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A Lattice Boltzmann Model to Study Sedimentation Phenomena in Irrigation Canals

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Abstract. Fresh water is one of the most significant resources for human activities and survival, and irrigation is among the most important uses of water. The sustainibility and performance of irrigation canals can be greatly affected by sediment transport and deposition. In our previous works, we proposed a Lattice Boltzmann model for simulating a free surface flow in an irrigation canal, as an alternative to more traditional models mainly based on shallow water equations. Here we introduce the sedimentation phenomenon into our model by adding a new algorithm, based on the earlier work by B. Chopard, A. Dupuis and A. Masselot [9, 11, 12, 27]. Transport, erosion, deposition and toppling of sediments are taken into account and enable the global sedimentation algorithm to simulate different transport modes such as bed load and suspended load. In the present work, we study both the behaviour of a sediment deposit located at an underflow submerged gate (depending on the gate opening and the flow discharge) and the influence of the presence of such a deposit on the flow. Both numerical and experimental validations have been performed. The experiments were realized on the micro-canal of the LCIS laboratory at Valence, France. The comparisons between simulations and experiments give good qualitative agreement.

AMS subject classifications: 76T10, 76B07, 76D06, 76T20

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1 Introduction

Nowadays, water resources are becoming more and more scarce. As the world population increases, so does the demand of fresh water, while the supplies are slowly decreasing due to various causes. Therefore, good management of water resources is a problem of increasing importance. Since one of the most important uses of water is irrigation, the development of efficient and optimal controllers for irrigation canals systems is a challenging engineering problem.

Various types of perturbations can affect irrigation canals. Among them, one can count sediment or algae transport and deposition. The topic of sedimentation in general covers a wide variety of situations and phenomena. The formation of ripples and dunes under various types of flow has been studied as well (for instance, in [17, 33, 34]). The general problem of erosion and transport in shallow water has also been treated by several authors (see, e.g., [2, 13]; see also [10] for a study on the structure and formation of sediment deposits in an experimental channel).

Sedimentation in irrigation canals cause various problems, usually resulting in a decrease in the discharge provided by the system, and affecting maintenance costs. Understanding and modeling the sedimentation processes is thus a necessity in order to improve control systems operating on irrigation canals. Predictors have been developed in order to calculate the sediment transport capacity for an irrigation canal. However, these methods are usually designed for a given set of situations and flow conditions, and even when used accordingly, their accuracy is limited [32].

In this work, we will propose an introductory study of sedimentation problems in the context of a LB modeling of an irrigation canal.

Irrigation canals are hydraulic systems where the flow dynamics is usually described with a set of partial differential equations which derives from the Navier-Stokes equations, and known as shallow water equations; they may also be called Saint-Venant (SV) equations. These equations can be expressed as follows:

$$B\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=0, \tag{1.1}$$

$$\frac{\partial Q}{\partial t}+B\frac{\partial h}{\partial x}\cdot\left(gh-\frac{Q^2}{h^2B^2}\right)+\frac{\partial Q}{\partial x}\cdot\frac{2Q}{Bh}+gBh\cdot(S_f-\bar{S})=0 \tag{1.2}$$

for all $(x,t)\in]0,L[\times R^+$ where x is the spatial location along the canal and t is the temporal variable; Q is the discharge, g the gravity, h the water elevation, B the width of the channel. The quantity $\bar{S}$ is the channel slope and S_f is the friction between the water and the canal walls.

Such equations are used for modeling the flow inside a given section of a canal. The different sections communicate through various types of gates. The behavior of these gates is also described by specific equations that basically define the boundary conditions of the previous SV equations. For instance, the following equation is a standard discharge