DRAINAGE CONTROL IN WATER MANAGEMENT OF POLDERS[1]

MSc. Peter-Jules van Overloop[2]

ABSTRACT

One of the impacts drainage has on the downstream part of a water system is a higher risk of peak flows caused by heavy precipitation. In polders this is a well known problem. The heavy precipitation flows easily from the paved areas and with some delay from the unpaved areas into to many small canals and through these canals towards the downstream pump station. Here, high water levels occur resulting in an unacceptable high groundwater table. This problem has grown over the past years as more area has been paved and storm events have become more extreme. Until recent, the solution for this problem was to increase the pump capacity, but nowadays the Government's and Water board's opinion about solving this problem is changing. Rather than shifting the problem to more downstream lying parts of the water system, the philosophy has become 'first retain, then store, only then discharge' (Water Management for the 21st Century).

A way to retain water in upstream parts of the waters system is to use (Real-Time) control structures in the upstream canals. In this paper a control method is presented that can effectively retain water in the upstream parts, until the downstream part can accommodate for this amount of water. The method is based on upstream PI-control with adaptation of the set point. The control is referred to as Cascade PI-Control. Basically, the goal of the control method is to equally fill the available storage in the whole area.

Tests are performed with a calibrated model of an existing polder in the Netherlands. Results show that application of the control method is enough to avoid drainage problems.

Keywords: Real-Time Control, Drainage Control, Polders

1 INTRODUCTION

Large parts of the Netherlands, mainly in the West and North, are cultivated as polder land. These low-land areas serve as agricultural land as well as for living. Many cities, villages and small communities are situated throughout the polders. The water management of the polders is organized to serve the local water level requirements of each part of the polder resulting in many fixed drainage level areas.

During and directly after a storm event the precipitation drains into the many small canals and flows from one area to the next, towards the downstream pump station. Here, the ground water level sometimes rises to an unacceptable level, blocking the drainage from the land. A solution that normally is applied to solve this problem is to enlarge the capacity of the pump station. Clearly, by doing this the problem is shifted to the water system lying downstream of the polder. Recently, the government and the water boards have changed their opinion about this short term solution. New solution should fit into the philosophy "First retain, then store, only then discharge".

A promising method to retain water, is to utilize the free board that is available in the upstream lying parts of the polder. How much water has to be retained depends on the actual situation and changes over time. This dependence of the actual situation requires measurements and adjustments of the structures between the fixed drainage level areas by means of Real Time Control.

In general, the best way to retain water in the polder and avoid local drainage problems is to continuously strive for an equal filling of all areas. In this article a control method is proposed that can achieve this goal. The method takes the basic requirements on controlled systems into account:

For robustness reasons, the structure of the control must be as simple as the requirements allow it to be;
To be general, tuning rules for the control must be available. In this way, the control method can be tuned without an extensive trial-and error procedure and it can be re-used on other, similar water systems.
To be cost-effective the method should be applicable with minor infra-structural adjustments to the water system and should use standard hardware as much as possible;

2 CONTROLLED POLDER SYSTEM

A polder is divided into fixed drainage level areas. The polder Zuidplas that serves as a test case in this article consists of 133 areas each with their own set point and maximum allowed water level. The difference between maximum allowed water level and the set point (free board) is available for temporary storage of water. Rather than to use a fixed set point, an adaptive set point can 'cut off' the peak in the drainage flow by utilizing this volume in each of the fixed drainage level areas.

The maximum allowed water level is considered as the 100% volume filling of the area. The set point is the normal level, which is considered as the 0% filling. A percentage filling curve can be constructed for the level in between 0% and 100%. The curve is determined by area characteristics like the side slope of canals and extra available storage. In figure 1 and 2 the percentage filling curves of two areas are shown. Area 1 discharges into area 2.

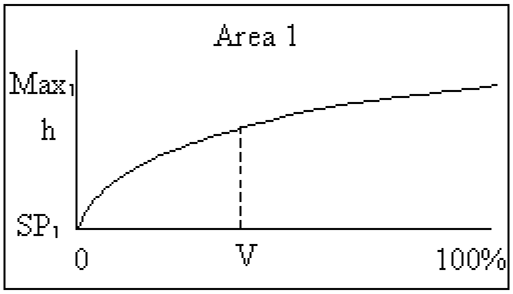

Figure 1 Percentage filling curve area 1

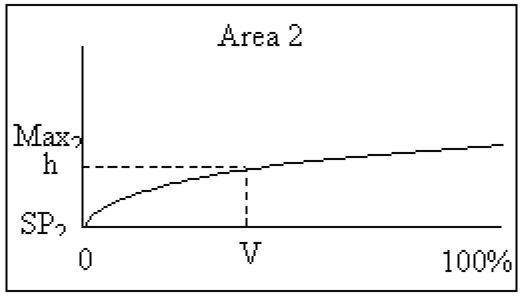

Figure 2 Percentage filling curve area 2

At a certain moment in time area 2 has a water level h_2. From figure 2 the percentage filling V is found. If the same percentage is taken from figure 1, level h_1 can be found. If this level is taken as the set point for area 1, a local controller can steer the water level of area 1 towards this set point. This results in an equal filling of area 1 and 2. To avoid control actions on short wave disturbances (for example from wind effects) a first order discrete filter is applied with the following algorithm:

$$h_{2,fil}(k) = f_c h_{2,fil}(k-1) + (1 - f_c) h_2(k) \qquad (1)$$

with k the time step index, $h_{2,fil}$ the filtered water level of area 2 (m Mean Sea Level), f_c the filter constant and h_2 the measured water level in area 2 (m MSL). The filter constant can be chosen such that waves with a time period shorter than T_c are suppressed:

$$f_c = \frac{T_c}{T_s} \qquad (2)$$

with T_c the cross-over period and T_s the sample time.

The local controller in area 1 that brings the water level to set point is a Proportional Integral controller. The algorithm used is the standard incremental PI algorithm [VandeVegte]:

$$\Delta Q(k) = K_p\left(e(k) - e(k-1)\right) + K_i T_s e(k-1) \qquad (3)$$

with DQ the change in discharge (m^3/s), K_p the proportional gain, K_i the integral and e the error between set point r and measured water level h (m). The control method is referred to as Cascade PI-control.

Once the discharge is derived, the structure setting is computed. In case of a pump this discharge is imposed or rounded to the nearest stage. In case of a gate the gate position is computed by inverting the structure's discharge equation using measurements of the local water levels. Figure 3 shows a schematic overview of the control method.

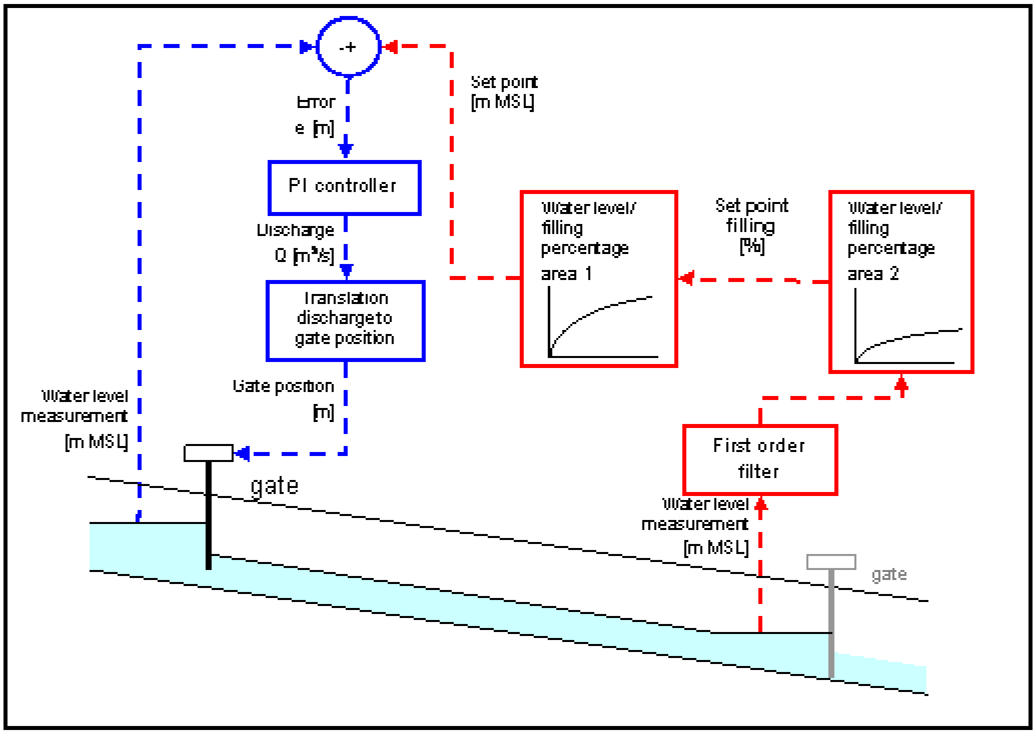

Figure 3 Schematic overview of Cascade PI-control

3 ANALYSIS CONTROL METHOD

To guarantee a proper functioning of the controlled water system the performance and the stability need to be analyzed. If low gains and tight filtering are used the controller reacts too slow. On the other hand, if high gains and a low filter constant are used the controlled water system can become instable resulting in oscillating water levels.

The PI-controller is tuned according to the tuning rules for canals from [Schuurmans]. These rules result in stable control with high performance. If more controlled areas are lying in series the performance can decrease, though. In that case an optimization can be used to tune the controllers [Overloop]. In [Roos] a control system for a large urban drainage system consisting of closed conduits is developed. The local controllers are tuned with the optimization and the cascade set point adaptation is applied.

For the control loop between water level of the downstream area 2 and the set point of area 1 an analysis of the stability is made. For this analysis the parameters of the test case are used. The tests run with the test case show that the performance is sufficient, but the stability needs to be examined in more detail to be sure that no oscillating water levels will occur. The transfer function linearized around the worst case situation is analyzed. The water levels are at set point, so the least storage area that can serve as damping is available. Also the delay times are high as waves travel slower through shallow water [Chow]. The areas are modelled as the Integrator Delay model [Schuurmans] consisting of a delay time with a reservoir in series. The percentage filling transfer function is taken as a constant factor. Figure 4 shows the block scheme of two area is series.

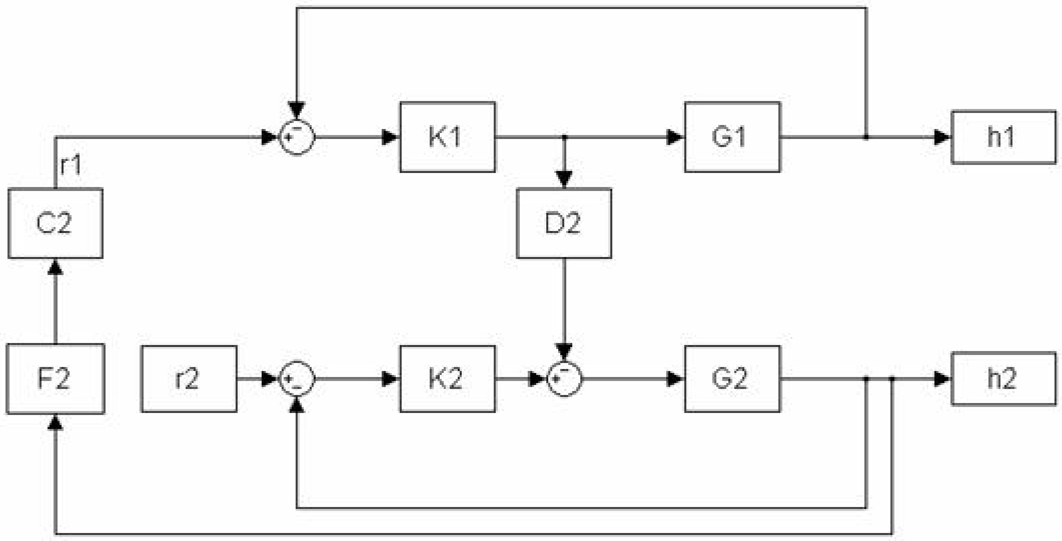

Figure 4 Block scheme of Cascade PI-control

The open loop continues transfer function H is:

$$H = \frac{-K_1 D_2 G_2 F_2 C_2}{1 + K_1 G_1 + K_2 G_2 + K_1 K_2 G_1 G_2} \quad (4)$$

with

$$D_2 = e^{-T_{d,2}s} \quad (5)$$

$$C_2 = \frac{MAX_1 - SP_1}{MAX_2 - SP_2}$$ (see figure 1 and 2) (6)

$$F_2 = \frac{1}{T_c s + 1} \quad (7)$$

$$K_1 = \left(K_{p,1} + \frac{K_{i,1}}{s} \right) e_1 \quad (8)$$

$$K_2 = \left(K_{p,2} + \frac{K_{i,2}}{s} \right) e_2 \quad (9)$$

$$G_1 = \frac{1}{A_1} \quad (10)$$

$$G_2 = \frac{1}{A_2} \quad (11)$$

with s the Laplace operator, $T_{d,2}$ is the delay time of area 2 (s), $K_{p,1}$ is the Proportional gain of the local controller of area 1, $K_{i,1}$ is the Integral gain of area 1, $K_{p,2}$ is the Proportional gain of area 2, $K_{i,2}$ is the Integral gain of area 2, e_1 is the error between set point (r_1) and water level (h_1) of area 1 (m) , e_2 is the error between set point (r_2) and water level (h_2) of area 2 (m), A_1 is the storage area of area 1 (m^2), A_2 is the storage area of area 2 (m^2).

The stability is analyzed in a Nyquist diagram (see figure 5) [Matlab]. Here, the Magnitude (ratio of output amplitude to input amplitude) and the Phase angle (phase angle of the output relative to that of the input) of sinusoidal input signals to the open loop transfer function are given as points in the complex plain. The points together form a graph that enables the analysis of the stability.

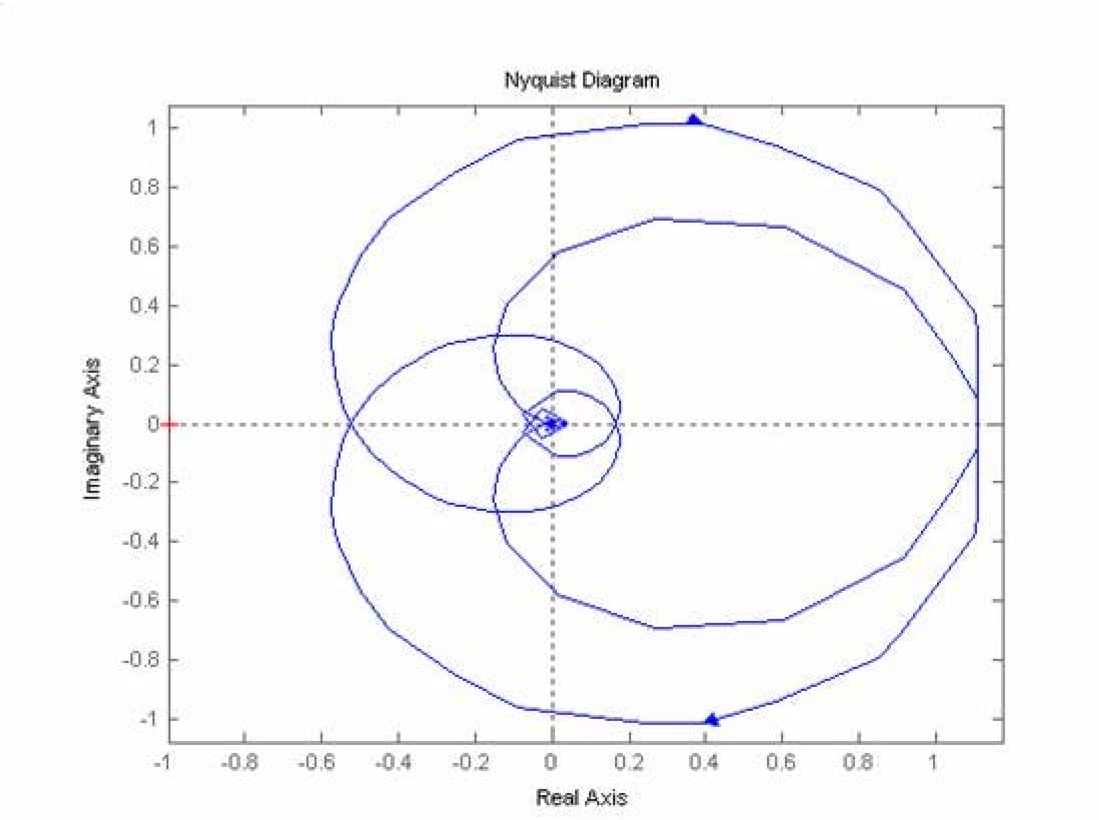

Figure 5 Nyquist diagram of controlled water system

The point (-1, 0) is not encircled, indicating that the system is stable [VandeVegte]. In table 1 the parameter values are given that are used in the analysis.

Table 1 Parameter values used in analysis

Parameter	Value
T_s (s)	300
T_c (s)	600
$T_{d,2}$ (s)	2700
C	1.57
A_1 (m^2)	36000
A_2 (m^2)	60000
$K_{p,1}$	-13.3
$K_{i,1}$	-2.5e-3
$K_{p,2}$	-7.4
$K_{i,2}$	-0.5e-3

4 TEST CASE

The polder Zuidplas of the water board Schieland is used to show the functioning of the control method. A detailed hydro-dynamic is developed [Sobek] that is calibrated with measurements of real storm events [Zuidplas]. On the model the extreme storm event of May 1998 is simulated. In fixed drainage level area 2 the drainage water inundates the surface level due to drainage problems (see figure 6).

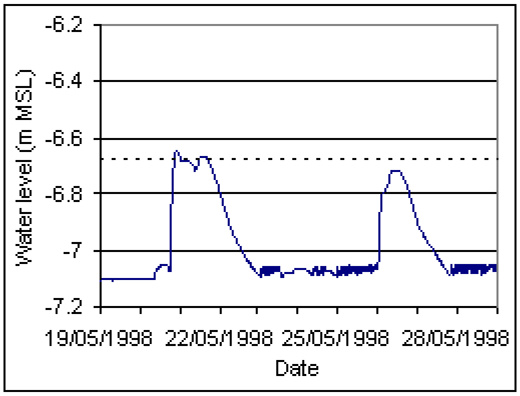

Figure 6 Water level in area 2 without control

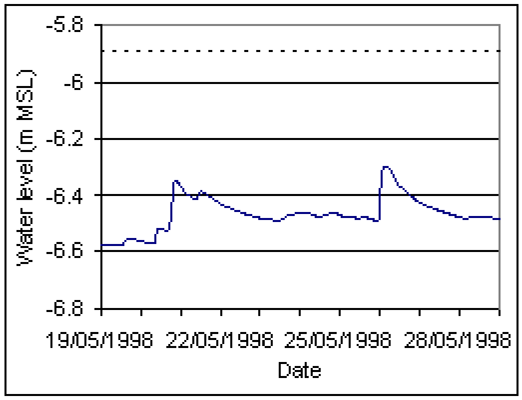

Figure 7 Water level in area 1 without control

In the upstream lying area 1 there still is storage available during the inundation of area 2 (see figure 7). The discharge between area 1 and 2 is given in figure 8.

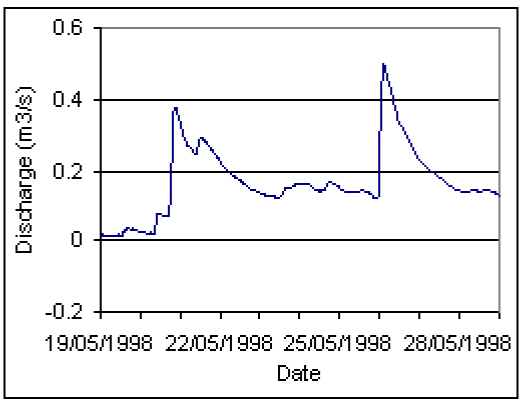

Figure 8 Discharge between area 2 and area 1 without control

Now, the inundation/drainage problem is tackled by applying the Cascade PI-control. Figure 9, 10 and 11 show the result of the controlled water system.

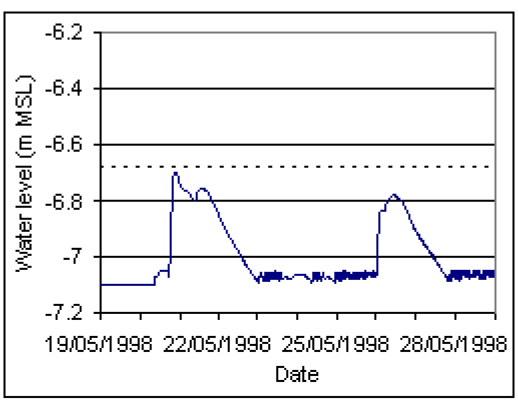

Figure 9 Water level in area 2 with control

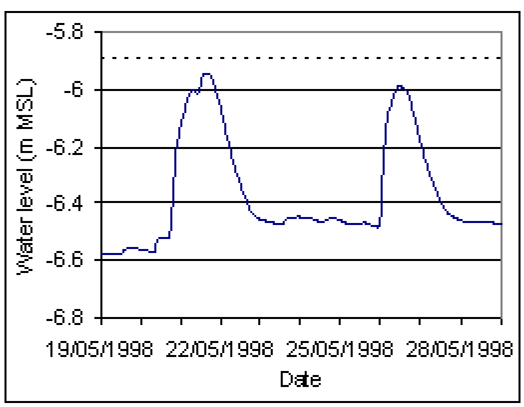

Figure 10 Water level in area 1 with control

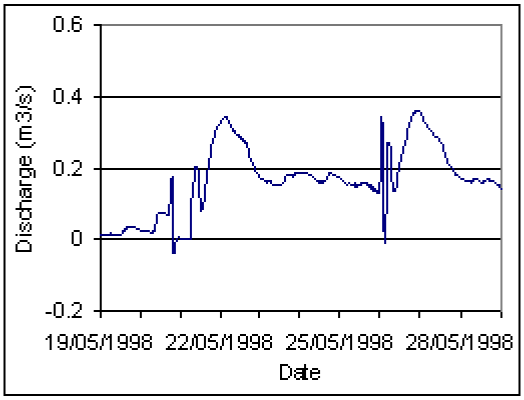

Figure 11 Discharge between area 2 and area 1 with control

It can be seen that the inundation is avoided now. During the period that inundation occurs in area 2 the discharge between area 1 and 2 is decreased by the control.

5 PRACTICAL IMPLEMENTATION

Cascade PI-control can be implemented in a robust and cost-efficient way. Locally, a Programmable Logic Controller together with cable measurements (water level upstream, water level downstream and the gate position) are required. The adaptation of the set point is only required during and directly after a storm event, so this communication system can 'wake up' once a certain water level is exceeded. The communication between the areas can be established by an existing wireless telephone network using Short Message Service. Even if this communication fails for a certain period, the local controller will continue to function with its previous set point.

The control units can be applied in a modular way throughout the water system. In the test case for example, the performance of the control method is shown with only two fixed drainage level areas. When more areas are controlled the performance will improve even further, as unused available storage is then utilized in the upstream areas. A sensible procedure is to start with the areas that have maximum problems and to add modular control units in series in upstream direction until the problems are fixed.

6 CONCLUSIONS

A control method is presented that can equally fill the available storage in a water system during and directly after a storm event. In this way local inundation/drainage problems can be avoided. If the control is tuned correctly, the performance is sufficient and the controlled water system is stable.

The Cascade PI-control has a simple structure, is modular and easily applicable.

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[2] Delft University of Technology, Civil Engineering and Geosciences, Water Management, The Netherlands, p.j.vanoverloop@citg.tudelft.nl