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Adrien Bonneu
Acceptables Avenirs

Grégory Espitalier-Nöel
Université de Toulouse, CNRS, ECOLAB

Patrice Torquet
IRIT, Université de Toulouse

Jean-Pierre Jessel
Université de Toulouse

José-Miguel Sanchez-Pérez
Université de Toulouse

See next page for additional authors

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Presenter/Author Information

Adrien Bonneu, Grégory Espitalier-Nöel, Patrice Torquet, Jean-Pierre Jessel, José-Miguel Sanchez-Pérez, Vervier Philippe, and Sabine Sauvage

Accept'Hydro: a tool for evaluating potential wetland areas at floodplain scale.

Bonneu, Adrien ⁽¹⁾, Espitalier-Noël, Grégory ^(2,3), Torquet, Patrice ⁽⁴⁾, Jessel, Jean-Pierre ⁽⁴⁾,
Sanchez-Pérez, José-Miguel ^(2,3), Vervier, Philippe ⁽¹⁾, Sauvage, Sabine ^{(2,3)*}

¹ Acceptables Avenirs, Labège, France

² Université de Toulouse; INPT, UPS; ECOLAB (Laboratoire Ecologie Fonctionnelle et Environnement), Ecole Nationale Supérieure Agronomique de Toulouse (ENSAT), Castanet Tolosan, France

³ CNRS, ECOLAB (Laboratoire Ecologie Fonctionnelle et Environnement), Castanet Tolosan, France

⁴ IRIT (UMR 5505 CNRS INP UPS UT1 UTM) - Université de Toulouse, France

* Contact: sabine.sauvage@univ-tlse3.fr

Abstract: Alluvial wetlands have the functions of hydrological regulation and water purification, but are also of interest for preventing flooding and improving the water quality of the natural environment that serves as a reserve for drinking water and biodiversity.

Delimiting these areas is often difficult because it involves both the physical characteristics (topography, river morphology etc.) and hydrodynamic characteristics of the porous medium (permeability etc.) The proposed tool, Accept'Hydro, includes a hydrodynamic simulation of the river, the alluvial aquifer and their interaction, and produces maps of alluvial wetlands with using hydrological criteria. The tool's primary step consists of selecting the studied area using Google Maps, which automatically triggers the generation of a non-uniform mesh covering this area, as well as all the inputs needed for the hydrodynamic simulation to run. The hydrodynamic model based on the equations of Peyrard *et al.* (2008) allows water levels and flow rates in the river and the alluvial aquifer to be simulated with a non-uniform mesh (cells from 1 to 200 metres per side), combined with a good performance in CPU calculation time. The software program allows the impacts of climate change (changes in hydrology and temperature) and/or anthropogenic change on the hydrodynamic functioning of wetlands to be assessed, and the impact of infrastructure and hydropower facilities on the river to be tested.

Key words: alluvial wetlands, hydrodynamic, automatic tool, floodplain

1 INTRODUCTION

Wetlands are a fundamental hydrologic landscape unit that generally form on flat areas or shallow slopes where perennial water lies near the soil surface. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. The method for wetland delineation consists of making field observations. If one of the two indicators (vegetation or soil markers) is confirmed, the area is considered a wetland. However wetland hydrology is the most basic characteristic of wetlands. Without it, hydric soils would not develop and this specific vegetation could not be sustained. The main functions of alluvial wetlands are hydrological regulation and water purification (Sanchez-Perez *et al.*, 2003a and b; Weng *et al.*, 2003), but these wetlands are also of interest for preventing flooding and improving the water quality of the natural environment that is a reserve for drinking water and biodiversity. Water is a critical factor for wetland protection. Without sufficient water, the site will not be a wetland and specific functions or improvements of functions may not be possible. This is why simulating hydrology can be useful for past, present and future evaluations of potential wetlands. Moreover, delimiting these areas is often difficult and requires time in the field. Wetland hydrologic conditions, such as periodic soil saturation at or near the soil surface, are quicker and easier to simulate with a hydrodynamic model that speeds up the delineation of potential wetland areas, *i.e.* areas in which the hydrologic conditions favour the development of hydrophytic vegetation. Existing hydrological models simulating the river/groundwater interface can be classified into three groups.

First, “surface water” models take into account exchanges between flows by source/sink functions, such as WASP5, QUAL2E, OTIS or OTEQ models. Then models based on groundwater (FEMWATER, HydroBioGeoChem, GIMRT, RT3D, PHT3D, MODFLOW, MARTHE) require several parameters and input data and generally do not manage the continuity between the surface and the porous medium. The third group concerns models that externally couple streams and aquifers, and are also based on exchanges between surface water and groundwater. They can generally simulate the effects of floods on the exchanges between runoff and aquifer (SWAT model). However, the space scales of hydrodynamic models simulating interfaces between river/groundwater are often too large (river or watershed scales) or too thin (porous medium scale), with a considerable amount of input data, long calculation times and sometimes costly field studies (MOHID, MODFLOW). The proposed tool, Accept'Hydro, which includes a unified hydrodynamic simulation of the river and the alluvial aquifer, allows maps of potential wetlands to be generated quickly and automatically based on a small amount of input data and a short calculation time.

2 METHODOLOGY

Accept'Hydro is a software program based on a hydrodynamic model simulating the hydrological functioning of a river section. This model, based on 2SWEM equations (Peyrard *et al.*, 2008), only requires a small amount of input data and has a short calculation time. First, users select a study site, then the default parameter values for the simulation are validated or modified before the automatic launch of the simulation for a minimum of ten years. The resulting water levels field is then combined with hydro/biological criteria in order to delineate potential wetlands. This is undertaken by using the characteristic parameters of wetlands such as duration and frequency of saturation near the soil surface, temperature history and length of growing season. Moreover this tool allows users to assess the impact of public/industrial projects on hydrology and therefore on wetland distribution. Accept'Hydro is therefore a useful tool for identifying, managing and protecting potential alluvial wetlands using easily obtainable data.

The program execution can be broken down into three steps: pre-processing, hydrodynamic simulation and post-processing (see Figure 1).

Accept'Hydro

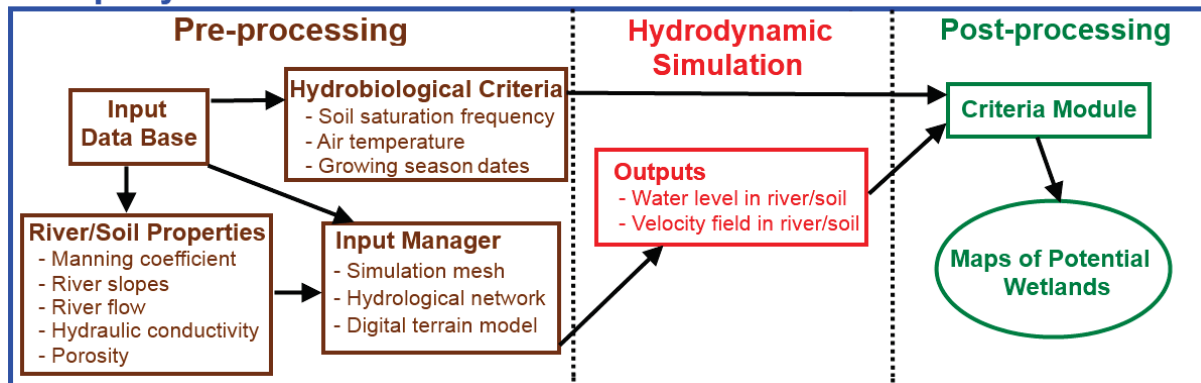


Figure 1: Program structure of Accept'Hydro

2.1 Pre-processing

The first step of the proposed tool, Accept'Hydro, includes the selection of the study site using Google Maps. After that, the software program allows users to modify the default values of river/soil properties and hydro/biological criteria (Fig. 1). The default growing season is pre-calculated by using air temperature data (Natural Resources Conservation Service, 1995), but can be modified by users. River flow and air temperatures can also be modified in order to simulate changes in climate conditions, such as amplified events of drought or flood. Moreover, Accept'Hydro allows project managers to define their construction type and area with Google Maps in order to simulate their impacts on the functioning of alluvial wetlands. The input manager uses the GDAL library for

Geographical Information System (GIS) data manipulation and then automatically generates the following inputs for the hydrodynamic simulation:

- non-uniform and static mesh: mesh cell size increases with distance from the river
- digital terrain model (DTM) of the study area: gives altitudes calculated in each mesh cell using interpolation or extrapolation methods
- main river: extracted from a hydrological network database containing river surfaces.

2.2 Hydrodynamic simulation

The hydrodynamic model, based on the 2D equations of Peyrard *et al.* (2008) and discretised by the finite volume method, allows water levels and velocities in the river and the alluvial aquifer to be simulated in a non-uniform mesh (mesh cells from 1 to 200 metres per side). A variable time step is used to preserve the convergence of numerical solutions during sizeable flood events, characterised by rapid variations in river flow. Concerning the boundary conditions, the river flow per day is applied at the river inlet. Water levels are fixed in the up/downstream aquifer and in the downstream river. Neumann conditions are defined by default along the sides of the study site, but the user can also define others, such as the Dirichlet conditions. The model is run for a minimum of 10 continuous simulated years in order to have sufficiently good precision for alluvial wetlands delineation. All simulation outputs, such as water levels and flows, are stored on a daily time step by default, although the user is allowed to modify the storage frequency. All the model parameters can be made variable in space and time, depending on the effects that the user wishes to simulate.

2.3 Post-processing

At the end of the simulation, the criteria module allows the hydrodynamic model outputs to be combined with hydro/biological criteria defined in the pre-processing step. Therefore, the water level in each cell of the soil is compared to the digital terrain during the growing period of each simulated year. If the water level is continuously near the soil surface during a sufficiently long period of the growing season, called the saturation period, then this cell is potentially a "wetland cell". This algorithm is repeated for each cell and if this criterion is validated most years in the climatic cycle, then these whole cells are considered to be potential wetlands, therefore generating maps of potential wetlands. The default values of the hydro/biological parameters of the criterion, such as the duration of the saturation period, are based on the criterion of the US Army Corps of Engineers (Environmental Laboratory, 1987; Carolyn *et al.*, 2000). The soil should be flooded or saturated near the surface during the growing season, calculated by using air temperature data (Natural Resources Conservation Service, 1995), for a period longer than 5 per cent of the growing season (the saturation period). Furthermore, this criterion must be satisfied in more than half of the simulated years for the wetland to be perennial.

3 RESULTS

3.1 Inputs

In order to test the tool, it has been applied to the Garonne river floodplain in its middle part (France), stretching from Verdun-sur-Garonne upstream to Cordes-Tolosannes downstream (Fig. 2A). The mean annual discharge in this section of the Garonne river is around 200 m³/s. A mesh is generated, consisting of cells 10 metres long each side, in and close to the river and up to 150 metres from the Garonne.

Model parameters	Values
Mean hydraulic conductivity (in m.s ⁻¹)	10 ⁻³
Mean porosity (dimensionless)	0.30
Mean Manning roughness coefficient (in m ^{1/3} .s ⁻¹)	0.04
Mean river slope (dimensionless)	0.0008
Gravitational acceleration (m.s ⁻²)	9.80665

Table 1. Values of the river/soil properties for the hydrodynamic model applied to the middle section of the Garonne floodplain (Verdun-sur-Garonne/Cordes-Tolosannes)

The Garonne river description is retrieved from the hydrological network supplied by French database “Carthage”. The digital terrain model used for the simulation is provided by the French institute IGN (1m and 25m mesh resolution).

3.2 Mapping of potential wetlands

In the present paper, the period from 1 January 1995 to 31 December 2005 was simulated. The parameter values given in Table 1 were used. The model was calibrated using piezometric data from 1999 and 2000 issued by Weng *et al.* (2003) and from other unpublished sources. During this period, the river flow shown in Figure 3 was used at the river inlet. The hydrodynamic model simulates the water level in the river and the velocity field at each time step, with a mean value of around 10 seconds. After eleven simulated years, and with the use of the US Army Corps criterion detailed in section 2.3, the map of potential wetlands in this area was generated (Fig. 4A). The whole Accept'Hydro process, from site selection to map production, takes around 72 hours with 22,000 cells and uses eight processor cores.

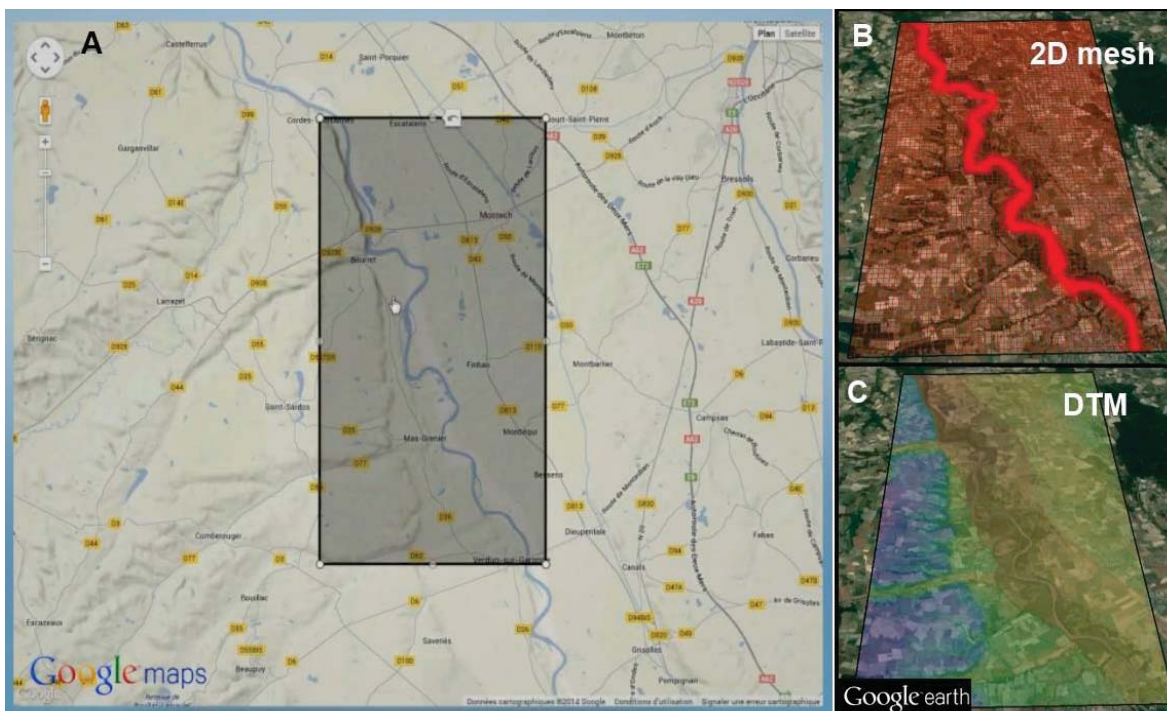


Figure 2. Pre-processing: after selection of the study site using Google Maps (A), the 2D mesh (B) and digital terrain model (C), visualised here on Google Earth.

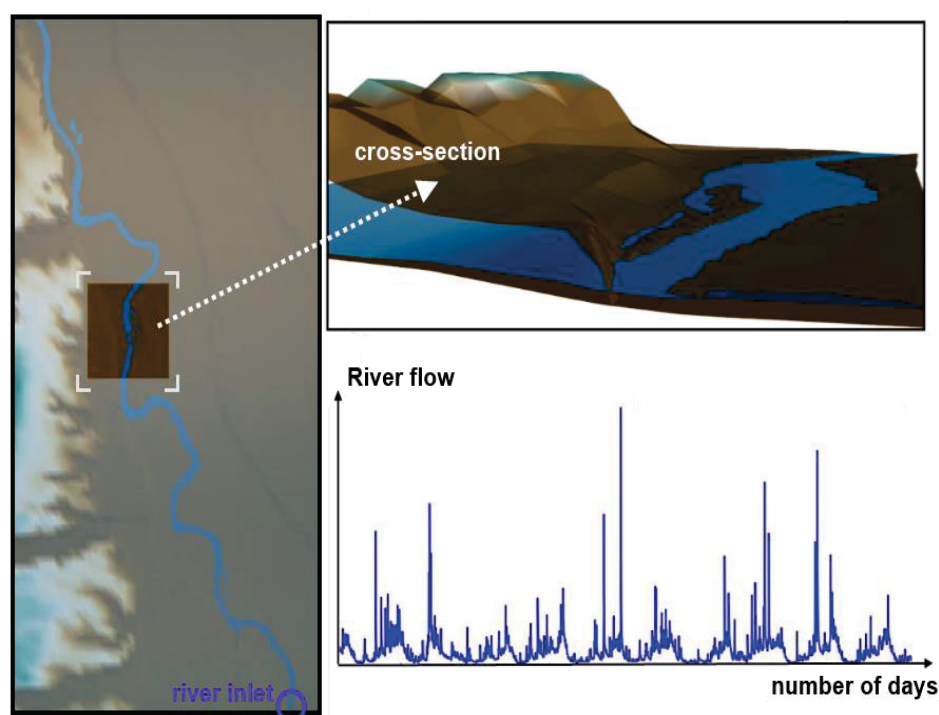


Figure 3. Example of a 3D visualisation of a cross-section, with water levels in blue, captured a few days after a flood event. The daily river flow for ten years in $\text{m}^3 \cdot \text{s}^{-1}$ is applied at the inlet.

The map of potential wetlands generated by the model and the one issued from field observations can be visually compared (Fig. 4). The potential wetlands include most of the real wetlands, which confirms the usefulness of this kind of software tool.

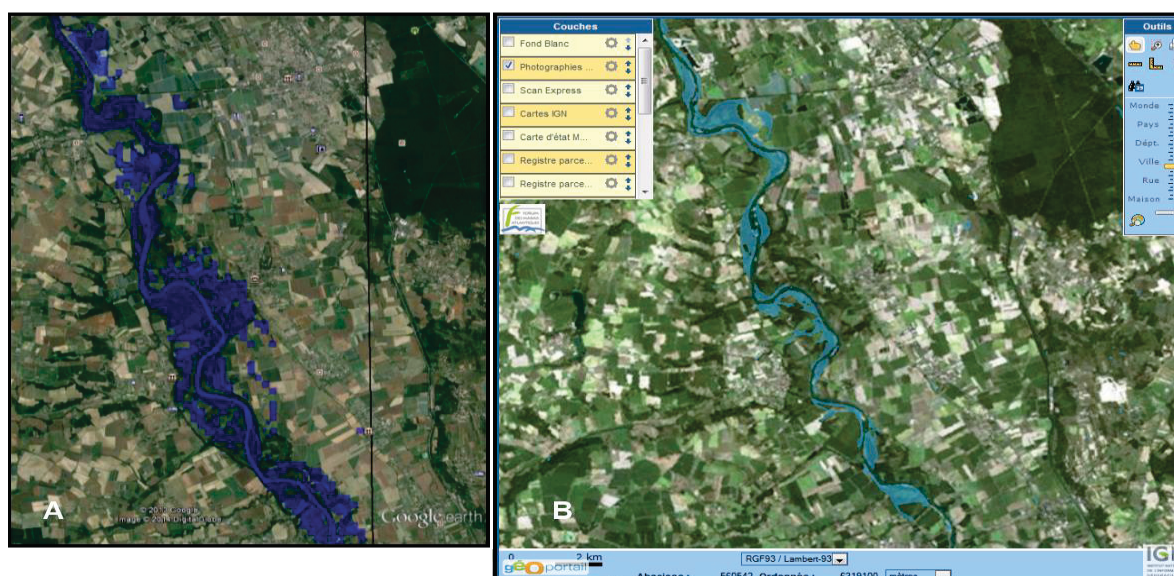


Figure 4. Comparison of maps of the potential wetlands generated by Accept'Hydro visualised on Google Earth (A), and maps of wetlands validated in the field issued by <http://www.sig.reseau-zones-humides.org/> (B)

3.3 Climate change: predicted maps

Accept'Hydro allows users to consider and simulate changes in climatic conditions, especially by modifying the inlet river flow and/or air temperature. These predictive maps can be useful for understanding and anticipating the impacts of climate change on the distribution of potential wetlands. Figure 5 presents a virtual example of the modification of the flow at the inlet. The river flow was amplified in order to increase the effects of flood events as well as the water level. After eleven simulated years using the amplified flow, the distribution of potential wetlands is much more extensive than in reality (see the green map in Figure 5B). The same method can be applied for theoretical cases where the flow is greatly reduced. The water level is much lower than in the previous cases (see the orange map in Figure 5B). Each real daily flow of a magnitude above/below $400 \text{ m}^3/\text{s}$ was multiplied/divided by two in order to create the virtual amplified/reduced flow in Figure 5.

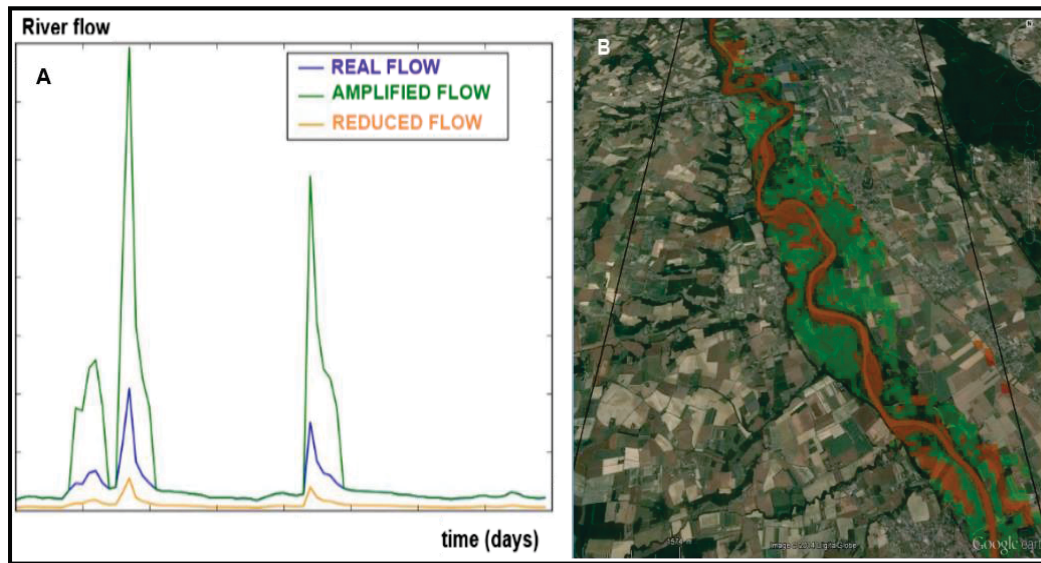


Figure 5. A: The blue curve is an example of real flow taken from data, the green and orange curves correspond to the amplified and reduced flow respectively, taking climate change into account for a few days. **B:** Predictive wetland maps from the amplified and reduced flow curves (green and orange respectively) are shown on the right side (with Google Maps). The predictive wetland maps from the amplified river flow include the smaller predictive wetland map from the reduced river flow.

The resulting maps can be useful for evaluating predictive scenarios of climate change (flow and temperature) and for estimating the drying up of rivers and wetlands, or extension of flood events over the longer term.

3.4 Impact of industrial or restoration projects

Accept'Hydro also allows project managers to evaluate the impact of river restoration or industrial projects on the distribution of potential wetlands. Building on the alluvial floodplain or restoring the river modifies water flow locally and may therefore impact on potential wetlands in space and time. The user can modify soil and/or river properties locally, such as hydraulic conductivity, porosity, Manning coefficient *etc.* The digital terrain can also be modified in any of the mesh cells. In the present paper, a virtual case is presented in Figure 6A. A sketch of a factory has been added, and a meander in the river has been replaced by a straight channel. Values of hydraulic conductivity and porosity are 10^{-3} m.s^{-1} and 0.3 (dimensionless) respectively throughout (Table 1), except in the factory area in which it becomes 10^{-8} m.s^{-1} and 0.1 respectively. After 11 simulated years, the resulting maps of potential wetlands are shown on the right of Figure 6. As in the case of climate change, this predictive map provides invaluable information for assessing the impact of construction on alluvial wetlands.

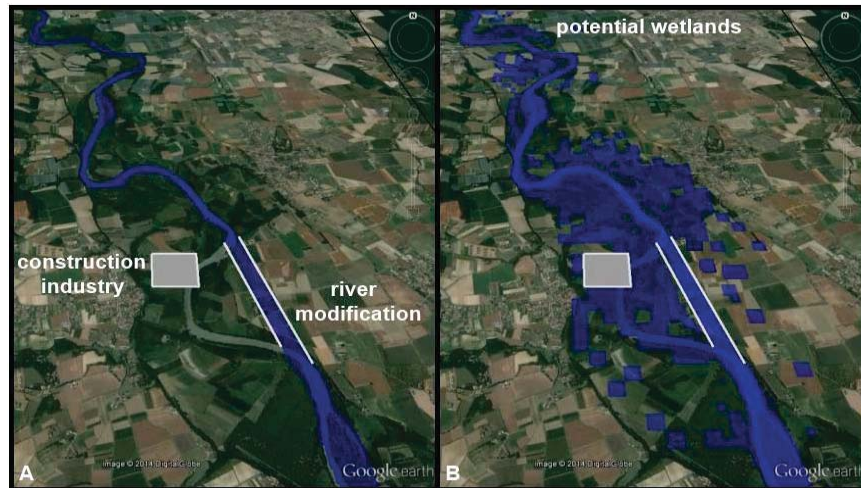


Figure 6. Definition sketches of a factory and a river modification by the user (A); map of potential wetlands generated by Accept'Hydro after considering these modifications (B)

4 DISCUSSION

Accept'Hydro is a software program that includes a 2D hydrodynamic model validated at floodplain scale. However, in order to improve the accuracy of the simulation, a multi-scale model approach can be useful for considering the impact of different land and settlements on the floodplain. A local 3D model around the modified area for industrial/public projects could help provide a better description of the hydrology and modifications in river flow, although this approach needs additional input parameters.

Furthermore, the criteria module has to be calibrated on different climate conditions. The US Army Corps criterion was used by default (Environmental Laboratory, 1987). However, the criterion should require a duration that is inversely dependent on soil temperature (Wakeley, 2002). In other words, the required duration of saturation should intuitively be longer when soil temperatures are low (in the winter and early spring in temperate areas) than when they are high (in summer and early autumn in temperate areas). This assumption must be tested on different study sites with differing climate conditions in order to develop regionalised hydrological criteria.

5 CONCLUSIONS

Accept'Hydro is an automatic tool for evaluating potential wetland areas at floodplain scale. This software requires a small amount of input data which is relatively easy to obtain or buy. The whole process in this software requires relatively short CPU times. Moreover, the dynamic aspect of Accept'Hydro is useful for studying the evolution of wetlands over time, for the delimitation and restoration of current wetlands (with yearly updates for example), but also for the evaluation of potential wetlands in future by considering constructions in rivers and/or on their floodplains, and changes in climate conditions.

Maps of potential wetlands generated by the software program can have a precise space step, depending on the accuracy of the digital elevation model input. Stakeholders responsible for drawing up wetland inventories in the field may be interested in buying an approach of this kind because Accept'Hydro allows them to target potential wetland areas for confirmation in the field.

This tool is particularly flexible and useful for project managers, helping them to evaluate use impacts and also plan issues related to water management. Accept'Hydro allows stakeholders to evaluate the impacts of projects and helps them choose a solution that has a smaller impact on both water flow and water quality. This approach can be combined with socioeconomic models to help develop a solution that is acceptable to all stakeholders.

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