SPAARWATER

Sustainable and profitable usage of water in the agricultural brackish environment of the Wadden Sea region

Results of 2013-2015

2017

SPAARWATER

COLOFON

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1

INTRODUCTION

1.1 Context

Securing the availability of fresh water in the area along the Wadden Sea is of great importance to economical position of the agricultural sector in the Netherlands. Rising sea levels, soil subsidence and intensification of extremer weather phenomena like droughts and heavy summer rains do have their risk on the agricultural conditions. This region is very well known to be one of the best agricultural lands in Europe. It is located in the North of the Netherlands and facilitates half of the total Dutch flower bulbs and most of its seed potatoes. Because of good soil conditions the production intensity is above average is comparison to the rest of the Dutch production fields.

The area along the Wadden Sea is also characterized by a shallow fresh-salt water interface. A thin fresh rainwater lens, which floats on top of the salty groundwater, enables the land to be cultivated with fresh water crops. Due to climate change, soil subsidence and ocean level rise it is expected that the fresh rainwater lens in the cultivated area will decrease significantly and will be replaced by brackish groundwater, which reaches the root zone through capillary forces and could cause salt damage to the plants.

Due to salinization in the polders it is necessary to flush the surface water system in order to gain the desired water quality for irrigation and drinking water for the livestock. Under changing conditions this will cause an increasing demand on water from the IJsselmeer, a problem which affects all regions which depend on additional water supply in the Netherlands. Also, the regions which are not affected by salinization have to secure the availability of sufficiently clean freshwater and have access to irrigation water. This makes resilience towards climate change possible and minimizes the soil subsidence.

1.2 Spaarwater measures

Spaarwater develops and tests measures for the mitigation of salinization and the guarantee of availability of clean and fresh water. The fundamental concept is to optimize the technical feasibility of measures and make them economically viable at the same time. Therefore, the Spaarwater research very much focus on its stakeholders, and extra effects like reduction of crop diseases and the discharge of fertilizers and pesticides into the surface water.

Spaarwater contains four locations across the Wadden Sea region in the provinces of North Holland, Friesland and Groningen, where the components mentioned below are created and tested. They can be applied either individually or in combination with each other:

- Self-sufficient fresh water availability: collecting drainwater
- Self-sufficient fresh water availability: storing fresh water underground
- Efficient usage of water and fertilizers: drip irrigation and fertilization
- Increase of the fresh rainwater lens and mitigating salinization: system controlled tile drainage

Self-sufficiency in fresh water availability

The "self-sufficiency in fresh water availability" is a measure to ensure fresh water availability for farmers. Spaarwater seeks to demonstrate whether this is possible in the Wadden Sea Region and whether the system can be profitable for the flower bulbs and seed potatoes. The goal is for the farmer to become less dependent or even independent on external water supply. This would enable a more natural water resource management by which high fluctuations in water quality (fresh and salt water peaks) can be avoided. The collection of tile drainage water for underground fresh water storage also aims to reduce the discharge of nutrients and pesticides into to surface water, which contributes to the EU Water Framework directive and improves the surface water quality.

The development of a "closed" water system reduces the risk of contamination of the water by harmful germs such as brown rot and Erwinia. By storing the fresh water underground, the germs are expected to die. This offers the prospect of reusing the water for the sprinkle irrigation of the seed potatoes (where at the moment sprinkle irrigation with surface water is banned) as well as the irrigation of the flower bulbs with a much lower risk of contaminating the crops.

Efficient usage of water and fertilizers

With the drip irrigation and fertilization Spaarwater wants to take the next step in innovative agriculture. The test areas are a sandy plot containing flower bulbs, irrigated by surface drip irrigation and a clay plot with seed potatoes, constantly irrigated by underground drip irrigation. The goal here is to combine an increase of crop yield and a reduction in water and fertilizer usage. The latter should, therefore, lead to reduced outflow of nutrients to the surface water.

Strengthening the freshwater precipitation lens and controlling salinization

The freshwater lenses float on top of saline groundwater and are very vulnerable towards changing conditions, like climate change, land subsidence and sea level rise. As a result, the risk of salinization of parts of the Wadden Sea in the future increases. System controlled tile drainage aims at controlling the salinization, further development of the rainwater lenses, strengthening existing rainwater lenses, creating new lenses as well as the reduction of discharge of salt and nutrients into the surface water.

BREEZAND	BORGSWEER	HERBAIJUM	HORNHUIZEN
sand plot with flower bulbs	clay plot with seed potatoes	clay plot with grass	sand plot with wheat/sugar beet

Breezand and Borgsweer

self sufficient fresh water supply

- compiled drainwater collection and sub-irrigation (Breezand)
- compiled drainwater collection (Borgsweer)

self sufficient fresh water availability
underground fresh water storage

- single system (Breezand)
- multiple system (Borgsweer)

efficient use of water and fertilizers
drip irrigation and fertigation

- temporary surface drip irrigation and fertigation (Breezand)
- permanent subsurface dripirrigation (Borgsweer)

secondary goals

- nutrients
- pesticides

Herbaijum and Hornhuizen

reinforcing fresh water lens
system controlled tile drainage

- Herbaijum: adjusting existing tile drainage; compiled tile drainage with controled drain level; two drain disctances
- Hornhuizen: deepened tile drainage; compiled tile drainage with controlled drain level; one drain distance

secondary objectives

- nutrients

1.3 Pilot locations

Spaarwater seeks to develop measures which are close to the current agricultural practices and the fastest development of measures takes place by applying them directly in practice. For this reason, for developing and testing the measures at four different farms in four different regions in the Wadden Sea in order to be able to represent the whole region of the Wadden Sea. Two of the test sites (Breezand and Borgsweer) focus on their own water supply and on the efficient usage of water and fertilizers, true to the motto “capture, store, use”. Innovative tile drainage designs are applied to the other two pilot locations, Herbaijum and Hornhuizen, in order to achieve a maximum increase in the freshwater precipitation lens.

Breezand

Breezand is located in one of the most Northern polders of the Water Board Hollands Noorderkwartier, which depends on the water supply from the Ijsselmeer. The flower bulb production is the most important agricultural sector in Breezand and sufficient fresh water is vital for growing the bulbs. In cooperation with Spaarwater the own fresh water supply and efficient usage of

Spaarwater develops and tests measures for the mitigation of salinization and the guarantee of availability of clean and fresh water

water and fertilizers is being worked on with surface drip irrigation. Secondary objective is to reduce the use of fertilizers and discharging nutrients and pesticides. The work on the pilot location Breezand takes place on the field of bulb grower Langeveld and it affects an area of 2.7 ha bulbs on sandy soil.

Borgsweer

Borgsweer is located in the eastern part of Groningen in the region of Hunze and Aa's and is a superb area for seed potatoes. The marine clay has perfect conditions for the cultivation of this crop. However, due to the high risk of brown rot in the surface water drip irrigation on the surface in banned in this area. The self-sufficient water supply, where water is stored underground and the brown rot is expected to die, offers prospects of (surface) irrigation. New in this region is efficient water use due to constant drip irrigation in to subsurface. These investigations take place on the fields of seed potato grower Noordam and it contains a field of 1.5 ha, where crop rotation is executed on sandy clay loam (including seed potatoes).

Hornhuizen

Hornhuizen is located in the northern part of Groningen in the area of Noorderzijvest. This pilot field lays directly behind the dike, the only barrier which keeps the salt water away from the plot. Therefore, the groundwater underneath the plot is also saline. The Owner, Mr. Oosterhuis, noticed in the past that the construction of a tile drainage system in his field increased the conditions of the sand plot. Due to the application of the system controlled tile drainage the precipitation lens could grow stronger and the salinization could be controlled, which again lead to an increase in fresh water storage above the saline groundwater. The plot (7.2 ha) is located in an area where the cultivation of fields with seed potatoes is very common. Due to the crop rotation, also other crops like sugar beet and winter wheat can be found on these fields.

Herbaijum

Herbaijum in located in the area between Harlingen and Franker in Friesland in the region of Wetterskip Fryslân at about 3.5 km distance to the dike. The area of the study field is influenced by soil subsidence, which makes salinization of the groundwater a current risk. Due to the application of a system controlled tile drainage the size of the precipitation lens was increased and the salinization could be contained and fresh water supply storage above the saline groundwater was increased. In the past, the field was split into three smaller fields, which were now combined into one big one. On the field two pilot plots with different tile drainage distances can be found. Secondary objective of these plots is to reduce the discharge of fertilizers. The plot of Hofstra is used as pasture for cattle and sheep and is 4.9 ha in size.

2

LESSONS LEARNED

In the period of 2013-2015 the technologies were constructed and tested, the results are promising. We succeeded to realize a self-sufficient fresh water supply, with which the farmers are less dependent and even completely independent on external water supply. With drip irrigation in the flower bulbs as well as in the seed potato fields an increase in yield was obtained and with the system controlled tile drainage the precipitation freshwater lens was increased. All this does not happen by itself and there are still problems to be fixed, especially in the construction, design and operational management. From this a number of important system improvements have emerges, which have to be dealt with.

Strengthening the freshwater lens

The system controlled tile drainage turns out to work in sandy soil as well as clay soil and to be able to hold freshwater precipitation in the field, by (temporarily) increasing the discharge in the drains. On both plots measurements show that the amount of water which runs off unused is diminished towards the sluice after the application of the system controlled tile drainage. Therefore, the freshwater remains in the field, increases the freshwater lens and the risk of salinization decreases.

The pilot plots showed that in practice it works to increase the freshwater buffer in the field by setting up a level. The most effective method is the combination of the deepened construction of the tile drainage with the setting up of the level. Herewith, an increase in thickness of the freshwater lens by approximately 15-20 cm was already obtained in the sandy plot. In addition to set-up level, it is also apparent that the distance between the drains influences the thickness of the freshwater lens. The thickest lens develops when the drains are further apart.

Self-sufficient water supply

A fully self-sufficient freshwater supply is possible, without being dependent on external water supply. Collecting water from the field through the drains, storing freshwater in the subsurface and drip irrigation/fertilization were applied on three fields. The measurements show that 65-100 % of the water, which is collected by the drains, can be reused for sprinkling or drip irrigation, depending on the desired salinity threshold value. This is sufficient to provide the crops with the necessary amount of freshwater.

The very small clay particles in the water from the drains for the field in Borgsweer will cause very fast clogging of the different filter systems and hence have very high maintenance costs. By now several solutions have been implemented, so that the system is more suitable for clay plots. In the case of Borgsweer (a clay field with seed potatoes) a field of 10 ha will provide enough water to irrigate an area of 12 ha. In the case of Breezand (a sandy field with tulips and hyacinths) the water collected by the 10-ha big field is sufficient to irrigate up to 20 ha.

From different sectors, the greatest interest is to decrease the risk of diseases within the system. The great advantage of storing the fresh water collected by the field into the subsurface, is that it will not be in contact with surface water outside of the system, and has a small chance to be contaminated by germs. So, by storing the water in the subsurface the risk of pathogenic bacteria can be reduced even further. Moreover, the crops stay dry due to the drip irrigation, so that any bacteria will not be able to spread by irrigation spray of the reel irrigation. The combination of both systems, subsurface storage and drip irrigation contributes significantly to the prevention of fungal and bacterial diseases.

Due to the storage of fresh water in the subsurface the freshwater bubble will stay present within the original saline groundwater. The amount of fresh water which can be recovered from the storage bubble is influenced by the mixing processes at the freshwater/saltwater interface and the upwelling of the freshwater bubble. By only pumping the shallower wells the recovery of the freshwater bubble can also be greatly increased. Simultaneously, it is sensible to set up a year in which the water is only stored and not withdrawn, in order to improve the efficiency. According to model simulations, this can achieve a recovery rate more than 90%.

Effective water usage

The results of the drip irrigation by fresh precipitation water stored in the subsurface are very promising. During the second year of Spaarwater an increase in yield could be achieved on all test locations. In the fields with seed potatoes this could be achieved by improving the water supply. They were irrigated by the water stored in the subsurface, as it is forbidden to irrigate with surface water due to the risk of brown rot. This resulted in over 20 % more tubers, due to the precise fertilization of drip irrigation. This also made it more cost effective. The increase in yield can be seen in a surplus of approximately 1.000-1.500 € per hectare for seed potatoes and several thousand Euros per hectare for the flower bulbs. This increase in crop yield highlights the expected economic feasibility of the Spaarwater System. The price of the underground freshwater storage system for sand parcel was halves due to the development of simpler and more compact system. On a clay

> We succeeded to realize a self-sufficient fresh water supply, with which the farmers are less dependent and even completely independent from external water supply

> Drip irrigation helped to achieve an extra yield of 20% in seed potato production. This increase in crop yield highlights the expected economic feasibility of the Spaarwater system

field and on the system controlled tile drainage a number of functional enhancements need to be executed. The follow up project Spaarwater 2 further investigates the cost reduction innovations further.

Costs and benefits

The Spaarwater technologies deliver several benefits for the farmer, like an increase in crop yield, a decreased risk in salt- and drought damages and a reduction of risk of infection by germs. This leads to a higher security for the company, due to an increase in qualification to obtain contract cultivation, and therefore the certainty of a constant income. If these measures are applied more widely, they could help to maintain and strengthen the leading position of agriculture in the Wadden Sea Region , also under a changing climate and land subsidence. Therefore, the Spaarwater measures brings a number of benefits for the water manager along with it. Because the vast majority of the water is collected and stored, the discharge peaks could be reduced to 15 % of the peaks which occur without the system. This means, that the surface water system is much less stressed by a peak discharge.

Nutrient and salt stress

By the system controlled tile drainage system, the salt stress could be decreased by 50 % in the clay fields in comparison to the year 2015, in the sandy fields it could be decreased by 30 %. By storing the redundant water from the field into the subsurface also the discharge of nutrients into the sluice is reduced. This way the Spaarwater measures will be able to contribute to the WFD objectives.

Promising results

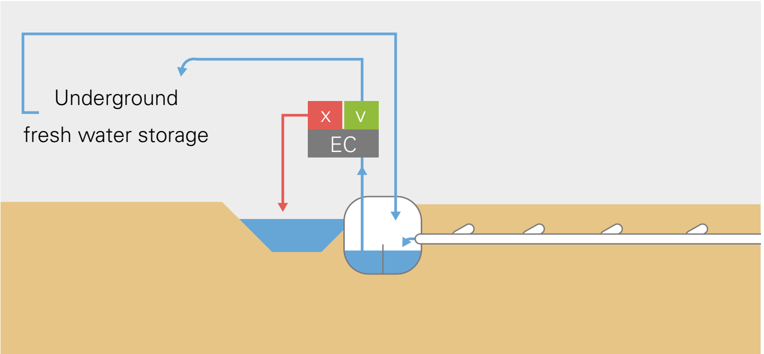
It can be concluded that the results of Spaarwater 2013-2015 are very promising. Several adjustments, which improve the accessibility and operation of the Spaarwater system, could be done by developing the measures and them in the daily practice at the farm. This includes the intensive contact with the agricultural sector in various meetings, consultations and discussions with the water management (waterschap, provincie en rijk) who have tightened as well as widened the application range.

3

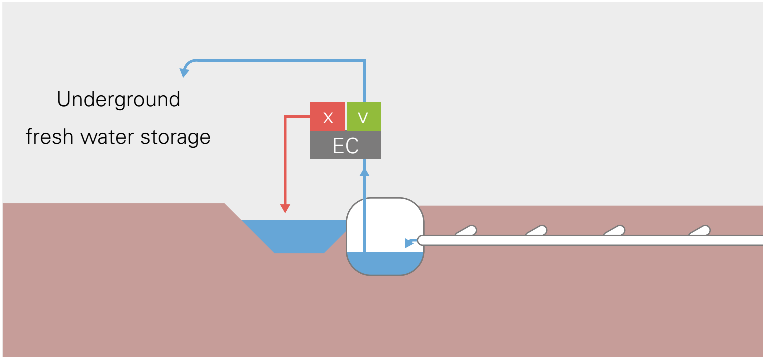
SELF SUFFICIENT WATER AVAILABILITY: COLLECTING DRAIN WATER

3.1 Introduction

The improvement of the water supply through freshwater measures is important in areas where the water inflow is insufficient or does not have the required quality. One of the measures is to increase the self-sufficiency by creating a freshwater storage, like a basin or underground freshwater storage. An important question when doing so, is with what can the freshwater storage be filled? In the greenhouse, where both storage systems are applied, the rainwater runoff from the roofs is being used. This is not possible in the open ground cultivation. Therefore, an alternative method was developed to catch the endogenous water from the drains. This innovation was recently developed and successfully tested in the trail self-sustaining freshwater storage on Texel and will be



Breezand: sand plot



Borgsweer: clay plot

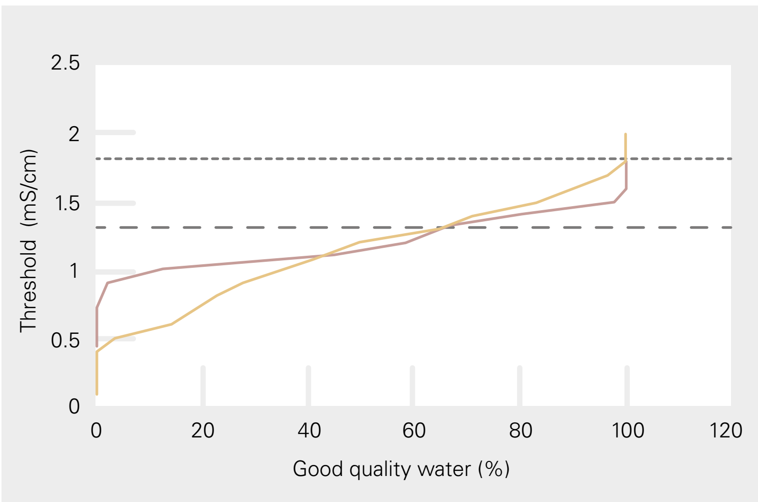
developed further in Spaarwater in order to make the water available from a well, not only a through the ditches. The measure is very similar to the common practice of agriculture in the Wadden Sea region, where almost all the plots are drained.

At the clay plot in Borgsweer the existing tile drainage is connected to a manifold (also called composite drainage) in order to collect the water. At the sand plot in Breezand a new assembled tile drainage-infiltration system was applied. Hereby, the water from the subsurface storage can regulated the water in the field. The manifold of both plots comes from a collecting pit. In the collecting pit the water quality is measured and when the salinity does not reach a certain threshold the water will be returned to the storage in the subsurface. When the water is to saline, it will be discharged into the sluice. This way it is avoided, that the fresh rainwater will ever come in contact with potentially contaminated or too saline groundwater, but the good quality of the rainwater collected from the field will remain. This way a complete independence on external water supply is guaranteed.

3.2 Results

3.2.1 The amount of water in relation to threshold of salt content

The collected water from the drains provides a substantial source of fresh water. The sand plot in Breezand provided 9.000 m3 and the clay plot in Borgsweer 4.000 m3 of water, which was collected in the drains in 2015 (according to quality requirements). The percentage which is suitable for underground storage depends on the set threshold value. During the testing phase, this threshold was varied in order to find out what kind of effects it had on the collected amount of water. In Borgsweer the threshold of an EC (electrical conductivity) lays between 1.1 and 1.8 mS/cm and in Breezand it is between 1.3-1.7 mS/cm. The differences in the amount of collected water between the two sites is also influenced by the combination of a different seepage pressures and the setting up of a



well above the tile drainage level in Breezand.

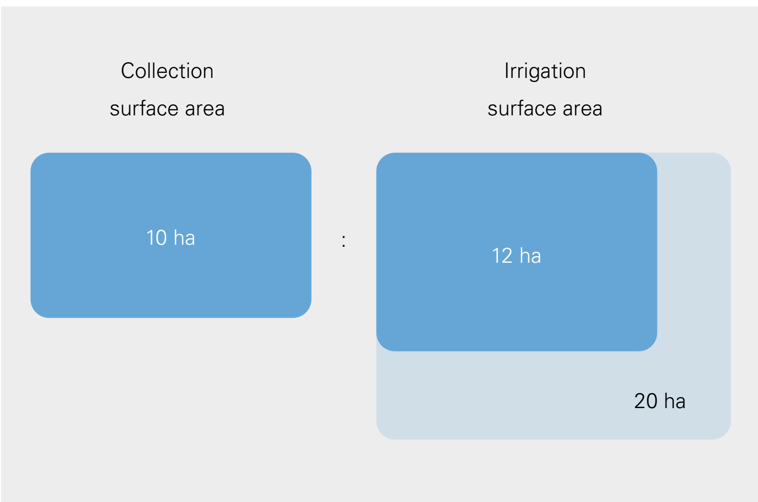
Ultimately, the end value of the threshold depends on the purpose for which the collected water will be used. If the water is used for drip irrigation the salt content can be higher, than if it was used for traditional irrigation. According to literature, seed potatoes (Borgsweer) show a damage threshold in soil moisture conditions at 4.3 mS/cm. In the testing phase, it was set to 1.3 mS/cm, but was later increased to 1.7 mS/cm, which enabled it to collect more water. According to literature, the tulips and hyacinths (Breezand) tolerate values between 1.0 – 1.3 mS/cm. In practice, the water used on flower bulbs has a slightly higher EC than suggested in the literature. In consultation with the grower the threshold value was, therefore, increased slightly.

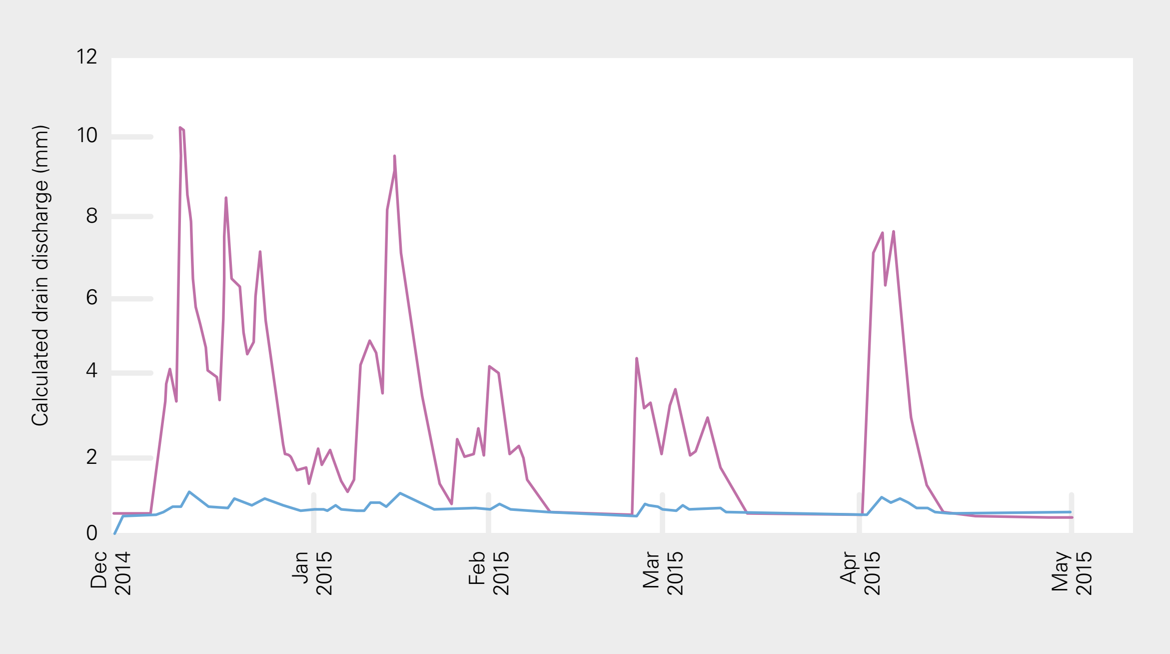
The sand plot has a threshold value of 1.3 mS/cm and approximately 65 % of the drainage water fulfilled the quality requirements of 2015, whereas as with a threshold of 1,7 mS/cm almost 100 % of the drainage water fulfilled the quality requirements of 2015. However, on very different fields, the same percentages were found. Therefore, a small increase in the threshold value causes a high increase of the suitability of water from the drains and thus a higher freshwater availability.

> The pilot results are used in hydrological models, which resulted in estimates of the storage vs irrigation efficiency, For seed potato cultivation on clay a capture zone of 10 ha is needed to irrigate 12 ha. Flower bulbs on sand the 10 ha capture zone enables 20 ha irrigation

3.2.2 Areal retention versus areal irrigation

On the basis of results a model was developed, with which the whole system of retention, recharge, reuse (analysis of full self-sufficiency) could be calculated. It calculates how much land can be irrigated with the collected water from the plot. The model combines all results from every subplot, with the yield of the underground water storage (with the assumption of integrating a year of only infiltration without obstruction, "Spaaryear" (consider Chapter 4.)) and drip irrigation as a supplement for rainfall deficit (see Chapter 5) and a pre-set threshold value of 1.7 mS/cm. with the model long term series were calculated, so that also dry years were included. It turns out that in Borgsweer (a clay plot with seed potatoes) a plot of 10 ha collects water to sufficiently irrigate an area of 12 ha, and therefore, would never lead to a soil moisture deficit in the next 50 years. In case of Breezand (a sandy plot with flower bulbs), the plot collects enough water to fully irrigate a field of 20 ha. In a scenario taking climate change into account





(calculated with a strong climate change, WH scenario) this ratio remains the same for Borgsweer and is even more positive for Breezand.

3.2.3 Effects of the surface water

Peak discharge

A great additional advantage of storing the water from the plot is a reduction of the peak discharge in the ditches, as the majority of the water is collected and stored. This will cause the peak to be reduced to 15 % of the peaks which would occur without the Spaarwater system. Therefore, the surface water system will be much less challenged during a peak discharge.

Salt stress

Due the collection of fresh water from the drains less water will end up in the sluices, which will cause the sluices to become saltier. This can be an advantage for the development of a saltier biotope, at the same time it could create a disadvantage if the agricultural land close by still depends on fresh water from the sluices, in which case the need for flushing would be increased. Therefore, it might be sensible to collect the water from the field in (parts of) the polder, so that the sluices are separated from the flushing regime.

Nutrients

In Breezand the discharge and collection of water is investigated with respect to nutrients. The measured nitrogen and phosphor concentrations in the drainage water show a value above the GEP concentrations (good ecological potential) based on the WFD (Water Framework Directive). By collecting the water discharged from the field, the nutrients will not end up in the sluices, but will be stored underground. By reusing the water from the field via infiltration the concentration of nutrients in the surface water discharged into the sluices is decreased significantly. NO3-N showed a concentration of 77 % of the original and PO4-P showed 60 % or the original concentration. Please note, that these conclusions are only based on weekly sampling, thus, possible peaks were missed. Further analysis and comparison of the water samples showed a higher concentration sulphate, which disrupted the results and made them unreliable. Therefore, in Spaarwater 2 an automated sampling system was installed, in order to determine the behaviour of nutrients during the peak flows.

Plant protection products

In 2015 the tile drainage discharge and the groundwater from the subsurface storage on the sand plot in Breezand were sampled and analysed for pesticides. There is a wide range analysis package applied, which can analyse 29 substances, 14 of which were mentioned in the pesticide control plan of 2014 and 2015. The substances which were used in 2015 display a higher concentration in the drainage water from April until November. The substances which were used in 2014 and earlier exhibit a more constant

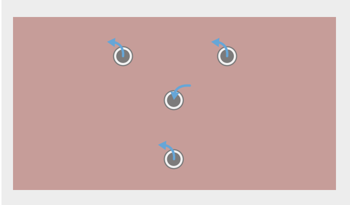
Retention and reuse of drain water enables to decrease the outflow of nutrients to the surface water.PO4-P with is reduced with 60% and NO3-N even with 77%

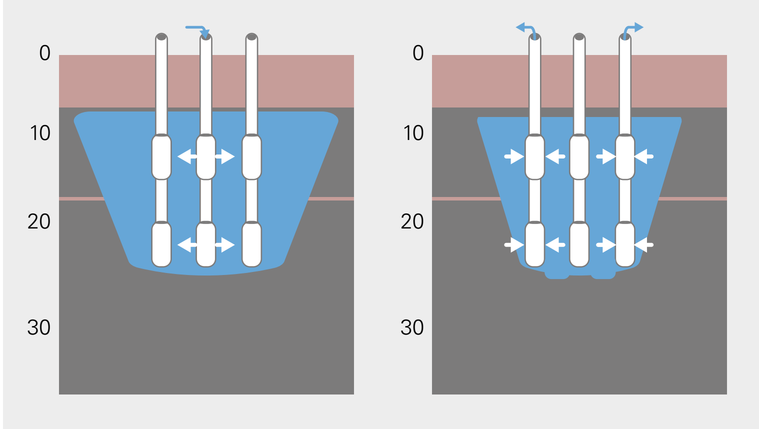
concentration throughout the year. It seems that in anaerobe conditions of the groundwater in the plot and the stored groundwater the substances sometimes shower higher and sometimes lower degradation rates. The analysis of the drainage water shows that the concentrations of three out of the 29 of the substances are exceeding the EQS or MTR standards. It appears that in principle the three substances which exceeded the threshold can be degraded. This leads to the final assessment of a limited risk, where the permit can be granted, if appropriately monitored.

SELF SUFFICIENT WATER AVAILABILITY: UNDERGROUND FRESHWATER STORAGE

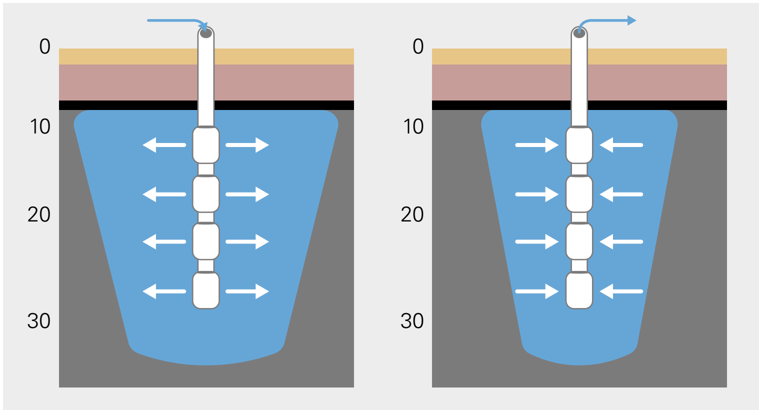
4.1 Introduction

The subsurface freshwater storage of Spaarwater was realised with two companies in order to show whether it is possible for the system to be applied in an open ground cultivation. Underground freshwater storage has previously been used in the greenhouse, but the wider application in other agricultural sectors in the Netherlands is new. In Spaarwater, the lessons learnt from the former project in Bangladesh, where a simple form of subsurface freshwater storage system for drinking water was installed, were combined with the experiences in





Borgsweer: infiltration and extraction with multiple system



Breezand: infiltration and extraction with single system

horticulture, in order to develop a (cost) effective system. At both locations, the water is infiltrated into the aquifer beneath the clay layer. With the single-well system in Breezand the water is stored and extracted in a depth between 10 until 29 meters below a corn field. In the multiple-well system of Borgsweer the water is stored and extracted between 10 and 21 meters below ground level.

There are two different designs applied: the single-well system in Breezand contains one well and can infiltrate and extract water from four different depths. The multiple- well system in Borgsweer contains one well from which the water is infiltrated at two different depths and three surrounding wells with a 5-meter distance to the infiltration well, from which the water can be extracted from two different depths. Here the functionality of the multiple-well system with an additional soil passage is examined, in order to optimise the storage of fresh water and to improve the water quality by a decrease in germs, nutrients and pesticides.

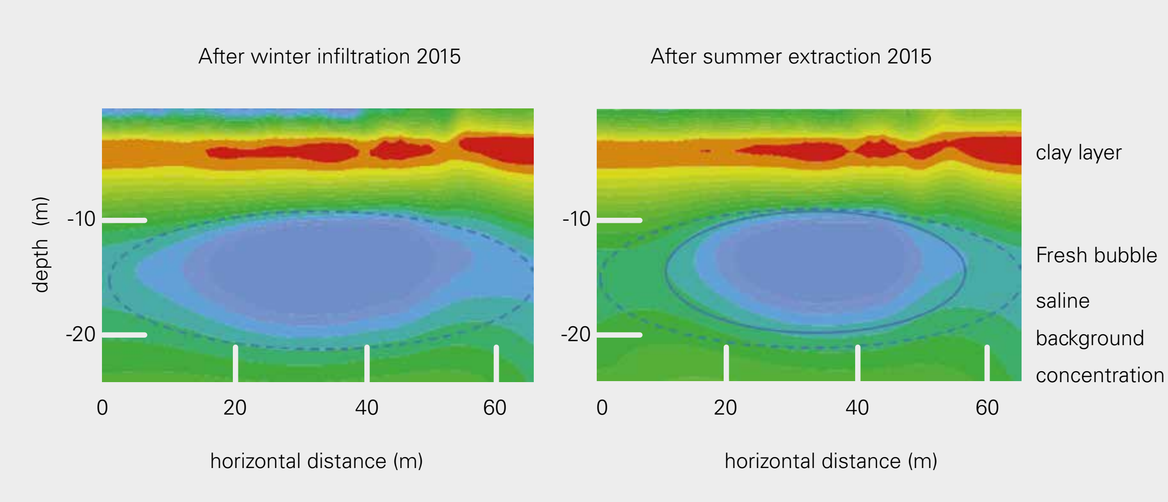
4.2 Results

4.2.1 Development of the fresh water bubble

The construction of the freshwater bubble in the overall brackish to saline groundwater was successful on both locations, Breezand and Borgsweer. Within the two years of application of this system 15.000 m3 of water were infiltrated in Breezand, 5.700 m3 were infiltrated in Borgs-weer. This infiltration is alternating with the extraction of water during the growing season of a total amount of 1.050 m3 in Breezand and 2.030 m3 in Borgsweer.

An insight into the subsurface was delivered by geophysical measurements and continuous measurements in the wells. In those measurements, the bubble was clearly visible against the background concentration. They show that the bubble grows in the winter months, due to infiltration, and shrinks during the summer months, caused by the extraction of water for irrigation. Thus, the measurements also show that the unused stored water remain in a compact fresh water bubble. The successive infiltration and abstraction create a compact "breathing" freshwater bubble in a saline environment.

During the infiltration, a fresh water bubble is created along the full depth of the infiltration well. However, the shape of the bubble is not constant in time. At the bottom of the bubble (at 30 m depth in Breezand) the salinity increases over time. When the infiltration starts again the fresh water – salt water interface is pushed back down and the bubble is growing again. Time series of the salt concentration at different depths and distances to the infiltration well show that the salinization of the bottom bubble boundary at 30 m depth does not coincide with the abstraction of water for irrigation and, will, therefore, not have any consequences. Interestingly, the change in concentration coincides precisely with the moment when



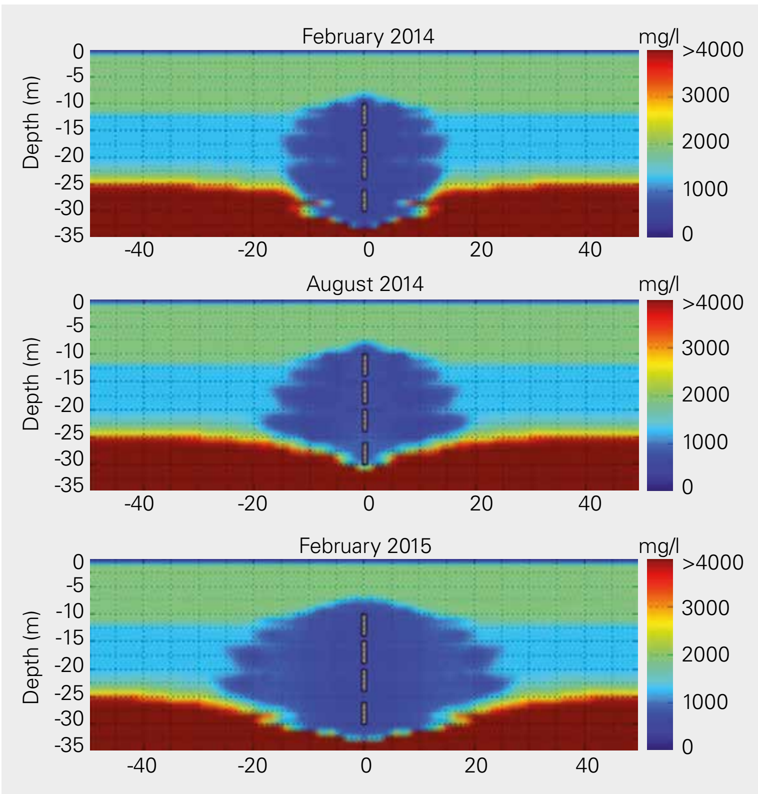
Geophysically measured size of the fresh water bubble

there is hardly any abstraction but infiltration. This indicates, that buoyancy of the fresh water occurs, where the fresh water is bubble pushed up the denser saline water.

4.2.2 The recovery

For the effective extraction of water buoyancy plays a major role. In the single-well system in Breezand, having four filters at different depths, where the deepest filter only functions for infiltration and not for abstraction, so that salt water will not be extracted from the greater depths. This way the water can be extracted in a more efficient way as opposed to using all filters at the same time. In order to investigate the recovery efficiency groundwater models were created for both plots, which were calibrated on the available measurements. Hereby is was calculated, how the system could be applied on a larger scale and how the recovery efficiency can be optimized. The model simulations show that the recovery efficiency of the single well system in Breezand can be optimized by extracting water from the upper three filters in the begin of the growing season, using the first two filters as time passes and only using the upper filter towards the end of the season for water extraction. This way the water yiield can be increased by 80 %. However, this only applies to the situation in Breezand, where the brackground salt concentration is relatively low (from previous international studiesit was shown that it is possible to even reach a recovery rate of 100 % if the difference in background and desired concentration is not too large).

At the location in Borgsweer, where a multiple well system is being used, the model simulations show that with the current infiltration rate a maximum efficiency of 50 % can be obtained. This is in line with the



Development of the fresh water bubble in Breezand (modelled) recovery yields that are found in studies such as Westerland. This lower theoretical efficiency of Borgsweer in comparison to Breezand can be explained by the combination of a higher background concentration, the existence of the clay layer and the system configuration with extraction filters at two instead of four depths and a distance to the infiltration well. By adjusting this system, the efficiency can be further increased.

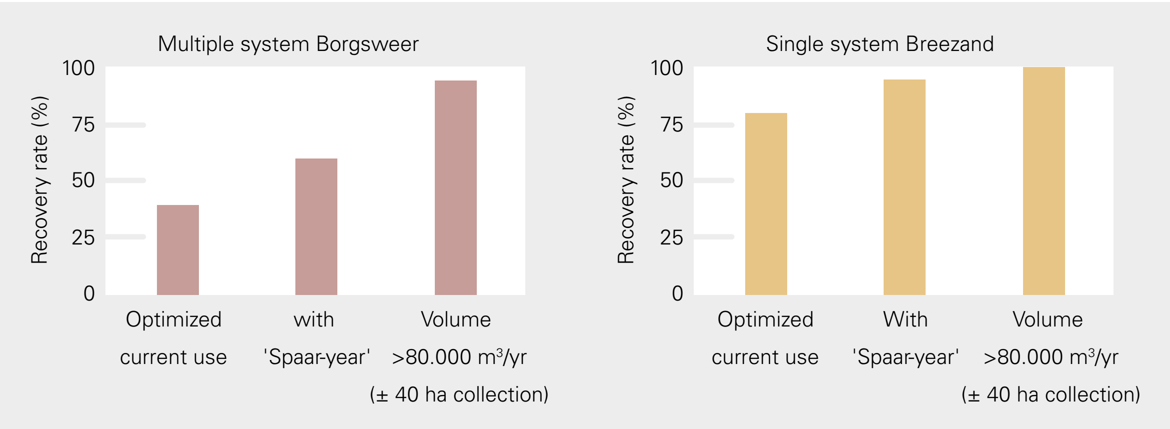
Proces of sedimentation of clay particles in the drian water

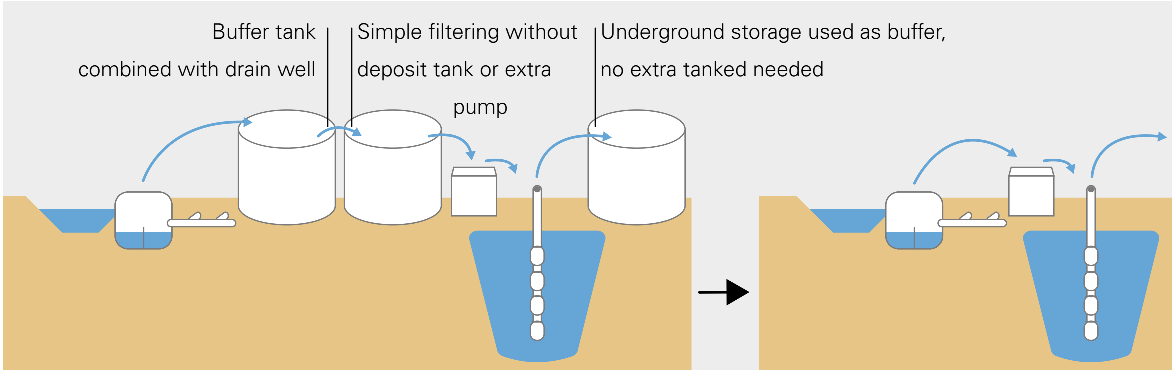
It appears that next to the buoyancy, the mixing zone at the salt- fresh water interface also contributes to the resulting yield. As soon as the fresh water is mixed with the surrounding salt water, this mixing process cannot be reversed. The mixing zone is measured in the wells, where the time series shows a gradual transition between the concentration of the surrounding groundwater and the infiltrated water. One solution to increase the yield of the fresh water is to include a "Spaaryear": a year in which water is only infiltrated into the subsurface and not extracted. The mixing zone stays along the edge of the fresh water bubble, so that a buffer is created which protects the core of the bubble, from where water is infiltrated and extracted. In Breezand, it was calculated that even with a small volume of recovery water, due to the buffer the recovery rate could still be increased up to 95 %.

With the setting as in Borgsweer the simulated efficiency can be increased, whenever it was combined with a Spaaryear and larger amounts could be infiltrated and extracted. With a volume of approximately 50.000 m3 a recovery rate of 90 % was simulated. The extent of the scale can, therefore, contribute greatly to efficiency.

4.2.3 Construction and operation of the system

In order to be able to apply the system in the open field, several practical innovations were executed in those first few pilot years. Especially the application at the clay plot proved to be a challenge. The water from the underground water storage shows a lack of oxygen and is directly applied to the plants via drip irrigation and, thereby, deteriorating the crop yields in the first pilot year. Due to an adjustment of the tank for the storage of the day's water, the water is now aerated naturally, so that (not only because of that) a second pilot year and an increase in yield could be realized. In addition, very small clay particles from the water cause the filter systems to clog very fast and, therefore, create a very high maintenance costs. For the latter several solutions are being investigated. The most promising solution is to prevent the clay from running off into the drains. This is accomplished by adjusting the tile





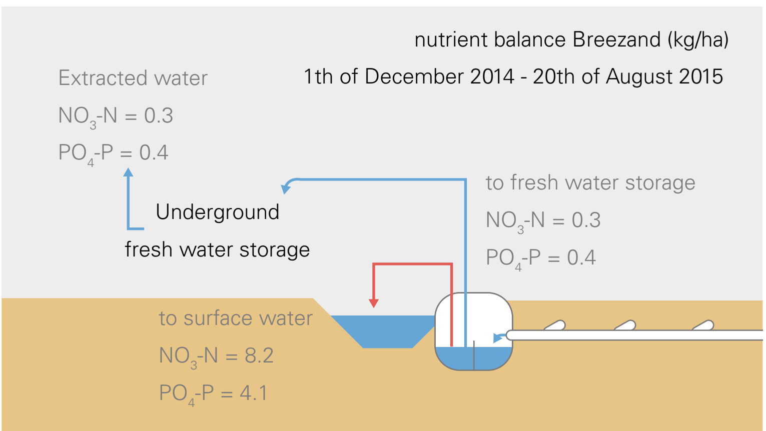
Introducing a 'Spaar-year' increases the recovery efficiency with more than 10%

drainage system and reducing the flow rate, so that the clay particles have more time to settle. This solution has already been installed and is being test in practice. If the results are sufficient, the system in the sand plot could be simplified, as described below, and also applied to the clay plot.

The water from the sand plot in Breezand shows that it does not contain any particles which need to be filtered out. Here, the soil itself functions as a filter, which creates a lot of possibilities for the system to be simplified. The large sand filter and the successive filters used in the original system could therefore be replaced by the much more compact filters, so that the space occupied by the system will be even smaller. In addition the water can be used in a smaller amounts in fertigation and surface drip irrigation. The required flow rate is therefore limited and at the same time the previously mentioned aeration is not necessary. This may also enable the collecting tank to not be used and removed. Underground freshwater storage can be directly used as a buffer for the drip irrigation. The measurements show that the infiltration capacity of the system is sufficient to infiltrate virtually all the water from the drains directly, which also may void the buffer tank. Because of these simplifications, the system is more compact and cost effective. This will bring a broader application, especially for sand plots close by.

4.2.4 Germs and nutrients

In addition to the quantity aspects of the underground, fresh water retention are also important for the quality aspects of the chances of success of the system. From the different sectors it becomes clear that the reduction of germs and diseases within the system is of great interest. In areas where surface irrigation is banned due to risk of brown rot, this system can be used in order to introduce irrigation again. But also, other sectors, like the flower bulb sector, are interested in avoiding an infestation of brown rot. For that reason, it is investigated how the system can be applied even broader, to not only to increase and secure the fresh water supply but also to fight against diseases. The biggest benefit of subsurface



Using ondergground storage reduces risky plant diseases coming from the surface water

storage is that the water will not contact the surface water and, therefore, the chance of getting contaminated with diseases is minimal. Thus, due to subsurface water storage the risk of contamination of the water by bacteria can be decreased even further.

Previous studies have focussed on pathogens, which pose a direct harm to the people. However, literature about the degradation of pathogens, which are specifically threatening for agriculture, does not exist yet. On the basis of a comparison of other bacteria it can be concluded that the pathogens are filtered out of the water in three ways due to fresh water storage: by degradation (in a anoxic environment, e.g. brown rot bacterium has an oxidative metabolism), fixation on organic matter and minerals in the subsoil and filtering by soil passage. In Spaarwater the conditions in the fresh water bubble in the subsurface are tested in order to substantiate the likelihood of these processes.

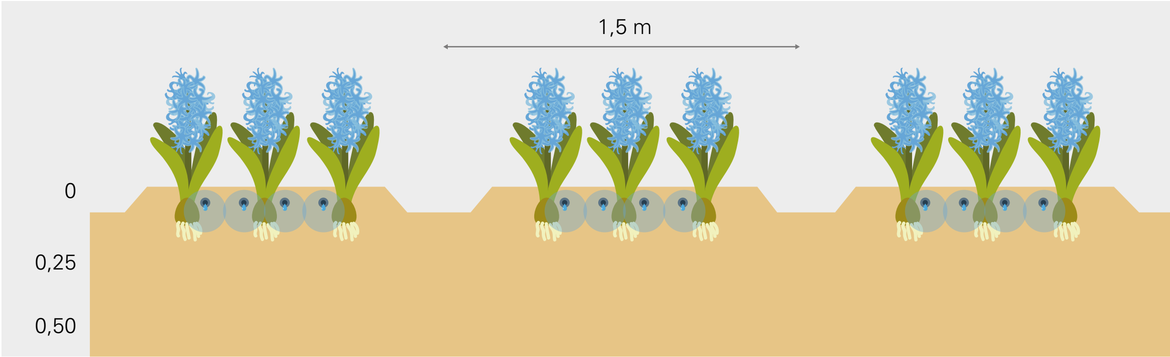
Next to the bacteria, the behaviour of the nutrients in the subsurface fresh water is investigated. In order to reduce the nutrient load in the field, it is sensible to reduce the nutrient influx into the system. If the nutrients can be stored as well, it could mean less fertilizer is needed to be add to the irrigation water. The analysis (executed in the Breezand) shows that the amount of nutrients in the water withdrawn from the aquifer exhibit much lower values than the water infiltrated into the system. NO3-N was degraded almost completely and only 1% of the original amount is left in the water. For PO4-P 94 % could be degraded or fixed. This shows that almost the whole amount of nutrients is being fixed or degraded.

5

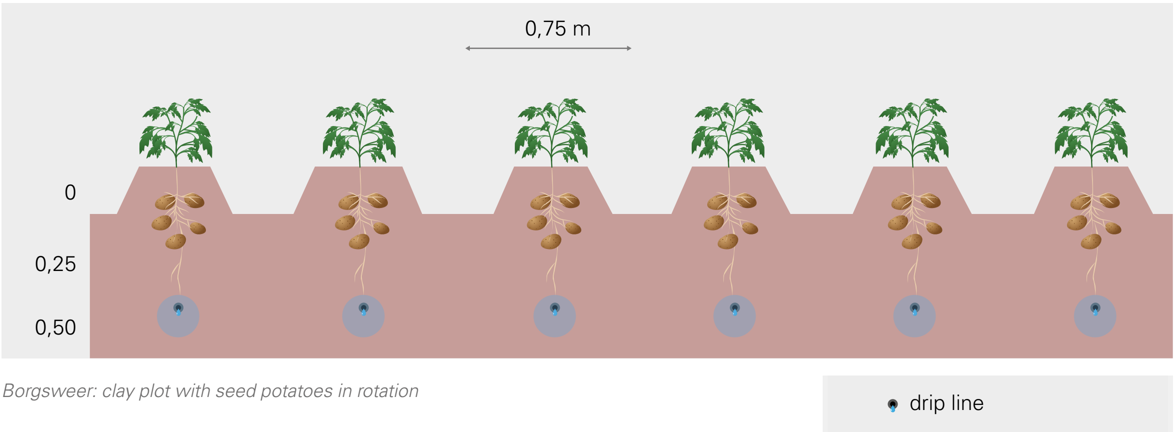
EFFECTIVE WATER USAGE: DRIP IRRIGATION AND FERTILIZATION

5.1 Introduction

By using traditional irrigation methods water is lost due to drifts, evaporation and the relatively high amount given at once. Drip irrigation enables water to be given to the plants in a much more controlled way and precisely where it is needed, in the root zoot. This way fresh water can be handled in a much more sustainable way than in



Breezand: sand plot with flower bulbs



Borgsweer: clay plot with seed potatoes in rotation

traditional manner. In arid regions applying drip irrigation can save up to 10-50% of water. How this will turn out in Dutch conditions is yet to be seen. Irrigation is not only used for water supply but also used for a better absorption of added fertilizers. With drip irrigation, it is possible to apply fertilizers in a much more efficient way through the infused water: 'fertigation'. Fertigation has the advantage that the leaves of the crops stay dry, so that the infection risk by bacteria due to sprinkling water droplets is very low. This encourages the prevention of fungal and bacterial diseases. Drip irrigation, therefore, saves potential water resources and fertilizers, restricts failure due to diseases, can increase crop yields and reduce the use of pesticides.

Internationally, drip irrigation is already used frequently, especially in arid areas. The application under Dutch conditions is very new. One of the most important questions regarding irrigation and fertilization is when and how much water and fertilizers have to be added, in order to optimal results in crop yields. The goal is a more effective use of the available water, either by saving water and/or by increasing the re-usage rate of water. Within Spaarwater drip irrigation is applied in two different ways. The first and more traditional way is to lay the irrigation tubes on the ground during the growing season. Next to this a second, more innovative method is being developed, where the irrigation tube is being permanently installed in the subsurface underneath the ploughing level.

5.2 Results

5.2.1 Increase in yield

An increase in yield of seed potatoes and flower bulbs (hyacinths) was realised in the trial plots within in the second year of the pilot. The quality

> Using innovative techniques makes it possible to install the drip lines permanently in clay soils

and size of the bulbs determine the increase in yield. During the second year (2015) a few optimizations were executed, which led to a greater yield by an increase in size. Such a difference can be translated carefully into a surplus of several thousand euros per hectare.

For an increase in yield of the seed potatoes an increase in the amount of potatoes and their sorting is necessary. During the second year (2015) clear differences can be detected between the reference plot and the part where drip irrigation is applied. The difference in yield can be translated into a more cautious revenue of approximately € 1,000 to € 1,500 per hectare.

Reference

Fertigation

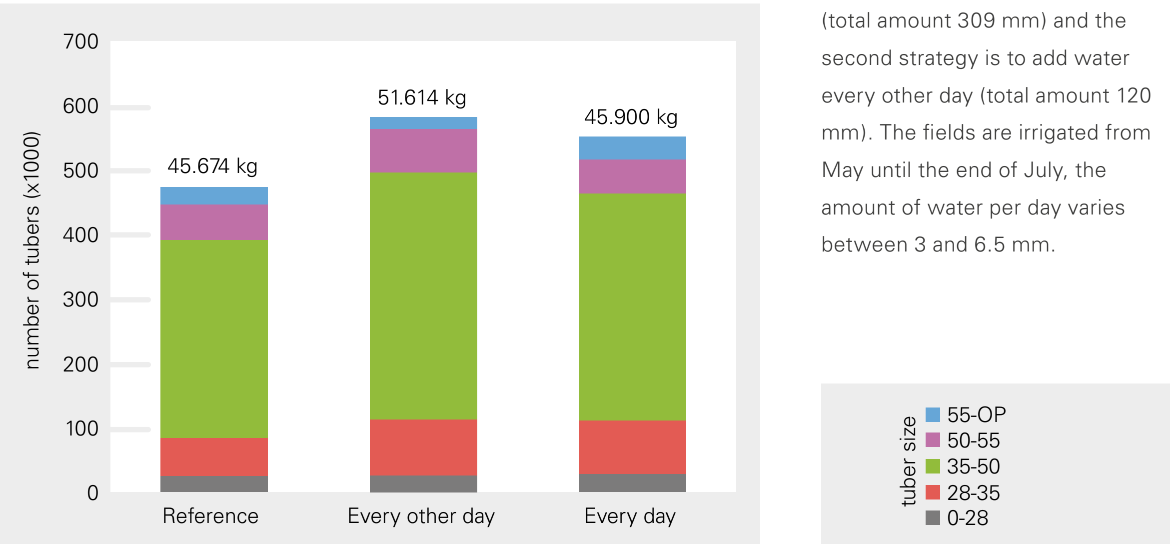
5.2.2 Water use

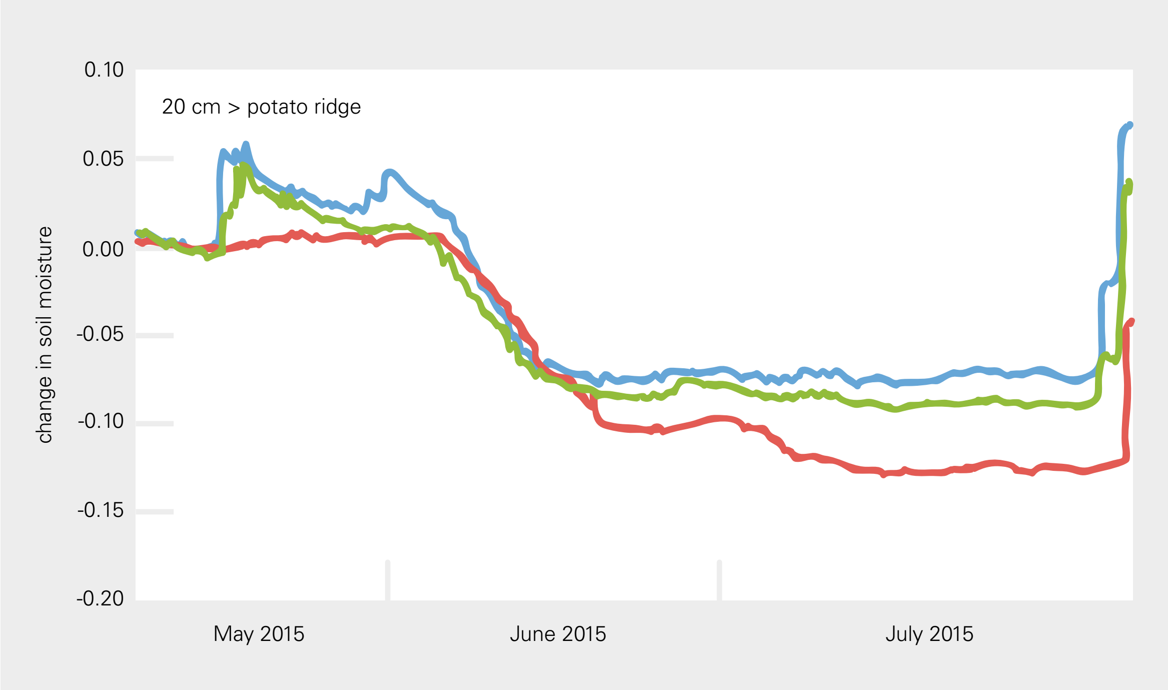
The amount of water administrated by drip irrigation is primarily based on the knowledge of the farmers, so that the processes are as close as possible to the daily operations of the agricultural business. Subsequently, the system was being refined based on the measurements of soil moisture done at the different depths. Important to note is that in both plots the soil moisture is controlled in order to get the perfect conditions for plant growing, not necessarily focussing on efficient water use. Doing so increases the chance for a wider agricultural application of the system and ensures an ideal utilization of the available water.

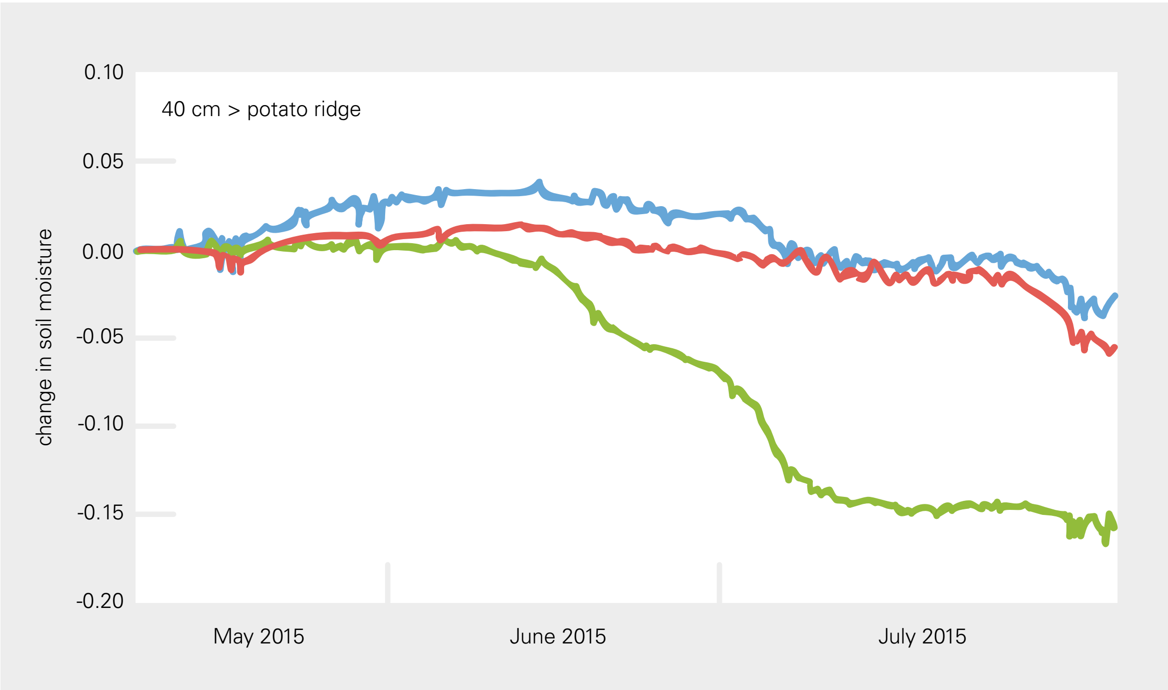
Clay plot and seed potatoes

In the clay plot the ground water level is lowered during the growing season by 1 m. Here, therefore, the soil moisture has to be adjusted with drip irrigation. This is particularly important at the start of the season, as the best moisture conditions lead to a higher tuber growth (growth of new potatoes per plant), and later in the season for equal sorting.

In the first year of research the decision of how much irrigation water should be applied was mainly based on the soil moisture in the surface, while the water was administered at deeper depths. By doing this (too) much water was being used, to be precise 404 mm and no difference in yield in comparison to the reference field was detected. During the second year the decision on how much irrigation water to use was based on 'real time' information gathered by sensors in the ground, measuring soil moisture and its tension, and is regulated so that the soil moisture stays constant. The pilot plot is split into two parts in order to test two different watering strategies. In the first strategy water is added every day (total amount 309 mm) and the second strategy is to add water every other day (total amount 120 mm). The fields are irrigated from May until the end of July, the amount of water per day varies between 3 and 6.5 mm.







Daily
Every other day
Reference

The second strategy, where water is given every second day, seems to be the most successful one: with a much lower water use and much higher yield could be obtained. This strategy will be further developed in Spaarwater 2.

Sand plot with flower bulb cultivation

In Breezand it is slightly more difficult to test the effectivity of the amount of water used due to the drip irrigation, because the groundwater level is regulated with water from the sluice. The measurements of the soil moisture content display that the moisture in the root zone of the plot is at field capacity during the entire growing season, due to the regulation of the groundwater level. Therefore, in this plot sufficient water was available for the plants, so that drip irrigation was not necessary anymore to regulate the soil moisture. Nevertheless, drip irrigation on this plot has proven its added value (increase in size), which was caused by the targeted delivery of fertilizers.

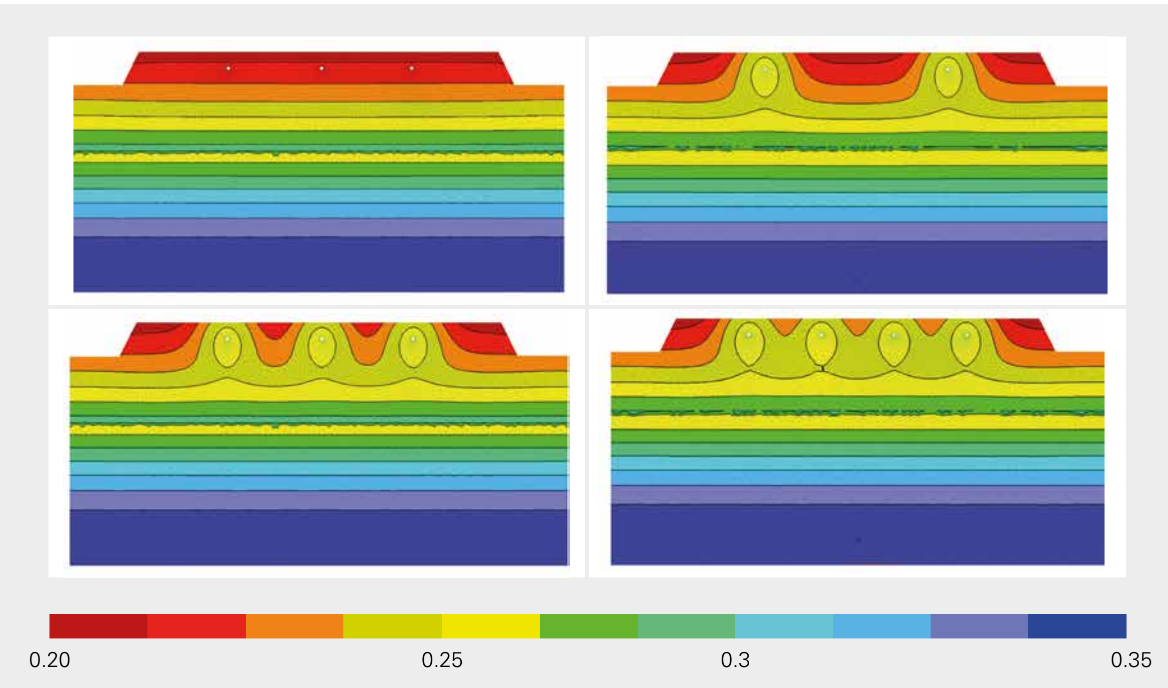
To optimize drip irrigation practice, a balance has to be found within water volume for the crops and conservation of soil structures

The last seasons the sluices in Breezand were still used to regulate the groundwater level in the plots. The upcoming seasons it is planned to only use the stored fresh water from the subsurface freshwater storage. Regulating the groundwater level from the drains is an effective and efficient way of watering, as previously demonstrated in the pilot plot 'self-sufficient freshwater storage' on Texel. On the base of the results a model was developed with which the entire system from collection, storage and usage (analysis of full self-sufficiency) can be recalculated. The model calculates how much area can be irrigated with the collected native water. The effectivity of the entire system including the regulated groundwater level (sub irrigation) was also calculated with the model. This shows that catching and storing of the native water of a plot of 10 ha can provide irrigation water for a field of 20 ha, depending on the water quality.

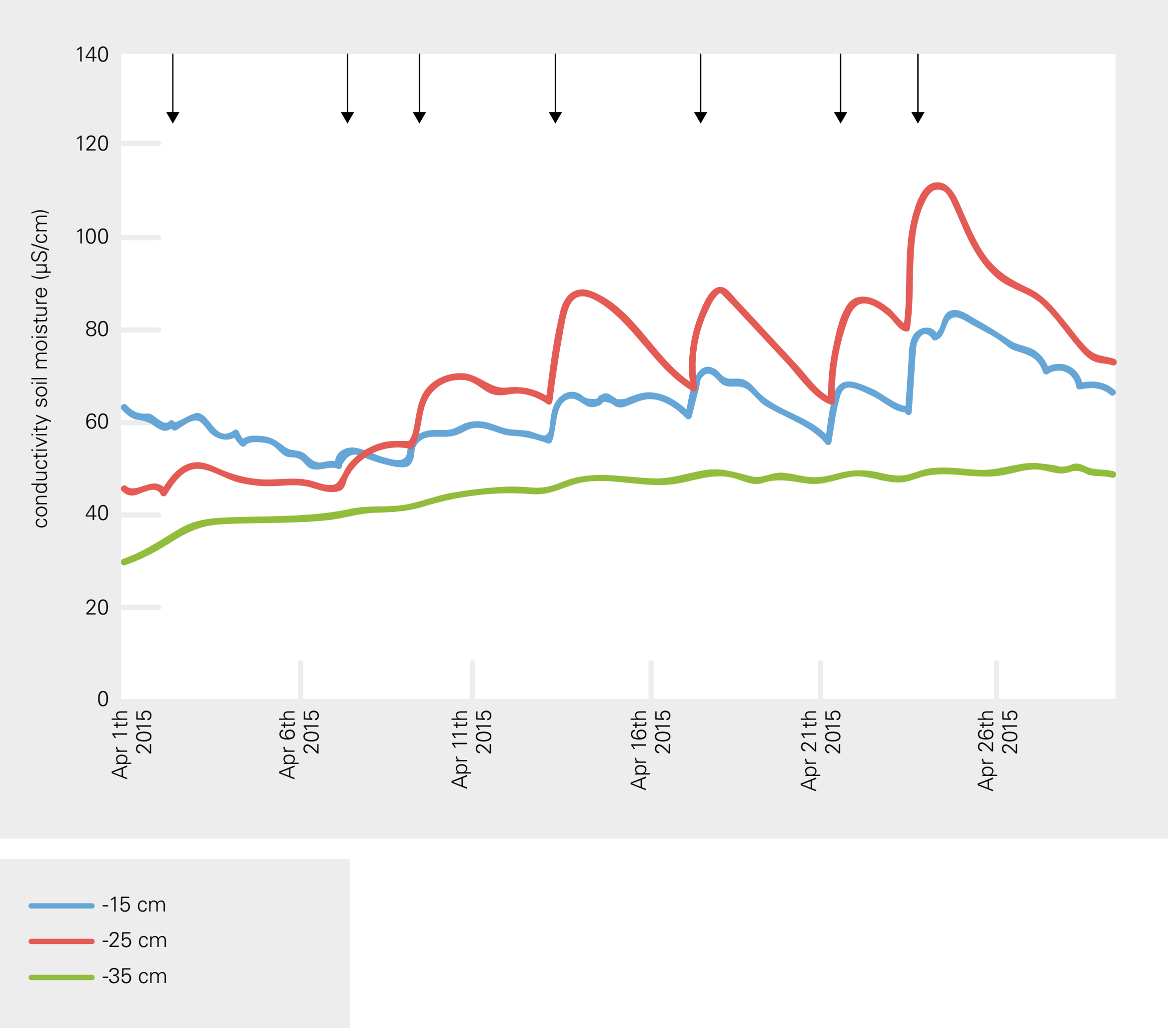
5.2.3 Nutrients

The measurements show that fertilizer through fertigation is absorbed almost entirely by the plants. This is derived from the development of the EC value in the soil moisture. The EC values can be used as an indicator for dissolved fertilizers in the water. At the depth of the roots until maximal 25 cm underneath the ground level an increase in EC values were measured after each fertilization. The EC sensors below the root zone show no peaks in the EC values. From this it can be concluded that the added nutrients were taken up by the plants and not gotten lost to the groundwater.

Prior to the growing season the plot is equipped with a base level of fertilizers and additional fertilizers during the growing season. The plot includes a normal nitrogen content and a high phosphate content. The latter can probably be explained by the administration in the past, wherein the phosphate is bound to the soil. The phosphate appears to be released under certain conditions from the soil around 1 to 2 days after fertigation. With this, the added phosphate can be further refined and less can be administered if the fixed phosphate from past fertigation t can be made available.



Spatial variation soil moisture Breezand in a bulb field with 2, 3 and 4 driplines and without driplines (modelled)



In the clay plot in Borgsweer fertigation is not being used. However, the nitrogen content in potato plants is examined. The reason for this was the reduced growth compared with the adjacent plots. It appeared that the plant had a strong nitrogen deficiency. This might have been caused by wet conditions. Another possibility is that the water for the drip irrigation comes from the freshwater storage in the subsurface. This water is oxygen-free, and is directly introduced into the root zone. It is possible that because of the combination of different waters the nitrogen is reduced, and therefore, no longer available for absorption by the plant. This problem was solved in the second year of the pilot (see Chapter 4). Within Spaarwater 2 the research will be extended by fertigation.

5.2.4 Construction and operation of the system

Every season the drip irrigation system is being improved on the base of gained experiences from the previous year. On the sand plot with the flower bulb in Breezand hoses were installed due the plantation of the flower bulbs. After the growing season but before the harvest the hoses can be retrieved from the land. They will be rolled up so that they could be used again in the next season. Together with the bulbs grower and supplier various the machines have been improved, in order to implement and retrieve the hoses to and from the field, respectively. This way the hoses can be rolled out precisely on the cm and required labour can be reduced.

Another approach, which is now being tested, are recyclable hoses for single use only. These hoses are cheaper than the previously used hoses that will last several years, so the costs are comparable. The one-time use hoses have the advantage that the roll out can be faster, minimizes labour, and another major argument stated by the producers is that by using the one-time use hoses will prevent any growth of pathogens when the hoses are stored during winter.

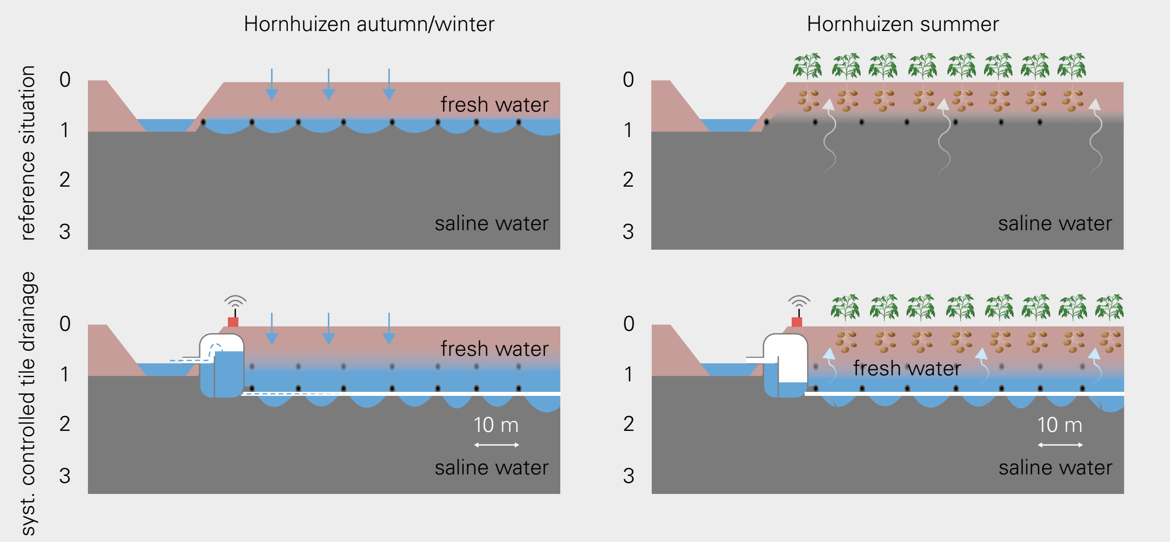
The use of permanent underground drip irrigation, as used in the clay plot Borgsweer, is new. The hoses are laid down below the ploughing level at 40cm depth, so they do not become rutted by ploughing, crop inspection, spraying or harvesting. These hoses can, therefore, stay in the ground permanently and have a life span which is comparable to one of the drainage tube (ca 20 years). In case of non-recurrent or limited soil preparation, the system can be laid possibly still shallower.

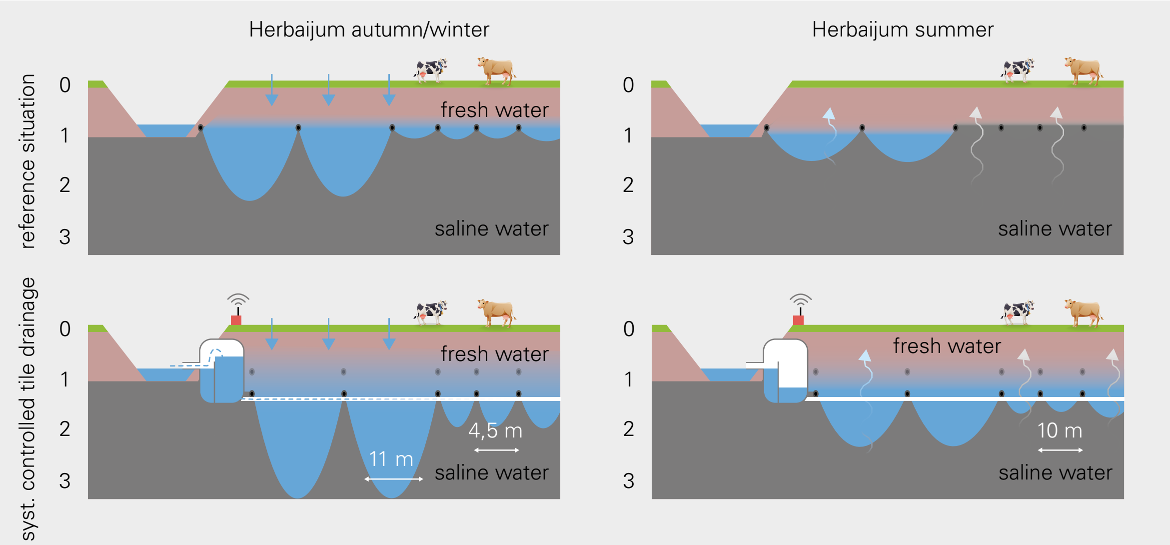
6

STRENGTHENING THE FRESH WATER LENS: SYSTEM CONTROLLED TILE DRAINAGE

6.1 Introduction

At large parts of the clay soil along the Wadden Sea farming is possible thanks to the thin fresh rainwater lenses 'floating' on the salty groundwater. The thickness of the rainwater lenses varies throughout the year, where the lens grows during winter due to a precipitation surplus and shrinks during summer (crop) evaporation. Under dry





conditions, it is possible that the lens disappears and that the saline groundwater reaches the root zone, in which case, crop damage can occur by salinization. The rainwater lenses are vulnerable to the effects of climate change, subsidence and rising sea levels. Consequently, future risks of salinization of the soil will increase.

An innovative method of combating salinization is to optimize the tile drainage system by means of system controlled tile drainage. Due to the optimized depth and distance of the tile drainage and the automated regulation of the groundwater level the size of the fresh water lens can be increased. The optimum is to create maximum size fresh rainwater lens, keeping the original purpose of tile drainage: dewatering and preventing water damage to the plants.

Within Spaarwater project a directed tile drainage system is applied in two ways. 1. On a clay plot with grasslands (Herbaijum, Friesland) regulated groundwater levels in the plot are possible. The guideline is to have plots with two tile drainage distances, one with 4.5 m and 11 m distance. For each pilot plot there also has to be a reference plot. 2. On a plot with fine sand, where agriculture, e.g. beets and seed potatoes, are being grown (Hornhuizen, Groningen), a new tile drainage system was installed at a greater depth. Here, like in the clay plot, the groundwater level can be regulated. In both cases, the tile drainage systems are connected with each other via a collecting conduit (composite drainage), which opens into a central well from which the level can be regulated. The outflow level, the actual drainage level, can be varied in height via telemetry (e.g. an SMS). For both systems, water levels are only created by holding parcel own water and no water is used from the ditch.

6.2 Results

6.2.1 Shape and thickness of the freshwater lenses

The shape and thickness of freshwater lenses vary greatly between the two plots of sand and clay and even inside the clays with different tile drainage distances. In the sand plot Hornhuizen is in the beginning of virtually no sign of a precipitation lens. In the sand plots, where seepage exists, like the plot in Hornhuizen, the development of a freshwater lens at a normal situation is limited. Precipitation does not lead to a long-term increase in groundwater levels, but a temporary downward flux as a result. Therefore, it is very difficult to create a freshwater lens with the traditional tile drainage.

In the clay plot in Herbaijum a freshwater lens does exist. Here, it can be seen that the distribution of variations between fresh and salt water in the subsurface is stretched over a length of 100 m. It seems like some lenses developed themselves between two drains and can reach a depth of 3 meters. Other lenses appear to be 'interrupted', which is probably caused by old drainage pipes, which might still be in the ground. At the places where the drains are located close to each other, the lenses are much smaller. It is not recommended to lay new drainage hoses between the old drains (as has been common practice) because this will cause the salt to be pulled up even further.

6.2.2 Installation and setting up of the groundwater level

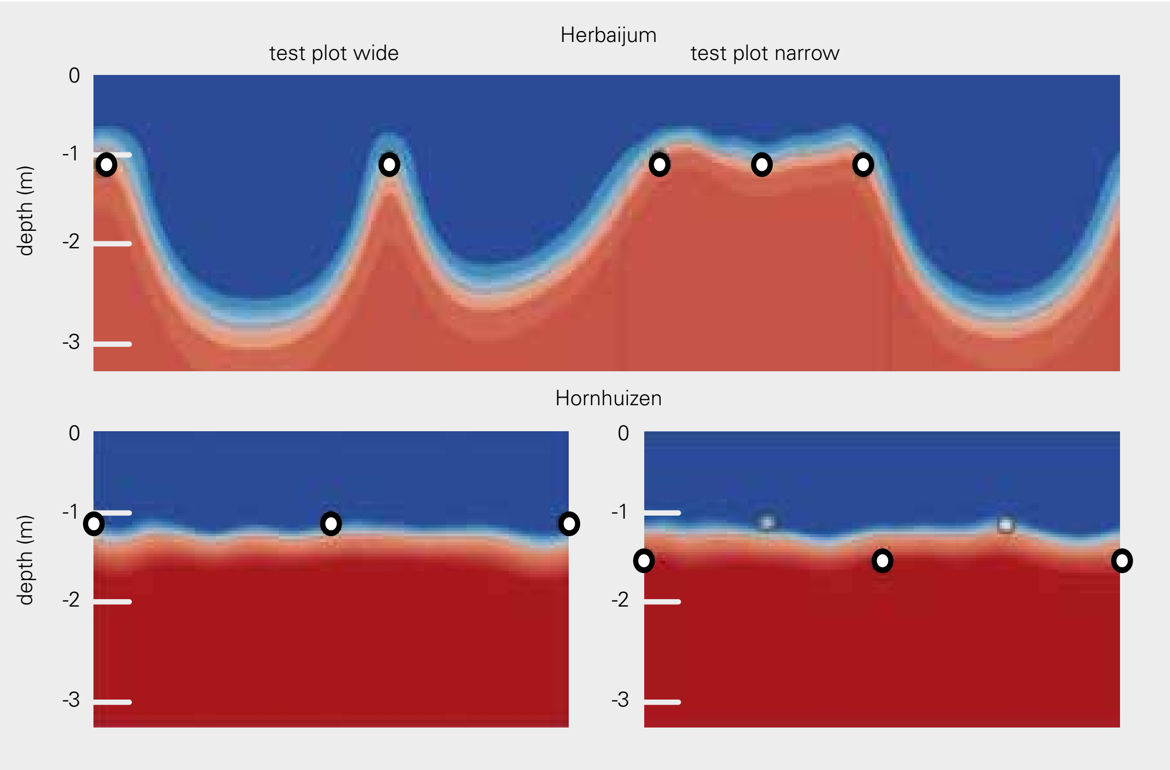
On the clay plot in Herbaijum four areas were arranged, two for each drainage distance (4.5 m and 11 m with a depth at 1 m), one reference plot and one test section in which the groundwater level is regulated. Sensors are placed to compare the reference situation (traditional drainage) with boxes where the new system is applied.

On the sand plot in Hornhuizen two boxes are arranged, a reference and a test section. In both cases, the distance is 10 m. In the reference area contains the existing (traditional) drainage which is maintained at a depth of 1.2 m depth. The test area contains the new drainage constructed at a depth of 1.6m.

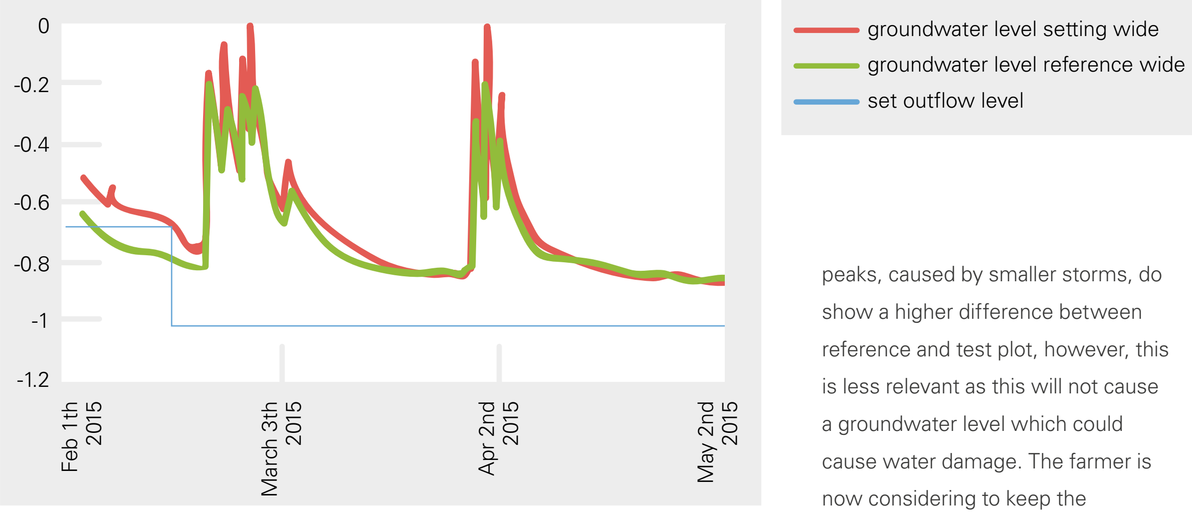
In Herbaijum the level set to 30cm during the winter months and decreased during the summer to the original level. In Hornhuizen the water level is kept at a standard level, 40 cm. Only two times of the year it is reduced to the outflow level, when planting and harvesting. During the summer months the outflow level is raised again but due to the rainfall deficit the groundwater decreased below the desired level.

6.2.3 Development of groundwater level

One of the objectives is to maintain the original purpose of tile drainage, an adequate removal of water and



Difference in shape and thickness of the fresh water lens in the plots



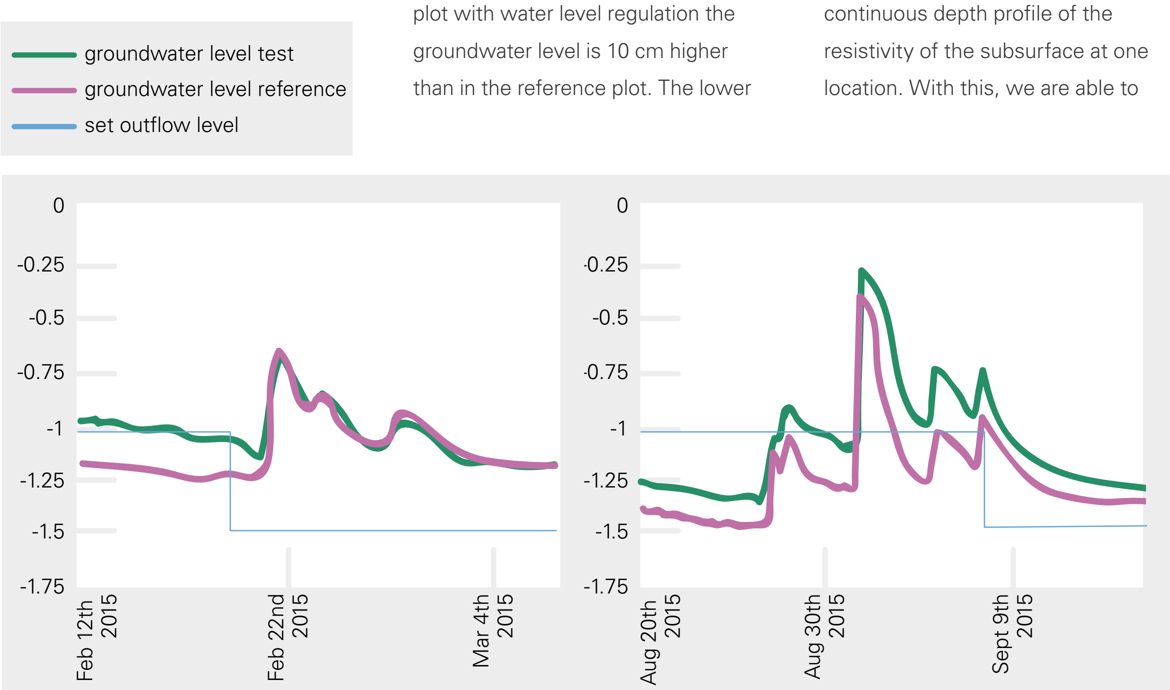
Groundwater level development in Herbaijum

prevent water damage. The measurements in the clay plot in Herbaijum show that after a rain event causes the peak to increase by 20 cm more in the trial plot than in the reference plot. Even after lowering the water level a significant difference in peak height can be seen in between the two plots. This can be explained by several factors, such as higher soil moisture content in the clay with respect to the reference field or by possible changes in soil structure formation during the winter months. The continuation of Spaarwater will deliver longer time series and should give further information about this.

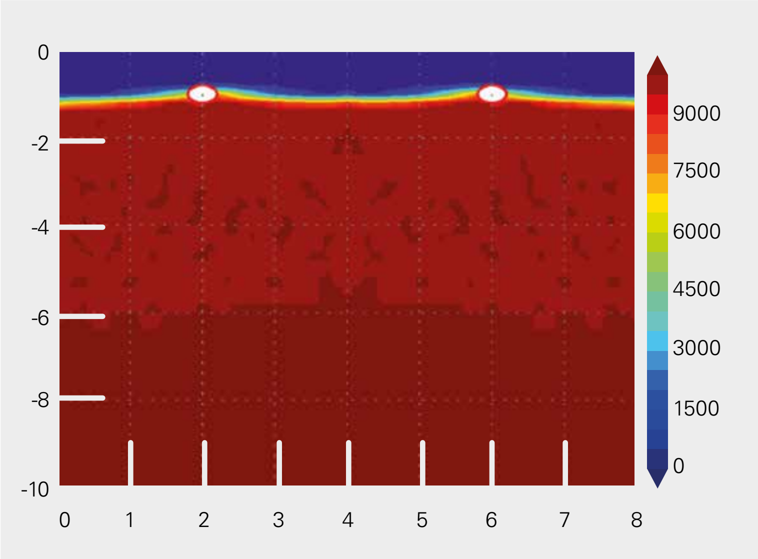
Due to the high conductivity of the sandy soil the ground water level in Hornhuizen will respond to changes of the level really fast and the differences in measured groundwater levels here in comparison to the reference plot disappear fast after the level was changed. The measured peaks of the groundwater level, occurring after a rain event in Hornhuizen, show that at the test plot with water level regulation the groundwater level is 10 cm higher than in the reference plot. The lower peaks, caused by smaller storms, do show a higher difference between reference and test plot, however, this is less relevant as this will not cause a groundwater level which could cause water damage. The farmer is now considering to keep the groundwater level high all year round. This will benefit the growth of the fresh water lens and the fixation of fresh water in the plot. Furthermore, the peaks will quickly settle at the fixed level and will only lead to limited increase in water level.

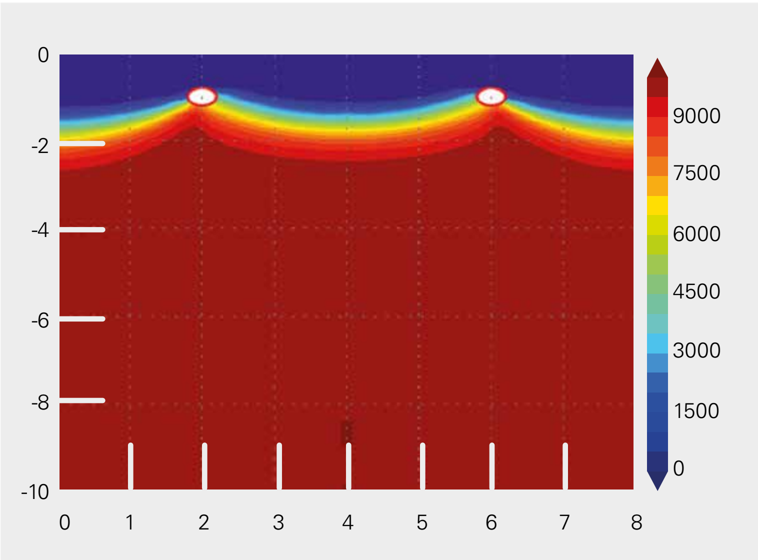
6.2.4 Growth of the fresh rain water lenses

The structure of the fresh rain water lens is measured in different ways. Periodically, high resolution geophysical surveys are being executed, where the extent and thickness of the freshwater lens is displayed in a 2D cross section of the plot. Furthermore, a 'ResProbe' was developed in order to create a continuous depth profile of the resistivity of the subsurface at one location. With this, we are able to



Development of the groundwater level in the sand plot in Hornhuizen





Fresh water lens with a drain distance of 4.5 m in Herbaijum. Left with traditional tile drianage, right with system controlled tile drainage including level setting

calculate the salt content and thereby to follow the freshwater lens even more accurate in the soil.

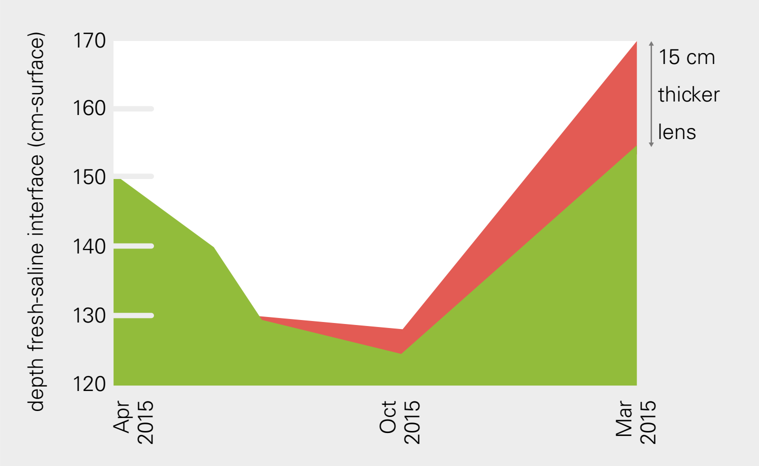
Clay plot Herbaijum

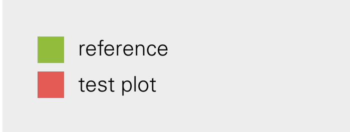
For each plot, a fully integrated saturated-unsaturated model is set up, which simulates the density dependant flow of water. With the aid of model calculations, which are calibrated with field measurements, it is investigated how the growth of the fresh water lens will develop. In the clay plot of Herbaijum the groundwater level in the winter months is assumed to be regulated and during the summer months the initial flow level is used. With a drainage distance of 10 m the lenses in the model range from 2.5-3.0 meters below the surface. The thickness of the freshwater lenses is approximately 1.5 to 2 m measured from the location of the tile drainage. When the water levels are regulated the freshwater lenses can grow until a depth of 5 meters. During the first 5 years the lens will grow approximately 20 cm per year. With a distance of 4 meters and no freshwater lens present, the maximum depth of where fresh water could be found at 1.5 m when the level in the ditch is increased. After the first year of measurements no differences in thickness between the trail and reference plot could be detected. Regulation the water level in the ditch has not been done long enough. In order to see a change, this needs to be done for several years.

Sand plot Hornhuizen

In the sand plot in Hornhuizen four different systems have been evaluated. The model forecasts that the traditional tile drainage system will only create a very thin rainwater lens, more like a very thin freshwater layer. This is also measured in the reference plot, with a thickness of 10-20 cm. By only regulating the level in the ditch and using the original model, the results show that a thicker precipitation lens of 0.5 m will develop. The calculated lens is thinner than the one in the clay plot in Herbaijum, due to the higher conductivity of the soil.

When placing the drains deeper and keeping the outflow level at the previous level, it will lead to further increasing the supply of fresh water (deeper underside of the precipitation lens). The use of regulated water levels with lowered drains (as tested in the trail plot) will result in the biggest increase of thickness of the freshwater lens. The deepened location of the drains causes further freshening of the water around the drains itself. Above the drains a fresh groundwater layer can be detected, which could cause the brackish water to reach the root zone in dry periods. According to the model a stable thickness could be created on the sand plot. After a year an increase of 20 cm is expected. After five years the thickness of the freshwater lens will no longer increase. The calculations show that with this measure the freshwater lens will reach a satisfactory thickness so that it will not disappear during a dry





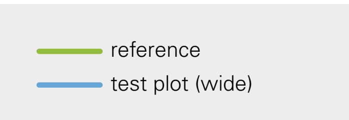
summer and that brackish water will not reach the root zone.

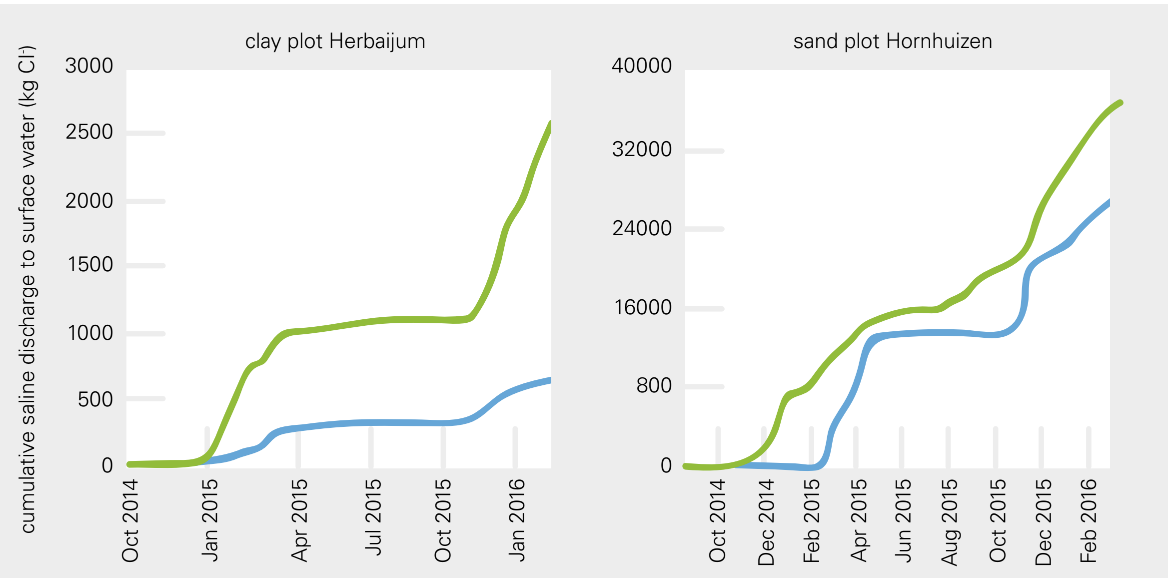
The measurements in Hornhuizen confirm the image of the calculated situation where the traditional tile drainage was used. Throughout the season small fluctuations in thickness of freshwater lens can be seen. In becomes clear that after the wet winter period in 2015/2016 (March 2016) the thickness of the freshwater lens is much bigger in the field whit the deeper drainage pipes and regulated levels with respect to the reference plot with the traditional system. This way the results of the model are been confirmed. The pilot shows that it is possible to increase the freshwater buffer.

6.2.5 Discharge area and salt load

With the aid of a discharge gauge and EC- meter (for the salt content in the water) the discharge of the reference and trail plot is being monitored. In the clay plot in Herbaijum as well as in the sand plot in Hornhuizen, more water is being released from the reference plot onwards, than where the water level is temporarily regulated. During the summer months, there will be no discharge of water into the ditches(?) from the trail plot of the sand plot with regulated water levels. The explanation for both plots is that, after a rainy period the groundwater levels in plot with regulated levels can further increase before water in released into the ditches. The (extra) fresh water which is not being released into the ditches can be infiltrated into deeper layers, or can be extracted via evapotranspiration. In the reference plot, with a lower drainage level, the excess rainwater will be discharged into the ditches straight away.

Regulating the water levels, in the clay plot in Herbaijum as well as in the sand plot in Hornhuizen, lead to lower EC values of the discharged water which will end up in the ditch. By combining these values with the discharge,





the salt load can be determined. Hereby, it can also be seen that regulating the water levels will result in lower salt loads. During year 2015 the salt load was reduced by 50 % in the sand plot and by 30 % in the clay plot. The largest amount of salt content can be found outside the summer months, as the discharge is limited during the summer months.

6.2.6 Nutrients

System controlled tile drainage is able to cause a decrease in amount of nutrients being discharged into the ditches. A decrease in amount of nutrient levels can in fact be achieved due to the longer travel time of the water through the soil. For this reason, within Spaarwater measurements are being executed in the clay plot in Herbaijum. In this plot fertilizers are being applied at the start of the growing season of the grass and after every harvest. The water coming from this system does not contain any nitrate of phosphate. This could be explained by the efficient use of fertilizers in this plot. In order to manifest this, Spaarwater 2 will, additionally to the regular samples, collect discharge dependant samples in the clay plot (Herbaijum). Measurements will also be executed in the sand plot in Hornhuizen.

6.2.7 Construction and operation of the system

In the clay plot in Herbaijum it appeared that during the first winter, where the system was still optional (winter 2014/2015), the drainage system with the smaller drain distances did not work. The central well, where the collective well emerges and the regulation of the water level is intact, still seems to lose water to somewhere. Further investigations pointed out two reasons. First, it was found that along the flushing mechanism of one of the drains a leakage was detected. Furthermore, it appears that during the restoration of the system an extra drainage pipe was found, which caused the two existing ones to be slightly deeper. This allows the actual drain distance to be only 4.5 m. The problem is now solved and the actual trail started properly in 2015.

The most important challenge in the sand plot in Hornhuizen are the salty conditions, which cause corrosion of the measuring instruments. The drainage water regularly measures salt contents of 12.500 mg/l (Chloride), which is approximately the same as a mixture of 75 % ocean water and 25 % rainwater. After a few initial problems the system now working.

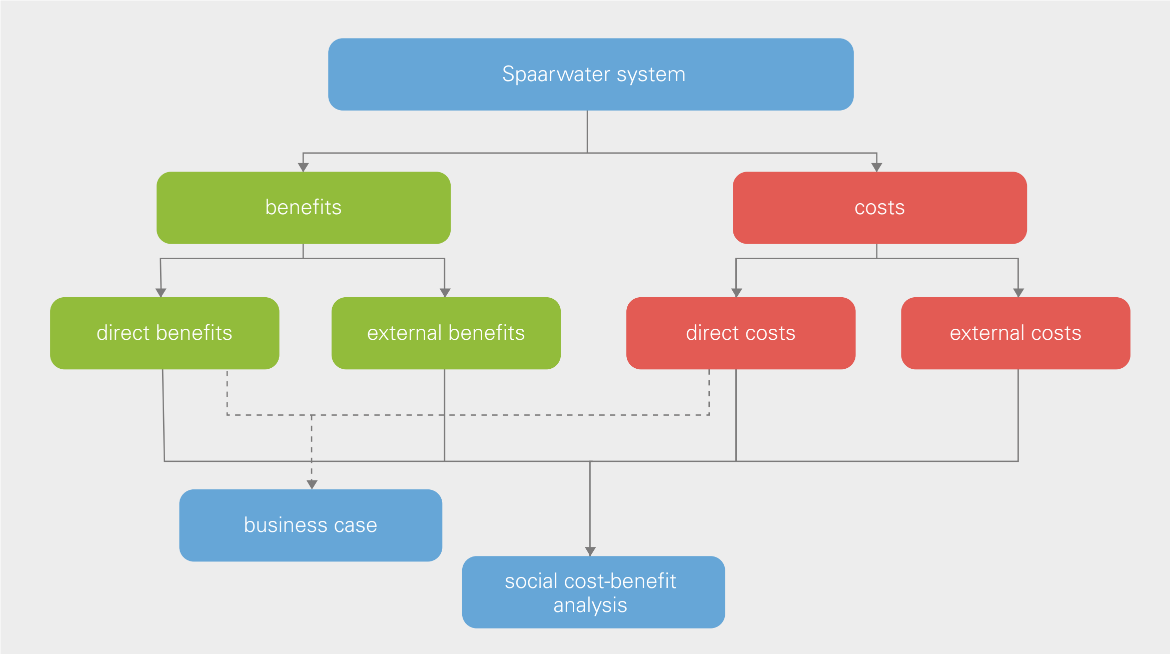
> In the clay soil the salt load halved, at the sand plot a decrease of 30% is measured

ECONOMIC FEASIBILITY

7.1 Introduction

Spaarwater brings not only benefits on plot level, but it can influence the entire water system of a polder. Therefore, two different cost-benefit analyses seem reasonable. The economical cost-benefit analysis (CBA) includes the financial impact of the farmer. At the same time, the social cost-benefit analysis (SCBA) is relevant to water management, containing costs and benefits of external effects of the measures. An example is the falling costs of electricity for the pump (a benefit for the water board), when less flushing is necessary because farmers are less dependent on external water supply (benefit for the farmers).

It is common, when doing a cost-benefit analysis, to calculate the costs of a 1 m3 fresh irrigation water created by the measure against the cost of 1 m3 drinking water. On the basis of this comparison it is then determined whether the investment in a freshwater measure is feasible or not. However, this comparison is not always true. In many cases drinking water is not used as irrigation water, simply due to the low capacity of the pipelines. Therefore, other alternatives were researched: using shadow prices. Examples of these methods to determine the marginal value of water, the hedonic price method, determining opportunity cost and willingness to pay or accept damage. Within Spaarwater a wide overview of benefits was created, containing all sorts of benefits it brings along, for the farmer, as well as for the water boards. Also, an estimate is made of the price trend in order to form a more complete picture of the economic feasibility.



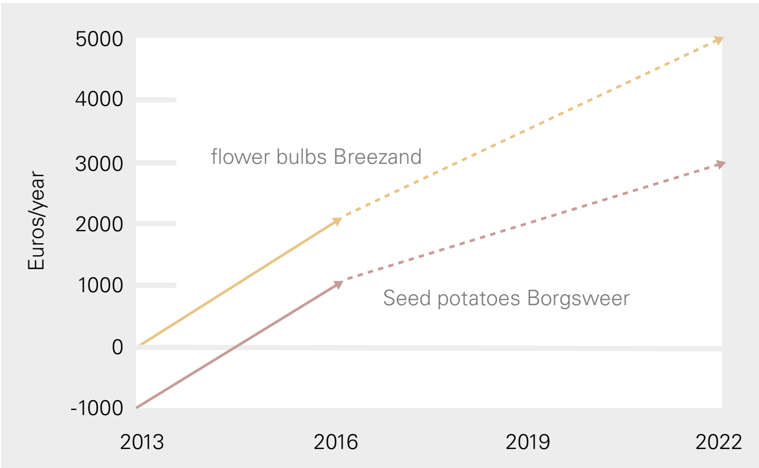
7.2 Results

7.2.1 Benefits for the farmer

The Spaarwater measures deliver both so-called structural as well as cyclic benefits. Structural/ economic benefits do not occur every year. The main added value of the additional stored fresh water will be expected in the dry years. The extra fresh water available during the dry years provides benefits which are not there in wet years. These fluctuations can be considered as economic benefits. There are a number of structural benefits, which generate additional revenue for the farmer each year, e.g. fertilization. The diversity of benefits shows that it is necessary to draft a CBA for freshwater measures in order to establish the feasibility.

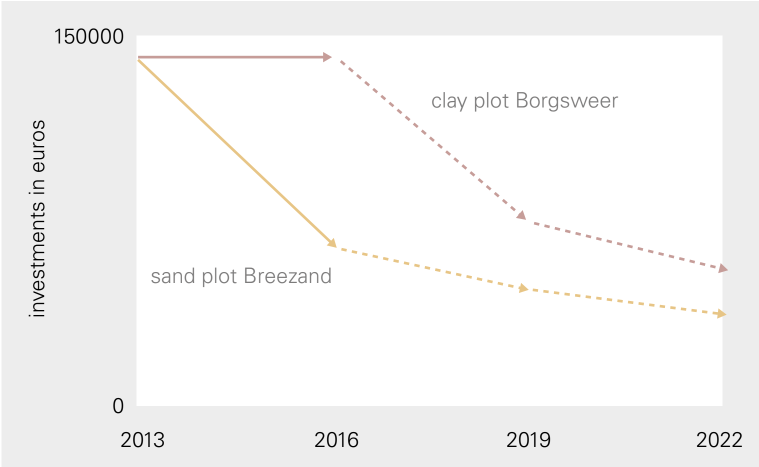
In a significant part of fields where Dutch seed potatoes are being grown it is prohibited to irrigate the crops with surface water in order to avoid possible contamination and brown rot. This results in a loss of yield as the plants do not receive the optimal amount of water. When the Spaarwater system is applied the crops can be irrigated with native freshwater stored in the subsurface. This will result in a great structural benefit for the farmer. This was tested in the pilot plot in Borgsweer. Here it resulted in an increase of yield of ca. 1,500€ per hectare (see Chapter 5). Seed potatoes are grown in rotation with, for example, onion and carrots. For a full analysis this system will also be applied and studied in these crops. A combination of storing native freshwater in the subsurface and drip fertigation also resulted in an increase in yield on the field in Breezand (growing flower bulbs, see Chapter 5). The higher yield is estimated at several thousand euros per hectare. Further development within the Spaarwater 2, focussing on efficiency of drip irrigation/ fertilization, are expected to provide higher yield improvements.

Major benefits were mapped through interviews with farmers and industry specialists, which are important for making an investment decision. By doing so, in addition to



Crop yield increase

the direct improvement of crop yield a number of other benefits were generated. For example, will it be possible to create delivery contracts on larger markets with higher prices, due to a constant freshwater supply for the crops. When parts of the harvest is used as seed or seeds for the next growing season, a bad year can be overcome (relevant in the seed potato sector). The risk reduction by securing water supply can lead to increased reliability without major income fluctuations. The Spaarwater measures can, therefore, be seen as a kind of insurance against dry years and diseases.



Realised and estimated decrease of investment costs due to innovation and upscaling

7.2.2 Benefits for water boards

The specification of external effects of the Spaarwater measures on the water boards will create a more precise environment of potential incentives, such as grants. A decrease in discharge and need of intake (?) of nutrients is only an example of one of the external benefits. Also, the quality of the surface water and the aquatic ecology can be improved, by decreasing the amount of phosphate and nitrate being discharged from the plot, due to the Spaarwater measures. In Breezand, for example, a decrease in discharge by 60-75 % of nutrients into the ditch was measured (see Chapter 3), which is a significant reduction in the load of nutrients to the surface water. This contribution to the European Water Framework Directive (EWFD) might be monetarised.

By increasing the self-sufficiency of a farm, a smaller dependency on surface water system for the agriculture can be realised. The reduction of the water demand can contribute further to reduction of the need for flushing. This way the measures also contribute to the objectives of Delta Program Zoetwater, in which Spaarwater was recognized as a climate pilot. These mutual benefits for farmers and water managers can be monetised.

Moreover, the discharge peaks are flattened considerably by the own fresh water supply, because the discharge water is often fresh water and can, therefore, be stored in the subsurface (see Chapter 4). This also allows to focus more on the natural values. Due to the separation of (parts of) the water courses from the agriculture different water level regimes and water quality management can be chosen. This could allow a more natural water level management in the ditches. The water level during winter, for example, could be set to a higher level and during the summer a more natural, lower level (if it will not cause an undesired dewatering of the plot). Additionally, a more natural salt gradient can be maintained, because the ditches do not have to hold fresh water for agriculture during the summer anymore, where they are naturally saline.

The above-mentioned benefits can only be achieved, when more farmers in one polder work together and apply the Spaarwater measures. So, the Spaarwater measures also work on a regional and economical scale. Within Spaarwater2 this will be investigated further on three pilot polders in each of the participating provinces.

7.2.3 Costs of the Spaarwater measures

The costs of the construction of the system corresponds to that of controlled tile drainage. The easiest way is to install a system which can be regulated manually and where the existing pipes, as used in Herbaijum, can be adjusted to the new tile drainage. In this case the costs for the manifold and the well for regulating the water level are 500-1,500 €/ha. When the entire system, including the new tile drainage, is installed in order to, for example, deepen the existing system like in Hornhuizen, it will cost almost 2.5 times as much as the installation of a traditional system (ca. 2,500 €/ha). The costs are higher when the system is equipped with telemetry, which allows monitoring and control from a distance. This system lasts for 20 years.

The construction and operation cost of a drip irrigation system lie between 1,500 €/ha and 3,500 €/ha per year. It should be mentioned that the systems installed in the pilot plots are more expensive than just mentioned, as they have extra monitoring installations.

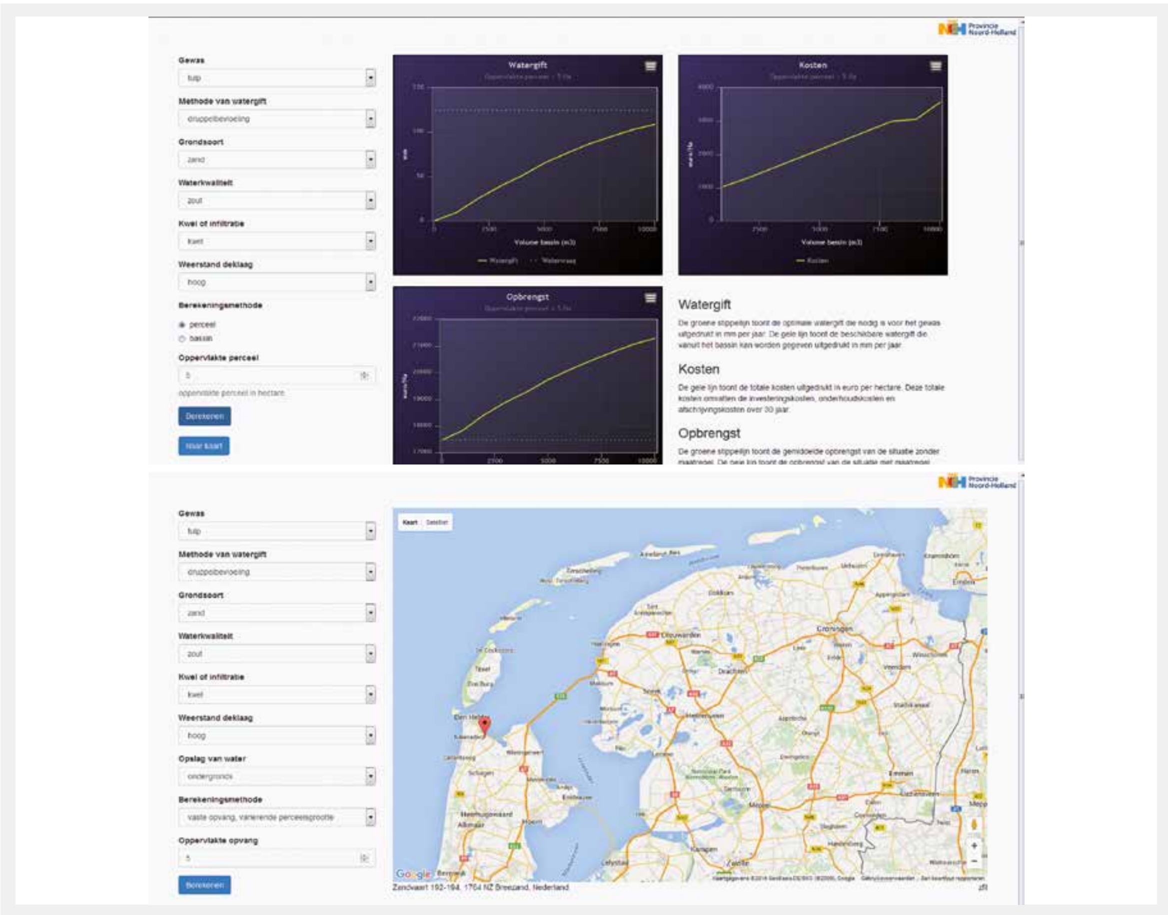
The underground fresh water storage system as they were constructed in the greenhouses, cost around 100,000 – 150,000 € per system plus 10,000 – 30,000 € maintenance and operating costs per year. These systems have a lifespan of about 20 years.

The costs of the measures are developing rapidly and decreasing of the costs of the system is one of the objectives of Spaarwater, in order to make it more attractive to a wider audience. This has already been developed for the subsurface freshwater storage for the flower bulb plot in Breezand. Simplifying and compacting the system (see Chapter 4) results in a reduction of construction costs by approximately 50,000 € per system. In Spaarwater 2 it will be investigated, if the improvements to control the clay fraction in the collected water succeed, which would again, cause system costs may be reduced.

If the Spaarwater measures are becoming more commonplace the prices are expected to continue to decrease at the end of the project as well. A definite comparison between costs and benefits of the system is, therefore, not possible yet. The improvements of the system which will be made in Spaarwater 2 will allow a better estimate of the actual reduction of cost at the end of the project.

7.2.4 Insight into the costs and benefits with Zoetwaterberging.nl

The first step towards CBA for the growers has been made by the development of the digital calculator zoetwaterberging.nl. Here, growers can gain an insight into the possibilities of their own freshwater supply, drip irrigation or sub-irrigation for their business. Based on indicators growers can get detailed information about water shortages and potential water availabilities for its business. By entering crop, soil, desired freshwater solution and the surface area of the plot, the farmer can get gain information about the options of his/her field. For different soils and crops the tool shows how much water could be supplied, depending on a certain catchment area (see Chapter 4). Because the costs and benefits are still in development, these will not be stated here. This will be added in 2016 and will be further refined and improved during Spaarwater 2.



8

INTERNATIONAL MAR: ASIA

8.1 Introduction

Coastal regions are among the most densely populated areas in the world, with large cities and vast agricultural areas. Therefore, many of these regions require a substantial amount of fresh water for drinking, domestic use, irrigation and fresh water dependent industries. Fulfilling this demand can be challenging, especially in areas with a pronounced dry period.

In some coastal areas groundwater provides a reliable source of fresh water. However, in many deltas groundwater is saline or contaminated and not suitable as drinking water. One of the most vulnerable deltas is Bangladesh, where a few million people suffer from sever water scarcity. Here the groundwater is mostly brackish to saline or is arsenic contaminated. As a result, many people use surface water from ponds or rivers which are often bacteriological contaminated and turn brackish over the course of the dry season. Fresh water scarcity in this region becomes extremely severe after the cyclonic storms which hit the coastal region regularly.

In addition to Bangladesh, populations in other deltas in Asia experience similar challenges in securing safe water supplies due to the presence of saline or otherwise polluted water sources and the risk of natural disasters. For example, in Vietnam rainfall is decreasing, sea levels are rising and salt water is migrating further inland along the Mekong Delta, threatening fresh water supplies in this area.

8.2 MAR in Bangladesh

The Managed Aquifer Recharge (MAR) concept was implemented as a solution that provides communities with access to year-round, sustainable safe drinking water. This implementation model can serve as an inspiration for fresh water supply in the region and worldwide, for coastal areas that suffer from scarcity of safe drinking water.

Capturing and storing water can be a solution in periods when it is normally scarce, thus increasing the resilience to droughts. In many regions where people suffer from water scarcity, the actual yearly rainfall is more than enough to fulfill the demand. However, de rainfall is not distributed equally over the year. During monsoon season, large amounts of water fall within a relatively short period of time, while in the dry period fresh water in scarce. The lack of clean, fresh water – now or in the future – could be solved by storing water when it is abundant and making it accessible in a safe manner when it is required throughout the year.

8.3 Advantages of underground fresh water storage

MAR systems provide numerous advantages compared to traditional water supply options which make them attractive solutions for safe fresh water supply. Here an overview is provided of the general advantages of the application of the MAR system for the local, rural scale in Asian Delta's:

Improved year-round water availability
Fresh water can be collected and stored when it is abundant, for example during monsoon season. This is a particularly important advantage in areas with a pronounced dry season. Thus, MAR systems increase the amount of fresh water that is available throughout the year.

Improved water quality and reduced health risks
Because MAR systems provide a water buffer by storing water underground, water can be infiltrated at specific time when the quality is best. Thus storing only relatively high quality water. Furthermore, the advantage of groundwater storage is that it is largely protected from external pollution. The underground storage has therefore a low risk of contamination from water borne diseases. Also, the microbiological quality of MAR water is improved in comparison to surface water by the residence in the aquifer.

> Fresh water scarcity becomes severe after cyclonic storms which hit the region regularly

Suitable for local-scale application
MAR systems can be applied at the scale of a small village, while also larger scale appliactions are possible. The small scale application provides the opportunity to apply the MAR technique for rural communities, and construct systems closely to the users. MAR systems can be operat-ed by local trained users and main-tained by local trained technicians.

Cost-effective

The costs for MAR systems are competitive to the cost of other fresh water solutions that provide year-round safe water. In areas with saline groundwater, water supply measures like rainwater harvesting and reverse osmosis and water supply by a water vendor are other options. MAR is has a competitive advantage towards these other options. MAR systems thus provide a cost effective solution in coastal areas.

Resilient to disasters

The underground stored fresh water is protected from cyclones and floods that often hit the coastal region. The fresh water bubble is protected by the clay layer and is not polluted when the area is flooded with saline and/or contaminated surface water. Also the hardware can be designed to withstand natural disasters, making the MAR system resilient in cyclone and flood prone areas. Collection and underground storage of surface water during peak evens can also manage flood-water. Especially in cities and other areas with relative limited water storage opportunities, artificial into the ground, e.g. of water captured from the rooftops, can help to reduce peak flow.

8.4 Resilient coastal deltas through large scale application

Application of MAR in Bangladesh demonstrated MAR as an attractive option for sustainable, disaster resilient water supply option for saline deltas. The ± 100 systems that were implemented during the pilot and subsequent upscaling phase showed the high potential of managed recharge of water in the aquifers. With further scaling up, it is anticipated that over a million people in coastal Bangladesh could be provided with sustainable access to fresh water.

MAR systems are a feasible option both in the short and long term. Geographical scaling of the MAR technology on a short term is manageable through replication of the system that were piloted and upscaled in Bangladesh. Further optimization of the systems could increase infiltration capacity, optimize water quality and establish user conditions which will support large scale implementation. Construction of multiple systems in a concentrated area will result in a cost-effective replication.

In the long run, the development of a larger underground fresh water bubble, by increasing the amount of infiltration, can provide safe water for larger populations. Larger MAR systems could be combined with piped water schemes to provide safe drinking water to the household level. Both the ease of use and the cost-effectiveness of MAR systems could potentially increase through this application at a larger scale.

Translating the present findings to future prospects shows that underground fresh water storage is a promising solution to tackle water scarcity challenges. Population growth and potential impacts of climate change are expect to further stress the limited fresh water resources in the future. MAR systems can provide year round safe water in disaster prone areas, thereby increasing the resilience for disasters, climate change and scarcity, both in Bangladesh and other saline coastal deltas in Asia and all over the world.

9

SPAARWATER II 2016-2018

During the first part of Spaarwater 2013 – 2015, which is completed with this publication, various measures have been implemented and their operation have been investigated. The first results are promising. With the system controlled tile drainage, the water level could be regulated and the first growth in freshwater lens could be observed in the sand plot. It also appears to be possible to collect the water from the drains, store it in the subsurface and make it available for irrigation. The efficient usage of water and fertilizers in drip irrigation, installed in the flower bulb field in the sand, or with pipes in the clayey subsurface of the seed potatoes field, lead to an increase in productivity during the year 2015.

> Spaarwater 2 will focus more on economic analysis and a regional upscaling of the measures

In cooperation with the parties involved it was concluded that a continuation and completion of the project would be useful. Additionally, to this, Spaarwater has become part of the climate plot Ijsselmeer area within the freshwater program and receives a contribution from the Deltafonds. The project duration of Spaarwater has been extended by three years (until 2018).

To properly demonstrate the operation of the different systems, they have to be "exposed" for multiple wet and dry years. The systems of inherent freshwater supply have to prove themselves for a several years. Next to this, also the improvements on the system are tested, such as the simplification of the subsurface freshwater storage in Breezand.

When it became clear that a decrease of risk due to diseases was one of the benefits of this system, a more elaborate research, focussing on filtration of pathogens in the subsoil, will be executed in the following project Spaarwater 2 (2016-2018) and in a PhD Thesis as a spin-off of Spaarwater.

The application of drip irrigation in under Dutch circumstances in new. It is necessary to take into account the variability of the Dutch weather, in order to make a viable statistical analysis and create operative measures. A longer period is also necessary in order to make adjustments in the configuration and control. This also counts for the system controlled tile drainage, where developing or changing the fresh water lens are very slow processes.

Since 2014 Spaarwater is part of the Dutch 'Deltaplan fresh water'

Up until now, Spaarwater was focussed on the effects on the field and business level. Spaarwater 2 will focus more on economic analysis and a regional upscaling of the measures. The entire Wadden region will be analysed as to where the systems would be promising. In addition, the effects on regional systems will be examined and quantified. The effects of the measures on the regional water system will be researched and quantified. Additionally, this will look at the impact of the measures on the business economics level for the farmer and costs / benefits for the water manager combined with the effects on the entire water system. In short, we also want to look at the project from a water managers point of view. What does it mean for a water system if the Spaarwater measures are applied. We are doing this in three pilot polders (Noord-Holland, Friesland and Groningen) along the Wadden Sea. Here, we will work together with the farmers and water managers.

Finally, Spaarwater was extended to the province of Flevoland (Spaarwater Flevoland). Next to saving water, in this plot the focus also lies on the reduction of land subsidence. This project started on four plots in South Flevoland and the North-East Polder with continuous measurements of soil moisture, groundwater levels and EC values in several soil layers. This way it can be examined if and how a shallow peat layer can be kept wet (in order to avoid oxidisation of the peat) without causing water damage in the field. In 2016, two plots will be equipped with a system controlled tile drainage, in order to investigate if these goals are achievable in this way.





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INVOLVED STAKEHOLDERS

Financiers: Waddenfonds, Provincie Groningen, Provincie Friesland, Provincie Noord-Holland, Hoogheemraadschap Hollands Noorderkwartier, Wetterskip Fryslân, Waterschap Noorderzijlvest, Waterschap Hunze en Aa's, LTO Noord fondsen, STOWA, Achmea Agro and Rabobank.

Involved farmers: VOF MCA Langeveld & zn – pilot location Breezand, Maatschap P.L.Noordam & E.A.Noordam-ten Have – pilot location Borgsweer, Maatschap J.W. Oosterhuis – pilot location Hornhuizen,
Maatschap A. Hofstra – pilot location Herbaijum.

Performing parties: Secretary office Acacia Institute in collaboration with Acacia Water, Delphy, Broere Horticulture, BE-deLier, VU University Amsterdam, TU Delft, LEI, Han de Kreuk, Combidrain, Vermaire Breezand, Netafim and Yara.

Other involved parties: PWN, LTONoord, KAVB, NVWA and Pootgoedacademie.

2017

SPAARWATER