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Simulations of possible floods linked to the wadi banks widening in the Somâa city at Cap Bon-Tunisia

Hela Romdhane [a], Amel Soualmia [a*], Slim Houssem Talbi [a]

[a] *National Institute of Agronomy of Tunisia, Water Science and Technology Laboratory, University of Carthage, 43 Avenue Charles Nicolle, 1082 Tunis, Tunisia*

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amel.inat@hotmail.fr ;

Abstract

In Tunisia and during these last years, the phenomenon of floods becomes more and more frequent. Indeed, each year several regions of the country are affected and human losses and material damage are recorded. In fact, according to the diagnosis made in the Somaa area in Cap Bon-Tunisia, there is the phenomenon of the bank's degradation under the lateral flows effect. This causes the wadi widening, and then the amplification of the possible flooding risk in this area. Scenarios were considered in this study in order to visualize the impact of high flows on the water level control at a river in the soma city, in order to protect the city from possible flooding. The simulations show that, for the different flows, only the flow from 50 m^3/s that can generate the banks overflows, with a chosen roughness.

1. Introduction

The flow regime in rivers depends on several factors such as the climate, the terrain slope, the geological layers crossed, the stream width, or the water quality [1,2,3].

These rivers actually form a complex dynamic system subject to large-scale variations, in fact precipitation is considered to be the fundamental cause of these fluctuations. Over time, the rivers morphology evolves under the influence of several parameters, in particular floods, hydraulic structures, sediment transport, erosion, etc. [4]. These changes can favor the phenomenon of floods and loss of relationships [5].

High intensity regional rainfall or flooding is the main cause of soil erosion [6]. Several studies have also shown that the vegetation cover in the watershed has also influenced soil erosion: a light vegetation cover aggravated soil erosion even in periods of low flooding frequency, while a dense cover reduced soil erosion even in periods of high flooding frequency [7,8,9]. For this, precautionary measures must be taken to limit vulnerabilities due to flooding and erosion [10,11].

Indeed, the Somaa region, which is located in the Cap Bon area in Tunisia, is suffering from banks erosion problems of the Touttet wadi which crosses this region and the extension areas. These erosions lead to the steepening slopes of the two wadi banks, and thus they cause the cross-section's modification, and that amplifies the overflows and the floods risk. In fact, following erosion, sediments are deposited at the section bottom, generating a depth reduction, hence decreasing the wadi transit capacity, and subsequently amplifying possible overflows in the areas. [6]

The present study aims to consider the changes impact in the wadi morphology and the possible risks of possible flooding by means of numerical simulations.

2. Presentation of the study area

Somâa is a Tunisian city located in the region of Cap Bon, about ten kilometers north of Nabeul, attached administratively to the delegation of Beni Khiar from the governorate of Nabeul (Fig 1). It is a municipality with 7,017 inhabitants in 2014.

It is located in the "semi-arid upper" bioclimatic floor. The average annual precipitation is around 424 mm / year. The average annual temperature is around 18.7 ° C. It is characterized by high thermal amplitudes. It is also characterized by varied and rugged reliefs with alternating mountains and plains. From upstream to downstream, the altitudes surrounding the project area are between 185 m NGT and 75 m NGT.

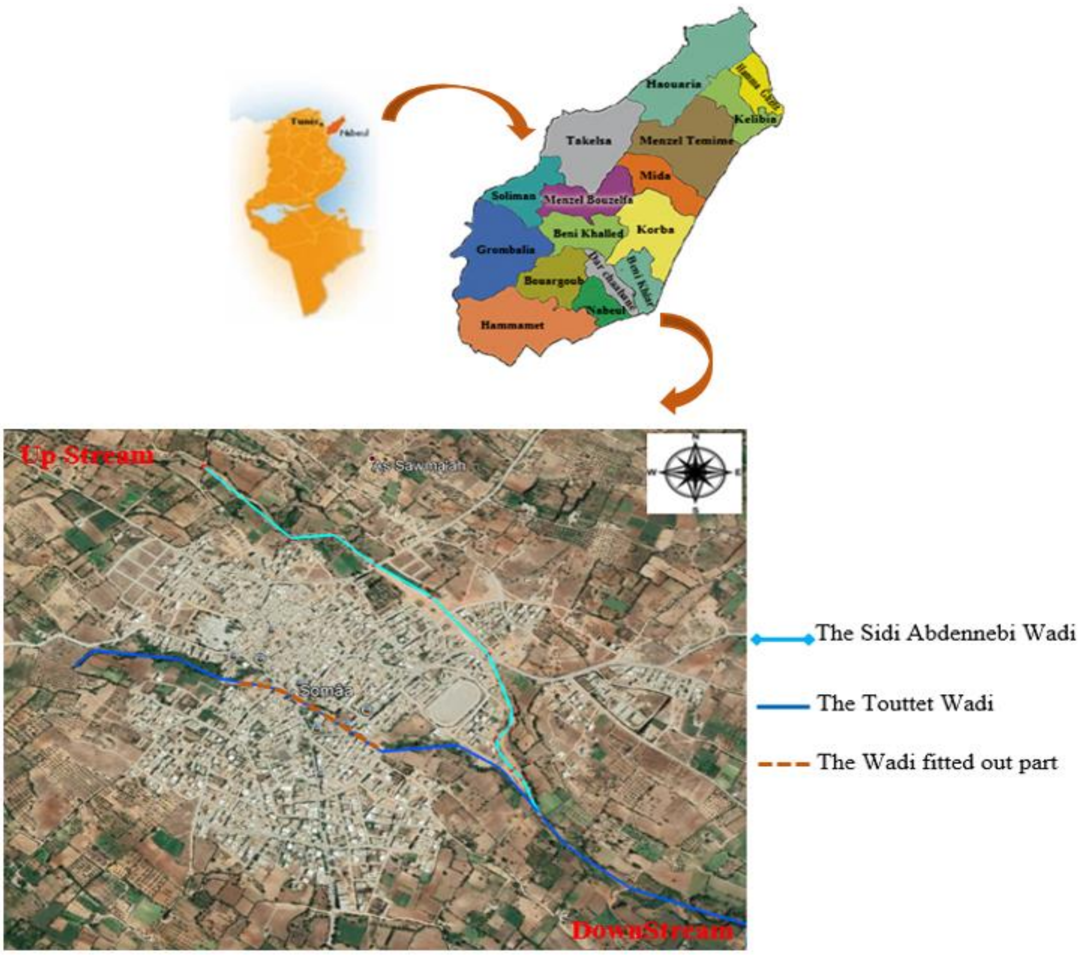


Figure 1: Geographic location of the study area 'City of Somaa at Cap Bon Tunisia'

The hydrographic network of the study area is made up of flows starting from the northwest side of the city in the hilly area with relatively large slopes to flow towards Touttet Wadi and Sidi Abdennibi Wadi (Fig 1). These two flows cross the town of Somâa and meet by making a delta downstream of the agglomerations.

This hydrographic network is divided into 2 watersheds:

- BV-1: the watershed of Sidi Abdennebi Wadi, slope 2.99%
- BV-2: the Touttete Wadi watershed, slope 3.80%

The Touttet Wadi receives flows from the small watershed with an area of 108.4 ha. It crosses the town of Somâa on a section of about 2.35 km in length. However, the section that crosses the city is laid out by a rectangular underground crossing at road level and by an open trapezoidal canal inside the urban area.

According to interviews with local officials and field visits to different areas of the city, it was noted that the problems are mainly due to anarchic urban development at the level of the wadis' rights of way. Indeed, this anarchic urban development is very remarkable at the level of the two new popular districts like Cité El Chabbeb and Cité El Mâaleb, where the constructions did not respect the wadis limit which must be greater than 25 m. However, the constructions are about 2 m from the two wadi banks.

Historically and according to the inhabitants of the area, there have been no floods during the last decades causing floods. As far as, the CES facilities built on Sidi Abdennibi Wadi (gabion sills) are in good condition and there are no traces of flooding.

According to the diagnosis, there is only the degradation banks phenomenon under the effects of lateral flows, consequently causing the wadi widening by the reduction of the two banks slopes, hence the probability and the amplification of the future flooding risk in this area. [12,13]

The choice was made on the Touttet Wadi since it cuts the Somaa city center, in addition to its downstream part crossing the future expansion zones.

3. Methodology

To analyze consequences of the morphology Wadi modifications on flood control, water line numerical simulations were carried out in the Somâa area. These simulations were carried out using the HEC RAS code. [14,15].

3.1. Software used

For the simulation of flood flows at the level of the town of Somâa, hydraulic simulations with the HEC RAS software were carried out in order to follow the Wadi water level evolution for different flows.

The new version of HEC-RAS makes it possible to model two-dimensional flows thanks to a 1D modeling of the river coupled with a 2D modeling of flood areas or rivers sections. It is also possible to simulate an entire system in 2D. [16]

This software has already shown itself to be very efficient for this type of study [17,18,19,20], and a large number of companies and research laboratories consider it as a first approach tool. All this is part of a final objective allowing, flood protection of overflow areas and their controls.

For our study, we have four cross sections data's, which were subsequently interpolated between them; relying on the software and after several sensitivity tests we kept a space step of 10 m leading to 106 cross sections.

3.2. Calculation of frequency flows

The flows studied area are estimated by applying empirical methods since the flow measurements are not available. As the watershed's areas are small, the methods to be used are the rational, Caquot, and Speed methods in this region.

3.2.1. Rational Method

The reduced surface area project flow is calculated by the following formula:

$$Q(T) = \frac{C*A*I(T)}{3.6} \quad (1)$$

With:
Q (t): Peak flow for a return period T in m^3/s
C: Runoff coefficient
A: Area of the concerned watershed in Km^2
I (T): Rain intensity in mm/h

The rational formula although very simple it is of universal application since it is based on the rain intensity which in turn is a function of regional climatic conditions and the watersheds concentration time which takes into account the watershed slope and its size. [21]

3.2.2. Caquot Method

The Caquot method is the most used for urbanized watersheds. The peak flow at a given point in the network is expressed by:

$$Q(T) = K(T) * I^{U(T)} * C^{V(T)} * A^{W(T)} \quad (2)$$

$$I(t,T) = a(T)\ t^{b(T)} \quad (3)$$

With:
Q (T): Flow rate of a return period T in m^3/s
A(T): Area of the concerned watershed in ha
I (t): Rain average maximum intensity of duration equal to the concentration time tc and of the return period T
P: Watershed average slope in m/m
C: Runoff coefficient
The CAQUOT method is also a universal application since it is similarly based on the rain intensity which in turn is a function of regional climatic conditions and the watersheds concentration time which takes into account the basin slope and her size. [21]

3.2.3. Speed Method

This method was adopted within the framework of the National Project of Protection against Floods. It was adopted for central and southern Tunisia. [21]
Flood peak flows are calculated by the formula:

$$Q(T) = A^{0.75}(PT - P_0)/12 \quad (4)$$

With**:**
A: Area of the concerned watershed (km^2)
PT: Daily rain for a return period T in mm
P0: Runoff threshold in mm

4. Simulations and Results

The section studied extends over a length of 0.3 km at the Touttet wadi which extends from the stadium in the Somaa city to the confluence with Sidi Abdenebi Wadi. This section is divided into 106 cross sections, leading to sub-sections of length 10 m. The table below presents the flood flows obtained using the frequency flow calculation methods that we are previously presented, for the different return periods T ranging from 2 years to 100 years [17,22]. For our simulations, we chose to simulate the flows found by the rational method, which is the simplest and the most suitable for our study area (from point of view of the watershed area and its slope). The table 1 illustrate the retained method results.

Table 1: Flood flows used for different return periods T

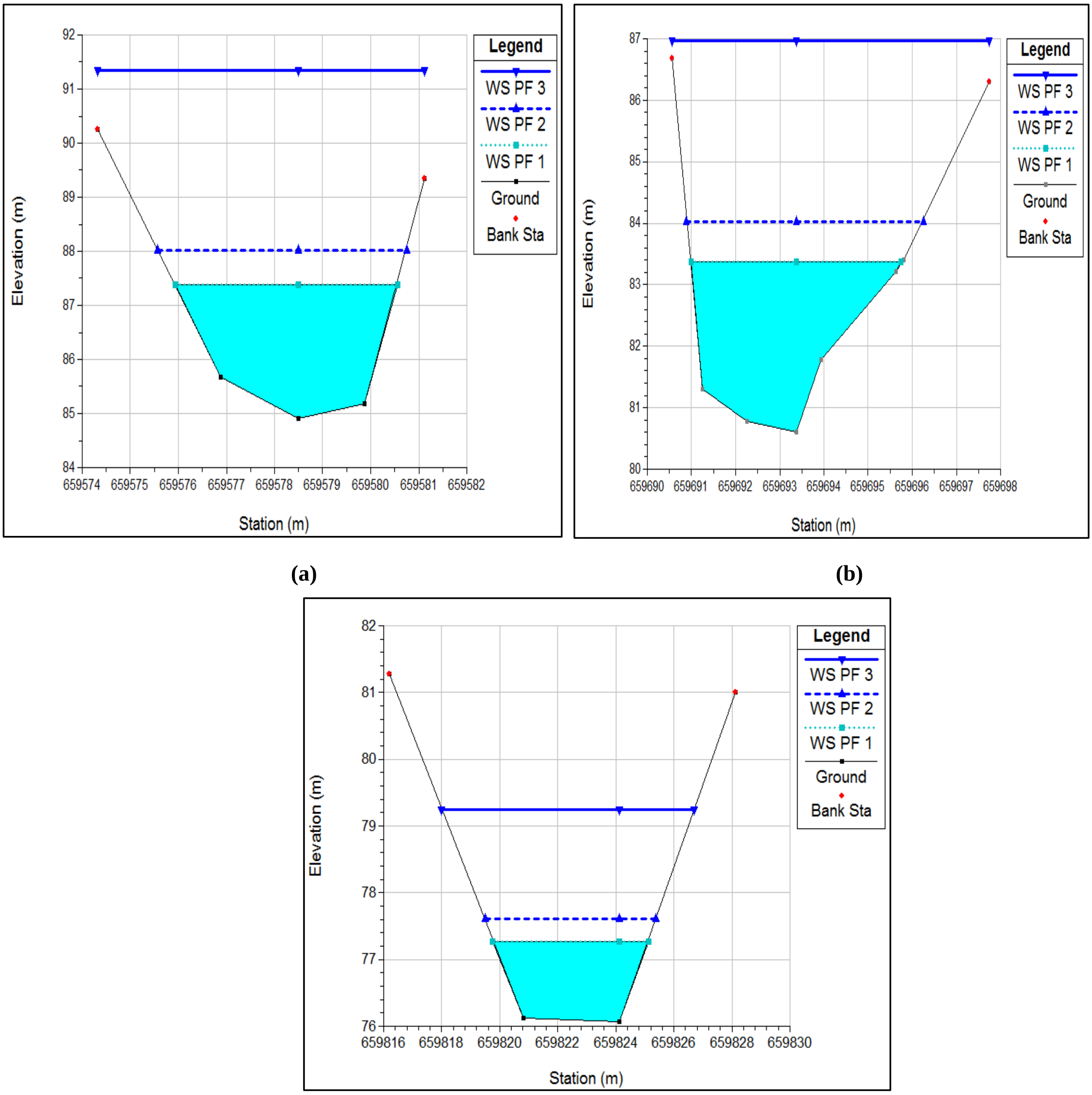
BV	A(ha)	Calculation method	Flows (m^3/s)					
			2	5	10	20	50	100
BV1	108.4	Rational Method	3.9	5.1	6.4	8	10.6	12.5

Regarding the boundary conditions, upstream we considered several scenarios flows 8 m^3/s (return period T = 20 years), 12.5 m^3/s (return period T = 100 years) and 50 m^3/s (a simulated flow beyond the 100-year period), and downstream we considered a known water depth of 3m.
The Ks coefficients are chosen based on the literature (Table 2). In fact, previous works and laboratory experiments have clearly shown the influence of this parameter on flood control and flow behavior in rivers or in artificial or irrigation channels [5,23,24]. Indeed, the sediments deposition at the wadi bed increases the wall roughness and subsequently causes an overflow. For these raisons, this coefficient must be carefully chosen by taking into account the walls nature.

Table 2: Strickler coefficient according to the wall nature

Nature des parois	Valeur de K en $m^{1/3}/s$
Béton lisse	75-90
Canal en terre, non enherbé	60
Canal en terre, enherbé	50
Rivière de plaine, sans végétation arbustive	35-40
Rivière de plaine, large, végétation peu dense	30
Rivière à berges étroites très végétalisées	10-15
Lit majeur en prairie	20-30
Lit majeur en vigne ou taillis	10-15
Lit majeur urbanisé	10-15
Lit majeur en forêt	<10

Below we present the sections water level for the different simulation scenarios with the software (Fig 2). These Scenarios were considered to visualize the impact of large flows on the water level control at the river in order to protect the city from flooding.



(a) (b)

(c)

Figure 2: Water level in the upstream (a), middle (b) and downstream (c) section for the different flows (Q = 8 m^3/s (PF1); Q = 12.5 m /s (PF2) and Q = 50 m^3/s (PF3))

The simulations show that, for the different flows (Fig 3), only the 50 m^3/s flow causes overflows at the banks, with a chosen roughness from literature of 10 $m^{1/3}/s$ (case of river with very vegetated banks). This is more observed at the upstream sections accompanied by an average velocity around 1.5 m/s. As far as for the Wadi average velocity (Fig 4), it increases as a function of the flow and very strong for the 50 m^3/s flow (an increase of around 0.5 m/s compared to a low flow 8 m^3/s), which greatly promotes the banks overflow. On the other hand, the high roughness chosen will cause a low flow velocity that does not exceed 2.5 m/s, and hence this leads to sediments depositions in the wadi bed and subsequently to overflows [23,25]. The simulation results confirm that even for very important events (T = 100 years, Q = 12.5 m^3/s), the wadis do not cause overflows in any places. All existing structures are capable to transit high-frequency flood flows but the nozzles of the structure are only capable of transiting flows of ten-year period, which was noticed during the transition from a very large flow of 50 m^3/s [9,22].

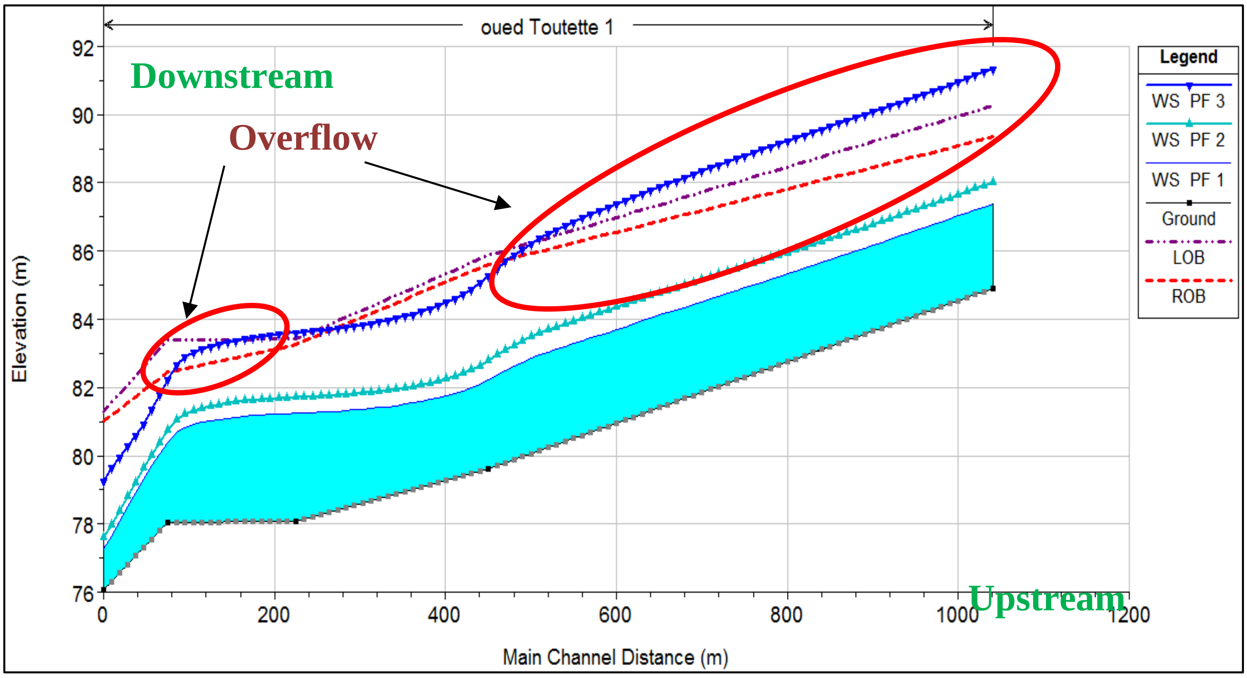


Figure 3: Longitudinal profile for the different flows (Q = 8 m^3/s (PF1); Q = 12.5 m^3/s (PF2) and Q = 50 m^3/s (PF3))

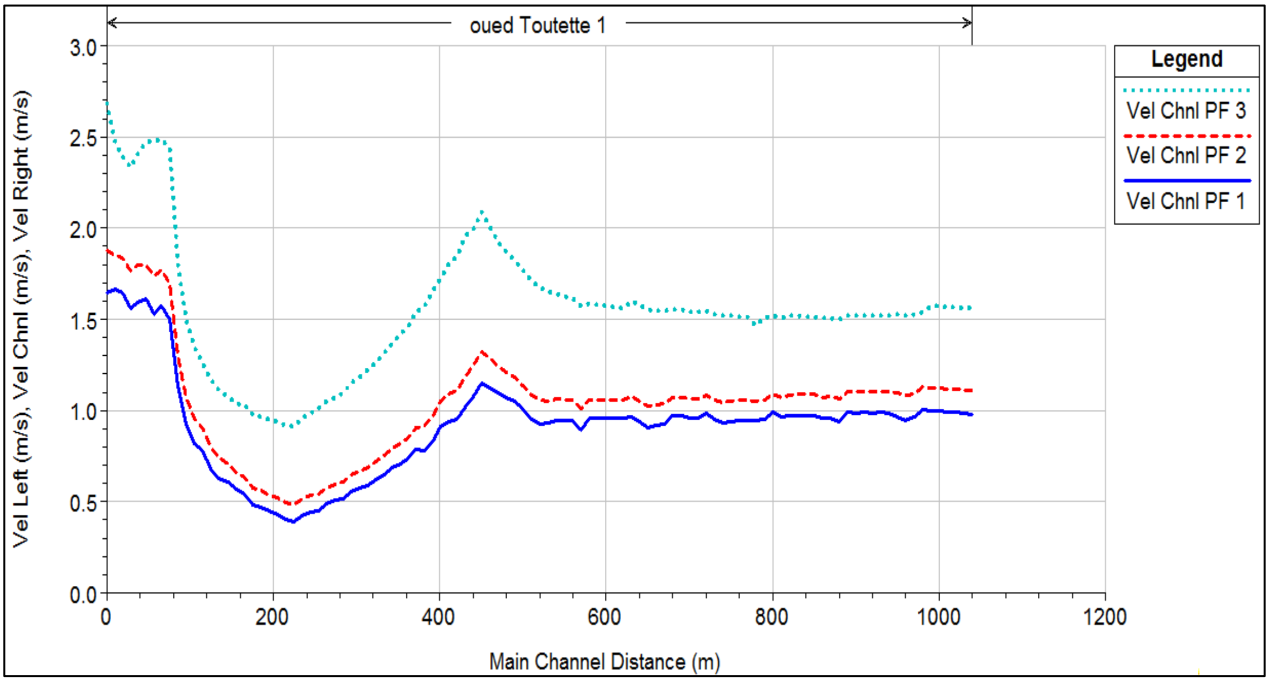


Figure 4: Longitudinal average Velocity Evolution for the different flows (Q = 8 m^3/s (PF1); Q = 12.5 m^3/s (PF2) and Q = 50 m^3/s (PF3))

The development of the upstream and downstream part of the Touttet wadi will be done by gabion walls over a length of 780 m in order to stabilize the banks and slow the wadi widening reaching, following the last rain, a distance of around 2 m between the limit of the left bank and the buildings, hence the great risk of flooding. So, for the protection against the wadis overflow, it is not only sufficient to manage the banks, but also it is necessary to clean the bottom and the banks by removing the deposited sediments and vegetations. Indeed, previous works have clearly shown the importance of bottom cleaning to reduce floods risk [5,6,7].

Conclusion and perspective

According to the diagnostic made on the Somaa city, there exists only the banks degradation phenomenon under the effect of the lateral flows consequently causing the wadi widening, hence the probability and the future flooding risk in this area.

Indeed, this wadi banks instability problem caused after the last rain a wadi widening by a distance of the order of 2 m between the limit of the left bank and the constructions, hence an overflow possibility for intense events.

Scenarios were considered in order to visualize the impact of significant flows on the water level control at river in order to protect the city from future floods.

The simulations show that, for the different flows, only the 50 m^3/s flow causes banks overflows, with a chosen roughness of 10 $m^{1/3}/s$. This is an important result which allows to take necessary measurements for protecting this area against possible future flooding.

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