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Flood Forecasting Based on GIS and Hydraulic Model

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Abstract

Flood plains and the area near to the rivers channels, because of their special circumstances such as fertility and water resources are appropriate situations for the social and agricultural activities, but due to morphological characteristics usually, these area are affected by different flood hazards. Interaction between some river hydrologic models and geographical information systems (GIS) cause some gains and methods, which are reasonable to the planners. This study was carried out with the purpose of using hydraulic model of HEC-RAS with Arc View software to estimate the flood zone of 5-km distance on Neka River in Northern part of Iran, where during the last decade we had different flood events with a high magnitude damages. Topography maps at 1:1000 scales were used for the flood zonation for different periods of 2, 5, 10, 25, 50, 100 and 200 years. The results obtained attest to the fact that the combination of GIS and HEC-RAS model used in this study is useful and efficient in delineating the flood zonation. Finally the flood zone of 25 years is predicted to be more hazardous than the other periods for the selected areas.

Key words: Flood zonation, HEC-RAS, GIS, Neka River.

Introduction

Hydraulic modeling and flood zonation mapping are performed in order to predict important information from a flood event including the extent of inundation and water surface elevations at specific locations. A hydraulic model is essentially a representation of the processes that occur during a flood event. The processes needing to be modeled are often up for debate, as many different simplifications and assumptions have been made to create models capable of accurately representing compound channel flow while being computationally efficient. A compound channel can be described as the combination of the main river channel with floodplain areas on either side of the main channel. When the depth of flow during a flood

event exceeds the height of the main channel, the flow expands into the relatively flat floodplains. In practice, high flows are often simulated using one-dimensional or two-dimensional models with a steady-state assumption. Flow processes in compound channels include momentum exchange between fast moving flow in the main channel and slower moving flow in the floodplains, formation of turbulent eddies, and formation of shear layers between the main channel flow and storage areas in the floodplain¹.

A theory of forecasting for large rivers has interesting features which demand a high degree of sophistication of concepts. In contrast to small rivers, where a rainfall - runoff model may suffice for the forecast, a large river requires also forecasting of discharges by means of upstream stages. Purpose is to estimate the future output at

different time (2, 5, 10, 25, 50, 100 and 200 years) as accurately as possible, starting with measurements of present and past input quantities. Therefore, it is data based: data are needed for feeding a forecast model. Because data on rainfall and other natural processes are never accurate, and because hydrological models always simplify actual conditions and thus add uncertainties, the outputs also are uncertain quantities, which in a scientific sound approach should be described by means of probability distributions². Although many people see forecasting models as just another application of typical hydrologic rainfall runoff models or hydraulic routing models as used for design purposes, there exists a principal difference between the two types of models. A forecasting model must yield accurate forecasts of the real discharge or stage within narrow error bounds: this is more important than physical accuracy. On the other hand, for design purposes one needs to know a possible extreme event without regard of its time of occurrence, such as the 100 year flood. However, it is never known if the design flood really is the actual 100 year flood, and one has to live with large uncertainties which must be properly allowed for in design of flood protection works by suitable margins of safety. Such design information is obtained by means of extreme value analysis of discharge time series for gaged locations, or by means of rainfall runoff models for ungaged catchments. Advantage of a physically based rainfall-runoff model is its ability to predict the effects of changes in the river system. Flood protection and awareness have continued to rise on the political agenda over the last decade accompanied by a drive to improve 'flood forecasts'^{3,4}. Operational flood forecasting systems form a key part of 'preparedness' strategies for disastrous flood events by providing early warnings several days ahead⁵, giving flood forecasting services, civil protection authorities and the public adequate preparation time and thus reducing the impacts of the flooding.

Due to the expansion of agricultural activities along the river banks and concentration of population in the region of submergible areas, the flood-induced compensation is in a increasing trend. The complete flood protection with installation of great flood control structures like flood dams are not defensible due to its high cost⁶. It is not environmentally, socially and economically a most advantageous idea either. For this reason, the flood zonation can have a substantial role in flood management through logical consumption of weir gates and dam reservoir⁷. In this direction,

different systems have been innovated in different countries of the world, but lack of equipment and tools, and also high cost of installation are the limiting factors in Iran⁸. According to the recorded data, recently the flood return period has decreased in Neka Basin in the Northern Iran, so an appropriate method of prediction to decreasing the flood-damages is required, which can be gained using flood zonation results. The aim of this study is to find out the efficacy of GIS technique in simulating a comprehensive hydrological model. For that reason the main requirement of a hydrological model is description of flow channel characteristics and land surface as input data to the watershed model. The flood zonation is actualise, development and perfection of the applied engineering hydrology and its aim is to acquire a real time rainfall data and river flow by short wave, radio and satellite network, and using them in rainfall-runoff models to forecast and also zonation of the floods in consecutive time and space intervals⁹. The quality of flood forecasting systems mainly depends on the quality and the amount of the collected basic data about hydrology and the hydrological yield of the related watershed¹⁰.

The study area with 5.5 km long of Neka watershed is located between Chaman and Bezminabad villages. The UTM coordinates of the study area is; Xmin=699000, Xmax=704000; Ymin=4058000, and Ymax=4062000, and it is located in northern part of Iran (Figure 1).

The mean annual rainfall of the region is estimated to be 800 mm by Isohyet's method, and 816.2 mm by Thiessen system. The main part of the basin has very humid climate and the northern part of the basin which has lower elevations has humid climate which is indicated using De-marten method. Based on Emberger method, the middle and northern part have cold humid conditions and southern part of the basin with higher elevations has mountain climate.

This study which has combined GIS with hydrologic model is based on some of the previous research works. Smith¹¹ created a hydrological information development system, by using GIS and hydrological watershed parameters such as design storm, soil hydrology, time of concentration, runoff coefficient, etc^{12,13} and U.S Army¹⁴ used GIS technique, obtained primary stages data including the elevations, separated the reach network and sub-basins, recognized the hydrological elements, created continuity among them and finally input them in the hydrological model. The results obtained from the used HEC-RAS showed that determination of spatial parameters is easy by

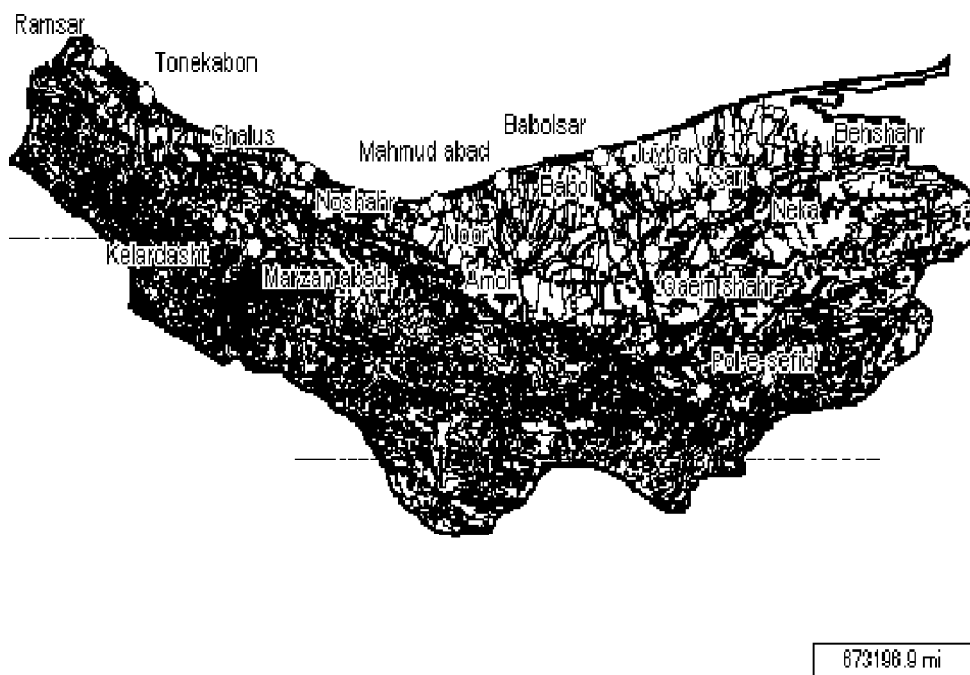
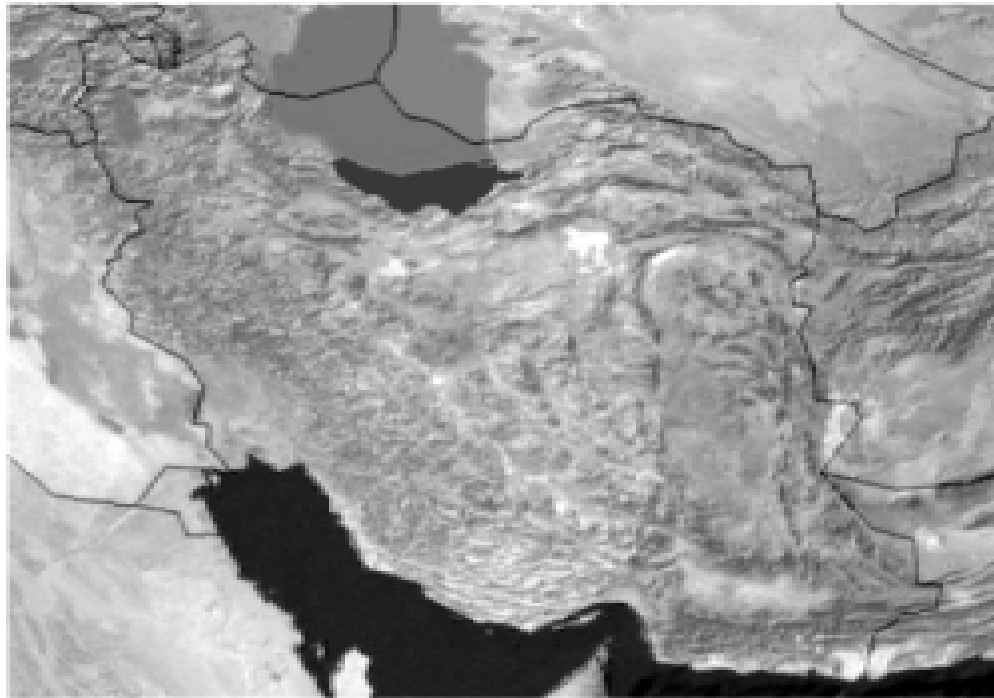


Figure 1: Neka River study area in S.Eastern part of the Caspian Sea.

hydrological models and the results can be extendable.

Experimental

HEC-RAS is a numerical model which is developed by the American Army Corps of Engineers; and allows users to perform one-dimensional steady and unsteady flow calculations^{15,16}. In a HEC-RAS steady state simulation, water level profiles are computed from one cross-section to the next by solving the normal step iterative procedure to solve the energy equation. The energy equation is intended to estimate water surface profiles for steady gradually varied stream. The energy equation is shown below for two closest cross-sections XS1 and XS2;

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Y_1 and Y_2 = depths of water at adjacent,
 Z_1 and Z_2 = elevations of the main channel inverts,
 V_1 and V_2 = average velocities (total discharge/total flow area),
 α_1 and α_2 = velocity weighting coefficients,
 g = the gravitational acceleration and h_e is energy head loss.

The energy head loss term is defined as-

$$h_e = L\bar{S}_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right|$$

L = discharge weighted reach length, \bar{S}_f = representative friction slope between, XS1, XS2, and C = an expansion or contraction loss coefficient.

The representative friction slope using the average conveyance equation and the distance weighted reach length are defined as follows-

$$\bar{S}_f = \frac{Q_1 + Q_2}{K_1 + K_2} k$$

$$L = \frac{L_{lob} \bar{Q}_{lob} + L_{ch} \bar{Q}_{ch} + L_{rob} \bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}}$$

K = conveyance,
 L_{lob} , L_{ch} , and L_{rob} = cross-section reach lengths for flow in the left over-bank, main channel, and right over-bank, respectively,
 \bar{Q}_{lob} , \bar{Q}_{ch} and \bar{Q}_{rob} = arithmetic average of the flows between sections for the left over-bank, main channel, and right over-bank, respectively.

To determine total conveyance and the velocity coefficient for a cross-section, HEC-RAS subdivides flow in the main channel from the over-banks. Conveyance is calculated for each subdivision using following equations-

$$Q = KS_f^{3/2}$$

$$K = \frac{1.486}{n} AR^{3/2}$$

K = conveyance for the subdivision,
 n = Manning's roughness coefficient for the subdivision,
 A = flow area for the subdivision, and R is hydraulic radius for each subdivision.

The total conveyance for each subdivision is calculated as the sum of the conveyance from the left over-bank, main channel, and right over-bank. Flow in the main channel is subdivided only when the Manning's roughness coefficient changes within the channel area. The composite main channel Manning's roughness coefficient is defined as follows-

$$n_c = \frac{\sum_{i=1}^N P_i n_i^{1.5}}{P}^{2/3}$$

n_c = the composite or equivalent coefficient of roughness, P is the wetted perimeter of the entire main channel, P_i is the wetted perimeter of subdivision i , and n_i is the coefficient of roughness for subdivision i .

Limitations in the HEC-RAS steady flow simulation include the assumptions that the flow is steady, the flow is gradually varied, the flow is one-dimensional, and the river channels have small slopes. For situations when the flow may be rapidly varied, the momentum equation is used to solve the water surface profiles. These situations include hydraulics of bridges, river confluences, and mixed flow regimes such as hydraulic jumps. The momentum equation used in HEC-RAS is shown as-

$$\frac{Q_2 \beta_2}{gA_2} + A_2 \bar{Y}_2 + \frac{A_1 + A_2}{2} k S_0 - \frac{A_1 + A_2}{2} k \bar{S}_f = \frac{Q_1 \beta_1}{gA_1} + A_1 \bar{Y}_1$$

β is momentum coefficient that accounts for a varying velocity distribution in irregular channels, \bar{Y}_1 and \bar{Y}_2 are depths measured from the water surface to the centroid of the cross-sectional area at XS1 and XS2, Q_1 and Q_2 are discharge at locations XS1 and XS2, A_1 and A_2 are wetted area of the cross-

section at locations XS1 and XS2, L is distance between sections XS1 and XS2 along the channel, \bar{S}_0 is slope of the channel based on mean bed elevations, \bar{S}_f is slope of the energy grade line.

Additional information can be found in the HEC-RAS Hydraulic Reference Manual¹⁷.

Required model parameters for HEC-RAS include topographic data in the form of a series of cross-sections, a friction parameter in the form of Manning's n values across each cross-section, and flow data including flow rates, flow change locations, and boundary conditions. For a steady state sub-critical simulation, the boundary condition is a known downstream water surface elevation¹⁸.

The original HEC-RAS project data is imported to GIS environment using HEC-GeoRAS, a GIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for input to HEC-RAS and generation of GIS data from HEC-RAS output. The data imported by HEC-GeoRAS consists of a river centerline and cross-sections. Using the HEC-GeoRAS toolbar, bank lines and flow paths are digitized by overlaying a topographic map. In HEC-RAS, it is common practice to place cross-sections on either side of channels or other hydraulic structures. Ineffective flow areas, defined as any area that contains water that has zero velocity, and flow obstructions, or any area that has no water and no flow, are digitized by referencing the topography map¹⁶. To complete the representation of the HEC-RAS project file in GIS, in addition to geometry data such as cross-sections, river centerline and left and right banks, HEC-RAS requires Manning's n values and levee locations. The distribution of Manning's n values in the original HEC-RAS project file is used to create a land use polygon in GIS. Figure 2 shows the selected area along the Neka River with 93 cross sections file necessary for a HEC-RAS analysis.

For the flood zonation of the Neka watershed, different map layers were prepared such as vegetation, geology, soil and the other required data. Then through the GIS application this data layers were pre-processed for hydrological analysis. In this processes the channel vegetation of the basin was created to gain a regional model for the channel and watershed characteristics. The used data of the early model of elevations was prepared in GIS environment and is transferred to the hydrological model. In order to comparison of the results of hydrological model to the observed data for the calibration of the model, the evaluation of the correctness of the input to the model and the modeling

system has been performed. For the regional modeling, simulation and the flood zonation, some of

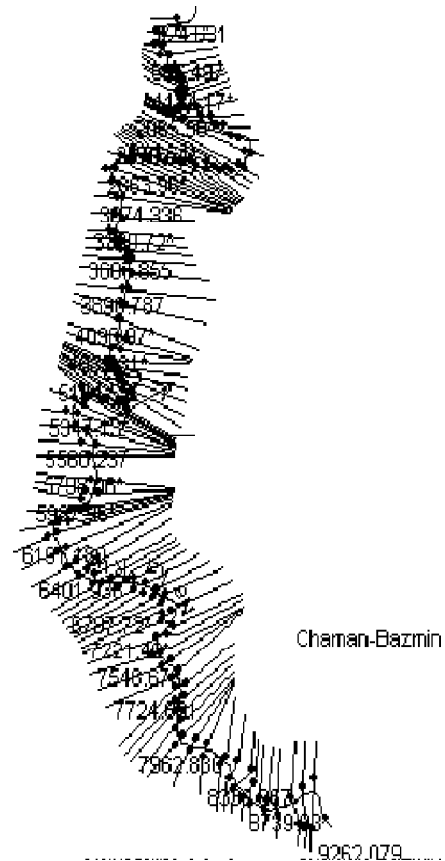


Figure 2 : Neka River Cross-Sectional Configuration (approx. scale 1:34000)

common techniques and softwares were used such as Arc View software and HEC-GeoRAS extension v.3.1, Spatial Analysis and 3D Analysis¹⁹.

To determine the water velocity in the selected reaches, a cross section was surveyed between the highest and lowest main channels for each of hydrological unit. A series of regular sections with a steady form was considered. After estimation of roughness coefficient using²⁰ method, the water velocity was calculated for the main river, and each tributary using Manning equation.

The lag time of the sub-basins was calculated from US-SCS method described by²⁰ as-

$$T_c = L^{0.8} W[(1000/CN) - 9]^{0.7} 31.68S^{0.5}$$

Finally, for the flood zonation 5.5 km of the Neka river channel was selected for the purpose of flood prediction with different return period of 2, 5, 10, 25, 50, 100 and 200 years. Different parameters were used in relation to the geometric characteristics of the river channel such as height, profile, depth and velocity along the selected sections.

Results and Discussion

Discharge Estimation for Different Return Period

Different statistical distributions were used to preparing the probability maximum discharges for Ablo station using Hyfa software and then the best one was selected with different return period for each of the used station in Neka Basin. The results from Pearson type III model has shown an optimize and the best statistical distribution than the other used models. The flow rates used to simulate of flood discharge in Neka watershed are shown in Table 1.

Table 1. The best statistical distribution of data used for simulation of flood discharge in Neka watershed.

Distr./Ret.(yr)	2	5	10	20	25	50	100	200
Log.Normal (2 parametre)	73	189	310	468	527	742	1010	1338
Log.Normal (3 parametre)	73	231	371	532	589	783	1005	1258
Pearson III	62	113	229	406	475	719	1008	1337
Log.Pearson III	74	180	303	480	553	837	1239	1801
Gambel	108	312	447	577	619	745	871	997
Selected Pearson III	62	113	229	406	475	719	1008	1337

Maning Roughness Coefficient

For determination of Manning's roughness coefficient first of all the characteristics of the selected sections in right, left and the main bed of the river channel were measured separately in the field based on Table 2.

Table 2. Determination of Manning's coefficient for each section

No. Section	Right Bank	Left Bank	Main Channel	Number for each section
1	0.050	0.050	0.040	1 to 46
2	0.035	0.035	0.030	46 to 93

Figure 3 and 4 shows the hydrological characteristics of water level profiles during different return period. The quantity obtained in condition (I) for events 2, 3 and 4 are indicated in Figure 3, 4 and 5 as simulated and observed hydrographs at Valikbon hydrometric station.

The first objective of this research is to evaluate the effect of topography on hydrodynamic model. This is accomplished by using different steady parameters to produce floodplain maps using HEC-RAS for Neka river in North of Iran. For the selected river reach evaluated, the area of inundation and average width of inundation along the original cross-sections increase as the resolution of the time decreases. For the Neka downstream, with a high flow rate, most of the flow is routed through the floodplains making the topographic representation of the main channel less important. Results from this research are similar to those found in other studies that decreasing resolution of the topographic data causes an increase in the floodplain area. In earlier studies it was found that increasing the resolution of the DEM leads to a decrease in inundated area^{21,22}.

The next topic concentrated on in this paper is the effect of geometry on hydraulic models. For Neka River, increasing the number of cross-sections generally results in an increase in the inundation extent. Removing specific cross-sections generally results in a decrease in width of inundation along the cross-section removed for the selected river reach analyzed except when the cross-section being removed is located near a levee. In earlier study it was found that increasing the mesh resolution results in a decrease in inundation area similar to what was found in this paper for the Neka River²³.

The results from this study shows evaluation of the efficiency and application of GIS in hydrological modeling as a winning technique. GIS as an appropriate technique prepares the immense and accurate data bases for the watershed and is beneficial for places with an available ground data for example, the rainfall distribution and its conversion to a clear format which is utilizable for hydrological model.

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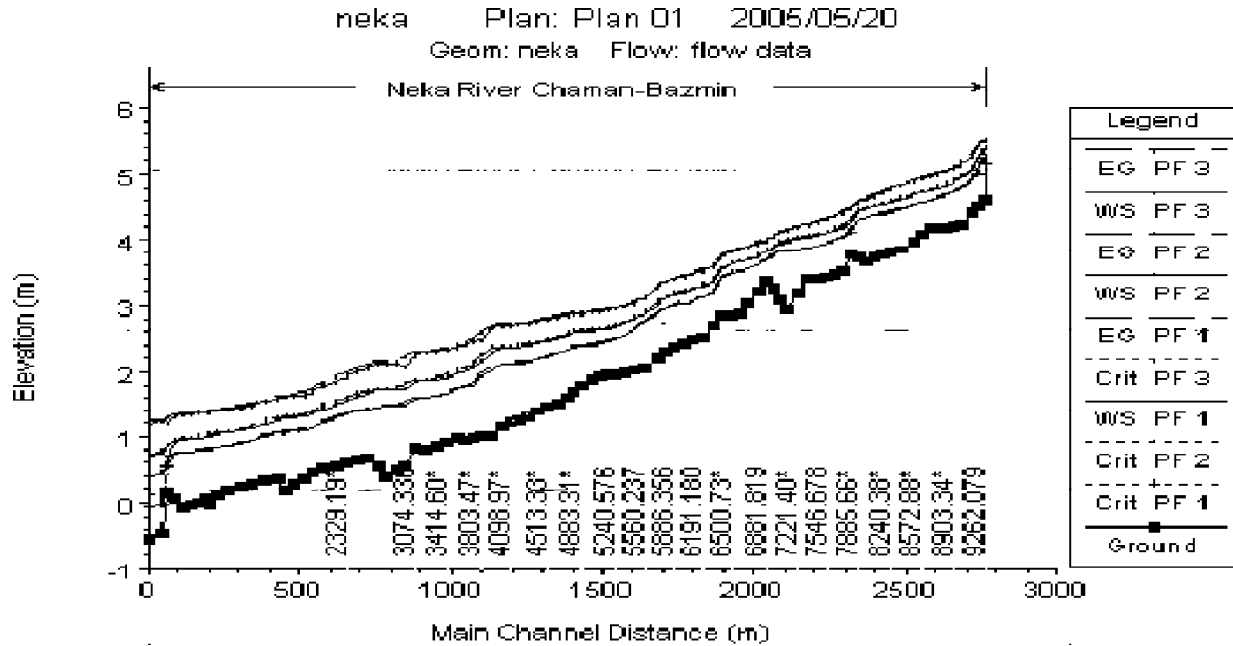


Figure 3. Long profile of water level for the return period of 2, 5 and 10 years

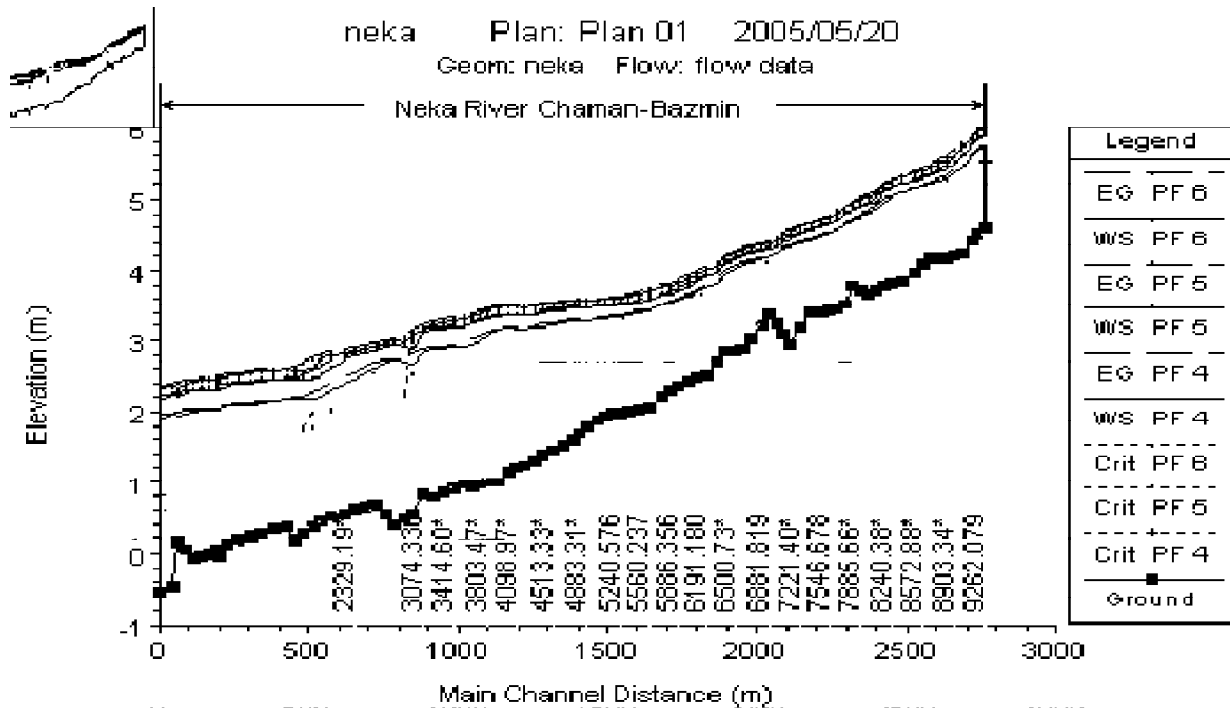


Figure 4. Long profile of water level for the return period of 25, 50 and 100 years

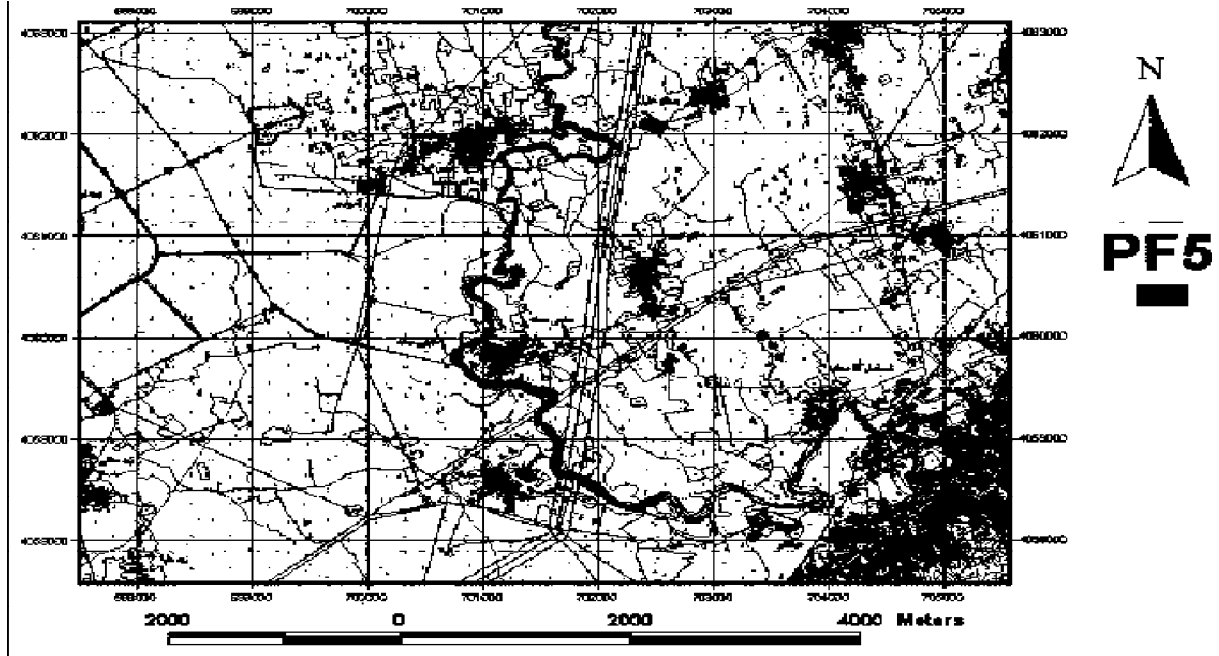


Figure 5. Flood zonation for return period of 5 years

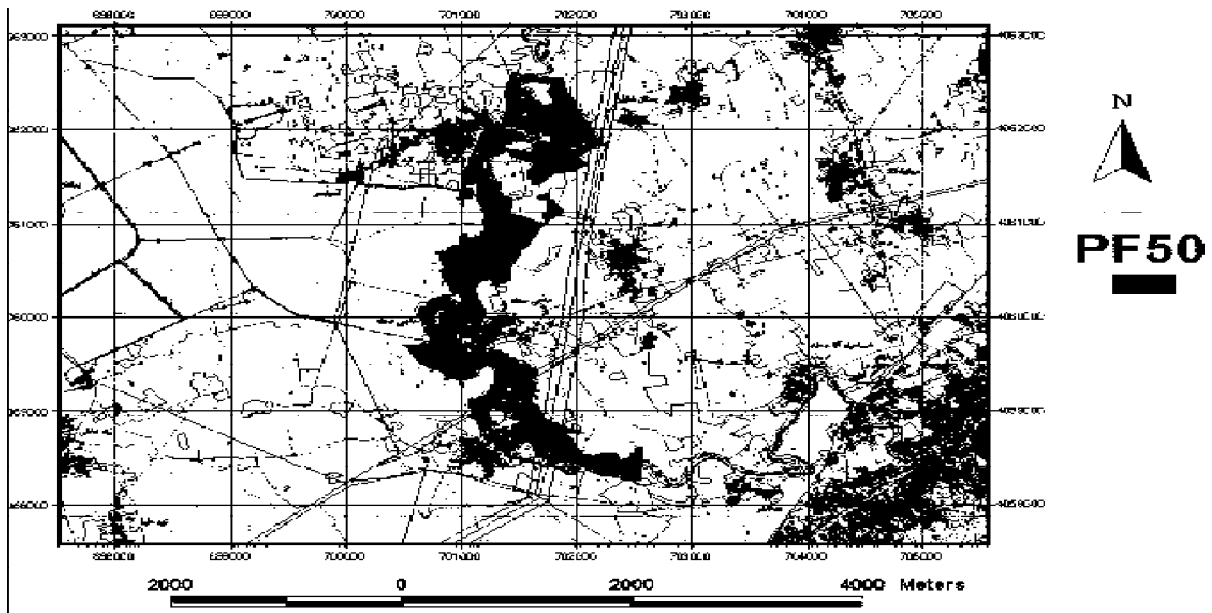


Figure 6. Flood zonation for return period of 50 years

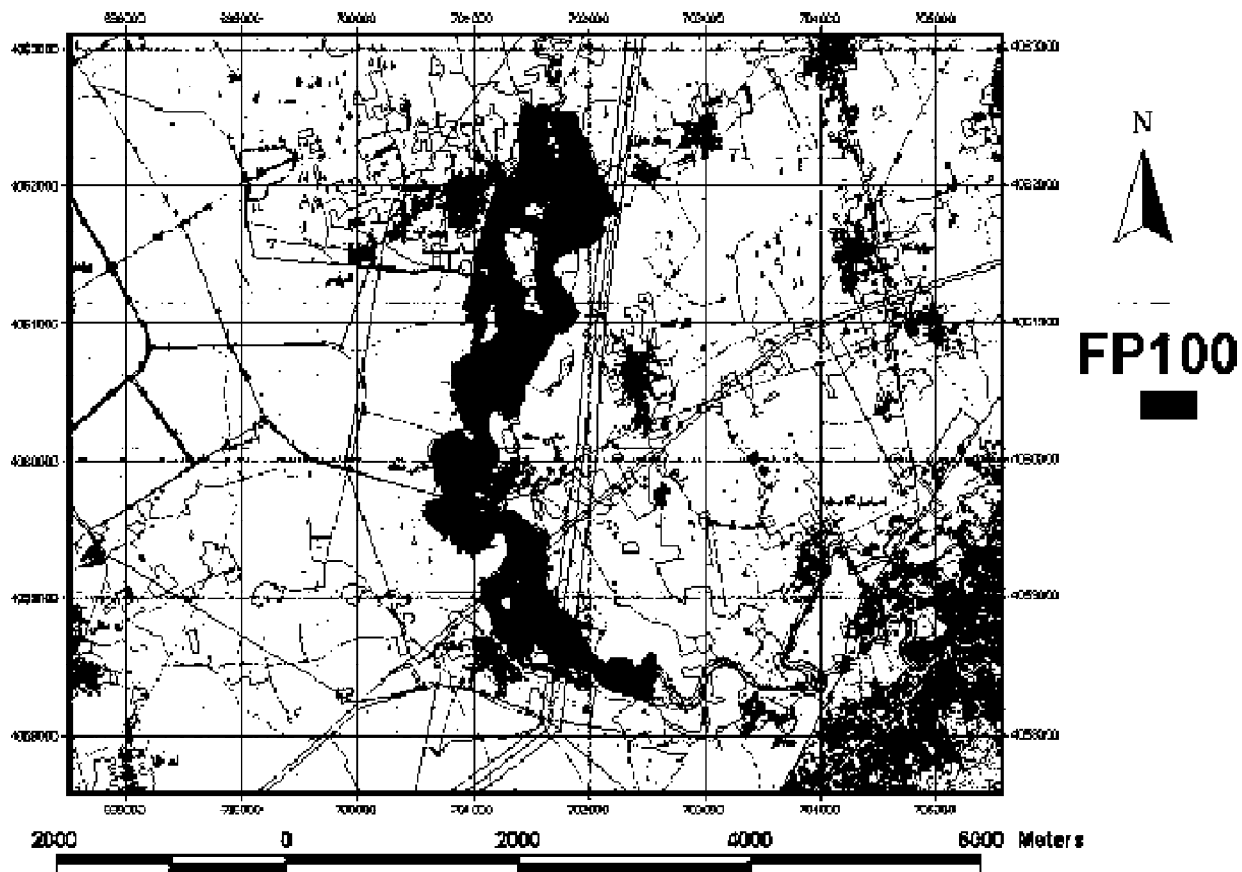


Figure 7. Flood zonation for return period of 100 years

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