Modelling a complex lowland irrigation channel network to optimize management operation under future scenarios of climate change

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1. INTRODUCTION

At the global level, nearly 70% of freshwater withdrawals is used for irrigation purposes [1], additionally, the world population, whose alimentation is based on the products of the agricultural sector, is growing and estimated to reach 9.7 billion inhabitants in 2050 [2]. On this basis, the relevance of the optimization of water volume distribution in the agricultural sector is undeniable. In Lombardy (northern Italy), Consorzio Irrigazioni Cremonesi (CIC) was founded in 1883 and inherited a pre-existing and ancient channel network. The maximum discharge derived by CIC is 57.8 m^3/s which is distributed at many withdrawal points by 261 km long network of open channels. These discharges are provided by the regulation of pre-alpine Lake Iseo and Lake Como (Figure 1). Although the management of these lakes is expected to change under the effects of climate change, on the other hand the management of the irrigation water system is very stiff, based on pure historical custom and relying on the practical experience of a small group of people. It is likely that this traditional management will become unsuitable in the future under the evolving scenaria of climate change. One can expect that the regressive knowledge provided by practical experience will be of little use in search of new optimized water distribution frameworks. In this direction, the opportunities provided by a mathematical model will be essential for enhancing the performance of the irrigation system, providing the opportunity to analyze the consequences of new water distribution patterns in the channel network [3].

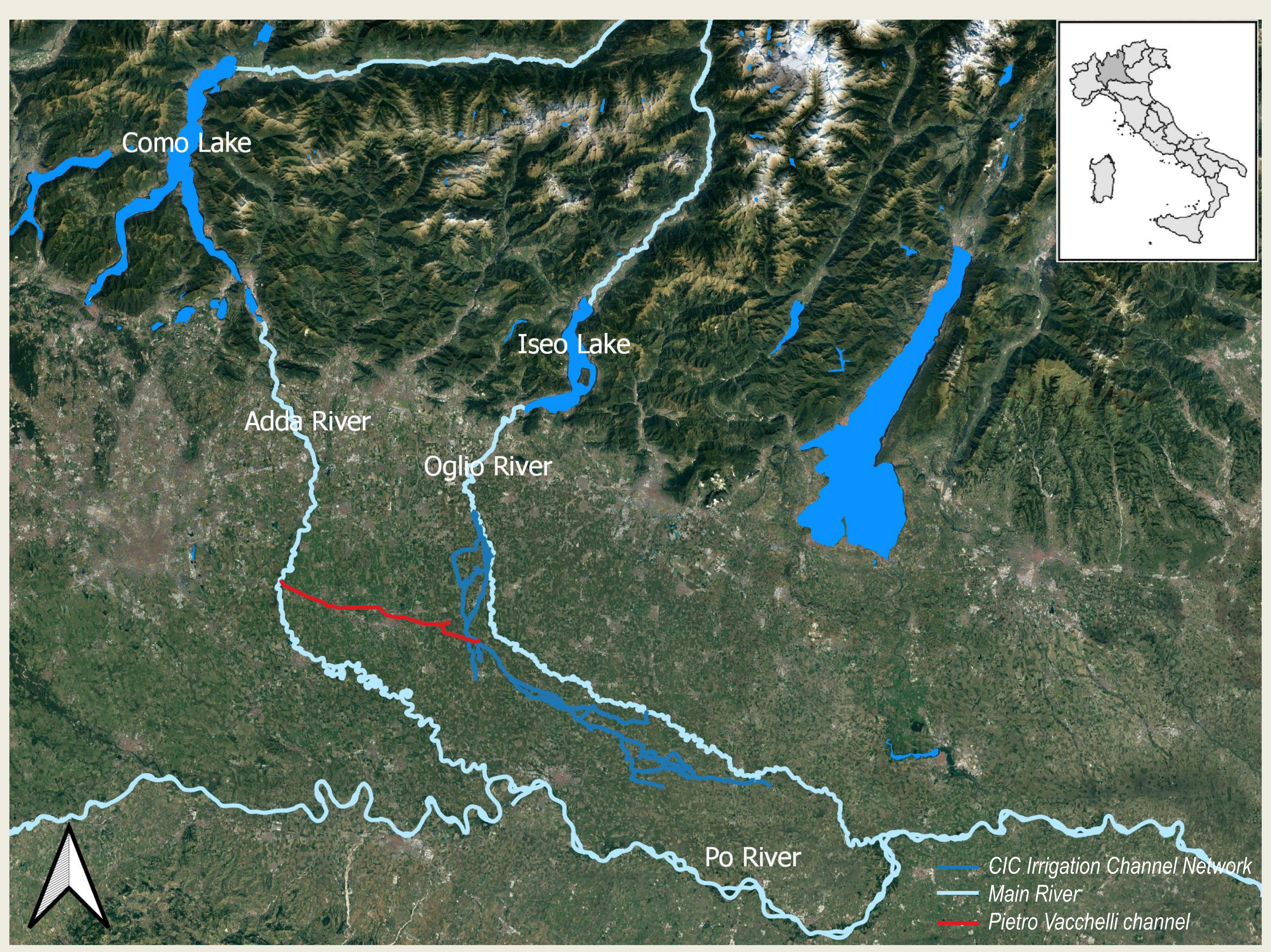

Figure 1. Satellite view of the study area highlighting the channel network managed by CIC. The figure shows the regulated prealpine lakes Como and Iseo that supply water to the network. The red line show the most important distribution channel in the network, i.e., the Vacchelli channel whose simulations are shown on the right

2. METHODS

The one-dimensional shallow water equations governing the unsteady flow in an open channel network are based on the conservation of mass and momentum (1) and (2).

$$\frac{\partial A}{\partial t} + \frac{\partial Au}{\partial x} = q \quad (1) \qquad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = -g\frac{\partial \eta}{\partial x} - \gamma u \quad (2)$$

where t [s] is the time, x [m] is the spatial position, $u(x,t)$ [m/s] and $\eta(x,t)$ [m] are the unknown velocity and water surface elevation, $A(x,t)$ [m^2] is the area of the cross-section, q [m^2/s] is the source/sink term and γ [s^{-1}] is the friction term. To solve the system of equations (1) and (2) the numerical method proposed in [4] was implemented and validated with different test cases. The implemented solver was then applied to the reproduction of the flow distribution along the Vacchelli channel (red line in Figure 1) in unsteady conditions.

3. RESULTS

CASE 1 – IDEALIZED CHANNEL NETWORK

To test the performance of the model in an unsteady flow simulation through a general complex channel network we repeated the test case proposed in [6]. A schematic view of the looped channel network is shown in Figure 2-a. The results of the simulation are compared with the solution obtained with the software HEC-RAS 6 [5] and are shown in Figure 2-b,2-c,2-d,2-e.

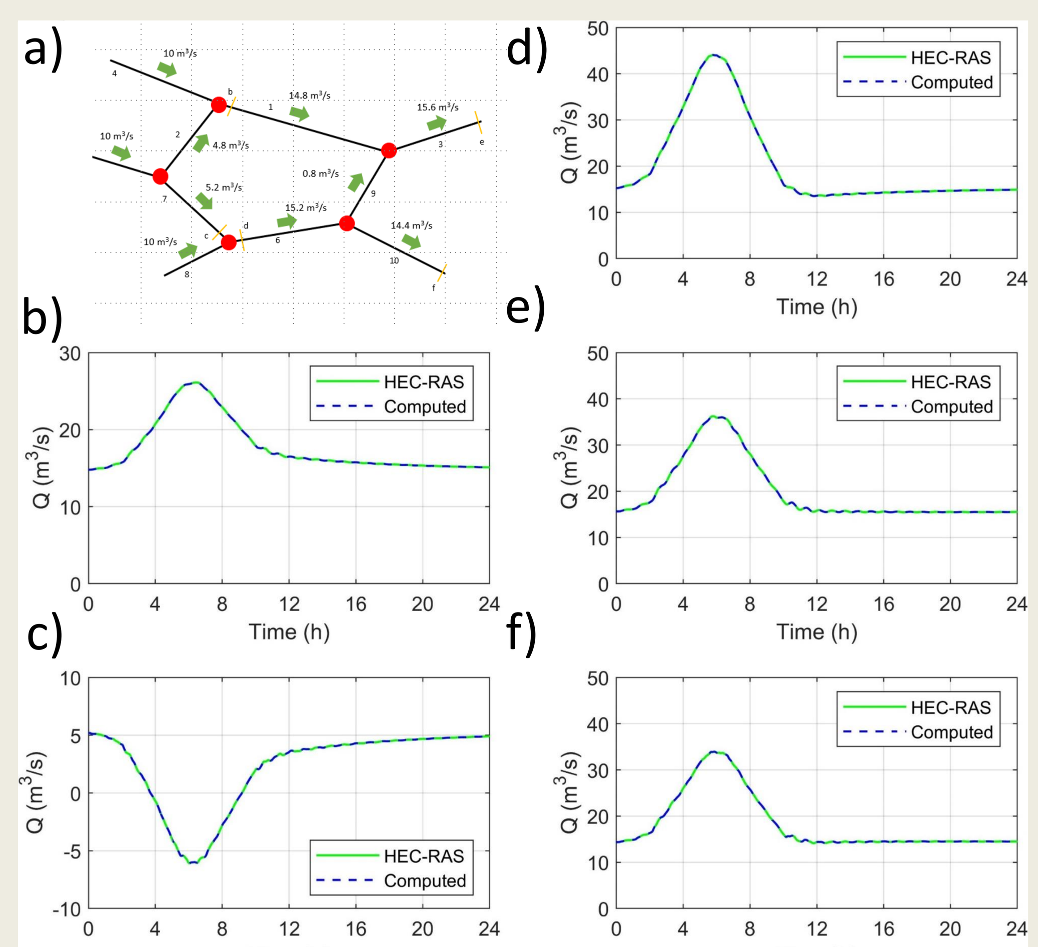

Figure 2. Comparison of the obtained results for the second test case; a) Schematic view of the looped channel network; b) computed discharge at the first node of the channel 1; c) last node of the channel 7; d) first node of channel 6; e) last node of channel 3; f) last node of channel 10.

CASE 2 – PIETRO VACCHELLI CHANNEL

The Vacchelli channel dates back to 1892 and is the most important channel managed by CIC. The length of this 25 m-wide trapezoidal channel is 34.5 km and it transfers 38.5 m^3/s outside from the Adda river watershed to the CIC irrigation area. Along the route the discharge is distributed to several secondary channels that feed the CIC channel network.

After digitalizing the complex timetable of the water distribution at the secondary channels, we performed some numerical simulations with the implemented solver for the 2022 irrigation season, which was characterized by a severe drought.

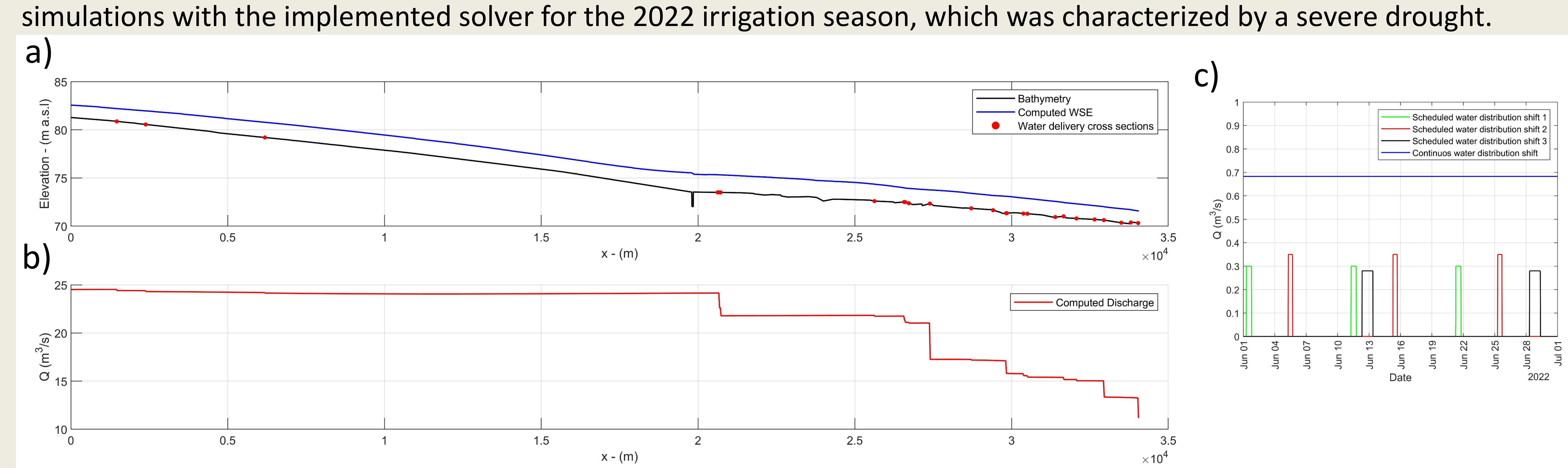

Figure 3. a) Example of water surface profile computed during the unsteady flow simulation, b) example of the discharge profile along the Vacchelli channel computed during unsteady flow simulation, example of different water shift digitalized from the complex timetable of the water distribution.

The comparison of the preliminary results obtained with the implemented solver and the data collected by CIC highlights some criticalities:

- The assumption of a roughness coefficient constant in time is unrealistic. There is clear evidence that the vegetation growth during the summer season has a surprisingly strong effect on the channel conveyance.
- The assumption of the instantaneous water withdrawals at the secondary channels, according to theoretical timetable of the water distribution, implemented as a space and time-variable source term in eq. (1), is simplistic with respect to the progressive gate adjustments done by the CIC operators.

4. CONCLUSION

Some preliminary results obtained in the mathematical modeling of the complex historical water irrigation channel network managed by CIC are presented. This network, dating back to the 16th century, is one of the most important in northern Italy and until now has been managed only on the basis of empirical experience. We believe that in a changing climate scenario, the advantages provided by mathematical model of the irrigation channel network will be essential to analyze the future behavior of the system. To this purpose, the numerical method proposed in [4] was implemented and tested for different numerical test cases. The numerical method proved accurate, simple and robust. It was easily generalized to a complex network of channels. The proposed approach has already provided interesting feedbacks that led to a deeper understanding of the system

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