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Situation and priority based control of a polder-boezem system

Ronald van Nooijen[1], Alla Kolechkina[2], Thomas Berends[3], and Elgard van Leeuwen[4]

***Abstract*— A Dutch polder-boezem system was used as the basis for a hydrodynamic model. The model is being used to simulate the system behavior when a situation and priority based controller is used to operate the polder and boezem pumps. An analysis of the results will be presented.**

I. INTRODUCTION

As a result of human activities coastal regions now contain large areas that lie below sea level. In these areas pumps are needed to provide drainage. When necessary, sluice gates supply water for agriculture and ecological purposes from nearby rivers. Usually these systems consist of areas enclosed by dikes, called polders, that discharge surplus water into a network of waterways, called “boezem” in Dutch (Fig. 1). Information on the history of this landscape and current challenges can be found in [1]. This network transports the drainage water to pumping stations that discharge it into a river or into the sea. Climate change, land subsidence, increasing land value, and urbanization complicate water management in these areas considerably. The rising sea level due to climate change causes an increase in groundwater seepage, hinders natural drainage, and existing pump stations need to lift water higher. Climate change may also lead to increased precipitation intensity [2], which means that the water system will need to move a given volume of water in a shorter period of time. This is exacerbated by the increasing urbanization which usually translates into an increase of the impermeable land surface, which in turn causes rapid run-off of precipitation into the water system. The rise in land value means it becomes much more expensive to keep areas reserved to serve as buffers to temporarily store excess water during periods of high intensity precipitation. Management of such a polder-boezem system is always a balancing act between the interests of different stakeholders. Different stakeholders may wish for different target water levels in the boezem and different acceptable lower and upper bounds on that water level. In the case of the boezem, there are hard constraints on that water level. Exceedance of these hard constraints may lead to either extensive flooding for high levels or damage to infrastructure for very low levels. Both high and low levels could cause dike failures [3]. The balancing act is complicated by the fact that the pump stations may not have enough capacity to deal with peak loads, so it is necessary to prepare for heavy precipitation by lowering the polder and/or boezem water level. If the anticipated precipitation does not arrive, then this type of preparation can lead to a water shortage. In that case water from outside the polder-boezem system will be needed to raise the levels back to the target level. This in turn may lead to a water quality problem when the water shortage can only be resolved by letting in outside water of lower quality. If the water levels are not lowered before the event arrives, then the pumps may not be able to cope. In that case the risk of damage to the boezem system due to high water levels is usually deemed greater than the risk of damage to the polders. Polder pumps are then deactivated in an order from low to high risk of damage to the polder in question. Stopping polder pumps is called a “maalstop”. Examples of application of control to boezem pump stations can be found in, for example, [4], [5], [6]. The need for anticipation on future events suggests that Model Predictive Control (MPC) is a suitable methodology for this type of water system. A review of MPC in water management in general can be found in [7].

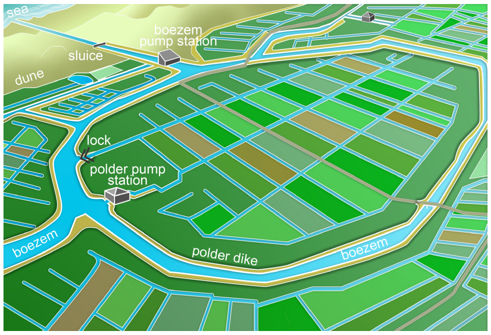

Fig. 1. Polder-boezem system

II. THE CONTROLLER

The following simplified model of the polder-boezem system and the system goals serves as the basis for the controller algorithm. The boezem is modeled as a reservoir R with a fixed area a and time varying level $h(t)$. The inflow from the polders is modeled by flows F_i with $i = 1, 2, \ldots, n_\mathrm{S}$; the controller can set these flows to zero to simulate a maalstop. For each polder the controller needs a forecast of the hourly flow for n_T hours into the future. There are also several pump stations and sluice gates G_j with $j = 1, 2, \ldots, n_\mathrm{T}$ that can discharge water from R to

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[1] Ronald van Nooijen is with the Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, Netherlands `R.R.P.vanNooyen@tudelft.nl`

[2] Alla Koleckina is with the Delft Center for Systems and Control,Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, Netherlands `A.G.Kolechkina@tudelft.nl`

[3] Thomas Berends is with the Innovation & Impact Centre, Delft University of Technology, Delft, Netherlands `T.Berends@tudelft.nl`

[4] Elgard van Leeuwen is with Bureau Water, De Bilt, Netherlands `elgardvanleeuwen@bureauwater.nl`

water bodies outside the system. Each of these can be in one of several states, corresponding to different flow rates; the number of states depends on j. The number of available states may also depend on wall clock time. It is necessary to allow for this dependency because some boezem pump stations may have time dependent operational constraints, and because the capacity of a sluice gate that discharges from the boezem to the sea depends on the tide. Examples of time dependent constraints are: available personnel on-site, noise abatement regulations, scheduled or unscheduled maintenance, or even the safety of recreational users of the connected water bodies. There is a lower bound $h_{\min}(t)$ and an upper bound $h_{\max}(t)$ on the level in R. In general, these bounds vary with the seasons. They may even be adjusted temporarily in case of expected heavy precipitation, pump station problems, or other special circumstances. Each state of each pumping station has an associated priority that can vary in time. Operational and economic aspects related to pump operation can be taken into account by varying these priorities.

The full controller algorithm and the conditions under which it is guaranteed to keep the water level in R, which is a proxy for a mean representative water level in the boezem within the given bounds, are given in [8]. It is a "greedy" algorithm that approximates the following strategy:

- add a pump state or sluice gate state only when not acting would result in constraint violation;
- add the means of discharge in order of decreasing assigned priority, considering the entire period up to the potential constraint violation.

This algorithm can be applied to the above problem statement as well. An implementation in Java$^{\text{TM}}$ was already available. The algorithm can switch from "wet weather mode", where it increases the amount of water removed from the system, to "dry weather mode" where it increases the amount of water let into the system. The ability of the algorithm to cope with time varying constraints, pump availability, and priorities means it is a situationally aware controller (SiCon).

III. THE SIMULATION ENVIRONMENT

A real Dutch polder-boezem system was taken to serve as the basis for a hydrodynamic model in the 3Di simulation environment [9]. This computer model is being used to simulate the system behavior when the controller is used to manage the polder and boezem pumps. An analysis of the results will be presented.

A simulation environment has been created, where 3Di simulates the water system and SiCon provides the control actions. In this environment we examine how the resulting system performs and to determine how its performance can be improved. This environment uses Python$^{\text{TM}}$ to allow data interchange between 3Di and the Java code. It obtains weights of states, historical tides, simulated forecasts, and historical polder discharges from external files (Fig. 2).

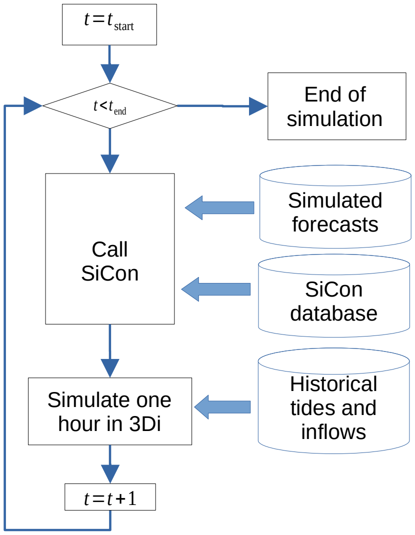

Fig. 2. Diagram of the simulation environment

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