MODELLING OF THE FLOODS OF THE RIVER SIAGNE

MODELISATION DES CRUES DE LA RIVIÈRE SIAGNE

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ABSTRACT

The Siagne is a coastal river located on the French Riviera, near the town of Cannes. After a mountainous watershed, the coastal plain extends from the town of Pegomas to the sea. In this area, the river needs to be developed in order to limit the impact of floods, and thus, to improve the protection of persons and possessions. The Siagne study represent a real field case endowed with typical conflicting agricultural, urban, environmental features.

The numerical software we have used is Telemac-2D. Telemac-2D is a program for the solution of the two dimensional Saint-Venant equations in their depth-velocity form, with Strickler formulae for friction force, using triangular finite elements.

The main features of the modelling and particularities will be explained. Two sub-domains, separated by the embankment of a highway and differing by their urbanization can be distinguished. The model includes the whole flood plain of the river up the sea. It includes a small drainage canal too. The upstream and downstream boundaries are of fluvial liquid type. At the upstream part a flood hydrograph is imposed. At the downstream part of the model (the sea), the level is known and the velocity stays free. All the other boundaries are of solid type

The simulation presented in the paper concerns the flow evolution during a centenal flooding, the upstream hydrograph of which is given. The results show the main events and the order in which they take place. In particular one can evaluate the role of the various structures like the highway embankment and its siphons, the drainage canal, the way in which the whole plain is flooded and the time needed to the drop.

RÉSUMÉ ET CONCLUSIONS

La Siagne est un fleuve côtièr située sur la Côte d'Azur, près de la ville de Cannes. Après un bassin versant montagneux, la plaine côtière s'étend de la ville de Pegomas jusqu'à la mer. Dans cette région la rivière nécessite d'être aménagée afin de limiter l'impact des crues, et ainsi améliorer la sécurité des personnes et des biens. Un syndicat intercommunal nommé SISA a été créé à la fin des années 1990 afin de gérer les projets d'aménagements.

Nous pensons que l'étude de la Siagne représente un cas illustratif comportant les caractéristiques agricoles, urbaines et environnementales typiques et conflictuelles. En effet, à cause de sa situation près de la côte méditerranéenne, la pression d'urbanisation est très forte

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mais doivent être pris en compte la protection de l'environnement, la construction d'infrastructures et les contraintes de sécurité.

Le SISA a demandé à la Société du Canal de Provence de réaliser un modèle numérique capable de simuler le déroulement d'une crue dans cette région afin de tester les projets de contrôle de crue et ainsi d'optimiser les investissements. Ces résultats présentent une grande importance en ce qui concerne le développement futur du bassin de la Siagne.

Le modèle numérique que nous avons utilisé est Telemac-2D, développé par EDF-DRD et distribué par la SOGREAH. Telemac-2D est un logiciel qui résout les équations de Saint-Venant à deux dimensions dans la forme profondeur- vitesse en utilisant des éléments finis triangulaires. La formulation de la force de friction est du type Strickler.

Nous exposons ci-après les principales caractéristiques de la modélisation mise en œuvre :

- Modélisation de la rivière : Des cartes détaillées sont données dans le papier. Le modèle comprend toute la plaine d'inondation jusqu'à la mer. Il comporte aussi un petit canal de drainage. On peut remarquer que la plaine est divisée en deux sous-domaines séparés par le remblai d'une autoroute. Le premier est caractérisé par une relativement faible urbanisation, alors que le second est fortement urbanisé mais protégé de la crue par le remblai de l'autoroute. Ce remblai est équipé de quinze siphons et de quelques ouvrages de traversée. Ils nécessiteront une attention particulière lors de la modélisation.

- Le maillage : Le domaine est maillé par des triangles sur une grille non structurée d'environ 11000 nœuds. Quelques lignes définies par l'utilisateur ont pour fonction de polariser le maillage afin d'améliorer la description géométrique du lit.

- Conditions aux limites: Les conditions aux limites amont et aval sont de type liquide fluviales. A l'amont un hydrogramme de crue est imposé et le niveau est libre. Dans la partie aval du modèle (la mer), le niveau est connu et la vitesse est libre. Toutes les autres conditions aux limites sont de type solide.

- Conditions initiales: Afin d'obtenir des conditions initiales réalistes, nous sommes partis d'un état initial stationnaire satisfaisant toutes les conditions aux limites.

- Calage des coefficients: Les coefficients de Strickler ont été fixés par sous-domaines. La crue de Décembre 2000 a été utilisée pour le calage.

Résultats de simulation

La simulation présentée dans le papier concerne l'évolution d'une inondation durant une crue centenale dont l'hydrogramme amont est donné. Les résultats montrent les évènements principaux et l'ordre dans lequel ils interviennent, la manière avec laquelle la plaine est inondée et la durée nécessaire pour l'évacuation des eaux. En particulier, on peut mettre en évidence le rôle des différentes structures comme le remblai de l'autoroute et ses siphons, le canal de drainage.

Le modèle est actuellement opérationnel. Nous pensons que ce travail illustre un cas de terrain impliquant une collaboration entre une collectivité territoriale et le département de recherche d'une société de développement régionale.

INTRODUCTION

The Siagne is a coastal river located on the French Riviera, near the town of Cannes (see figure 1). After a mountainous watershed, the coastal plain extends from the town of Pegomas to the sea. In this area, the river needs to be developed in order to limit the impact of floods, and thus, to improve the protection of persons and possessions. In order to manage all the operations of the river development, an intermunicipality district was created at the end of the 1990's, named SISA (Intermunicipal district from the Siagne and its affluents).

Figure 1: Global Location Map (Carte de localization)

We think that the Siagne study represent a real field case, endowed with typical conflicting agricultural, urban, environmental features. Indeed, due to the location near the Mediterranean coast, the land ownership pressure is very important, but, on the other hand, one has to deal with landscape protection, infrastructure constructions and safety constraints.

Therefore, the SISA wishes to equip himself with a tool allowing a precise and reliable river modelling, in order to test all the flood control projects and then to optimize investments. The SISA asked then the "Société du Canal de Provence" (SCP) to build a numerical model of the flood plain, in order to simulate the flow through the area. This work is the subject of this paper.

The basic equations are recalled in the next section, along with the characteristics of Telemac-2D which is the numerical model we have used. The section 3 is devoted to the description of the application, with the main geographical and physical characteristics. The results concerning the centenal flooding are shown section 4. These results are of great importance for the future development of the Siagne basin.

BASIC EQUATIONS AND NUMERICAL MODEL

Physical model

We shall only give here the outline of the basic model, for more detail on the physical and numerical model, one can refer to the book of Hervouet (2003)

Saint-Venant equations

We shall use the depth-velocity form of the 2D Saint-Venant equations.

Continuity equation:

$$\frac{\partial h}{\partial t} + \mathbf{U} \cdot \nabla h + h \nabla \cdot \mathbf{U} = S$$

Momentum equations:

$$\frac{\partial \mathbf{U}}{\partial t} + \mathbf{U} \cdot \nabla \mathbf{U} = -g \nabla Z + h\mathbf{F} + \nabla \cdot (h \nu_e \nabla \mathbf{U}) + \frac{S}{h}(\mathbf{U}_S - \mathbf{U})$$

with:

h : water depth

Z : free surface elevation
$\mathbf{U}$: the velocity
$\mathbf{F}$: friction force
S : bottom source term
$\mathbf{U}_S$: source term velocity . The momentum source term is then nil if the source velocity is equal to the current one.
ν_e : effective viscosity which include the dispersion and the turbulence contributions

Friction force
The Strickler formulae for friction force will be used:

$$\mathbf{F} = -\frac{1}{\cos\alpha}\frac{g}{h^{4/3}K^2}\mathbf{U}U$$

α : the steepest slope at the point
K : Strickler coefficient

Boundary conditions
Physically we distinguish between two types of boundary conditions: the solid boundaries and the liquid boundaries.

- In solid boundaries there exists an impermeability condition: no discharge can take place across a solid boundary. In order to take account of friction the following relations are imposed:

$$\frac{\partial \mathbf{U}}{\partial n} = a\mathbf{U}$$

with a the boundary friction coefficient and n the normal vector.

- Liquid boundary condition assumes the existence of fluid domain that does not form part of the calculation domain. Four types of liquid boundaries will be distinguishes:
  - Torrential inflow: velocity and depth prescribed
  - Fluvial inflow: velocity prescribed and free depth
  - Torrential outflow: free velocity and depth
  - Fluvial outflow: free velocity and prescribed depth

Numerical model

The numerical model we have used is TELEMAC-2D. TELEMAC-2D is a program for the solution of the two dimensional Saint-Venant equations in their depth-velocity form using triangular finite elements. It has been developed by EDF-DRD and is now distributed by SOGREAH. All the features and the directions for use can be found in Telemac Reference and User Manual (SOGREAH 2002)

APPLICATION DESCRIPTION

River modelling

Detailed maps are given on figure 2. The model includes the whole flood plain of the river, from the bridge across the river in the town of Pegomas, to the sea. It includes a small drainage canal called "Canal du Béal" too. One can notice that the plain is divided in two sub-domains, separated by the embankment of the highway. The first one is characterized by a small urbanization, and a first bottom situated beneath the main channel. The second one is strongly urbanized, but is protected from the upstream overflowing by the highway's embankment.

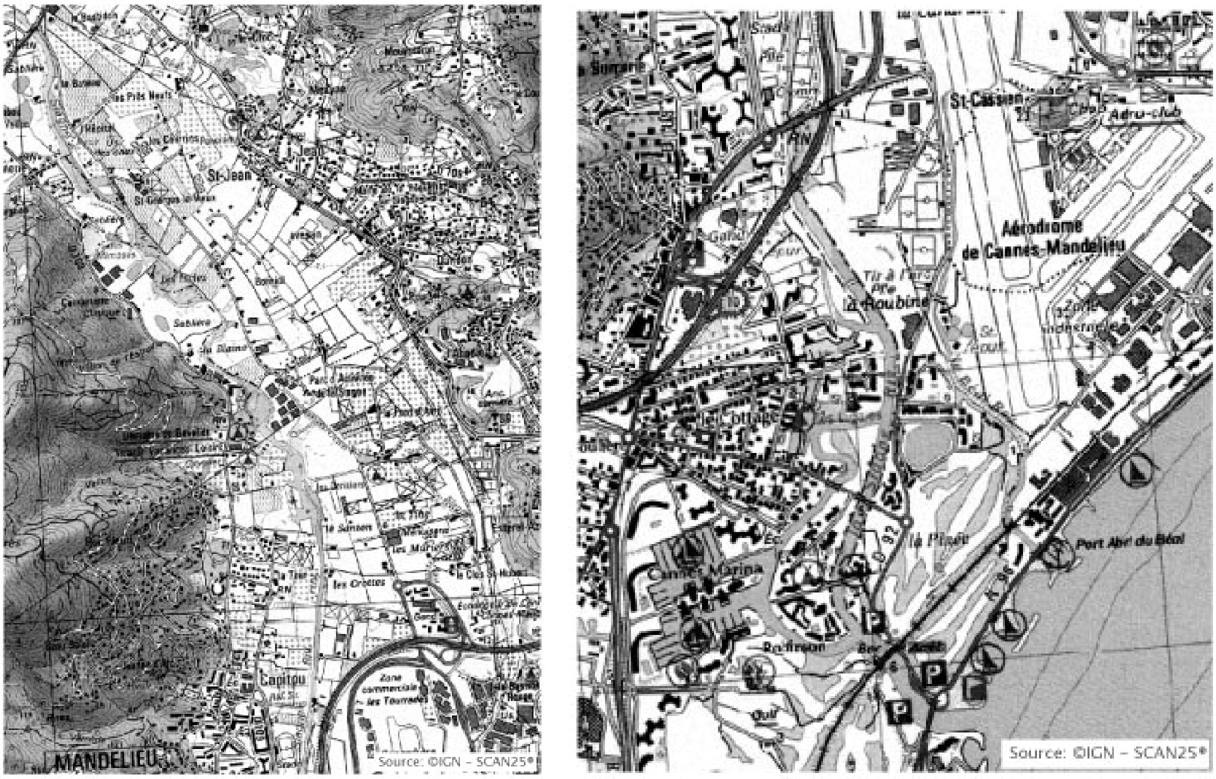

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Figure 2: Upstream part and downstream part of the modeled area (Amont et aval de la zone étudiée)

The mesh

The field is meshed with triangles on a non-structured grid of about 11000 nodes. The meshing software called MATISSE, is free to compute the mesh, except a criterion used to define the size of the triangles, and some user-defined lines situated in the main channel (see figure 3) and used to polarize the mesh in order to improve the geometric description of the bed.

Boundary conditions

The upstream and downstream boundaries are of fluvial liquid type. At the upstream part of the river, since we need to impose a flood hydrograph, the velocity is fixed, and the level is free. At the opposite, on the downstream part of the model (the sea), the level is known, so it is imposed (eventually function of time) and the velocity stays free (see figure 4).

All the other boundaries are of solid type. However, since the limit of the domain have been chosen sufficiently far from the flooding limits, the friction coefficient is not required and has been set to zero.

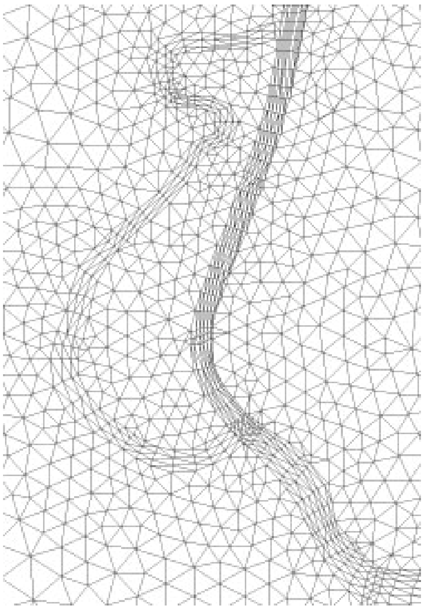

Figure 3: Mesh detail (Détail du maillage)

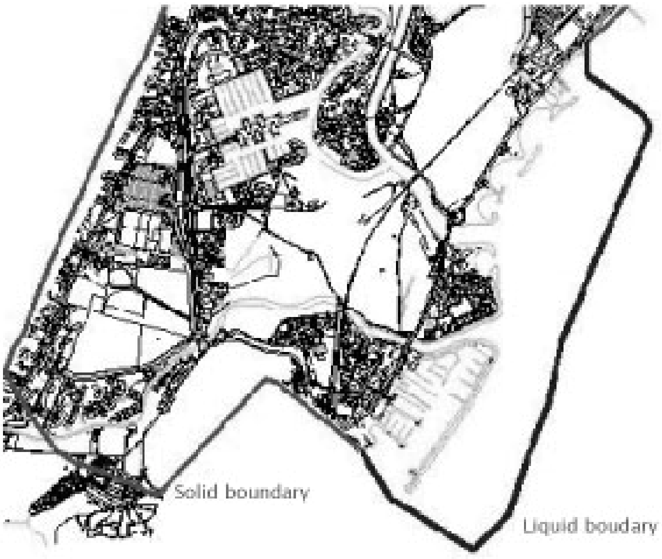

Figure 4: Boundary conditions on the downstream part of the model
(Conditions aux limites sur la partie aval)

In addition, since we need a very clean flow at the upstream, the boundary needs a particular treatment. We first add a small regular channel of a few meters in the axis of the river in order to canalize the flow. We also need to impose a velocity profile on the boundary nodes, in order to have high speed where the water depth is important (see figure 5).

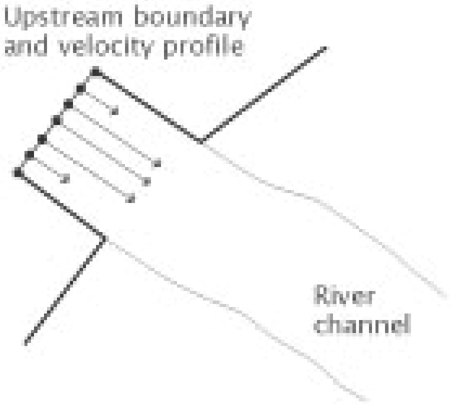

Figure 5: Upstream boundary and velocity profile
(Condition limite amont et profile de vitesse)

Initial conditions

In order to obtain realistic initial conditions, we start from a fictive reasonable state satisfying all the boundary conditions. Keeping the upstream discharge equal to the initial value of the flood hydrograph, the calculation is run, and a final stationary state is obtained, with water only in the main channel. It is this stationary state which is used as initial state for the study of the flooding.

Particular structures

The highway's embankment is equipped with fifteen siphons and some crossing works. They are modelled with pairs of nodes on each side of the highway and linked with a special law giving the discharge as a function of water elevation:

$$Q = S_{12}\sqrt{\frac{2g(z_1 - z_2)}{C_{E1} + C_{S2} + L_{12}}}$$

where S_{12} is the cross section of the structure, z_1 and z_2 are the elevations of the inlet and outlet, C_{E1} is the head loss coefficient in the case of inlet, C_{S1} is the head loss coefficient in the case of outlet, and L_{12} is the linear head loss coefficient usually equal to $\lambda\frac{L}{D}$, where L is the length of the pipe, D its diameter and λ its friction coefficient.

Coefficient calibrations

We have distinguished:

- For the main channel three different values calibrated on the high watermark let by the flood of December 2000 given in figure 6:
  - Strickler coefficient of the upstream part (from the input to the exit of the meanders), fixed to 50.
  - Strickler coefficient of the middle part (from the exit of the meanders up to the highway), fixed to 40.
  - Strickler coefficient of the improved downstream part, fixed to 45.
- For the flood plain, only one value estimated relatively to the other coefficients and fixed to 30. We choose to use only one coefficient in the flood plain, because the nature of the ground is similar everywhere where the main flow takes place. The small urbanized places where there might be some overflowing are submitted to very small velocity, and so the Strickler coefficient has little influence.

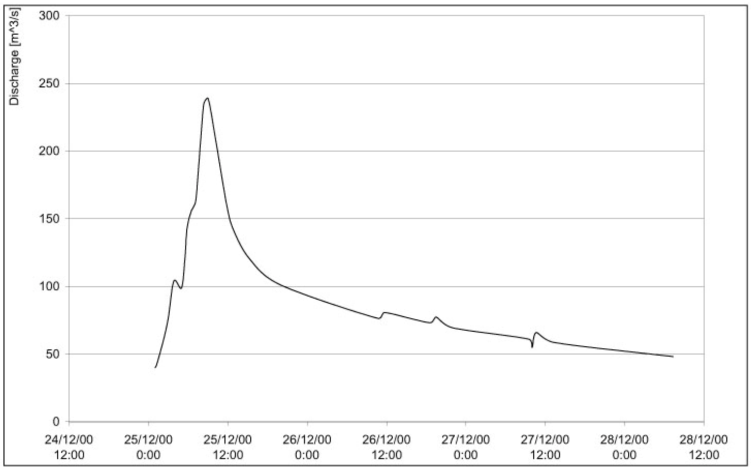

Figure 6: Flood hydrograph of December 2000 in the station of Pegomas
(Hydrogramme de la crue de Décembre 2000 à la station de Pegomas)

SIMULATION RESULTS

Flood dynamic

This subsection describes the flow evolution during a centenal flooding, the hydrograph of which in Pegonas station is shown in figure 7. The beginning of this flood hydrogram is taken as initial time.

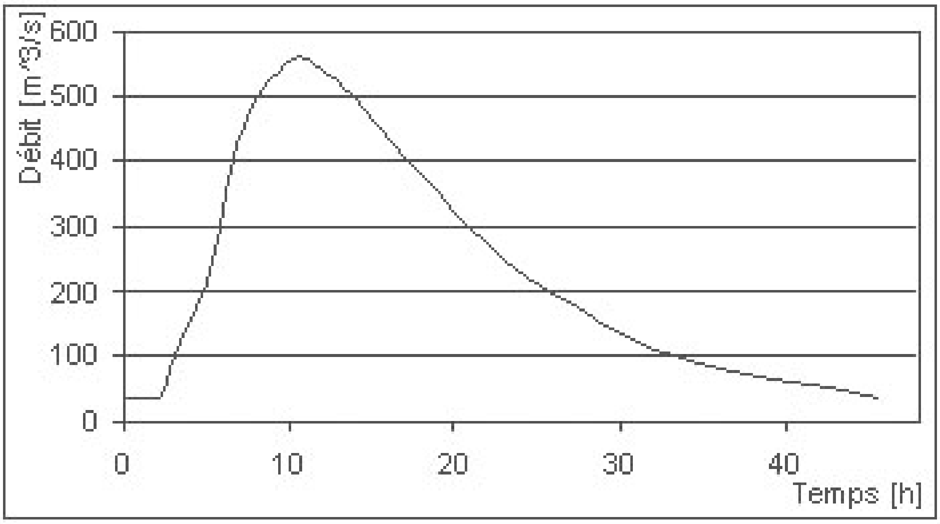

Figure 7: Centenal flood hydrograph in the station of Pegomas
(Crue centennale à la station de Pegomas)

The main events take place in the following order:

1. At around 3.5 hours only overflows upstream of the Iscles village and the N7 road. These first overflows reach rapidly the highway embankment. The discharges values are at this moment of 290 m^3/s at Pegonas and 230 m^3/s at Iscles.
2. At 6.5 hours the river Beal begins to overflow between the A8 highway end the aerodrome. The discharge is at that time of 5 m^3/s s through the siphons under the highway. Half an hour later, the overflows reach the aerodrome siphon and the water pour out on the runway, meeting those coming from the overflows of the A8 safety canal. The discharge value at Pegonas is of 520 m^3/s.
3. The maximum discharge at Pegonas (560 m^3/s) takes place at 8.5 hours. The whole plain upstream the highway is flooded. In the downstream part, the aerodrome is under the water and the overflows of the downstream Beal river meet those of the Siagne river. Also, the town of Argentieres, which is located at south-west of the region, is reached two hours after by the overflow, following the old Siagne bed.
4. The drop in levels of the water begins at 13 hours. The depths decrease in the whole area and become practically lower than 1 meter four hours later. At 24 hours, it remains water only against the highway embankment. Between 35 and 40 hours it remains no trace of the flood event.

The figure 8 gives the map of maximum depths reached in the whole area. This map is, of course, important in order to evaluate the flood effects. One can see clearly the influence of structures like the highway embankment.

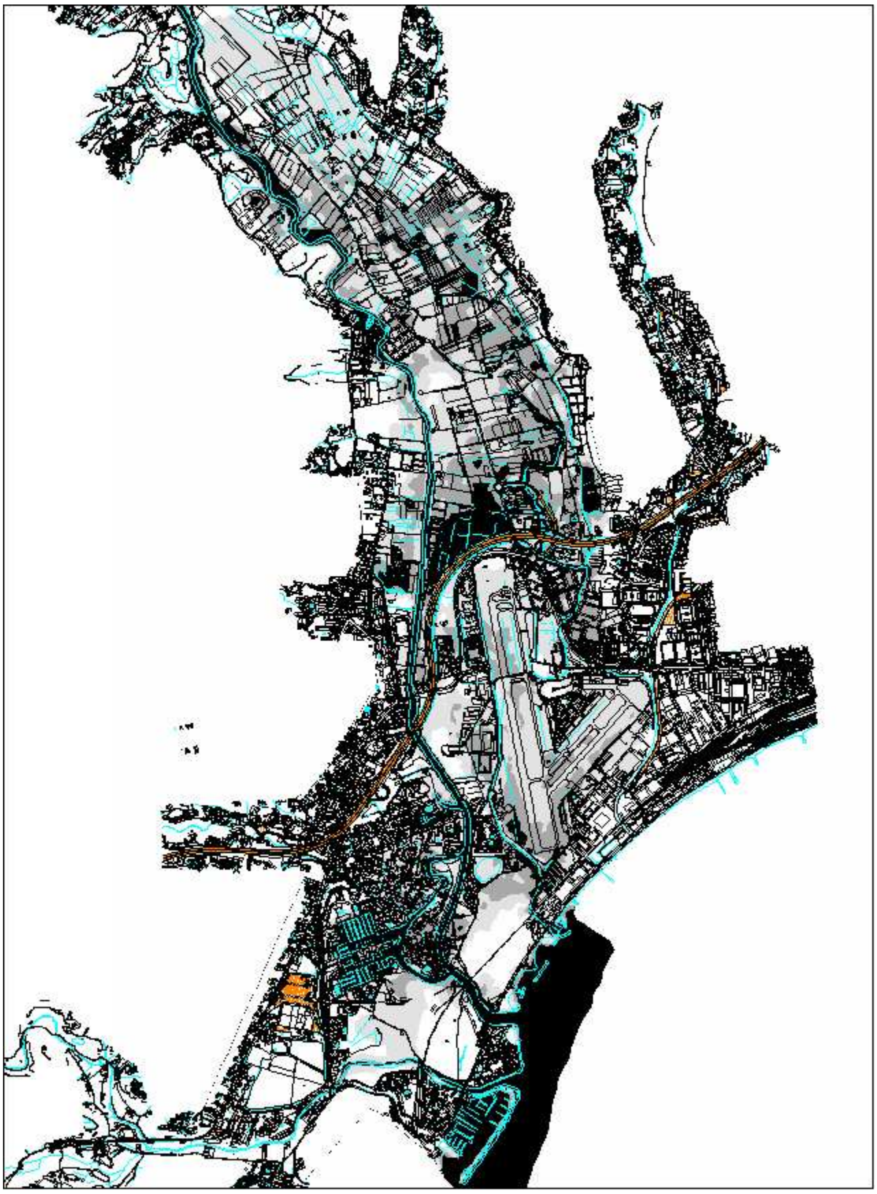

Figure 8: Maximum depths map (Carte des hauteurs d'eau maximum)

CONCLUSION

For a flooding event and due to its 2D feature, Telemac-2D appears to be well adapted for the simulation of the phenomenon. We have also tested the consequences of some new developments, mainly on the Siagne bed:

- Shape modification of the cross section toward a berm shape
- Enlargement of the bed when possible
- Silt clearance in the downstream part, where enlargement is not possible

Figure 9 shows the map of maximum depths after these developments. The improvements are clearly seen in this map. In particular the areas submerged by a depth larger than 1m have almost all disappeared.

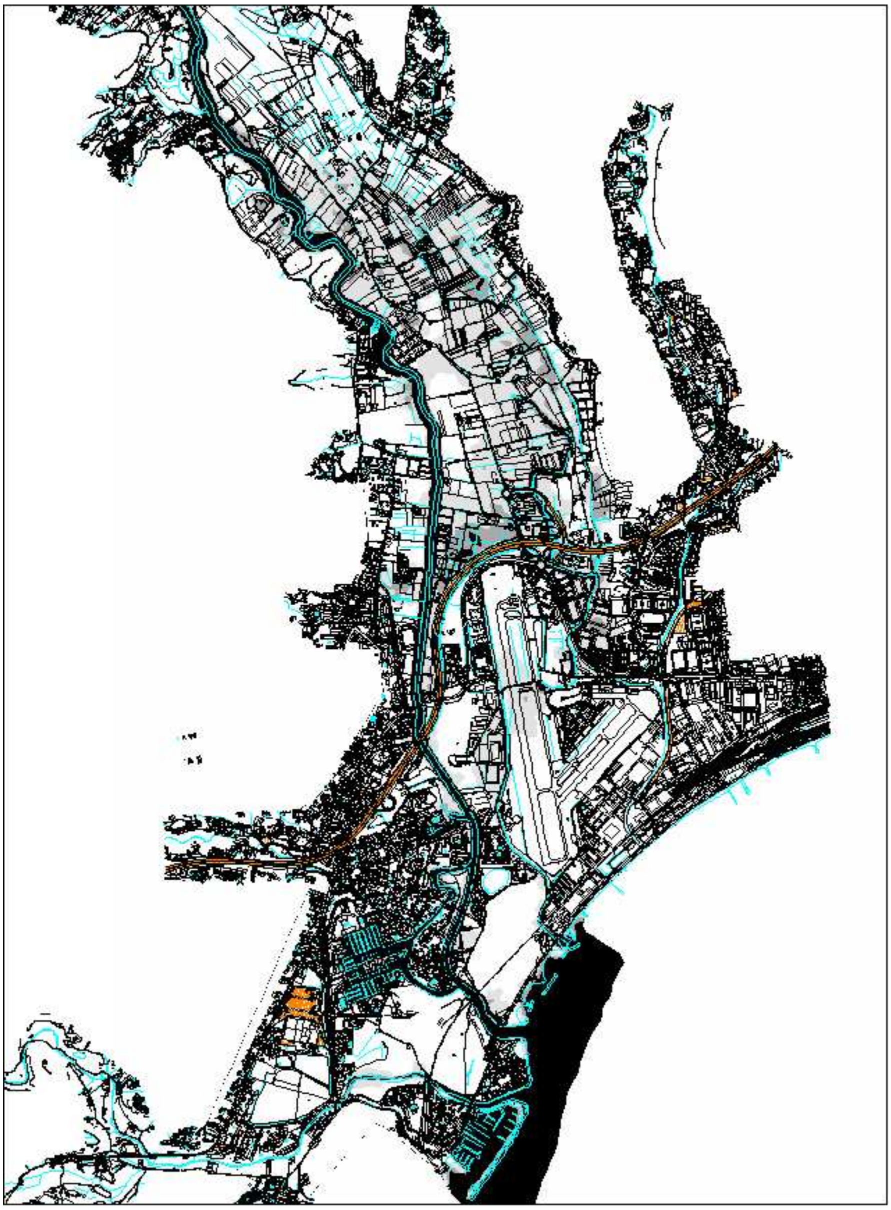

Figure 9: Maximum depths map after developments (Carte des hauteurs maximum après aménagements)

An extensive description of all the application can be found in the SCP reports on the Siagne river (2004).

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