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Developing large-scale flood risk management plans under uncertainties about hydrodynamic system behavior

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Most of large-scale river systems around the world are protected by embankments and it is well recognized that the presence of such structural defenses alter the hydrological regime. Dike heightening at upstream locations exacerbates high water levels downstream and, conversely, dike failures upstream produce an unloading effect on downstream dikes, which are then less likely to fail. These effects clearly show the presence of hydraulic interdependencies between upstream and downstream locations. In the present work, we refer to hydrodynamic system behaviour while indicating the complex mechanisms that can emerge from these interdependencies.

Previous risk analysis studies have shown the importance of considering hydraulic system behavior which affects e.g. the flood frequency curve, the number of expected dike failures as well as the estimated economic damage and casualties. However, a due consideration of hydraulic system behavior in flood risk management is still lacking, and current flood risk management plans are based on worst-case scenarios where all dikes are designed as if their flooding probability were independent from the ones of the neighboring dikes.

The neglect of hydraulic system behavior is mainly due to the highly uncertain factors that need to be taken into account. They include the breach locations, the moment of breach, the final breach width and the breach development and expert judgment or upfront assumptions about probability distribution functions about these uncertainties may prove to be wrong. In such a context, taking flood risk management decisions requires developing plans which are expected to perform well under a wide range of uncertain factors, i.e. plausible system behaviors.

The present work aims at investigating the effect of hydrodynamic system behavior on the choice of optimal dike heights by minimizing total costs of each of the considered locations along a stretch of the Ijssel River, in the Netherland. The study follows a Many-Objective Robust Decision Making framework, where Evolutionary Algorithms are used to find optimal solutions for a reference scenario (i.e. a given model parameterization), which are then stress-tested under uncertainty using a Monte Carlo approach.

Interestingly, when no hydrodynamic interdependencies are considered (current approach), a single unique solution is found. On the contrary, considering the effect of hydrodynamic system behavior turns the problem into a multi-objective decision problem, where actions taken at an upstream location affect the total costs downstream. As a consequence, no single solution exists but, rather, a much wider set of Pareto dominant solutions is found, where trade-off emerges between upstream and downstream communities. Together, the set of Pareto dominant solutions describe a wide decision space hidden from view by the current practice by only considering the most conservative case. In addition, when stress-tested under uncertainty, the set of optimal solutions accounting for hydrodynamic system behavior shows more robustness in retaining their Pareto dominance than the solution found under the current practice.