

Thesis

B.C. Albers

Delft University of Technology

Faculty of Civil Engineering and Geosciences

Water management, Section of Water Resources Management



Rainfall fed inundation in greenhouse dominated polders

Research of water system assessments



Master Thesis

Rainfall fed inundation in greenhouse dominated polders

B.C. Albers

July 2011

TU Delft and Nelen & Schuurmans

Graduation committee:

Prof. Dr. Ir. N.C. Van de Giesen	Delft University of Technology
Dr. Ir. P.E.R.M. Van Leeuwen	Delft University of Technology
Dr. Ir. J.A.E. ten Veldhuis	Delft University of Technology
Drs. Ir. S. Jouwersma	Hoogheemraadschap van Delfland
Ir. J.G. Leskens	Nelen & Schuurmans

July 2011

Preface

This thesis is the final result of research carried out for the completion of the Master Water Management at the faculty of Civil Engineering and Geosciences of the Delft University of Technology. The research was conducted in the period December 2010 till July 2011 at the water management consultancy company Nelen & Schuurmans in Utrecht.

I would like to thank all the people who have supported me throughout this study. First I would like to thank the graduation committee: Prof. Dr. ir. Nick van de Giesen, Dr. ir. Elgard van Leeuwen, Dr. ir. Marie-Claire ten Veldhuis, Drs. ir. Saskia Jouwersma and ir. Anne Leskens. I would like to thank them for their feedback and advise during the research. I also want to thank the employees of Nelen & Schuurmans who have been very helpful in the research process.

Special thanks go to my family and girlfriend who have supported me during the entire graduation process and the rest of my study.

July 2011

Ber Albers

Summary

Since the end of the last century, polders in the Netherlands have suffered from inundation due to heavy rainfall. Inundation occurrences in 1998 have led to large economic losses, especially in polders with a fast rainfall runoff process due to the high percentage of land occupied by greenhouses. The area of the water board of Delfland was severely struck.

This thesis focuses on water system assessments, conducted in greenhouse dominated polders. The water system assessment is divided in a technical analysis (using a hydrodynamic model) and an analysis on the cooperation between the different parties involved in water management. The research questions in this study are:

How can hydrodynamic models of greenhouse dominated polders be improved, to contribute to the development of effective measures to prevent rainfall fed inundation?

How can the cooperation between the parties involved in water management of greenhouse dominated polders be used to improve water system studies?

The inundation of 1998 had a large impact in the area managed by the water board of Delfland. As a reaction to the inundation, policies were created containing storage capacity standards for the open water of polders. Based on these standards the project ABCDelfland (Afvoer- en Bergings Capaciteit Delfland, in English: Drainage and Storage Capacity Delfland) was started, in which water systems of main canals and polders were assessed. The polder assessment was aimed at reviewing if the new standards were met. In the assessment the water board focused on the water system under its own control. The focus of that study was not on how to solve the inundation problem, but on how the open water system could comply with the standards. The solutions which were identified to make the water system meet the standards were financially not feasible. It was found that a better representation of the water system was needed to develop new solutions. Cooperation between the parties involved in water management would be needed to make this happen.

This study was conducted to improve the assessment methods of rainfall fed inundation in greenhouse dominated polders. It uses the Oranjepolder (located in the management area of the water board of Delfland) as a case study, since inundation has occurred several times in this polder and is well documented and parties are engaged in finding new innovative solutions for the problem. In this assessment a form of participatory modeling was applied.

Input for a new hydrodynamic model was given by all parties involved in the management of water in the Oranjepolder. The water board of Delfland is responsible for the management of the open water, the sewer systems are managed by the municipality of Westland and horticulturists influence the runoff to open water by the storage of water in basins. By sharing information and experiences during workshops, this research has been made possible. Through the cooperation of these parties, the important elements of the water system and the key to future solutions are identified.

A hydrodynamic model of the Oranjepolder with a high level of detail is achieved. All important hydrologic processes are included. The hydrology of greenhouses is included on an individual level, resulting in a runoff to open water which represents the actual situation. Secondly, the channel flow model contains all channels and water structures located in the polder. This makes it possible to review inundation at every channel. Thirdly, the sewer system of the village Maasdijk is included in the model. Water flowing out of manholes and the interaction between the sewer and open water system are made visible. Finally, the aspect of overland flow is included. By taking all these hydrologic processes into account, predictions with a high level of precision can be

made. The high level of detail and the high precision of the model lead to better insight in the factors that influence inundation. Testing the model with real rainfall data resulted in the identification of multiple inundation locations, which were also reported in reality.

Due to this high predictive value it was possible to devise precise measures to prevent future inundation. These measures are not confined to the open water system but also concern the sewer system and the hydrology of greenhouses. It is expected that the total cost and amount of land needed, will be substantially lower than in previous assessments and that all stakeholders will support the implementation of measures.

Contents

Preface	i
Summary	ii
Contents	iv
1 Introduction	1
1.1 Background	1
1.2 Problem definition	2
1.3 Report outline	2
2 ABCDelfland	3
2.1 Meeting standards	3
2.1.1 Storage capacity standards	3
2.1.2 Drainage capacity standards	4
2.2 ABC conclusions	4
2.3 Influence of capacity standards	5
3 Research method	6
3.1 Participatory modeling	6
3.2 Case study: Oranjepolder	6
3.2.1 Water system	7
3.2.2 Greenport Westland/Oostland	8
3.2.3 Spatial situation	8
3.3 Modular modeling	9
3.3.1 Modules	9
3.3.2 Simulation mode	10
3.3.3 Simulation settings	11
3.4 Model development	11
3.4.1 Modeling approach	11
3.4.2 Rural rainfall runoff	12
3.4.3 Urban rainfall runoff	15
3.4.4 Channel flow	16
3.4.5 Overland flow	17
3.5 Rainfall scenario	18
3.5.1 Measurements	18
3.5.2 Rainfall event	19
3.6 Testing of model predictions	20
3.6.1 Testing of Sewer Flow model	20
3.6.2 Testing of runoff to Channel Flow module	22
3.6.3 Testing of complete model	23
4 Results	24
4.1 Model output	24
4.1.1 Rural area	24
4.1.2 Urbanized area	26
4.2 Identification of problems	27
4.2.1 Identified problems	28
5 Measures	29
5.1 Measures based on new model	29

5.2	ABC measures	30
5.3	Comparison of measures	30
5.3.1	Level of detail of measures	31
5.3.2	Involved parties in implementation of measures	31
6	Cooperation in water management	32
6.1	Cooperation within water management organizations	32
6.1.1	Cooperation during development of policies	32
6.1.2	Cooperation during projects	33
6.2	Cooperation between stakeholders	33
6.2.1	Cooperation during ABC study	33
6.2.2	Cooperation in new assessment approach	34
6.3	Effects of new assessment approach	34
7	Conclusion and recommendations	35
7.1	Conclusion	35
7.2	Recommendations	35
	References	37
	Appendices	38
A.	Model assumptions	38
B.	Greenhouse horticulture	39
C.	Greenhouse modeling	43
D.	Sewage flow	46
E.	Interview and workshops	47

1 Introduction

1.1 Background

In the Netherlands over 10.000 hectares of land is occupied by greenhouses (Figure 1.1). Clearly, these greenhouses are not spread evenly. The concentration of



greenhouses is highest in the province Zuid-Holland. The reason there are so many greenhouses in Zuid-Holland is partially because historically inhabitants from several large cities (among which Rotterdam) desired year round crops and partially because the number of hours of sunshine is relatively high in this coastal region (the Westland). Originally, most land in this region was used for agricultural purposes. However, due to higher profits in greenhouse horticulture, greenhouses have replaced the original fields and pastures. Aiming to create a globally competitive greenhouse area, greenhouses and supporting industries are also encouraged to choose for the profitable region of the Westland [Greenport Nederland, 2010].

Figure 1.1: Greenhouses in the Netherlands marked by black dots

In eighteen polders greenhouses occupy over 40 percent of the area [Hazeu, 2006]. In contrast to open agricultural land (fields and pastures), rainfall runoff from greenhouses is directly discharged to open water. This causes an increase in the runoff peak of rainwater and through this, an increase of the peak water level in the open water [Albers, 2010]. In some greenhouse dominated polders, this water level rise has led to inundation resulting in large economic losses. For example, in 1998 inundation of greenhouses in the Westland led to losses of hundreds of millions guilders [CDA Westland, 2006]. The problems concerning inundation caused by rainfall are a major topic of research of water management authorities. In the Westland, this research is conducted by the water board of Delfland and the municipality Westland.

The inundation of 1998 had a large impact on the area managed by the water board of Delfland. The board started a vast program aimed at improving the main canal system (boezem) and the polders, the project ABC Delfland (Afvoer- en BergingsCapaciteit Delfland), in English: Drainage and Storage Capacity Delfland. Moreover, the board introduced storage capacity standards for the polders. These standards dictate a predefined storage volume per area of land.

In 2002 the board started a research project aimed at assessing the current drainage and storage capacity of the polders. Measures to improve the storage capacity were designed and the board made water plans (Waterplannen) with all the municipalities in its area. In new developments it was advocated to improve the water system according to the new standards. All these efforts were aimed at creating more open water, as this was seen as the most effective way of preventing inundation in the future. Other storage facilities and measures aimed at reducing peak discharge were not encouraged since they could not be controlled by the water board. By 2005 the program was well under way but it met resistance with municipalities and private parties because of the large amount of land needed and the concurrent loss of economic activity. The areas with most inundation problems were the most problematic to improve: the extensive greenhouse areas. Although inundation on the 1998 scale had not recurred, local

inundation occurred in several areas in the past decade. A new approach was needed. In 2006 the local authorities and the water board started an innovation program aimed at reducing the total cost of the inundation program and the amount of land needed by designing tailor made solutions for specific economic activities. In order to design these new solutions the assessment of polders needed readjustment.

During a study in the Oranjepolder [Albers, 2010], the importance of the level of detail used in water system studies, was shown. This study showed that in modeling water systems, it is essential to model with a high resolution to gain a correct understanding of the system. The water system of such a model comprises the open water system, the sewer system and the effect of greenhouses on the water system.

The water system in and around greenhouses is managed by several parties. The water board is responsible for the management of the open water, the sewer systems are managed by municipalities and horticulturists influence the runoff to open water by the storage of water in basins. The cooperation between these parties is essential in water management of greenhouse dominated polders.

1.2 Problem definition

Due to the high costs of measures resulting from the ABC assessments, a new approach to prevent inundation in greenhouse dominated polders is needed. In this research, the methods and principles used in these assessments are reconsidered and a new method is being devised. This study is divided in a technical analysis (using a hydrodynamic model) and an analysis on the cooperation between the different parties involved in water management.

The first research question in this thesis is:

How can hydrodynamic models of greenhouse dominated polders be improved, to contribute to the development of effective measures to prevent rainfall fed inundation?

This research question contains multiple underlying questions, which need to be answered individually. The following underlying questions are posed:

- *What is the effect of more detailed models on the precision of the predictions?*
- *Can more detailed models lead to better insight in the factors that influence inundation?*

The second research question is:

How can the cooperation between the parties involved in water management of greenhouse dominated polders be used to improve water system studies?

1.3 Report outline

A review of the ABCDelfland method is given in chapter 2. Chapter 3 describes the research method, used to develop a new hydrodynamic model in a case study in the Oranjepolder. The focus of the technical research is explained and the model is tested. The results of the simulations are presented in chapter 4. Using these model results, a number of measures are described in chapter 5. Hereafter, a comparison between the measures proposed by the ABCDelfland assessment and the new assessment, is made. The organizational part of this research, focused at cooperation in water management, is described in chapter 6. Finally, the conclusion and recommendations of this thesis are presented in chapter 7.

2 ABCDelfland

The rainfall fed inundation events of 1998 in the management area of Delfland, called for an immediate response by the water board. In 2002 the ABCDelfland project was started. In this project the water board desired an approach which would lead to a robust solution that could prevent inundation in heavy rainfall scenarios. In this chapter the methodology is explained and the results are reviewed.

2.1 Meeting standards

After the 1998 inundation, the National Administrative Agreement Water [NBW, 2003], was developed. In this agreement, inundation safety standards were introduced. The water board Delfland adapted before the standards came into effect by the implementation of these standards, because of the severity of the inundation. To show how these standards were going to be met, Delfland had created policies [Hoogheemraadschap van Delfland, 2005]. These contained storage capacity standards which were aimed to lead to a robust solution to the inundation problem. The inundation standards were assumed to be met when the water storage capacity of a water level area and the drainage capacity meet the requirements as described in 2.1.1.

The water board reviewed the situation in all polders in ABC studies. Creating open water was seen as the most desirable solution. The water storage would be managed by the water board whereby it was not dependent on other parties. Open water storage was also seen as a robust manner to prevent inundation as technical failure could not decrease the effects. The focus of that study was not on how to solve the inundation problem, but on how the open water system could comply with the storage and drainage capacity standards. And if this was not the case, where could the capacity be increased [Tauw, 2002]. It was assumed that meeting the storage and drainage standards would prevent inundation in a worst case rainfall scenario.

2.1.1 Storage capacity standards

The translation of the inundation standards into storage capacity standards was done as shown in Table 2.1. These standards consist of a predefined storage volume per area for different types of land use (such as agriculture, greenhouses and urban).

Table 2.1: Safety standards

Function	Inundation standards [years]	Storage capacity standards [m ³ /ha]
Grass	1 : 10	170
Agricultural land	1 : 25	275
Greenhouses and high cost agricultural land	1 : 50	325
Urban areas	1 : 100	325

Reviewing the storage capacity in polders is done in two steps. First the available storage capacity and required storage capacity are calculated and then the difference is calculated. This is called the “storage deficit”.

The available storage capacity is calculated by multiplying the area of open water with the maximum allowable water level rise. Then an area of land per function (as described in Table 2.1) is calculated using a Geographical Information System (GIS). These areas

are multiplied with the storage capacity standards. The resulting volume is the required storage capacity.

For the management area of the water board of Delfland, the analyses led to a total calculated storage deficit of almost 900.000 m³.

2.1.2 *Drainage capacity standards*

The drainage capacity standards dictate the maximum allowable energy gradient and flow velocity in canals and culverts. These standards are tested in a number of standardized tests.

The drainage capacity standards were assessed using a hydrodynamic model, created in the Sobek software package. This model contained the rainfall runoff and channel flow (1D) processes in polders.

The rainfall runoff of greenhouse dominated polders was divided in areas based on land use, either urbanized or greenhouse area. The division assumed a ratio of 50% paved and 50% unpaved area for urbanized area. The greenhouse areas are modeled as 75% paved and 25% unpaved area. The rainfall runoff of the polder was modeled with an average runoff area of 20 hectares draining at one location.

In the channel flow part of the hydrodynamic models, the main and some secondary canals and the important water structures located in these canals were modeled [Tauw, 2002].

Four rainfall scenarios were simulated in this model:

- A constant stationary rainfall (28 mm/d)
- A rainfall event with an expected return period of 10 year
- A rainfall event with an expected return period of 50 year
- A rainfall event with an expected return period of 100 year

These scenarios were used to test how a water system would react to rainfall with different intensities. Reviewing the situations which occurred could tell whether a water system was functioning as desired.

The result was that in stationary rainfall scenarios the maximum allowable energy gradient at water structures was exceeded. The drainage capacity was not high enough and enlarging specific water structures was supposed to solve this problem. In the rainfall events with an expected return period of 10 years and more, high water levels were found.

2.2 **ABC conclusions**

Results from the ABC- studies were used to create solutions to the identified problems. The largest problems were found in greenhouse dominated polders. The total calculated storage deficit in the area of Delfland (41.000 ha) was 900.000 m³. In the greenhouse dominated Oranjepolder (area of 702 ha) a calculated storage deficit of 90.000 m³ was found.

From the storage deficit calculations, it was concluded that, in order to achieve the required storage capacity, additional water storage needed to be created.

With the hydrodynamic model a number of hydraulic bottle necks concerning the included canals and structures were identified. This has led to the enlargement of culverts and weirs.

2.3 Influence of capacity standards

The water board of Delfland had chosen to assess the open water system. This choice led to the approach of using the capacity standards as a basis for the analyses. The ABC-studies had become a search of how to meet these standards.

In greenhouse dominated polders, the storage capacity standards led to very high storage deficits. The calculated required volume was then spatially distributed over a polder. Creating the required volume of open water proved to be a problem in some polders. Finding plots of land and changing this land into water storages was a last resort. The location was chosen, based on where plots of land were for sale for an acceptable price. But, if the storage is created downstream of the inundation, the water will cause problems before it reaches the storage, especially with narrow culverts.



Figure 2.1: Open water in greenhouse dominated polders

The tests of drainage capacity standards only considered the open water and a very simplistic influence of rainfall runoff.

The water system in greenhouse dominated polders is very sensitive to rainfall (Figure 2.1). Therefore it is important to have a level of detail in the model that includes the small canals and the runoff on it. Apart from this, the effect of the storage of greenhouses on the runoff process is not included in the assessment.

The hydrodynamic models could not identify the bottle necks in the water system, because they were not included in the model. The hydraulic problems, which have been identified working with these models, could have been a result of the low level of detail in the model.

3 Research method

In the previous chapter, the ABC methodology has been reviewed to see how previous assessments of rainfall fed inundation in greenhouse dominated polders were executed. One of the polders in which this methodology has been applied, but in which inundation still occurs, is the Oranjepolder. This polder is used as a case study to find an approach how to assess rainfall fed inundation in greenhouse dominated polders. For the water board Delfland this study is a pilot project to find a new methodology to review polders in the future.

The approach used in this thesis differs from the ABC studies. Due to a new form of cooperation the development of the hydrodynamic model has also changed. This chapter describes the method of participatory modeling (paragraph 3.1). This method describes the form of cooperation between parties involved in the rainfall fed inundation of greenhouse dominated polders. Using this approach the hydrodynamic model is developed. This process is described in this chapter.

3.1 Participatory modeling

The research done in the ABCDelfland project was executed by the water board of Delfland. The identification and implementation of measures was done by the water board as well. Because inundation presented a problem to both water board and municipality, both organizations desired a new approach. Measures identified in this new study were to be financially feasible and better in both a social and economic sense. The cooperation between these governmental institutions is organized in a project group called Waterkader Haagland [Programmabureau Waterkader Haagland, 2009]. It was found that a better representation of the water system was needed. To gain the information required for the study, cooperation with other parties was needed.

The difference with previous research is the inclusion of stakeholders in the research. The included parties are the water board, municipality, horticulturists and civilians. In the research of the Oranjepolder a form of participatory modeling is used [Voinov et al., 2010]. The participation was aimed at engaging stakeholders for three purposes: passive participation (informing stakeholders), exchanging information for the development of the hydrodynamic model and shared learning [Pretty, 1995; Lynam et al., 2007]. This approach is a bottom-up procedure, which means that the hydrodynamic model created in this research is an extension of the old model, based on extra information input.

Through the organization of workshops with stakeholders, the research process is made interactive. Exchanging information with stakeholders is an important aspect of the new method. Newly executed parts are used as feedback to validate and further improve upon the research result. In this way the research is iterative leading to a final result.

3.2 Case study: Oranjepolder

The greenhouse dominated Oranjepolder is located in the province of Zuid-Holland (Figure 3.1). The polder is part of the management area of the municipality Westland. Water management of the open water is organized by the water board of Delfland. The total surface of the polder is 702 hectares.

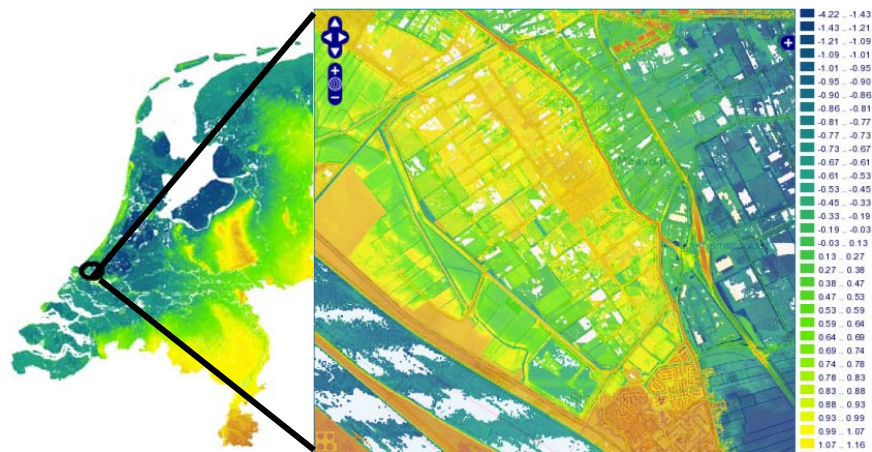


Figure 3.1: Elevation map of the Oranjepolder (AHN, 2011)

3.2.1 Water system

The situation in the polder is a result of a long history. In 1712 the settlement of Maasdijk consisted of a couple of houses and the land was used for agriculture (Figure 3.2A). Now over seventy percent of land has been filled by greenhouses and the town of Maasdijk has almost 4000 citizens (Figure 3.2B). The change in land use is obvious, while the main infrastructure and the waterways have stayed largely the same.



Figure 3.2A: Oranjepolder [Cruquius, 1712] Figure 3.2B: Oranjepolder [Google, 2010]

In the urbanized area of Maasdijk a mixed sewer system is used to drain sewage and rainwater. When excess rainfall is drained by the system, the sewer system can't handle the volume of water. On the edges of the town centre of Maasdijk three spillways are located, which allow excess water to spill to the open water. The municipality Westland manages the sewer system.

In Figure 3.3 the open water system of the Oranjepolder is portrayed. The polder consists of four water level areas. The water level in the Oranjepolder is elevated above the surrounding main canal (boezem) level. Water is pumped into the ring canal of the polder by two pumping stations (gemaal) and is drained naturally under gravitational flow. Water levels in the polder are maintained by weirs, set throughout the polder. The total polder area is split into four different sections with different water levels, maintained by weirs.

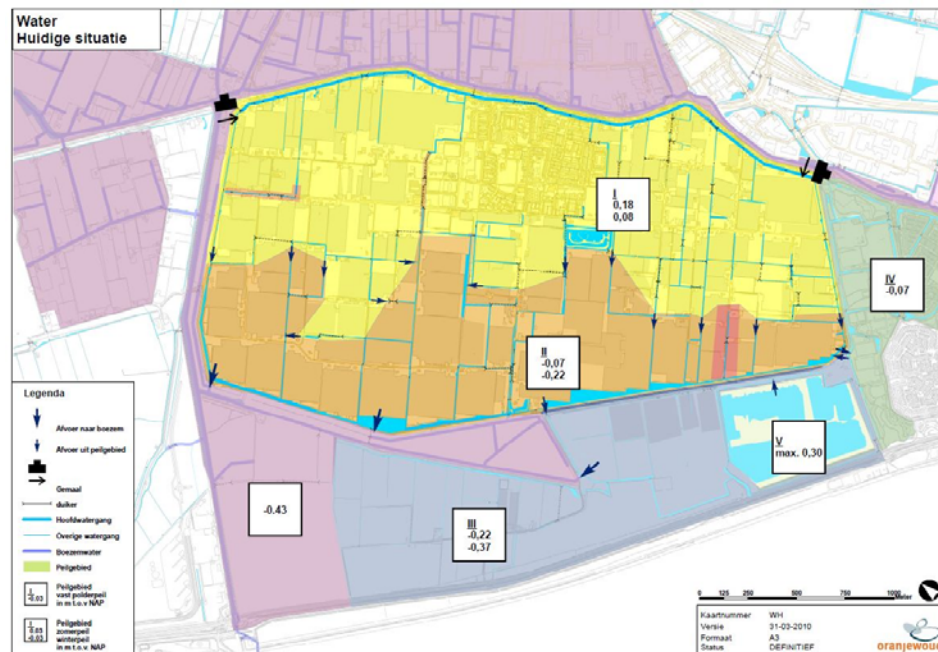


Figure 3.3: Water level areas, canals and hydraulic structures [Oranjewoud, 2010]

Along the dike, that surrounds the polder, a ring canal is located. This canal is the largest in the polder and surrounds smaller canals in the polder. Water drains by gravity to this canal, which again drains by gravity to the weirs at the edge of the polder. Due to the development in the Oranjepolder, 146 culverts were constructed in the inner polder (water level areas I and II).

The total surface of open water in the water level areas I and II (Figure 3.3) is only 3.9%. Drainage of rainwater is important to prevent excessive water level rises. The drainage capacity is dependent on the size of channels, friction and hydraulic structures. The large number of culverts in the water ways and the small size of the water ways have proved to be a problem [Oranjewoud, 2010].

In August 2004 an emergency pumping station was placed in the ring canal next to the urbanized area. In extreme rainfall situations this pumping station can be used to minimize the flooding problems as much as possible.

3.2.2 Greenport Westland/Oostland

The greenhouse intensive area of the municipality Westland has been designated to become a “Greenport”. The municipality, the province of Zuid-Holland and the national government, all support the development of Greenports. The Oranjepolder is a part of the Greenport Westland-Oostland. This area is meant to develop to an international competitive greenhouse area. All supporting industries which can positively influence the development of greenhouses are promoted to be located within the Greenport. An important aspect is the sustainable development of the greenhouse area. The aim is to create an economy of scale, good infrastructure (both water and roads) and to achieve sustainable water usage by greenhouses [Greenport Nederland, 2010].

3.2.3 Spatial situation

The inner part of the Oranjepolder (water level areas I and II) is 490 hectares. In this area the main functions are greenhouse horticulture and urban area (Figure 3.4). The village Maasdijk has around 4000 inhabitants, which are primarily living in the urban neighborhood of 33 hectares. Industries, cemetery and sports area take up another 11.4 hectares.

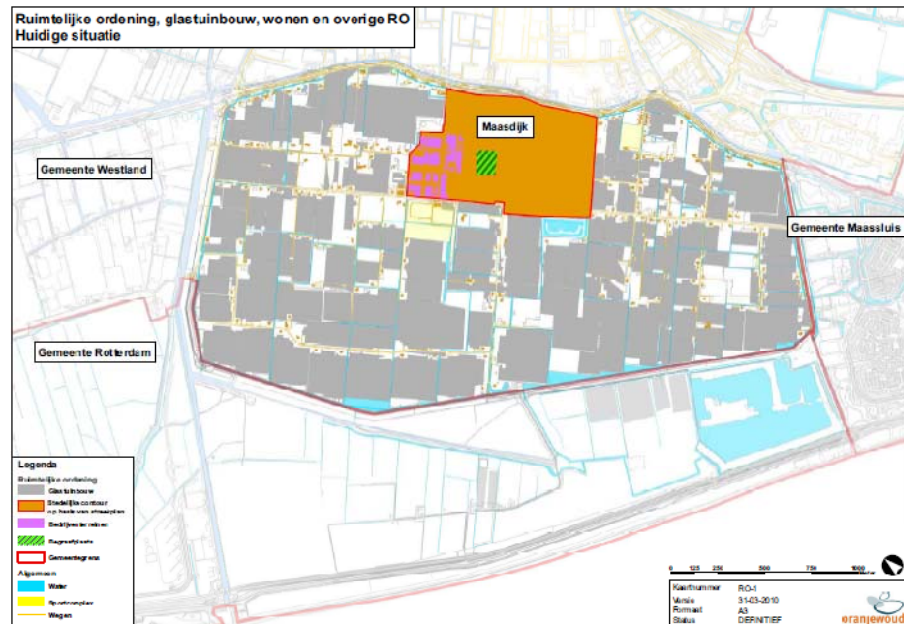


Figure 3.4: Spatial situation [Oranjewoud, 2010]

The open water in the Oranjepolder only accounts for 16 hectares of the total surface. Including the newly created water storage, this comes to 3.9% of the polder.

The glass surfaces of greenhouses fill up 344 hectares of the polder. Sizes of greenhouses differ roughly between 1 and 12 hectares. The larger greenhouses are the result of restructuring in the last ten years. This has primarily occurred in the western, lower part of the polder. The newly created greenhouses are often used to enable growth of crops with a higher quality and quantity demand than older greenhouses. Securing water to fulfill the irrigation demand is done by creating additional storage. Therefore new greenhouses often have more storage than old greenhouses. With the legislation in the Decree on Greenhouses [Besluit Glastuinbouw, 2002] it has become a legal demand for greenhouses to have at least 500 m³ of storage per hectare of glass surface. Old greenhouses which have proved that either a reconstruction or stop of cultivation is imminent have not been forced to meet this requirement.

3.3 Modular modeling

Sobek is a hydrodynamic software package which has a modular structure. This means that one software model is constructed using one or more modules of the software. Each module represents a different aspect of a water system. By combining modules an integrated model can be created. The modular construction of the model made in this research and the choice of simulation settings are explained. A list of made assumptions is found in Appendix A.

3.3.1 Modules

Combined 1DFLOW

The Combined 1DFLOW module is a direct combination of the two modules SOBEK-Rural 1DFLOW and SOBEK-Urban 1DFLOW. The combination means that a real time interaction and bilateral influence will be assumed and calculated.

The SOBEK-Rural 1DFLOW module is used for the simulation of one-dimensional flow in small canals. This module is used to simulate and study problems in regional water management. Typical assessments made with this module are automation of weirs in canal systems, dredging and flood protection.

The SOBEK-Urban 1DFLOW module is used for the simulation of one-dimensional flow in sewer systems. Simulations using this module are made to study problems in urban drainage systems. The assessments of urban water systems are specifically made in this module. Reviewing the urban drainage capacities and sewer overflow frequency are just two of the possible assessments made with this module.

Rainfall-Runoff

The RR (Rainfall-Runoff) module is used for the simulation of rainfall-runoff processes. This module is required for the inclusion of rainfall in a simulation model. Greenhouses, paved and unpaved surfaces are functions in the RR module most used in greenhouse dominated polders. The RR process can be linked to the Combined 1DFLOW module to simulate the influence of rainfall on the water flowing in the water system. It is possible to let the software make calculations for both modules simultaneously or sequentially.

Overland Flow

The Overland Flow (2D) module is used to calculate two-dimensional flow on land. The hydrodynamic simulation engine solves the Saint-Venant equations: continuity equation and momentum equation. The 2D module is fully integrated with the Combined 1DFLOW module to create accurate flooding simulations. To create such a model the module requires a bottom level grid and a friction of the surface. A situation where a 2D bottom level grid is connected to a 1D branch is shown below in Figure 3.5.

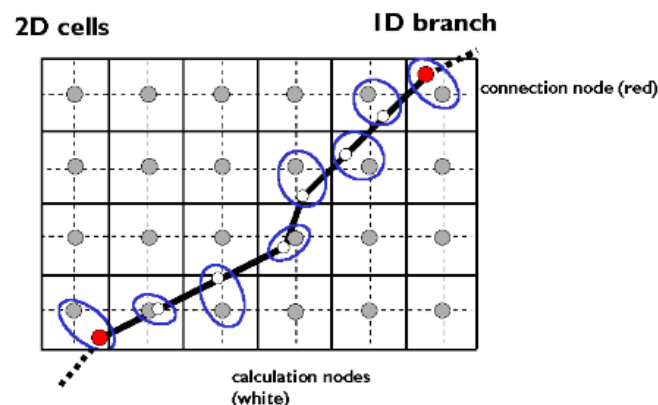


Figure 3.5: Connection between 1D branch and 2D grid cells

In Sobek 1D, the hydrodynamic software makes water balance calculations at defined points. These points are either connection or calculation nodes. These nodes are connected to the centre of the grid cell in which the node is placed. For all connected calculation points a mass balance is made. A cell will flood, if the water level calculated in the 1D module is higher than the ground level found in the grid cell.

3.3.2 Simulation mode

The modules used to model the Oranjepolder are: Combined 1DFlow (containing both Channel and Sewer Flow), Rainfall Runoff and 2D Overland flow.

The modules can be simulated either sequentially or simultaneously. The bilateral influence between the Rainfall Runoff and Combined 1DFlow modules makes it important to run the simulation simultaneously. The interaction between the Combined 1DFlow and Overland Flow is also modeled simultaneously (Figure 3.6). At every time step a simulation of all modules is made. The output from calculations which are made in one module, are used as input to the interacting modules at the next timestep.

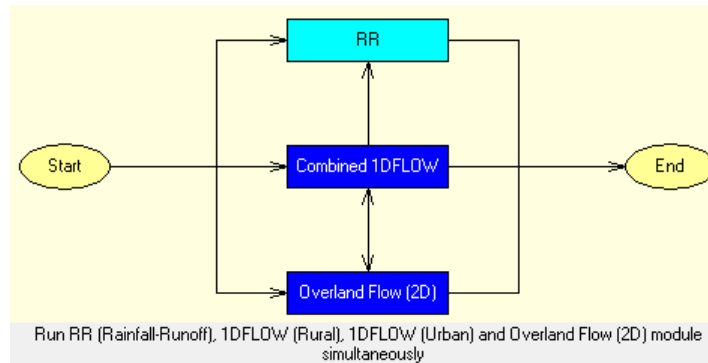


Figure 3.6: Sobek model simulating RR CF SF 2D simultaneously

3.3.3 Simulation settings

The complete model is used to make a simulation to generate results. Important settings which are used in this simulation contain are the period and time step.

Simulation period

The model will be used to simulate a rainfall event in the month August in 2004. In this period, inundation has been registered in the Oranjepolder. To make sure that the starting values are properly used, the period from January up until August is also modeled.

Time step

The interval between calculations is a result of the time step which is chosen. The decision is made to ensure that the Courant condition is met, which is required to obtain a stable calculation. The condition dictates that the flow velocity must be smaller or equal to the distance between two calculation points divided by the time step. If this condition is not met, the mass balance can't be solved and iterations will be made to make an approximation. If the balance is not calculated correctly in eight iterations, a balance error occurs. It is assumed that, as long as this balance is smaller than 0.1% of the total amount of water in the system, the accuracy is acceptable. To prevent a large balance error, a time step of 10 seconds is chosen.

3.4 Model development

In this paragraph the development of the model is described. The model objective and approach has led to a new hydrodynamic model.

3.4.1 Modeling approach

The ABC approach is used as a basis for the water system analysis in this research. Weaknesses in the modeling approach are used as a focus for improvement of the water system analysis. The objective of the production of the new model is to create accurate information of rainfall fed inundation situations in greenhouse dominated polders. The weakness in the previous approach was found to be in the rainfall runoff process. A low level of detail was used in both the spatial situation (runoff locations) and the description of the runoff process (in rural and urban parts of the polder).

This new model is created by researching these parts of the rainfall runoff process in greenhouse dominated polders after identification of important influences on the open water level. Based on input of water experts about these polders, possible important influences on the open water are identified. The influence is then researched to better understand the process and the exact characteristics of the influence.

3.4.2 Rural rainfall runoff

The rural area of the Oranjepolder is dominated by greenhouses. The transition from agricultural land to greenhouses has increased the pace of the rainfall runoff process. However the exact rainfall runoff relation had not been researched. The hydrology of greenhouses was not taken into account in the modeling of the rural area. The size of storage facilities (see Figure 3.7), the water use, fluctuation of water storage and the spill locations were all unknown.



Figure 3.7: Greenhouse storage facilities: silo (left) and basin (right)

The rural area in the polder was represented in 22 parts, instead of basing the representation on the number of dwellings. An average of 13 hectares was chosen to have one spill location to the open water. The closest open water channel was chosen as a runoff point for these parts. Rural surfaces were split up in paved (representing greenhouses, houses and roads) and unpaved (grassland) areas. This division was made assuming that 75% of the land was paved and 25% was unpaved area for the rural greenhouse area. All rural paved areas were assumed to be able to store a 10 mm layer of water on the paved area.

Size of storage locations and discharge location

From an aerial photo the exact locations of greenhouses and water storage was identified. By calculating the surface area, both the surface of a greenhouse and its storage are found. These exact dimensions are used in the new model. In field research [Albers, 2010] it was found that close to water storage drains can be found which act as spills from the storage at greenhouses. These drains can be found from a high detail aerial photo (Figure 3.8). The drain locations have been linked to storages that again have been linked to greenhouses. This has been used as input for the hydrodynamic model.



Figure 3.8: Greenhouses and water storage

Water usage and fluctuation of water storage at greenhouses

The fluctuation of available water storage capacity is dependent on water usage and the total available storage. The water use in a greenhouse is primarily dependent on the type of crop that is grown. Horticulturist will construct additional storage to meet the water demand of crops. Besides rainfall, horticulturists will use additional water sources such as surface water from canals, ground water (pumped up and desalinized) and tap water. Usage of these water sources is researched, non quantified data of these sources and horticulturist reasoning when to use which source is explained in Appendix B.

The actual water usage found during field visits is not used in the hydrodynamic software package Sobek. This model software contains a standardized representation of greenhouses. In this representation, the filling percentage of the water storage on a given day is dependent on the size of the storage of the greenhouse. In Figure 3.9 these percentages are shown for a storage of 500 and 2500 m³/ha.

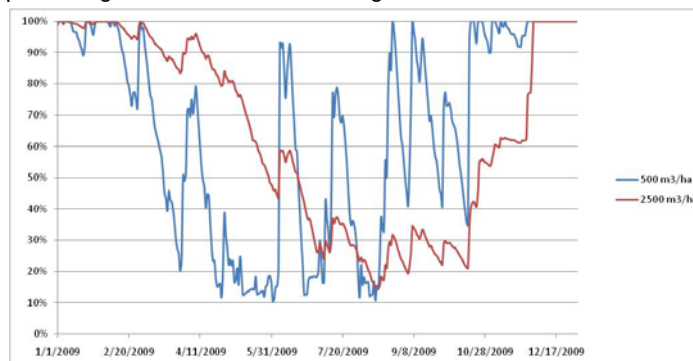


Figure 3.9: Water storage fluctuation in Sobek files (applied to 2009)

This standardization of filling percentages seems doubtful compared to the validated water balance found in earlier research (Figure 3.10). This water balance is found by quantifying the hydrological processes in greenhouses and the important water flows.

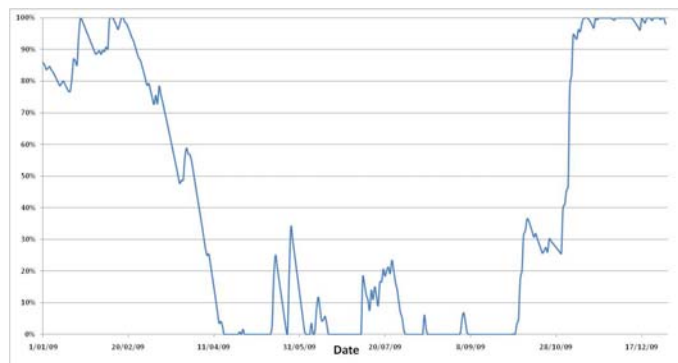


Figure 3.10: Water storage fluctuation [Albers, 2010]

The water storage fluctuation shown above is assumed to be correct. A general trend is maximum filling in winter and low water levels during summer. In winter the water storage capacity does not fluctuate much. It can be assumed that all water storages are filled. When rainfall simulations are made it is preferable to start a simulation in the winter, as this situation is known. In this research simulations of the water system will be started in winter to guarantee the correct usage of the startup period.

Modeling greenhouse runoff

A way of implementing greenhouse details in Sobek is using the standard greenhouse node. The only important variables which can be chosen are the surface of the greenhouse and a basin size to greenhouse area ratio. These ratios are given in different categories (Table 3.1).

Table 3.1: Water basin categories

Basin size (m ² /ha)
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 4000
4000 - 5000
5000 - 6000
6000 >

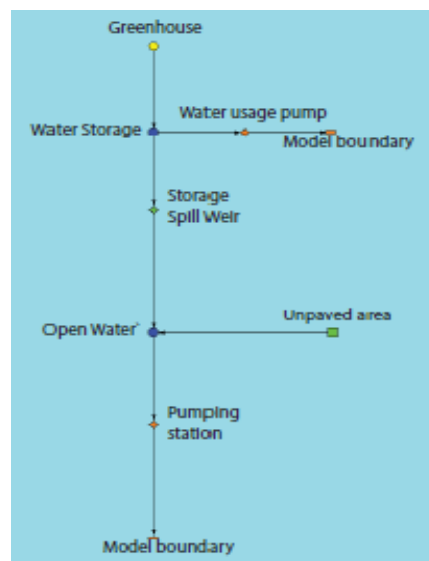
The categories use the lower bound as the actual basin size. This means that every greenhouse with a storage capacity per hectare of glass below 500m³/ha is modeled as having no storage at all. All greenhouses are standardized to have the same water use which is withdrawn from this storage. These and other simplifications are reviewed in Appendix C.

It was found that a greater degree of freedom in the modeling of greenhouses was preferable. The standardizations in the Sobek model have an impact on the water balance of the greenhouses. Because 70% of the Oranjepolder is covered with greenhouses, it is important to represent the rainfall runoff as accurate as possible. Improvements are made in both the schematization and initial values.

New greenhouse schematization

Due to the standardization in the Sobek greenhouse schematization, it is not possible to precisely represent the actual situation. This is changed by making the greenhouse node fulfill only the rainfall runoff task. The greenhouse in Figure 3.11 catches rain which is drained to the water storage. The storage has the exact area found in the polder.

The water storage is influenced by rainfall and evaporation. When water is used, it is pumped out of the water storage and when the storage is completely filled, it starts to spill. The spill is modeled as a weir, which separates the water storage from the open water. Other aspects of the polder remain unaltered in the new model.

**Figure 3.11: New polder schematization**

Because in this schematization the water usage is separated from the greenhouse, it is possible to vary in water usage between two greenhouses. In the Oranjepolder, a distinction is made between three types of greenhouses with different use of water. In the new schematization, water usage is easily adjustable for individual greenhouses.

In literature it was found, that heights of storage could vary up till 4.64 m [Glastuinbouw techniek, 2010]. In field visits, it was observed that storage silos and basins have an average maximum filling depth of 4 meter. A volume of water storage is calculated using the exact area and average height.

3.4.3 Urban rainfall runoff

The municipality Westland has had problems in the village Maasdijk with water flowing on streets. Water flowing out of manholes and channels at sewer spill locations has led to water flowing through houses. The ABC model could not portray water levels in the village Maasdijk. Inclusion of a sewer model in the polder water system model was thought to be important. And information which depicts the water level in the village Maasdijk was desired to predict urban inundation.

Rural rainfall runoff modeling of urban area

In the original model (Figure 3.12), the urban rainfall runoff model was simplified to a rural model with a given storage and pump capacity. The assumptions were made, that in the sewer system approximately 7 mm of storage would be available and 0.7 mm/hour pumping capacity. The runoff locations were chosen, where the sewer spills in reality. Problem of this method is that the bilateral interaction between sewer and open water is neglected.



Figure 3.12: Urban area depicted in rural rainfall runoff

Sewer flow

The exact representation of urban rainfall runoff in the village Maasdijk is depicted in Figure 3.13A. The combined sewer system, which transports both waste and rain water, is represented with dimensions of the actual sewer. The sewer transport pipes and its gradients as they are known to the municipality Westland are all used for this model (Figure 3.13B). This results in a sewer flow model that portrays the urban drainage.



Figure 3.13A: Urban rainfall runoff, sewer flow model

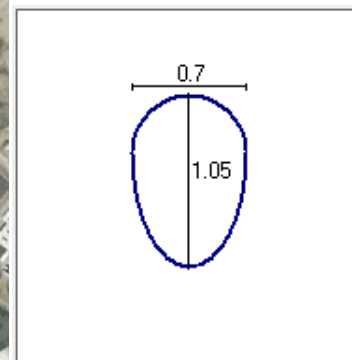


Figure 3.13B: Sewer pipe

All manholes, pumping facilities and spillways are used in this model. The model as it was created in 2007 is updated to the latest situation. However, the spillways use a fixed water level, which is lower than the spill crest level. In this model the sewer can always discharge water to open water (Figure 3.14).

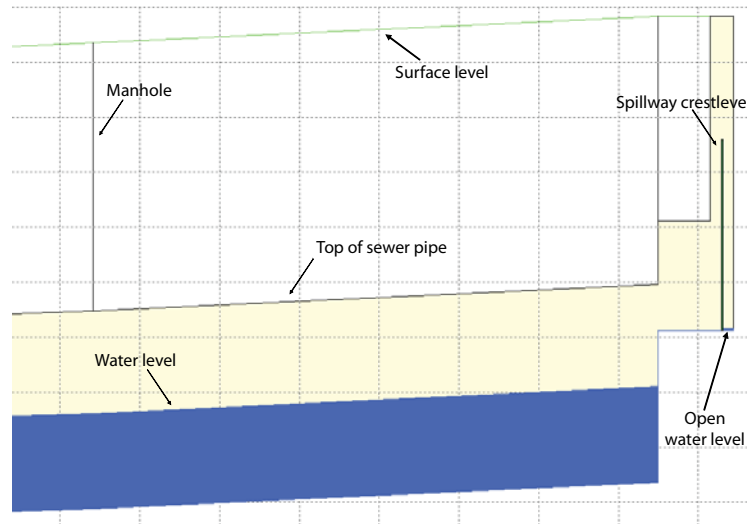


Figure 3.14: Sewer model with spillway

Combined 1D flow

A direct link is made between the sewer flow and channel flow models. This means that the fixed water level given in the channel is replaced by the real time water level. The links between sewer and open water have an automatic non-return valve. In reality these valves have often functioned less than perfect. This means that a high water level in the channels could create a flow into the sewer system. The assumption is made that the valve works properly, as it was designed.

3.4.4 *Channel flow*

As mentioned before, the channel flow model in the ABC studies only contained the primary and secondary canals and the structures placed in them. This model has been updated to contain all canals and water works in the Oranjepolder [Oranjewoud, 2010]. A part of this new model is shown below in Figure 3.15. The dimension of cross sections and water works are used in this model.



Figure 3.15: Channel flow model

In the above shown section of the ring canal, 14 culverts are placed. All lengths and cross sections of these culverts are placed in the model. A side view of this area of ring canal is shown below (Figure 3.16).

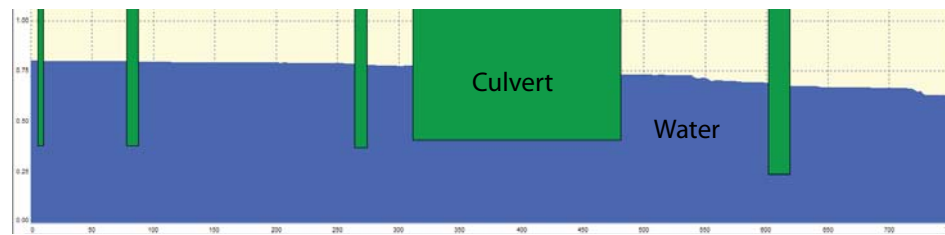


Figure 3.16: Side view ring canal

The model is updated to represent the latest situation. The cross sections of the canals and culverts are updated.

3.4.5 Overland flow

Including the overland module in the simulation of rainfall fed inundation leads to a different water level found in the open water (Figure 3.17). The reason is that instead of calculating a fictional water level, inundation of land will be assumed as soon as the level surpasses the ground surface level.

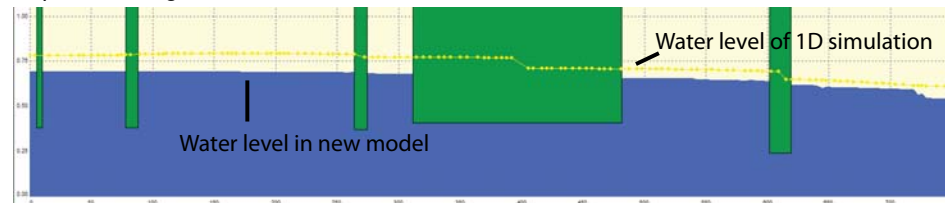


Figure 3.17: Water level comparison after inclusion of overland flow

Grid cells

The Digital Elevation Model (AHN2 detail 0.5x0.5 m) was used as a basis for the overland flow grid. On the Oranjepolder a grid was created. To create a model which has a relatively low calculation time, the size of grid cells is chosen at 25x25 meter. The median of the surface levels found in the AHN2 is used to determine the surface level in the grid cells.

The overland flow module is used to determine the location at which water problems occur and what the water level is at this location. These factors influence the costs occurring from inundation. It can be important to know, whether a house will inundate or not. Therefore a higher level of detail is required in the urbanized area. In the village Maasdijk the grid size is chosen at 5x5 meter. To speed up the simulation process, the high detailed grid is not used in the entire polder. A nested grid is used which has larger grid cells for rural areas, where the scale of buildings greenhouses is larger and smaller grid cells in the urban area (Figure 3.18).

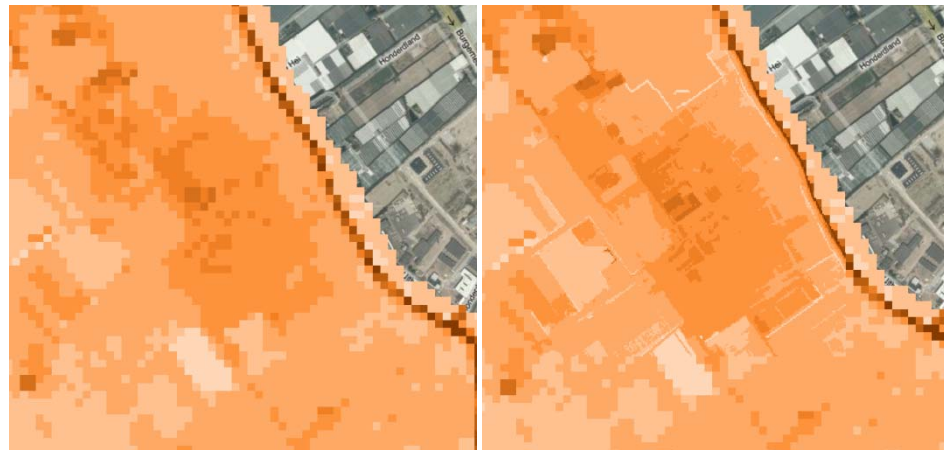


Figure 3.18: Surface elevation 25x25 m

Nested grid with 5x5 m in village

Friction

An important factor in flood simulations is the friction factor. A friction grid is often used to distinguish between different types of land coverage, to correctly model flood speeds. In case of rainfall fed inundation the differentiation in overland flow speed is not of great importance. Therefore one friction factor is chosen in the entire polder. A Nikuradse roughness coefficient (k_n) of 0.5 m is used calculated with the White Colebrook formula to calculate the Chézy Coefficient.

3.5 Rainfall scenario

In recent years the Oranjepolder has inundated a number of times. In August 2004 the large rainfall events have led to inundation on three occasions. Inundation was found in the urbanized part and in the greenhouses. In the notification systems of both the water board and municipalities reports have been made. Assessing the rainfall fed inundation with hydrodynamic models requires data of the rainfall event. The month August 2004 is chosen as the simulation period.

3.5.1 Measurements

Considering the pace of the runoff process in urbanized areas, the desired measuring interval of rainfall should be at most 15 minutes [Van de Ven, 2007]. The convective rainfall that is found in summer can be relatively short but with high intensities. The intensities are important, as they can cause fast rises in water level.

It is also typical for convective rainfall, that a spatial distribution is found. In the close vicinity of the Oranjepolder three measurement stations are located (see Figure 3.19). The water board of Delfland has two rainfall measurement stations (located in Maasdijk and Schipluiden) and the Royal Netherlands Meteorological Institute (KNMI) has a daily rainfall station in Maasland. The distance between the measurement stations is around 10 kilometers.



Figure 3.19: Location of measurement stations

Data of the stations of the water board was available at an interval of 15 minutes. However the measurement station in Maasdijk did not register any values until the end of August in 2004. The daily rainfall sum of Maasdijk did resemble the daily measurements of Maasland after this period. The station in Schipluiden showed a lower daily sum.

The aim is to have a rainfall distribution on a 15 minute interval with a total volume that fell in Maasdijk. To approach this value, it was chosen to use the temporal variability of rainfall of Schipluiden with the daily amounts measured in Maasland.

3.5.2 Rainfall event

The rainfall measured in August 2004 in Maasland was found to be the highest registered monthly rainfall amount in history. In the entire month 324.9 mm was measured, with four daily amounts above 40 mm (Figure 3.20).

Number of values: 32. Timestep: 24:00:00 Maximum: 67.1 mm. Total : 324.9 mm.

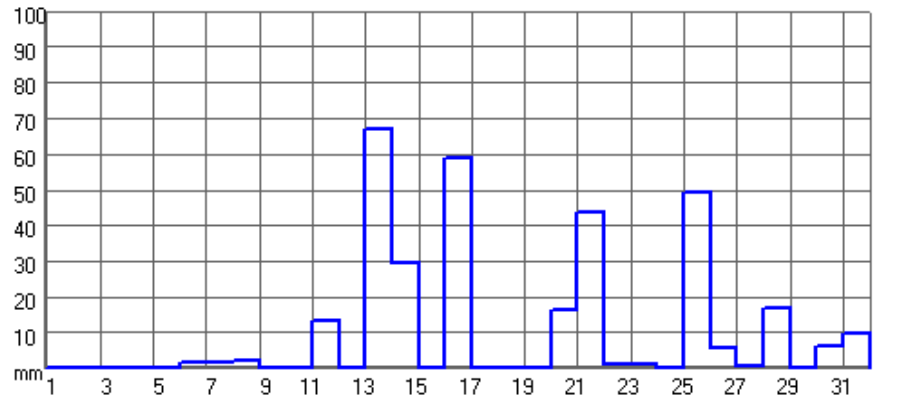


Figure 3.20: Daily rainfall measured in Maasland

Using the temporal distribution measured in Schipluiden, a quarterly rainfall distribution is created (Figure 3.21). Using this method a number of extreme quarterly rainfall peaks are found.

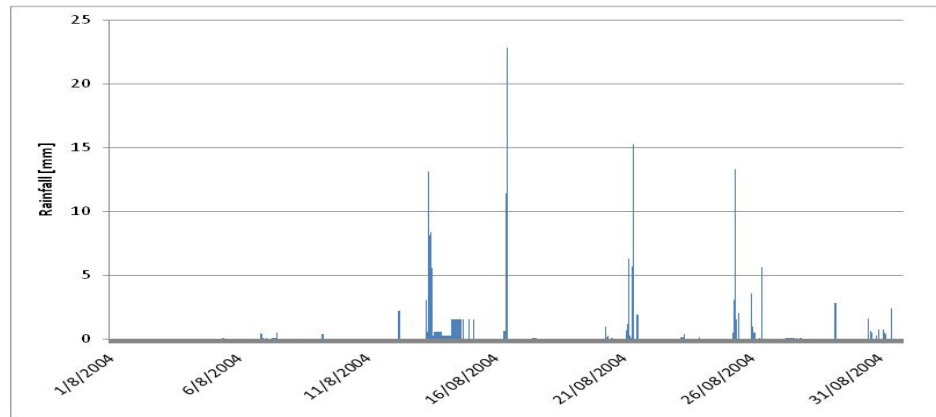


Figure 3.21: Constructed rainfall event with 15 min interval

3.6 Testing of model predictions

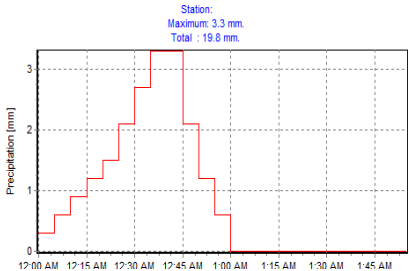
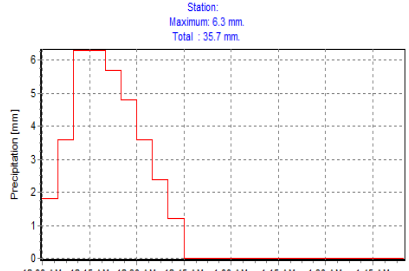
The hydrodynamic model, which has been created during this research, needs to be validated. A number of tests are applied to the individual modules and to the combined model. Using test scenarios a number of standard tests are applied to see if the model would represent a “normal” situation. Structural validity, number of iterations, balance error and unexpected results are checked to see if the model is working correctly.

3.6.1 Testing of Sewer Flow model

The structural validity of this model is tested by checking, if the sewer system works the way it should. A check is made to see, if the representation is made correctly. Reviewing the use of pumping stations and spill locations gives insight in the model structure. The pumping stations have a combined pump capacity of 1.7 mm/hour, which is high compared to a “normal” pump capacity of 0.7 mm/hour. The stations are working according to design data. The spill locations work correctly and are modeled as free spilling. A check is made if the assumed sewage distributions and drain locations are applied (for sewage distribution see Appendix D). And finally it is checked, if the total surface area connected to the sewer actually drains via the sewer. In the village of Maasdijk with a total of 49 hectares, only 19 ha is drained by the sewer system. The additional 30 ha does not drain via the sewer system, because it is unpaved area.

The structurally valid model is tested, to see if the results represent the results, which are to be expected. The model of the sewer system is applied to five fictitious rainfall events.

Table 3.2: Test results of RR-SF model

Test scenario	Findings
Duration: 1 day Start: Full Rainfall: 0 mm/day	Sewer system is pumped dry after 12 hours. However water always stays behind at a few locations. Water balance error is small (<0.1%)
Duration: 1 day Start: Empty Rainfall: 0 mm/day	Only inflow occurs from sewage Total inflow equals number of inhabitants * 120 [L/d] * number of days = 11270 m ³ Water balance error is small (<0.1%)
Duration: 1 week Start: Empty Rainfall: 10 mm/day	No water on street No discharge over spillways Water balance error is small (<0.1%)
Duration: 2 hours Start: Empty Rainfall: Storm event with expected return period of 2 years 	This test is used as a maximum stress test for the sewer system. Results in a properly working sewer system should be no water on streets. On 30 manhole locations water on street is found. Discharge is found at all spill locations. Water balance error is small (<0.1%)
Duration: 2 hours Start: Empty Rainfall: Storm event with expected return period of 5 years 	This test is used to find problems in a sewer system. The sewage flow is much smaller than the rainfall flow. Discharge occurs on all spill locations. Water on street occurs on half of the manhole locations. At the end of the simulation there is no water on street. Water balance error is small (<0.1%)

The results of the tests of the sewer flow model are acceptable. The simulations have shown that the sewer system does not prevent inundation. It is known indeed, that problems occur in the urbanized area of Maasdijk. The model seems to represent the sewer system adequately.

Finally, the rainfall scenario described in the previous paragraph is simulated in the sewer flow model. It is known, that the rainfall in 2004 caused problems in the urbanized

area of Maasdijk. Water on street does occur on a large number of manhole locations even though all spill locations are working on six occasions. Water is drained very fast when rainfall stops.

3.6.2 Testing of runoff to Channel Flow module

The influence of rainfall on the water level, represented in the channel flow module, is also tested. In this research, the linkage of greenhouses with open water and the influence of spillways from the sewer on open water are new aspects. These interactions are specifically reviewed to see, if the results are logical. Testing of the runoff is done using the rainfall scenario in August 2004.

The sewer system is a fast responding water system which spills water, if the water level in the sewer system rises above crest level of the spillway. The situation in August 2004 led to spills a number of times (Figure 3.22).

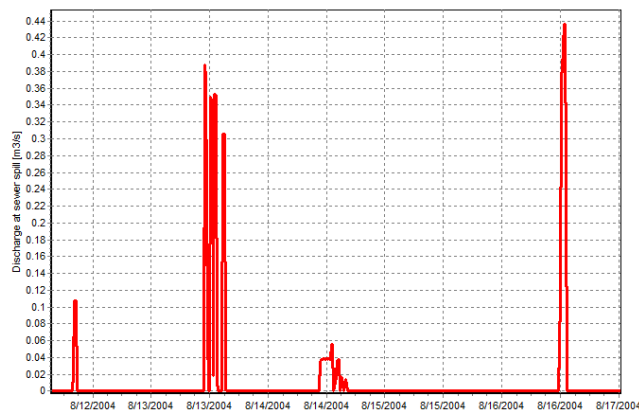


Figure 3.22: Discharge of sewer to open water

The new rainfall runoff simulation of greenhouses is reviewed. This is done by comparing the expected influence of rainfall on the storage of greenhouses and reviewing the reaction of the spill at greenhouses. The dry period before August 12th has resulted in a low storage level (Figure 3.23). When the rainfall starts a sudden rise in the water level is found. The water storage is completely filled on the 14th of August. When another large rainfall amount is added, the spill of the greenhouse starts to work.

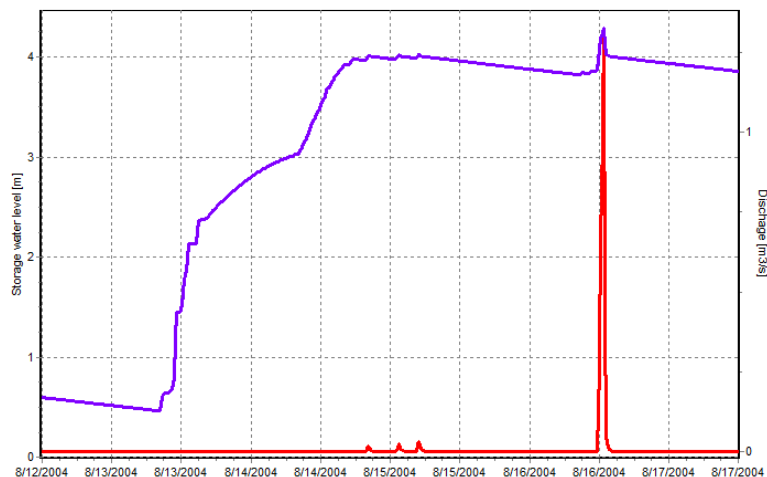


Figure 3.23: Modeled greenhouse storage water level and discharge to open water

The spill in a greenhouse acts as a weir, which means that the water level needs to exceed the crest level of this weir before water spills. When a sudden water level rise occurs the water is not instantly discharged, keeping the water level exactly on the maximum. This means that the water level can become higher than 4 meter (assumed maximum filling level) as can be seen on the 16th of August in Figure 3.23.

3.6.3 Testing of complete model

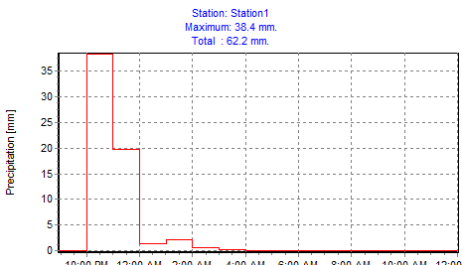
The structural validity of the channel flow module is reviewed by checking whether structures and cross sections are correctly modeled. The dimensions measured by the water board of Delfland are used as a reference. Five hydraulic structures were found that did not match the dimensions registered by the water board. Apart from this change an error was found in the friction, applied to the inside of culverts. A friction was defined in both the cross section of a channel and within the culvert. As a result the friction used in the calculation is higher than the friction in the culvert. Changes have been made to solve the above described errors.

The total surface of the Oranjepolder is compared with the surface modeled in the hydrodynamic model. Because both the channel flow and sewer model used a rainfall runoff module, a combination could lead to double counting of surfaces. The area of the modeled greenhouses is deducted from the paved surfaces and the urban sewer system also replaces paved surfaces. These changes have been made by hand. The deduction of the surfaces is done by hand and has led to a small deviation from the real surface area. The manual changes made in the entire model have resulted in a decrease of 0.6% of the polder surface.

Testing in rainfall scenarios

Two testing scenarios are used to test the usage of the new hydrodynamic model (Table 3.3). These tests were simulated to take place in the month August; this is chosen because the problems in 2004 also occurred in this month.

Table 3.3: Test results of complete model

Test scenario	Findings
Stationary discharge according to maximum drainage capacity of paved area in polder Duration: 48 hours Rainfall: 28 mm/day	No inundation occurs When all basins are assumed full at start of simulation, still no inundation occurs Water balance error is small (<0.1%)
A rainfall event with expected return period of 50 years 	Inundation occurs at rural and urban area Discharge is found at few greenhouses. Due to the filling process of greenhouses Water balance error is small (<0.1%)

Reviewing the simulation results have led to the identification of model errors. Changes have been made in the hydrodynamic model to correct these errors. The adjusted model runs is verified as working correctly.

4 Results

The new hydrodynamic model has been used to simulate the situation in August 2004. Model output of this simulation in the urban area and rural area are presented and explained. The problems in the water system identified with the new model are reviewed.

4.1 Model output

To simulate overland flow in the Oranjepolder, a nested grid was used. This has resulted in more detailed inundation visualization in the urbanized area than in the rural area. This was a choice for calculation speed and made on the level of detail required to review inundation of specific buildings. The results found in the rural and urbanized area are reviewed separately to see what information is produced with the new model.

4.1.1 Rural area

The new hydrodynamic model creates a large amount of information. The visualization of the water levels on land is shown in Figure 4.1. The visualization shows that inundation occurs on a number of locations in the rural area. The circular area is one of the areas where a large rainfall runoff from greenhouses causes inundation. The square area shows inundation at the location where culverts cause head loss and limit drainage capacity.



Figure 4.1: Inundation in Oranjepolder (August 16, 2004)

Inundation occurred on August 16, 2004. The greenhouses which discharge on the open water close to the inundation are analyzed in detail. Greenhouse water storage levels

and their runoff discharge to open water are shown below in Figure 4.2. It is found that the greenhouse storage was almost completely empty at the beginning of August. The impact of heavy rainfall before August 16 (over 100 mm) filled the storage completely. The water use drains the storage only a little in the period between the 14th and 16th august. The storm event on the 16th of August creates a large spill to the open water.

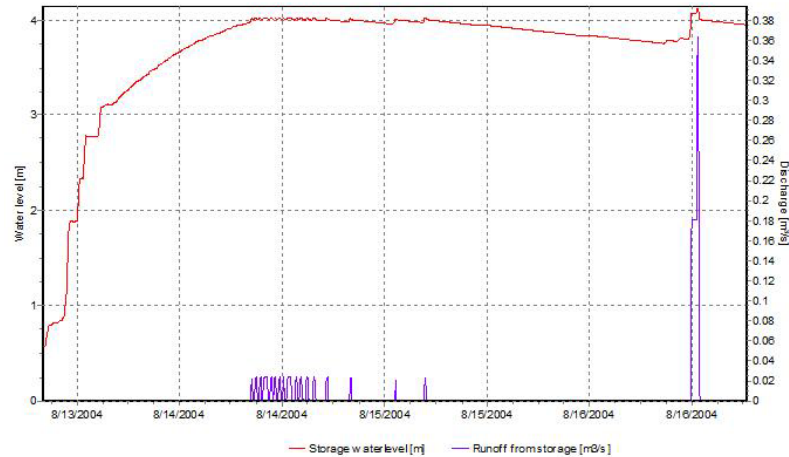


Figure 4.2: Water level in greenhouse storage

The ring canal of the Oranjepolder contains many culverts. Each culvert has been constructed according to standards prescribed in legislation of the water board. The dimensions of the culvert allow for a maximum head loss caused by each culvert. However when a large enough number of culverts are constructed in a row the summed head loss becomes large. The inundation shown in Figure 4.3 is partially caused by water which can't flow freely away.



Figure 4.3: Inundation from ring canal caused by head of culverts

A cross section of this part of the ring canal is shown in Figure 4.4. The effect of the culverts is a delayed drainage through the canal. At the point where the water level is highest, two smaller channels are connected to the ring canal. The water level in these

channels has risen fast due to runoff from the surrounding greenhouses. The water which flows through the ring canal is slowed down by the culverts. The head over each culvert is relatively small, however over the area shown in Figure 4.4 it sums up to 10 centimeter.

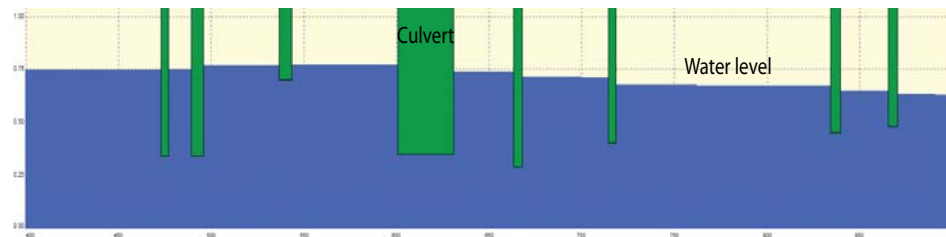


Figure 4.4: Water level along canal in side view, showing head loss caused by culverts

4.1.2 Urbanized area

The inclusion of the sewer system in the hydrodynamic model makes it possible to review, how the water level rise in the sewer influences the open water, the other way around and results in inundation.

On the August 16 of 2004 the inundation in the village Maasdijk is reviewed. The situation when the inundation was largest is represented in Figure 4.5. The spill location of the sewer system is located at the circular location. The effect of the inundation is that the water flows onto streets. This is clearly shown due to the inclusion of an overland flow in the simulation. The level of detail makes it possible to see whether just the street or also the houses become inundated.



Figure 4.5: Inundation in urbanized area

Reviewing what exactly happened on the link between the sewer system and open water system is important to see if an interaction occurred. A side view from an inundated part of the village to the nearest spill way gives a water level trajectory shown in Figure 4.6. It can be seen that both the sewer water level and the open water level are above crest level. The weir is “drowned” resulting in a non free flowing spill. The water level in the sewer system is above the open water level. This would consider a flow towards the open water.

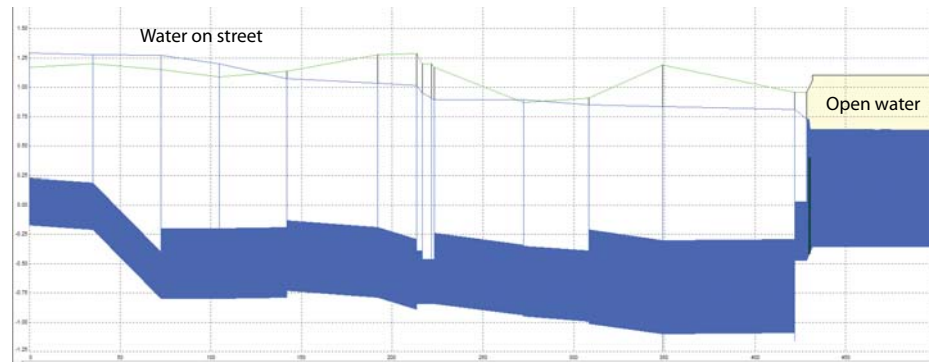


Figure 4.6: Sewer to open water flow

Reviewing what happens at the spill location is done using Figure 4.7. The graph shows the water level in the sewer system rising. When the water level exceeds the crest level of the spill, water starts discharging to the open water. The water level of the open water rises both as a result of this spill and the open water level rising. At the moment that the water level of the open water approaches the water level of the sewer system, the discharge decreases. When the water level in the open water rises above the sewer water level the discharge is minimized. The water level in the sewer system decreases by discharge and drainage by a pumping station.

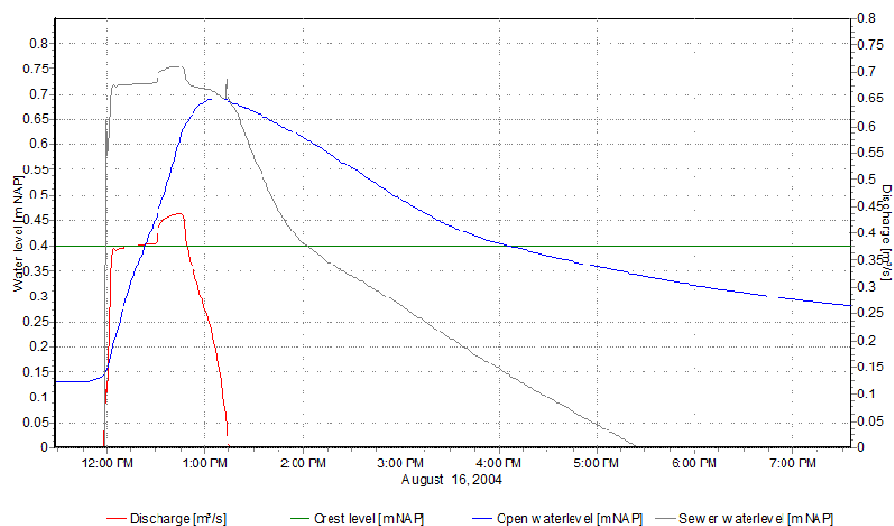


Figure 4.7: Discharge of sewer on open water

4.2 Identification of problems

The new hydrodynamic model has been used to review the situation concerning inundation in the Oranjepolder. The level of detail of the information makes it possible to analyze, where problems are thought to occur with a location and depth.

Both the municipality and water board have a report system that is used by citizens to report water problems. The reports only have qualitative descriptions of location and water depth of the inundation. Using this information certain inundation locations can be verified and certain hydraulic problems in the water system are noted. However the number of reports is extremely low, making it impossible to validate the complete model.

The reports have shown problems on the locations encircled in Figure 4.8. However, the model predicts inundation also on other locations.

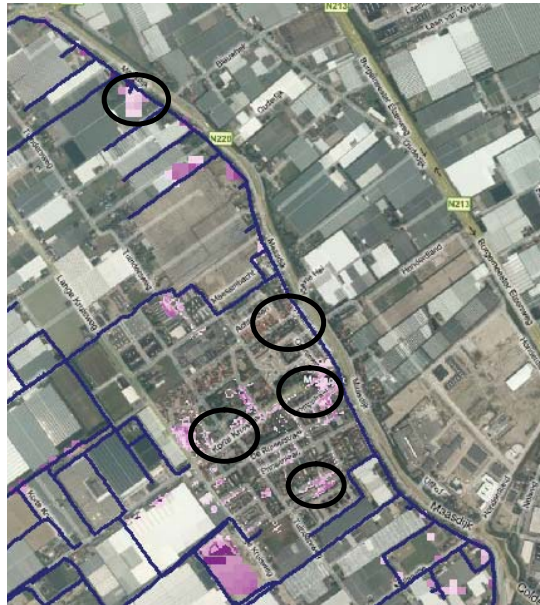


Figure 4.8: Reported problem locations

4.2.1 Identified problems

Inundation of land in the rural area often occurs at locations, where water can't flow away freely due to culverts. This problem was not only found in the model, but was also found in reports.

The influence of greenhouses is found to be very large, when the storage at greenhouses is filled. Water spills to the open water lead to a water level rise. When the receiving body of open water is very small or drainage is limited due to structures in the open water, inundation occurs. This is seen as an important influence on the occurrence of inundation in the rural area.

Because the sewer system, storage and drainage combined, was not large enough, water was discharged over the spill, to the open water. The spills could not prevent the inundation of the streets as rain is not drained into manholes and away through the sewer. The sewer system could not spill under free flow; the volume of water and the duration of inundation were very large on multiple locations in the village Maasdijk.

The ring canal passes the village Maasdijk along the Willem III street. This is where one of the spill locations of the sewer system is located. Water was reported to flow out of the canals onto the street.

In the northern part of the sewer system, it uses a pump to drain water to the main sewer system. The pump capacity was not large enough to drain water and prevent inundation in the northern area. This has led to inundation of two streets, the specifically reported water inside houses. These locations were also found in the simulation results.

5 Measures

The water management authorities have used the water system assessment to prevent future inundation in the Oranjepolder. The hydrodynamic model has been used to review an inundation situation. The results of the model have been studied and based on this a number of problems are described. Solving these problems is done by taking measures. Which measures will be taken is dependent on choices of the water management authorities. This procedure has led to measures which are further researched. When a selection of measures is made, these are presented to the decision makers of the water management authorities. Then a decision is made whether or not certain measures are taken.

At this moment the research in the Oranjepolder has not been completed and measures are still being researched. The measures based on the new model are described in the first paragraph. Furthermore the measures that were selected during the ABC studies are described. Finally, a comparison between the new measures and the selected ABC measures is made to see if the new assessment has lead to other measures and what the differences are.

5.1 Measures based on new model

The limited size of culverts in the ring canal is a result of current legislation of the water board. If only a few culverts were constructed this would not have led to a problem. However, the large number of culverts causes problems in the ring canal. Therefore the culverts need to be enlarged. To prevent culverts with similar dimensions to be constructed in the future, a change in legislation dictating other standards for culverts is required.

One of the major influences on the water level in the open water is the discharge from greenhouses to the open water. Although storages at greenhouses are built, the storages are generally full when the inundation occurs. In the Oranjepolder almost 400.000 m³ of storage is created by horticulturists for irrigation purposes next to greenhouses. It is desired to free a volume in this storage at greenhouses where and when this storage is needed. This requires cooperation between the water board and horticulturists. The exact implementation of this measure requires further research.

The rapid increase in water level is dependent on the size of the channel that receives the water which is discharged. An option which the water board has is to dictate where water may be discharged by greenhouses. By adding policy that dictates that water may only spill on channels that are adequately sized, the water board can limit the rapid increase of water level that leads to inundation.

Inundation of greenhouses can also be prevented by raising the surface level on which they are built. This is not a solution that can prevent inundation in already constructed greenhouses. However future reorganization can be used to make the situation safer. Making sure that the future greenhouses are built on a higher surface can be done by changes in policies of both the water board and municipality.

The municipality has suggested that parts of the sewer system in the village Maasdijk need to be disconnected. The problems in the urban part of the Oranjepolder will be partly solved. Apart from this measure, the municipality is investigating the possibility to change the combined sewer system in a separate system in which rainfall and sewage are collected separately.

The open water system in the Oranjepolder consists of a large number of small channels. One of the measures is to increase the drainage capacity in the polder by

creating two new larger channels connecting the northern to the southern part of the ring channel.

As a last resort, the water board can choose to create a permanent pumping station in the ring canal close to the village Maasdijk. This pumping station would make it possible to pump water out of the polder into the surrounding main canal.

5.2 ABC measures

In the ABC study, the type of measures was used as a starting point for the study approach. This means that the study would always result in measures in the open water system. And these measures would entail the creation of additional open water storage and increasing the drainage capacity of primary and secondary channels.

After the water system analysis, a search had started to enlarge the storage capacity in the open water system. Search locations are marked in the map (Figure 4.8). All water storage capacity measures combined would lead to an increase of 34.395 m³ [Waterplan Westland, 2008]. This would be more than a third of the total storage deficit (90.000 m³). However, due to a financial discussion only 10.000 m³ additional storage capacity has been created till date.

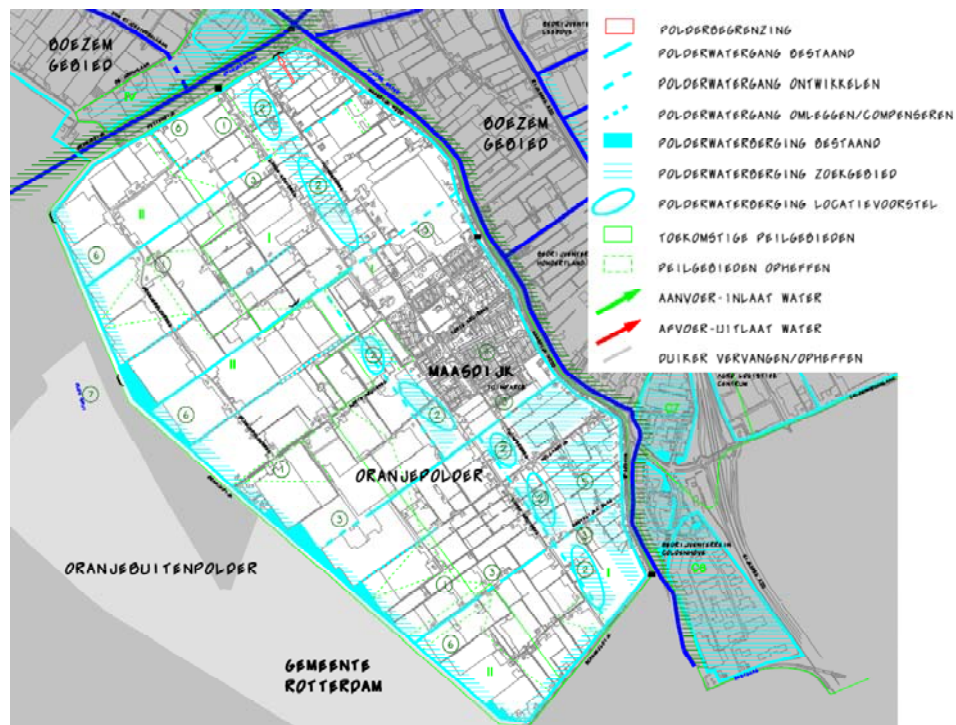


Figure 5.1: Measures based on ABC study

A measure which was implemented after the ABC study was to automate and increase the size of the drainage structures of the polder. Three of the weirs draining water from the polder to the surrounding main canal, was enlarged. A number of culverts in the primary and secondary culverts which caused the largest head loss were widened.

5.3 Comparison of measures

When a comparison is made between the suggested measures of both studies, it becomes clear that both studies led to measures of increasing storage and drainage capacity. However, the differences are found in the level of detail and the suggested approach of implementation of the measures. Another difference is that the total costs of the measures from the new assessment will be lower.

5.3.1 *Level of detail of measures*

The ABC measure of creating water storage somewhere in the Oranjepolder does not assess the effects of the created water storage. It is suggested that this measure is required to meet the storage capacity standard. The new study suggests that creating additional storage at a location and time when it is required is more effective to prevent inundation. Storing water in basins at greenhouses could have a large influence on the water level rise of small channels. Because the new detailed model now shows the expected inundation locations, creating water storage can be done at the right locations. Making storage possible at greenhouses at the location where problems are thought to occur (based on observations and model predictions) could prevent inundation.

The level of detail of the new model has led to more detailed measures. The fact that only primary and secondary canals and problematic water works in these canals were used in the ABC study, limited the insight to this level of detail. The measures have improved the drainage at the location where they were implemented. However, they did not solve the actual problem which occurred on different locations. Besides increasing the size of water works in smaller channels, changing the spill locations of greenhouses is identified as a possible measure as well.

In the ABC study, the sewer system was not included. Therefore, no measures were taken to improve the sewer system. With the new model it became clear that the sewer system had a large role in the inundation problem and improvement of this system was required. The inundation in the urbanized area was further increased by the influence of the open water on the sewer system. Preventing inundation of the urban area can be decreased by both improving the open water and sewer system.

5.3.2 *Involved parties in implementation of measures*

As mentioned before the horticulturists are involved in the implementation of some of the measures. The inclusion of horticulturists in the research process (described in chapter 6) has led to measures in which they were included as well. The cooperation with the horticulturists has potential to support the water system assessments.

The new hydrodynamic model has shown the relation between the open and the sewer water system. Knowledge of this interaction has led to the selection of measures in the sewer system. Municipality and water board now combine their efforts to prevent future inundation in the village Maasdijk.

6 Cooperation in water management

The new assessment of the polder differs from the previous approach, not only on the technical but also on an organizational level. The cooperation in an organization is explained first. Then the cooperation between different organizations in the reviewed water system studies is compared. A conclusion on the effect of cooperation in these projects is explained. The information which is used to formulate this chapter comes from an interview and two workshops (Appendix E).

6.1 Cooperation within water management organizations

In a water management organization different functions can be identified, the decision makers, policy makers and water experts. This distinction is often made, based on the function and the corresponding responsibility that a person has in the organization. A function description based on the information requirements for each role and the decisions which are made, using this information, is shown in Table 6.1.

Table 6.1: Role description and information requirements in water management

Function	Information		Decisions
	Required detail	Rawness	
Decision maker	Graphical representation to show different alternatives and level of preference of alternatives	Visualization of solutions Costs and benefits of solutions	Final decision
Policy maker	Enough detail to see bottlenecks in water system but graphical representation preferred	Verified results and geographical visualization with costs	ranking potential of solutions
Water expert	High level of detail with references. Zooming from geographical map desirable.	Hydrological and hydraulic basic information and detailed results with references	interpretation of hydrological situation.

Within a water management organization an interaction takes place between people with other functions. The cooperation between people with different functions differs between situations. The situation, of a project being carried out and of the development of policy is reviewed in this chapter.

6.1.1 Cooperation during development of policies

Making policies is a way for water management organizations, to show the intention of the organization on a specific topic. This could also be done by creating legislation, but policies have a less legally binding value, which makes them a useful tool. The content of policies is not uniform. They can contain anything ranging from intentions to concrete plans.

The choice to create policy on a certain topic is made by decision makers. After the inundation occurrences in 1998, the water board of Delfland had chosen to create policy on inundation. A description of the content of the policy was given to the policy makers. The policy makers created conceptual designs of the policy, which could be used. The policy that best met the purpose of the decision makers was chosen. After the policy was accepted it became active. The actions of the water board followed the procedure put forward in the policy.

6.1.2 *Cooperation during projects*

Policy makers and water experts both work on projects in which they should keep the active policy in mind. Decisions made during a project are influenced by the interpretation of the active policy. The desired cooperation during a project concerning rainfall fed inundation is explained.

The expert is part of a project team, in which making an assessment of the problem is an important role. An overview of complaints and reports is required to see, if a problem is noted by citizens and water managers in the polder. Then validated information input from the water experts is needed to create insight in the situation. In cooperation with the policy maker decisions are made to solve hydraulic bottle necks.

The policy makers and water experts then work on solving the inundation problems. Measures are defined based on technical analyses. The policy maker finally selects the best measures which can be implemented. This selection is presented to the decision makers who choose what actions are taken.

6.2 **Cooperation between stakeholders**

In the case of rainfall fed inundation in the Oranjepolder, a number of stakeholders are involved. Four stakeholders have been identified as most important and have therefore been approached in the process of this water system assessment. The stakeholders are the water board of Delfland, the municipality Westland, horticulturist and citizens. The cooperation between stakeholders in both the ABC study and the new assessment is described in this paragraph.

6.2.1 *Cooperation during ABC study*

The ABC- studies were executed by the water board of Delfland. Measures had to be taken on short terms, so the water board took the lead and focused on solutions which they could implement. In the description of the inundation problems, a focus was made on the open water as this is the responsibility of the water board.

After the inundation, the decision makers wanted to review the current situation in the management area. Policy showed the intent of the water board. This introduced water capacity standards based on national inundation standards which had not yet been agreed upon.

In the ABC- study an interpretation of the policy was made, which led to the approach of meeting the standards. The policy makers and water experts worked on making assessments of the current situation. The immense storage deficit, that was calculated, was presented.

The storage deficit was used as a starting point for further investigations. The lack of storage capacity in the polder was debated on its exact size, instead of whether using this capacity as a goal was useful. The advised measures were in line with the ABC approach and came from technical analyses, which were deemed appropriate.

One of the limitations of the ABC assessment was caused by a problematic cooperation. The limited cooperation was a result of the focus on solutions whereby the water board was not dependent on other parties for ensuring inundation safety. The technical analysis was therefore focused on the open water system. Measures which had been selected lead to problems when they were presented. Both public resistance and the high costs of the measures obstructed the implementation of measures.

6.2.2 *Cooperation in new assessment approach*

Because inundations in the management area of Delfland still occurred, a new assessment was started. This assessment was started by the water board of Delfland with the idea, not to hold on only to the storage capacity standards. Instead the focus was made on the actual inundation problems. Inundation occurred both in rural and urbanized areas thereby affecting citizens and horticulturists. Therefore, cooperation of the water board with the municipality Westland, citizens and horticulturists was arranged. This would make it possible to review both rural and urban inundation.

The water board and municipality decided to make a new assessment focusing on the inundation in rural and urbanized areas. Inundation in the rural area had led to high costs for horticulturists. In the new assessment they shared information, making it possible to create a more detailed model, containing all rainfall runoff processes. Through research in greenhouses and workshops with horticulturists the advancements in the project are fed back to horticulturists. These workshops supported the exchange of experience and knowledge of the situation in both directions. This has triggered additional research, such as the research of the hydrology of greenhouses.

Citizens of the village Maasdijk have also been kept up to date with the advances of the research. This has led to their support of the project which is important for the support of future measures. The goodwill of the inhabitants is important, because they are the taxpayers, who deliver the money, used to fund the project. The inhabitants who experience the inundation need to support and cooperate during the implementation of measures.

Another important effect of the cooperation between the involved parties is the type of selected measures. In the development of measurements the horticulturists were also included, making it possible to do research in controlled storages at greenhouses. The implementation of the measures has become a combination of actions by the water board, municipality and horticulturists.

6.3 **Effects of new assessment approach**

The new assessment did not focus on meeting standards, but on solving the inundation problem. A change within the water board was required for this new approach to work. As a result of the new approach, additional information has become available in the analysis of the situation. The cooperation with municipality and horticulturists has added information and possibilities to the assessment.

The new approach was needed in the development of the new hydrodynamic model. Research to identify important influences on the inundation was possible due to the cooperation with municipality and horticulturists. Identification of important water flows and modeling these flows, has led to a more complete description of the water system.

Due to the enhanced model, bottle necks concerning multiple stakeholders were identified. Important bottle necks are run off at greenhouses and the spill ways of the sewer system in the village Maasdijk. The cooperation has enabled the formulation of new measures, which are to be undertaken by one or more parties.

7 Conclusion and recommendations

7.1 Conclusion

In this thesis about the water system assessment, two aspects have been researched. The assessment consists of a technical analysis using a hydrodynamic model and an analysis on the cooperation between the different parties involved in water management.

The research questions defined at the beginning of this study were:

How can hydrodynamic models of greenhouse dominated polders be improved, to contribute to the development of effective measures to prevent rainfall fed inundation?

- *What is the effect of more detailed models on the precision of the predictions?*
- *Can more detailed models lead to better insight in which factors influence inundation?*

How can the cooperation between the parties involved in water management of greenhouse dominated polders be used to improve water system studies?

The research questions are answered as following:

The hydrodynamic models created for the ABC studies of greenhouse dominated polders, were improved by increasing the level of detail. The model predictions correspond with the reports of the rainfall fed inundation in the Oranjepolder in August 2004, both in location and water depth. The model from the ABC study which had a lower level of detail could not make these predictions.

A hydrodynamic model of the Oranjepolder with a high level of detail, in which important hydrologic processes are included, is made. The first important hydrologic process is the hydrology of greenhouses. In the new model individual greenhouses are included. This results in a runoff to open water which represents the actual situation. Secondly, the channel flow model contains all channels and water structures located in the polder. This makes it possible to review inundation at every channel. Thirdly, the sewer system of the village Maasdijk is included in the model. Water flowing out of manholes and the interaction between the sewer and open water system are made visible. Finally, the aspect of overland flow is included. By taking all these hydrologic processes into account, predictions with a high level of precision can be made. The high level of detail and the high precision of the model lead to better insight in the factors that influence inundation.

This research used the participatory modeling method, in which cooperation between involved parties was found to be important. By sharing information and experiences during workshops, this research has been made possible. This method led to the implementation of details in the model, to measures to prevent inundation and to the support of all stakeholders to carry out these measures.

7.2 Recommendations

When an assessment of another greenhouse dominated polder is made, it is important to use the approach as described in this thesis. The use of participatory modeling is important for the development of the model, to create measures and to gain support of all involved parties to carry out these measures. It should not be a goal to include as many parties as possible, but to include those which have a large impact on the water system. The cooperation between the water board and municipality during water system analyses is important. The municipality manages public space and is in charge of spatial

planning. This knowledge and authority is important for the success of the research and implementation of measures.

When model predictions are used in the development of measures, the precision and accuracy are important. The predictions of the model of the Oranjepolder created in this research, have a high level of precision and are known to correspond with reports. Even when a model prediction is very precise, it remains a simplification of the actual situation. Confidence in the accuracy of a model can be increased by validating the results with additional data. More measurement locations and data over a longer period are needed. Both rainfall and water levels are should be used to validate the model.

References

- AHN (2011) <http://www.ahn.nl/viewer> Visited: 27-04-2011
- Albers, B.C. (2010). *Hydrologie van glastuinbouw – onderzoek en modellering van kassen in de Oranjepolder*. Water Resources Management, University of Technology Delft. Stageopdracht bij Nelen & Schuurmans.
- Besluit Glastuinbouw (2002). *Besluit van 21 februari 2002, houdende regels voor glastuinbouwbedrijven en voor bepaalde akkerbouwbedrijven* (Besluit glastuinbouw)
- CDA Westland (2006) *Bergen op water meervoudig ruimtegebruik van openbaar gebied*. 22 November 2006
- Cruquius, N./ J. (1712) *'t Hooge Heemraedschap van Delfland*. Delft
- Financieel Dagblad (2010) *Miljoeneninvestering in glastuinbouw* Krantenartikel gepubliceerd: 25-10-2010
- Glastuinbouw techniek (2010) *Glastuinbouw techniek magazine* 2nd edition, 5th volume, Maart 2010
- Greenport Nederland (2010) *Strategische agenda mainport 2010-2013: Denken en doen!* Juni 2010
- Hazeu, G. W. (2006) *Land use mapping and monitoring in the Netherlands (LGN5)*. Wageningen University and Research Centre - Alterra, Centre for Geo-Information.
- Hoogheemraadschap van Delfland (2005). *Beleidsnota normering wateroverlast: Resultaten NBW wateroverlast en uitgangspunten ABC-bergingsnormen*.
- Lynam, T., de Jong, W., Shell, D., Kusumanto, T., Evans, K., (2007) *A review of tools for incorporating community knowledge, preferences and values into decision making in natural resources management*. Ecology and Society 12.
- NBW (2003) *Nationaal Bestuursakkoord Water* Inwerking getreden: Juli 2003
- Oranjewoud (2010) *Brede Verkenning Oranjepolder*, Gemeente Westland en Hoogheemraadschap van Delfland.
- Pretty, J.N., (1995) *Participatory learning for sustainable agriculture*. World Development 23(8),1247-1263.
- Programmabureau Waterkader Haaglanden (2009) *Onderzoeksagenda Waterkader Haaglanden*. May 2009
- Van de Ven, F.H.M. (2007) *Watermanagement in Urban Areas* Delft University of Technology, Faculty of Civil Engineering and Geosciences, Watermanagement, Section of Water Resources. January 2007
- Voinov, A., Bousquet, D. (2010) *Modelling with stakeholders* Environmental Modelling & Software 25, pages 1268-1281
- Waterplan Westland (2008) *Westlands Water Nu en Later*. Gemeente Westland en Hoogheemraadschap Delfland. Waterstructuurvisie.

Appendices

A. Model assumptions

Channel flow

The shape of cross-sections in channels as they have been documented in a so-called legger is used in the channel flow model. For each channel trajectory, one cross-section containing a friction coefficient is defined. A friction coefficient is chosen which resembles a channel with vegetation growing as found in summer. The chosen friction value is a Strickler coefficient (k_s) of $20 \text{ m}^{1/3}/\text{s}$.

Structures in the water system, such as weirs and culverts are also modeled as they are registered in the legger. Maintained water levels in summer and winter are used to define the crest height of weirs. The friction modeled in culverts is modeled at a Strickler coefficient corresponding with a smooth concrete culvert ($k_s = 75 \text{ m}^{1/3}/\text{s}$).

The automatic weirs are modeled by using an upstream controller. This controller compares the water level measured upstream of the weir and will try to maintain a target water level up stream. When the water level deviates more than 3 cm from the target level, the weir will respond by changing the crest level.

Rainfall Runoff

The rainfall runoff modeled in the new hydrodynamic model uses a precise representation of greenhouses and the urbanized area. However assumptions are made to model paved and unpaved areas in the rural part of the Oranjepolder and for unpaved areas in the village Maasdijk. The assumptions are listed below.

- Storage on roads is assumed to be 1 mm and 5 mm on other paved areas
- Unpaved areas are supposed to be covered by grass
- Initial groundwater levels are assumed to be 0.10 meter above target level used in channels
- Infiltration capacity of the bottom is chosen at 20 mm/hour
- Four different soil types are distinguished based on geographical information. Storage coefficients are used for these soils.
 Clay and light clay: $\mu = 0.062$
 Sand maximum: $\mu = 0.115$
 Sand average: $\mu = 0.084$
 Sabulous clay average (in Dutch zavel): $\mu = 0.058$
- Reaction factor of 0.4 dag^{-1} for a soil profile above and 0.05 dag^{-1} for a soil profile below drainage level

B. Greenhouse horticulture

Horticulturists

Modern greenhouses are owned by companies with millions of revenue. Decisions made by horticulturists are business decisions. The aims are to maximize revenues and to minimize costs. Water management as a broader goal is of no interest for the horticulturists. As long as there is enough water to cultivate crops, horticulturists are satisfied. Costs arise from inputs for crop growth and depend on the required amounts and its prices. The largest inputs are electricity for lamps, heating and pumps, fertilizer and water.

Dependent on the ratio of costs and revenues, horticulturists will make the choice to grow a certain type of crop at a certain moment. Because prices of flowering plants are highest in spring and summer, these are times horticulturists will grow them. Water availability can limit growth and thereby limit revenues in summer. In winter prices for crops can be low, making it less profitable to grow them. Costs are also high due to electricity requirements for lighting and heating. Horticulturists limit the number of crops to be grown and use this time to clean and prepare for a new growing season.

Types of greenhouses

Based on the way management is conducted three basic types of greenhouses are distinguished. Soil cultivation, pot cultivation and substrate cultivation are all found in the Netherlands.

Soil cultivation: This manner of cultivation occurs in greenhouse structures constructed on agricultural land to cover crops. Plants are still directly placed in the soil. It is used for crops which can cope with changes in water quality. These crops are irrigated with water from open water mixed with chemicals. Water is not recycled and infiltrates towards the ground water, ending up in the open water. Soil cultivation in Zuid-Holland is found in older greenhouses. Often flowers (like tulips and daffodils) and trees are still cultivated in this type of greenhouse.

Pot cultivation: A newer type of greenhouses has a separation from the water system outside of the greenhouse. A concrete foundation creates a barrier restricting groundwater to influence the roots of plants in the greenhouse. In these greenhouses pots are placed directly on the concrete floors. The concrete is slanted in order for excess irrigation water to drain towards drains on the floor. All excess water is collected, filtered and stored for reuse. Because of evaporation the drained water has a higher than appropriate concentration of salt and nutrients. Drain water is mixed with rainwater and some fresh fertilizer to create irrigation water with the desired chemical composition. This type of greenhouse is used for shorter grow periods. Typical crops are vegetable sprouts (like tomatoes and cucumber) and flowering plants (like hyacinths and hortensias)

Substrate cultivation: The greenhouses with a concrete foundation can also be used in a different way. On the concrete floor, substrate layers are used for plants to root in. Vegetable plants with a high water demand (like tomatoes, cherry tomatoes and cucumbers) can be grown from an early phase until ripening. The substrate layers have an advantage above soil cultivation as it is easy to remove all plants at the end of the growth cycle. Another advantage is the recycling of irrigation water through drains in the concrete. The usage of substrate is increasingly used due to the high level of control.

Water supply of crops in greenhouses

Of all inputs required for growing crops a horticulturist has least control over water. While the greenhouse is the ultimate attempt to fully control the climate in favor of the agriculture, external influences still have a large impact. Light intensity, wind speed and humidity dictate the transpiration rate of plants inside the greenhouse. High transpiration

rates found in summer lead to a large water demand. Rainfall however does not fall freely on the crops. Somehow water needs to be transported into the greenhouse. The solutions to this water problem are dependent on the quality of water required by the crops and on the costs of watering methods.

A horticulturist has five sources from which irrigation water can be drawn from, each with a different quality. Each source has advantages and disadvantages concerning costs, quality and availability (Table B.1). The crop characteristics and preference of a horticulturist dictate which sources will be used.

Table B.1: Properties of water types

Type of water	Quality	Availability	Costs
Rain	Best quality	Dependent on size of storage and weather	Free but storage basins take up expensive space
Drainage	Best quality but needs mixing with clean water	Available if irrigation water is available	Free after creating a drainage system and storage
Osmosis	High quality but low on salts	Dependent on size of pump and regulations by water board	0.5 €/m ³ operational costs not including osmosis pump
Drinking	Too clean, fertilizer and salts to be added	Always available	1.3 €/m ³
Open	Can contain organic and chemical pollution	Usage may be limited by water board in droughts	Free with license

Hydrology of greenhouses

The reduction in potential water storage and increase in runoff pace due to the change in land cover have been a point of concern to the Dutch government. Through the act on greenhouses [Besluit glastuinbouw, 2002], the government has attempted to force a compensation for this change. The act states that all greenhouses require facilities to store a minimum of 500 m³/ha. This storage is equivalent to 50 mm of water. The intention was to store potentially problematic rainfall events. This approach has not proved to be as successful as initially intended, due to rainfall structure and managerial

Water storage at greenhouses

Rain- and drainage water are the cheapest and best water sources for horticulturists, but using it without water storage is not possible. A crop like the hortensia, requires 750 mm of water a year on average. The average rainfall in the Netherlands is 800 mm a year. The problem faced by horticulturists is the time difference between rainfall and water demand. Storing water in silo's or water basins makes it possible to use water when required instead of when it falls down.

The investment of horticulturists in water storage is an economical trade-off between costs of storage, costs of non-used land and revenue arising from a decrease in drought risk. It is found that horticulturists who grow crops with high water quality and quantity demands have invested in water storage. Considering the value of crops in a greenhouse, this action is logical; yearly profits can be 0.8 mln €/ha [Financieel Dagblad, 2010]. So a lack of water can lead to high costs. Therefore horticulturists will always try to stock up on water for the driest months of the year.

Dependent on water use (quality and quantity) of a crop and projected revenues, horticulturists built storage next to or in their greenhouses. For a crop requirement of 750 mm high quality water, storage of 1000 m³/ha is not uncommon. Where requirements are on average 1000 mm per year, both storage of 1500 m³/ha and groundwater pumps

can be found [Albers, 2010]. If water quality is not a concern and open water licenses are adequate, no water storage is needed. The compulsory 500 m³/ha is often not installed, because exceptions are made for greenhouses which have indicated that alterations are going to be made in nearby future.

Water cycle in a greenhouse

The important water flows in a greenhouse are depicted in Figure B.2. Horticulturists can add water to their storage by withdrawing surface- or ground water. Because of cost and quality concerns rainwater is always preferred. However when the storage dries up other sources of water will be used.

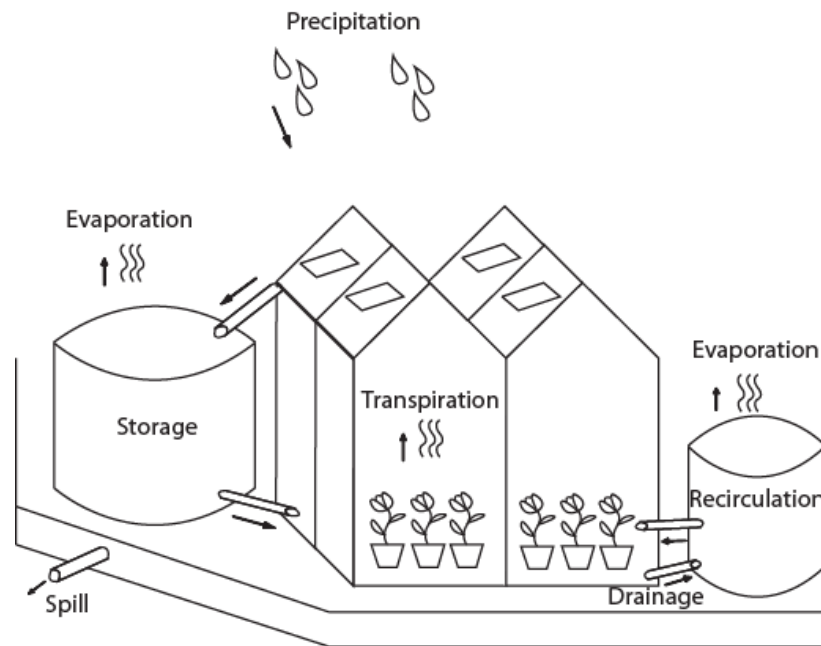


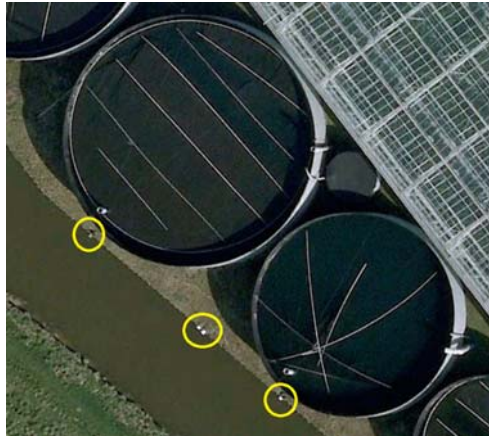
Figure B.2: Water cycle in a greenhouse

The water usage through transpiration is largely dependent on external circumstances. Increase in wind speed, humidity, light intensity and temperature all increase the transpiration of crops.

Based on available land, the location of water storage is chosen. Every last square meter is filled optimizing production potential. Water storage is often scattered around the greenhouses, the storages are connected underground. These connections create one large volume available for water storage; however delay created by the connections decrease the effectiveness of the buffering capacity.

Influence on open water

Water storage of 1000 m³/ha is equal to 100 mm of rain. When the storage at the greenhouse is filled all excess rainwater which drains to the storage, will spill. This spill system will work all through the winter when the storage is already full. However it is known that water storages also spill in summer. These spills happen after a number of intensive rainfall events. In August 2004 measurements have shown that within two weeks over 200 mm of rain has fallen. The first 100 mm could have been stored assuming that all storage was empty. However all additional rainfall would have spilled.



Considering the surface of a greenhouse of 5 hectares would mean that 5000 m³ of water would spill. This spill would be concentrated on just a few locations as it would flow through the spills of the water storage facilities (Figure B.3). Spilling of such large quantities of water in small canals can lead to high local water rises.

Figure B.3: Water spill locations

C. Greenhouse modeling

The influence of greenhouse models is reviewed in a polder which is predominantly filled with greenhouses (Figure C.1). A clay polder of 100 hectares is considered to be filled for 80% by greenhouses. 7 percent of the surface is dedicated to open water and 13% is unpaved area. The greenhouses are considered to be modern and therefore can store 2000 m³ of water per hectare. The polder is drained by a pumping station with a realistic pump capacity.

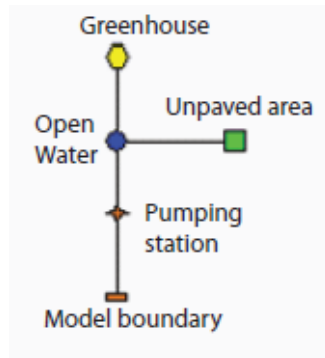


Figure C.1: Polder schematization

The aim of the research in the test polder is to review the change of the open water level in rainfall situations.

Simulations are made of a series of 204 rainfall events falling on the polder. The reaction of the open water level will be reviewed. The maximum water level rises of the open water are noted.

The chance of each water level value is calculated, based on the measured maximum values. The Gumbel distribution is used for the analysis and from the chance of water level occurrence, a return period is derived. The return period is the estimated time between events of a certain intensity. The maximum water levels occurring with a certain return period can be compared to see if the change in schematization has an influence on the modeled water level.

Traditional greenhouse modeling

In the rainfall runoff (RR) model created in the Sobek software, the option is available to model greenhouses. The usage of the Sobek RR-model requires data of greenhouses which is supplemented by standardized data about greenhouses. This standardization makes the modeling of greenhouses easier and less data intensive. However the standardization simplifies the actual situation which leads to a difference between the real greenhouses and the model. The standardizations are divided in standardizations due to schematization and due to initial values.

Standardization in schematization

There is only one type of greenhouse node available, the water usage assumed for this greenhouse resembles a water intensive crop such as tomatoes. However the differences in water usage between types of greenhouses are not included. This has an effect on the water levels of storage facilities.

When in a greenhouse node the volume of storage facilities is included, no size of the area of this storage is assumed. This means that the usage of storage facilities does not reduce the available greenhouse area. In reality the construction of additional water storage is a tradeoff between greenhouse surface and water availability. When storage is present in a polder an overestimation of greenhouse surface is made by the assumption that storage does not take up space. For example: if a greenhouse of 80 ha is modeled and a storage capacity of 2000 m³/ha is assumed, a basin of four meters high with a surface of 40000 m² (4 ha) is required.

Table C.1: Water basin categories

Basin size (m ³ /ha)	
0 - 500	In modeling water storage at greenhouses a number of different basin sizes can be chosen. The volume is dependent on the size of the greenhouse. Table C.1 shows the different categories which can be chosen. In the model the lowest value in the range is used by Sobek. If the actual storage at a greenhouse is 400 m ³ /ha, the value used in the model is 0 m ³ /ha. The simplification makes it impossible to model storage at greenhouses accurately and for larger greenhouses the error can be very large.
500 - 1000	
1000 - 1500	
1500 - 2000	
2000 - 2500	
2500 - 3000	
3000 - 4000	
4000 - 5000	In greenhouse modeling it was assumed that no water evaporates from storages smaller than 1500 m ³ /ha. At greenhouses water can either be stored in water basins or silos. Evaporation will over time decrease the volume of stored water in water basins but also in most silos. Though silos are sometimes covered to prevent pollution of the stored water. Most of these covers float in the water not fully sealing the silo, which means that water can still evaporate.
5000 - 6000	
6000 >	

Standardization in initial values

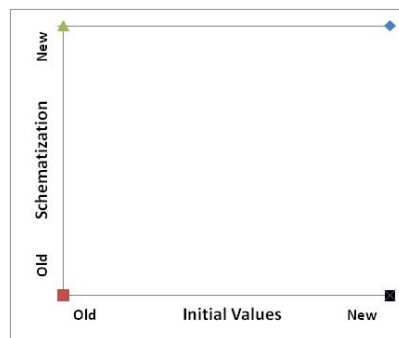
Water usage in greenhouses is standardized to resemble an unknown crop. Data is available from 1951 to 1995 and varies from day to day, suggesting measurements to determine these values. Every year the water usage is zero for 20 days on end, however this behavior is not found in researched water usage at greenhouses.

Using a model to simulate a certain period of time requires data for the start of the simulation. Starting in a well known situation is the way to be certain that the initial values are exact. This approach is time intensive; therefore often just the period of interest is simulated to decrease simulation time. When this method is used the initial values are very important. For greenhouses an important initial value is the water storage. The differences between the amounts of water stored in the different sizes of water storage in the standardized files do not resemble data as found in research. In winter time it can be assumed that water storages fill up completely. Water storage should resemble the water balance as found through research. For the standardized files this is not the case.

Testing of water level rise

To test the impact of changes in schematization and initial values, four tests are conducted. Using the series of rainfall events four different combinations of initial values and schematization are made (Figure C.2). The impact of changes in either schematization or initial values becomes clear.

Not all changes can be reviewed, because comparison of the same system has to be made to be able to make valid conclusions on the impact of changes. This means that



the possibility of the new schematization to have multiple different types of greenhouses with different water usage in one polder is not reviewed. Neither is the possibility of flexible storage size tested, because only the new schematization would be able to vary this. The comparison is made between two greenhouses with 2000 m³/ha storage. Changes in model approach not included in this test can be seen as additional advantages made possible in the new schematization.

Figure C.2: Four model configurations

The maximum water level rise for a certain return period is shown for all investigated models (Figure C.3). It is clear that the usage of new initial values has a large impact on the maximum water level rise. It seems that using the traditional model would lead to an underestimation of the maximum water rise. If the rise would cause inundation of land, the level of inundation would be underestimated.

Changes in schematization also lead to an increased maximum water level rise. The difference is relatively small compared to the change caused by the implementation of new initial values. However, in reality it can be the difference between inundated and normal land, which is a big difference.

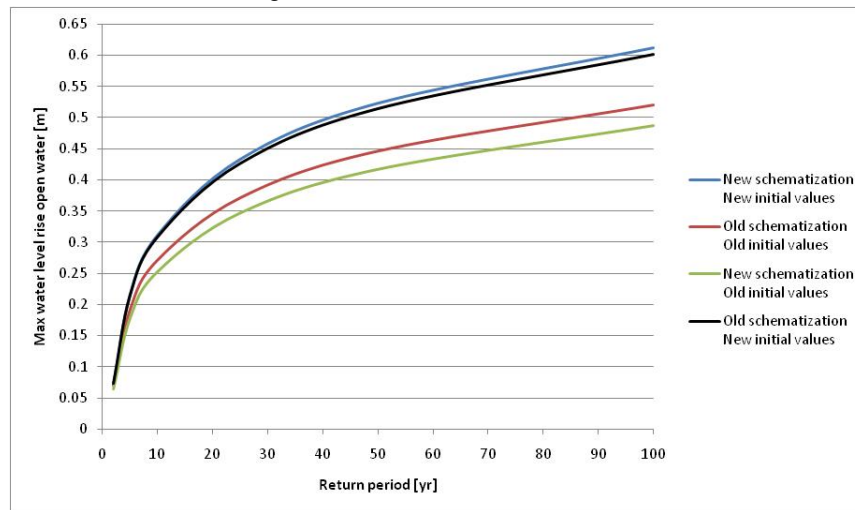


Figure C.3: Maximum water level rise with return period in four model configurations

D. Sewage flow

The total sewer flow for every inhabitant is 120 L/day. The sewage distribution which describes how this flow is spread over a day is described in Table D.1.

Table D.1: Sewage distribution

0 hr	1.5%	8 hr	6%	16 hr	5%
1 hr	1.5%	9 hr	6.5%	17 hr	5%
2 hr	1.5%	10 hr	7.5%	18 hr	4%
3 hr	1.5%	11 hr	8.5%	19 hr	3.5%
4 hr	1.5%	12 hr	7.5%	20 hr	3%
5 hr	3%	13 hr	6.5%	21 hr	2.5%
6 hr	4%	14 hr	6%	22 hr	2%
7 hr	5%	15 hr	5%	23 hr	2%

A distribution of the location where sewage enters the sewer system is used as it was found in data given by the municipality Westland.

E. Interview and workshops

Summaries of an interview and two workshops are presented in this appendix.

Interview

An interview is conducted with a policy maker of the water board Delfland. The aim was to gain more insight in the cooperation within organizations and between organizations in projects. Specifically the previous and current projects concerning rainfall fed inundation of greenhouse dominated polders were targeted.

Tasks of policy maker

Important roles of a policy maker at a water board are to lead projects and to guide the creation of new policy, when required. Technical information has limited relevance in policy making due to the general nature of policies. In projects the policy maker is informed by technical researchers. The technical research is an important input in the problem solving procedure. Technical experts deliver input to the problem solving process. The policy makers can set the focus to solutions, which are likely to be best based on knowledge and experience.

Projects of a water board require information concerning spatial planning. In this respect they are in part dependent on municipalities. Information of municipalities about spatial development is input for the water board to select a solution. The communication between water board and municipality can improve insight in a problem.

The problem assessment process is described as iterative and convergent towards a final set of solutions. The technical experts and policy makers are the actors, which have most influence on this process, in which they are guided by the institutional framework of the water board. The policy maker delivers a (set of) solution(s) to the board of directors, which gives approval for implementation of a solution.

Workshops

Observations during two workshops concerning inundation in the Oranjepolder have been used in this research. The first workshop was held on the 27th of January 2011 and the second on the 3rd of March 2011. The workshops have used information produced in this research and have been used for input for further research.

Workshop information use

The first workshop is prepared using the information, created in simulations using the new hydrodynamic model. At the workshop technical experts and policy makers of the water board of Delfland and the municipality Westland were present. The aim of the workshop was to assess the approach of the inundation in the Oranjepolder by different actors. A division was made between the different roles and two groups were formed (one of water experts and one of policy makers). Each group was lead in the workshop by a supervisor who reported on the actions of the group. At the end a discussion of the combined groups was held to review the differences between the groups. To review what information was found useful by individual actors, a questionnaire was handed out at the end of the workshop and participants were asked to fill this out. The observations during this workshop are summarized below

Water experts

The order, in which data is required, is dependent on the way a problem is approached. Using extensive basic data of water system and geographical orientation, experts try to become familiar with the polder. To diagnose problems a global overview is required, in which can be zoomed to gain access to specific information. After this the attention of the experts goes to notifications of inundation problems and assessing the impact of the

inundation. To find a solution to the problem, criteria are needed which make ranking of different scenarios possible.

Experts need very detailed basic information to assess the water system. The technical problems in the system can be identified using this information. Water experts can make the decisions to solve these problems. In cooperation with the policy maker decisions are made to solve hydraulic problems.

The expert is part of a project team, in which making an assessment of the problem is an important role. Furthermore the expert is needed to validate technical information and report to the policy maker. After a thorough assessment, the insights in the situation are used to work on solving the problem at hand.

When using technical information the expert needs references of the information. The desired level of detail in the technical information is high. A spatial overview helps to put the specific information about a location into perspective. The possibility to zoom in on a map is considered desirable.

Policy maker

The term policy maker proved to be non specific. Policy makers of a municipality and a water board focus on different aspects of a polder. The first has a focus on spatial planning and the sewer, solving a water problem can be done by changing the development plan or enhancing the sewer system. Policy makers of a water board will focus on the open water system.

The focus of the policy maker dictates, which specific information is required. However the approach of a policy maker in general seems to be the same. To start assessing the inundation problem in a polder, first an overview of the problem is required. An overview of complaints and reports are required to see if a problem is noted by citizens and water managers in the polder. Then information input from the water experts is needed to define the problem.

The problem definition is used to search for solutions. A task for water experts is to define scenarios relevant for solution. When solutions are apparent policy makers can rank them.

The technical information used by policy makers is less detailed and requires validation by experts. The geographical inundation visualization is highly valued. A combination of water depth of inundation and a cost overview of this inundation is desired. An overview of current and future spatial planning helps to put the water problems in perspective

Questionnaire

The questionnaire used at the end of the workshop is shown below (in Dutch).

Algemene vragen

1. Hoe omschrijft u uw eigen rol in het watermanagement (omcirkelen)
 - a. Specialist
 - b. Beleidsmaker
 - c. Bestuurder
 - d. Anders, namelijk:...
2. Welke taken horen bij deze rol (invullen):
 - a. ..
 - b. ..
 - c. ..

Vragen over de 3D-visualisatie

3. In welke mate gaf de 3D-visualisatie u inzicht in het probleem van wateroverlast in de Oranjepolder? Op een schaal van 1 (weinig) tot 5 (veel): ...

4. Wat is voor uw rol de toegevoegde waarde van een 3D-visualisatie ten opzichte van huidige methoden als kaarten en indicators voor de waterbergingsopgave
 - a. ..
 - b. ..
 - c. ..

Vragen over het informatieportaal

5. Wilt u in de derde kolom van onderstaande tabel aangeven welke informatie u heeft gebruikt om uw rol te vervullen
6. Wilt u in de vierde kolom aangeven in welke mate deze informatie bruikbaar was (1=laag, 5=hoog)
7. Wilt u in de vijfde kolom aanbevelingen geven voor de wijze waarop de informatie was gevisualiseerd?

Nr	Informatietypen	Informatielaag	Gebruikt (kruis aan)	Waardering bruikbaarheid (1-5)	Aanbeveling visualisatie
1.1	Kaarten	Gebiedskenmerken (landgebruik, bodemhoogte, locaties kassen, bassins)			
1.2		Riolering (leidingen, gemalen)			
1.3		Rioolplannen (afkoppelplannen, vervanging)			
1.4		Ruimtelijke ontwikkelingen natuur (EHS, EVZ, natuur toekomstig)			
1.5		Ruimtelijke ontwikkelingen: herstructurering glastuinbouw			
1.6		Ruimtelijke ontwikkelingen: bebouwing			
1.7		Ruimtelijke ontwikkelingen: Recreatie			
1.8		Watersysteem (duikers, stuwen, waterlopen, peilen)			
2.1	Model	Berekende inundaties bij de bui van juni 2004			
2.2		Stremmende werking oppervlaktewater bij riooloverstorten			
3.1	Metingen	Waterstandsmetingen bij stuwen			
3.2		Afvoer rioolstelsel bij overstorten			
4.1	Meldingen	Meldingen			

8. Heeft de informatie in het informatieportaal u inzicht in de problematiek verschaft (omcirkelen):
 - a. Veel
 - b. Redelijk
 - c. Weinig
 - d. Geen
9. Kunt u combinaties van informatielagen aangeven die u inzicht gaven in de problematiek (gebruik nummers uit kolom 1)?
 - a. ..
 - b. ..
 - c. ..
10. Kunt u combinaties van informatielagen aangeven die u inzicht gaven in oplossingsrichtingen (gebruik nummers uit kolom 1)?
 - a. ..
 - b. ..
 - c. ..
11. Welke informatie heeft u gemist (invullen)?
 - a. ..
 - b. ..
 - c. ..
12. Heeft u nog overige opmerkingen of aanbevelingen?

--

Workshop new measures

The identification of measures to prevent inundation in the Oranjepolder was done previous to this workshop. During this workshop, measures concerning the water system in relationship to spatial planning and on storage at greenhouses were reviewed. Water experts and policy makers of municipality Westland and the water board of Delfland were present.

By the usage of presentations, new finding of the research in the Oranjepolder was presented. This workshop was one of many to share information and create insight in progress of the research. Comments and thoughts on the presented topics were noted to be used in further research.