Socio-hydrological modelling: the influence of reservoir management and societal responses on flood impacts

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INTRODUCTION

Over the last few years, several socio-hydrological studies have investigated the risk dynamics generated by the complex interactions between floods and societies, with a focus on either changing reservoir operation rules or raising levees [1-5]. Yet, the mutual relations between changing reservoir management strategies and societal responses to flood risk remain largely unexplored. Within the socio-hydrological context, no models able to clarify the interactions between the water management reality and the social sphere can be found.

This work gains insights into the interactions between reservoir management policies, societal strategies and the occurrence of floods. In particular, the aim of this study is to:

- explore how changes in water management policies can influence flood risk and societal flood mitigation strategies;
- evaluate how different future flow scenarios can influence flood impacts.

METHODOLOGY

A new socio-hydrological model of human-flood interactions that represents both changes in the reservoir management strategies and updating of the levee system was developed (*Albertini et al., 2020 – submitted to Water*). This model couples the reservoir management module proposed by Di Baldassarre et al. [1] and modified in some of its parts by Ridolfi et al. [6] with the downstream flood module developed by Di Baldassarre et al. [3]:

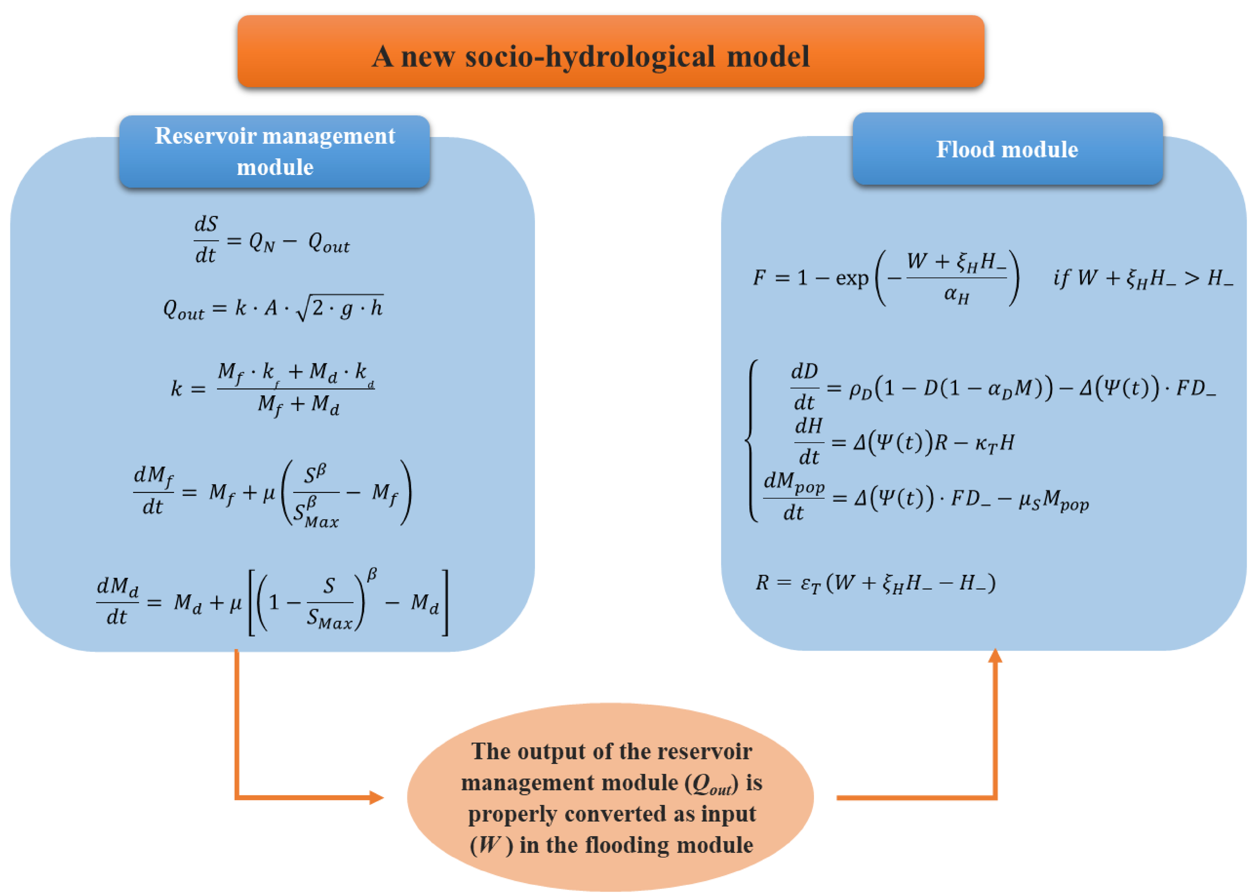


Figure 1

- A sensitivity analysis was carried out to assess how reservoir management policies may alter the occurrence and magnitude of extreme flood events and highlight how societal flood mitigation strategies can be affected by changes in the operating rules of reservoirs.

- Floodplain dynamics were explored by simulating future flow scenarios in the city of Brisbane, Australia. The reservoir management module was applied to the Wivenhoe Dam, Queensland's main dam.

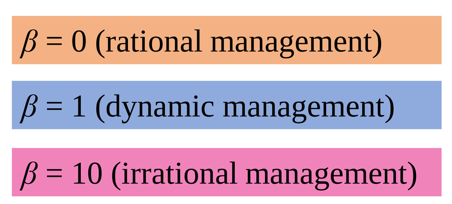
The proposed model was applied to simulate three prototypes of floodplain management strategies:

- **green systems**, in which societies resettle outside the flood-prone area;
- **technological systems**, in which societies implement structural measures, such as levees;
- **green-to-techno systems**, in which societies shift from green to technological approaches.

The green system was assumed to be the initial condition. The parameter of the model that describes the societal inclination to technological or green approaches is δ_D, called *green-to-techno shift threshold.*

SENSITIVITY ANALYSIS AND RESULTS

By simulating the management of a fictional reservoir, the sensitivity of the model against the β parameter was carried out. This parameter describes the level of bias between flood and drought memories of the reservoir management system.



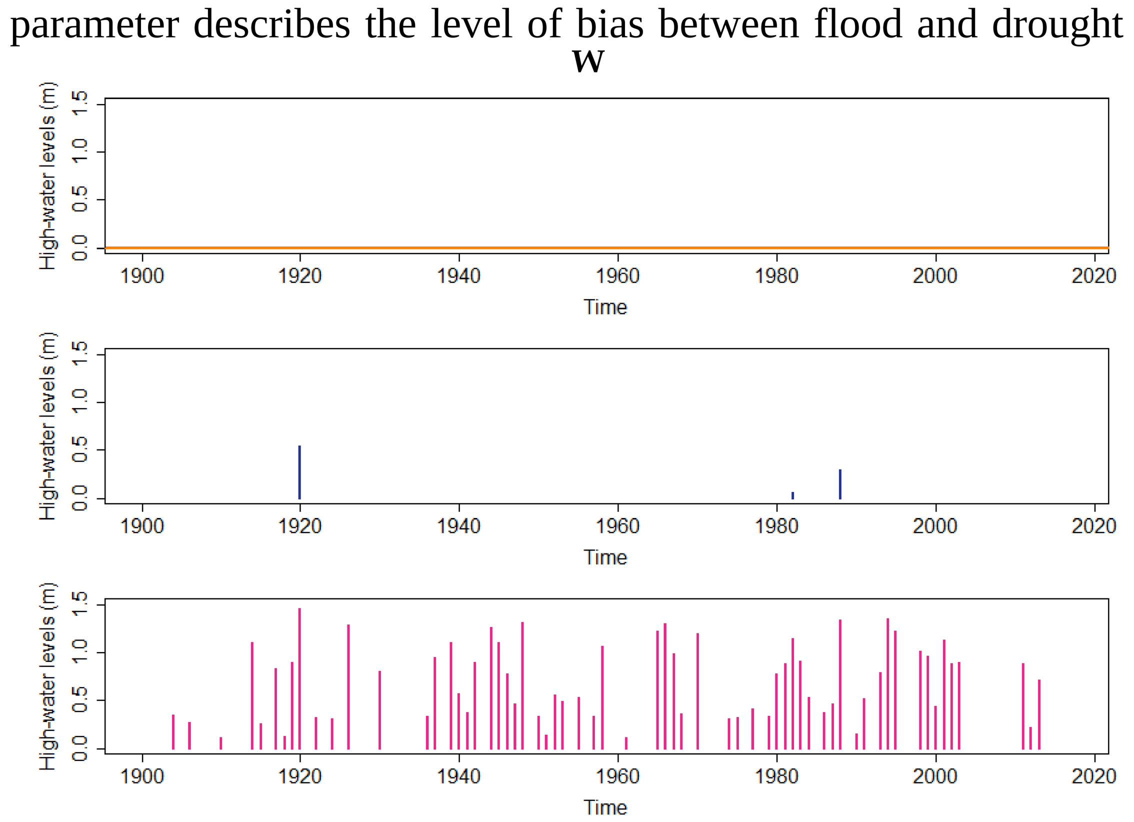


Figure 2

The level of bias β significantly influences flood risk (Figure 2). Indeed, high-water levels (W) are recorded only in the case of β = 1 (3 flood events) and β = 10 (63 flood events).

A comparative analysis of the dynamics of floodplain management strategies of green (δ_D= 0.90), green-to-techno (δ_D = 0.38) and technological systems (δ_D = 0.01) in response to variations of reservoir policies is reported in Figure 3.

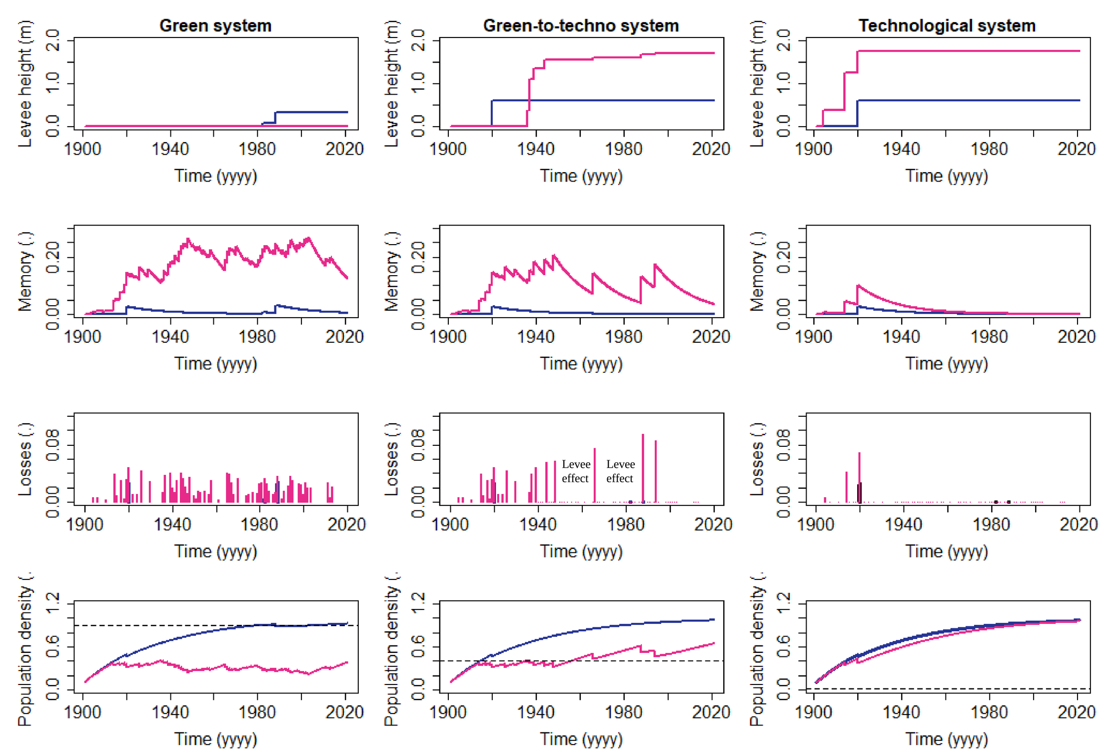


Figure 3

The main results are:

- For β = 1 the green system shifts to a technological system because of the human-induced lack of flooding;
- For β = 10 the levee effect can repeatedly be observed in the green-to-techno system;
- Technological systems build levees in response to each flood events.

MODEL APPLICATION AND RESULTS

The model was applied to the Brisbane River region, Australia, by simulating the operations of Wivenhoe Dam under four different future hydrological regime scenarios synthetically generated based on the available historical flow data (Figure 4).

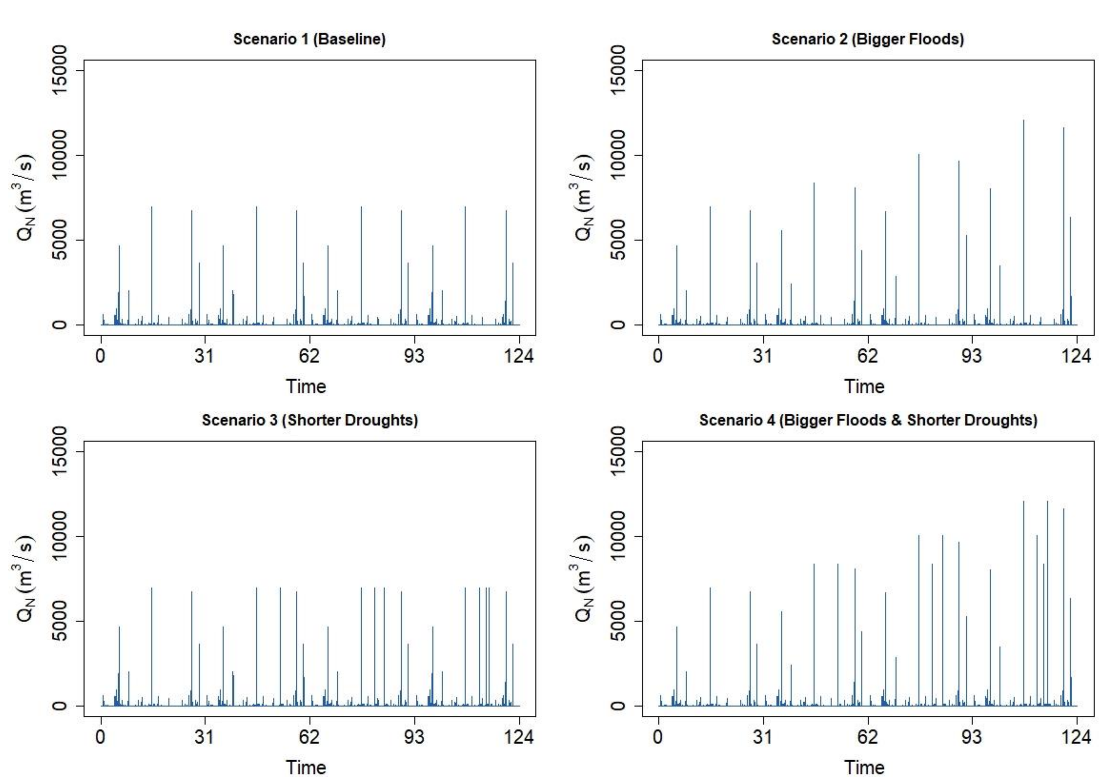


Figure 4

Figure 5 reports the dynamics of green, green-to-techno and technological systems for the high-water levels (W) of scenarios 1 and 4 (Figure 6). The lighter colour indicates scenario 1 while darker colour indicates scenario 4.

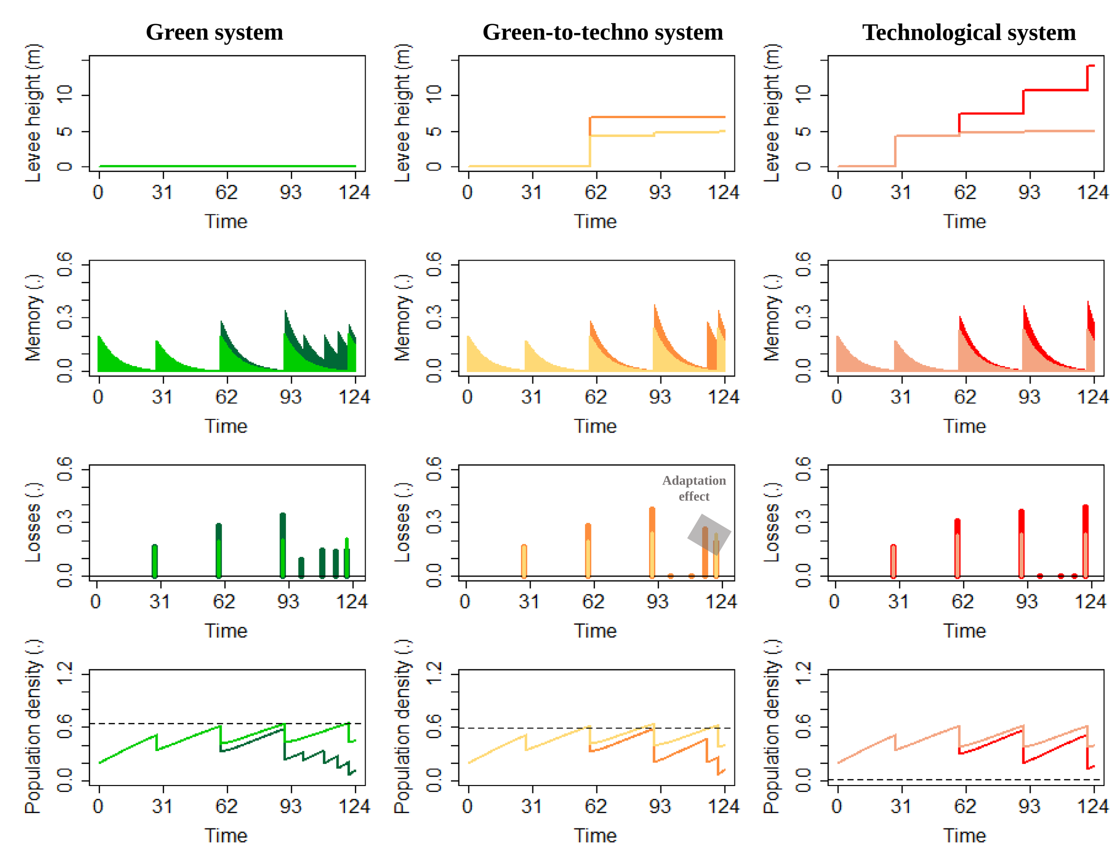


Figure 5

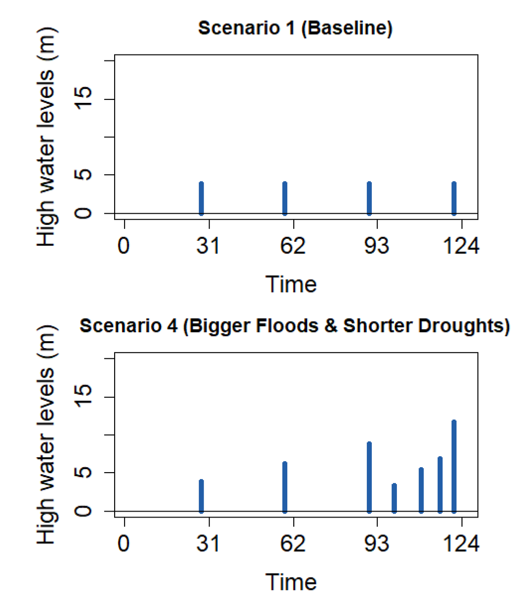


Figure 6

Comparing scenarios 1 and 4 it emerges that increasing magnitude and frequency of floods (scenario 4):

- Contributes to high levels of collective flood memory and encourages adaptation behaviours, as well as reduction of floodplain population density in green systems;
- Induces technological systems to continuously heighten flood protection structures at the cost of more damage;
- Leads green-to-techno systems to shift back to green systems, adapting to flood events and reducing the population density in the floodplain area, instead of continuing to heighten the levees.

CONCLUSIONS

This study has sought to provide better insights into the coupled human-flood system by conducting a first evaluation of the interactions between floods, reservoir management policies and societal flood-coping strategies. Results from the sensitivity analysis showed that flood risk is strongly influenced by the flood and drought memory of reservoir operators and their risk-awareness levels control the development of communities. From the model application, it emerged that scenarios of more frequent and higher magnitude events prove to enhance social flood memory in green systems, while technological systems experience much higher losses. Interestingly, green-to-techno systems may also switch back to green approaches in response to large losses and technical/economical unfeasibility of larger structural measures. The proposed model can be used in future research studies around the world for analysing interactions between policy-makers, institutions and individuals and also look for feedback mechanisms between societies and reservoir operators.

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Acknowledgments

The authors would like to thank Niko Wanders and Elena Ridolfi for their comments and constructive suggestions with respect to the reservoir model developed and implemented in this work. Part of this research was supported by the Swedish Research Council FORMAS, by the Centre of Natural Hazards and Disaster Science (CNDS) in Sweden and by Politecnico di Bari through program for international mobility of students.

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