A 1D NUMERICAL TOOL FOR REAL TIME MODELLING OF A COMPLEX RIVER NETWORK

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KEY WORDS

1D modelling, flood, real time modelling, operational modelling, tidal river, Adour.

ABSTRACT

This paper introduces a numerical code, named MAGE and developed at INRAE Lyon, that is able to compute efficiently a flood propagation in a complex river network. MAGE solves the Barré-de-Saint-Venant equations using a finite difference method. It is applied to the Adour River located in the South-East of France. The Adour River is a tidal river with a pluvio-nival regime. It is characterized by a complex system of tributaries including mild-sloped tributaries (Upper Adour) and mountainous tributaries (Nive, Gave d'Oloron) and a significant influence of the tide in its downstream part. As a consequence, flood hazard is an important issue for the city of Bayonne located at the Adour-Nive confluence, approximately 6 km from the sea. The SPC (Flood Prevention Service) uses 1D modelling to possibly provide real time evaluation of the flood hazard (using the alertness colours) at Bayonne depending on a combination of upstream floods and tide. Presently, they used the 1D code MASCARET developed by EDF. A comparison is provided between results from MASCARET, MAGE, and water level measurements at different stations for typical floods. If both codes provide accurate results for a tidal regime at low discharge, they can deviate significantly for large flood where flood expansion zones are active. A system of storage area is implemented in the MAGE model to improve the model behaviour during large flood. Result accuracy are notably improved though some improvements could still be done locally. Eventually, results from MAGE code are significantly improved compared to those obtained with MASCARET. Also computation time are largely reduced; as an example, using a classic laptop (Intel Core i7, 7.7Go RAM), a 64 day time-series was modelled within 3 min using MAGE, against nearly 10 hours using MASCARET. Thus, the MAGE model is a useful tool for real time modelling.

1. INTRODUCTION

Tidal rivers are complex system where both water discharge coming from upstream and tide interact. Consequently, it is often very difficult to properly model discharges and water levels in these rivers. The transition between riverine and estuarine environments is generally defined as a change from unidirectional to
bidirectional flows [1]. In addition, since other complex phenomena occur such as salt intrusion or silt plug, 2D and 3D modelling is generally applied to model such systems [1, 2, 3, 4]. However, for relatively narrow estuaries, if the main objective is to accurately predict water levels for real time modelling [5], or for bed evolution modelling [6, 7], 1D modelling is robust enough and can be very efficient in term of time-computation.

The purpose of this study is to develop a robust and efficient 1D modelling of a complex tidal river network: the Adour River, France. Because of the concomitance of floods and high tides, several sections of the Adour

River are regularly flooded, which is a significant issue for the cities of Peyrehorade or Bayonne [8, 9]. In particular, flood hazard is very difficult to evaluate at the city of Bayonne located at the Adour-Nive confluence, approximately 6 km from the sea. The SPC (Flood Prevention Service) uses 1D modelling to possibly provide real time evaluation of the flood hazard at Bayonne depending on a combination of upstream floods and tide. Presently, they used the 1D code Mascaret developed by EDF. We present here the Mage code, developed by INRAE [10], and compare it to Mascaret and data to check its capabilities to properly reproduce water elevations in case of combined flood and tide constraints. A discussion is also provided on the interests and limits to add storage areas in the model for particular zones where significant interaction with the floodplain occurs.

2. 1D MODELLING

2.1 Mage

Mage solves the 1D Barré-de-Saint-Venant equations, which includes the mass conservation equation (Eq. 1) and momentum conservation equation (Eq. 2):

$$\frac{\partial S}{\partial t}+\frac{\partial Q}{\partial x}=q_{lat} \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\beta\frac{Q^2}{S}\right)+gS\frac{\partial Z}{\partial x}=-g\frac{Q|Q|}{K_s^2 S R_h^{\frac{4}{3}}} - gSJ_s+k\,q_{lat}\frac{Q}{S} \tag{2}$$

with S the wet section, Q the water discharge, q_{lat} a lateral input or output (overflow), P (P_{lat} a hydrostatic pressure (lateral), Z the water surface elevation, K_s a Strickler coefficient, R_h the hydraulic radius, J_s a singular head loss and k a boolean ($k=1$ if $Q_{lat}<0$: $k=0$ if $Q_{lat}\geq 0$). Friction head losses are represented using the classical Manning-Strickler law.
It uses a finite difference method using a Preissman scheme and an iterative method (Newton-Raphson) for solving the system of non-linear discrete equations [10]. The Mage module allows the flow calculation for a compound channel following the Debord formulation; assuming the same energy slope for both main channel and active floodplain [11]:

$$Q_m=\varphi K_{sm} S_m R_{hm}^{2/3} J^{1/2} \tag{3}$$

$$Q_M=\left[1+\frac{S_m}{S_M}\left(1-\varphi^2\right)\right]^{1/2} K_{sm} S_M R_{hM}^{2/3} J^{1/2} \tag{4}$$

with $\varphi\approx 0.9\left(K_{sm}/K_{sM}\right)^{-1/6}$, subscripts m and M correspond to the main channel and the active floodplain.
In addition, in order to take into account floodplains isolated from the main channel, it is possible to use a set of interconnected storage areas linked to the river with various exchange laws and possibly short channels. It has already been validated for many river cases including the Rhône River for which a dam module has been developed [12].
The PamHyr interface (Figure 1) can be used to edit the network topology, geometry (cross-sections, mesh), hydraulic conditions (friction coefficients, boundary conditions, initial conditions), to set numerical parameters, and to visualize main results (water lines, discharge time series at different positions, etc.). PamHyr is presently written in Java; a new version in Python is in construction.

2.2 Mascaret

As a comparison, we also used the Mascaret module [13], which corresponds to the 1D free surface flow modelling software of the Telemac-Mascaret system owned by the Laboratoire National d'Hydraulique et Environnement (LNHE), part of the R&D group of Électricité de France (EDF). The Mascaret module solves Eqs. 1 and 2 using a finite volume scheme. It includes three hydrodynamic calculation cores allowing calculation of steady subcritical flows, unsteady subcritical flows (DF Preissmann scheme) or transcritical unsteady flows (VF Roe scheme). This module is typically used by the SPC (Flood Prevention Service) in France to possibly provide real time evaluation of the flood hazard.

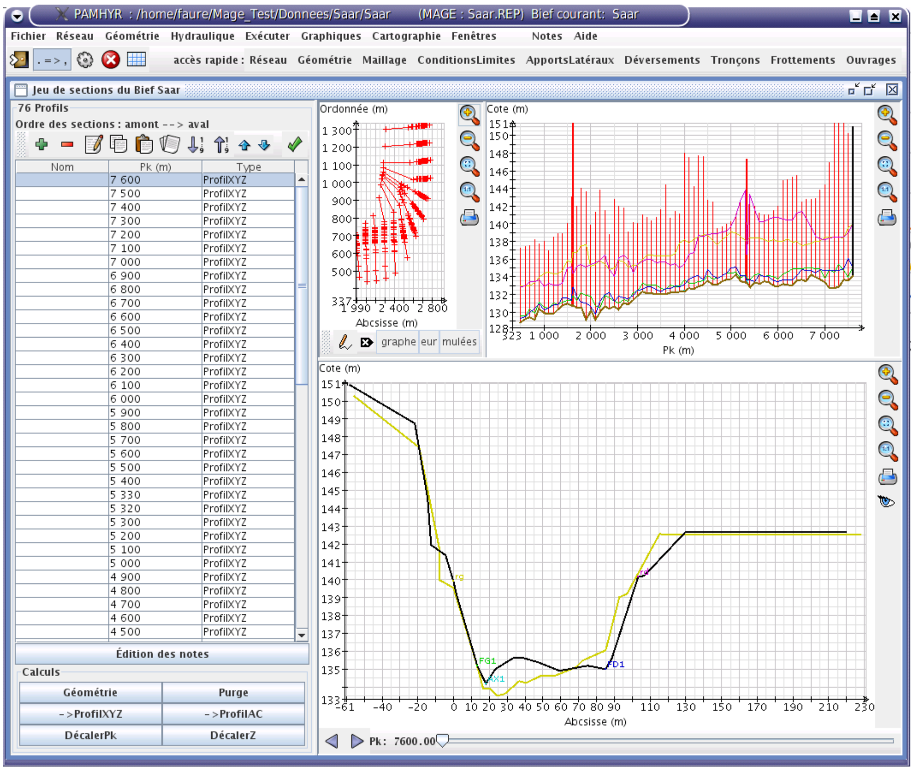


Figure 1: PamHyr interface, window representing a set of cross-sections of the reach.

3. A COMPLEX TIDAL RIVER NETWORK: THE ADOUR RIVER

3.1 Localisation of the study site

The Adour River is located in the South-East of France (Figure 2).

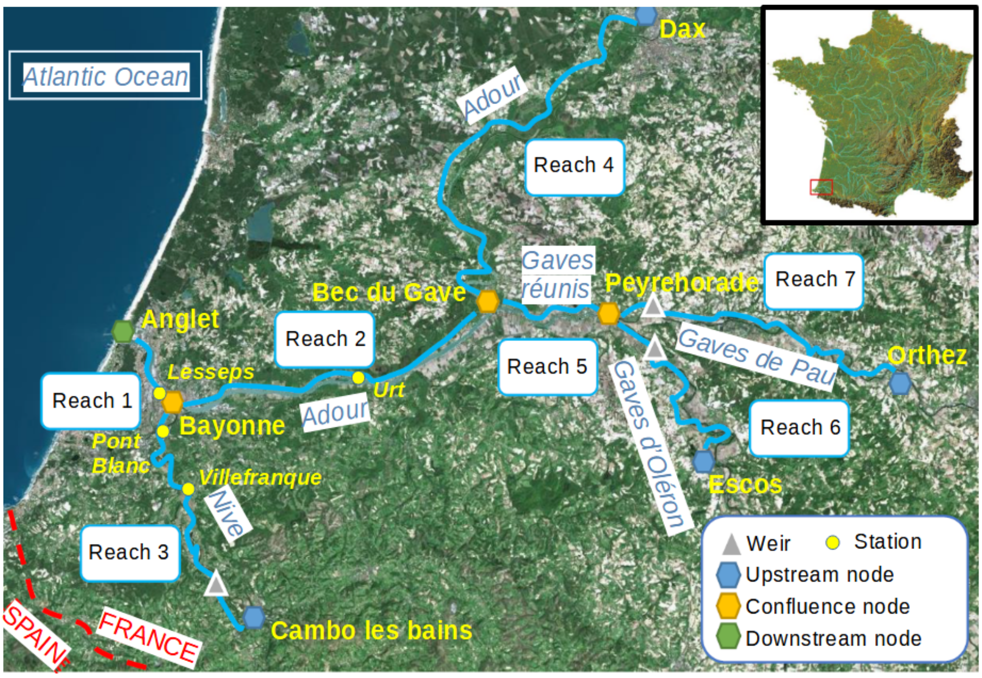


Figure 2: Location of the Adour River and main nodes and reaches modelled.

The Adour River has a pluvio-nival regime and is affected by different types of flood depending on the tributary, from slow wintery flood for the upstream Adour River to fast spring flood from mountainous tributaries (Nive, Gave d'Oloron). Also, the downstream part of the Adour River is significantly influenced by tide with an averaged tidal range of 2.1 m. As a consequence, flood hazard is an important issue for the city of Bayonne located at the Adour-Nive confluence, approximately 6 km from the sea.

3.2 Construction of the model

Two models of the Adour river system were built first by SPC using the Mascaret module, and then by INRAE using the Mage module. Both models describe the downstream part of the Adour river system (Figure 2), which consists in seven reaches. The river network is in total 161 km long and its geometry is based on cross-sections (Table 1) that were measured in the 2000s.

Table 1: Summary of the reach characteristics (ups: upstream; dns: downstream)

Reach	River	Upsstream Node	Downstream node	Reach length (km)	Nbr sections	Averaged distance between sections
1	Adour	Anglet	Bayonne	5.7	23	250
2	Adour	Bayonne	Bec du Gave	25.2	99	250
3	Nive	Bayonne	Cambo-les-Bains	22.8	216	1800 (ups. weir) 60 (dns. weir
4	Adour	Bec du Gave	Dax	34.5	95	360
5	Gaves réunis	Bec du Gave	Peyrehorade	9.4	50	190
6	Gave d'Oloron	Peyrehorade	Escoz	25.3	16	2500 (ups weir) 90 (dns weir)
7	Gave de Pau	Peyrehorade	Orthez	38.0	46	1000 (ups weir) 260 (dns weir)

The model was first calibrated (Strickler coefficients) using the Mascaret module; same coefficients were used for the Mage module. Boundary conditions correspond to discharge time series measured at the hydrometric stations of Cambo-les-Bains, Dax, Escoz, and Orthez as well as water level time series measured at Anglet (station located just at the river mouth). No storage area were included in these models; this version of the Mage model is named hereafter ANS (Adour No Storage).

4. MODELLING RESULTS ON A TYPICAL FLOOD PERIOD

4.1 Hydraulic conditions

In order to compare models, a simulation of a typical flood period from November to December 2019 has been achieved. It includes several small flood events and a large flood in the beginning of December (Figure 3). Heavy rains in the Pyrénées led to a flood of all tributaries between the 11th and 15th of December. One can notice the delay in the flood occurrence for the Upper Adour reach (at Dax).

For the same period, the water level time series at Anglet was barely influenced by the flow discharge (Figure 4). Several periods of spring and neap tides can be observed with a tidal amplitude varying from 1 to nearly 5 m.

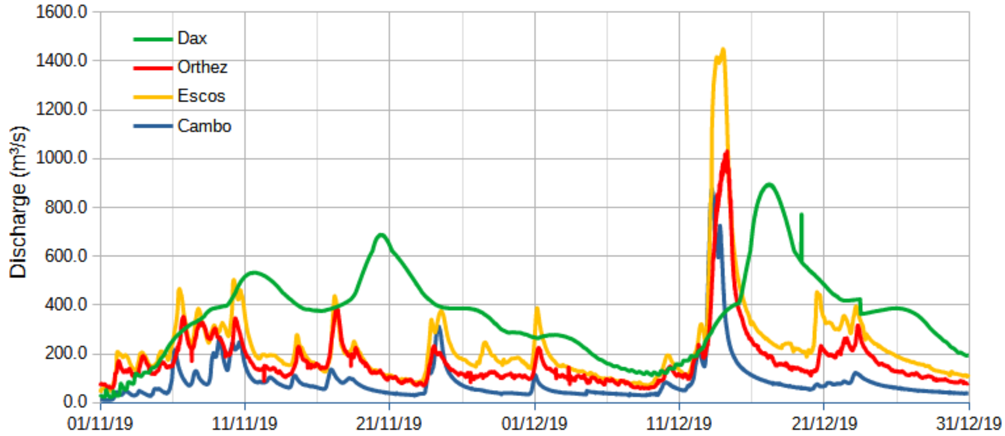


Figure 3: Discharge time series for each upstream boundary conditions of the November-December 2019 period.

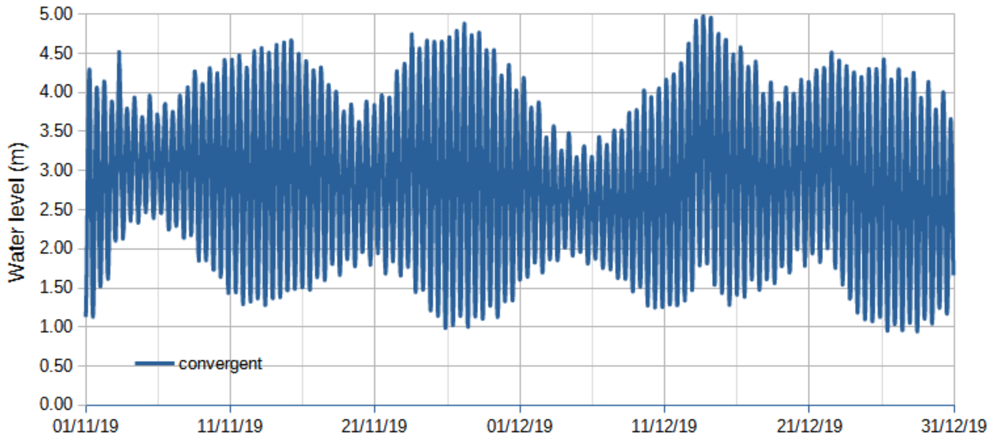


Figure 4: Water level time series for downstream boundary condition at Anglet of the November-December 2019 period.

4.2 Results with simple models without storage area

A comparison of the results is made for four critical hydrometric stations: Peyrehorade, Urt, Lesseps and Pont-Blanc (Figure 2). Results are presented in Figure 5 for the period between the 11th and 16th of December 2019, i.e. during the largest flood. At Lesseps, where tidal effects prevails on the river discharge effects, both Mage ANS and Mascaret models yield results in very good agreements with measurements. At Peyrehorade and Urt, both also behave similarly. At low tide for a medium discharge, they tend to underestimate river discharge effects and yield water levels up to 50 cm below measurements. On the contrary, for high discharges where tidal effects become negligible, both model tend to overestimate water levels up to 1 m. Main differences observed between the two models occur at Pont-Blanc station on the Nive River. The Mage model presents poor results during the flood peak with a large over-prediction of the water levels, up to 3.5 m. It clearly corresponds to overflowing in the downstream part of the Nive River that is not taken into account in the present model. The Mascaret model yields even worse results with a general overestimation of the water levels during medium and high discharges and also a time shift for the high tide. On the contrary to the Mage ANS model, the Mascaret model is not able to reproduce water levels for the period just after the flood. One could note that the Mascaret model also presents some instabilities (at around 6 pm on 13th December). Eventually, results from Mage ANS model, based on the same geometry and calibration, are similar and even improved at Pont-Blanc compared to those obtained with Mascaret. Also computation time are largely reduced; as an example, using a classic laptop (Intel Core i7, 7.7Go RAM), a 64 day time-series was modelled within 3 min using Mage, against nearly 10 hours using Mascaret.

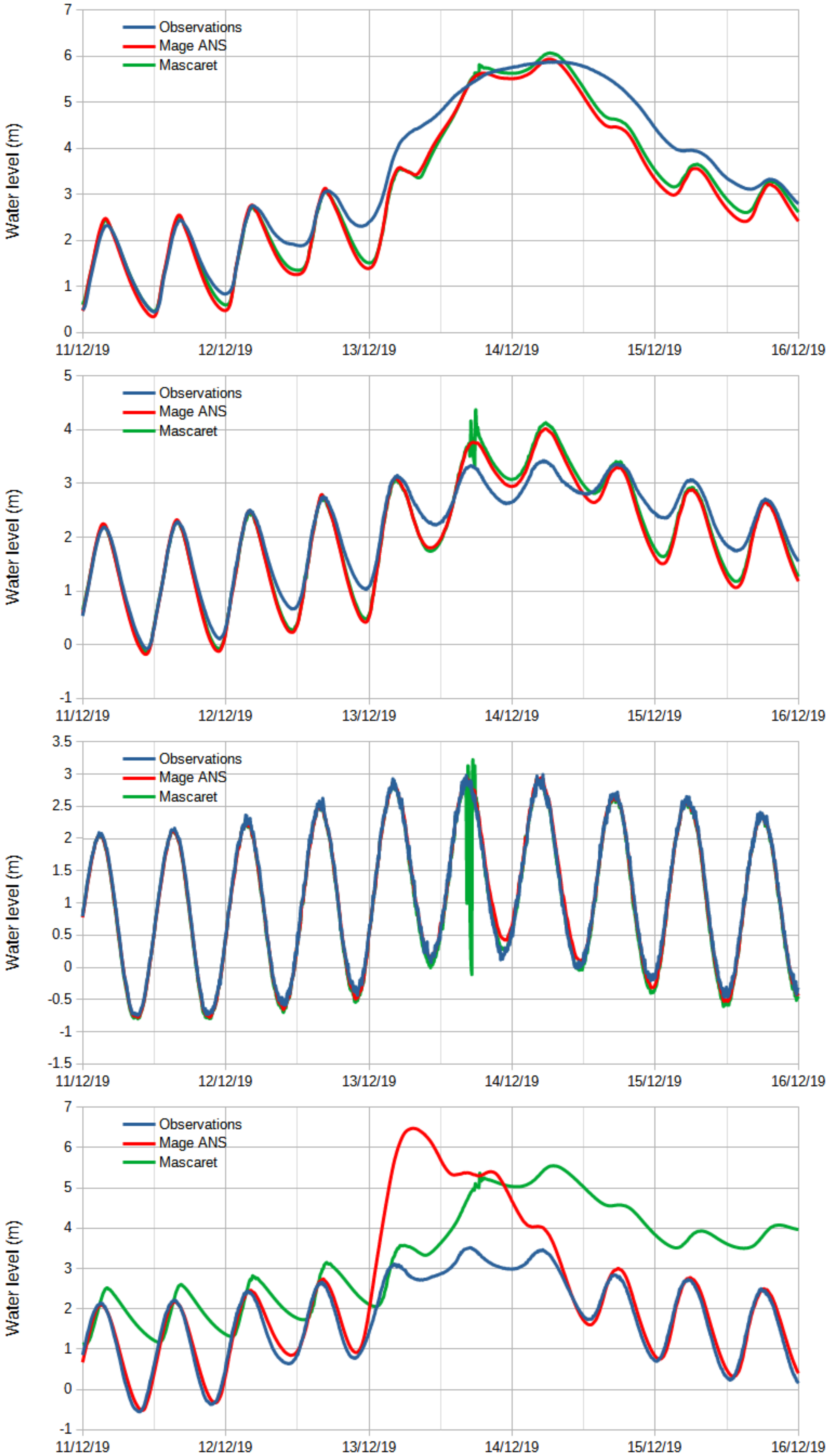


Figure 5: Comparison between model results and water levels measured at Peyrehorade (a), Urt (b), Lesseps (c), and Pont-Blanc (d) from 11th to 16th of December 2019.

5. IMPROVEMENT OF THE MAGE MODEL USING STORAGE AREAS

5.1 Construction of storage areas on the Nive River

As discussed previously, one observe regular overflows of the Nive River in its downstream reach around the A63 motorway (Figure 6). These storage areas are called "barthes" and correspond to a complex flood area system made of fields, forests around a canal network. Based on the topography, location of main canals, and land cover specificities, we create 10 storage areas in the Mage model (Figure 6) with surface areas varying from 6 ha (storage area 10) to 60 ha (storage area 2). In total, the surface area of these 10 storage areas is about 330 ha. Two different models were builds based on these storage areas. For the first one named ASS (Adour Storage Simple), storage areas 1 to 4, 6 to 7 and 8 to 10 are connected in series without any other connection to the river leading to a successive filling of the storage areas; for the second one named ASC (Adour Storage Complex), in addition to the series connection, each storage area presents some direct connections to the Adour River. Each connexion between the river and a storage area or between two storage areas are modelled by a rectangular channel (5 m large and 10 m long or 3 m large and 5 m long, respectively) with a Strickler coefficient of 30 $m^{1/3}/s$ and a overflow level 2 m above the storage area bed levels.

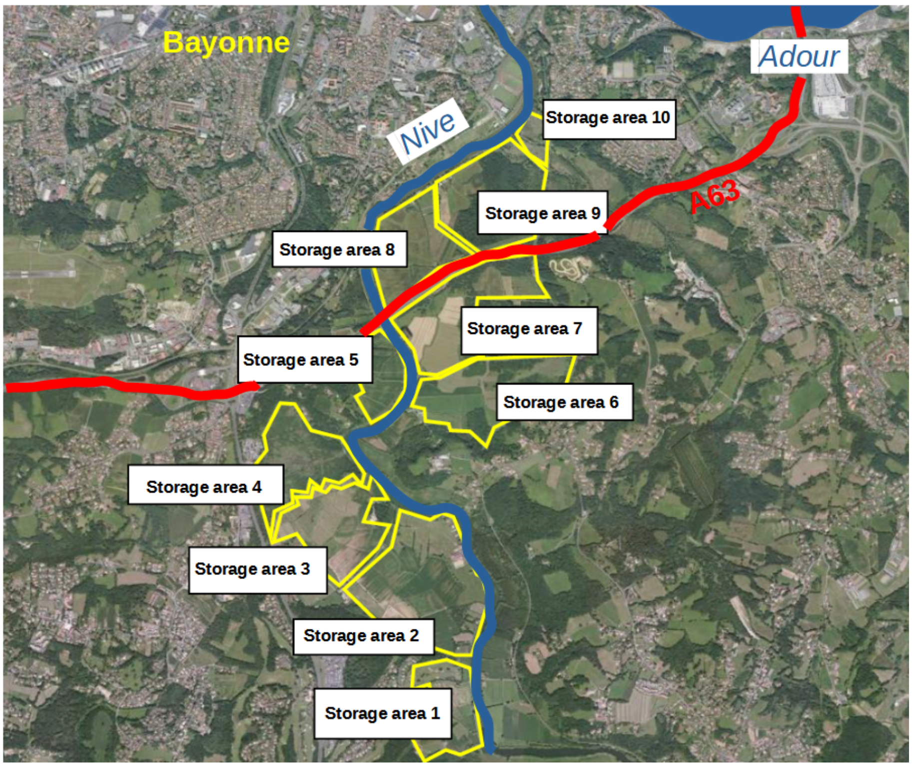
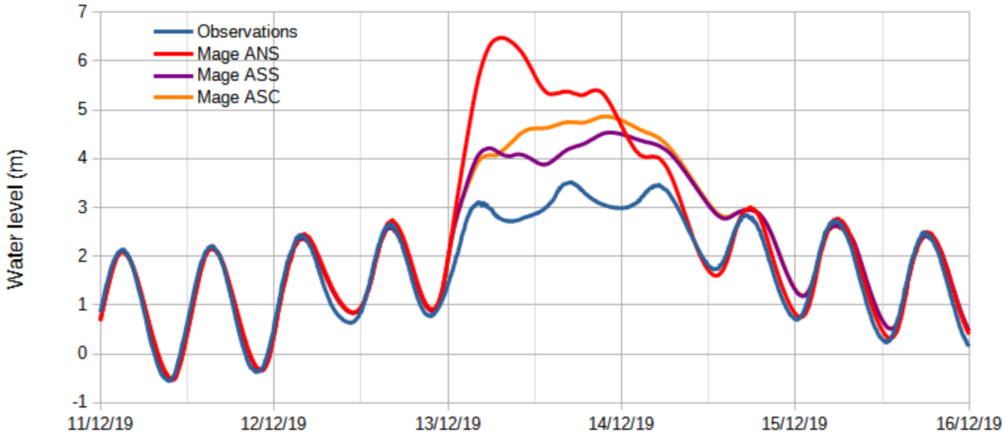


Figure 6: Description of the different storage areas at the downstream part of the Nive River defined in the 1D model.

5.2 Results with the Mage models including storage areas

In order to compare results of the three different Mage models, plots are presented in Figure 7 both at Pont-Blanc station on the Nive River and at Villefranque located 5 km upstream (see Figure 2). Both models with storage areas significantly improve the results at the flood peak, especially at Villebranque station. At Pont Blanc, there is still an overestimation of water levels at the peak flood of approximately 1 m. There may be some other areas of possible overflow or channel widths for overflow may have been underestimated. Also, if the ASC model yields some even more accurate results at Villefranque, it yields poorer results at Pont-Blanc.



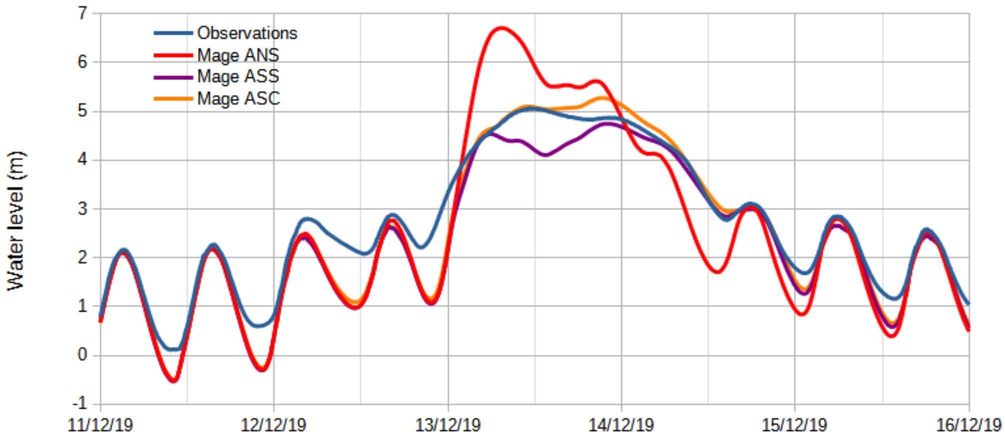


Figure 7: Comparison between the different Mage model results and water levels measured at Pont-Blanc (a) and Villefranque (b) from 11th to 16th of December 2019.

6. CONCLUSIONS

The 1D hydraulic software, Mage, is introduced here and compared to Mascaret code for a complex tidal river system. Mage appears to be both more accurate and more efficient numerically. Since it can simulate the hydrodynamics of the Adour river system for a two-month period in less than three minutes using a common PC, the Mage code can be used for real time modelling. The Flood Prevention Service (SPC) of the region Nouvelle Aquitaine will apply this model for operational use.

The Adour model can still be improved. In particular, Strickler coefficients in the downstream part of the Adour River need to be adjusted to properly model velocities. However, there is a lack of velocity measurements in this section highly influenced by tidal fluctuations. In addition, there are other sections, such as next to Peyrehorade, where results could be improved by adding new storage areas. Eventually, the Mage model will be coupled with an advection-dispersion model (AdisTS) to possibly simulate fine sediment resuspension in the downstream part of the Adour River [14, 15].

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