

# HYDRAULIC MODELLING USING HEC-RAS AND GIS, APPLICATION TO OUED INAOUEN (TAZA, NORTHERN MOROCCO)

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**KEY WORDS:** Hydraulic modeling, river basin planning, GIS, Oued Inaouene, Morocco.

### ABSTRACT:

This paper discusses a GIS approach for floodplain mapping to aid in the design of the drainage facilities. The approach establishes a connection between the one-dimensional HEC-RAS hydraulic model and GIS software, allowing for improved three-dimensional visualization and analysis of floodplain data. It also permits GIS to function as an effective planning tool by making hydraulic data easily transferable to floodplain management, flood insurance rate determination, economic impact analysis, and flood warning systems. The methodology is applied to a reach of Oued Inaouene, located in the west of the city of Taza (Northern Morocco). The research was conducted in the Hydraulic Basin Agency of Sebou, in order to help improve their hydraulic design capabilities.

## 1. INTRODUCTION

Since antiquity, hydraulic schemes created by man have the objective not only to use the vital functions of water but also to protect humans against its destructive forces. These last years, climate change and the resulting services required by society challenge the cadastral surveyor to increase skills in unfamiliar areas. Some topics covering the wide field of hydraulic schemes are developed. Research activities will include new subjects like: river training works and flood protection measures, water supply systems, water resources management and natural hazards in catchments areas, safety of dams and storage schemes as well as environmental aspects in relation with river restoration and definition of minimum discharge and finally financial and contractual questions of hydraulic schemes.

Today, computer models play a pivotal role in these analyses by aiding in the determination of water surface profiles associated with different flow conditions. Many works tried to connect the information describing the water profiles with their physical locations on the land surface (Beavers, 1994; Tate *et al.*, 2002).

From many hydrologic software, HEC-RAS (Hydrologic Engineering Center – River Analysis System) is a good choice for 1D flood plain modelling (USAC, 1997). The model is fully available from the web and copes with a variety of problems as rainfall-runoff modelling, river and civil works hydraulics, and the mapping of hydraulic hazard. Its ArcGIS application companion HEC-GeoRAS makes it easier to gather physical data required by the model from a high resolution DEM (USAC, 2009). The extension allows users to create an HEC-RAS import file containing geometric data from an existing digital terrain model and complementary data sets. Results exported from HEC-RAS may also be processed.

The study was carried in the reach of Oued Inaouen, located in the west of the City of Taza in northern Morocco. Analysis

shows that the computed program HEC-RAS contains a calculation module adequate to short time flooding events, which is typical of Mediterranean climate.

## 2. STUDY AREA

The Oued Inaouene basin is a 3322 Km<sup>2</sup> square basin situated between the Middle-Atlas mountain in the south and the Rif Chain in the north. The Oued Inaouen river flows along an east-west direction (figure 1 & 2). The Oued Inaouen basin is characterized by impervious marly substratum more or less reinforced limestone and sandstone beds covering 60% of the total area of the basin. These soft rock formations are continuously subjected to strong mechanical erosion, unlike the carbonate formations that outcrop in the South and affected by major karsts dissolution.

The Oued Inaouen basin has a Mediterranean climate with oceanic influence. Examination of series of annual rainfall shows an average annual rainfall of 600 mm and a clear interannual irregularity.

Rainfall inputs to the model cover the period from 1970 to 2007 collected by 16 stations situated in and around the basin. Climate series are composed of real weather data and disruptions due to changes in measurement conditions. The correction of these artificial discontinuities is made by the cumulative method. The double-mass curve is used to adjust inconsistent precipitation data by comparing date for a single station (Oued Amlil station as a reference) with that of a pattern composed of the data from several other stations in the area. The graph of the cumulative data of one variable versus the cumulative data of a related variable is a straight line so long as the relation between the variables is a fixed ratio (figure 3).

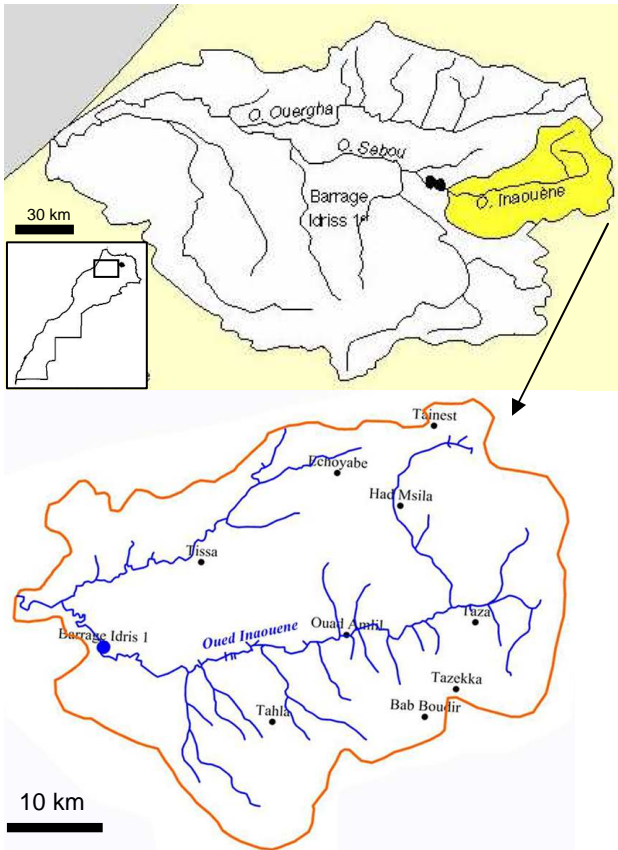


Figure 1: Location of the Oued Inaouene watershed within the Sebou basin

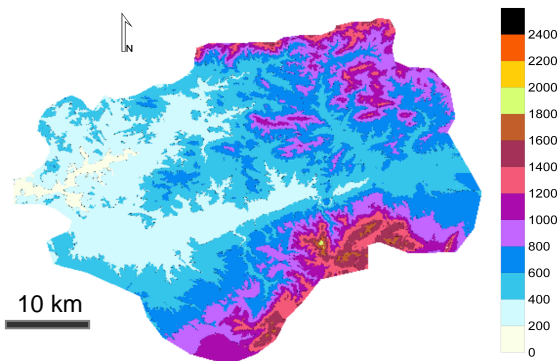


Figure 2: Hypsometric map of the Oued Inaouene watershed

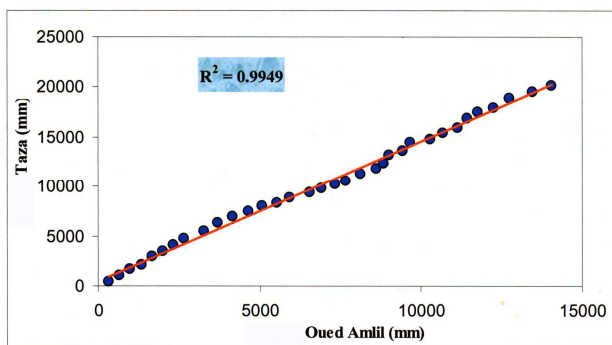


Figure 3. Graph of the cumulative data of one variable (Taza station) versus the cumulative data of a related variable is a straight (Oued Amlil station)

The morphometric parameters of the watershed provide valuable information for understanding the flow regime. Representativeness of the results obviously depends on the quality of the maps used. The calculations were made from topographic maps of Taza and Tahala of 1/50000 scale, on which the equidistance between contours is 10 m.

To characterize the drainage basin, various shape indices are proposed that may be used for inter-basin comparison and possibly for estimation of unmeasured characteristics. The index most commonly referred to is the compactness coefficient proposed by Gravelius (1914). This is the ratio of the perimeter of the watershed to the circumference of a circle whose area is equal to that of the given drainage basin. It is calculated by applying the following formula:

$$K_G = \frac{P}{2 \times \sqrt{\pi \times A}} \approx 0.28 \times \frac{P}{\sqrt{A}}$$

Where:

P is the perimeter stylized basin (in km)

A is area (km<sup>2</sup>).

K<sub>G</sub> is equal to 1 for a circular basin and is growing especially as the compactness decreases (Dubreuil, 1974). For this study, the value of 1.30 found for the Oued Inaouene basin is an elongated basin unfavorable to the concentration of flows.

The equivalent rectangle is to facilitate comparison between catchments in terms of their influence on the flow characteristics (Roche, 1963). The length of the equivalent rectangle combined to the catchment area is used to calculate the shape index Sf. The watershed of the Oued Inaouene corresponds to an equivalent rectangle whose length is three times larger than the width (Table I). The form factor leads to the same diagnosis as the compactness coefficient.

A : Area (Km <sup>2</sup> )	P : Perimeter (Km)	K <sub>G</sub> : Compactness coefficient
5152,29	330,7	1,30

L: Length of equivalent rectangle (km)	l: width of equivalent rectangle (km)	Shape index Sf
123,7	41,6	2,97

Table 1 : Shape indices of the Oued Inaouene watershed

Where (Roche, 1963):

$$L = \frac{K_G \sqrt{A}}{1,12} \left( 1 + \sqrt{1 - \left( \frac{1,12}{K_G} \right)^2} \right)$$

$$l = \frac{K_G \sqrt{A}}{1,12} \left( 1 - \sqrt{1 - \left( \frac{1,12}{K_G} \right)^2} \right)$$

The drainage density is expressed in km/km<sup>2</sup> as follow:

$$D_d = \frac{\sum L_i}{A}$$

Where:

L<sub>i</sub> : Total length of streams in km

A : watershed area in km<sup>2</sup>.

$$D_d = 0,17 \text{ km}^{-1}$$

### 3. GENERAL STRATEGY

In this work, two keys software are used: ArcGIS (ESRI, 2000) for GIS applications and HEC-RAS (USACE, 1997) for the hydraulic part. The link between the two software, is being performed by the HEC-GeoRAS. This later automates the stages of export - import between the two existing software (USACE, 2009). The HEC-GeoRAS interface is created for ArcGIS in the form of a dropdown menu in the toolbar of ArcGIS. This application allows the design of the components of the topographical model and automated export to HEC-RAS and then imports the results of hydraulic simulation to ArcGIS.

The proposed method of this research involved several steps:

- (1) Data collection and development of digital spatial database of the hydrologic system in ArcGIS;
- (2) Generate a Digital Elevation Model for the entire basin (raster and TIN). TIN is used as Digital Elevation Model required in GeoRAS environment in order to prepare data sets required as input to the HEC-RAS simulation;
- (3) Hydraulic modelling: determination of flood peak discharge;
- (4) Flood plain analysis: It consists of three steps: (a) HEC-GeoRAS processing to generate HEC-RAS import files, (b) HEC-RAS application, (c) Post-processing of HEC-RAS results and flood plain mapping in ArcGIS.

### 4. RESULTS AND DISCUSSION

#### 4.1 Data preparation and development of digital spatial database of the hydrologic system

Data preparation consists of inputting geo-referenced maps projected into Merchich (Morocco) coordinate system. The GIS layers of the Oued Inaouene basin correspond to geo-referenced rasters (orthophoto, topographic maps, geological maps, pedological maps with soil characteristics), land use modes (arable land, meadows, forests - that is the corresponding polygons of the drainage coefficients, Manning roughness, etc.), meteorological data (particularly rainfall) and hydrographic network. During the field study, detailed information regarding old river courses, old flood marks, bank height, channel shifting, and effect of flooding on civil structures was collected. Also field observations and data about the heights of the walls, river talweg and bank elevations, bridge, and the location of other hydraulic structures were included in the base map, and digitized.

#### 4.2 Development of digital elevation model

After the collection of two topographical maps of 1/50000 scale having 10 m interval contours (Taza and Tahala), detailed measurements from field work were reported and both data were combined in the same coordinate system. The topographical data were analyzed by ArcGIS, and 3-Dimensional field model: Triangulated Irregular Network (TIN) has been prepared. TIN outputs are used as input for Digital Elevation Model (DEM), which is raster data in GeoRAS in order to prepare data sets required as input to the HEC-RAS simulation

#### 4.3 Determination of flood peak discharge

Warning level and danger level of flood within Oued Inaouen basin was calculated using the maximum instantaneous discharge data from 1970 to 2007. The instantaneous maximum discharge data were used in statistical analysis of the flood data. After testing different statistical distributions such as Normal, 2 and 3 Parametric log-normal distributions, Parametric Log-normal, Pearson Type III, Log-Pearson Type III, and Gumbel; the Gumbel's method was selected because it gave largest discharge comparing to others. The Gumbel's method is found as best fit to calculate peak discharge.

From the adjustment maximum flow chart by the Gumbel distribution, we draw the annual maximum flows for different return period. The discharge values of return periods-recurrence intervals of 2, 5, 10, 50, 100 years were defined (Table 2).

Station	D.max 2 years	D.max 5 years	D.max 10 years	D.max 20 years	D.max 50 years	D.max 100 years
Bab Marzouka	395	647	800	962	1180	1360

Table 2. Flood frequency analysis for various return periods

Since the Manning Roughness coefficient, n is one of the most important parameters affecting the results, n values for different sections of the river were determined as representative of the existing conditions as possible. In order to see the influence of the variability of the Manning coefficient on the depth of water at the Oued Inaouen, we studied the sensitivity of the numerical model to address such changes, by changing the values of this coefficient of +/- 5%, +/-10% and +/-15% compared to the values of timing. 5 well-spaced of 35 sections were selected. For each of these sections, we traced the evolution of the maximum water depth according to the variation of the friction coefficients (Figure 4).

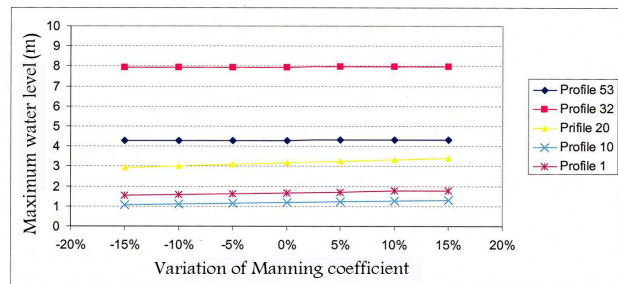


Figure 4. Variation of the maximum water level depending on the Coefficient of roughness.

In this study, it was possible to calibrate the profiles of surface water from rating curves from the gauge station of Bab Marzouka in the upstream of Oued Inaouen. Equations deduced from the curves are in the form of second-degree polynomials.

The equation at the gauge station is:  
 $H = -0.0014Q^2 + 0.0083Q + 0.4585$ .

The equation at the downstream section of the study area is:  
 $H = -0.0156Q^2 + 0.0054Q + 0.1001$

#### 4.4 Flood plain analysis

It consists of three steps:

(a) HEC-GeoRAS processing to generate HEC-RAS import files:

The RAS layers are the basis for the geometric data extracted in the GIS for hydraulic analysis in HEC-RAS. The geometric data included stream centreline, bank lines, cross-sectional data, and bridges/culverts. The stream centreline is used to establish the river reach network. The river network was digitized from the east to the west in the direction of flow. The bank lines of the main channel are also digitized for velocity analysis. The Cross-sectional cut lines are selected according to the rules listed by Kreis (2004). The current model has 35 cross-sections and 5 hydraulic structures (bridges) (Figure 5). The number of cross-section is sufficient to capture bends and sharp elevation changes in the channel. The export of these data files to HEC-RAS using HEC-GeoRAS is a task that has possibilities and limits, especially regarding issues of export file size and format.

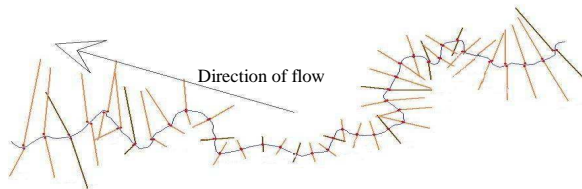


Figure 5. Oued Inaoued river system schematic

(b) HEC-RAS application:

This is the major part of the model where simulation is done. The import file created by GeoRAS was imported within HEC-RAS. All the required modification, editing was done at this stage. The flood discharge for different return periods were entered in steady flow data. Reach boundary conditions were also entered in this window. The bridge data (height, opening abutment and pier dimensions) obtained during the field investigations has also been entered. The ineffective flow area data are revisited and the spatial location and elevation around bridges are adjusted. Then, water surface profiles were calculated in steady flow analysis window. A digital terrain model is synthesized from HEC-RAS cross-sectional coordinate data and a digital elevation model of the study area. The resulting surface model provides a good representation of the general landscape and contains additional detail within the stream channel. Viewing these plots for anomalies is a good diagnostic tool to search for cross sections with irregular geometry (figures 6, 7 & 8).

After finishing simulation, RAS GIS export file was created. Water surface profiles were computed from one cross section to the next by solving the energy equation. The flow data were entered in the steady flow data editor for four return periods as 10, 20, 50 and 100 years. Boundary condition was defined as critical depth for both upstream and downstream. Sub-critical analysis was done in steady flow analysis. Then after, water surface profiles were computed. The result was exported creating the RAS GIS export files.

(c) Post-processing of HEC-RAS results and flood plain mapping in ArcGIS:

The results of hydraulic simulation are exported into a GIS. HEC-GeoRAS interface permit to export the results of the simulation from HEC-RAS to ArcGIS and generate flooding maps. The intersection between the profile of water level and the DTM (TIN) gave as results a flood hazard map containing the maximum water level and the maximum hydraulic load expected in a given location.

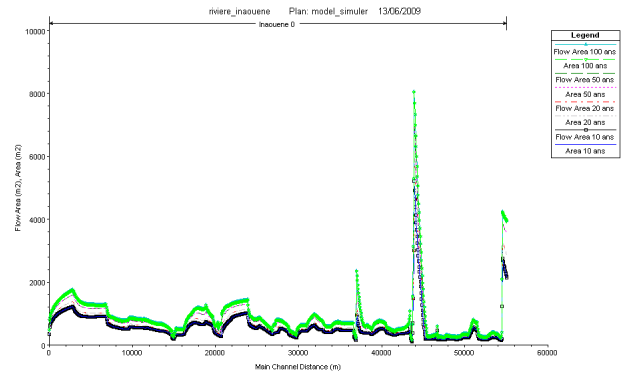


Figure 6. General profile plot of Flow versus distance

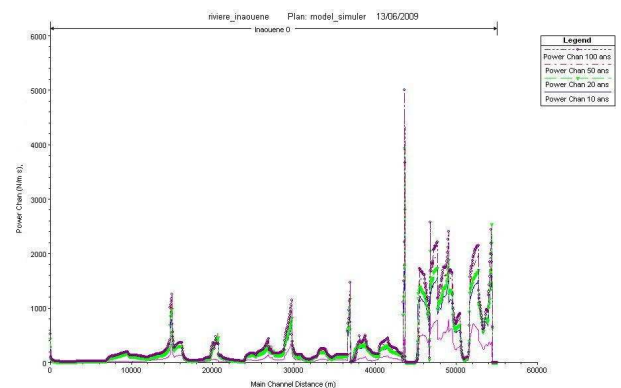


Figure 7. General profile plot of Energy versus distance

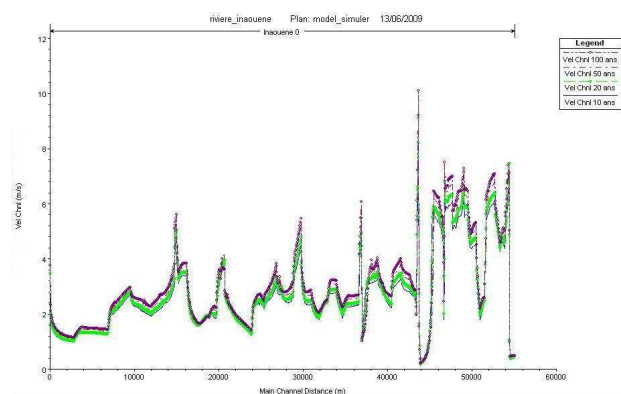


Figure 8. General profile plot of Velocity versus distance

## 5. CONCLUSION

This paper presents a methodology and case study of a floodplain mapping model conducted along Oued Inaouen in northern Morocco. The approach establishes a connection between the 1-D HEC-RAS hydraulic model and spatial display and analysis of floodplain data in ArcGIS. HEC GeoRAS extension facilitated the exchange of data between the two softwares. The flood discharge of different return period is derived by different model. For the safe side, the maximum of different method are taken as flood discharge for the analysis.

The approach may aid in the design of drainage facilities. It can be incorporated into both regional hydrological studies and/or a regional alert system for flood mitigation.

Using these tools, the decision makers can evaluate the conditions that lead to flooding and erosion, and identify where changes can be made to make the most significant impact. This knowledge will allow us to set the hydrometric installations and better predict the characteristics of the river during flood events as the night of January 14, 2010 and that of March 14, 2010.

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