Two-dimensional numerical modeling of the uprooting of macrophytes on a reach of the Rhône River

Modélisation numérique bidimensionnelle de l'arrachage des macrophytes sur un tronçon du Rhône

Geraldine Nogaro[1,] Florian Cordier[1], Nicolas Claude[1,3], Bastien Jouy[1], Sara Puijalon[2]

Organismes et adresses
[1]EDF Research and Development, National Hydraulics and Environment Laboratory (LNHE), 6 Quai Watier, 78401 Chatou, France (contact: geraldine.nogaro@edf.fr)
[2] Univ Lyon, Université Claude Bernard Lyon 1, CNRS, ENTPE, UMR 5023 LEHNA, 3-6 rue Raphaël Dubois F-69622, Villeurbanne, France
[3]Adresse actuelle : EDF Centre d'Ingénierie Hydraulique (CIH), 4 allée du Lac de Tignes, 73290 La Motte Servolex, France

RÉSUMÉ

Depuis quelques années, le développement de certaines espèces de macrophytes (plantes aquatiques visibles à l'œil nu) dans les cours d'eau français entraîne des problèmes récurrents pour les usagers et les gestionnaires des milieux aquatiques (pêche, navigation, pompage d'eau, etc.). Un enjeu majeur est que ces végétaux, s'ils sont transportés par les cours d'eau (par exemple, en cas d'augmentation des débits), risquent de colmater les dispositifs de filtration des ouvrages hydroélectriques. Un programme de recherche entre EDF et l'UMR CNRS 5023 est actuellement en cours afin de mieux comprendre les mécanismes de mise en dérive (*i.e.*, force et modalités d'arrachage) des macrophytes en milieu fluvial. L'objectif de cette étude numérique est de déterminer les conditions de débits entrainant l'arrachage des herbiers de macrophytes (*i.e*. quand la force de trainée associée aux plantes devient supérieure à la force d'arrachage) et d'étudier leur mise en dérive au sein d'un tronçon du Rhône. Ce travail s'appuie sur l'utilisation du code hydrodynamique bidimensionnel Telemac-2D (développé au sein du système *open-source* Telemac-Mascaret) couplé à un module simulant l'arrachage des macrophytes.

ABSTRACT

In recent years, the development of certain species of macrophytes (*i.e.,* aquatic plants large enough to see with the naked eye) in French streams and rivers has led to recurring problems for users and managers of aquatic environments (fishing, navigation, water pumping, etc.). A major issue is that if these plants are transported by rivers (for example, during high flow events), they can induce the clogging of the water intakes of hydroelectric structures. A research program between EDF and UMR CNRS 5023 is currently underway to better understand the drifting mechanisms (uprooting conditions and force) of macrophytes in fluvial environments. The objective of this numerical study is to determine the flow conditions leading to the uprooting of macrophyte meadows (*i.e.,* when the drag force of the plants becomes greater than the uprooting force) and to study their transport within a reach of the Rhône River. This work is based on the use of the two-dimensional Telemac-2D hydrodynamic code (developed within the open-source Telemac-Mascaret system) coupled with a module simulating the uprooting of macrophytes.

1 INTRODUCTION

In recent years, the development of certain species of macrophytes (i.e., aquatic plants large enough to see with the naked eye) in French streams and rivers has led to recurring problems for users and managers of aquatic environments (fishing, navigation, water pumping, etc.). The major issue is the risk of clogging of the water intakes of hydroelectric structures occurring when the plants are transported by rivers (for example, during high flow event). A research program between EDF and UMR CNRS 5023 is currently underway to better understand the drifting mechanisms (conditions and force of uprooting) of macrophytes in fluvial environments. The objective of this numerical study is to determine the flow conditions leading to the uprooting of macrophyte patches (i.e., when the drag force of the plants induced by flow is higher than the uprooting force) and to study their transport within a reach of the Rhône River.

2 MATERIAL AND METHODS

The study site is located on a cut-off channel of the Rhône River between Loriol's dam and Cruas Power Plant (Fig. 1A). A two-dimensionalhydrodynamic code called Telemac-2D (developed within the open-source Telemac-Mascaret system) was coupled with a module simulating the uprooting of macrophytes such as *Callitriche sp.* (Fig. 1B) and *Elodea canadensis* (Fig. 1C).

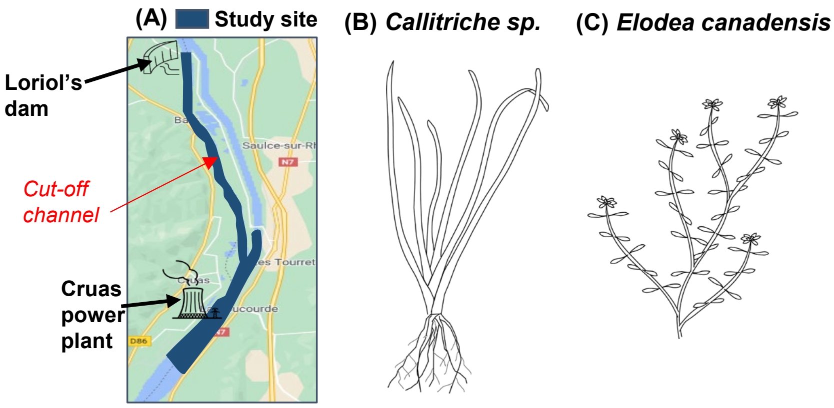

Figure 1. (A) Study site on the Rhône River (cut-off channel indicated by the red arrow), (B) *Callitriche sp.* and (b) *Elodea canadensis*. Original drawing by S. Puijalon.

3 RESULTS AND DISCUSSION

3.1 Laboratory measurements of macrophyte's drag forces

Plant patches were sampled in the field with different biomasses (from 8 to 800 g fresh mass) and the drag force of each patch was measured using a force transducer (50 N) for different water velocities (0.1 to 0.8 m/s) in a laboratory flume (Fig. 2A). Results showed that the drag force of plant patches increased with increased velocity with a certain level of reconfiguration (see examples for *Callitriche platycarpa* in figure 2B).

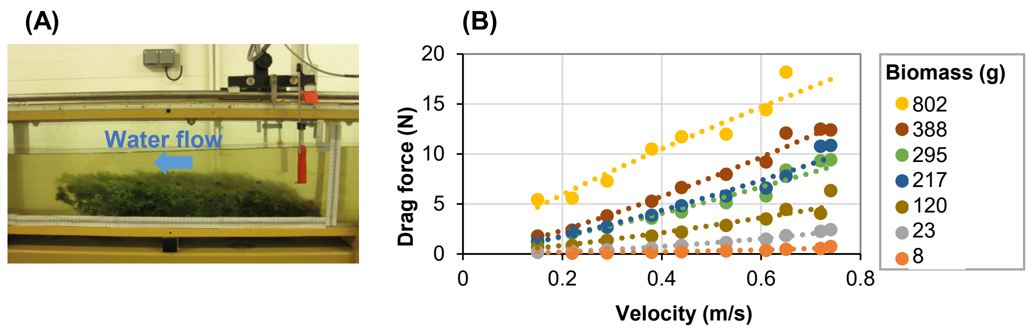

Figure 2. (A) Measurements of macrophyte's drag force in a laboratory flume (example with *Callitriche platycarpa*) and (B) Drag forces of *Callitriche platycarpa*'s patches with increasing biomass, depending on the water velocity in the flume

3.2 Use of Sand-Jensen's model (2008) on isolated plants

Sand-Jensen (2008) described the combined effect of velocity and biomass of isolated plants and their interaction in determining the magnitude of drag with the following regression model:

$$\log(F_d) = z_U\log(U) + z_B\log(B) + z_{UB}\log(U)\log(B) + k_{UB}$$

where F_d = drag force (N), U = velocity (m/s), B = biomass (g fresh weight), z_U, z_B, z_{UB}= slopes, and K_{UB} = constant.

The Sand-Jensen's model (2008) correctly predicted measured drag forces in the flume for the 2 tested species (Figs. 3A and 3B) and seemed to be a valid formulation for implementation on the numerical model. The numerical model will compare the macrophyte drag forces with the uprooting forces measured in field using a new experimental device (Puijalon et al., 2021).

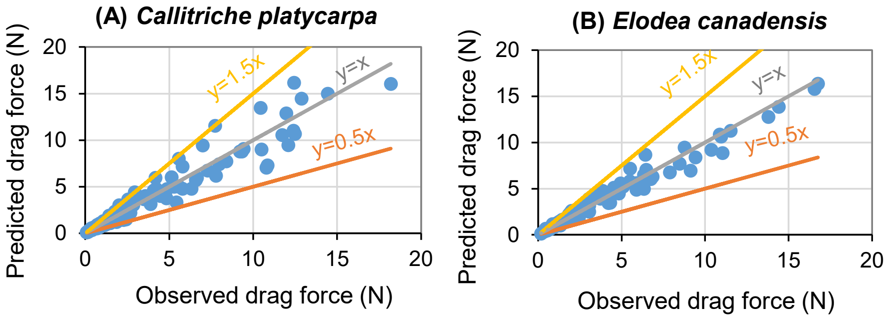

Figure 3. Relationships between observed and predicted drag forces by the model log(Fd) = zUlog(U) + zBlog(B) + zUBlog(U)log(B) + kUB from Sand-Jensen (2008) calibrated on the measurements made in the flume with (A) *Callitriche platycarpa* and (B) *Elodea canadensis*

3.3 First simulations from the numerical model

First results of our study showed that water flow of 650 m³/s in the cut-off channel downstream of Loriol's dam could trigger strong biomass uprooting suggesting a threshold flow for massive macrophyte uprooting (Figs. 4A and 4B).

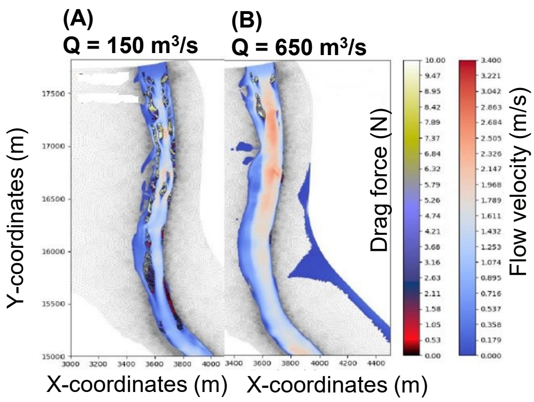

Figure 4. Maps of drag forces from the numerical model associated with macrophytes and water velocity for a water flow (Q) in the cut-off channel of the Rhône river of (A) 150 m³/s and (B) 650 m³/s.

4 CONCLUSIONS AND PERSPECTIVES

Our numerical study showed the coupling of a hydraulic model (Telemac-2D) to a macrophyte uprooting module (based on measurements of drag forces in a laboratory flume) to estimate the uprooting rates and threshold of macrophytes on a reach of the Rhône River. Uprooting dynamics might be very sensitive to the drag force equation, macrophyte biomasses, and flow rates in the river, but not very sensitive to the type of morphology and species of macrophytes. Those very first results need to be confirmed by field data from a new experimental device for measuring uprooting force of aquatic plants (Puijalon et al., 2021) tested with long term data of macrophyte dynamics in order to study the transport of uprooted macrophytes within a reach of the Rhône River.

REFERENCES

Sand-Jensen, K. (2008) Drag forces on common plant species in temperate streams: consequences of morphology, velocity and biomass. *Hydrobiologia*, 307-319

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