On the combined effects of socio-hydrology and climate change on water resources management – a case study

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Introduction

Water scarcity is a growing problem impacting human health, economic development and ecological systems in many regions around the world (Rijsberman 2006; Wimmer et al. 2015). Improved understanding of how human-water interactions may influence future water supply and demand is pressingly needed to achieve sustainable management of water resources (United Nations 2018). Most previous studies have (understandably) focused on regions with a long history of water scarcity (Fabre et al. 2015; Fernald et al. 2012; Gohari et al. 2013; van Emmerik et al. 2014). On the other hand, regions such as Scandinavia, where freshwater has historically been a plentiful resource, are poorly represented in the socio-hydrology literature. In the recent years however, unusually dry summers have caused periods of local-to-regional seasonal water scarcity even in these typically water-abundant areas (Ahopelto et al. 2019; Stensen et al. 2019) and recent assessments predict that the frequency, intensity and duration of seasonal water shortages will increase in Scandinavia in the coming decades (Asp et al. 2015). To manage these challenges, and to enable proactive and robust water management strategies to be developed, we claim that building local understanding of how socio-hydrological interactions influence water supply and demand is pressingly needed.

In this paper we present the preliminary results from a case study on the Swedish island Fårö where we explore how historic water management policies have contributed to escalating water use, periodic water scarcity, and the increasing reliance on seasonal inter-basin water transports in the last two decades. We present and discuss the results from simulation experiments conducted to explore the implications of five climate scenarios and six policy strategies on the future water self-sufficiency of Fårö. We also suggest a mix of policies that could serve as a long-term solution to improve the water self-sufficiency on the island and almost eliminate the need for transported water for many decades to come.

Fårö island

Fårö is a small island in the Baltic Sea (57.9°N, 19.1°E) belonging to the Swedish municipality of Gotland. There are 300 permanent and 725 holiday households on the island, the dominating industries are tourism and agriculture, and drinking water is supplied exclusively from groundwater sources. In the last 20 years, Fårö has developed into a popular tourist destination and the exploitation pressure is high from both the tourism industry and the private sector. In the summer season (June – August) about 10,000 tourists and part-time residents visit the island (Region Gotland 2014), putting a lot of pressure on the municipal water supply system. On several occasions', the local aquifer supplying water to the public water grid has been insufficient to meet demand. Since 2006, the municipality has been relying on inter-basin water transports (water delivered by truck to the municipal water plant) every summer to keep up with the high demand. Worryingly, the need for transported water has been increasing despite targeted policies to reduce water consumption and improve water self-sufficiency.

Model structure and behavior replication

A model consisting of ten interconnected submodules (Climate, Public Water Supply, Private Water Supply, Household Water Use, Aquifer Exploitation, Tourist Water Use, Water Transports, Economy, Desalination and Rainwater Collection) was developed using a combination of Group Model Building (GMB), literature studies, statistical data, and domain expert consultation. The model simulates with a monthly time step over the time horizon from January 2000 to January 2050. Key model outputs include total public water use, groundwater level, water transports and bedding capacity (a proxy for the size of the tourism sector). Behavior replication tests were conducted for all key output variables and qualitative as well as statistical evaluation (Sterman 1984) against historical data indicate that the model is capable of replicating the dynamic behavior of the system (see Fig. 1a – 1d).

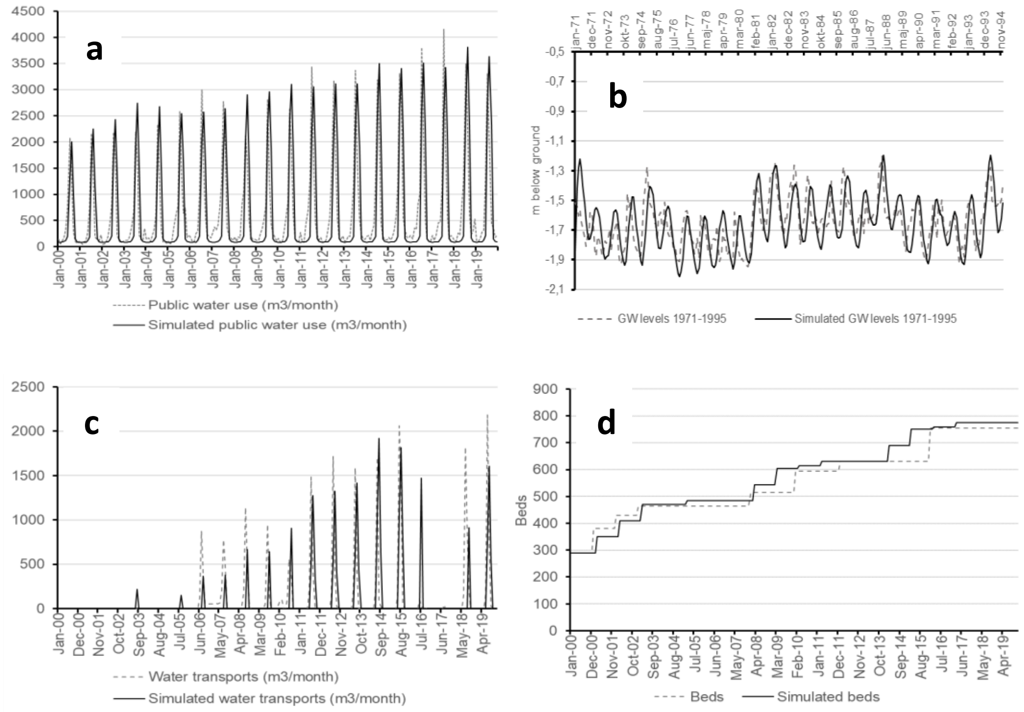

Figure 1. Observed (dashed lines) and simulated (solid lines) public water use (1a), groundwater level (1b), water transports (1c) and bedding capacity (1d).

Climate scenarios and policy tests

To assess future (up to 2050) reliance on inter-basin water transports we applied the above-described model to first explore how future climate may influence the groundwater supply on Fårö. In total five climate futures were explored with the Middle of the Road (MoR) scenario corresponding to the regional climate forecast with regards to future precipitation and temperature, developed by SMHI (Asp et al. 2015). The remaining four climate scenarios were developed by adjusting the projected change in temperature and precipitation 50 % up and down around the MoR projection. Second, we tested the effect of six different water management policies, including continuation of water transports (BAU), exploitation of a new aquifer, investment in desalination technology, distributed rainwater collection systems, centralized rainwater collection and a 15 % improvement in water use efficiency across all sectors, on future water transports, total water use and water production cost. The policies were tested across the range of potential climate futures presented above. Third, the most promising policy interventions identified through our simulations were combined into a policy mix, aiming to minimize the need for inter-basin water transports in the future.

Results and conclusions

Our simulation results indicate that climate change will cause groundwater levels on Fårö to decline substantially in the coming 30 years. This will reduce the local groundwater supply, increase the need for water transports, and, most likely, lead to a growing number of households experiencing seasonal water scarcity. Because of delays between the decline of the water table, registering the change, and acting on it, the tourist sector can continue to grow for several years despite falling groundwater levels. This leads to a buildup of future water demand that is significantly greater than the projected future groundwater supply. These results are remarkably robust to variations in climate inputs and even in the "wettest" of the climate futures explored we expect the groundwater table to decline to levels below the observed historic range, causing water transports to increase well-above its record level from 2019.

Among the individual policies explored, the most effective strategies for reducing water transports are desalination and aquifer exploitation. However, both these policies trigger an increase in total water use that drives up the need for water transports back to its 2019 level by the mid 2040's. Thus, neither desalination nor aquifer exploitation can (when implemented in isolation) be considered long-term solutions to the challenges facing Fårö. In terms of total water use, the centralized rainwater collection and improvements in water use efficiency are the most effective policy interventions. Both result in an initial reduction in total water consumption, but the dip is followed by a rebound, caused by growth in the tourist sector, that brings water use back up to its current level by 2030. From an economic perspective (measured as cost per cubic meter water delivered by the public grid), BAU, centralized rainwater collection and improvements in water sue efficiency are the most cost-effective policies. On the other hand, all these strategies require a 50 to 75 % increase in water transports by 2050. Although outside the scope of this study, one needs to contemplate how future changes in climate will influence the availability of, and competition for, these exogenous water resources in the coming 30 years. It is not unlikely that growing competition for water will make inter-basin transfers less attractive, or even a source of social tension, in the future decades.

In the individual policy scenarios, improvements in efficiency, and expansions of supply, tend to generate water supply-demand cycles (Kallis 2010). This causes a rapid growth in total water use that often end up exceeding the historic levels of water demand, resulting in further need for water transports. To provide a long-term solution to Fårö, a policy mix is needed that reduces the need for future inter-basin transports and disrupts the supply-demand cycle so efficiency improvements can be implemented without the subsequent increase in water consumption. In the policy mix scenario, this was achieved by combining aquifer exploitation with multiple policies to reduce total public water demand (efficiency improvements, centralized rainwater collection and higher water prices). To break the supply-demand cycle, we also made the tourist sector more responsive to the water self-sufficiency of the system. Historically, the tourist sector has been able to expand freely even at low levels of water self-sufficiency (the size of local supply capacity compared to total demand). In the policy mix scenario, the threshold level for water self-sufficiency was significantly reduced (from allowing a 2500 m3/year deficit down to 100 m3/year). This adjustment can be interpreted as the implementation of water resource management practices where economic expansion is adapted to the carrying capacity of the hydrological environment. The policy mix significantly reduced both water transports and total water use. However, the strategy also resulted in a more moderate growth in the tourist sector compared to a purely supply-oriented policy approach. With tourism being the biggest industry on Fårö, and with Region Gotland looking for further growth in the tourism sector in the coming 20 years (Jansson 2021), it is unclear if this is an acceptable tradeoff for local policy makers and further work needs to be conducted to explore the technical feasibility and socioeconomic implications of the suggested policy mix.

Future research

In the coming months, extensive sensitivity testing will be conducted to explore how sensitive the presented simulation results are to variations in parameter inputs. Particular focus will be devoted to testing the sensitivity to variations in parameter values in the groundwater modules. Further work will also be allocated to exploring how increasing water scarcity outside the municipal water system can come to influence future grid expansion, and what effects this would have on water self-sufficiency and attractiveness of the different policy options. Lastly, the ambition is to isolate the core feedback structures of the Fårö model and so these can be applied and tested in other case studies. In the long-term, we hope these structures can be developed into a generic, high-level, socio-hydrology model that can inform water resources management in many regions around the world.

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