Flow modelling and investigation of flood scenarios on the Cavaillon River, Haiti

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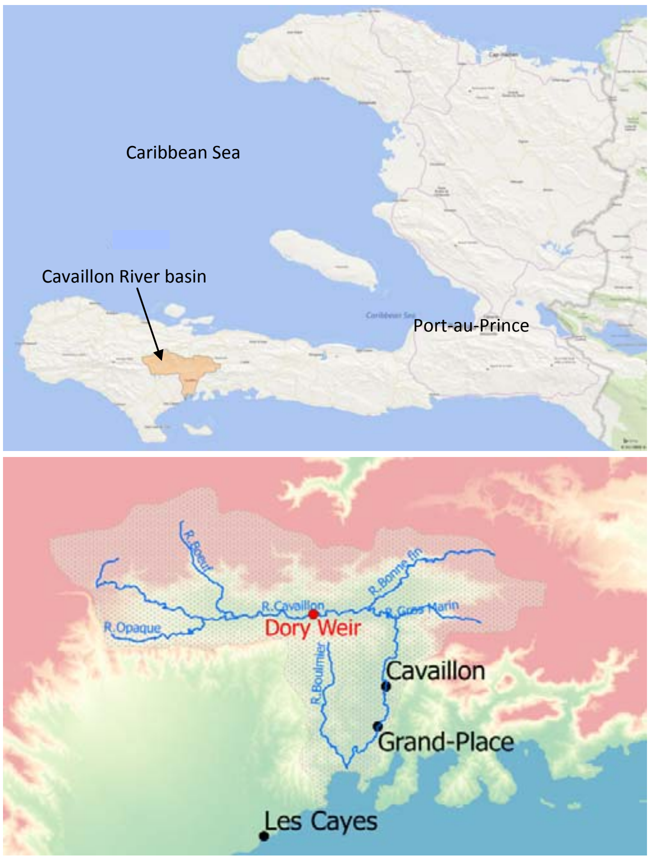
ABSTRACT: The vulnerability of riverine populations confronted to rivers floods and the socioeconomic consequences of floods remain a major concern for the Haitian public decision-makers. However, the use of modelling tools for flood prediction and mitigation purposes is not yet well established in the country. This paper presents the first results of an ongoing study on the Cavaillon River in Southern Haiti, with the aim of constructing a methodology to design a suitable model for the river and to run flood scenarios. First, old topographic data were combined with new data obtained from field measurements to construct the hydraulic model. The roughness parameter in this model was calibrated using the scarce available water level and discharge measurements. On this basis, flood scenarios were run using an estimate of the 100-year discharge available from previous studies. Then, an adapted procedure to construct flood maps is presented.

1 INTRODUCTION

The flood problematic is crucial in Haiti and the vulnerability of riverine population confronted to river floods constitutes a major concern for Haitian decision makers. However, flood prevention strategies still need to be developed and the use of modelling tools for this purpose is not yet well established. This is a crucial issue since Haiti is one of the poorest countries in the Western Hemisphere, with eighty percent of the population living under the poverty threshold, and most of them depending on the agricultural sector, which is very sensitive to river overflow.

Flooding events that occur regularly during the cyclonic periods are disastrous for the surrounding residents but also for the river evolution itself. As an example, during the year 1986, between the 2nd and the 3rd of March, a flood occurs in the Haitian subregion "Les Cayes" with a total of 79 deaths and 85000 affected people. Moreover, sediment transport and bank erosion often become uncontrollable due to catastrophic deforestation of rivers basins. As an example, the forest area for the Cavaillon River basin in Southern Haiti has decreased from 380 km² in 1983 to 51 km² in 1995. Such over-exploitation of the forest areas significantly increases the dramatic consequences of flood event.

Within the frame of a cooperation project funded by ARES-CCD (Académie de Recherche et d'Enseignement Supérieur – Commission de la Coopération au Développement, Belgium), the present work is part of a broader study aiming at improving the ability of Haitian institutions to better manage their rivers and prevent or at least decrease potential damages of flood events.



(a)
(b)

Figure 1: Localization of the studied river reach: (a) general map of Haiti and indication of the Cavaillon river basin, (b) Details of the Cavaillon River

Part of the work is devoted to the development of a methodology aiming at constructing simple and efficient hydraulic models for Haitian rivers, based on the existing knowledge and on field surveys, and using free modelling tools, considering the limited available resources in the country. This methodology is built using the case of the Cavaillon River, located in southern Haiti, in the department Les Cayes (Figure 1).

The paper is organized as follows. First the study site and the available data are presented. Then, the hydraulic model of the river is described, with the chosen upstream and boundary conditions. This model is calibrated using the available discharge and water level data, and used to study flood scenarios on the river. Finally, the results are discussed and perspectives are given for future work.

2 DESCRIPTION OF THE STUDY SITE

The Cavaillon River flows over approximately 50 km (Figure 1) until reaching the sea. The studied area has a length of 25 km, located between the Dory weir and Grand Place.

Before the start of the project, the only topographical data available for the region consisted in a 30 m × 30 m digital elevation model (DTM) which is not sufficient considering that at many locations, the width of minor bed of the river is less than 30 m. Besides, no bathymetrical data were available. Following a field survey (Joseph et al., 2015), 96 cross-sections were measured along this reach, yielding the bed profile illustrated in Figure 2. Typical cross sections are shown in Figure 3.

For each cross section, the Pebble Count method (Wolman, 1954) was applied to obtain the grain size distribution. Results for the two cross-sections of Figure 3 are shown in Figure 4: it can be observed that the bed is made of coarse material with typical sizes of about 50 mm (Carlier d'Odeigne et al., submitted). This is illustrated in the grain size distributions, e.g. at the upstream end of the study reach (Dory, blue curve in Figure 4) and at the downstream end (Grand-Place, red curve in Figure 4). This evolution is illustrated in Figure 5. The d_{50} diameter along the study reach is shown in Figure 5.

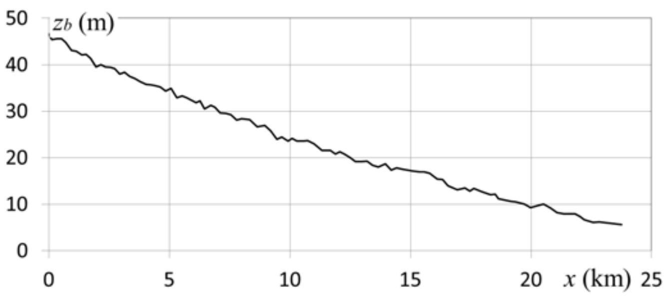


Figure 2: Bed profile of the Cavaillon River

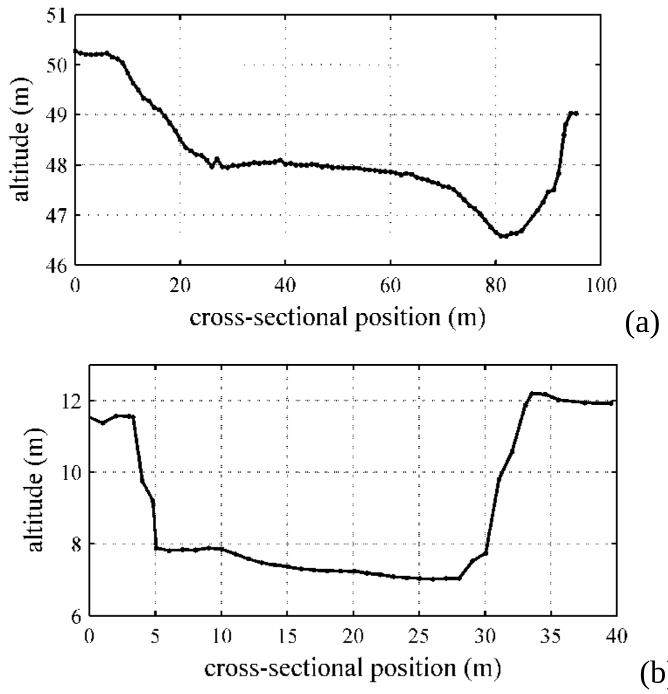


Figure 3: Cross-sections in the Cavaillon River (a) upstream end of the study reach (Dory) and (b) downstream end of the study reach (Grand-Place)

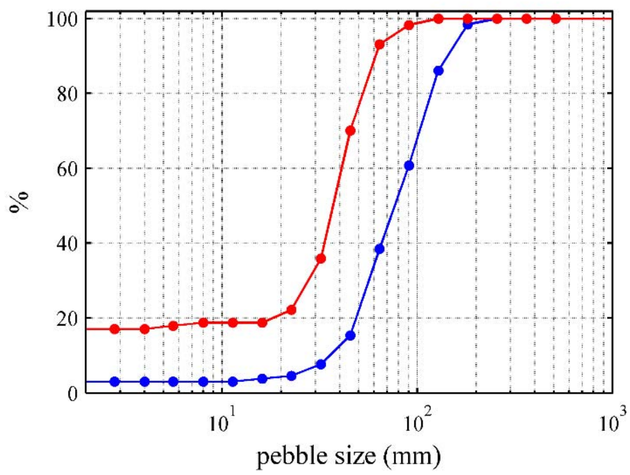


Figure 4: Bed material size distribution at Dory (blue) and Grand Place (red)

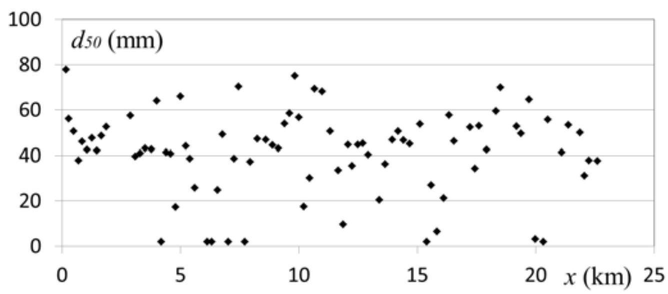


Figure 5: Evolution of the median diameter d_{50} along the study reach

The Cavaillon River has two main tributaries: River Gros-Marin and River Bonne-Fin, as illustrated in Figure 1. During the dry periods, no water flows from the tributaries into the Cavaillon River. However, during floods, the contribution of these tributaries will be considered by estimating the additional discharge issued from runoff over the corresponding watersheds.

According to previous works (Gonomy, 2012), discharges up to 400 m³/s were observed in the region. However, within the frame of the present project, only very low discharges were measured in the river as the region is experiencing a severe drought in the last 4 years. The data available for the current project are detailed in Table 1: for each measured discharge, the water depths at three stations located along the river were also recorded, yielding a first database that will be used to calibrate the hydraulic model. Each station is identified by its kilometer distance from Dory as PK00.000. Station PK23.016 corresponds to Grand-Place, the downstream limit of the study reach.

Table 1: Measured discharges and water depths

Q (m³/s)	PK13.115 h (m)	PK18.815 h (m)	PK20.984 h (m)	PK23.016 h (m)
1.886	0.80	0.46	-	1.28
2.085	0.86	0.47	0.41	1.30
2.759	-	0.52	0.45	1.35
3.876	-	0.60	0.58	1.43

3 HYDRAULIC MODEL

3.1 *Bathymetry*

A one-dimensional model of the river reach is constructed based on the collected field data. As can be observed in Figure 6, abrupt changes in the cross-section width occur in the river, with local adverse slopes (Figure 2)

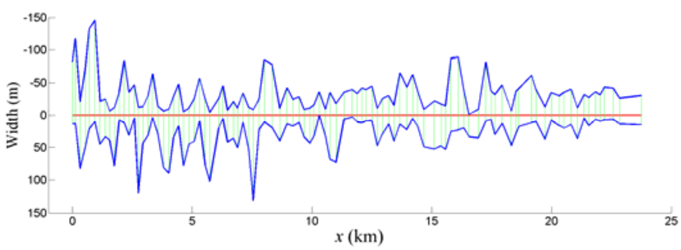


Figure 6: Cross-section width along the Cavaillon River

3.2 *Upstream boundary condition*

The upstream end of the study reach is located at the Dory weir, for which a stage-discharge relations has to be established. Indeed, as can be observed from Figure 7, the weir has a typical Creager shape, but was seriously damaged during previous floods. In particular, the crest level is no more horizontal and the downstream concrete slab was lifted upwards, probably due to important under pressures.

As the water level is monitored both at the upstream and downstream side of the weir, one of the objectives of the study is to construct a stage-discharge relationship that could be used to measure the discharge entering the study reach. The stage-discharge relationship can be written as

$$Q = \mu L \sqrt{2g}\, H^{3/2} \qquad (1)$$

Based on the field measurements reported by Rousseaux (2014), an average discharge coefficient $\mu = 0.46$ could be estimated for the weir.

Figure 7: Dory weir

3.3 *Downstream boundary condition*

The downstream boundary condition of the model is located at Grand Place, i.e. about 4 km from the mouth of the river. At this location, the water level is recorded using an OTT PLS device and the discharge is measured by an OTT SLD water velocimeter. However, in low-flow conditions, this latter device is no more submerged and no discharge measurements can be obtained.

Because of the proximity of this downstream boundary condition to the mouth of the river, the influence of the tidal sea level variations on the water level at this station was investigated. A 24-hour measurement campaign was carried out to record the water level at Grand Place and at three other stations located further downstream. The results are illustrated in Figure 8. While the influence of the tide is clearly visible close to the mouth of the river, its influence at Grand-Place appears to be negligible. This should however be confirmed with further measurements for different tidal conditions and rived discharges.

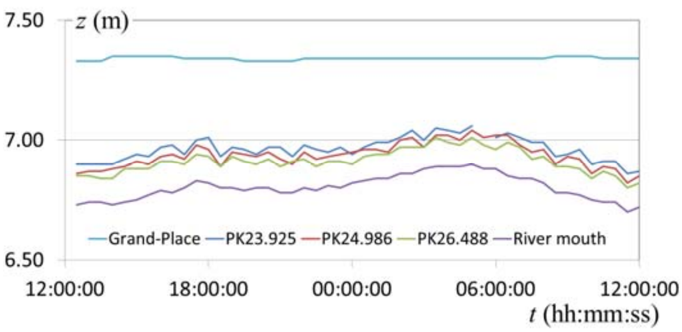


Figure 8: Water-level evolution during a tidal cycle (Grand-Place: PK23.016)

4 MODEL CALIBRATION

4.1 *Simulation tool*

The steady-flow AxeRiv tool is used, solving the Bernoulli equation considering cross-sections of arbitrary shape. Different levels of interpolation of the flow variables between the cross-sections can be defined, in order to increase the accuracy of the calculated water profile. This feature is particularly useful in the present case, where the distance between the measured cross-sections is about 200 m and where the cross-section can vary significantly from one section to the other (Figure 2 and Figure 6). Typically, in the present calculations, 10 interpolation points were used.

4.2 *Calibration of the bed roughness*

Using AxeRiv, flow profiles were calculated for the different measured discharges of Table 1, and the downstream water depth imposed at Grand-Place, i.e. PK23.016 in Table 1. Using the available water depth measurements, an average value of the Manning coefficient for the considered river reach could be calibrated as $n = 0.030$. Such a water profile is illustrated in Figure 9 for a discharge $Q = 2.085$ m³/s.

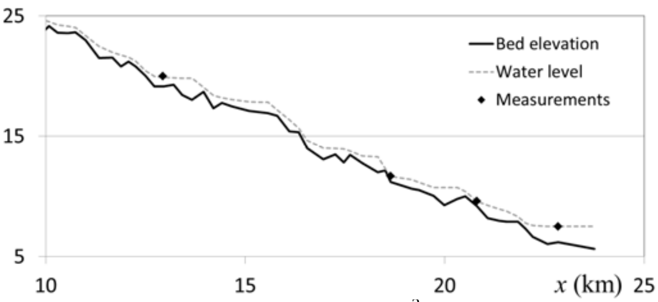


Figure 9: Water profile – $Q = 2.085$ m^3/s, $n = 0.030$

5 FLOOD SCENARIOS

The Cavaillon River is located in a region where hydrological extremes are frequent. So, determining flood and inundation risk is one of the main goals of the present study.

Most of the classical approaches are not usable in the present case, due to poor availability of topographical data. So, the used methodology aims at providing results accurate enough in a context of inaccurate data.

5.1 *Considered discharges*

No systematic hydrological data are available in Haiti, especially regarding extreme discharges. One of the main issues for the future is the reconstruction of past events in order to determine at least approximate discharges for the evaluation of floods and extent of inundation area.

An estimate of 535 m^3/s for the 100-year return period discharge was found in Gonomy (2012), but the way to go to this value is not known. So, this value was used but, considering that such a value leads to water levels below what was observed in situ, an arbitrary value of 1000 m^3/s was also considered. This high discharge presents the advantage to lead to results more visible on the maps.

5.2 *Methodology*

Some characteristics of Haitian topographical data are challenging for flood scenarios: only a 30 m × 30 m DTM is available, its geo-referencing is not completely clear and the reference elevation is not linked to other data.

The following classical steps for evaluating the inundation extent along the Cavaillon River were applied. Firstly, the water profile is computed, using the cross-sections measured every 200 m and assuming a steady-flow. At each section, two points are selected at some distance from the river axis (Figure 10). Assuming the same water level at these points as the computed one along the river axis; these points form a shapefile that can be used in GIS software (in the present study the free software QGIS was used).

Figure 10: Example of fixed levels (in yellow) for spline interpolation – $Q = 535$ m^3/s, $n = 0.030$ – Section 34 corresponds to PK7.062 and section 37 to PK7.720

These points form a basis for a spline interpolated raster surface (Figure 11) that could represent approximately the flood water table, even in river bends (in the present study the SAGA tool box was used in combination with QGIS).

The spline interpolated raster surface may be created with any density but, as the result has to be compared to the 30 m × 30 m DTM raster, the same density has been adopted as can be observed in Figure 11.

The spline interpolated surface is now compared with the DTM and, in case of positive difference of water table and terrain levels, a new raster is created representing the water depth at the different raster cells (Figure 12). Once again the resolution of such a map is the same as the DTM one, leading to results that are to be interpreted because, among others, of the coarseness of the grid.

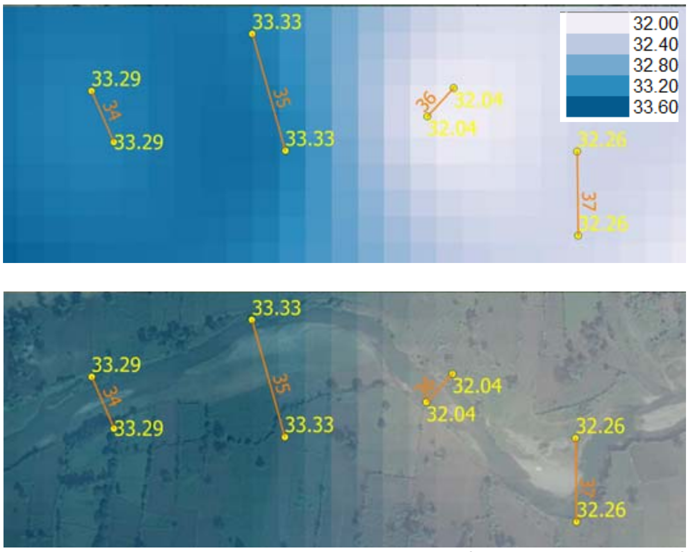


Figure 11: Spline interpolated raster surface with points of Figure 10 as basis (each square is a 30 m × 30 m cell). Top: interpolated water table; bottom: interpolated water table with transparency to identify the background photograph.

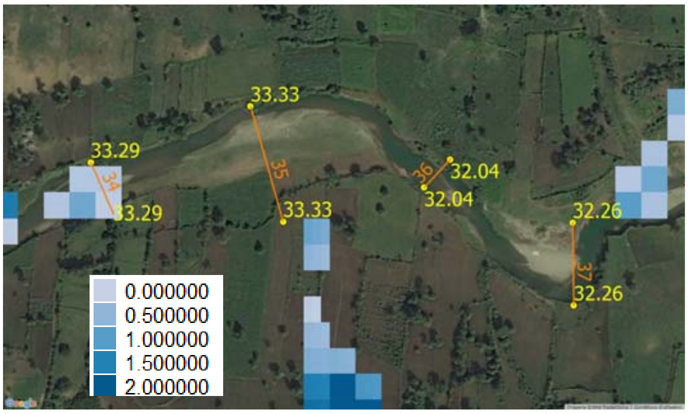


Figure 12: Water depth from the positive difference between spline interpolated raster surface and DTM (each square represents a 30 m × 30 m cell)

5.3 *Results and discussion*

The procedure described before was applied along a part of the Cavaillon River for discharges *Q* of 535 and 1000 m^3/s, respectively. The resulting water-depth maps are presented in Figures 13 and 14.

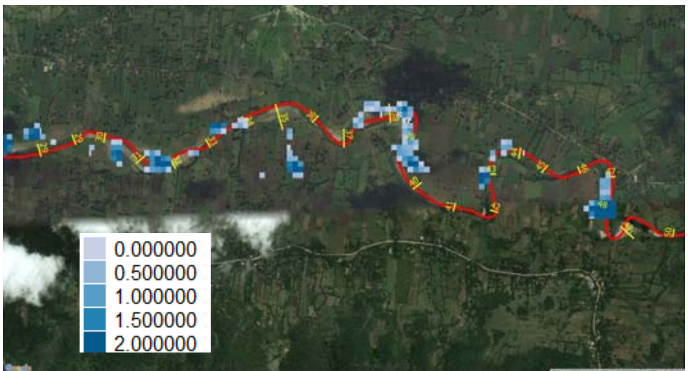


Figure 13: Water depth – $Q = 535\ m^3/s$

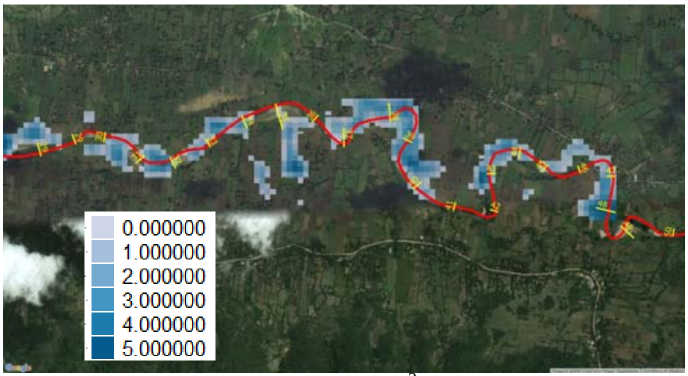


Figure 14: Water depth – $Q = 1000\ m^3/s$

Considering as well large scale maps of Figures 13 and 14 as detailed map of Figure 12, some points of discussion clearly arise.

As expected the flood extent is considerably larger for the largest discharge and the water depth is significantly increased. However, even if flood areas are generally located along the river axis (materialized by a red line in Figures 13 and 14), some appear outside the river path, while the river itself appears as emerged. This is clearly the case for sections 35 to 37 in Figure 12 that are unsubmerged while a rather deep inundation occurs at some distance of the southern bank of the river.

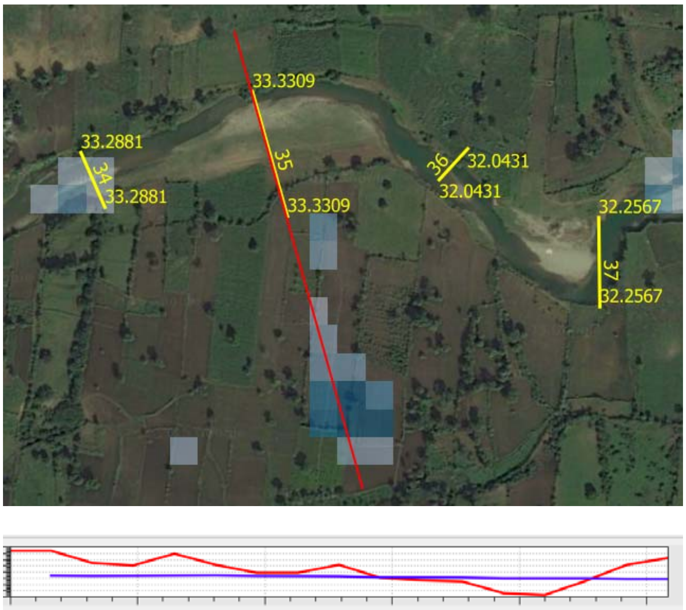


Figure 15: Profile across section 35: the red curve represents the DTM profile, the blue curve is the section across the spline interpolated surface (the water depth color bar is the same as in Figure 12 but some transparency was allowed to the water table layer, so altering the colors)

It could be suspected that something was wrong in the process, but an extended profile across section 35 (Figure 15) shows that the flood area is perfectly in accordance with the DTM and water table levels. According to this profile, the river bed would be higher than the water level, which is impossible in case of flood, and the lowest point of the terrain would be outside of the river path. It is interesting to observe that the water table (the blue profile in Figure 15) is practically horizontal, so indicating that the always possible distortion of the spline interpolation does not affect too much the water table even in sinuous river path.

Since the 30 m × 30 m DTM is not really documented, some discrepancy might exist between this DTM and the real situation: the river seems rather instable in the considered reach and the depression along the southern bank of the river could be an old course of the river, which is partly suggested by the Google satellite view in Figures 12 and 15, where a sinuous path may be observed near the depression.

On the other hand, the fact that the river seems unsubmerged at some place during flood events could be due to the too coarse available DTM. Considering Figures 12 and 15, where each square of the water depth map represents a 30 m × 30 m cell, it is clear that the minor bed of the river is often less than 30-m wide, in such a way that the DTM may miss the actual thalweg of the river. Moreover it is probable that the DTM was built without accounting for the submerged part of the river, so artificially erasing the river bathymetry.

Another explanation could be found in the fact that the reference level of the DTM is uncertain, so opening the possibility that the reference level used for the cross sections could be distinct from the one used for the water profile computation, in such a way that a systematic shift between both data sets occurs.

So, the methodology seems promising as far as a more reliable and denser DTM will be available.

A tentative effort in that sense will be carried out in the future by using a drone along the flood plains of the river, but such a methodology, while promising, has to be tested in the local context with difficult accessibility of the areas to be flown and poor access to electricity supply for the batteries.

6 CONCLUSIONS AND FUTURE WORK

The work presented in this paper aims at developing a methodology to build a simple and effective hydraulic model for the Cavaillon River in Haiti, based on current knowledge and field surveys, using free modeling tools, given the limited resources available in the country.

The methodology used to measure the bathymetry of the river and to determine the roughness of the riverbed is adapted to the Haitian context and can easily be reproduced on other rivers in the country. The first simulations results and the flooded areas representation show the relevance of the methodology based on free software tools.

However, the quality of these results must be improved by taking into account the floodplains and by developing a methodology for the establishment of a flood hydrograph for the Cavaillon River.

REFERENCES

Carlier d'Odeigne O., Soares-Frazão S. Determination of bed roughness parameters from field survey: application to the Cavaillon River, Haïti. Submitted to the River Flow 2016 Conference, to be held in July 2016, St-Louis, USA.

Gonomy N. (2012). Projet d'études et élaboration de plans d'aménagement de trois bassins versants dans le cadre du programme de mitigation des désastres naturels en Haïti. Rapport d'études (in French).

Joseph A., Carlier d'Odeigne O., Zech Y., Gonomy N., Soares-Frazão S. (2015). Construction of one-dimensional model for the Cavaillon River, Haiti, from an in-situ survey of the bathymetry, e-proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands

Rousseau A. (2015). Modélisation unidimensionnelle de l'écoulement dans la rivière Cavaillon en Haïti. Travail de fin d'études, Université catholique de Louvain, 88 pages (in French).

Wolman G. (1954). A method of sampling coarse river-bed material. Transactions, American Geophysical Union, 35 (6), 951-956