

Restoration master plan for improving hydro-sedimentological processes in the Loire Estuary: the actions and the three-dimensional hydro-sedimentological modelling tool

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Abstract

This article shows the possibility to adopt a restoration master plan to improve the Loire Estuary environmental health. Some actions and modelling tools are proposed as alternative strategies for restoration scenarios in order to support the integrated coastal zone management.

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1. Introduction

As is the case with most estuaries, that of the river Loire has undergone significant development in the past two centuries in order to maintain navigability. To provide favourable conditions for tidal propagation as far as Nantes, the river bed has been deepened and intertidal zones and secondary arms have been filled in.

Today, the phenomenon of fine sediment trapping in the form of a maximum turbidity zone and liquid mud is being amplified by an asymmetric tidal wave reinforced by the morphological changes in the estuary, especially the great depths of the channel located downstream of the estuary.

This disturbed hydro-sedimentary functioning poses a number of problems for the various uses of the river:

- impact of recurrent anoxia on the living environment*
- clogging of secondary water courses*
- difficulty managing abstraction of water for agricultural and industrial use*
- impact on the landscape of stretches flowing through urban areas, etc.*

In light of these factors, in the 1990s the estuary stakeholders decided to undertake an ambitious programme of studies and monitoring, incorporated into the Plan Loire Grandeur Nature initiative, which has been managed since 2000 by the Groupement d'Intérêt Public Loire Estuaire (Loire estuary management agency - GIP Loire Estuaire, 2006 [1]). This programme aimed to gain a greater understanding of the estuary system, share objectives in order to improve the functioning of the estuary and investigate restoration scenarios.

The Etudes Prospectives Aval (downstream prospective studies) performed between 2000 and 2006 led to the definition of various scenarios for intervention, among which the Plan Loire partners adopted one consisting of morphological restoration (GIP Loire Estuaire, 2007 [2]). To implement this scenario, it was decided to conduct an initial experimental phase, which is included in the 2007-2013 operational programme to restore the estuarine Loire downstream of Nantes (GIP Loire Estuaire, 2008 [3]). This programme includes the development and exploitation of a three-dimensional hydro-sedimentary model of the Loire estuary, a task which has been assigned to Sogreah. This is in fact the second version of an existing model developed in 2006 in the framework of the Etudes Prospectives Aval, which is described in Walther et al. (2007) [4] and which has been improved in the following respects: consideration of areas subject to tidal flooding between Nantes and the sea, refining of the

vertical grid construction strategy, improvement of the friction charts taking into account the presence or absence of liquid mud on the bed, improvement of the vertical turbulence model to represent haline and turbid stratification more accurately, and improvement of the configuration of all silt consolidation, deposition and erosion laws.

2. Changes to development principles

When they undertook the “prospective modelling” in 1995, the estuary stakeholders were looking to draw up a preliminary assessment of the situation and study various scenarios. Even at that stage the approach adopted was proactive.

During this phase a number of objectives relating to the various uses were defined and quantified: raise the low-water level in Nantes, push back the salinity and turbidity fronts, and restore natural habitats while avoiding exacerbating flood flows and maintaining approach conditions to the various port facilities.

Hydraulic regulation of the estuary: the cut-off structure

The levers tested on the estuary at that time were used as the basis for scenarios. The so-called “cut-off” scenario appeared to provide the best response to the stated objectives, in particular succeeding in raising the low-water levels in Nantes by 3 metres.

This scenario is based on the construction of a gated flow-regulating structure in the river downstream of Nantes, to reduce the oscillating volume propagated as far as Nantes. The principle of this structure, managed according to the tide, is to raise the low-water level in Nantes by creating a reservoir at low tide. This reservoir disappears at high tide and during flood flows. The structure also provides a means of reducing the oscillating volume, which has a favourable impact in terms of pushing back the salinity and turbidity front.

The operating principles of the structure, its preferable location next to the town of Le Pellerin (44), and very general geometric aspects were defined during the “prospective modelling” studies (1995 – 2000).

In 2000, on completion of the “prospective modelling” studies, the stakeholders agreed to examine this scenario in greater depth (assess its feasibility and impacts). They also decided to investigate an alternative to the “cut-off scenario”, in view of its high cost and unprogressive nature.

Investigation of a less invasive estuary restoration solution

The exploratory phase of the scenario investigations, carried out between 2004 and 2005 by various service providers (Delft Hydraulics, HR Wallingford, expert committee, etc.), had highlighted the possibility of developing an alternative to the cut-off scenario, focusing more on modifying sediment dynamics by combining measures to modify the estuary geometry and gradually restore habitats with important biological functions for the estuary.

This change in restoration approach was instigated by Delft Hydraulics and the expert committee mobilised at that time by GIP Loire Estuaire, in light of the asymmetric nature of the tidal wave and better knowledge of how the estuary functions.

This type of approach constituted a real alternative to the cut-off scenario, and brought encouraging results in this respect. However, it failed to meet all the objectives that had been set, in particular those relating to raising the low-water level in Nantes by 3 m.

The studies performed in 2005 and 2006 aimed to give concrete form to this type of action, in particular by endeavouring to identify realistic levers.

3. The restoration scenario currently being considered

The principles of the morphological scenario that has now been adopted are to limit tidal intrusion and reduce the sediment trapping mechanisms in the inner estuary by modifying the tidal wave dissymmetry.

To do so, two levers are proposed (see Figure 1 below):

- *Creating intertidal mud flats upstream of Paimboeuf in order to “store” the flow entering the estuary; the other advantage of this type of action is ecological, since it recreates habitats with rich biological diversity of a type that has declined significantly over the past century;*

- *Filling in trenches in the Nantes channel, which are currently very deep for the requirements of shipping; these trenches trap sediment that then feeds the maximum turbidity zone in certain tidal conditions.*

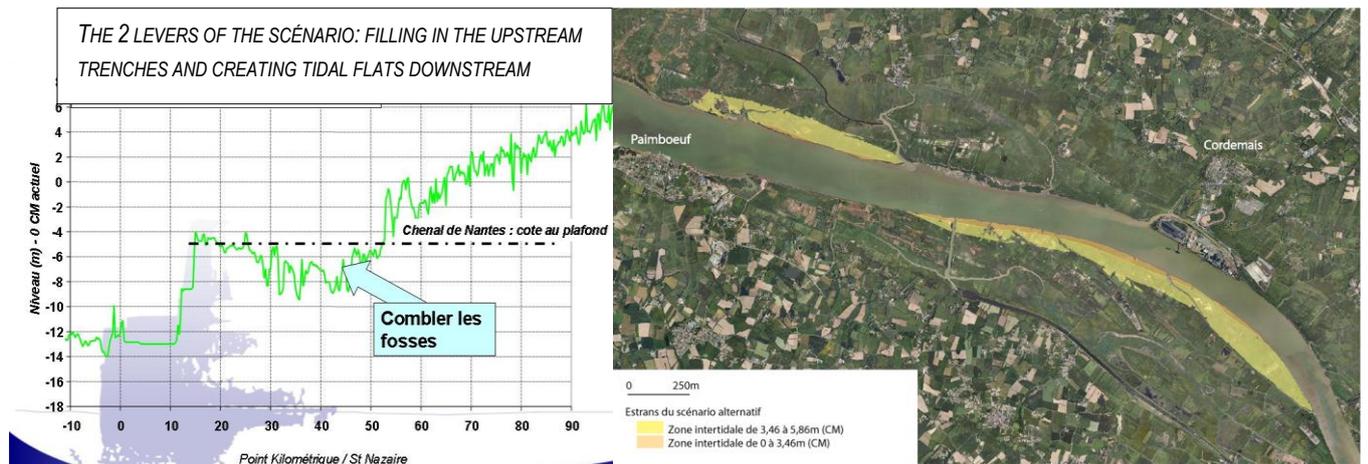


Figure 1: the two levers currently constituting the estuary morphological restoration scenario

The hydro-sedimentary assessment reveals the following:

- The trend relating to the low-water level downstream of Nantes island is inverted, with this level being raised from 0.8 m to 1 m over 30 km (during spring tide and low flow periods) in comparison with levels in the absence of any action.
- As regards salinity, the scenario causes the haline front to retreat by approx. 6 km.
- Turbidity is significantly reduced mainly in the section between kp 30 and 60. The total capacity of the maximum turbidity zone also decreases significantly. The question of the long-term stability of the mud flats created is vital, and this point is currently being studied in greater depth in order to clarify the related risk.

The Plan Loire 2007-2013 includes the implementation of a pilot project entailing recreating a downstream “experimental” mud flat measuring about 100 hectares and filling in the trenches in the shipping channel between Nantes and Le Pellerin, to demonstrate the possibilities for correcting trends relating to water levels downstream of Nantes and turbidity.

The sector with the most favourable characteristics for recreating a mud flat lies between Donges and Cordemais, as indicated on Figure 2 below by a blue rectangle. In addition to a favourable land tenure status, this area includes shallows with a tendency to erode, which would ensure mud flat stability in the longer term. It is also crossed by a large number of

creeks, which can help to maintain mud flats thanks to a flushing effect. The land in this area is used for numerous purposes including extensive livestock farming, hunting, hydraulic management, etc.

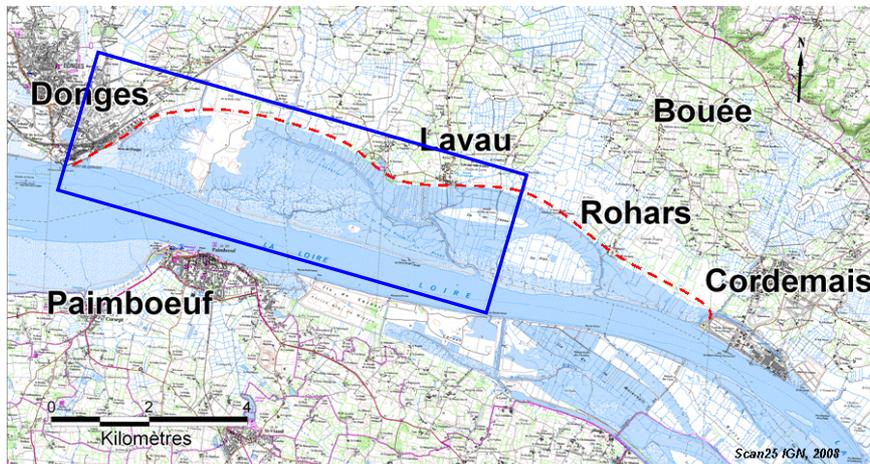


Figure 2: broad sector studied for creation of the experimental mud flat

4. Finalisation of restoration scenario: Pilot mud flat recreation project design

Key characteristics of the project

The goal of this pilot project, covering an area of approx. 100 ha, is to verify the efficiency of this type of action before it is implemented on a larger scale in the estuary, on an area covering approx. 500 ha.

Technical studies

Under the authority of GIP Loire Estuaire, the technical studies will be pursued as far as the preliminary design stage. On the basis of data concerning soil properties, the configuration and functioning of the drainage network, environment sensitivity, land use, the characteristics of the adjacent mud flats, etc., Sogreah is designing the experimental mud flat in terms of its levels, slopes, location and the fate of extracted materials. Using the new three-dimensional hydro-sedimentary model of the estuary implemented by Sogreah, the design office has developed a detailed model of the area in order to study the project impact in terms of flooding of the adjacent agricultural land and check that the mud flat remains

stable in the long term.

Consultation

To take into account all the uses within the designated area and define the precise location of the future mud flat, in September 2009 GIP Loire Estuaire started the process of consulting the main stakeholders and users in the area. After the objectives had been defined and validated by the various stakeholders, this procedure led to the production of functional specifications, which provided a working basis for the design office responsible for putting together the experiment.

Since agriculture is widespread in the area, GIP Loire Estuaire asked the Loire-Atlantique chamber of agriculture to draw up a precise inventory of farmers likely to be affected by the mud flat recreation project, draw up a grid to analyse the potential impact farm by farm and conduct individual interviews with the farmers directly affected. This work must enable the location of the mud flat to be optimised and its impact on grazing in the sector kept to a minimum.

Mud flat environmental impact assessment

Creating the mud flat will make it possible to restore habitats with important biological functions for the estuary, while eliminating others with special ecological interest (reed marshes or wet meadows). The tool for modelling the ecological functions of the estuary that GIP Loire Estuaire has at its disposal is being deployed to help locate the project and check that its impact at an estuary-wide scale is positive.

Data acquisition campaigns

A bird count and analysis of benthic fauna on the main mud flats in the downstream part of the estuary was carried out in 2008, 2009 and 2010. This was used to identify the mud flat sites with the greatest biological wealth, to help with selection of the experimental site.

Further data acquisition campaigns have been carried out to aid the design of the mud flat. This entailed collecting data on soils, flora and fauna, etc.

Feasibility studies

In parallel with the technical studies, GIP Loire Estuaire is overseeing a study component focusing on the conditions for implementing the project: financial arrangements and legal

and studies concerning the transfer of works management to a new project owner.

Updating of the restoration scenario

In addition to deploying the 3D hydro-sedimentary modelling tool exploited by Sogreah, consistency with works being carried out on the estuary in the framework of the overall restoration scenario must be maintained. To do so, GIP Loire Estuaire has elected to retain control of the modelling tool in order to ensure that the various findings of specific studies, the levers defined and their updates, etc. are incorporated into it over time.

5. General presentation of the 3D hydro sedimentary model used to analyse the scenarios

The model stretches from Ancenis (44) at the upstream end, corresponding approximately to the tidal limit (KP 90 with respect to Saint-Nazaire), to 40 km off the coast of Saint-Nazaire (44) at the downstream end. This model includes the lateral flood-prone areas in order to take into account the storage area that may be constituted by certain meadows during periods of high tidal coefficients. The model is forced at the maritime boundary by a harmonic recomposition of the waves obtained from the model of the Bay of Biscay built by the LEGI (Laboratoire d'Écoulements Géophysiques et Industriels, MEOM team) and at the upstream end by the daily discharge recorded at Montjean-sur-Loire (44).

The model comprises two versions with different aims:

- An overall model with the aim of analysing the response of the morphology tested at the scale of the estuary (Figure 3: horizontal grid of more than 7000 nodes by 16 vertical planes);



Figure 3: Overall model area and grid

- A refined model of the mud flat with the aim of analysing the variations in the impacts of a development project at local levels (Figure 4: grid with more than 42,000 nodes by 16 vertical planes)

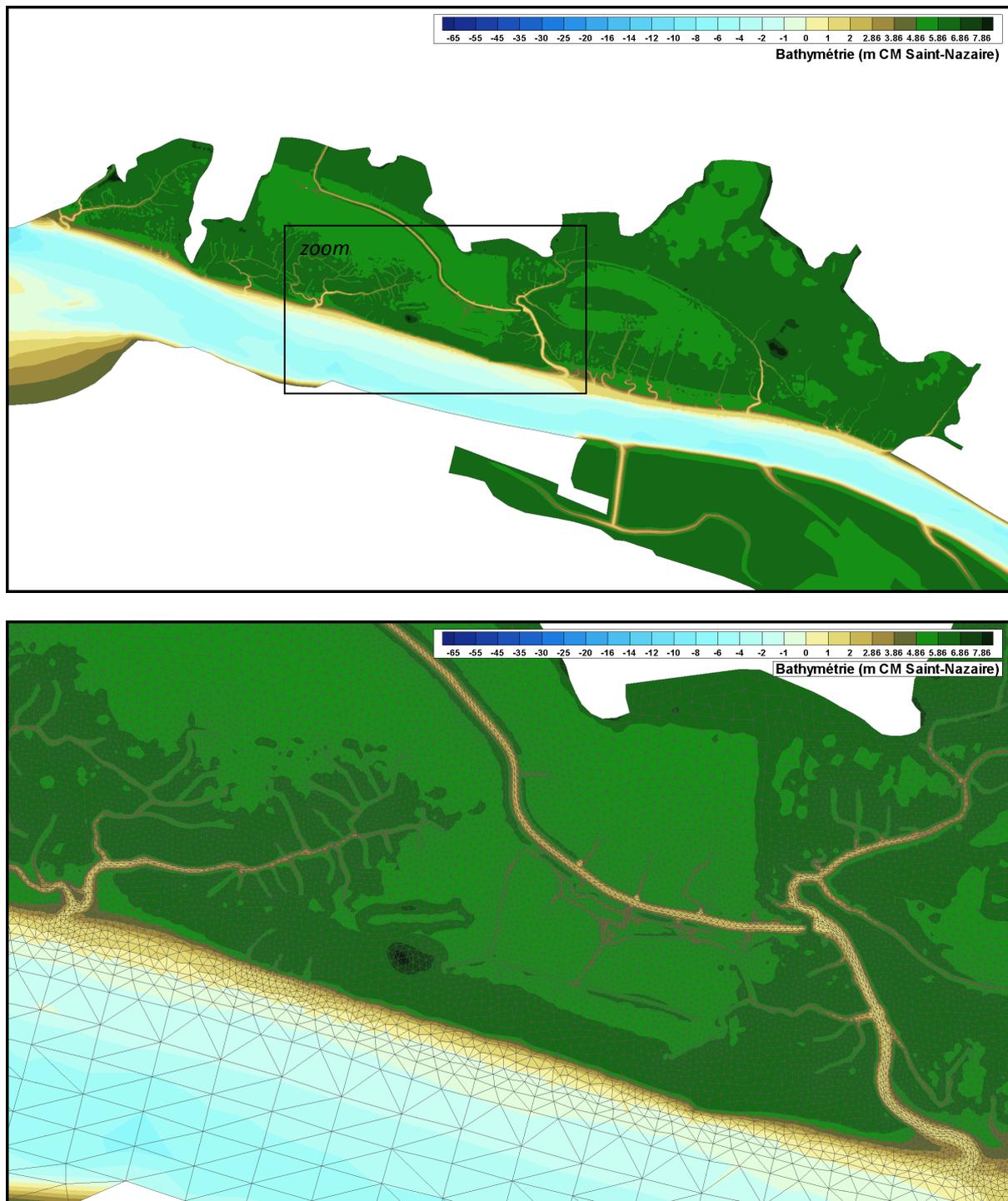


Figure 4: refined model of the alluvial plain to the north of the estuary (Donges – Cordemais sector)

6. Importance of process coupling

The various modelling studies demonstrated the importance of coupling the various parameters to adjust the model even if only by water level. This is because the presence of liquid mud in the estuary induces very low friction on the bottom, allowing easy tidal wave intrusion. Failure to take into account the low roughness of this liquid mud can result in differences of up to 0.5m in the low-water levels calculated in Nantes. The position of the liquid mud, which depends on the discharges and tides, hence results in friction charts that vary in time and space. The various developments tested are assumed to be capable of varying spatially the position of the liquid mud, so the friction charts cannot simply be fixed in light of knowledge of the present condition of the estuary. In this case, rather than being a model input parameter, the friction charts are a calculation variable that is modelled as a function of the silt deposit thickness at each model node. The model hence functions with completely coupled variables: hydrodynamics, salinity, suspended sediment, morphology and friction.

The model was adjusted over several instrumented periods, one of which lasted more than five months, making it possible to check that the model correctly represents reconstitution of the maximum turbidity zone following its expulsion out to sea during a winter flood.

Developing a multi-layer vertical turbulence model notably provided a means of substantially improving the results concerning stratification and haline intrusion phenomena in the estuary during periods of very low flows and heavy flooding.

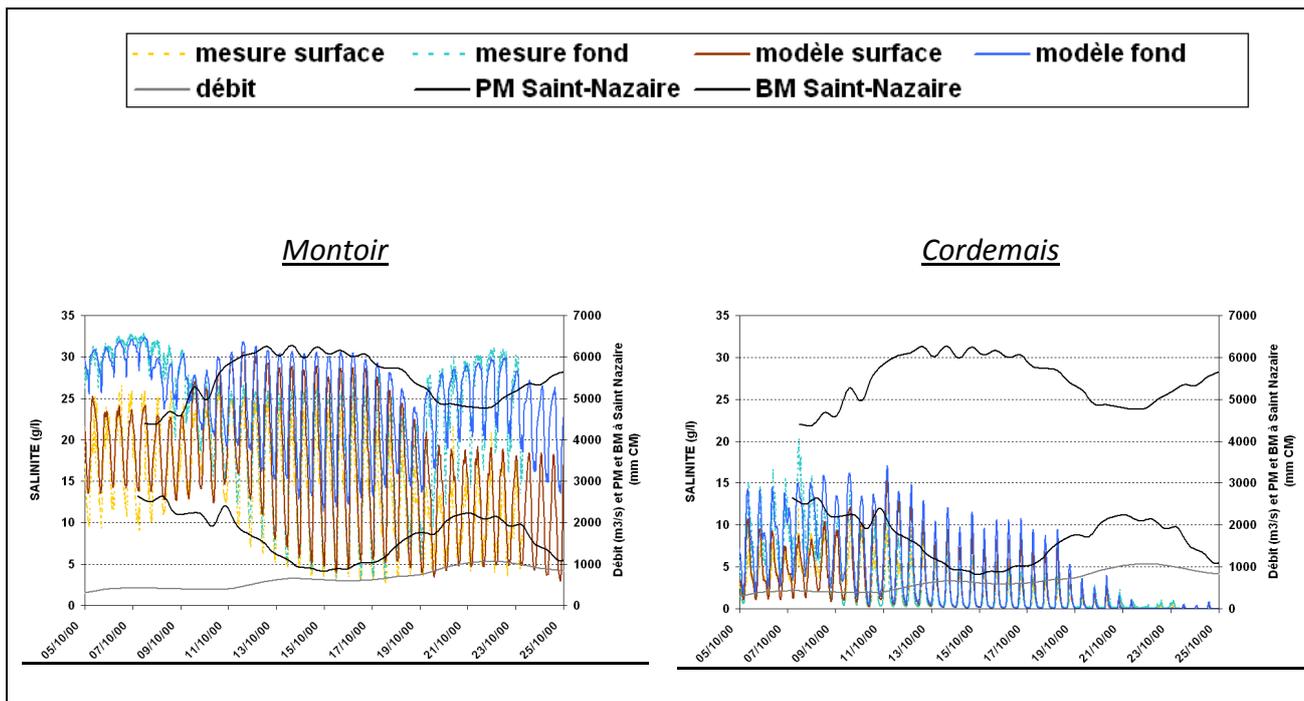


Figure 5: Comparison between measurements and model for salinity during average low-flow periods

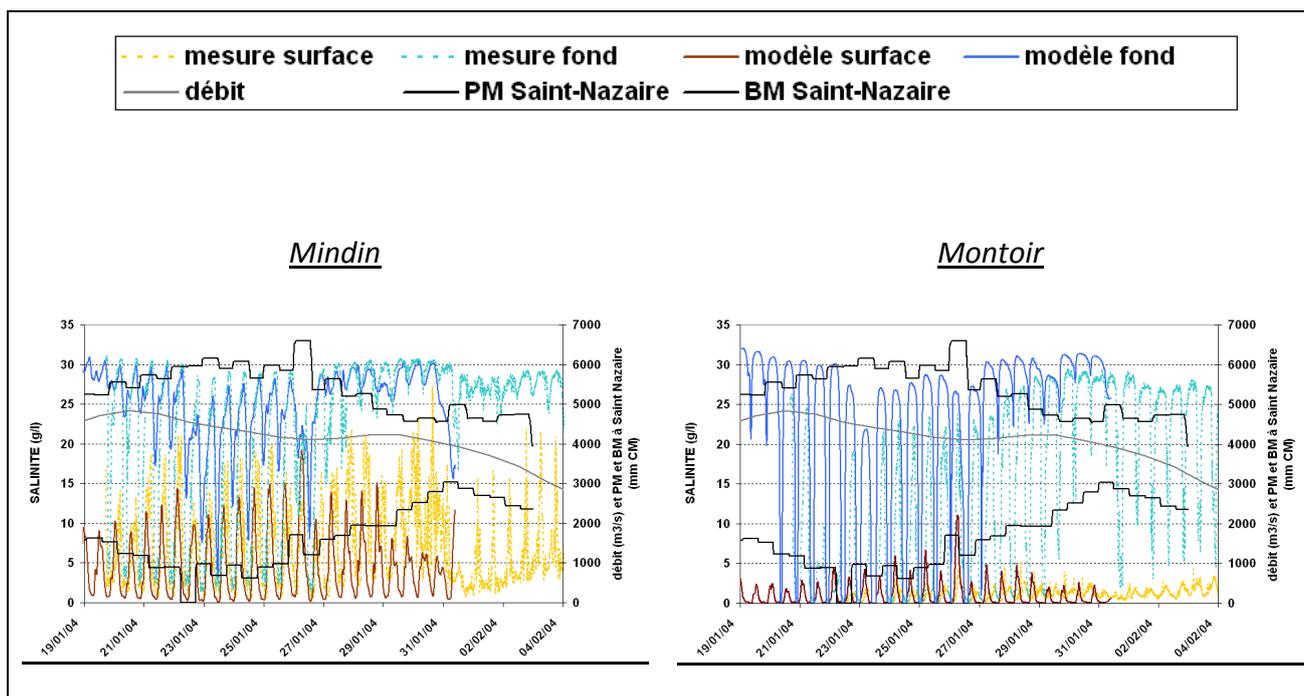


Figure 6: Comparison between measurements and model for salinity during flood-flow periods

The overall model is hence a decision-aid tool that can be used to compare the impacts of various developments on salinity, turbidity, hydrodynamics and the estuary's capacity to store or expel sediment.

The refined model of flood-prone areas, based on the same parameters as the overall model presented above, was built this time with a view to assessing the impact of the project on land submersibility and aiding the design of the mud flat. This model is hence highly refined on the study area, taking into account the drainage network and the main hydraulic structures. In particular, the farmers present on the site were able to validate the hydraulic functioning of the areas currently prone to flooding.

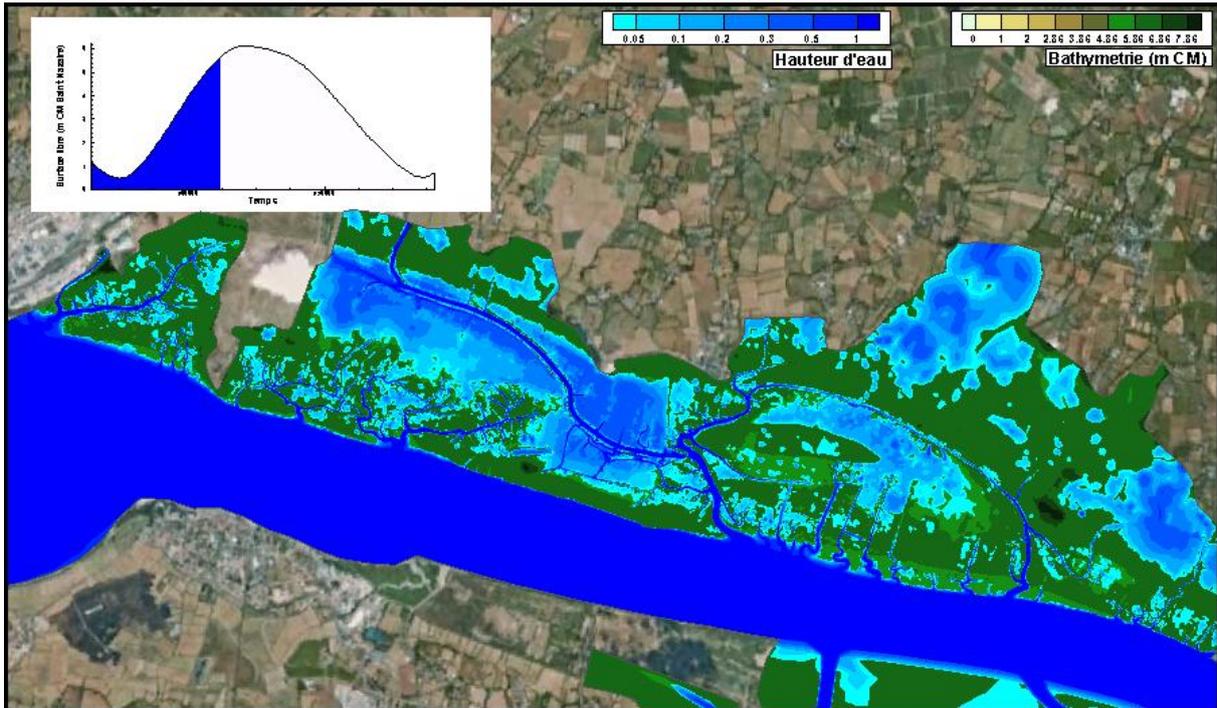


Figure 7: submersibility of the alluvial plain of the Loire estuary as calculated by the refined model (Donges – Lavau-sur-Loire sector)

7. Perspectives

The studies performed during the two previous Loire plans (1995 – 2006) proved that it was possible to implement measures with a favourable effect on Loire estuary sedimentary dynamics, opening up means of improving the functioning of the river and the habitats that depend on it for the benefit of all its users. This sizeable step forward was made using an approach based on three components that can interact as the studies progress:

- Knowledge
- Objectives

- *Levers*

The Loire estuary restoration programme is now entering a more operational phase, for which it seems important to maintain this three-component approach.

The studies and data acquisition campaigns required to complete the knowledge component will be continued: exploitation of the 3D hydro-sedimentary model of the estuary, further analyses of liquid mud dynamics, monitoring of mud flat dynamics, estimation of sediment inputs from the sea, completion of the estuary sediment balance, consideration of shipping channel maintenance dredging operations, development and extension of the continuous measurement network exploited by GIP Loire Estuaire, etc.

The consultation and communication aspect remains essential to implement more localised restoration work that is likely to affect the local stakeholders - such as the pilot project to recreate a mud flat. Using a set of collectively defined objectives as a basis ensures higher levels of project acceptance while minimising impacts on uses. In this regard, GIP Loire Estuaire intends to accompany the overall estuary restoration programme with a number of communication and consultation activities. The various events and awareness-raising activities organised on the subject of the Loire by the local authorities will also ensure that the local stakeholders and inhabitants become more conscious of the importance of the estuary on a regional scale, and of the issues in hand.

Lastly, finalising the overall restoration scenario involves examining the “channel restoration” (or “filling-in of trenches”) lever in greater depth and investigating supplementary levers, in light of progress made on the knowledge component being pursued in parallel. This search for levers will draw on the recommendations made by the expert committee formed by GIP Loire Estuaire, the Loire 3D hydro-sedimentary modelling tool and, at the final stage of the study approach, a parametric calculation tool used to quantify the morphological changes to the low-water bed and the mud flats in the medium term.

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