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Flood modeling using WMS Software: A case study of the Dez River Basin, Iran

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ABSTRACT
Flood is one of the natural disasters in many areas. This paper develops a framework for flood modeling that integrates GIS with WMS and interconnect terrain models and GIS softwares, with commercial standard hydrological and hydraulic models, including HEC-1, HEC- RAS, and others. The Dez River Basin (about 16213 km²) in Khuzestan province, IRAN, is domain of study because of occuring frequent severe flash flooding. As a case of study, a major flood in autumn of 2001 is chosen to examine the modeling framework. The model consists of a rainfall-runoff model (HEC-1) that converts excess precipitation to overland flow and channel runoff, and a hydraulic model (HEC-RAS) that simulates steady state flow through the river channel network based on the HEC-1, peak hydrographs. In addition, it delineates the maps of potential flood zonation for the Dez River Basin. These are achieved based on the state of the art GIS with using WMS software. Watershed parameters are calibrated manually to perform a good simulation of discharge at three sub-basins. With the calibrated discharge, WMS is capable of producing flood hazard map. The modeling framework presented in this study demonstrates the accuracy and usefulness of the WMS software for flash flooding control. The results of this research will benefit future modeling efforts by providing validate hydrological software to forecast flooding on a regional scale. This model designed for the Dez River Basin, while this regional scale model may be used as a prototype for model applications in other areas.

Keywords: WMS, GIS, flood zonation, flood modeling, rainfall-runoff.

1 INTRODUCTION

1.1 *General*

Flood is one of the serious natural hazards in the world. On the global scale, storms and floods are the most destructive of natural disasters and cause the greatest number of deaths (Casale and Margottini, 1999) and just few countries don't have problem with demolition and damages due to extreme flood. Sever flood in last 50 years in Iran (1951-2001) was 3700 occasions. It means that every five days we had one flood occurrence. Since the blueprint paper by Freeze and Harlan (1969), flood modeling has greatly improved in recent years with the advent of geographic information systems (GIS), radar-based, high-resolution digital elevation models (DEMs), distributed hydrologic models, and delivery systems on the internet (Garrote and Bras, 1995). An important prerequisite to develop provision management concepts for the mitigation of damages from extreme flood events is to identify areas of potentially high risk to such events (Lindenschmidt et al., 2006). Flood map hazard is also one of the important steps in non-structural flood control. In recent decades, non-structural flood control methods have been noticed as effective and economical methods in decreasing flood effects. These methods try to match flood condition and manage damage reduction. Non-structural methods have less cost in compare to structural methods and could show more effects besides each other.

Due to significant flood damage potential in Iran and specially Khuzestan Plain which is affected by Karun and Dez rivers in flood seasons, Dez catchment's has been chosen, as a case study and a series of hydrologic and hydraulic simulations and computations, based on the state of the art GIS technology that can do all the independent simulation processes with different modules in WMS software, were carried out to reconstruct the 2001 flood situation on computer.

1.2 *Study area*

Despite the progress in flood modeling research, flooding continues to plague many areas of the world, including Khuzestan Province in Iran. Khuzestan is located in south-western part of Iran, has a significant flood occurrence potential according to high flows of two major rivers in this region. In each year, considerable flood damages occur due to a lot of residential, industrial and agricultural areas located both sides of rivers. There are two major rivers in the region, the Karun and Dez Rivers. Karun River with average annually 387 m^3/s is the biggest river in Iran. Karun-Dez Rivers Basin has an area of 67000 km^2. This river system supplies the water demands of 16 cities, several villages, 300000 hectares of agricultural lands, and several hydropower plants. The increasing water demands at the project development stage including agricultural networks, fish hatchery projects, and inter-basin water. Figure1 shows the study area of the project.

The study area has been selected for model development, is the part of Dez Catchments. The Dez River is one of the most important branches of Karun River, with 520 km length and 258 m^3/s average annually from wellhead up to Talezang Station with 15858 km^2 catchment's area. The Dez River is subject to occasional flooding which causes serious amounts of damage. This river carries huge amounts of runoff from big areas like Lorestan Province which includes Aligodarz, Borojerd and Khorram-abad Cities, Khuzestan Province which includes Dezfull city, and Esfahan Province which includes Fereydoon Shahr City. The Dez River consists of two main branches and many small branches.

Bakhtiary and Sezar River are the name of two main branches of Dez River. Dez River has extensive catchments area at south-west of Zagros mountain hillside. Dez Basin from upside up to Talezang Station is highland and water channel is anfractuous with steep slope. The Dez River enters the Khuzestan Province from the northern plain of Dezfull, flowing in the south-east part and connecting to Karun River in Band-e-Qir. Dez River has a permanent flow. The temporal extent of the study was selected as November 29– December 5, 2001 to cover the duration of the storms of 2001. The information have been used in this project includes: rainfall data provide from digital gages over the basin, and these data were gathered from two institutes, Water Resource Research in Tehran Province and Water & Power Office in Khuzestan Province; three stream flow gages with complete hydrological datasets formed a base of stream flow observations over the study region, including discharge measurements and other basin parameters came from Dezab Consulting Company, topography map, DEM with a resolution of 50 meters and the Land-use/ Land-cover shape file were retrieved from Soil Conservation and Watershed Management Research Institute in IRAN. Finally, river geometry is necessary to run the hydraulic model; the data were delineated from the DEM.

2 MODEL DESCRIPTION

2.1 *Rainfall-Runoff model: HEC-1*

Runoff is modeled by HEC-1, flood hydrograph package, computer program was originally developed in 1967 by Leo R. Beard and other members of the Hydrologic Engineering Center (HEC) staff (Hydrologic Engineering Center, 1998). The current version, v4.1, is anticipated to be the final release of HEC-1. Future hydrology model development efforts will be directed towards the successor to HEC-1, the Hydrologic Modeling System (HEC-HMS). The U.S. Army Corps of Engineers now supports HEC-HMS rather than HEC-1, but the hydrologic calculations for the options within HEC-1 have not changed. Results of the two models will be identical (Brigham Young University, 2002).

2.2 *Hydraulic model: HEC-RAS*

HEC-RAS is a Windows-based hydraulic model developed by the Corps of Engineers to replace the popular, DOS-based HEC-2 model. HEC-RAS has the ability to import and convert HEC-2 input files and expounds upon the capabilities of HEC-2. Since its introduction several years ago, the user-friendly

HEC-RAS has become known as an excellent model for simulation of major systems (i.e., open channel flow) and has become the chief model to calculate floodplain elevations and determine floodway encroachments for flood insurance studies. The hydraulic model requires output hydrographs from HEC-1, as an input; its parameters are representative cross-sections for each sub-basin, including left and right bank locations, roughness coefficients (Manning's n), and contraction and expansion coefficients. In order to use the HEC-RAS model to develop floodplain maps, it must be geo-referenced to the basin. Hence, the DEM formed the basis for derivation of channel geometry.

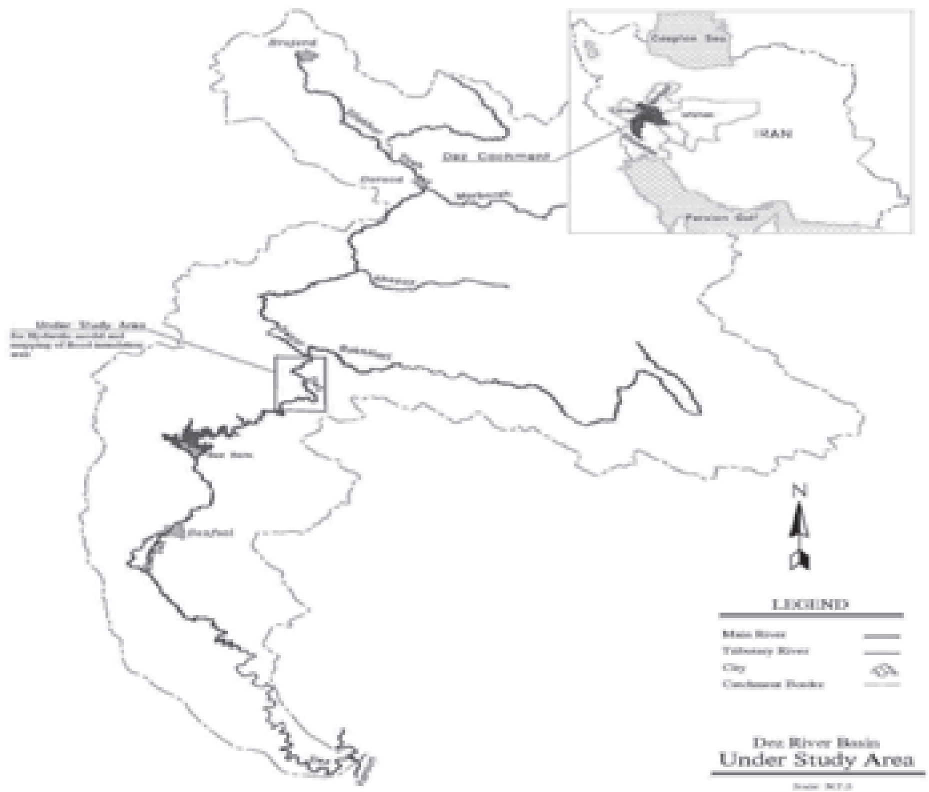


Figure 1. Location of the study area

2.3 *WMS (Comprise all modules)*

WMS was developed by the Engineer Computer Graphics Laboratory of Brigham Young University. WMS is a Windows-based user interface that provides a link between terrain models and GIS software, with industry standard lumped parameter hydrologic models, including HEC-1, TR-55, TR-20 and hydraulic model, HEC-RAS. The hydrologic models can be run from the WMS interface. The link between the spatial terrain data and the hydrologic models brings an ability to develop hydrologic data that is typically gathered by using manual methods within the program. WMS also provides floodplain delineation function. WMS delineates floodplains based upon stage values entered by the user interactively, read from a stage data file, or interpolated along a stream between known stage values.

3 METHODOLOGY

3.1 *Processing steps*

The present flood model has possibility of executing several processes together, such as HEC-1, rainfall-runoff model, HEC-RAS, river hydraulic model and delineation flood hazard map in WMS package. The first step was the inclusion of the topographic (DEM) and hydrologic data into the WMS system.

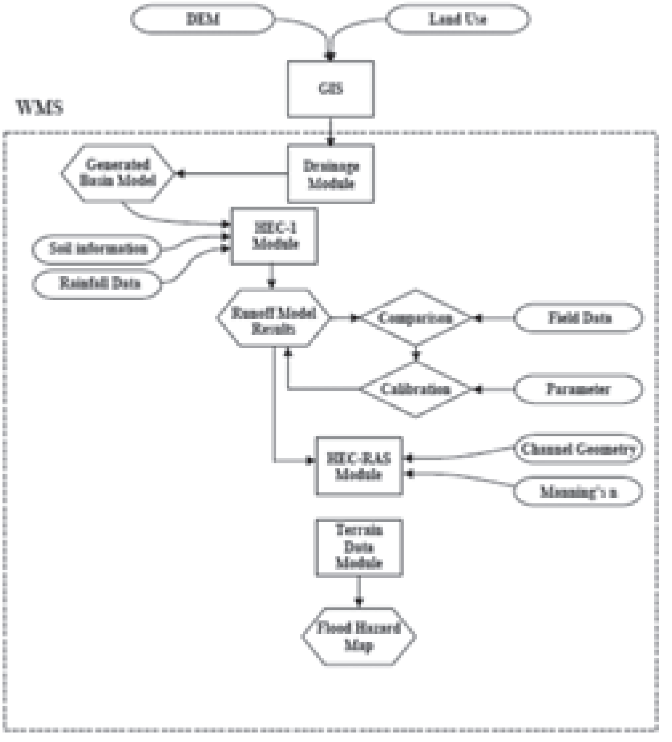


Figure 2. Methodology of study

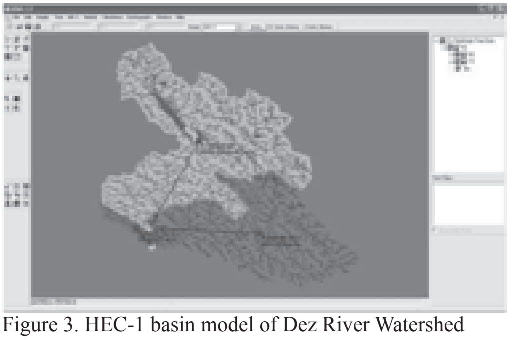


Figure 3. HEC-1 basin model of Dez River Watershed

Drainage module generated the basin model which contained parameter and connectivity data for hydrologic elements. This information was processed by WMS drainage module and exported into the basin file together with a series of parameters required by HEC-1 for the calculation of the runoff. Figure 2 shows methodology of modeling process and Figure 3 shows the basin model constructed in this study. It comprises the entire watershed of the Dez River.

The information that must be introduced into HEC-1 includes the precipitation model, with the meteorological data, the information required to process it, and the control specifications, with time related information for a simulation. These data were entered manually on the HEC-1 interface. Distributed gages measured precipitation at three sub-basins and Gage method were used for precipitation method to produce hyetographs. HEC-1 has this capability to input rainfall data for three sub-basins independently. In this method perpendicular bisectors are drown through the straight lines joining adjacent gages, leaving each gages in the center of polygon which will vary in size according to the spacing of the gages. The percentage of the total area of the catchment represented by each polygon or part of a polygon is calculated and applied to the appropriate raingage total. Because the terrain model is present WMS has this ability to compute gage weights (using the Thiessen polygon method), for each basin automatically. The gage weights can be changed/assigned manually on the gage weights button in the Precipitation dialog (Brigham Young University, 2002).

The Soil Conservation Service (SCS) Curve Number Method (CN) estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$Q = \left(P - I_a\right)^2 / \left(\left(P - I_a\right) + S\right) \quad (1)$$

$$I_a = 0.2S \quad (2)$$

$$S = \frac{25400 - CNx254}{CN} \quad (3)$$

Substituting Eq. (2) into Eq. (1) gives:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (4)$$

where:
Q= runoff (mm);
P= rainfall (mm);
S= potential maximum retention (mm);
I_a= initial abstraction (mm); and
CN= runoff curve number.

For Dez Area, CN value derives from Dezab Consulting Company that has classified soils in that area by gathering samples and examinations them and it is distinctive for each sub-basin. Initial abstraction is a variable parameter that takes into account losses prior to the start of runoff such as interception and depression storage. Evapotranspiration losses are considered negligible because ET volume is insignificant compared to runoff volume. SCS Unit Hydrograph method was used to transform rainfall data into runoff hydrograph. In this method, we estimate Q_p and t_p from these equations:

$$Q_P = \frac{0.208\,A}{t_p} \quad (5)$$

$$t_p = \frac{D}{2} + t_l \quad (6)$$

$$t_l = \frac{L^{0.8}\left(S+1\right)^{0.7}}{\left(1900\right)Y^{0.5}} \quad (7)$$

in which:
L= hydraulic length of watershed (feet);
Y= average watershed land slope (percent);
CN= Curve Number (-);
A= watershed area (km^2);
D= time interval (hour);
t_p= time to peak of unit hydrograph (hour);
t_l= equal to the lag (hour) between the center of mass of rainfall excess and the peak of the unit hydrograph;
Q_p= the peak flow of unit hydrograph (m^3/sec).

The values of runoff calculated by the model were compared with field data and new parameters were chosen and introduced back into the modeling system. This process was repeated until a good calibration was achieved for Dec(2001) storm. Then accuracy of adjusting parameters for calibrated model were examined with another flood event in March (1991). Once flood discharge hydrographs were generated from HEC-1, peak flood water surface profiles along the Dez River were calculated using HEC-RAS. The channel characteristics including surveying channel geometry which merge into DEM, formed the basis for derivation of channel geometry and Manning's roughness factor was entered into HEC-RAS interactively. The Normal depth downstream boundary condition was set at about S=0.001875. After computing water surface profiles along the channel geometry of Dez River, mapping of flood inundation areas was carried out using flood analysis function of WMS package. DEM (Digital Elevation Map) with resolution of 50 m (cell size of about 50m x 50m) was used as spatial data in WMS.

4 SIMULATION RESULT AND DISCUSSION

4.1 *HEC-1 runoff simulation*

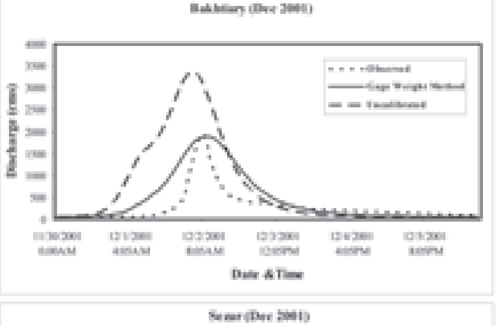
The HEC-1 model simulates rainfall transformation to runoff over the basin that happened in specific duration. The model result is the discharge hydrograph for each sub-basin. Sub-basin properties can be identified by characteristic of runoff hydrograph. Accordingly result for hydrological model showed logical fit between simulation and measurement. The peak flow hydrograph, shape of hydrograph and time of peak flow, are the most important parameters to predict flow hydrograph of flood. In simulated and observed flow, they are close and match well. However, the model over-estimated flood volume, thereupon sharpness of observed hydrograph can not be defined accurately by model. The over-estimation of flood volume by model exist in other modeling study such as Knebl et al. (2005). They used HEC-HMS/RAS and GIS and the extension program of GIS called HEC-GeoRAS due to modeling approach. Calibration the model causes the result fit better in all sub-basins. The time of concentration of the sub-basin, the initial abstraction (I_a), and the CN are the parameters that have significant effect on result during calibration process. CN has modified in the first step of calibration and due to CN modification, the value of time of concentration improved and it has an effect on modifying the time of peaks, both absolute and in relation to other peaks. Since each sub-basin has unique infiltration topography, soils, etc, the time of concentration in some sub-basins was increased while in others was decreased from its calculated value by changing CN, the amount of recharge into the watershed system changed and therefore runoff modified in the model. The initial and calibrated parameter for all sub-basins are given in table 1. In addition, hydrologic model routing method, Muskingum Cunge, have been done and lag or attenuation from upper basin up to lower basin has an effect on lower hydrograph and significantly improved the result on Bakhtiary Sub-basin. Figure 4 shows the results of hydrologic model for Dec (2001) storm.

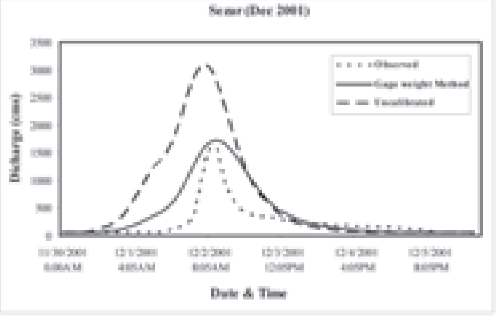
Table1.Initial and calibrated parameters for all subbasins

Parameter	Bakhtiary		Sezar		Talezang	
	initial	calibrated	initial	calibrated	initial	calibrated
CN (-)	75	64	77	69	76	65
STRL (mm)	22	32	25	35	20	27.35
RTIMP (%)	12	4	14	6	10	7

Note: RTIMP= Percentage of drainage basin that is impervious; STRTL= Initial rainfall abstraction.

For estimation the accuracy of calibrated model, the same parameters were used for March (1991) modeling. Figure 5 shows the results of calibrated model for March (1991). The relative error for each sub-basin in two years has been calculated and given in table 2 through 4. It is apparent form table 2 that model error in peak runoff simulation is low and Sezar Sub-basin shows best matching among others. Time estimation by the model is completely matched with time of flood occurance in all sub-basin for two years which is given by table 3. Flood volume calculation has been estimated closer to real volume of flood in March (1991) by the model.





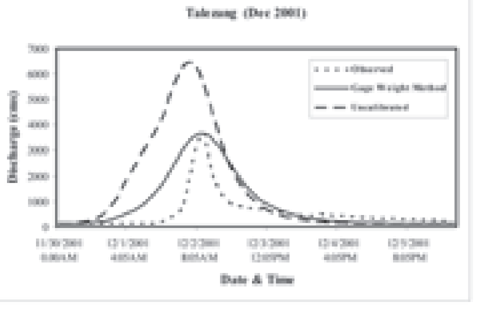
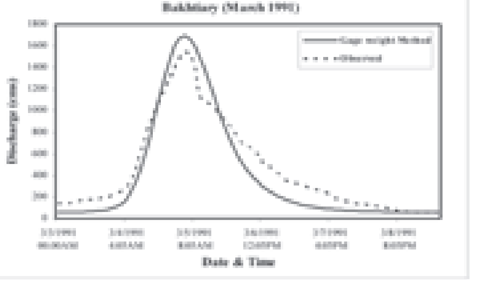


Figure 4. Comparison of uncalibrated, observed and simulated discharge hydrograph at Talezang, Dec (2001) storm

4.2 *HEC-RAS water surface profile computation*

Flood water surface profiles along the Dez River, computed from HEC-RAS. The condition of model computation was steady mixed flow regime and peak of discharges were entered for each tributaries. The water surface elevation compared with field elevation which derived from rating curve at the outlet of each sub-basin. Figures 6 and 7 show flood depth profile and perspective plot of the Dez River. Figure 8 shows one of the cross section along the river on peak flood discharge.



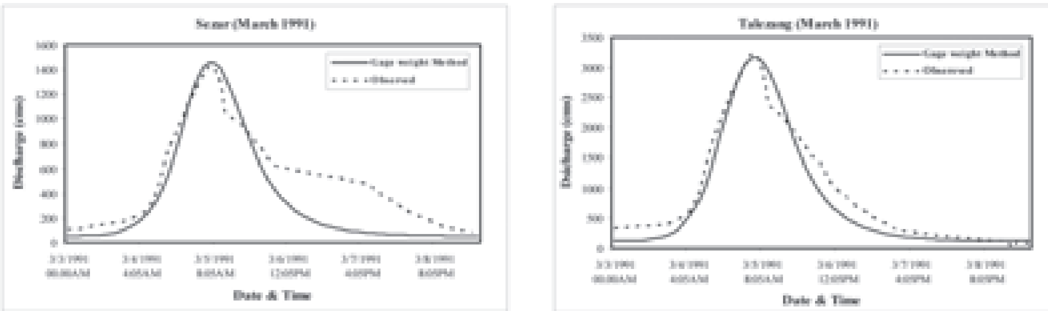


Figure 5. Comparison of observed and simulated discharge hydrograph at three sub-basins in March (1991) storm

Table 2. Observed runoff, simulated runoff and relative error

Station		Flood event	Runoff (m^3/s)		Relative Error (%)
			Observed	Simulated	
Bakhtiary	1	Dec(2001)	1944.04	1899.67	-2.28
	2	Mar(1991)	1551	1693.8	9.21
Sezar	1	Dec(2001)	1723.96	1729.82	0.34
	2	Mar(1991)	1426.92	1458.54	2.22
Talezang	1	Dec(2001)	3668	3643.25	-0.67
	2	Mar(1991)	3236.87	3165.57	-2.20

Table3. Observed volume, simulate volume and relative error

Station		Flood event	Volume (m^3 x10^6)		Relative Error (%)
			Observed	Simulated	
Bakhtiary	1	Dec(2001)	165.7	261.1	57.54
	2	Mar(1991)	262.8	226.9	-13.68
Sezar	1	Dec(2001)	143.9	233.8	62.48
	2	Mar(1991)	284.1	201.8	-28.95
Talezang	1	Dec(2001)	322.9	519.8	60.98
	2	Mar(1991)	521.4	451.2	-13.46

Table 4. Observed time, simulate time and relative error

Station		Flood event	Time		Relative Error (%)
			Observed	Simulated	
Bakhtiary	1	Dec(2001)	12/02/2001,08:00	12/02/2001,08:00	0
	2	Mar(1991)	03/05/1991,04:00	03/05/1991,04:00	0
Sezar	1	Dec(2001)	12/02/2001,10:00	12/02/2001,10:00	0
	2	Mar(1991)	03/05/1991,06:00	03/05/1991,06:00	0
Talezang	1	Dec(2001)	12/02/2001,10:00	12/02/2001,10:00	0
	2	Mar(1991)	03/05/1991,04:00	03/05/1991,04:00	0

4.3 *WMS floodplain delineation*

Finally the flood hazard map developed by reading solution from HEC-RAS model in WMS package and then terrain data module converts the result of hydraulic process on DEM. The output of the model consists of flood polygons showing inundated areas over the basin in Figure 9. Flood depth values on the TIN map and Figure 10 represent Flood inundation map from WMS for Dez River and seemed to be closely match with the real world situation reflecting geomorphic and hydraulic characteristics of the basin properly.

This research has displayed the capability of WMS software. Results show that this model was successful in all steps including hydrologic and hydraulic simulations and developing of flood map hazard for the Dez River Basin. The model can be used for other scientific questions concerning flooding in the Dez River Basin region. In addition, the methodology used in this study can easily be applied to other regions in Iran, and can be extended to other areas of the nature as well.

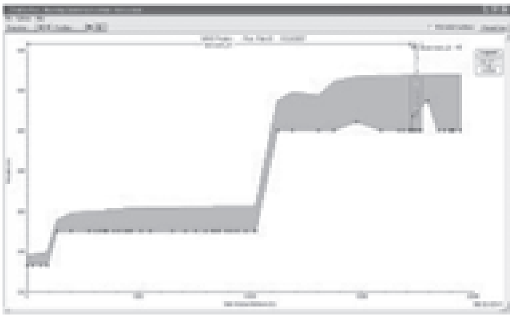


Figure 6. HEC-RAS water surface profile

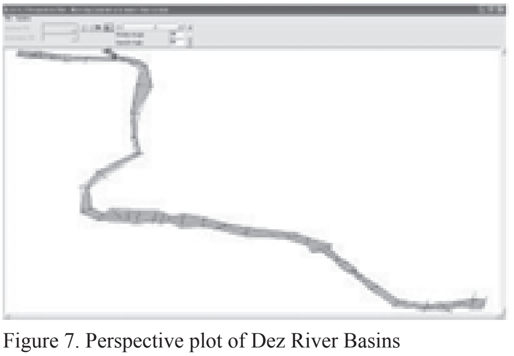


Figure 7. Perspective plot of Dez River Basins

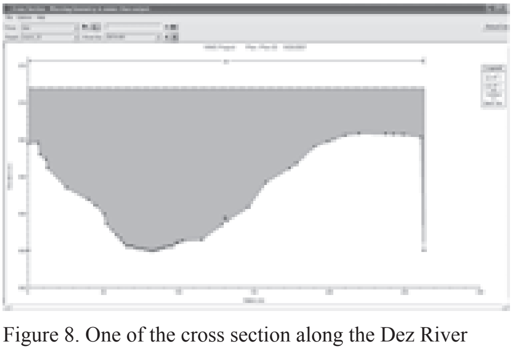


Figure 8. One of the cross section along the Dez River

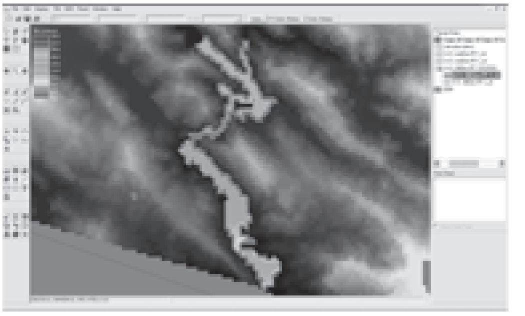


Figure 9. Flood depth values from WMS in Dec (2001) storm

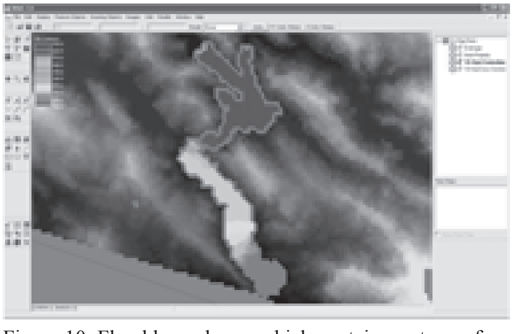


Figure 10. Flood hazard map which contains water surface elevations

5 CONCLUSION

Flood occurrence increases all over the world due to many reasons and loss of flood damage are huge. This paper presented the complete flood modeling since rainfall starts, up to flood occurrences by unique software package (WMS) with well accuracy. The model is capable in transforming rainfall to runoff then calibration process accomplished by changing the initial abstraction, curve number, impervious percentage and time lag. Adjusting parameters has done for Dec (2001) storm event for each sub-basin; and accuracy of the model examined by running the model for March (1991) storm event. The hydraulic simulation has performed to identify water surface elevation in river channels and finally developing flood hazard map for the Dez watershed. The results have widespread applications for city planners, environmental planners, flood control ministration, policy of determination of coastal river in flood prone area, emergency manager and totally will help flood hazard mitigation.

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