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OPTIMISATION OF WATER MANAGEMENT IN URBAN POLDERS CASE STUDIES OF THE NETHERLANDS AND THAILAND

P. Wandee[1], B. Schultz[2] and T. Tingsanchali[3]

ABSTRACT: Rainfall in the Netherlands has moderate intensities and is more or less evenly distributed over the year while in Thailand rainfall occurs at high intensities and predominantly in the rainy season. The aim of the water management system in an urban area in a polder is to provide good drainage and discharge out of the polder. This paper presents a mathematical model for the optimisation of the main components of the water management system in urban areas in polders in the Netherlands and in Thailand.

The main components of the water management system in an urban area in a polder are cross-sections of the sewers, distances between the canals, percentages of open water, canal water levels below the surface and discharge capacity of the outfall structures or the pumping stations. In order to find optional values for these main components the software package OPOL has been further developed. This package takes into account the relevant hydrological processes, construction and operation and maintenance costs for the water management system and damages due to high groundwater tables, water on the street, or even inundation under influence of rainfall and water level fluctuations in the urban canals. Optimising such a system aims at determining the main components in such a way that the annual equivalent costs will be minimal. The results of a case study for an urban polder in the area of the Principal Water-board of Delfland, the Netherlands and of another one in Bangkok, Thailand are shown. It was found that the canal water level has the largest influence on damages in these urban polders.

Keywords: Mathematical model, urban polder, water management system, optimisation, annual equivalent cost

INTRODUCTION

Related to water management the climate in the world can be divided into three main climatic zones, which are: temperate humid, humid tropical and arid and semi-arid zone.

The Netherlands has a temperate humid climate, with a rather even distribution of rainfall over the year. The mean annual rainfall is about 785 mm. The rate of evaporation from open water varies from 0 mm/day in winter to 3 - 4 mm/day in summer. During summer there is usually a rainfall deficit. On the other hand during winter there is a rainfall surplus that needs to be drained.

Thailand has a humid tropical monsoonal climate, marked by a pronounced rainy season lasting from about May to September and a relatively dry season for the remainder of the year. The annual rainfall in the central part of Thailand is about 1,200 mm. The evaporation from open water varies between 3.5 and 4.0 mm/day the whole year round.

The demand of land for producing food, for urban development such as housing, industry, shopping areas, infrastructure and recreation has rapidly increased during the past century. This has, among others, resulted in the reclamation of swamps, floodplains, tidal areas and even lakes by impoldering.

The urban area is generally a part of the water management system in a polder as sub-area. The aim of water management of this area is to provide good drainage and discharge. In urban areas in polders a more or less fixed water level is preferred to avoid possible damage to buildings and infrastructure.

Urban areas are characterized by their paved and unpaved areas. The paved areas generally consist of houses, buildings, streets and squares. The unpaved areas consist of the green areas, parks and gardens. Drainage from the paved areas is generally realised by means of sewer systems while drainage from the unpaved areas is generally absent or realised by sub-surface pipe drains. The storm water sewers generally discharge into urban

[1] Senior Irrigation Engineer, Royal Irrigation Department, THAILAND
[2] Professor, UNESCO-IHE and Senior Adviser Rijkwaterstaat, Civil Engineering Division, the NETHERLANDS
[3] Professor, School of Civil Engineering, Asian Institute of Technology, Klongluang, Pathumthani, THAILAND
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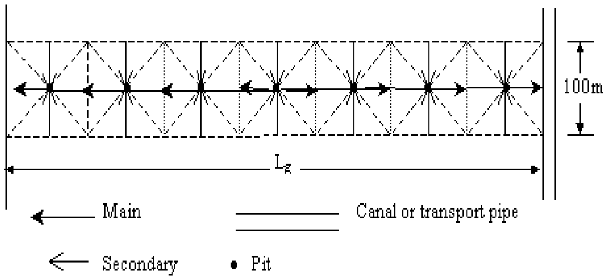


Fig. 1 Schematic layout of the sewer system in an urban area in a polder

canals. Wastewater may be separately discharged by way of wastewater treatment plants.

WATER MANAGEMENT IN URBAN AREAS IN POLDERS

In the urban environment sewer systems and sub-surface pipe drains discharge through the urban canals and over or through an outfall structure or by pumping to the main drainage system of the polder, or directly to outside water. The main components of drainage systems in urban areas in polders are as follows (Fig. 1):

The Netherlands:

- cross-section of the sewers;
- distance between the canals;
- percentage of open water;
- water level below the ground surface;
- discharge or pumping capacity;

Thailand:

- cross-section of the sewers;
- distance between the transport pipes;
- percentage of open water;
- water level below the ground surface;
- discharge or pumping capacity.

METHODOLOGY

The main components of the water management system can be optimised in such a way that the annual equivalent costs of the system are minimal (Schultz, 1982 and Schultz and Saiful Alam, 1997). In the annual equivalent costs the costs of construction, operation and maintenance of the system, as well as damage due to high groundwater tables, water on the street, or even inundation are represented. To determine the main components the method consists of three parts namely (Schultz, 1982):

- hydrological computation;
- economical computation;
- optimisation.

Hydrological Computation

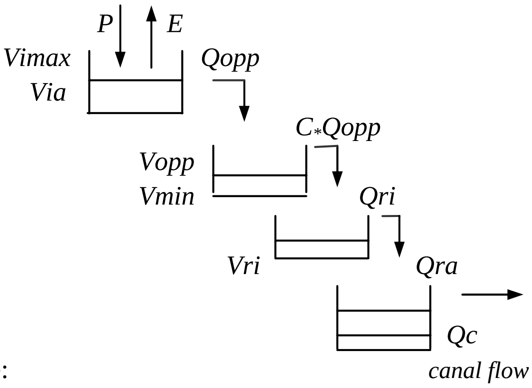
The hydrological computation consists of two parts. Firstly the model is calibrated based on time series of rainfall, evaporation and discharge of the outfall structure or pumping station (Fig. 2). The following parameters of the hydrological model are calibrated and validated:

- storage in depressions;
- runoff coefficient;
- parameters k_1 and n_1 for the transformation of rainfall into sewer inflow;
- parameters k_2 and n_2 for the transformation of sewer inflow into sewer discharge.

This is done with the model RAINURB. The aim of the calibration of the model is to obtain optimal values for these parameters, which most strongly affect the discharge in the urban area. In the hydrological model the transformation of runoff into sewer inflow and from inflow to sewer discharge is supposed to behave as a non-linear function as shown below (Ven, 1980).

$$Q_{ri}(\Delta t) = \left(\frac{V_{opp}(t + \Delta t)}{k_1} \right)^{\frac{1}{n_1}} \quad (1)$$

$$Q_{ra}(\Delta t) = \left(\frac{V_{ri}(t + \Delta t)}{k_2} \right)^{\frac{1}{n_2}} \quad (2)$$



where:

C = runoff coefficient (-),
E = evaporation (mm/time step),
P = rainfall (mm/time step),
Q_{opp} = discharge available for surface runoff (mm),
Q_{ra} = canal discharge (mm/time step),
Q_{ri} = sewer discharge (mm/time step),
V_{ia} = accumulate of precipitation (mm),
V_{imax} = maximum capacity of surface retention (mm),
V_{opp} = maximum volume available for sewer discharge (m^3),
V_{ri} = maximum capacity of sewer retention (mm).

Fig. 2 Scheme of the model for the transformation of rainfall into runoff from a paved area

Secondly with the validated parameters the optimal values for the main components are determined. These calculations are made with the program OWAP.

In order to determine the optimal values for the main components, the design periods are used to determine the following from the transformation of rainfall into discharge:

- groundwater rise, under influence of rainfall and water level fluctuations in the urban canals;
- occurrence of water on the streets;
- fluctuation of the open water level.

At first the values for the main components are determined, assuming free discharge over or through the outfall structure or by the pumping station. In this way optimal values for the main components of the water management system for the urban areas are found. Dependent on the situation these optimal values may still have to be optimised when the water management system for the whole polder is being considered.

Economical Computation

The costs for construction as well as for operation and maintenance of the water management system are taken into account. These costs may be divided into the following:

- subsurface or surface drainage;
- sewer system;
- open canal system;
- transport pipe;
- outfall structure or pumping station.

These costs are depending on the sizes of the five main components of the water management system in the urban polder. The annual equivalent costs for the five main components of the water management system are calculated by multiplying the construction costs with the annual recovery factor plus maintenance costs as described below. The annual recovery factor is expressed as follows:

$$V_t = \frac{r * (1+r)^L}{(1+r)^L - 1} \tag{3}$$

where:

r = annual interest rate, usually 5%,
L = lifetime of the project components (years),
V_t = annual recovery factor (-).

Therefore the annual equivalent costs for the five main components of the water management system are construction and maintenance costs:

$$cdt = V_t * \cos td + \cos tdm \tag{4}$$

where:

cdt = annual equivalent costs for the five main components of the water management system (€),
costd = total costs of the five main components of the water management system (€),
costdm = total maintenance costs for the four main components of the water management system (€/year).

In order to enable the determination of damages the value of buildings, infrastructure and facilities in the urban area have to be specified and the relation of level of waterlogging or inundation and damage to the different elements in the urban area has to be given. The damage is depending on the height of the exceedance of specific groundwater tables or levels of inundation (US Army Corps of Engineers, 1996\2000).

Optimisation

Optimal values for the main components of the water management system are obtained with the optimisation method of Rosenbrock (Kuester and Mize, 1973). The algorithm finds the minimum value of a non-linear goal function with multi variables and without constraints. The procedure assumes a unimodel function. Therefore several sets of starting values for the independent variables should be used if it is known that more than one minimum exists or if the shape of the surface is unknown. The algorithm proceeds as follows:

- a starting point and initial step sizes, *Si*, i = 1, 2, 3,…., N, are picked and the goal function is evaluated;
- the first variable *X1* is stepped a distance *S1* parallel to the axis, and the function is evaluated. If the value of the goal function (F) decreases, the move is termed a success and *S1* is increased by a factor α, $\alpha >= 1.0$. If the value of F increases, the move is termed a failure and *S1* is decreased by a factor β, $0 < \beta <= 1.0$ and the direction of the movement is reversed;
- the next turn variable, *X2*, is stepped a distance *S2* parallel to the axis. The same acceleration or deceleration and reversal procedure are followed for all variables in consecutive sequences until a success (decrease in F) and failure (increase in F) have been encountered in all directions.

The axes are then rotated by the following equations. Each rotation of the axes is termed as stage:

$$M_{i,j}^{(k+1)} = \frac{D_{i,j}^{(k)}}{\left[\sum_{i=1}^{N}\left(D_{i,j}^{(k)}\right)^2\right]^{\frac{1}{2}}} \quad (5)$$

$$D_{i,j}^{(k)} = A_{i,j}^{(k)} \quad (6)$$

where:

$$D_{i,j}^{(k)} = A_{i,j}^{(k)} - \sum_{i=1}^{j-1}\left[\left(\sum_{n=1}^{j} M_{n=1}^{(k+1)} * A_{n,j}^{(k)}\right) * M_{i,1}^{(k=1)}\right]$$
$$j = 2, 3, \ldots, N \quad (7)$$

$$A_{i,j}^{(k)} = \sum_{i=j}^{(k)} d_1^{(k)} * M_{i,1}^{(k)} \quad (8)$$

where:

i = variable index = 1, 2, 3,…, N (-)
j = direction index = 1, 2, 3,…, N (-)
k = stage index (-)
d_i = sum of distances move in the i direction since last rotation of axes (-)
$M_{i,j}$ = direction vector component (normalized)

A search is made in each of the X directions using the new coordinate axes. The procedure terminates when the convergence criterion is satisfied. The process starts with assumed values of the sewer diameter, distance between canals or transport pipes, the water level in the canals, the percentage of open water and the discharge capacity of the outfall structure or pumping station. The economical model computes the costs of construction and operation and maintenance of the water management system. Using the hydrological and the economical models together, the damages to be expected can be computed. The sum of costs and damages is calculated and transferred to annual equivalent costs. During the optimisation the sewer diameter, distance between canals or transport pipes, the water level in the canals, the percentage of open water area and the discharge capacity of the outfall structure or pumping station are increased or decreased with a certain range. If a good result is obtained, this value is stored for the next calculation. If not, then the original value is stored and in the next cycle of search is made in the opposite direction. This process is repeated until the total of costs and damage is at the minimum. The Rosenbrock routine contains possibilities to accelerate the process.

CASE STUDY IN THE NETHERLANDS

The urban area for the case study in the Netherlands was located in the area of the Principal Water-board of Delfland, located in the western part of the Netherlands.

Table 1 Polder water level related to ground surface in the Hoge and Lage Abtswoudse polder

Name	Polder water level in m-surface	Lowest sill level in m-surface	Allowable Water level rise in m
Hoge Abtswoudse polder	0.15	0.23	0.15
Lage Abtswoudse polder	0.55	-	0.55

Delfland is a typical polder area, which includes 60 polders with different water levels. The total surface is approximately 40,000 ha. This study focuses on an area in the Hoge and Lage Abtswoudse polder, which is drained by the pumping station Voorhof. This area concerns the total area of the Hoge Abtswoudse polder and the urban part of the Lage Abtswoudse polder. The area of the Hoge Abtswoudse polder is 216 ha, with an open water area of 8 ha at polder water level. For the urban part of the Lage Abtswoudse polder it is 497 ha, with an open water area of 25 ha. The total area is 713 ha, with an open water area of 33.6 ha or 4.7%.

The area of houses that is drained by the pumping station Voorhof is 86.8 ha. It is composed of 82.4 ha buildings and houses, 4.4 ha high buildings and 0.01 ha (closed) storage tanks.

Weirs control the water level in the Hoge Abtswoudse polder and the excess water discharges into the water management system of the Lage Abtswoudse polder. Total width of these weirs is 3.52 m and canal depth is 1.5 m. The present situation of the polder water level in the Hoge and Lage Abtswoudse polder is shown in Table 1. The sill level in the Lage Abtswoudse polder is not given, because the pumping station Voorhof directly drains this polder.

CASE STUDY IN THAILAND

The case study area in Thailand was located at the eastern side of Bangkok Metropolitan. This part of Bangkok is divided in 10 polders. The polder Sukhumvit was selected for this study. It is one of the inner urban polders of Bangkok Metropolitan. The majority of the land is used for residence. In this area there is a lot of industry and also a lot of high rising buildings. There is no agriculture.

Dependent on the flow direction the area inside this polder can be divided into 7 sub-polders. Sub-polder DF, which is more or less clearly separated from the surrounding areas, has been used for calibration and validation. This sub polder has a total area of 368 ha, which is drained by the pumping station Bangmakeor (Bangkok Metropolitan Administration, 1998).

The drainage system in the area is composed of secondary sewer pipes, mostly with a diameter of 0.30 m and at a distance of 40 to 50 m. It receives water from the adjacent areas. The water discharges into the main sewers, which are mostly pipes with a diameter 0.60 m and are at an average distance of around 100 m, located beneath the footpaths along the secondary roads. The water flows to transport pipes, which are located beneath the main roads, usually box culverts of 1.5 * 1.5 m to 2.0 * 2.0 m, then the excess water discharges into the main canals, which surround the polder area.

In practice the polder water level in the main canals is 0.50 to 1.00 m-MSL (1.05 to 1.65 m-surface) and the highest water level is at 0.50 to 1.0 m+MSL. (average ground surface 0.55 m+MSL). The crest heights of the dike/or retaining wall at the Ton canal or Prakanong canal is 0.6 to 1.2 m+MSL.

Levels for the Simulation of Damage

In both case studies the levels for the simulation were based on average conditions, as follows: the level of houses was set at 0.50 m+surface. The level of squares and paths was set at 0.40 m+surface. The quarter roads were at 0.30 m+surface and mains road at 0.00 m+surface.

CALIBRATION OF THE MODEL

The calibration for both areas was done with data of 2003. The data for calibration for the Hoge and Lage Abtswoudse polder were daily rainfall, daily open water evaporation, daily pumping discharge and average daily polder water level. The data for calibration for the Sub-polder DF were hourly rainfall, daily class A pan evaporation and daily pumping discharge. The calibrated parameters are shown in Table 2.

In Table 2 it can be seen that the runoff coefficient in the Hoge and Lage Abtswoudse polder is higher than in Sub-polder DF, probably due to the lower temperature resulting in a lower evaporation from the surface. The storage in depressions was found to be the same. Most of the depression storage is on flat roofs, on the streets and the static storage in the sewers. The pumping discharge in Sub-polder DF is much higher than in the Hoge and Lage Abtswoudse polder due to the higher rainfall and some leakage of water from outside to the Sub-polder DF.

Table 2 Calibrated parameters of the hydrological model for the Hoge and Lage Abtswoudse polder and for Sub-polder DF

Parameter	Hoge and Lage Abtswoudse polder	Sub-polder DF
Storage in mm	0.82	0.82
Runoff coefficient	0.59	0.54
Rainfall > sewer inflow:		
– k_1	2.34	2.50
– n_1	0.175	0.211
Sewer inflow > sewer discharge:		
– k_2	2.36	2.55
– n_2	0.220	0.210
Pumping discharge in mm:		
– observed	208	3,750
– computed	211	3,609

MODEL VALIDATION WITH CALIBRATED PARAMETERS

Based on the calibrated parameters the model was validated with data of 2003 for the conditions in the Netherlands and in Thailand. The results are shown in Fig.s 3 to 8.

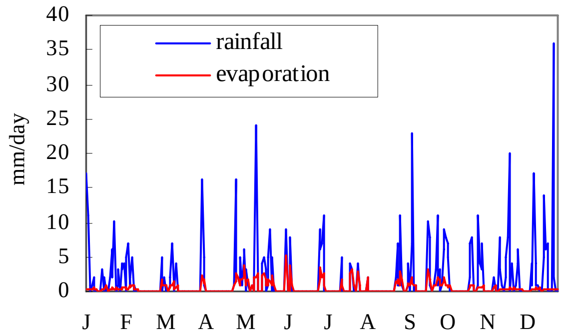


Fig. 3 Rainfall and evaporation in the Hoge and Lage Abtswoudse polder, 2003

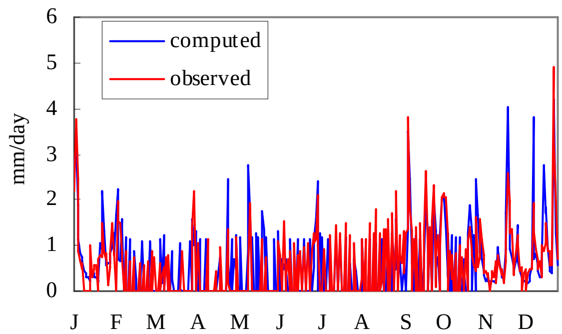


Fig. 4 Observed and computed pumping discharge of pumping station Voorhof, 2003

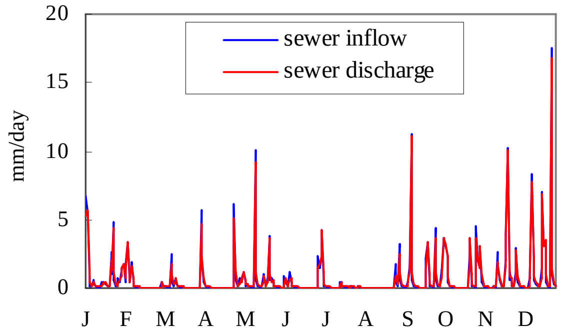


Fig. 5 Sewer inflow and sewer discharge in the Hoge and Lage Abtswoudse polder, 2003

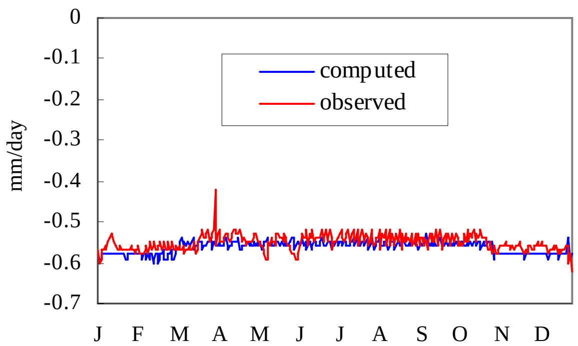


Fig. 6 Observed and computed water level at pumping station Voorhof, 2003

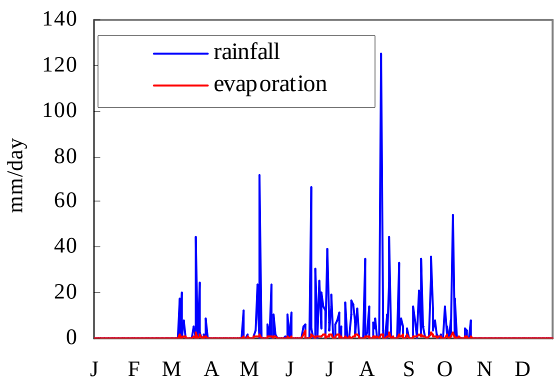


Fig. 7 Rainfall and evaporation at the Sub-polder DF, 2003

Validation of the parameters for the Hoge and Lage Abtswoudse polder

In Fig.s 3 and 4 there is a small lag time between rainfall and pumping discharge because the time step of 1 hour is large for the concerned process. During the summer period pumping is also required due to seepage to the polder area, especially for the Lage Abtswoudse polder, which is the low part of the polder area. Around

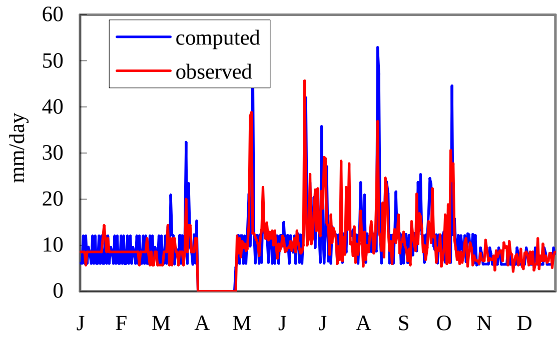


Fig. 8 Observed and computed pumping discharge at pumping station Bangmakeor, 2003

August there was no rainfall but still a high pumping discharge due to this seepage and also due to percolation from the Hoge Abtswoudse polder (Staringcentrum, 1976). Based on the results of the simulation it is estimated that during winter and spring (November to May) seepage and percolation are 0.2 to 0.3 mm/day and during summer and autumn (June to October) about 0.6 mm/day. The high water level in the surrounding area during summer and autumn may be the cause of the difference of seepage and percolation in the two periods. The pumping capacity of Voorhof is 8.5 mm/day, the maximum applied capacity during this year was about 5 mm/day, or only 59% of the installed capacity.

As shown in Fig. 5, there is a small lag time between sewer inflow and sewer discharge, because only a small volume can be stored in the sewer pipe before it is discharged into the canal.

The polder water level during summer (April to October) is about 0.05 m higher than during winter to reduce the chance of occurrence of high water levels during winter (Fig. 6).

Validation of the Parameters for the Sub-polder DF

In Sub-polder DF there is also a small lag time between sewer inflow and sewer discharge. As shown in Fig.s 7 and 8, there is pumping when there is no rainfall, because there is some leakage of water to the polder area. It is estimated that the leakage water and seepage into the Sub-polder DF is 8.6 mm/day between January and March, between May and October it is 9.6 mm/day and from November to December 6.7 mm/day. There is no seepage and leakage in April, because in this month there is a low water level in the surrounding canal and in the Chao Phraya River. It is also the driest period in Thailand. In Fig. 7, the computed pumping discharge is higher than the observed pumping discharge during high rainfall. This may be due to the aerial effect on rainfall in the area.

Table 3 Optimal values of the main components of the water management system in the Hoge and Lage Abtswoudse polder and in the Sub-polder DF

Main component	Hoge and Lage Abtswoudse polder	Sub-polder DF
Diameter sewer in m	0.30	1.00
Distance between transport pipes in m		1,480
Distance between canals in m	1,870	
Canal water level in m-s	0.87	2.56
Open water area in %	0.23	1.44
Pumping capacity in mm/day	5.0	117
Costs in € * 10^6	0.969	0.589
Damage in € * 10^6	0.004	0.065

DETERMINATION OF THE OPTIMAL VALUES OF THE MAIN COMPONENTS OF THE WATER MANAGEMENT SYSTEMS

Data for determination of optimal values for the Hoge and Lage Abtswoudse polder were from 1960 to 2001, which were daily open water evaporation and daily rainfall. Data for the determination of optimal values for the Sub-polder DF were from 1990 to 2001, which were daily class A pan evaporation and hourly rainfall.

The computed optimal values of the main components of the water management systems in the Hoge and Lage Abtswoudse polder and in the Sub-polder DF are given in Table 3.

In the Hoge and Lage Abtswoudse polder the sewer diameter at optimal conditions is 0.30 m while in Sub-polder DF it is 1.00 m. It can be concluded that in Sub-polder DF the damage due to surface water on the street is higher and that therefore a larger sewer diameter will be required to drain the water from the streets.

The optimal canal water level in the Hoge and Lage Abtswoudse polder is 0.87 m-surface, while in Sub-polder DF it is 2.56 m-surface. The canal water level in the Hoge and Lage Abtswoudse polder can be shallower because of the smaller fluctuation of the canal water level.

The computed optimal area of open water in the Hoge and Lage Abtswoudse polder is only 0.23%. In Sub-polder DF it is 1.44%, due to the more severe rainfall in a short time and the smaller green area. Damage due to a high canal water level will occur much more frequent than in the Hoge and Lage Abtswoudse polder. However, the computed open water area may be too small, because it was based on daily rainfall data and flash floods may have been underestimated. Moreover,

Table 4 Costs in million € for the drainage system of the Hoge and Lage Abtswoudse polder at optimal values for the main components of the water management system

Item	Living areas	Shopping- and office centres	Industrial areas	Total
Drains				
- construction costs	0.596	0.260	0.347	1.230
- maintenance/year	0.052	0.023	0.030	0.107
- annual equiv. costs	0.090	0.040	0.053	0.187
Sewers				
- construction costs	6.195	2.789	3.671	12.656
- maintenance/year	0.036	0.016	0.021	0.073
- annual equiv. costs	0.363	0.163	0.215	0.742
Canals				
- construction costs				0.198
- maintenance/year				0.011
- annual equiv. costs				0.021
Pump				
- construction costs				0.165
- maintenance/year				0.010
- annual equiv. costs				0.019
Total	7.332	3.291	4.337	15.419

Table 5 Costs in million € for the drainage system of the Sub-polder DF at optimal values for the main components of the water management system

Item	Living areas	Shopping- and office centres	Industrial areas	Total
Drains				
- construction costs	0.523	0.081	0.034	0.652
- maintenance/year	0.013	0.002	0.001	0.016
- annual equiv. costs	0.047	0.007	0.003	0.058
Sewers				
- construction costs	1.316	0.231	0.116	1.662
- maintenance/year	0.012	0.002	0.001	0.014
- annual equiv. costs	0.097	0.017	0.008	0.123
Canals				
- construction costs				4.447
- maintenance/year				0.012
- annual equiv. costs				0.302
Pump				
- construction costs				0.237
- maintenance/year				0.093
- annual equiv. costs				0.106
Total	2.008	0.340	0.163	7.722

constraints in layout and topography, which might affect this component, were not taken into account.

The pumping capacity at optimal conditions in the Hoge and Lage Abtswoudse polder is 5.0 mm/day, while in Sub-polder DF it is 117 mm/day. The higher rainfall intensity and the smaller green area are the reasons for this substantial difference.

In Table 4 the costs in million € for the drainage system of the Hoge and Lage Abtswoudse polder at optimal values for the main components of the system are shown. In Table 5 this is done for Sub-polder DF. In the Tables 6 and 7 the computed damage costs in the two

Table 6 Average annual damage in € in the Hoge and Lage Abtswoudse polder at optimal values for the main components of the water management system

Item	High groundwater level	Water at the street	Exceedence of the canal water level
Living areas:			
- houses with one floor	694	251	
- houses with two floors	694	251	
Shops and offices	776	228	
Industrial areas	1,117	544	
Green areas	0		
Urban area			0
Total			4,555

Table 7 Average annual damage in € in Sub-polder DF at optimal values for the main components of the water management system

Item	High groundwater level	Water at the street	Exceedance of the canal water level
Living areas:			
- houses with one floor	2,330	25,200	
- houses with two floors	2,330	25,200	
Shops and offices	1,090	8,360	
Industrial areas	275	28,600	
Green areas	0		
Urban area			0
Total			93,400

urban polder areas are given.

Table 4 shows that in the Hoge and Lage Abtswoudse polder the costs for the sewers - about 89% of the total costs at optimal conditions - are by far the highest. Operation and maintenance costs for the canals create 54% of total operation and maintenance costs. This is caused by the costs for dredging, mowing of the banks and maintenance of timbering.

Table 5 shows that the costs for canals - about 64% of the total costs at optimal conditions - are the highest in the Sub-polder DF. This is caused by the fact that the computed depth of the canal bed is deep due to the optimal water level of 2.56 m-surface and that most canals have concrete retaining walls. The costs of sewers and drainage system in the urban area are about 33% of the total costs. Operation and maintenance costs for the pumping station create 69% of the total. The required pumping of leakage water from outside contributes significantly to these costs.

In Table 6 it is shown that in the Hoge and Lage Abtswoudse polder at optimal conditions there is less damage due to water at the street than due to too high groundwater tables. The rainfall intensity and the water level fluctuation in the canal due to flash floods are not very high. The computed damage to houses with one floor and with two floors is equal because damage only occurs at the street and not at the houses, because the level of the houses is higher than the level of the streets. The damage due to too high groundwater tables and water at street was relatively high in the industrial area due to the indirect damage and a small green area.

In Table 7, it is shown that in Sub-polder DF, due to the high rainfall intensities, water at the street causes more damage than too high groundwater tables and exceedance of the canal water level. The fluctuation of the water level in the canals due to flash floods may be underestimated in the computations, while hourly data were used. The damage to houses with one floor and with two floors is equal, because also in this case the computed damage only occurred at the streets. The damage due to water at the street was also high in the industrial area due to the small green area.

In Fig. 9, the influence of deviations from the optimal values for the main components of the water management system in the Hoge and Lage Abtswoudse polder on the annual equivalent costs is shown. Deviations in the sewer diameter and the pumping capacity have most influence on the annual equivalent costs. If the sewer diameter is increased with 25% compared to the optimal value, the annual equivalent costs will increase approximately 600%. This is caused by the increase in damage due to a more rapid discharge to the canal system. Therefore a higher rise in the water level in the urban canals takes place and there will be less water at the streets. A decrease in pumping capacity with 25% from the optimal value will increase the annual equivalent costs by approximately 175%, because damage due to too high water levels in the canals increases. An increase or decrease in open water area

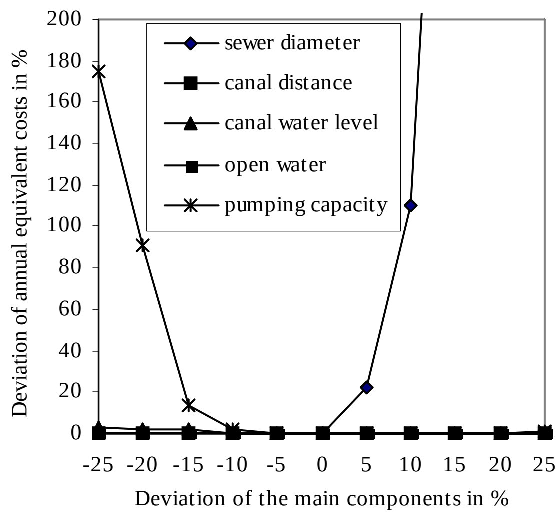


Fig. 9 Influence of deviations from the optimal values for the main components of the water management system in the Hoge and Lage Abtswoudse polder and resulting deviations of the annual equivalent costs

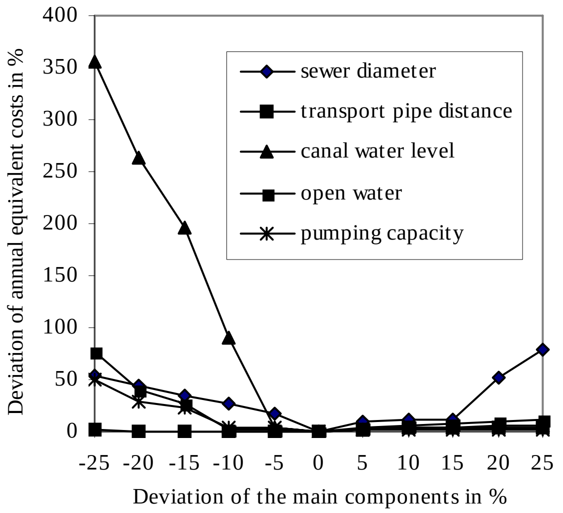


Fig. 10 Influence of deviations from the optimal values for the main components of the water management system in Sub-polder DF and resulting deviations of the annual equivalent costs

and distance between the canals has no significant influence on the annual equivalent costs, because the construction costs at optimal conditions are only a small portion of the water management costs. The canal water level has not much influence on the computed annual equivalent costs. This may be caused by the fact that the fluctuations in the water level due to flash floods were underestimated. Moreover the pumping capacity at optimal conditions may be high enough to control the water level in the urban canals.

In Fig. 10, the influence of deviations from the optimal values for the main components of the water management system in Sub-polder DF and the resulting deviations of the annual equivalent costs are shown. The canal water level has most influence on the annual equivalent costs. If the canal water level is 25% shallower compared to the optimal value, the annual equivalent costs will increase with approximately 350%, because of the increase in damage due to too high groundwater tables and water at the street. If the sewer diameter is reduced with 25% compared to the optimal value, the annual equivalent costs will increase with approximately 50%, because there will be a smaller storage capacity in the sewers. If the sewer diameter is increased by 25%, the annual equivalent costs will increase with approximately 75% due to the increase in construction costs and in peak discharge to the canal. When the open water area is reduced by 25%, the annual equivalent costs increase with approximately 75%, because of the increase in damage due to too high groundwater tables and water at the street. A change in the distance between the transport pipes has almost no effect on the annual equivalent costs, because only the costs for construction change and there is a small change in storage volume of the drainage system. A 25% decrease in pumping capacity results in 50% increase in the annual equivalent costs, while a 25% increase has almost no effect as only the construction costs increase.

DISCUSSION

Case Study in the Netherlands

At present the area of open water is larger than the optimal area and the pumping capacity is about 1.7 times the pumping capacity at optimal conditions. This may be caused by the fact that there are two pumps in the Hoge and Lage Abtswoudse polder and that the pumps generally work alternatively for different parts of the polder. However, the effects of flash floods due to heavy rainfall may have been underestimated in the simulations, while they were based on daily rainfall data.

It may be considered to lower the canal water level in order to reduce possible damage due to too high groundwater tables. However, the side effects of this, like settlement, slope stability and change in water quality have to be further studied.

Case Study in Thailand

At present the area of open water is smaller, the canal water level is shallower and the pumping capacity is larger than under optimal conditions. An increase in open water area may be considered. However, this may be complicated because of the density of the residential buildings and the layout of the city. In practice the preferred water level in the canals can be different, based on operation purposes and weather forecasts. This was not taken into account in the simulations.

Comparison of the Results of the Case Studies in the Netherlands and in Thailand

Due to the fact that in Thailand many people moved from the rural areas to the urban areas around Bangkok, the percentage of paved area in the area surrounding Bangkok is higher than in urban areas in the Netherlands. Also in this study the urban area in Sub-polder DF has a higher percentage of paved area than the Hoge and Lage Abtswoudse polder. Roads and squares in urban areas in the Netherlands have more bricks and tiles than in Thailand, where most of the paved surface is of concrete, or asphalt. In addition it plays a role that in urban polders in Thailand the level of buildings and infrastructure is close to the ground surface, therefore there is a higher possibility than in the Netherlands that damage may occur. Last, but not least rainfall intensities in Thailand are much higher than in the Netherlands. Therefore a significantly higher runoff may be expected in Thailand and easily higher damage can occur.

In the simulations on the optimal values for the main components of the water management systems this has resulted in a larger diameter of the sewers, a lower water level in the urban canals and a much larger pumping capacity for the Sub-polder DF. The canal water level has the largest influence on possible damage. The computed optimal water level in the Hoge and Lage Abtswoudse polder is 0.87 m-surface, while in Sub-polder DF it is 2.56 m-surface. In the Hoge and Lage Abtswoudse polder the sewer diameter at optimal conditions is 0.30 m while in Sub-polder DF it is 1.00 m. For the pumping capacity the values are respectively 5.0 mm/day in the Hoge and Lage Abtswoudse polder and 117 mm/day in Sub-polder DF.

The present open water area in the Hoge and Lage Abtswoudse polder is larger than in Sub-polder DF. The canals in Sub-polder DF were filled and converted into roads with a transport pipe underneath, which - instead of a canal - carries the excess water to the pumping station. At optimal conditions the required area of open water in the Hoge and Lage Abtswoudse polder would be only 0.23%, while in Sub-polder DF it would have to be 1.44%. The value in the Hoge and Lage Abtswoudse is probably too low because it has been determined based on daily rainfall data. Even the value for the Sub-polder DF may be low as it has been determined based on hourly rainfall, in which in the humid tropic conditions, the hourly period may be already too long.

CLOSING REMARK

From the case studies it can be seen that the climate has substantial influence on the main components of the drainage system in urban areas in polders. The higher rainfall intensity areas need larger water areas, larger sewer diameter, higher pumping capacity and deeper canal water level than the lower rainfall intensity areas. Moreover the annual equivalent costs increase tremendously when the values of the main components of the water management systems are taken smaller than the optimal values. Therefore the risk of under design of the main components has to be seriously considered.

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