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Hydraulic modeling of flooding in the Wadi Guigou watershed, Middle Atlas (Morocco)

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ABSTRACT

Given its geographical location within a fairly humid area generally characterized by a climatic regime marked by brutal and aggressive rains, a hydrographic network conducive to the rapid spread of floods and a geomorphological context favorable to flooding floods, as well as waterproofing of land through various economic and development activities ... the Guigou depression of 1227km2 has been subject for several years, particularly during the last decade (floods of 2001, 2002, 2003, 2005, 2008, 2009, 2010) to the several successive floods generated by the overflowing of the flood waters of the Guigou wadi and the other tributaries It is in this perspective that this work comes with the objective of achieving a hydraulic model by HEC-RAS allowing to limit, on the one hand, flood zones for each return period and, on the other hand, to propose measures to combat the floods caused by the Guigou wadi.

The hydraulic simulation results enabled us to note that the wadi overflows for all the return periods on a good part of the agricultural constructions and plots, which confirms the observations made during the diagnosis of the sections of the study area, as well define the development plans planned at Wadi Guigou, in order to remedy the flooding phenomenon and protect the center of Timahdite and the Guigou plain.

Key-words: *Middle Atlas, Almis ,Guigou wadi, Watershed, HEC-RAS, Landscaping.*

1. INTRODUCTION

Climate plays a fundamental role through precipitation and its characteristics (intensity, duration, spatial distribution and degree of rapprochement over time, etc.) in triggering runoff and generating more or less aggressive floods.

Given its geographical location within a fairly humid area generally characterized by a climate regime marked by brutal and aggressive rains, a hydrographic network conducive to the rapid propagation of floods and a geomorphological context conducive to floods, as well as the waterproofing of the land through various economic and development activities… the Guigou Depression has been subjected for several years, especially during the last decade (2001, 2002, 2003, 2005, 2008, 2009, 2010 floods) the several successive floods caused by the overflow of the flood waters of the Guigou wadi and the other tributaries that lead into this stream causing significant damage.

2. PRESENTATION OF THE STUDY AREA

The catchment area of the Guigou Wadi constitutes the upper part of that of the Wadi Sebou. It is part of an original structural morpho context between the Atlasic Middle Causse to the north and the Pleated Middle Atlas to the south. The latter is characterized by wide synclinal (plains of Guigou, Ain Nokra) of NE-SO orientation separated by narrow anticline wrinkles (Jebels Ben Ij, Tajda, Tichoukt). The Middle Atlantic Causse shows in the study area, a tabular morphostructure developed in the dolomites of Lias, corrugated by a flexible tectonics with large radius of curvature and affected by some accidents in the North-West. [6]

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It is topped with volcanic domes which are at the origin of the great basaltic effusions of the plain of Guigou The said zone belongs to the watershed of the Guigou wadi of which it occupies 14% and 2.2% of the Middle Atlas Central, and more precisely in its center. This basin, located upstream of the Haut Sebou watershed, covers a total area of 1227 km2, in a South-West/ North-East direction. (Figure 1).

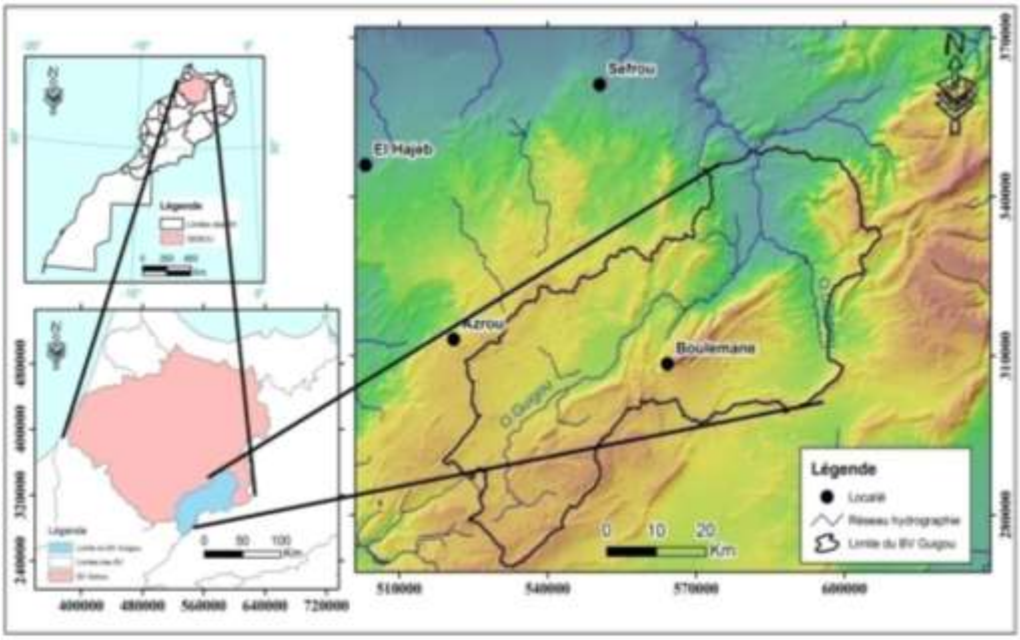

Figure 1: Study Area Location

The depression of the Guigou on both sides of the Guigou wadi and it is crossed by the tributaries of this stream that drains the chains of the Middle Atlas. It forms the centre of a vast set of terrain from the SW to the NE, with an average altitude of 1600m, passing through the main valley. The NW of the predominantly tabular depression (1700-2000m) consists of causses and links (Middle Atlas Tabular) and the SW is mountainous (2000-2400m) with high massifs and regions (Middle Atlas Pleated) (Figure 2). the hypsometric map shows that, the altitude ranges are equidistant of 400 m. The zones of high altitude (exceeding 2200m) occupy the south-west and the center of the basin, the flat areas occupied by the stream of Guigou until the confluence with Wadi Sebou. [1]

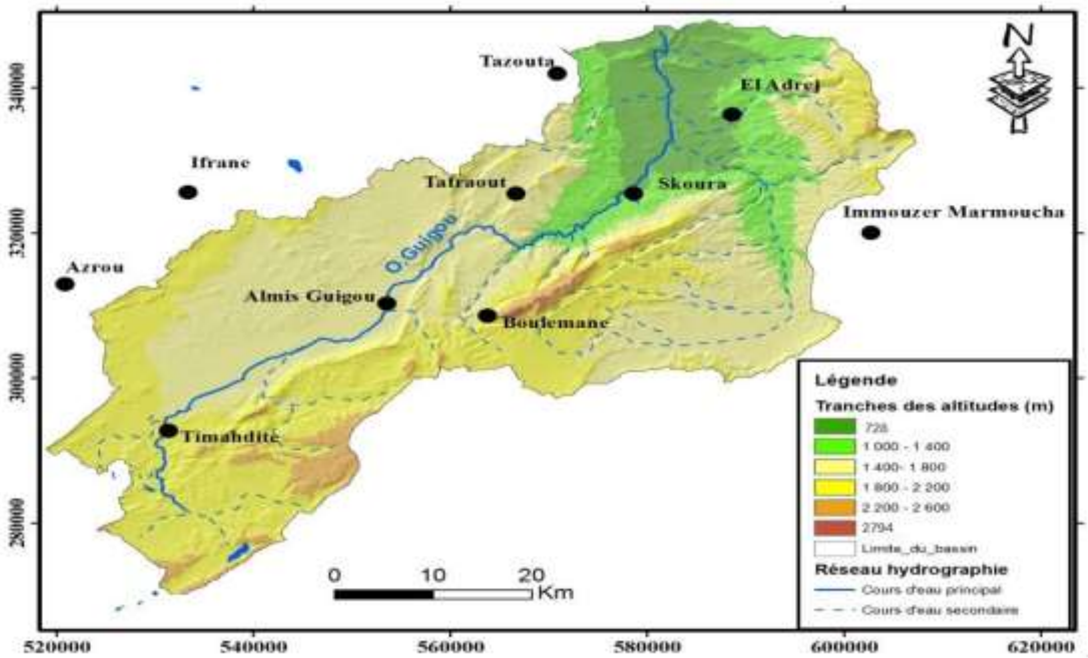

Figure2: Hypsometric map of the Guigou watershed

The Guigou depression is characterized by a flat to concave topography, with a slope not exceeding 5%. The longitudinal and transverse topographic profiles show the importance of the slope which decreases from upstream to downstream of the

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depression, as well as between the two structural units represented by the Tabular Middle Atlas and the Pleated Middle Atlas (Figure. 3). The map of slopes established for the Guigou basin shows that the small slopes (from 0 to 5%) occupy large areas in the basin, while the steep slopes are distributed at the level of the talwegs and high reliefs. The areas at high risk of flooding are generally located below the high reliefs and at the level of the plains. The regions in the vicinity of the great talwegs may also present flood zones in the case where the wadis beds do not support the sheet of water flowing during floods.

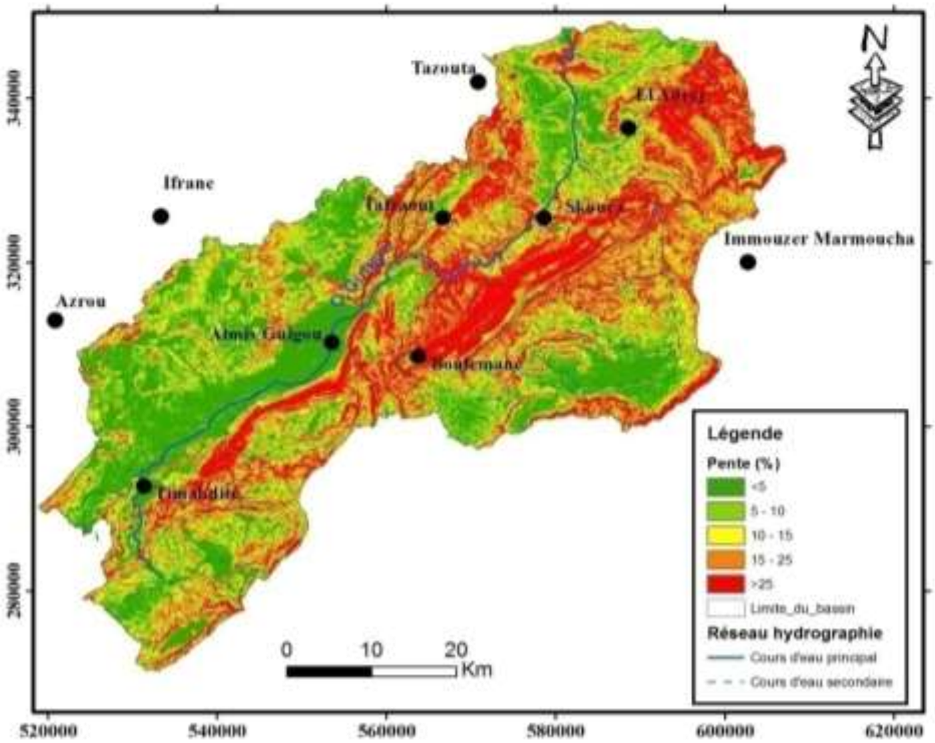

Figure3: Map of slopes distribution in the Guigou watershed

Wadi Guigou (from the source to the confluence with Wadi Maaser) first crosses the folded area to Timahdite where it receives WadiLarbi as a tributary of the right bank. Guigou then becomes perennial from the source of Aberchane then it borrows the long plain of Guigou, zone of transit and consumption of water until Ait Khabbach where a hydrometric station is established. In this section the flow is further inflated by the contributions of Tit-Zil. After Ait Khabbache, Wadi Guigou enters the pleated area and runs along the north slope of Jbel Tichoukt. In the second section, Wadi Guigou merges with its first large tributary on the right bank The Maaser (Figure 4) In the case of our basin, we can speak of two parts:

• Guigou at Ait Khabbache whose permeable outcrops, limestones and dolomites of the causal limestone condition a low drainage density of the order of 1.3 km / km².

• At Ait Khabbache at the M'dez bridge, the drainage density is higher than upstream and can be explained by the fact that Wadi Guigou and Wadi Maasser drain semi-waterproof formations in the large basins and synclines.

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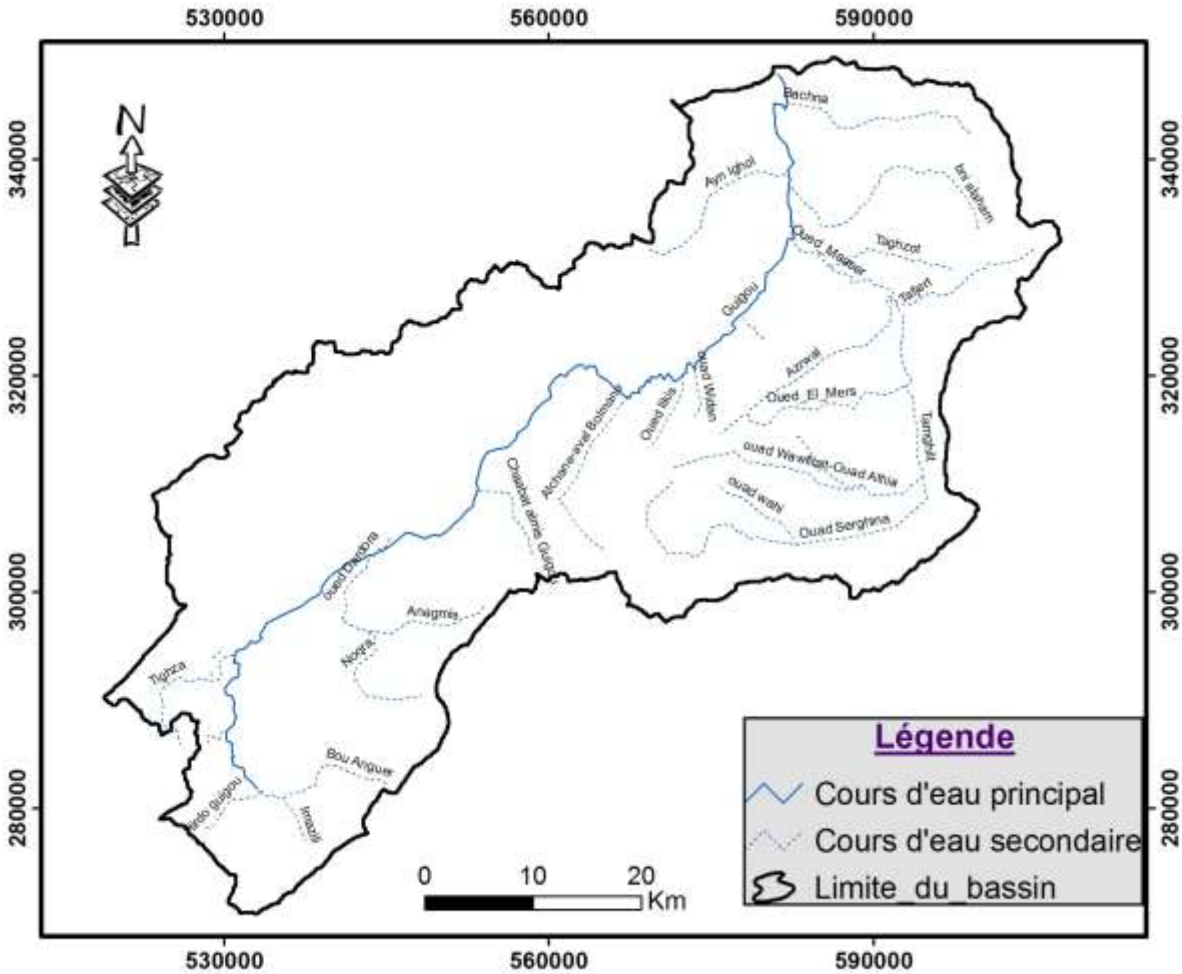

Figure 4: Map of the hydrographic network of the Guigou basin upstream

The main morphometric characteristics of the Guigou watershed are summarized in the following table:

Table 1: Morphometric characteristics of the WadiGuigou watershed

Surface Km2	*Périmètre Km*	*Indice de Gravilus*	*Rectangle Km Equivalent*	
1227	*184.5*	*1.47*	*16.54*	*75.42*

The Guigou watershed is characterized by a semi-arid Mediterranean climate influenced by the frequency of the foehn current. Winter is relatively humid and very cold with snowfall and a hot, dry summer. Winter temperatures can go down to -10 ° C and up to 38 ° C for summer temperatures; precipitation has the same characteristics, it is around 96.2mm in winter and 63.7mm in summer with thunderstorms accompanied by showers more concentrated in the space-time plane, with a large day-night amplitude.

3. MATERIALS AND METHODS

3.1 Hydrological study

The hydrological study aims to recognize project floods by aspects of peak flow. The flows selected will be of paramount importance for the hydraulic simulation of Guigou wadi. For that, it is necessary to pass by several stages namely a survey of floods in order to find the leashes of past floods and to collect the testimonies of the inhabitants, then an estimate of the times of concentration by different formulas, finally an estimate of the flows of peaks by different empirical formulas and by the Gradex method.

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3.1.1Estimation of the concentration times by empirical formulas

The time of concentration (Tc) of water in a watershed is defined as the maximum time necessary for a drop of water to travel the hydrological path between a point located as far as possible from the outlet to reach the latter.

The evaluation of the concentration time tc (time necessary for the water to flow from the point furthest from the basin to its outlet or to the calculation point) is generally based on the assumption that the raindrops move perpendicular to the level lines.

This parameter is determined by empirical formulas widely used in Morocco and which are presented and explained below.

Table 2 summarizes the various values of the concentration time obtained by these formulas. The value of the concentration time used is the average of the close values. Very large or very small extreme values have been eliminated, leaving only the central values.

Table 2: Concentration time used for Wadi Guigou

methods	Ventura	Epsey (1)	Espagnole	Van Te Chow	Californienne	US Corps	Kirpich	Turrazza / Passini	Giandotti	Valeur retenue [h]
	17,84	*8,92*	*10,77*	*4,65*	*11,95*	*9,98*	*5,39*	*20,15*	*6,20*	*6,29*

The concentration times calculated by the Ventura, Spanish, Californian, US Corps and Turrazza / Passini formulas are comparable and fairly similar but fairly high. The formulas of Epsey, Van Te Chow, Kirpich and Giandotti give shorter concentration times. The concentration time which is retained is the average of those calculated by the formulas of Epsey, Van Te Chow, Kirpich and Giandoti and which remain the most plausible.

Moreover, the article published in the Moroccan review of Civil Engineering n °: 62 of March 1996 confirms that the Kirpich formula is more appropriate for mountainous basins and that the Giandotti method slightly overestimates the concentration times.

3.1.2Estimation of flood flows by the usual formulas

- Empirical methods

The calculation methods identified using different empirical formulas take into account two essential factors:

• The topographic gradient of the watershed, by means of its slope or elevation.

• The size of the catchment area, through its surface and / or its length.

The formulas used in this case are: the method of Fuller II, Hazan Lazarevick and Mallet Gauthier. The flows used are those calculated by these formulas, the limits of validity of which essentially depend on the size of the basins.

- Transposition from neighboring basins

In order to better appreciate the probable peak flows in the study watersheds obtained by the usual empirical formulas, the estimation of the flows is also made by analogy with other similar and adjacent watersheds. The similarity criteria are essentially the morphology and the rainfall regime. [8]

The flood flows which have been taken into account are those calculated at the level of the catchment area of the Sehb EL Merga dam, and which were determined as part of the preliminary study of the dam in November 2012.

For non-gauged basins, a transposition from the statistical adjustments of the flows of the stations Ait Khabbach and Ait Aissa was also used. The Francou-Rodier formula commonly used in Morocco and which allows the transposition of flood flows.

- Gradex method

The Gradex method aims to find the maximum flood flows for rare to very rare occurrence frequencies. It is particularly applicable when there is a long series of rain in the basin, thus making the most of all the available data. In general, we often have more rainfall information [4] (Meylan, P. and Musy, A. (1999)). This method introduced by Guillot and Duband (1967) is used by several authors such as Naghettini et al (1996). [3-5]

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Table 3: Flow rates obtained and retained from different methods

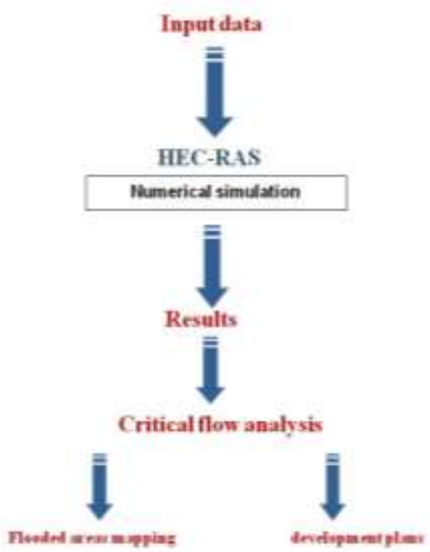
Methods		Return periods T (ans)			
		10	**20**	**50**	**100**
Débitsobtenus (m^3/s)	**Mallet Gautier**	*13.90*	*14.60*	*13.85*	*12.90*
	Fuller II	*397.99*	*400.12*	*507.13*	*556.63*
	HazanLazarevick	*384.6*	*456.48*	*543.8*	*629.33*
	Transposition	*385*	*486*	*640*	*710*
	Gradex	*389.5*	*437.86*	*514.6*	*579.43*
Debits withheld (m^3/s)		*382*	*463*	*534*	*610*

The flows selected are the result of an analysis and a comparison of the flows calculated by the different methods presented above. The flows calculated by the empirical formulas of Fuller II and Hazan-Lazarevick are lower than those determined by transposition but remain comparable to those calculated by the method of Gradex. While the debits calculated by Mallet Gauthier are underestimated.

Also, we will retain the average of the flows calculated by the empirical formulas and those calculated by the method of Gradex. Table 3 summarizes the different flow rates obtained and those retained.

3.2 Hydraulic study

The hydraulic study consists of diagnosing the study area for any hydraulic event. It consists in evaluating and integrating all the fundamental parameters, such as the geometry, the flow rate, and the boundary conditions in order to achieve a hydraulic model to calculate the water height, on the one hand, and on the other hand to determine the overflow areas.



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For a given hydrological event, the numerical model calculates at each previously defined point, the level, the flow and the speed of the flow.

As in any numerical calculation process, there are three phases that we had to respect:
Construction of the model;
Adjustment of variable parameters in order to best match the results of the calculation with field observations;
Establish sensitivity tests to get an idea of the validity of the setting and the boundary conditions.
For the purposes of this study, we used the HEC-RAS model (4.1.0), which and a hydraulic analysis software designed to model free surface flows in natural and artificial canals with the consideration of the works crossing. It simulates gradually varied flows in transient conditions and performs calculations of water lines in dynamic conditions by simulating the various obstacles along the river. The Wadi modeling is based on cross sections, takes into account all existing works, and allows to define different roughness coefficients for each section. [7].

❖ Input data

The topography of the profiles across the river and the distances between profiles were automatically extracted from the digital elevation model ASTER GDEM version 2.
Peak flows for a return period ranging from 10 to 100 years calculated by empirical formulas.
Boundary conditions, Manning coefficient, type of flow.

❖ The results of the calculations

• The water and energy levels in each cross section;
• The flow velocities in each section;
• The longitudinal profile over time of the water lines.

To carry out hydraulic simulations and delimit the extent of the areas liable to be flooded during the flooding of the various return periods, a hydraulic model was mounted for each section of the main river.
The principle of the reconstruction of the geometry of the wadi is based on the establishment of cross sections which must be perpendicular to the direction of flow. The modeling focused on a 47 km stretch of Guigou Wadi, between the two centers of Timahdite and Guigou. 114 cross profiles were noted.

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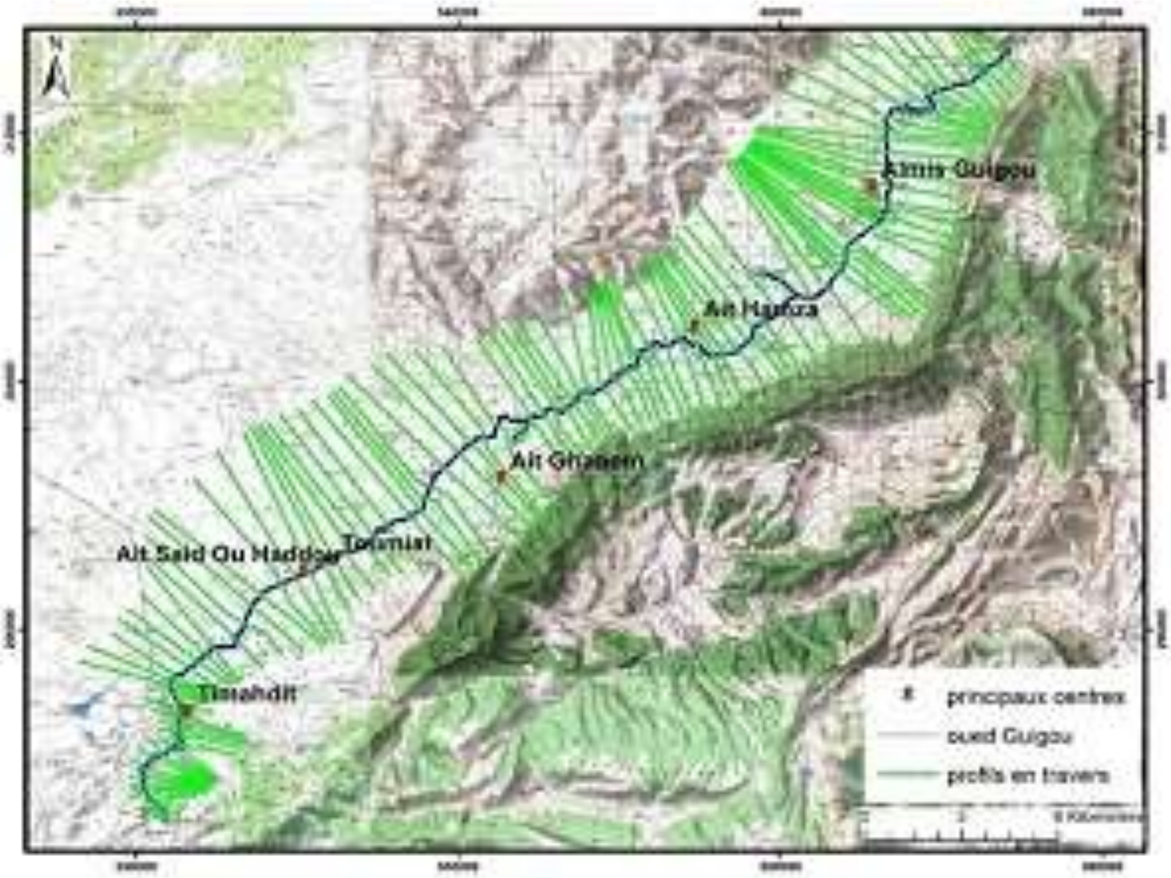

Figure 5: Geometry of the model imported into HECRAS

The next step in hydraulic modeling is to specify the flow rates used to calculate the flow profiles. The flow rates used were obtained from the hydrological study of the various sub-catchments of the Guigou wadi catchment by empirical methods.

Table 4: Debits used for different return periods

Bassins versants	Q 10(m3/s)	Q 50	Q 100	Q 1 000
Pont Ait Aissa (Guigou)	*19.5*	*94*	*139*	*412*
Passerelle Timahdit(Guigou)	*23.0*	*114*	*159*	*465*
Chaâba Timahdit	*1.4*	*9*	*16*	*61*
Douar BouDraan (Guigou)	*27.5*	*141*	*188*	*529*
Douar Toumiat(Guigou)	*27.8*	*142*	*191*	*533*
Wadi Dardoura(Pont Ait Ghanem)	*14.6*	*68*	*109*	*334*
Sehb EL Mergua	*13.9*	*65*	*105*	*321*
Pont Ait Hamza(Guigou)	*56.7*	*313*	*421*	*892*
Pont Ait Khabbach(Guigou)	*80.2*	*451*	*607*	*1147*

Hydraulic modeling will be done in steady state by transiting the peak flows for the different return periods. Moreover, the flows can be simulated by three regimes: torrential regime, fluvial regime, or by mixed regime (torrential-fluvial).

Boundary conditions are necessary to establish the initial water level at the ends of the river system (upstream and downstream). This initial water level is necessary to start the calculations. For this purpose, it has been assumed that the flow is of the infra-critical type, that is to say that there is a disturbance in the geometry of the watercourse (fluvial regime) or even a water level. high downstream, which causes gravity waves which partly propagate upstream. Also, we specified in the downstream section, an approximate level of the river, that is to say that this level will influence the water levels which will be calculated in the river The values of the roughness coefficients were estimated on the basis field observations, referring to the reference tables

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given in the literature, and also based on the experience of the Consulting Engineer in this field and on his good knowledge of geological and geotechnical conditions for having carried out several studies of watercourse modeling. The coefficients thus chosen were divided into two categories:

For steep rocky areas dotted with buildings and obstacles characterizing the section of the central Timahdit area, a Manning coefficient of 0.04 on the banks and in the minor bed was adopted. This coefficient was confirmed in the hydrological study for the calibration of the rating curve of the hydrological station of Ait Aissa, located on the Guigou wadi upstream of Timahdit in similar conditions in the center of Timahdit.

For the areas located in the plain downstream of Timahdit, they are characterized by a slightly wider minor bed, with silty-sandy granulometry and a valley with strong agricultural activity. Also, a Manning coefficient of 0.035 on the banks and 0.030 for the minor bed with sandy loam bottom was retained.

4. RESULTS AND DISCUSSION

4.1 Results of the hydraulic diagnosis

The geometrical data entry concerns the profiles of the cross sections and the peak flows of different return periods, as well as the boundary conditions in the HEC-RAS software made it possible to perform the calculations and extract results like:

• the profile view of the simulated section, The water line represents a profile view of the study section with the water level and surface of the Wadi and the water level of each return period. In the case of this study, the difference between the levels of the return periods exists and is clearly legible. The behavior of floods is sensitive to irregularities in the topography (Figure 77)

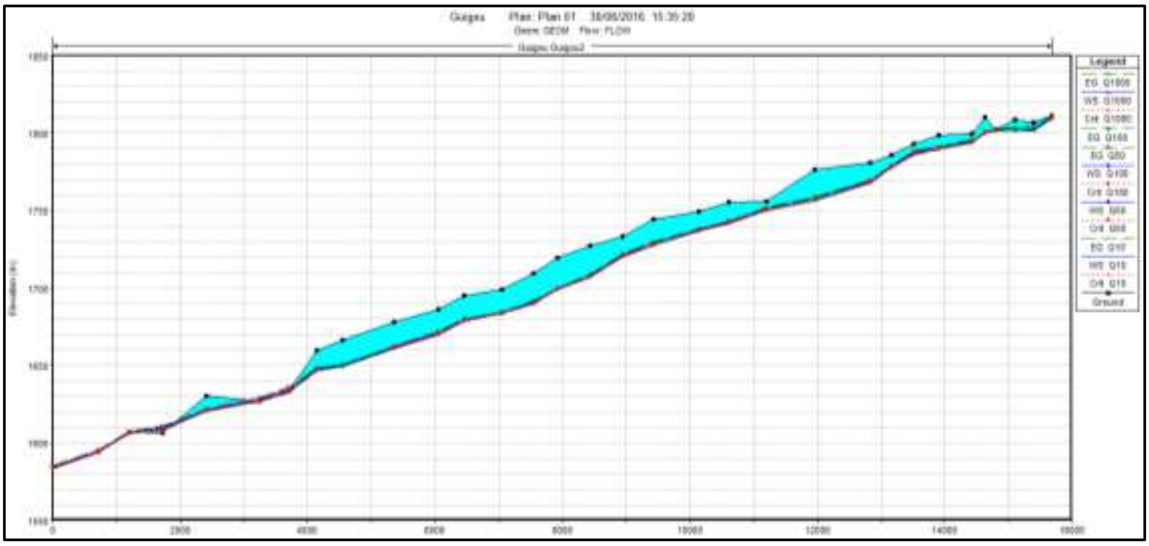

Figure 6: Water line of the modeled sections of Wadi Guigou Amont

a view (X, Y, Z) HEC-RAS provides a three-dimensional view which makes it easier to monitor the behavior of floodwater during the return period. Figure 7 shows that in the upstream part of the section, there is not a large overflow of the wadi because of the slope. The water concentration took place in the third quarter of the section, of which there is a huge overflow.

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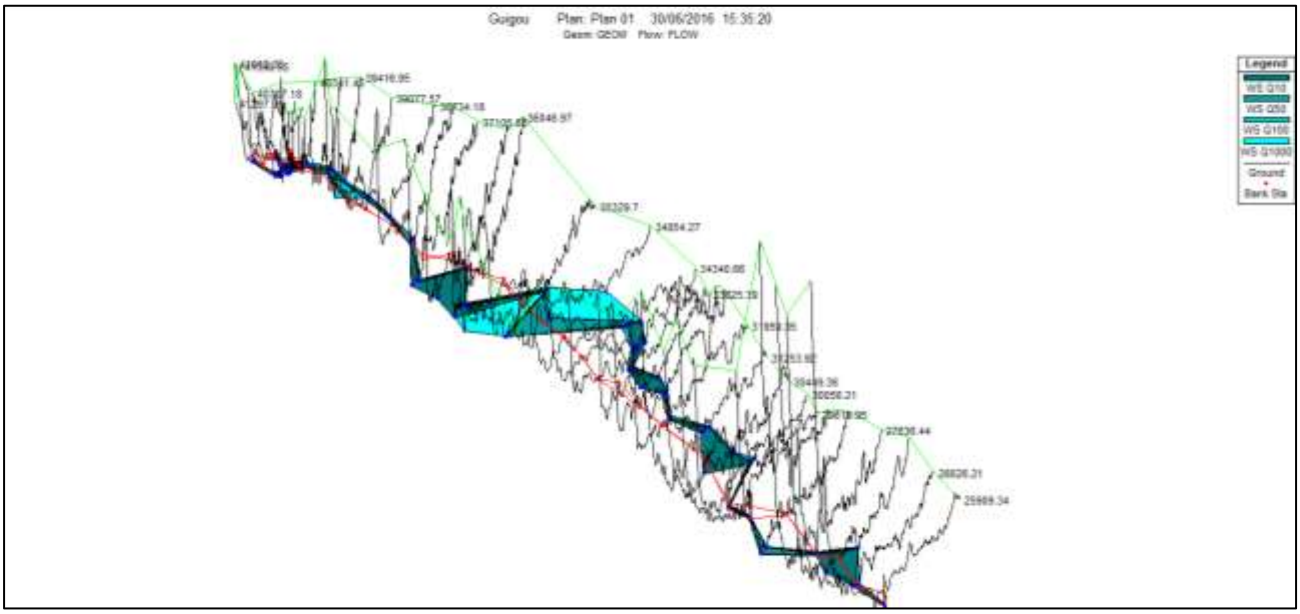

Figure 7: View (X, Y, Z) of the modeled section

• The calibration curve which allows to define the variation of the water height in (m) as a function of flow m / s.

• The speed of flow. Figure 8 shows the variation in water flow speed for each return period. There is almost the same pace for all return periods. The speed increases, however, as you travel downstream. This variation relates to the topography of the sections. At the outlet, the speed is moderately variable and represents high values. It becomes important especially along the sections located at distances between 2000-3500 m; 8000-9000; and 15000-16000m from the outlet. These places are characterized by a fairly steep slope. Finally, there is almost the same speed left and right of the river and which is lower than the speed in the center. The speed of flow directly influences the extent of erosion and the quantity of volume transported by flood water as well as the penetration force of water in urban areas.

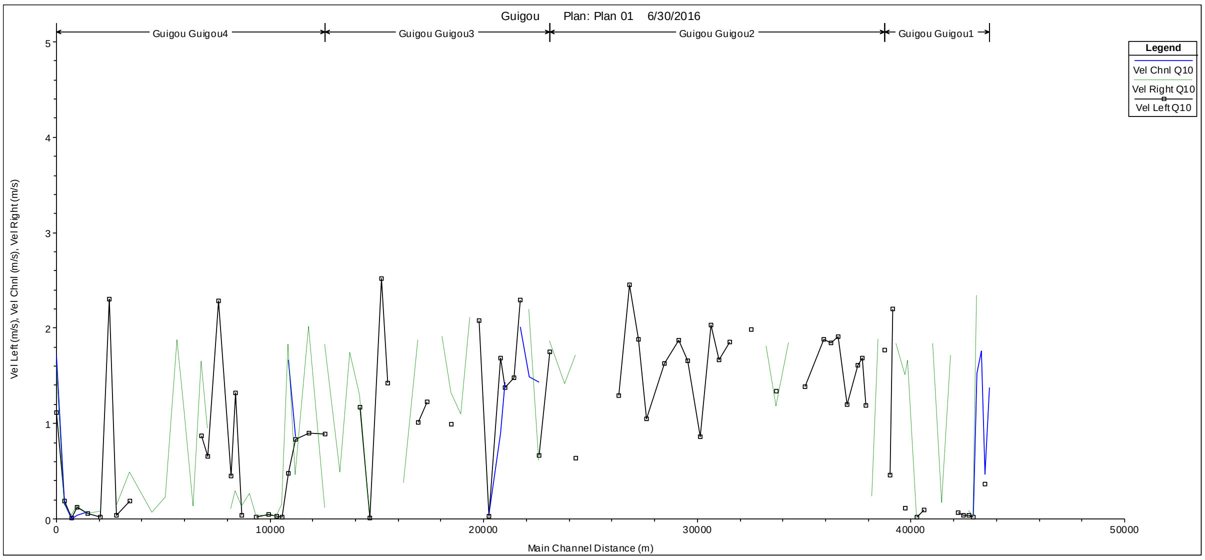

Figure 8: Variation of the flow velocity as a function of the distance from the outlet

The results of the various hydraulic calculations and simulations carried out are given for each watercourse in three forms:

• Tables summarizing the results of the wadi;
• Graphs showing the water levels reached at the level of the profiles across the wadi;
• Plan view of the hydraulic model on which the limits reached for the simulated floods of the wadi are plotted.

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For each simulated flood flow, the valuation of the many results produced by the study requires formatting adapted to the various calculated indicators and the targeted objectives. This layout includes tables and graphs to visually compare the results.

The results tables summarize some factors characterizing the flow regimes. Thus, for each calculation section, the following parameters are given:

• The maximum flow passing through the section.

• The minimum dimension of the section which provides information on the natural slope of the wadi bed.

• The maximum coast reached by water when the flood passes. These coasts make it possible to map the flooded areas and to identify the structures that have overflows.

• The critical dimension of the water line upstream of the crossing structures.

• The average slope of the water line.

• Maximum flow speed.

• The wet sections and the width in the mirror.

• The number of Froude.

The tables are used to draw the water lines on the longitudinal and cross sections which were used in the simulations as well as the graphical presentation on plans of the flooded areas.

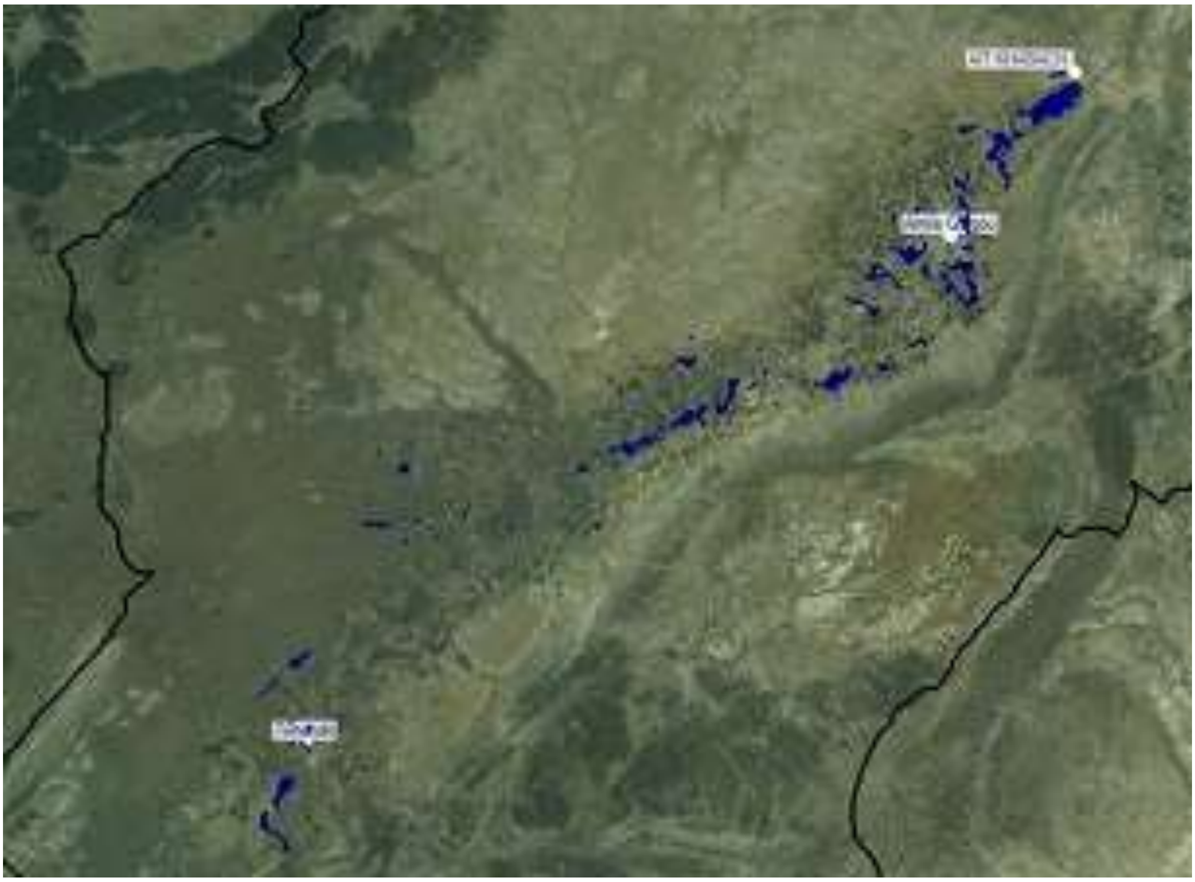

Figure 9: Flood zones delimited on Google-Earth

Hydraulic calculations, verifications and simulations confirmed the main findings made during the diagnosis of the sections studied. The main findings that emerge from the above results (Fig. 9) are presented below:

• Wadi Guigou overflows for all return periods (10, 50 and 100 years).

• Average maximum water level speeds are normally maintained at 4 m / s. However, at the time of the rising of the flood and in certain profiles which present constrictions and narrowing, the speeds are relatively high and generally vary between 4.00 and 8 m / s thus causing scour due to the high speeds.

• The flow is very unstable; highlighted by the number of Froude that fluctuates around the unit. This fluctuation is important in certain profiles where it can approach a value of 1.8.

• The center of Almis Guigou is exposed to the danger of flooding since all the return periods spill over onto a large part of the buildings and agricultural plots in this locality.

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• The Guigou wadi overflows practically every year, between Ait Hamza and the Ait Khabbach bridge, and that the entire Guigou plain appears as a major bed of the wadi.

• The wadi section has shrunk considerably in recent decades with a gradual encroachment of crops on the wadi bed.

• The plain knows intense cultures with scattered dwellings and presents a topographic plate with multiple depressions which form storage basins.

4.2Definitions of layout plans

The proposed development plans, in order to remedy the flooding phenomenon and protect the center of Guigou and Timahdit, are as follows:

• The re-profiling of Wadi Guigou over a distance of 22km between the Ait Hamza bridge and the Ait Khebbach bridge is among the interventions parallel to the project to construct a flood protection wall.

• Replacement of all existing agricultural catches by a single catch upstream of the plain of Almiss Guigou provided with two irrigation canals parallel to the Wadi and on both sides of it

• Channeling of Wadi Sehb El Mergua over a distance of 2300m, will allow the release of the dam. This channel is 20m wide and 1m deep;

• To mitigate the cartload phenomenon at the level of the WadiGuigou sub-watersheds, it is recommended to install sedimentation thresholds to be installed upstream of the study area. However, the effectiveness of this development remains dependent on the cleaning operations that must be started before each winter season.

5. CONCLUSION

The diagnosis of the existing situation made it possible to understand the problem posed by the floods of Guigou wadi and to determine the main flood zones. The modeling of the sections of the wadi by HEC-RAS, allowed us to reconstruct the geometry of the watercourse based on cross profiles, thus to extract different results, namely the profile view of the simulated section , the water level of each return period on the profiles, a three-dimensional view of the water level in the study section and the flow velocities. The hydraulic simulation results enabled us to note that the wadi overflows for all return periods overflows on a good part of agricultural constructions and plots, which confirms the observations made during the diagnosis of the sections of the study area, thus to define the development schemes planned at Wadi Guigou, in order to remedy the flooding phenomenon and protect the center of Timahdite, that of Almis Guigou and the Guigou plain.

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