Full Length Research Article

STEADY FLOW SIMULATION IN ANAMBE RIVER BASIN USING HEC-RAS

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ABSTRACT

In many developing countries, food safety became a top priority for authorities and water resources managers. It is directly related to human's life and economic development. Due to this necessity, the government of Senegal has selected the valley of Anambe of 16000 ha, to develop irrigated agriculture through rice cultivation. Two dams (Niandouba and Confluent) have been built to reinforce water availability due to climate change and variability effect on the rainfall. For a better management of this hydraulic system, the knowledge of flow dynamic is required. In this paper, we have used Hec-ras model to describe the hydraulic behavior of this system. The river reach selected, is located between the confluence dam and Kounkane threshold. From an image LANDSTAT of this area, we have divided the river reach into 24 cross sections perpendicular to flow direction and numbered from 1 to 24. ArcGIS software is used to extract bathymetry for each cross section. This allows creating the river geometry with Hec-ras. Four stream flows have successively fixed as upstream boundaries. For each stream flow, Hec-ras calculate the flow characteristics. The high and low flow characteristics areas have been located. The most of these flow parameters decreases from upstream to downstream.

INTRODUCTION

Understanding of the flow dynamics in a river system is an important step towards the satisfaction of the water needs. This understanding must include an appropriate modeling to monitor the spatial evolution of the flow characteristics (Traore *et al*., 2013). The use of hydraulics models as decision support, has become essential to better describe and knowledge the flow characteristics, particularly the water surface profiles (Seago and Mckenzie, 2008; Karim, 2009). However, the choice must be made by identifying a parsimonious model structure which provides good predictive power and represents the real behavior of the hydraulic system (Xavier *et al*., 2010; Bordbar *et al*., 2013). This representation passes by the estimation of the most important hydraulic parameters of flow such as water surface, Froude number, water flow velocity, slope… (Sanjay *et al*., 2014; Hunter *et al*., 2007). In this paper, we focus on the Anambe river basin located in the southern part of Senegal. Due to the climate change and variability whose effects are the decrease of the

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precipitations, this river has been selected by the government to develop irrigated agriculture in the research of food safety which is the first necessity for human's life and development. Thus, with a flood plain of 16000 ha and favorable climatic conditions have made, this region into an agricultural hub. Two dams (Niandouba and Confluent) have then been built to reinforce water availability. This hydraulic system aims at water allocation for irrigated perimeters of the Anambe area through Waïma storage lake. An efficient management of this river system for water allocation and for hydraulic structures implementation such as pumping stations needs a tool for hydraulic system analysis based on water surface profile and water depths calculation. A better understanding of the hydraulic behavior of this basin is required. This research investigates and analyses the dynamic of the flows of Anambe river basin for an application to the irrigation of lands suitable for rice cultivation. Hec-ras model based on hydraulic routing is selected to describe the hydraulic behavior of this river basin by performing steady flow calculations in order to generate water surface profiles for different discharges. This software is widely recommended in analysis of hydraulic systems because it provides useful information for water management and planning (Tayefi *et al*., 2007; Jensen *et al*., 2004; Brych *et al*., 2002; Santos *et al*., 2012).

This model is very little demanding in data, it is very easy to provide results (Pappenberger, 2005; Mohammed *et al*., 2006). Its application on the basin of Kayanga gives satisfactory results. It allows identifying the high and low flow characteristics areas such as water surface profiles, water surface elevation, flow velocity, top width, slopes, surface, volume, energy grade line elevation, wetted perimeter,… and the large and narrow width areas have been located .It also allows view the hydraulic parameters including water surface profiles evolution along the river reach. These results also indicate that Hec-ras model is suitable for investigation and simulation of hydraulic flows in irrigation network of Anambe river.

MATERIALS AND METHODS

Study Area

The Anambe Basin (12 ° 30 'and 13 ° 10' north, 14 ° 08 'and 14 ° 20' west), is located in high Casamance between the departments of Kolda and Velingara (OMVG, 2008). It is a tributary of the Kayanga river which rises in Guinea and drains a watershed of 1100 km2 (Dacosta and Gomez, 1998). The Anambe basin (Fig 1) has an almost circular shape with a stalk that connects the Kayanga (Soumare, 1999). It is the domain Sudanese climate with a rainy season from June to October and a dry season from November to May. The annual rainfall in the basin varies slightly from north to south (Dacosta, 1989). The average annual rainfall is 1040 mm at the Kounkane station.

Temperatures reach their peak in May before the rains and decrease during the winter; a new maximum occurs in November and a cool season from December to February. The relative humidity reaches its maximum in September and the minimum in January. The winds are generally moderate and evapotranspiration is estimated at 1800 mm / year (Dacosta *et al*., 2002).

Hydrology of Anambe

The Anambe water resources consist rainfall and runoff inputs of Kayanga River diverted by the Confluent dam for filling the bowl of Anambe. The one and the other depend on the climate regime characterized by alternating dry season and a rainy season. The framework of the activities on this basin is built around activities related to water such as agriculture which is dominated by rice cultivation (Diouf, 1999). The water management in the basin Anambe is based on the principle of mobilizing of the water resources of Anambe-Kayanga system and their use for irrigation of land suitable for rice cultivation (Coly *et al*., 2002). The key feature of the hydro system is constituted by the reservoir of confluence dam which receives water from the dam Niandouba by gravity and fills the lake Waïma. It also receives tributaries runoff. This operation is theoretically valid during the rainy season or during periods of high water. In low water, some of the water is trapped in the lake by the Waïma threshold of Kounkane Bridge. This store is used for hydro-agricultural activities in the Anambe flood plain of against season (Dacosta *et al*., 2002). We present in below the diagram of the general device of the Kayanga-Anambe system (Fig 2).
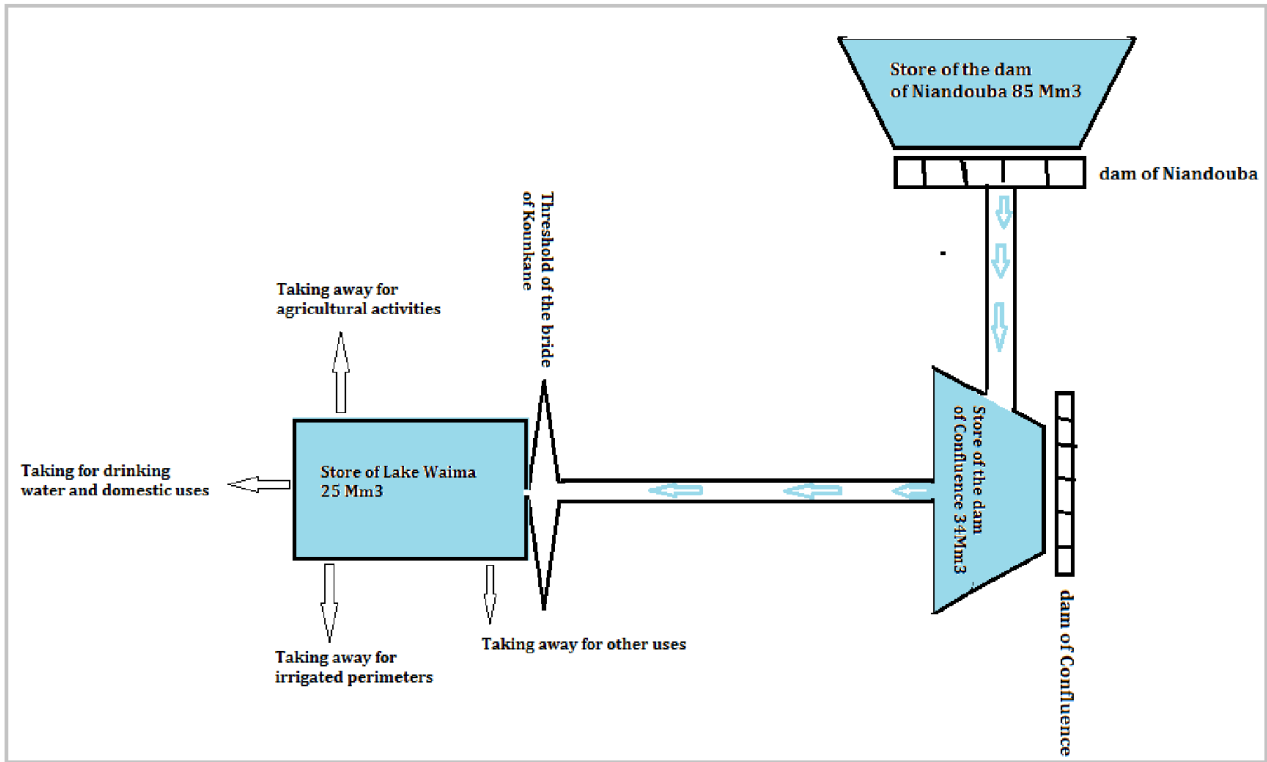

Figure 1. Anambe river basin

Figure 2. Kayanga-Anambe hydraulic system

Hec-ras Numerical Modeling

HEC-RAS (Hydrologic Engineering Center River Analysis System) is numerical software for flow river hydraulics calculations (Darshan, 2014). It was developed by the Hydrologic Engineering Center, a research group for the U.S. Army Corp of Engineers (Robert *et al*., 2012). This software contains three hydraulic components for flow analysis: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations (Hasani, 2013). A key element is that all the three components will use a common geometric data representation and common geometric and hydraulic computation routines (Amir *et al*, 2012). It is widely used in one-dimensional flow characteristics calculations including water surface profiles, energy grade line, water depth, velocity, wetted perimeter,… in case of steady and unsteady river flow regimes (Henry and Walton, 2008; Robert *et al*., 2012). These computations are essential in the analysis of various problems, including the determination of the effect of hydraulic structures on the upstream and downstream channels; the estimation of flood plain; the analysis of the capacity of river for irrigation; the monitoring of the depth at any point in river; the choice of implantations sites of hydraulic structures (such as dams, pumping stations,) ; the corrections of the rivers in order to avoid a possible overflow in the event of rising. These various applications deserve to give to the flow main parameters calculations a great interest (Karney *et al*., 2010; Ali *et al*., 2011). In this work, the steady flow component of Hec-ras was used to perform flow parameters (such as water surface profiles, water surface elevation, energy grade line elevation, water flow velocity,..) of the Anambe River in order to analyze this hydraulic system. The basic data requirements for simulation are included:

geometric data, river system schematic, cross section geometry, reach lengths, Manning's roughness coefficient, contraction and expansion coefficients, steady flow data, boundary condition, flow regime (Harman *et al*., 2008).

Basic equations of Hec-ras

In HEC-RAS steady state simulation, water surface elevation and energy grade line of two adjacent cross sections are calculated by applying the standard step iterative method to one-dimensional energy equation (Goodell and Warren, 2006). This equation is shown in (1) for two adjacent cross-sections (Nemati *et al*., 2011; Dragan *et al*., 2014). (Fig 3) illustrates the main computing process based on solution of energy equation (Maghsoud *et al*., 2012).
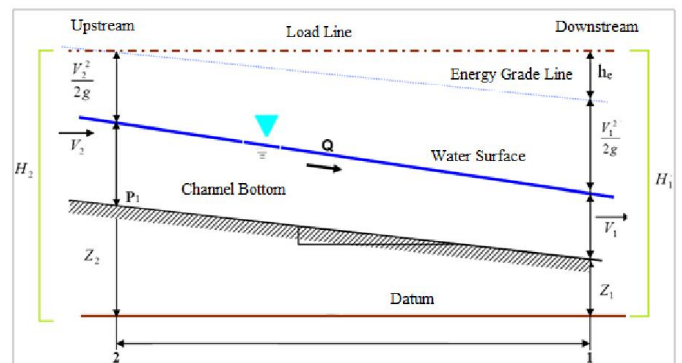

Figure 3. Energy equation between two spots (adapted of Maghsoud *et al*., 2012)

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

Where: Z_1, Z_2 are elevations of the main channel inverts in m; Y_1, Y_2 are depths of water at cross sections in (m); V_1, V_2 averages velocities (total discharge/total flow area) in m/s; α_1, α_2= velocity weighting coefficients; g is gravitational acceleration in m/s^2 ; he is energy head loss in (m).

The energy head loss (he) estimation is given by the Manning's equation (2) which is considered to be empirical (Mazhar *et al.,* 2010)

$$h_e = L\overline{S_f} + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \qquad (2)$$

Where: L is discharge weighted reach length in m; $\overline{S}_f$ is representative friction slope between two adjacent sections; C is contraction or expansion loss coefficient. The representative friction slope using the average conveyance equation and the distance weighted reach length are defined in (3) and (4), respectively (Dragan *et al.*, 2014).

$$\overline{S_f} = \left(\frac{Q_1 + Q_2}{K_1 + K_2}\right)^2 \qquad (3)$$

$$L = \frac{L_{lob}\overline{Q_{lob}} + L_{ch}\overline{Q_{ch}} + L_{rob}\overline{Q_{rob}}}{\overline{Q_{lob}} + \overline{Q_{ch}} + \overline{Q_{rob}}} \qquad (4)$$

Where K is conveyance, L_{lob} , L_{ch} , and L_{rob} are cross-section reach lengths for flow in the left over-bank, main channel, and right over-bank, respectively, and Q_{lob} , Q_{ch} , and Q_{rob} are arithmetic average of the flows between sections for the left over-bank, main channel, and right over-bank, respectively. The Conveyance is calculated for each subdivision using Equations (5) and (6) (Dragan *et al.*, 2014).

$$Q = KS_f^{1/2} \qquad (5)$$

$$K = \frac{1.486}{n}AR^{2/3} \qquad (6)$$

Where: K is conveyance for the subdivision; n is Manning's roughness coefficient for the subdivision; A is flow area for the subdivision; R is hydraulic radius for each subdivision.
Solving these equations requires knowledge of the geometry of the stream, its roughness characteristics, the flow rate and boundary conditions.

Boundary Conditions

The steady one-dimensional flow model can calculate subcritical, supercritical and mixed flow regime water surface profiles (Karney *et al.,* 2010; Sunil *et al.*, 2014). For subcritical flow, one condition is needed at the downstream boundary, and the computation starts from the downstream boundary and progresses to the upstream. Supercritical flow requires only one upstream condition; water profile is computed from upstream boundary to downstream boundary. When flow regime is mixed, both downstream and upstream boundary conditions are required (Karim, 2009; Beltaos and

Patrick, 2013). There are three kinds of boundary conditions (critical depth, normal flow depth, or a given depth downstream of the channel), but only one is needed (Alemseged and Rientjes, 2005). In the Anambe system, the river flow is subcritical. Depth at Kounkane is fixed as the downstream boundary conditions.

River Geometry creating process

From an image LANDSAT of the Anambe river basin, we have divided the river reach into 24 cross-sections perpendicular to flow direction from confluence Dam to Kounkane threshold. They have been numbered from 1 corresponding to Kounkane cross section (downstream) to 24 corresponding to confluence Dam cross section (upstream). ArcGis have been used to extract bathymetry and generate the distance between two adjacent cross sections. To increase the stability of calculation and have a step of space even finer, we have added by interpolation additional cross sections between two existing consecutive cross sections. Coefficient values of Manning roughness are fixed to 0.06 for left overbank, 0035 for main channel and to 0.05 for right over bank. The contraction coefficient is fixed to 0.1 while the coefficient of expansion is fixed to 0.3. Application of Hec-ras has allowed creating River cross-section cut lines (Fig 4).

Steady flow Calculations

After creating river geometry, the next step is to specify the discharges values, flow regime and boundary conditions to perform the calculations. In this paper, the flow is subcritical, and the known downstream depth equal to 2.2 m is then used as a boundary condition. Four steady flow discharges (50m3/s, 100m3/s, 200m3/s and 400m3/s) have been fixed at upstream corresponding to confluence dam outlet. For a given discharge, the water surface profiles, and the main hydraulic parameters have been computed.

RESULTS AND DISCUSSION

Cross section plots

We present in (Fig 5) cross sections plots at river station 24, 16, 8 and 1; in (Fig 6) interpolated cross sections plots between river station 24 and 23, 17 and16, 9and 8,2 and 1. These cross sections have not the same width because of significant changes in the topography of the bed in Kayanga River. It's been observed in these examples that the cross sections 8 and 16 are narrow, and cross sections 1 and 24 are larger. This is due to the significant change in the topography of Anambe river bed.

Energy grade line elevation

(Fig 7) shows energy grade line elevation for the different discharges. It increases with discharges. For given discharge, energy grade line elevation is constant from cross section 24 to cross section 8 due to a very low value of the free surface slope and it decreases quickly from cross section 8 to downstream due to a high value of the free surface slope. Energy grade line elevation is sensitive to deformation of bottom slope of the Anambe River
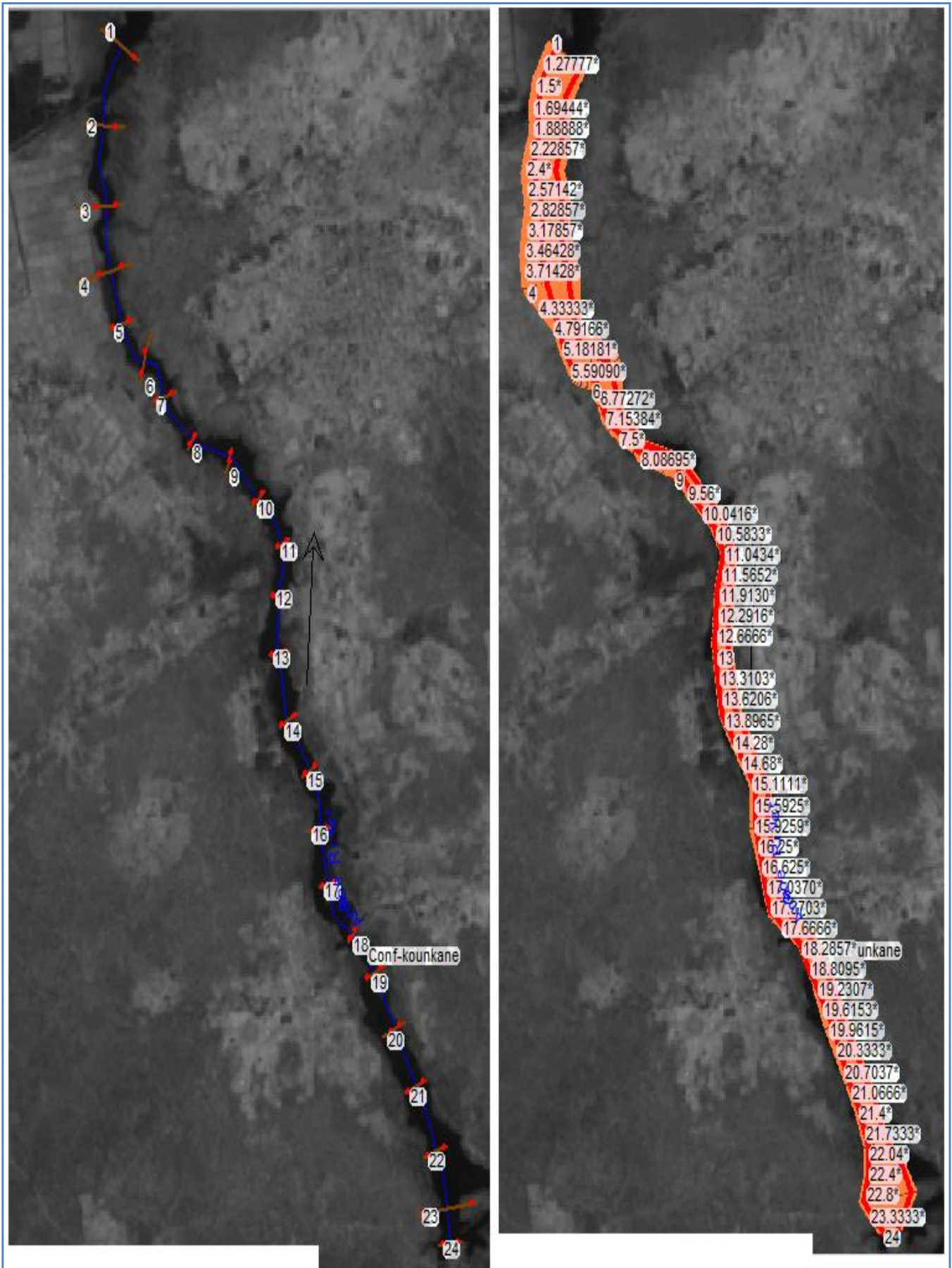
(a)　　　　　　　　　　　　　　　　　　　　(b)

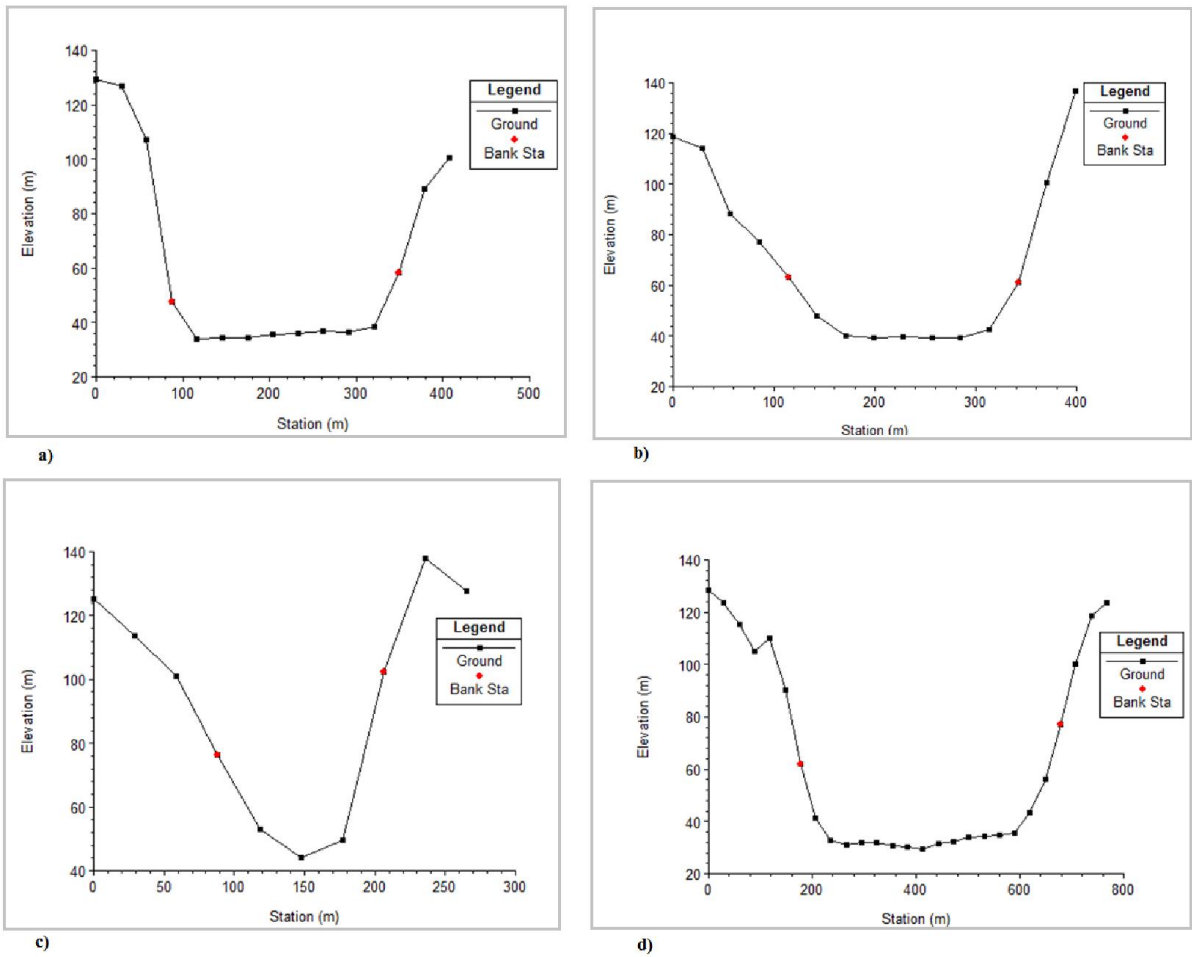**Figure 4. River cross-section cut lines: a) before interpolation; b) after interpolation**

Figure 5. Cross-section plots in HEC-RAS Model: a) at River Station 24; b) at River Station 16; c) at River Station 8; d) at River Station 1
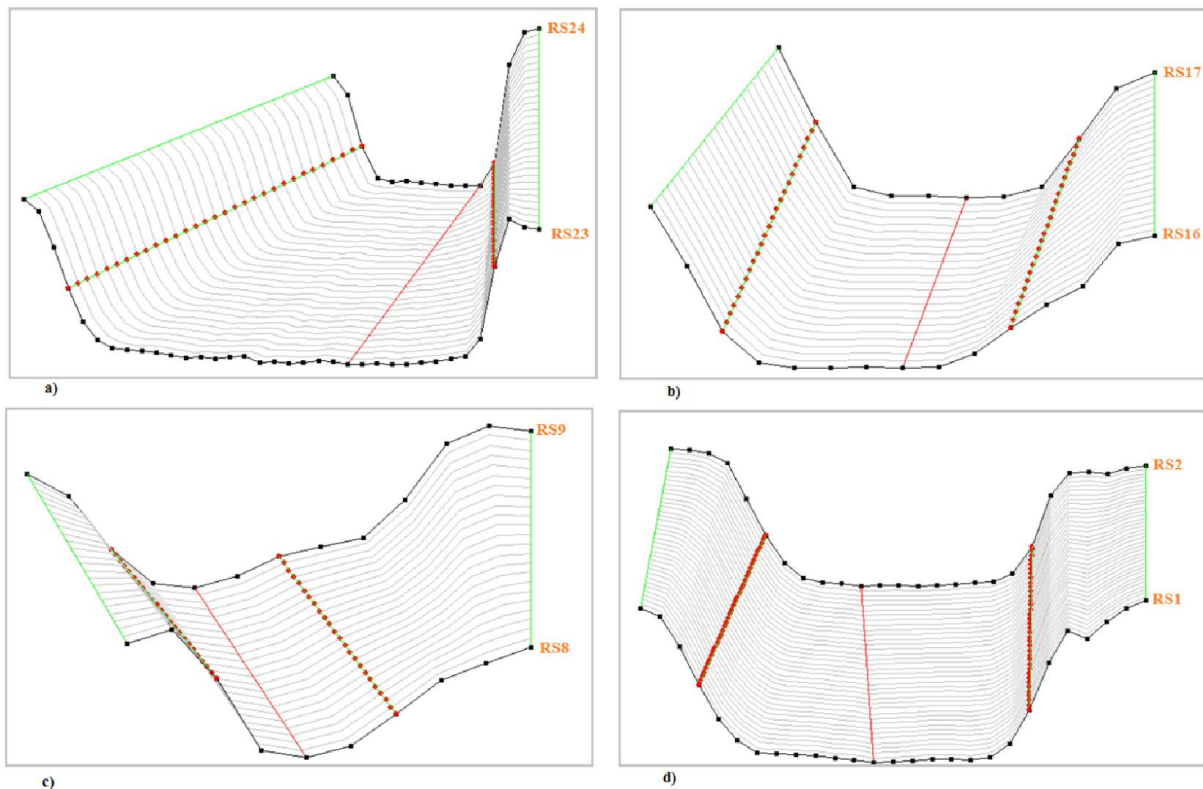

Figure 6. Interpolated cross-sections plots in HEC-RAS Model: a) Between RS24 and RS23; b) Between RS17 and RS16; c) Between RS9 and RS8; d) Between RS2 and RS1
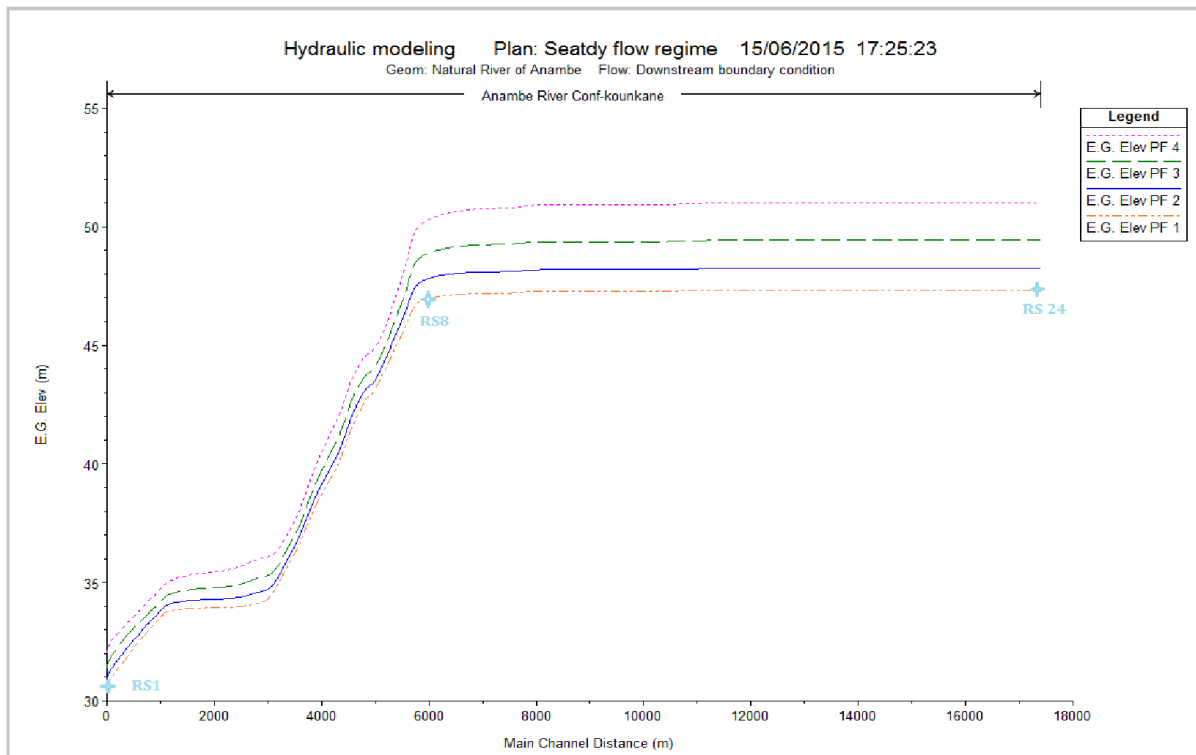
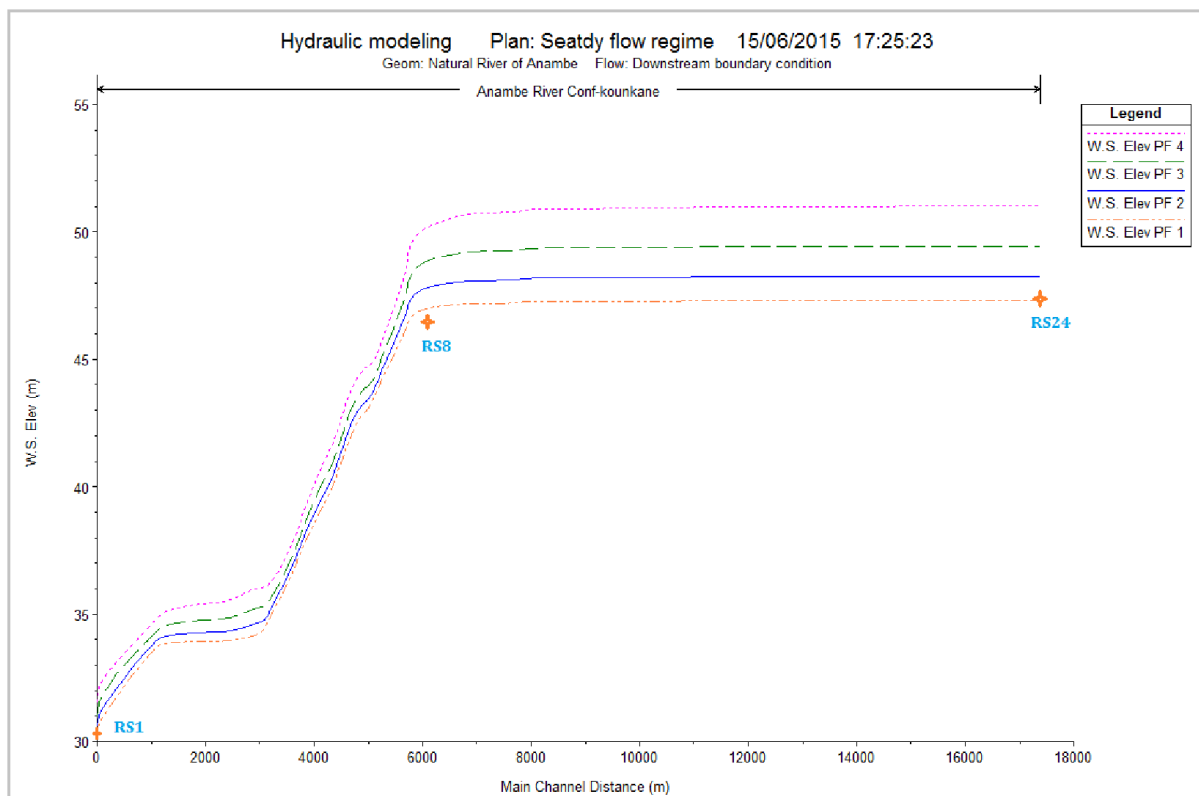**Figure 7. Energy grade line profiles**

Figure 8. Distribution of water surfaces elevations

Water Surface Elevation

(Fig 8) shows water surface elevation for the different discharges fixed at the upstream. It increases with discharges. For given discharge, water surface is constant from cross section 24 to cross section 8 due to a very low value of the free surface slope and it decreases quickly from cross section 8 to cross section 1 due to a high value of the free surface slope. Water surface elevation is sensitive to deformation of bottom slope of the Anambe River.
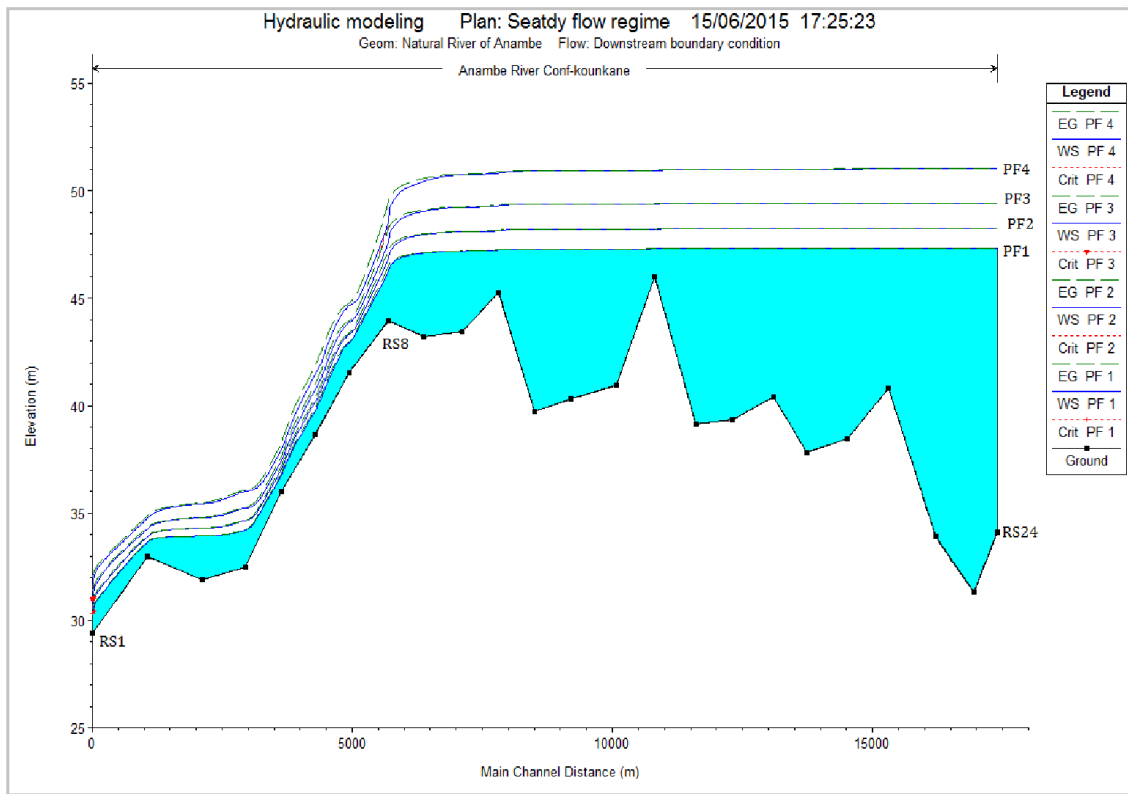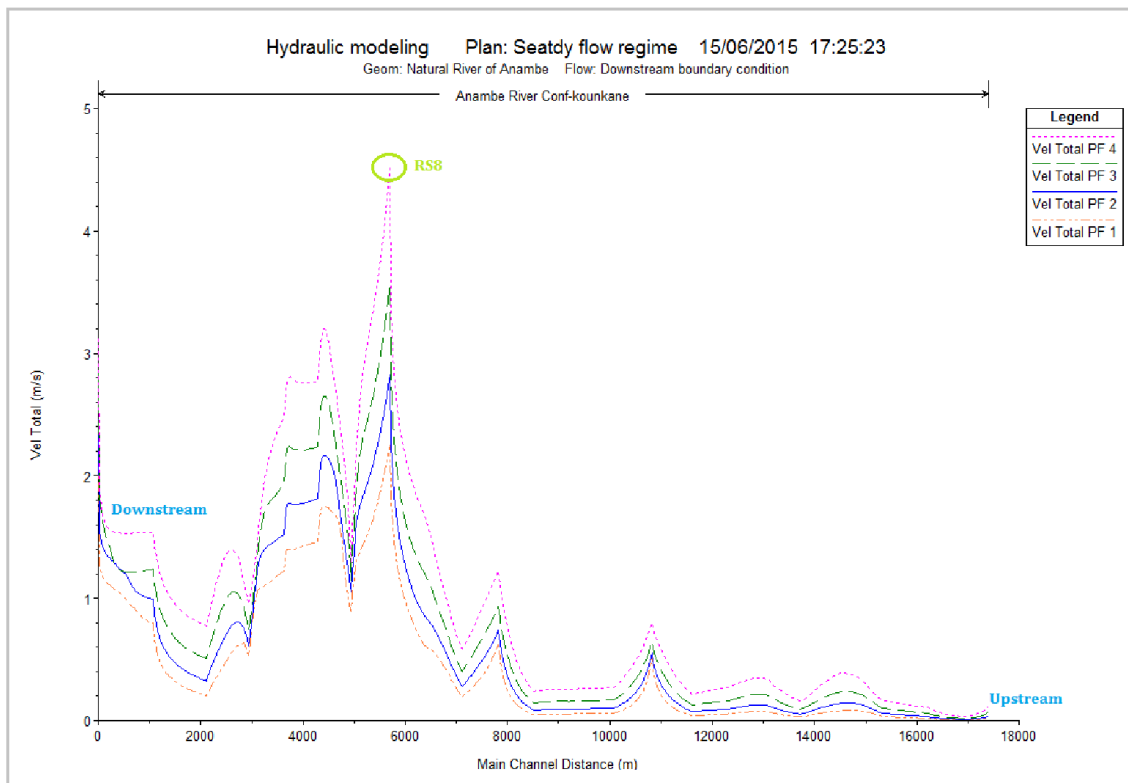
Figure 9. Distribution of Water surface profiles

Figure 10. Flow velocities distribution

Water Surface profiles

We present in (Fig 9) water surface profiles for the different stream flows fixed at the upstream. The free surface slope increases with discharges. For given discharge, water surface profile remains constant between cross sections 24 and 8; it decreases quickly from cross section 8 to cross section 1.We conclude that the free surface slope is important between cross sections 24 and 8 but it is very close to zero between cross sections 8 and 1. These results show that the Anambe area is

sensitive to water level profile fluctuations and deformation of bottom slope of the river.

Velocities Profiles

(Fig 10) shows flow velocity profiles for various discharges specified at the upstream. It's been observed that velocity increases with slopes for given stream flow. Low slopes correspond to low velocities (from upstream to cross section 8). In these cross sections, stream power, total shear are practically null.

The highest velocity is observed at cross sections 8. In this section slope, stream power and shear are more important but flow area is smaller. Thus, the variations of flow velocity are due to the significant changes in the topography of the river bed and the roughness coefficient effect.

Total Wetted perimeter

We present in (Fig 11) wetted perimeter profiles for the different stream flows fixed at the upstream. It is been observed that wetted perimeter increases with discharge.
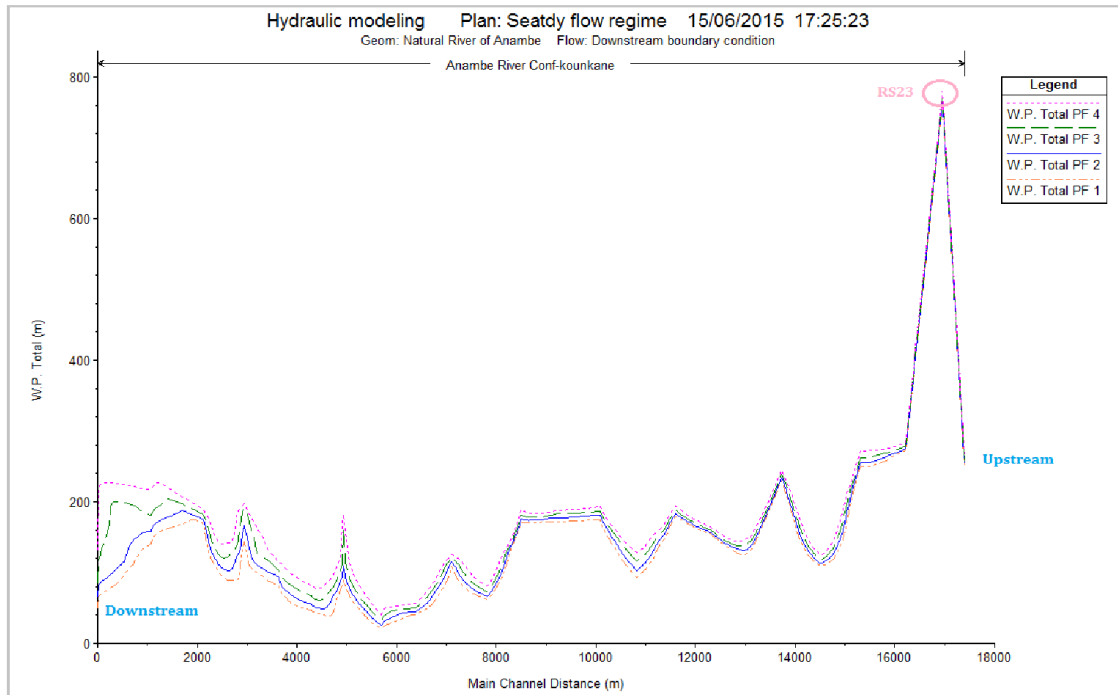

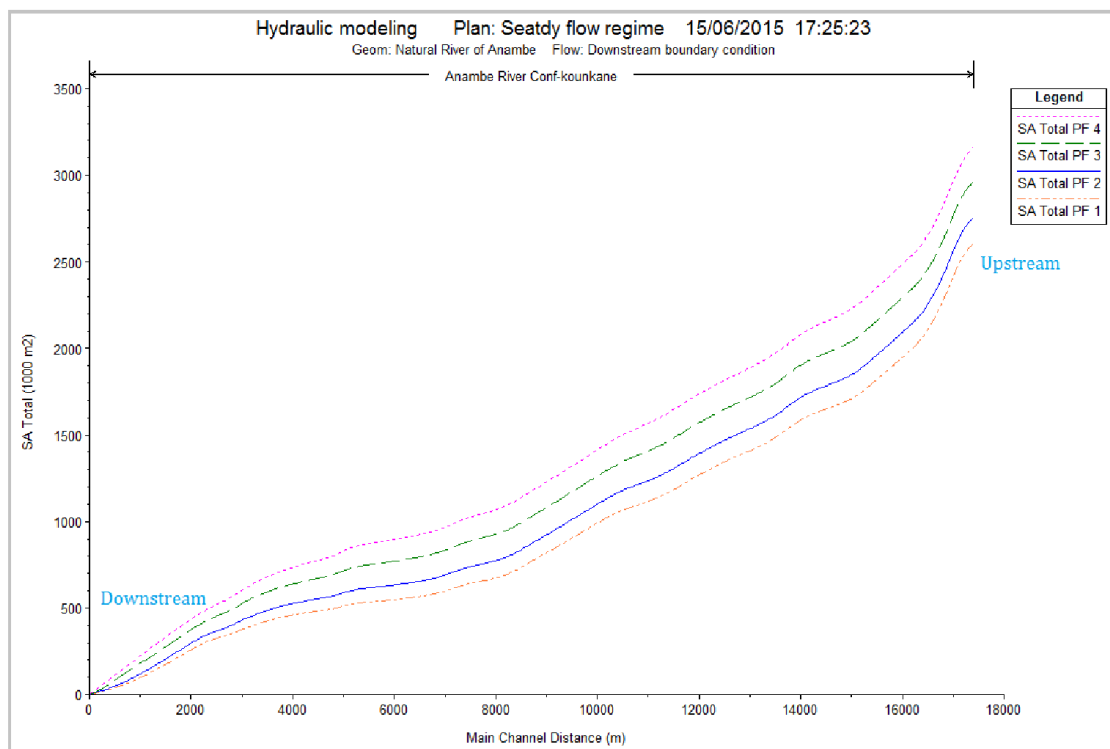**Figure 11. Wetted perimeters distributions**

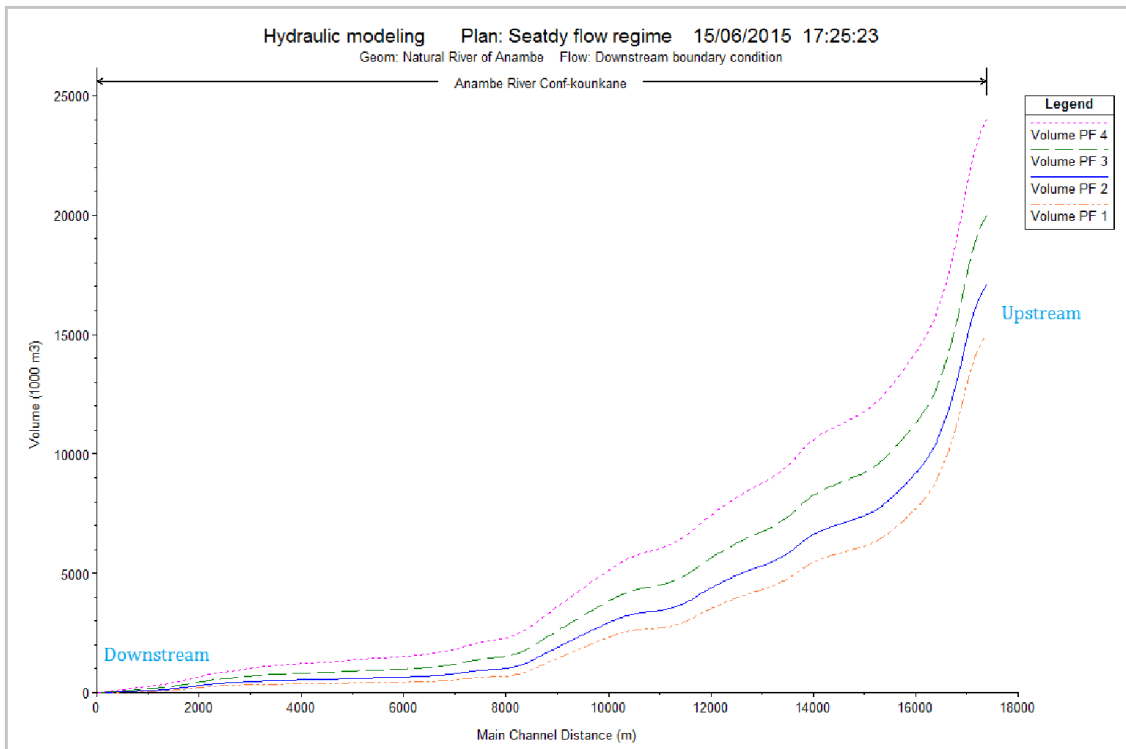**Figure 12. Total surface areas distributions**
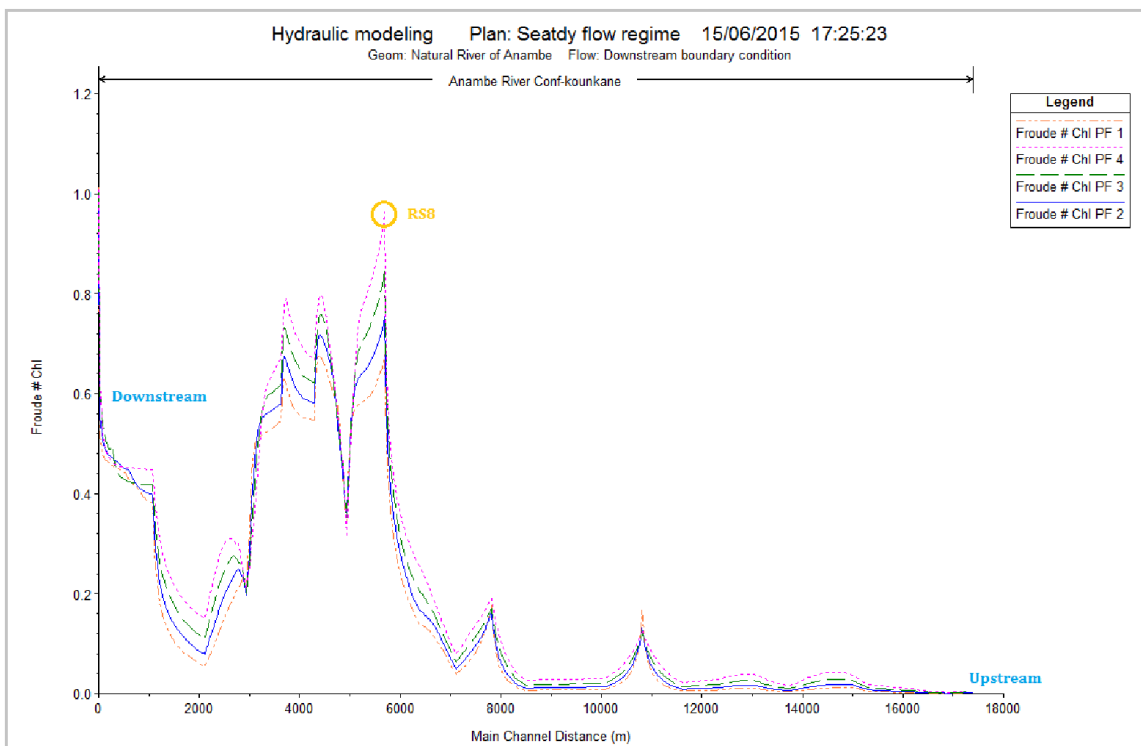
Figure 13. Total volume profiles

Figure 14. Froude number profiles

From cross section 22 to downstream, wetted perimeters have practically the same level. In these cross sections, flow area and specif force are lower. The highest wetted perimeter is observed at cross sections 23 corresponding to outlet of confluence dam. It is also observed that low wetted perimeter corresponds to narrow section and high wetted perimeter corresponds to larger section.

Thus, the water level profile in cross sections changes according to the top width and consequently leads to the decrease in river capacity.

Total Surface Area

We present the (Fig 12) the surface area profiles for different discharges. It is been observed that total surface area increases

with discharge. For given discharge, surface area decreases gradually from upstream to downstream. The reduction of the surface areas is due to the soil texture through its permeability, evaporation and to the roughness coefficient effect. This can affect the dynamics of the flow to the downstream of the river.

Volume distribution

(Fig 13) shows the total volume profiles for various discharges. It is been observed that the total volume increases with discharge. For given stream flow, the volume decreases slowly from upstream to downstream. This reduction can be due to the soil texture through its permeability, evaporation and roughness coefficient effect. This can negatively impact on the availability of water to downstream for agricultural needs.

Froude number

(Fig 14) shows the dimensionless Froude number evolution along the reach for various discharges. It is been observed that it increases with discharge. For each stream flow, Froude number is less than 1 at all cross sections except cross section 8 where it is equal to1. This indicates that the flow regime is critical in cross section 8 and subcritical in the other cross sections corresponding to the real case of the study river.

Conclusion

Food security is a necessary step for stability in developing countries. This important role has recently made him a focus of authorities and decision makers. This paper analyzes the dynamic of the flow in Anambe river basin The flood plain of this river is selected by the Government of Senegal to develop irrigated rice cultivation in the fight against hunger. Hec-ras model was used to calculate the main flow characteristics along the study reach to better understand the hydraulic behavior of this river. This allows identifying the high and low flow characteristics areas such as flow velocity, depths, slopes, surface, volume and their spatial evolution along the river reach. The large and narrow width areas have been identified. The analysis of the results show that the most of hydraulic parameters decreases from upstream to downstream. These results give a basis for reflection for decision makers to better understand the Anambe system and optimize water resources management o for an application to the irrigation. However, it is important to recognize the limitations of the 1D Hec-ras model. In this approach, the flow is supposed to be channeled while the natural flow is 3D. Complementary research using 3D approach, are required to better characterize the flow in this river basin.

Acknowledgment

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