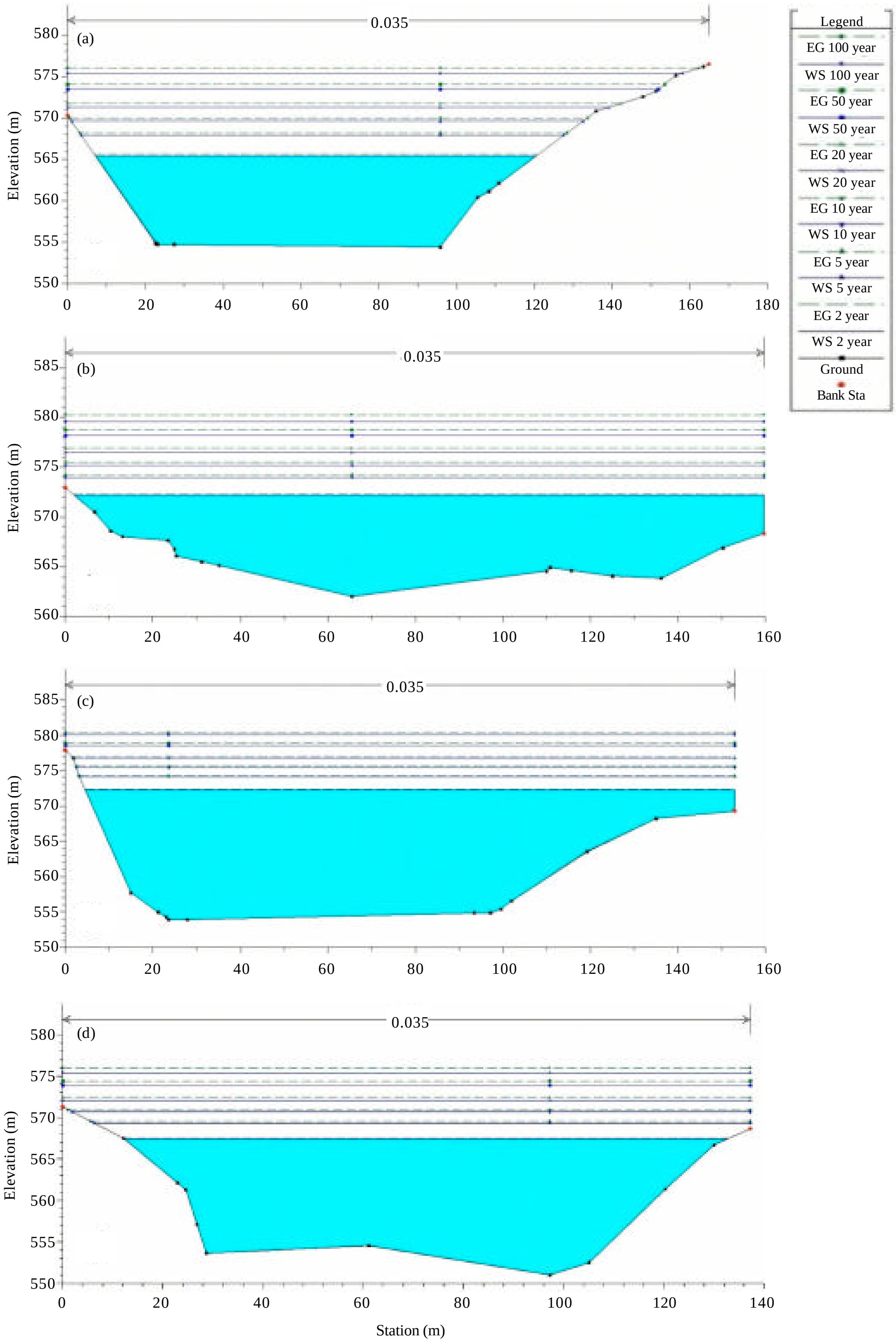

Fig. 3(a-d): Cross sections in (a) 923.2031, (b) 1469.997, (c) 1775.510 and (d) 1945.380 stations in the study area

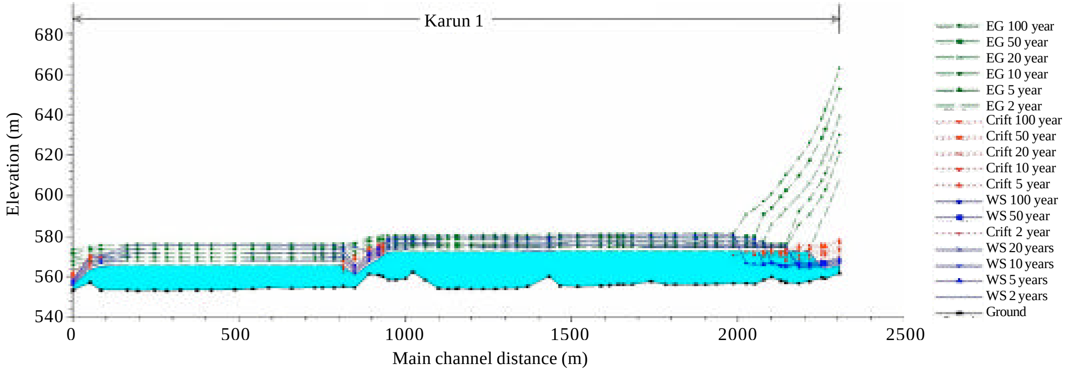

Fig. 4: Longitudinal profile of Karun river in the study area considering return time of floods

flood affected area for the 2 and 100 years flood events, as a sample in the study area.

Hydraulics simulation for floodplain mapping could be beneficiary in several aspects for land and water resources management and also engineering purposes. It can be applied to prevent unwise land use in flood prone areas and flood insurance studies, based on modeling of water surface elevations for design flood events (Whiteaker and Maidment, 2004). The design of bridge and culvert openings for roadway crossings of streams and consequences of flood reduction measures such as dams, levees and channel modifications could be predicated on proper floodplain hydraulic analysis. Increasing the size, slope, or depth of the channel or decreasing its roughness can lead to a reduction in flood levels because of the additional channel capacity. On the other hand, channel modifications can also have negative effects, such as increasing in flow velocity which could be simulated using hydraulic model.

Sensitivity analysis of hydrologic parameters: Sensitivity analysis of run-off lag time calculated using two methods (SCS and Snyder) shows high sensitivity of this parameter in the range of 0 and -30%, means that the catchment discharge is more sensitive to smaller values of lag time. In the other word, underestimation of lag time would cause more error on prediction of discharge in comparison to overestimation of this parameter. In addition, outputs of the model are slightly more sensitive to lag time calculated by SCS method than that calculated by the Snyder method (US/SCS, 1986).

Verification of the model: Table 3 show the predicted peak discharge and time to peak and the related observed values for a rainfall event used for verification of the model. The results show that calibration of parameters such as CN and initial loss could considerably improve the outputs of the model. The most important findings of the research can be concluded as follows:

- Comparing the outputs of the model in two different conditions (using SCS and Snyder methods) to the observed values indicates priority and robustness of SCS method for run off estimation (both in peak flow and lag time) in ungauged catchments
- The HEC-HMS program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed (Razi *et al*., 2010)
- Initial loss, curve number, impervious area, lag time, initial discharge are determined through calibration process where the parameters are adjusted until the observed and simulated hydrographs are close fit. By using soil hydrologic type classifications with soil maps and land use type classification tables with land-use maps, the Curve Number (CN) map was constructed
- For model calibration, the simulated results were compared with the observed water storage data for several storm events (Fig. 5). The same rainfall event in Izeh district generates almost twice as much of the surface water runoff generated in each of other downstream. This is mainly attributed to the large catchment area of Izeh basin as compared to the other two basins. The modeling framework presented in this study incorporates a portion of the recently developed GIS tool named Map to Map that has been created on a local scale and extends it to a regional scale. The results of this research will benefit future modeling efforts by providing a tool

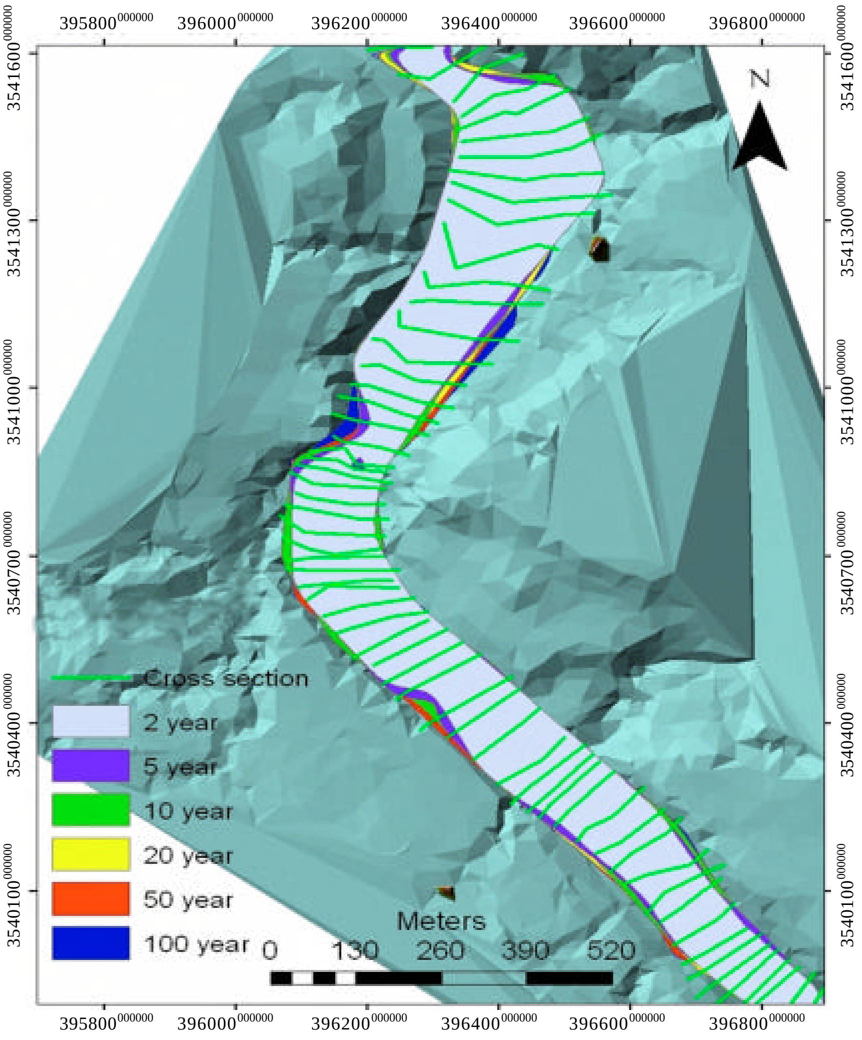

Fig. 5: Flood zonation of Karun River in the study area using HEC-RAS

for hydrological forecasts of flooding on a regional scale. While designed for the Karun River, this regional scale model may be used as a prototype for model applications in other areas

CONCLUSIONS

The modeling system here presented copes with a basic need of standardization of the databases. The main goal is to provide an environment in which all computations made by the different regional and municipal offices involved in river training, hydraulic works and similar activities can converge, share the same fundamental assumptions as far as roughness coefficients and hydrologic data are concerned and keep a continuous updating of the database including ongoing works, so to have a consistent and always realistic representation of the river network, its critical reaches and the priorities of intervention. Application of hydraulic modeling in GIS environment provides the capability to simulate flood depth in different part of the floodplain.

The need of such a modeling system is stimulated and sometimes even enforced, by the many activities required by river basin planning and management, ranging from flood timely alert to the individuation of areas at risk of flooding, to the programming of water budget at the basin scale, according to the national and regional regulations in the field. The main trouble with the construction of such a consistent and self-updating database is in that many different offices have been so far working separately in the field of hydraulic protection, river training and related public works. The availability of comprehensive software in the public domain allows to link databases to computing and design tools so to allow a strict pipelining of the activities of database construction, river basin planning, management, programming and financing of the interventions and design and construction of the works.

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