Integration of GIS and HEC-RAS in Floods Modeling of Martil River (Northern Morocco)

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Abstract

This work describes the application of Hec-RASas Hydrologic Engineering Center derived River Analysis System model to the establishmentof floodplain maps for Martil river. Modeling with Hec-Ras enables calculation of, among other variables, water levels, depths and flow velocities for the different flow configurations and different cross-sectional zones along Martil River, i. e., from the confluence with the Lakhmiss and Mhajrat rivers to discharge into the Mediterranean Sea. This investigation, therefore, presents flood mapping and classification of risk areas using the Hec-GeoRas and Hec-Ras hydraulic modelling tools integrated into the Arcgis information system. The results indicate that the use of aerial photographsprovidesa good knowledge of the morphology and physical characteristics of the river, which will help decision makers to prevent floodingin the urban area of Tetuan.

Keywords: Hydraulic modeling; GIS; flood area of Tetuan, Morocco

Introduction

A natural hazard involves exposure of human populations and infrastructure to a catastrophic event of natural origin. These risks are numerous and diversified: avalanches, forest fires, floods, landslides, cyclones, storms, earthquakes, volcanic eruptions, etc. The magnitude of these natural hazards is sometimes so massive that it causes huge damage. Moreover, the severity of natural disasters around the world requires continued prevention to reduce their impact. Therefore, it is necessary to develop and improve predictive models and monitoring tools, and establish regulatory measures and contingency plans. Tetuan Region is a high-risk area because of its geological and geomorphological context characterized by a very complex Alpine tectonics structure, and also for its climate conditions. Although its winter and summer both manifest tempered temperatures, due to the proximity to the sea, this area receives torrential rains. As a result; contrasting climate, sometimes causing inundations, floods and landslides (HCFP, 2001). Floods are periodical events that appear principally by water overflowing from the main drainage channels.

The inventory of historical floods is far from complete, but it's nevertheless indicative of the existence of extreme events, such as those of December 1976, February 1979, February 1991, February 1996, January 1997, February 1998, December 2000, 2005, September 2007, December 2009, August 2013, and of February 2016 (HCFP, 2001 ; Ben Moussa and al., 2014).These events are concentrated between the December and February, a period known with intense rainfall. Floods are considered the second most widespread natural risk in the region after landslides. Indeed, the flood of December 26/2000 is a good example of illustration. The damage was massive; a score of deaths and considerable material damage was estimated at several million dirhams. The water completely submerged in Coelma district, and partially that of M'hannech (where the water height exceeded 2 m). The bypass road, which had not yet been raised up to day, was submerged for several kilometers. Thus, resulting in a traffic interruption for 7 hours; industrial units located on both sides of the watercourse were particularly affected, inhibiting their activities and as a result, 400 workers lost their jobs. Traffic on Tamouda, Torreta and Coelma's bridges was also interrupted for several hours, which prevented citizens from reaching their homes or work. Moreover the construction site of the new bridge was flooded.

Study area

Tetuan and its coastline are part of the northern Rif (North of Morocco). The city, with its 380718 inhabitants (HCP, 2014) is limited to the North by the rural commune of Malaliyine and to the South by the rural communes Dar Ben Karriche, Zaitoune and Sahtriyine, to the East by the urban commune of Martil and rural of Azla and to the West by the rural community of Seddina.

Forming part of Tetuan province, the study area is located between the Tamouda Bridge and the Martil river outlet wtha flow South West to the North East, the stretch of the River crosses the Southern part of the city of Tetuan (Figure 1).

Of a torrential nature, the Martil River originates in the massif of Beni-Lait, benefits from the contribution of three tributaries; Lakhmis, Chakour and Mhajrate streams. It drains a watershed of 1200 km². Downstream, the river crosses the city of Tetuan to reach the Mediterranean through the plain of Martil. From a geological point of view, the city of Tetuan is located in an alluvial coastal plain. The mountains are formed by three major units: the Sebtides, the Ghomarides and the calcareous Dorsal. The two first unitsare formed by the partly metamorphic paleozoic rock, and the Dorsal is of secondary and tertiary age.

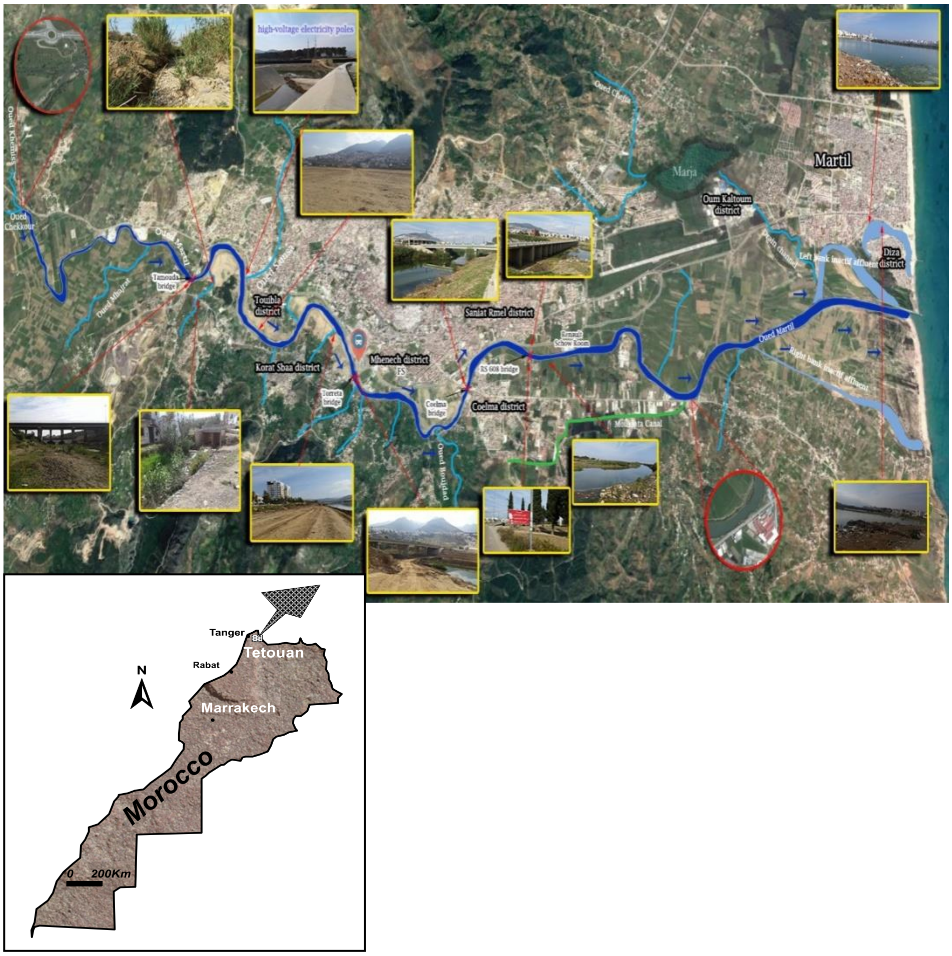

Figure 1: Geographical situation of Martil River, and problem of floods in Tetuan city and its coastline

The Martil River is of about thirty kilometers long and takes its source atthe Beni-Lait massif near the town of Chefchaouen. It crosses the city of Tetuan before entering the Mediterranean Sea. Usually calm, the Martil River shows episodically high and very rapid floods during intense rains (Figures 2 and 3). During these periods, the city of Tetuan is often flooded in several places.

Figure 2: Flood of Tetuan city: area between Romana and the bus station (Hotel Pristigia now).

Figure 3: Flood near the Paloma Hotel (near the Tamouda Bridge and the Gas Plant).

The province of Tetuan is generally characterized by two distinct seasons: rainy and wet from October to April and then clearly dry from May to September. This provinceis therefore classified among Mediterranean regions with diverse climate

The major part of the province records an annual rainfall exceeding 650 mm on average, except in The Eastern part of thewatershed where an average of 460 mm was recorded at the Oued Laou station.

At low altitude, the average temperatures result in a fairly mild climate, with very hot periods during July and August (28.3°C to 32.9°C) and very cold periods during January and February (5.3°C to 8.6°C) . The importance of precipitation, the impermeability of the land cover and the mountainous nature of the region make the runoff relatively serious With an important accumulation up tohydrographic network 540 Mm^3/year. However, the hydrological regime is characterized by a high degree of variability closely related to the amount of precipitationwheremaximum contributions are recorded between December and February (ABHL, 2014 ; Stitou El Messari, 2002).

Materials and methods

This investigation was initiated by collecting cartographic and bibliographic data and measurements available for the study area. This phase was decisive in the choice of the use of the Hec-Ras model.Therefore, based on the quality of summaries of previous studies of the assembled data, the complexity of theoretical calculations based on many equations and the absence of empirical methods, we opted for the Digital elevation model (DEM) (Shahzad and al., 2016 ; Azouagh and al., 2017). As a result, we obtained figures on the magnitude of the considered floods and their spatial distribution.

The available DEMs from the 30, 12 or 10 m resolution (NASA) satellite data did not satisfy the needs for study. These DEMs offer major variations in relief, while the problem of flooding related to our region requires more precision. For this reason, we used a set of points resulting from the photogrammetric restitution of stereoscopic aerial photographs with a resolution of two meters for the elaboration of our digital elevation model.

This DEM has been used to delineate the watershed boundary, to define the boundaries of sub watersheds and the hydrographic network. The DEM also allowed us to analyze the drainage profiles of the land. The river and floodplain geometry was obtained from aerial photographs. Google Earth's color images were used to classify land uses to estimate the Manning (n) values that Hec-Ras needed to run hydraulic calculations. The TIN of study area is presented in the (Figure 4).

The hydro-meteorological data used in this study were obtained from the Loukkous Hydraulic Basin Agency of the City of Tetouan. Data on maximum flow discharge rates were available from 1970 to 2013.We used the discharge data recorded on 3 stations: Amzal, Ben Karrich and Torreta. Amzal and Ben Karrich are located on two tributaries of Martil, Chekkour and Mhajrat River. The Torreta records the flows of the river on the lower part of the upstream. Records show that peak flows are observed in December and January over the entire recorded period. The Amzal station records maximums of 69 m^3 /s and 70 m^3 /s, the Ben Karrich station records 70 m^3 /s and 80 m^3/s, and the Torreta station records 177 m^3/s and 152 m^3/s in December and January respectively. On the available series, we noted that the highest flows were observed during the 1990s and 2000s.

TIN of the urban perimeter of the of Tetouan

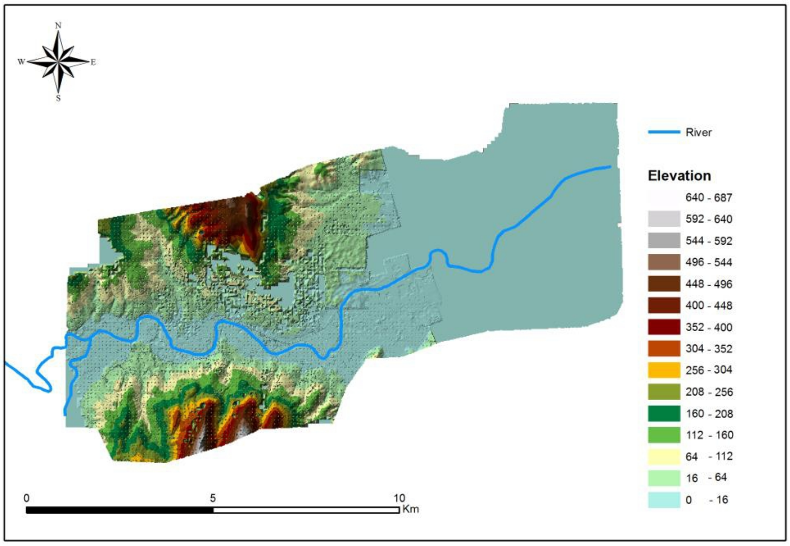

Figure 4: TIN of the study area (Azouagh, and al., 2017)

All this work, of uneven quality, already carried out or in progress has provided essential information on the flood hazard and its global stakes. The govermentspends huge amounts of money in structural protections. In the framework of this purely scientific work, and taking in account the available technologies, our research team have turned to models and softwares which are known for their effectiveness in the field of hydrological modeling. We propose a method based on hydrological and hydraulic forecasting platforms in which the Hec-Rasis intergrated for modeling. The advantage of "HEC-RAS" is its compatibility with the Arc GIS and Google Earth.

This software which offers a wide variety of options for modeling hydraulic systems has been successfully used in comparable areas of medium mountains and has been the subject of several international publications and thesis work (Gary and al., 2010 ; Iosub and al., 2016). The Hec-Ras hydraulic model is a simplified way to model a river flow. It allows evaluating the flows and the heights of water on all the sections of a river under different regimes (permanent and non-permanent, subcritical and supercritical flow). The Hec-Ras model can also include all hydraulic structures including bridges, pumping systems, dams, etc. Our hydraulic model developed by using the Hec-Ras software integrates the entire major bed and the hydrographic network between the confluence of Lakhmis river and Lamhajrat river.

The modeling implemented is of type "1D". The minor bed bridges, the major bed dams were also modeled. This modeling presents an analysis and a synthetic mapping of the hydraulic operation of the perimeter of study as well as the results of the hydraulic modeling of the floods in Martil River.

It is important to note that prior to the technical phase, we conducted a survey of some ripariansand testimonies that affirmed the existence of major floods in the region's past, and that the river had undergone profound alterations over time. Several tributaries have dried up, disappeared or been transformed into paths or connecting roads between neighbourhoods such as Kabul Street, which crosses the Taboula Soufla, Tiknia and Safir neighbourhoods as shown in (Figure 5).

Figure 5: Kaboul Street

The cartographic production in Morocco was until recently very limited, the precise information on the real and original state of Martil river remains incomplete, hence the incomprehension of certain aspects of its behavior.

This work combined raindata, hydraulic models and GIS tool. (Geographic Information System) for assessing flood flows and delineation of flood-prone areas in urban area of Tetuan.

The choice of the Hec-Rastool seems to be in accordance with the criteria of the Marti River, which has a unidirectional flow, with low slopes varying between 10^{-4} and 10^{-6} and depths not exceeding 4 meters. The Hec-Ras software uses 1D saint-venant shallow water equations to link water heights and discharges. These equations are deduced from the Navier-Stokes equations through simplifications related to the river model. The application of the Hec-Ras model for this investigation is based on three fundamental steps (Ackerman, 2009 ; Leon, 2013) :

Step 1: Creating, using the ArcGIS tool, the HecGeoRAS extension, the Digital elevation model (DEM) and aerial images, the geometrical data of Martil River with the minor, major river bed and cross-sections.

Hec-GeoRASis used as the main tool in ArcMapwhereas in ArcGIS environment, we used Hec-GeoRAS functions to digitize various vector elements that will allow Hec-RAS to generate the flood model and represent the results. The correct digitization of elements such as bridges, canals or flow areas is the basis for launching the flood study (Ackerman, 2009 ; Leon, 2013). Hec-GeoRAS therefore allows developping the basic cartography that the territorial elements of the study area will describe). The digitization of these elements is employed in subsequent phases to perform the potential simulation (Figure 6).

- The left and right banks
- Bridges
- Lines for simulation

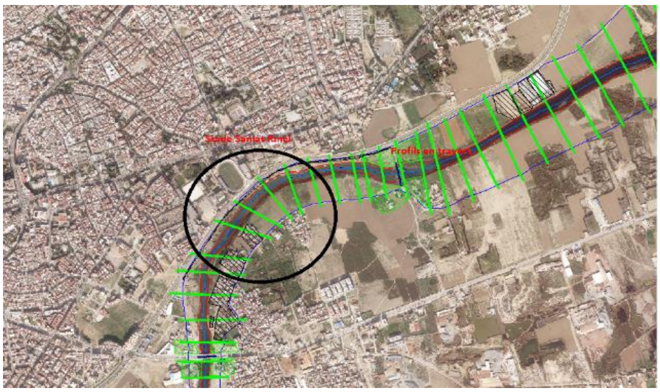

Figure 6: Stream Lines, Flow Paths, Bank Lines and Cross sections (Hec-GeoRas & Arcmap)

Step2*:* Apply permanent flow modeling with the Hec-RAS 4.1.0 model, which generates an export file for ArcGIS. Hec-Ras, a software independent of ArcMap but complementary to the analysis processes.

The calculation of hydraulic profiles along the bed of the studied section is fundamental for estimating water levels during exceptional flood events. The levels of river overflow and areas submerged by water will also be known (Figure 7).These profiles will also determine the drainage areas and those requiring maintenance.

Step3: Generating the results of water stain: flood surfaces and depth grids.

Hec-Ras Modeling made it possible to compute the different flow configurations for the cross-sections along the studied section. Water levels, depths, flow velocities and other variables were simulated. The aerial images used are of a resolution of 15cm. The banks, vegetation, obstacles and structures are well identified, which allowed obtaininga fairly precise geometry of our river. Therefore, we created the main axis of the channel.

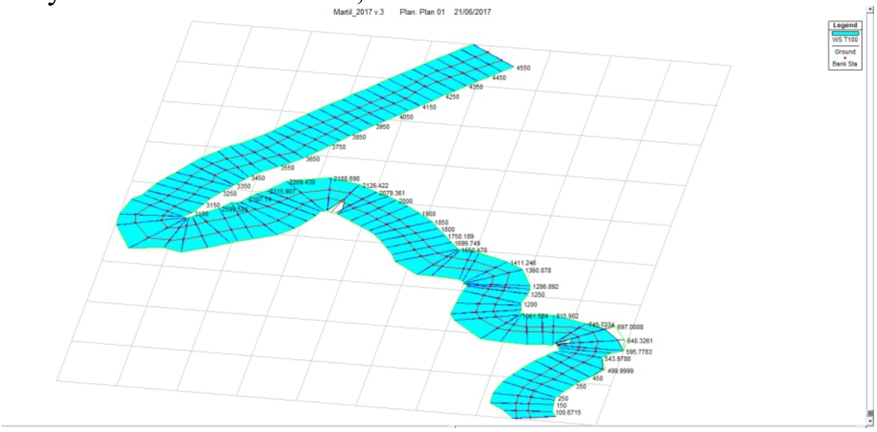

Figure 7: Modeling result (3D)

Moreover, and considering the characteristics of the watershed in terms of geology, geomorphology and vegetation cover, the Manning coefficients retained ranged between 0.04 and 0.045. Similarly, the river is characterized by its mixed regime, shallow meanders and weak slopes. The geometry of the water courses is defined by 146 cross-sections (96 stations) spread over the 30 km of the studied section (Figure 8).

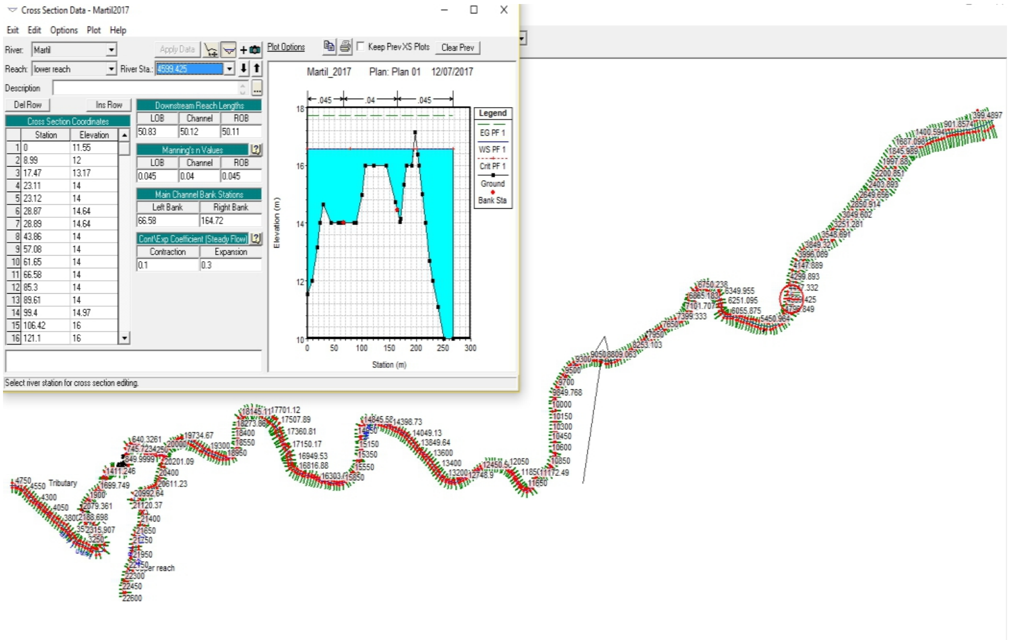

Figure 8: Detail of a cross section - Hec-Ras

Result and discussion

For a natural watercourse, the flow rate varies according to weather conditions over the watershed and other processes (e.g., groundwater flow). The obtained results Hec-Ras by modeling are exported to the tool Hec-GeoRAS4.1.0 which is an extension of Hec-Ras on Arcgis to create the flood zones for each profile (Figure 9), that is applied to flow of each return period T10, T20 and T50. We have zoomed in three sections **A** (Figure 10 ; Figure 11), **B** (Figure 12; Figure13) and **C** (Figure 14) where the overflows appear to be significant.

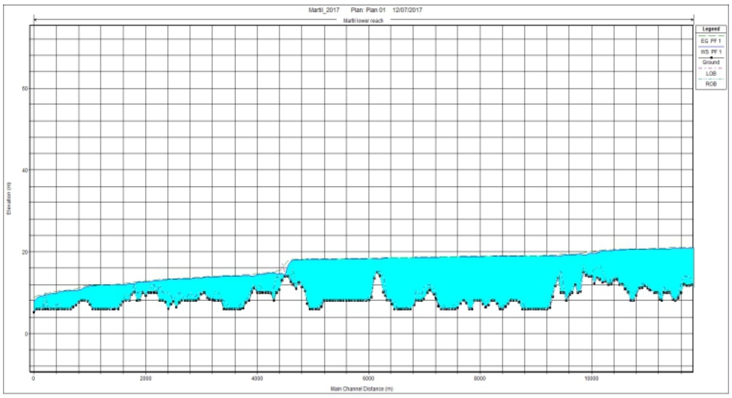

Figure 9 : Profile Plot –Martil River - Hec-Ras – PF1 3000m^3/s

The zone A: is located a few kilometers away from the Tamouda Bridge, built on the RS 608 road. Duringthe flood of December 2000, the water rose from 0.5 to 2 m above and below the Tamouda Bridge for a discharge of 2000 m^3/s. In this area the simulation highlights a large rise (increase) in water level that has invaded the road. The water extent is 60 m on the left bank and 90 m on the right bank. Depending on the shape of the river more or less circular, the water with its high speed deviates tangently and leaves its usual straight line.

Figure 10: Section A before the simulation (above), after the simulation (below)

The velocity diagram produced by Hec-Ras of the three peak flow profiles (3000, 6000 and 9000 m^3/s) confirms this result. Within the principal channel, the velocities are about 1.27 m/s and on both sides, the velocity varies from 1.08 on the right bank and 1.14m/s. Also for water heights, we visualize some differences between the main canal and the two banks. Floods in this zone occur whenever the volume of water from the upper parts of the basin exceeds the capacity of the riverbed, water overflows and flows over the plain. Due to the low slope of less than 5/1000, the river acts as a large holding tank.

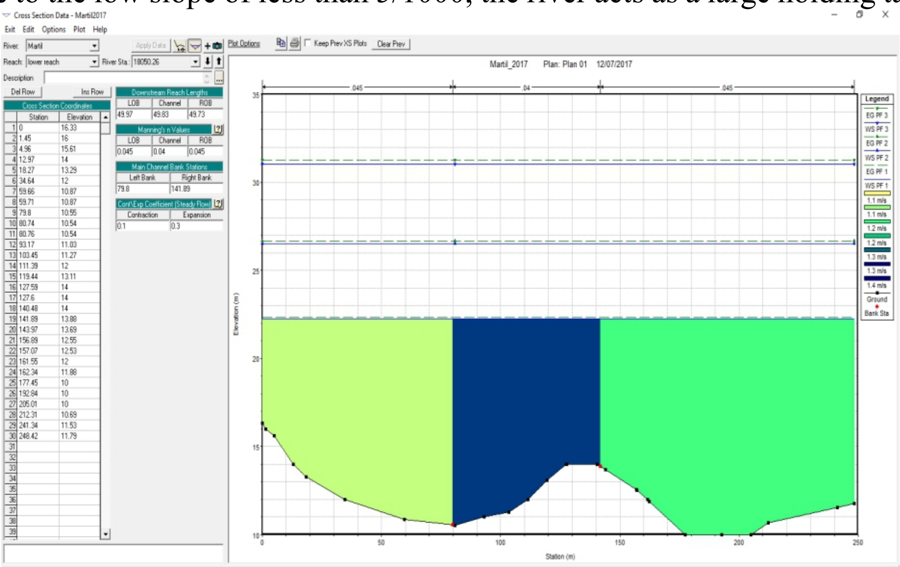

Figure 11: Zone A:Velocity profile along cross-section 1805.26

The Zone B: About ten kilometers from zone A, another important overflow appears on the side of the M'Hannech district zone B. In this part of the canal, where the terrain is poorly (less) permeable, the canal's watercourse changes shape and appears narrower with limited vegetation on the banks, thus, creating the effect of a funnel.

Figure 12: Zone B: M'hannech district.

The right bank has a depth of 12 m over an extension of 50m and becomes deeper when approaching the main channel. The velocities in this section reach 1.8m/s. In the main canal, the water depth is 20 meters and the current velocity is 2.21m/s and reaches 1.04 m/s on the left bank.

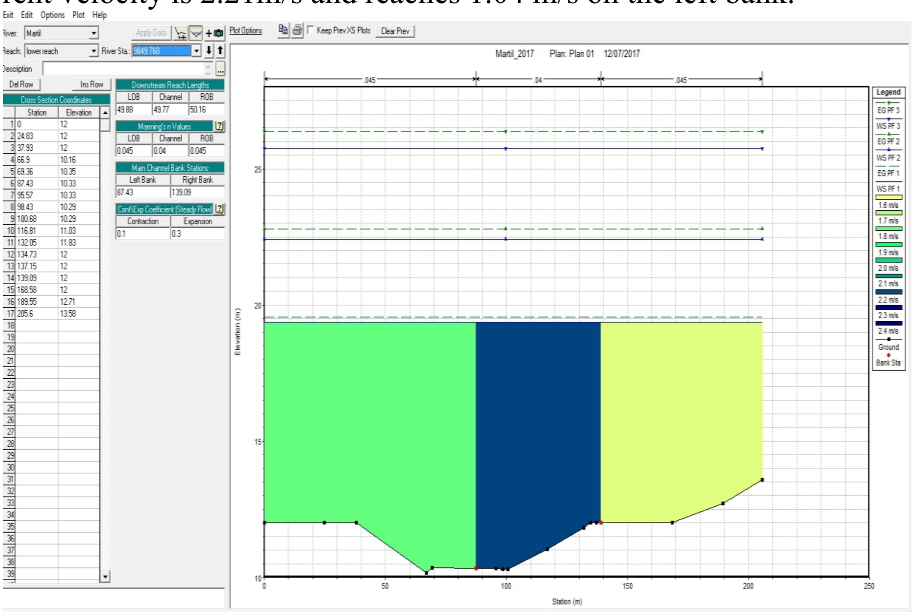

Figure 13: Zone B: Velocity profile along cross-section 9849.768

The zone C: corresponds to the OumKaltoum district. This district is connected with the river outletvia a drainage channel linked also to the inactive branch of the river, which during periods of intense rainfall becomes active. This area is submerged in water every year during these periods.

Figure 14: Zone C : OumKalthoum District

Conclusion

River flow modeling software is sophisticated and increasingly used in natural hazard management and mapping by delineating risk areas.

The overall results allowed to locate flood zones, velocities and heights of water, etc. These results are reliable and are consistent with the morphology of the field.

The study area has undergone profound restructuring during the last twenty years in parallel with the development of awareness of the flood issue: bridges, dams, tunnels, rehabilitation of the riverand its tributaries have been built, yet it only takes a rainy day for the streets and neighborhoods to be submerged in water allowing panic to set in again.

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