

INCREASE OF THE RUNOFF COEFFICIENT, HYDROLOGICAL SIMULATION AND RISKS OF FLOODING IN THE OUED FEZ UPSTREAM (FEZ, MOROCCO).

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Abstract

Throughout the period that extended from 1912 to 2014 the city of Fez has experienced an intensive urban extension upstream of the river system mainly of Oued Fes, making the city more exposed to possible flooding. In this sense an approach was conducted based on the study of: artificial natural areas, increased runoff coefficient (CR), and cutting the area of sub-watersheds with independent parameters (Slope, CR, Surface) that are the basis of the hydrological calculation.

The hydrological calculation is based mainly on the parameters of rainfall and on the parameters extracted from the division into sub-watersheds in order to obtain the peak flow generated by each sub-basin and then the downstream flow. This calculation was carried out primarily on the Oued Fes which is the main axis of the hydrography of the city. The formulas used are those of Macmat, Ziegler, and rational formula.

The result of the hydrological simulation performed on two decimal centennial flood Q10 and Q100 show that the SAÂDIYINE bridge connecting the upstream portion and the channeled part of the Oued Fes is in pre-saturation in the normal state, the application of a hundred-year flood makes this hydraulic structure unable to deliver peak flow making its upstream area most exposed to possible flooding.

Keywords: urban extension, runoff coefficient, hydrology, hydrological simulation, flood

Introduction

The urban area is by definition a concentration of activities and population, which the importance conditions the complexity of different equipments to implement. In terms of drainage of rainwater, as in many areas, the problems and practices are often determined by the size of the agglomeration, and greatly differ from one city having a few thousand people to a megalopolis counting many millions.

Urban extension and land artificialization are an important and topical riddle because they are counter to a number of key principles of sustainable development which advocates avoiding irreversibility, to decouple growth economic resource, and to pay the true costs. However, the process of urban sprawl takes place in opposition to these three principles.

The city of Fez as most Moroccan cities has experienced strong urban extension during the last years, that is attributed to several factors namely population growth and rural exodus, procreating a considerable loss of natural land and thus increasing the coefficient of runoff and consequently the risk of flooding in the city.

1. RESENTATION OF THE STUDY ZONE:

The city of Fez is situated at an altitude of 387 m, at the convergence point of four major natural regions, and at the crossroads of two major parties of Morocco: the Middle Atlas to the south, the Atlantic plains in the west, the Rif northern and the eastern highlands opening wide passages to the Tafilalet. Its site is located in the foot of the Tghat Mountain (837 m) and that of Zalagh (900 m) where the course of Oued Fes, after crossing the marshy plain of Sais, accelerates to join the Sebou River. [1]

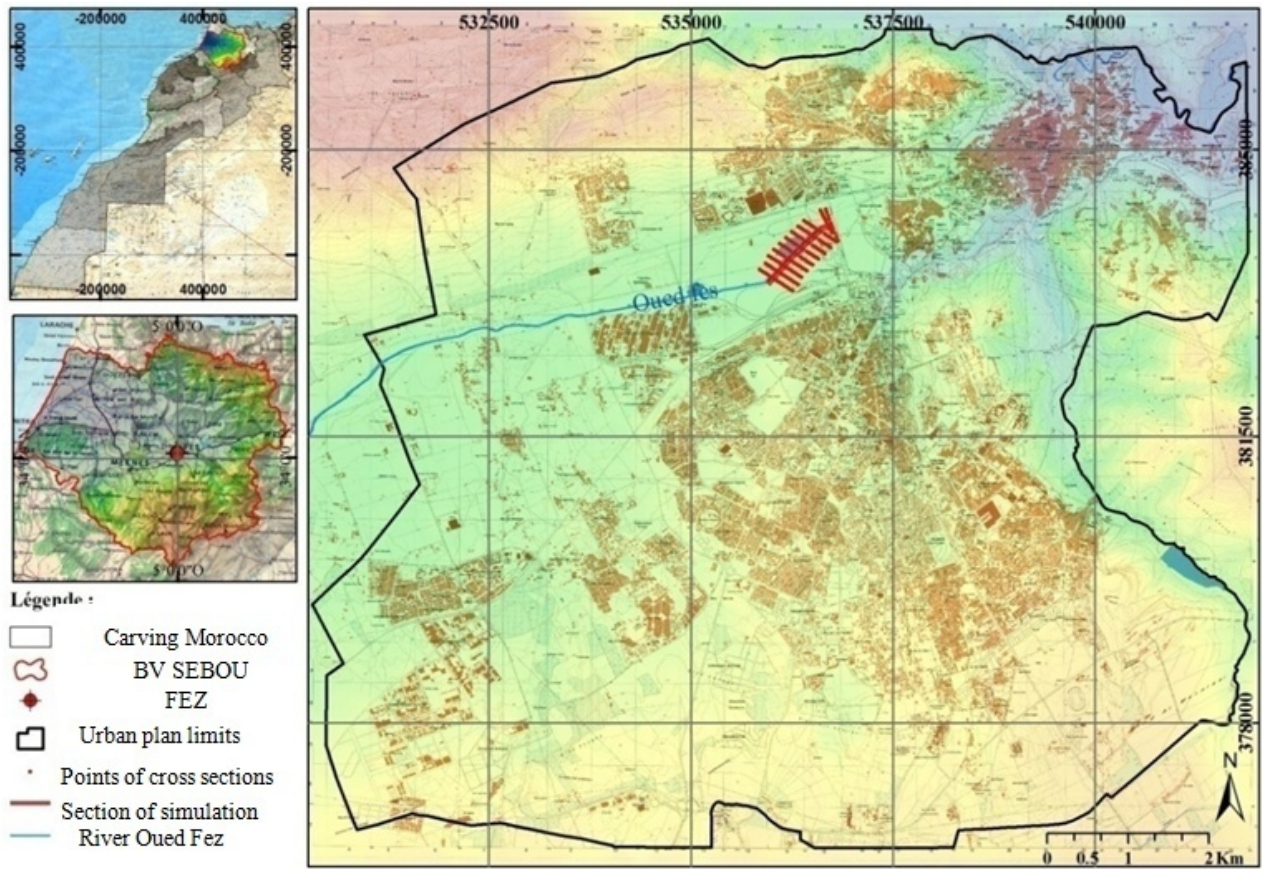


Figure 1 : Location map of the city of Fez

The geology of the city of Fez is characterized by the presence of lacustrine limestone, clay-limestone tuffs and conglomerates on set, silt in the alluvial terraces of the Sebou Valley, travertine, marls, and conglomerates in the valley, debris of limestone slopes, limestone, sandy loams, tuffs and conglomerates on north glaze reliefs, and blue marls altered on the southern hills [2].

The pluviometry data used in this study were provided by the agency of the Sebou basin hydraulic of the station HRD Fez (X: 535400, Y: 38480; Z: 415).

The climate of the region is semi-arid, the average annual rainfall is about 500 mm on the Sais basin, it has a considerable variability between 1980 and 2014 with poor correlation index (around 26%) (Figure2).

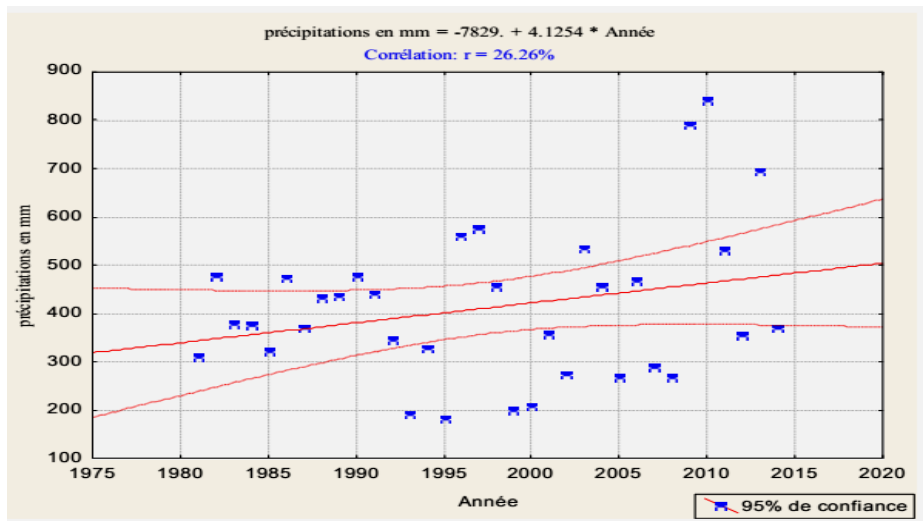


Figure 2 : Variation of the average annual rainfall in the city of Fez

The annual mean of the temperatures is around 17 ° C with a high thermal difference between the mean minimum of the coldest months (January 4 ° C) and maximum of the hottest month (July: 34 ° C). The natural vegetation of the city of Fez is composed of plants adapted semi-arid climate. [3]

The hydrology of the Fez region is characterized by a hydrographic system focused on _ Fes which flows from West to East, from its sources of Ras El Ma to Sebou crossing the old medina of Fez, the Oued Fes receives several tributaries throughout its path towards the Sebou river, and are fed by resurgences of groundwater as the Oued Mahraz, Oued Miyet and Boufkrane, and others that drain essentially runoff water: Oued Mellah, Oued Smen, and Oued Ain chkef [3]. It is limited to the north by the line of ridges corresponding to the pre-Rif wrinkles, to the west by the basin of Oued Nja, on the east by the Sebou basin and southerly by the cliffs of the Middle Atlas Cause Immouzer [4].

The runoff coefficient (CR) is one of the major parameters in the calculation of storm water flows generated by a sub-watershed (SBV). Hydrologically increasing this coefficient caused mainly by the artificialization soil is reflected in less recharge of the water table [5], resulting in increased flows generated by watersheds and thus amplifies the risk of flooding.

1. MATERIALS AND METHODS :

This work is based on the study of the increased runoff coefficient in the city of Fez, the topographical study the delimitation of sub-watersheds, and the hydrological study.

A. RUNOFF COEFFICIENT :

The runoff is the portion of rainfall that does not infiltrate into the soil and does not evaporate into the atmosphere. Once the vegetation retention capabilities and topsoil is saturated, this part flows on the surface before reaching the river system directly or through an artificial venting system. [6]

The goal of this step is to study the increased runoff coefficient; to do this We were based on the map of land use in order to delimit the areas undergoing transformation of natural areas into other artificial (Roads, buildings, ...), following these steps:

- Delimitation of natural areas between 1912 and 2014;
- Delimitation of artificial spaces;
- Calculating the equivalent runoff coefficient.

The method used is that of the equivalent runoff coefficient (CRE), elementary runoff coefficients (Ci), and elementary surfaces (Ai):

$$CR_E = \left[\frac{\sum(C_i \times A_i)}{\sum A_i} \right] \quad [7]$$

B. TOPOGRAPHICAL STUDY OF THE CITY

This step is based on the operation of division of the DTM _ following the perimeter of the study area, the wedging of the land cover map with the topographic map. And this in order to:

- Establish the elevation map;
- Obtaining the curve levels and altitudes of crests and roots;
- Establish the digital terrain model (DTM)
- Establish the slope map of the study area.

The topographical study allowed us to make the digital terrain model that allowed us create a map of level curves and slopes map (Figure 3) that show a variation in altitude over the whole of urban area of city with strong slopes to the north, northeast and east, and other weak in the West particularly along the banks of the Oued Fez.

C. DELIMITATION OF SUB-WATERSHEDS (SBV)

In order to estimate the flow generated by a rainfall, it is necessary to divide the study area in watersheds that are defined as a geographic area drained by a river, an Oued or even artificial wastewater canalization with independent characteristics (flow, runoff coefficient surface).

To do this we will utilize the wedging of the slope map (Figure 3) with that of land use, this step aims to:

- Have an idea about the paths of different drop fell on a waterproofed surface;
- Delimit the sub-watersheds;
- Pull the calculation parameters for each SBV namely area length.

Since most sub watersheds delimited present heterogeneity in terms of nature of the substratum and concentration of urbanization, many SBV occupying urbanized areas with other naturals. It is essential to calculate the equivalent runoff coefficient (CRE) for each SBV.

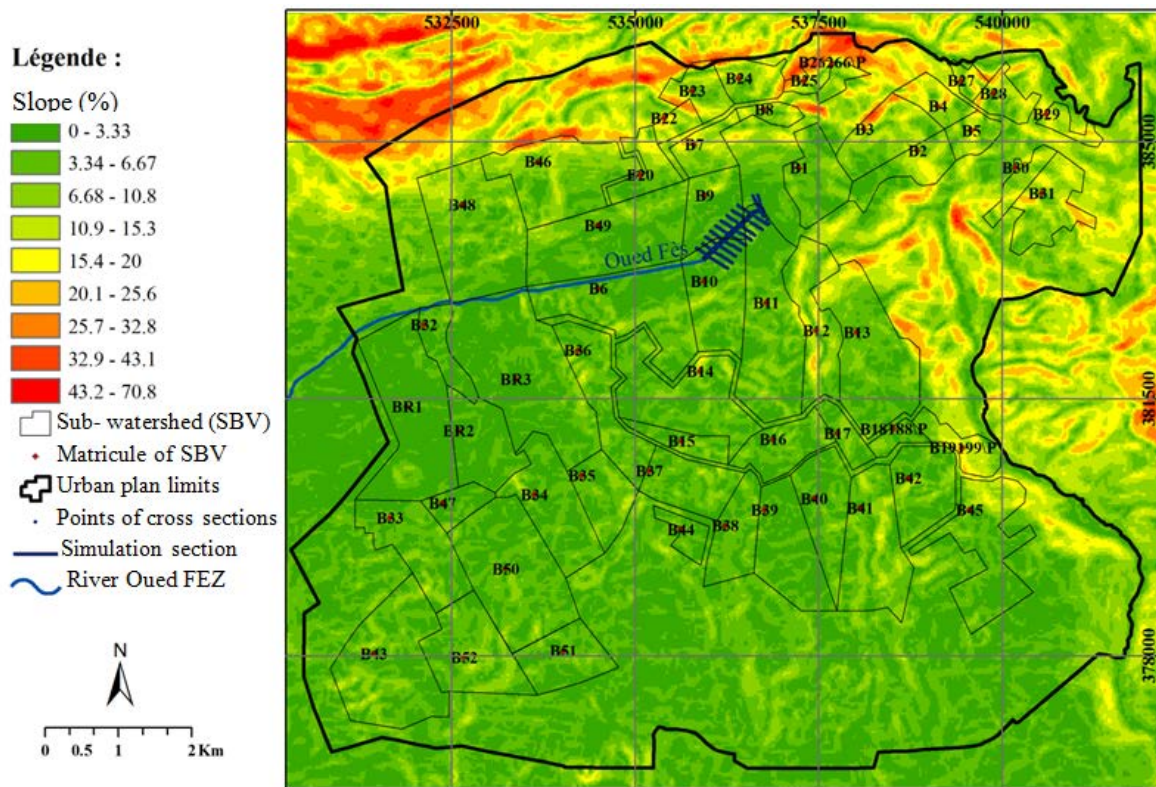


Figure 3 : Map of slopes and cutting of SBV

The results of the topographical study reveal a spatial heterogeneity, with a dominant slope from 0 to 15%. The usefulness of this study is extreme because the slope is an essential parameter in the calculation of storm water flows, Figure 3 is a superposition of the SBV cut and slope map, the area of the banks of the Oued Fez presents very low or even nulls slopes for some sections.

D. CALCULATION AND HYDROLOGICAL SIMULATION

The hydrological calculation is based primarily on data extracted from the previous steps; Figure 3 shows the map of SBV cut overlaid with slope map of the study area.

Table 1: Basic data for the calculation of storm water flow rates

S.B.V.	A Km ²	L Km	vertical drop (m)	I m/km	S.B.V.	A Km ²	L Km	vertical drop (m)	I m/km
1	0.80	1.192	24	20.126	27	0.16	0.390	17	43.617
2	0.59	1.600	89	55.625	28	0.36	0.549	33	60.129
3	0.86	1.342	96	71.553	29	0.21	0.387	13	33.569
4	0.42	0.845	74	87.610	30	0.31	0.434	12	27.653
5	0.32	0.529	39	73.668	31	0.85	1.462	19	12.999
6	1.80	1.658	13	7.841	32	0.45	1.515	3	1.981
7	0.45	0.647	62	95.842	33	1.19	1.522	20	13.141
8	0.20	0.420	15	35.731	34	1.27	1.522	21	13.798
9	0.69	0.953	20	20.993	35	0.71	1.002	14	13.976
10	1.20	1.693	24	14.176	36	1.07	2.508	25	9.967
11	1.99	3.000	35	11.666	37	0.83	1.189	14	11.775
12	1.07	2.187	28	12.805	38	0.76	0.574	22	38.331
13	1.93	2.151	49	22.779	39	1.23	1.702	21	12.337
14	1.67	2.183	34	15.574	40	0.96	1.161	30	25.844
15	0.36	1.559	30	19.248	41	1.51	1.942	39	20.078

16	0.71	1.444	14	9.695	42	0.94	1.129	20	17.712
17	0.31	1.030	22	21.350	43	2.10	2.095	39	18.613
18	0.21	0.710	9	12.682	44	0.26	0.790	10	12.659
19	0.45	0.637	40	62.834	45	1.54	1.897	86	45.340
20	0.47	0.606	43	70.905	46	1.58	1.106	82	74.166
21	0.10	0.293	12	41.001	47	0.35	1.027	3	2.921
22	0.21	0.515	34	66.066	48	2.10	1.874	100	53.369
23	0.46	0.919	45	48.962	49	1.99	2.015	14	6.949
24	0.45	0.818	29	35.458	50	2.60	1.884	30	15.923
25	0.19	0.384	18	46.873	51	0.83	0.924	15	16.230
26	0.17	0.447	42	94.035	52	1.29	1.261	14	11.100
BR3	0.96	1.579	10	6.333	BR 1	2.21	2.631	3	1.140
					BR 2	2.84	2.722	12	4.409

The formulas used for the hydrological calculation are presented in Table 2 (Tab.2).

Table 2: formulas used for the hydrological calculation

	Formula	Condition	Observation
Formula Rationale	$Q_r = \frac{1}{3.6} \cdot C \cdot i \cdot A$	A < 25Km ²	Q: Average flow in m3/s C: runoff coefficient i: intensity in mm/h A: Area of the Basin in ha. P: Maximum Precipitation in 24h (mm). I: slope m / km. H: Maximum Precipitation in 1h K: topographic coefficient
Burkli Ziegler	$Q = 0.0039 \cdot C \cdot H_{1h} \cdot A^{0.75} \cdot I^{0.25}$	A < 10 Km ²	
Mac-Math	$Q = K \cdot P \cdot A^{0.58} \cdot I^{0.42}$	A < 1 Km ²	

The hydrological simulation is focused on the region having the most reliable slope upstream of the hydraulic structure Saâdyne.

The figure (Fig. 4) locates the cross sections of the simulation section that was performed by means of HEC-RAS 4.0.

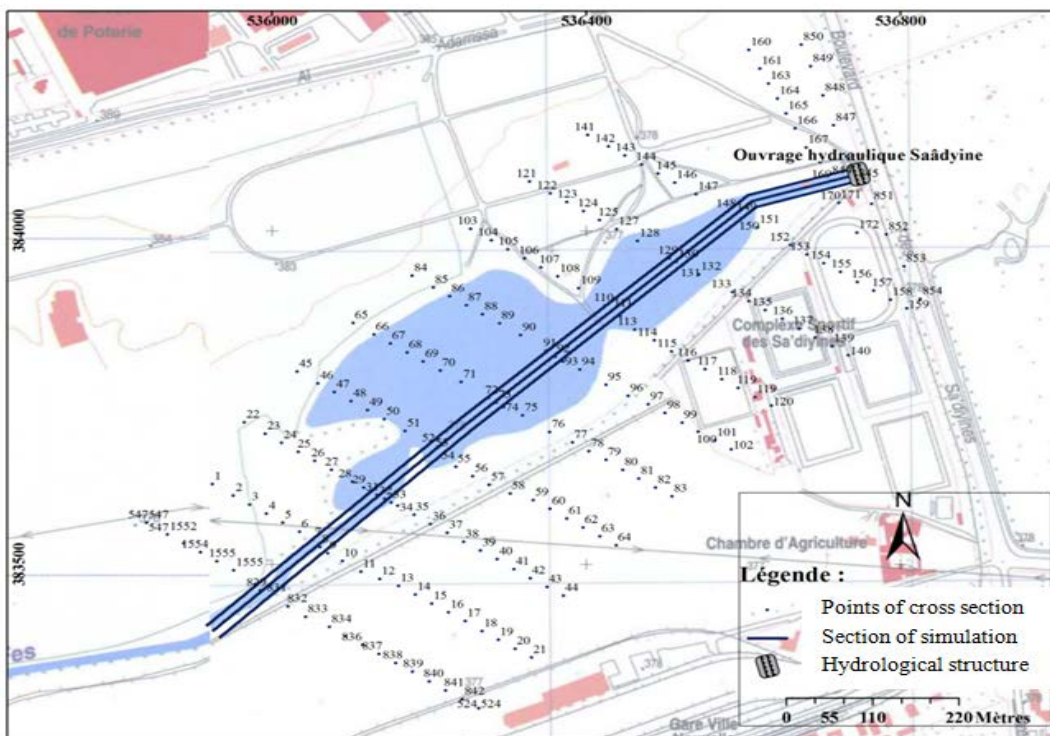


Figure 4 : section of the hydrological simulation

2. RESULTS AND DISCUSSION

A. RUNOFF COEFFICIENT (CR)

The result of the study of the variability of the runoff coefficient of Fez according to the urban extension shows a value which doubles for a century ranging from 31% in 1912 to 69% in 2014 (Figure 5).

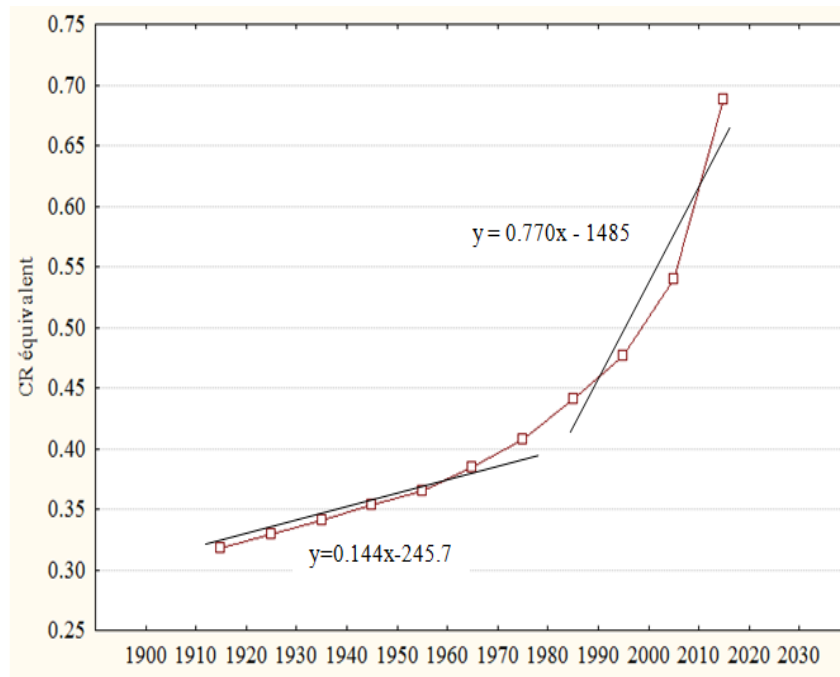


Figure 5: Evolution of the runoff coefficient between the years 1912 and 2014

The result of the study of the runoff coefficient shows a considerable increase between 1912 and 2014 from 31% to more than 68% recording an alarming elevation of more than 100% that said that 68% of the whole surface of Fez has a CR of approximately 90%.

The evolution of the runoff coefficient marked an increase in two distinct phases, the first one is from 1912 (31%) to 1980 (43%), and the second one more accelerated from 1982 to 2014 (68%).

This increase is primarily due to the urban extension especially to the west of the city upstream of the Oued Fez, which practically doubles the peak flow of the floods decimials and centennials.

B. HYDROLOGICAL CALCULATION :

The results of the hydrological calculation are presented in Table 3.

Table 3: Results of the hydrological calculation

B.V.	Mac Math (l/s)	Rational (l/s)	Burkli Ziegler (l/s)	Q "adopted" (m3/s)
1	1036.92	3486.63	2202.34	3.49
2	1332.00	4018.72	3073.60	4.02
3	1852.96	6525.38	4246.31	6.53
4	1326.10	4207.81	2517.69	4.21
5	1062.91	3904.46	1958.77	3.90
6	A>1Km ²	6105.24	3978.28	6.11
7	1442.17	4782.92	2477.08	4.78
8	586.62	2049.76	1015.83	2.05
9	969.02	2798.97	1634.16	2.80
10	A>1Km ²	4485.35	3119.64	4.49
11	A>1Km ²	5598.78	4656.22	5.60
12	A>1Km ²	3794.00	3040.19	3.79

13	A>1Km ²	8227.35	5825.01	8.23
14	A>1Km ²	5680.01	4180.37	5.68
15	642.83	1384.67	1154.31	1.38
16	711.64	2393.17	1710.22	2.39
17	613.17	1843.23	1294.83	1.84
18	389.52	1715.93	1094.83	1.72
19	1199.03	5608.08	2893.20	5.61
20	1294.42	5764.36	2880.25	5.76
21	431.04	1714.28	804.39	1.71
22	794.91	2999.05	1609.43	3.00
23	1098.68	4302.29	2633.69	4.30
24	950.12	4179.15	2432.48	4.18
25	637.84	2950.17	1412.19	2.95
26	803.25	2994.07	1571.70	2.99
27	563.14	2469.02	1227.75	2.47
28	1031.09	5120.98	2569.87	5.12
29	598.06	3163.73	1488.79	3.16
30	680.61	3945.75	1839.32	3.95
31	898.52	4756.78	3286.50	4.76
32	279.39	1161.34	956.64	1.16
33	A>1Km ²	6452.95	4282.73	6.45
34	A>1Km ²	6254.73	4099.71	6.25
35	832.70	4748.73	2842.12	4.75
36	A>1Km ²	4091.10	3509.39	4.09
37	846.41	4510.34	2854.14	4.51
38	1318.10	8058.05	3630.55	8.06
39	A>1Km ²	5517.98	3839.84	5.52
40	1283.94	6285.73	3777.29	6.29
41	A>1Km ²	7227.65	5111.66	7.23
42	1079.71	5703.44	3420.92	5.70
43	A>1Km ²	8771.11	6067.48	8.77
44	443.93	1805.93	1162.41	1.81
45	A>1Km ²	7556.17	5215.06	7.56
46	A>1Km ²	12331.25	6539.84	12.33
47	287.38	1496.53	1062.40	1.50
48	A>1Km ²	14141.84	9145.29	14.14
49	A>1Km ²	7195.44	5048.33	7.20
50	A>1Km ²	11890.99	7576.06	11.89
51	969.82	6531.28	3657.22	6.53
52	A>1Km ²	6700.39	4041.76	6.70
BVR 1	A>1Km ²	3802.47	3145.33	3.80
BVR 2	A>1Km ²	5904.32	4531.90	5.09
BVR 3	708.91	3976.26	2835.28	2.65

The results of the hydrological calculation through the three formulas mentioned in Table 2, the agreed flow is the maximum flow of these three flows, it will be useful, because the hydrological simulation is based on the survey points (ribs), and the flow generated from this calculation.

C. HYDROLOGICAL SIMULATION

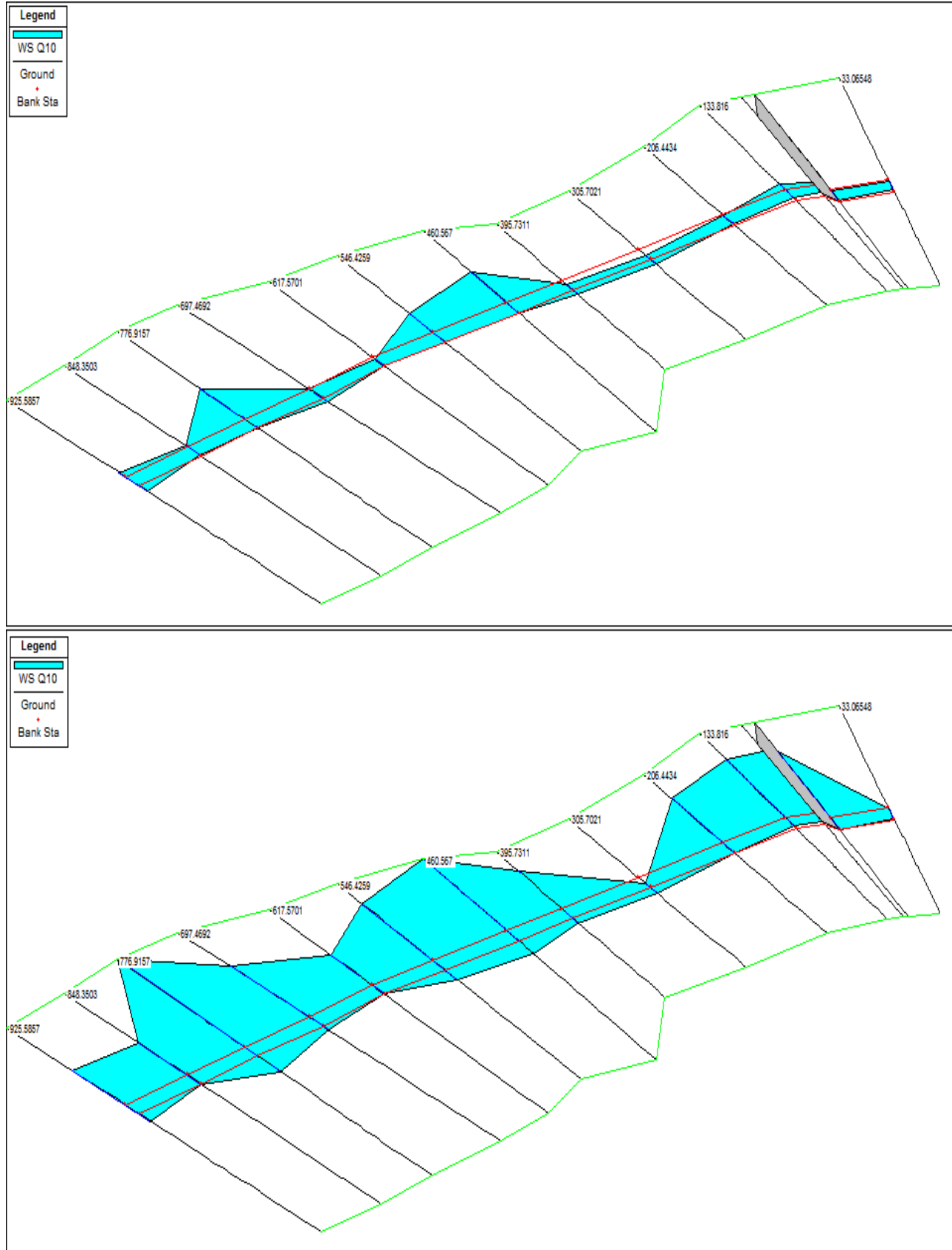


Figure 6 : Results of the hydrological simulation Q10 and Q100. (1Km before the hydrological structure)

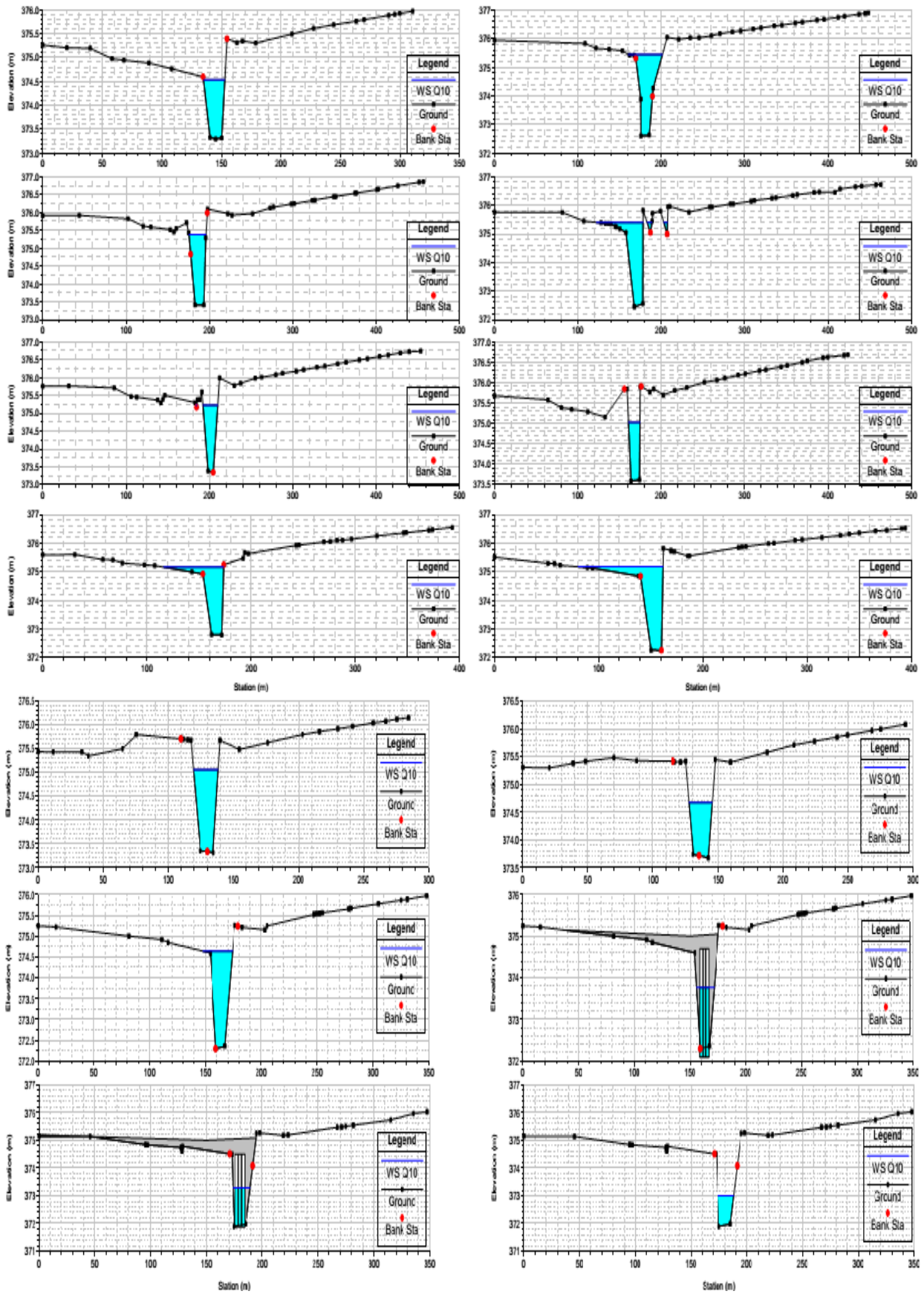


Figure 7: cross sections of the flood Decimal Q10

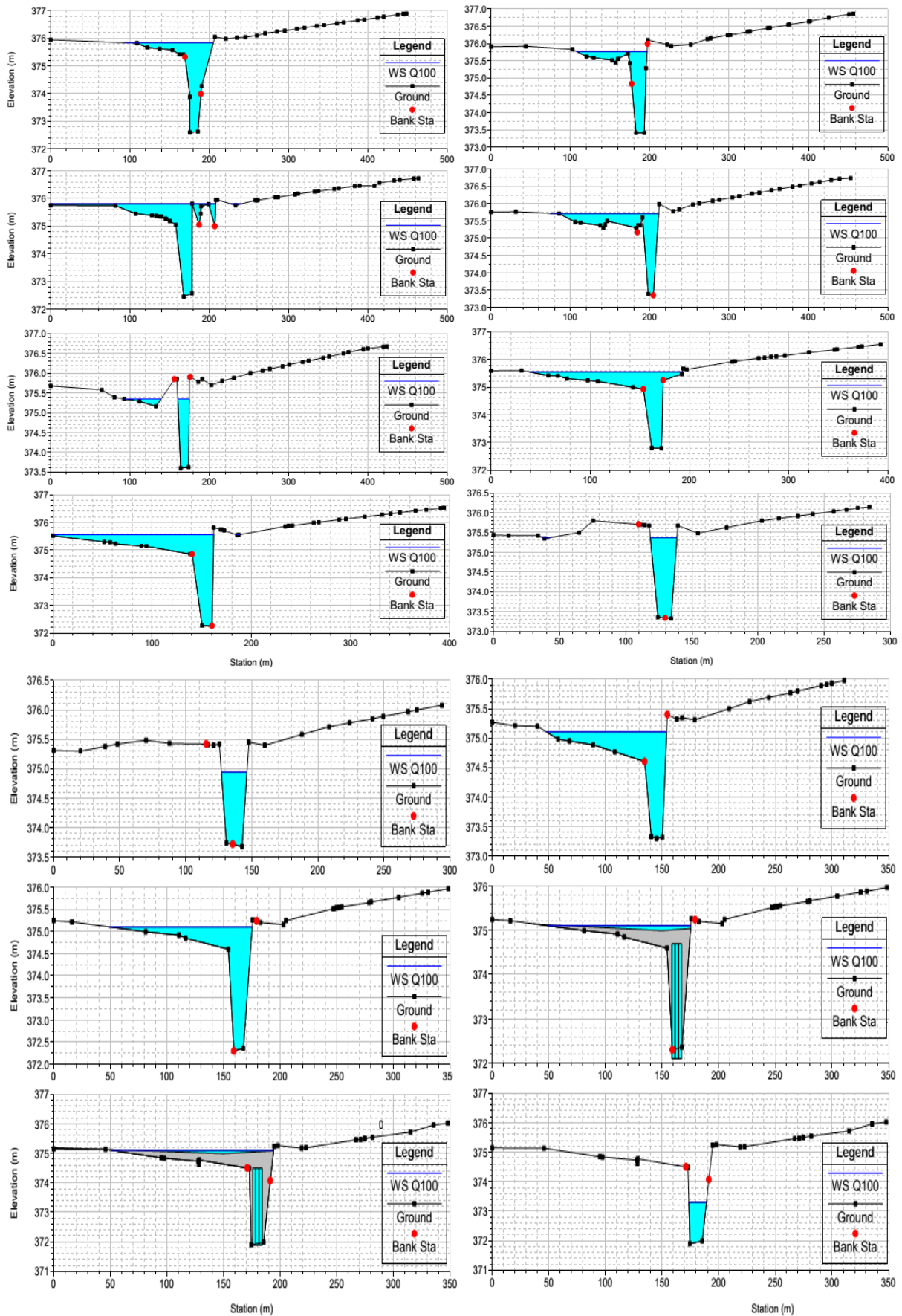


Figure 8: cross sections of the flood centennial Q100

The study and the hydrological simulation were applied to two different return periods Q10 and Q100. The results showed that during a hundred-year flood Q100 the hydraulic structure SAÂDYINE which is only a scupper of triple openings will not be able to deliver peak flows, this flow rate is much higher than its critical flow, which makes its upstream area most exposed to possible flooding and the presence of a shallow plain along the Oued accentuates the risk and makes this area most exposed to flooding and stagnation of storm water.

The result of the simulation of flood plains shows the presence of a flooded area of approximately 1.42 km². The spread of the surface that can cover the flood Q10 arrives at 0.49 km² is 34.50% of the total surface of the floodplain, this spread was primarily due to the

stagnation of rainwater and runoff with the presence of depression zones promoting their stagnation, by against the structure to Q10 (Figure 7) will be able to carrying the peak flow in Q10, while for the peak flow Q100 (Figure 8), the hydraulic structure present a saturation (sub-dimensions) will not be able to carrying the flow and in the presence of zones of depression, the surface of the eventual flood Q100 is approximately 0.86 km² is 60.56% Surface entire floodplain.

The average altitudes covering the right bank of the Oued is about 375.33m, while the left bank is of the order of 372.48m, which explains the extension of the flood more toward the left bank that towards the right bank.

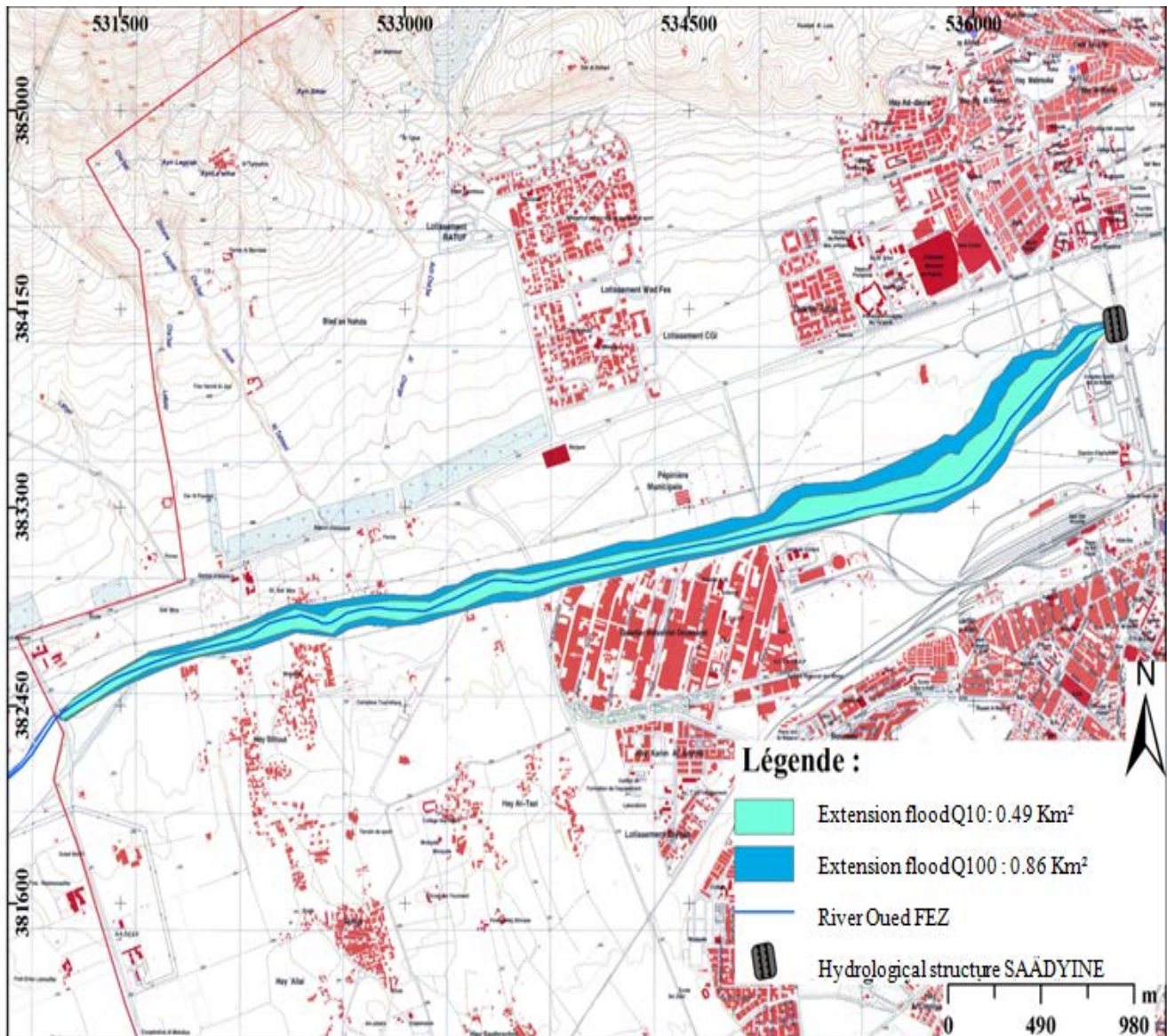


Figure 9: Extensions of flooding for the two different floods Q10 and Q100

3. CONCLUSION

Increase in runoff coefficient, the presence of a depression zone with very low slopes stretches over a large area along the river Oued Fez, and the dimensions of the hydraulic structure are determinants factors in the vulnerability of our study area for a possible flood.

In order to mitigate this situation we would have recourse to two different solutions: upstream risk management or downstream risk management, the first will engage the alternative stormwater drainage solutions, while the second will be based essentially on adding security openings in the hydraulic structure SAÂDYINE.

The addition of the openings at the structure seems to be the most economically practical because it is less expensive solution compared to alternative stormwater drainage system that needs a technical and economic study and this requires huge investments and very careful exploitation.

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