Fresh water supply from subsurface water storage

An investigation into the contribution of fresh groundwater to agriculture on Schouwen-Duiveland

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Wageningen University
Jan Snel

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MSc thesis

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Preface

In front of you lies my MSc thesis, ‘Fresh water supply from subsurface water storage, an investigation into the contribution of fresh groundwater to agriculture on Schouwen-Duiveland’. This thesis is part of my MSc in Integrated Water Management at Wageningen University & Research Centre and is conducted at Deltares in Utrecht and at Wageningen University, from September 2012 until March 2013. In this report the contribution of fresh water to agriculture in relation to the robustness of components of the physical system is assessed. These assessments are made based on the outcomes of a rapid assessment tool. This tool incorporates regions, future climate change and yield reduction by water deficit and salinization.

Enjoy reading,

Jan Snel

Acknowledgement

I would like to thank my supervisors Gualbert Oude Essink, Marta Faneca Sanchez and Jeroen Veraart. I would also like to thank Erik van Slobbe for guiding the research process, and everybody within the ‘fresh-salt group’ at Deltares, especially Esther van Baaren, Gijs Janssen and my student peers at the time, Marjan Sommeijer and Thomas Boerman. Finally, I’d like to thank Andre Slootmaker, farmer and chairman of agricultural Schouwen-Duiveland, and farmers Senny Capelle, Gilles Klompe, Huub Remijn and Dick van Noord for their time in being interviewed.

Summary

Deltares is part of the consortium cooperating in the project GO-FRESH (Geo hydrological Opportunities FRESH water supply), the third tranche of the Knowledge for Climate program. In the GO-FRESH project, research is being conducted on the 'Valorisation of promising measures of the local freshwater supply in the Southwest Delta'. This is one of eight hot spots in the Knowledge for Climate programme. The aim of the research conducted in the GO-FRESH project is to find out how local measures can increase fresh water supply in agriculture and the economic feasibility of scaling up these measures (Oude Essink, 2013).

This research is on the robustness and feasibility of the creek ridge measure. A creek ridge is a slightly elevated part of land existing out of sandy soils that contains a fresh water lens that can be between 10 and 15 meters thick. The thickness of this fresh water lens in the subsurface of the creek ridge could be increased by actively infiltrating fresh water into the sub surface by making use of controllable drainage. This is called the creek ridge measure and is currently being developed by Deltares. In summer yield reduction can occur due to a water deficit and this is linked to a yield reduction in salinity. The increase in water could potentially be used to overcome dry spells in the summer and decrease the yield reduction. This is likely to be useful in the future as the weather is likely to become more extreme and thus dry spells are likely to become longer and dryer.

A rapid assessment tool has been created to simulate these future scenarios to assess the future yield reduction in terms of water deficit and salinity, and the impact and costs of the creek ridge measure. The future scenarios are called '2050 Quiet' and '2050 Steam'. '2050 Quiet' represents a minimum of possible change in 2050 and '2050 Steam' represents the maximum of possible change in 2050 for the Netherlands. The aim of this research is to combine yield reductions and different costs (i.e. investments and water distribution costs) by visualizing the loss/ha in € for the region. By doing so the robustness and feasibility of investing in the creek ridge measure can be assessed. To do this the following research questions are asked:

1. What is the long-term robustness of the fresh water supply from the creek ridge for the agricultural sector under different climate scenarios?
2. What is the feasibility of investing in the creek ridge measure with different land uses under different climate scenarios?

Robustness is assessed by investigating if the creek ridge measure provides sufficient water to reduce the yield reduction in the region. The feasibility is determined by the reduction of yield loss versus the investment costs.

It is concluded that the creek ridge measure can be robust and feasible, in certain climate scenarios and in certain areas. The climate change needs to move towards the more extreme scenario (2050 Steam), because in the least extreme scenario (2050 Quiet) the decrease in costs by the yield reduction are not sufficient to cover the investment costs. Another requirement is that fresh water should be used locally, because transport costs rise when distributing fresh water away from the creek ridge, and quantities (mm) of fresh water are lower when distributing over a larger surface area.

Measures to ensure fresh water supply for agriculture in different types of areas on Schouwen-Duiveland are recommended to be continued to be further explored and researched.

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1. Introduction

In this chapter an introduction to the research is given starting with the context of the research, followed by the future climate change. Then the tool and its purpose is introduced shortly. Finally the creek ridge measure concept is described, followed up by an explanation of Schouwen-Duiveland's characteristics reasons for selecting Schouwen-Duiveland as research area.

Context of research

Deltares is part of the consortium cooperating in the project GO-FRESH (Geo hydrological Opportunities FRESH water supply, or 'Valorisation of promising measures of the local freshwater supply in the Southwest Delta'. The project is part of the Knowledge for Climate program. A consortium existing out of Deltares (main participant), Alterra, KWR, Acacia and 'University of Applied Sciences Zeeland', researches in what ways fresh water availability for agriculture can be increased in areas that are independent of the main fresh water system. For this the subsurface is used for storage of fresh water in periods of a water surplus, to be used in dry periods (Oude Essink, 2014).

The GO-FRESH project looks into two types of areas that are likely to get under pressure faster, due to climate change: (1) areas with creek ridges with a relatively thicker fresh water lens and (2) areas with a saline seepage and thin rainwater lenses. Within the GO-FRESH there three show cases have started:

1. Creek ridge infiltration experiment: increase of fresh water supply in creek ridge, by infiltration of surface water.
2. The Freshmaker: increase of fresh water supply in a creek ridge by injection of fresh water and draining saline groundwater.
3. DRAIN2BUFFER: enlarge or maintain fresh water supply of thin rainwater lenses by smart deep drainage.

The project also aims to find out the possibility of up scaling these solutions: besides hydrological feasibility also the economic feasibility is assessed (Oude Essink, 2014). This thesis research only looks into the creek ridge infiltration experiment and is, in this research, referred to as creek ridge measure.

Increasing pressures on fresh water supply.

Due to climate change Schouwen-Duiveland will likely experience a higher pressure on its fresh water availability. Climate change will cause the sea level to rise. A rising sea level will cause saline seepage in low laying areas on the island (figure 1.1), which consequently has a negative effect on crop growth. Other effects of climate change are an estimated increase of weather extremes, resulting

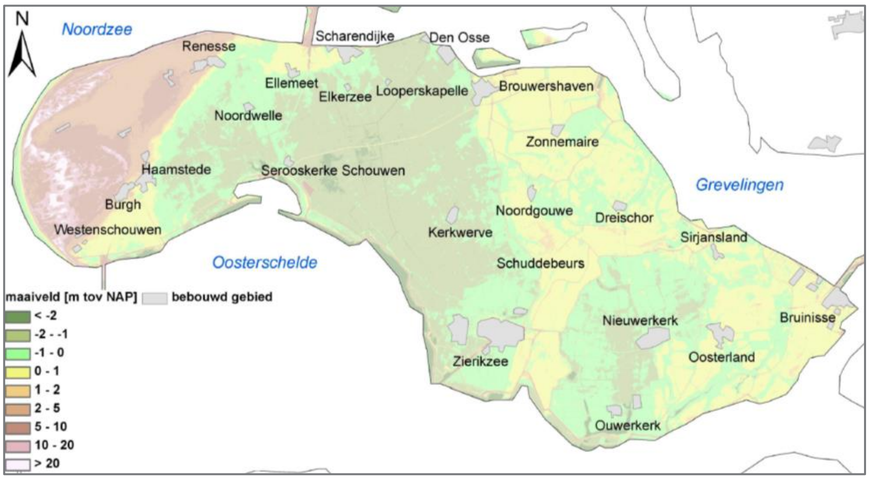

Figure 1.1 Ground surface level with respect to sea level (van Baaren & Harezlak, 2011)

in heavier precipitation and longer periods of drought (van Baaren & Harezlak, 211; Tolk, 2012). Fresh water shortages can lead to a decline in the average yield and a decline of the quality of crops (Polman *et al.*, 2012).

The current fresh water reserves in the creek ridge deposit are not sufficient enough to fulfil the fresh water demand from agriculture in times of drought, which causes crop damage. When the relatively thin fresh water lenses decrease in size, saline ground water can enter the root zone. In the past few years 10-30% of the crops suffered damage due to salinization[1] (van Baaren *et al.*, 2012). The relatively thicker water lenses are less vulnerable for damage from salinization as the fresh water buffer is larger and less saline seepage occurs. Active fresh water storage in areas with relative thicker lenses could increase these fresh water lenses in size. This can lead to a surplus of water availability that can prevent crop damage by drought and salinization elsewhere, by distributing this water. This would provide the opportunity for farmers to grow a higher variety of crops, since salt intolerant crops or crops with a relative higher water demand such as tree crops, might become viable. This is important as greater amount of fresh water leads to a greater crop choice (van Baaren *et al.*, 2012).

Evolution of the creek ridge
In the past creeks formed the lowest parts of the landscape in the region of Zeeland. People started to construct dikes and ditches in the 13th and 14th centuries. By the construction of the ditches, groundwater was abstracted from the soil. Due to the this human activity, creeks became inactive and would silt gradually with sandy materials. The peat and the clay soils that had been formed over the centuries before, subsided. As the silt in the creek beds mainly consisted of sandy materials, it subsided much less than in the surrounding areas. Therefore the silted creeks and trenches obtained higher elevation than their surroundings. In addition to the subsidence, peat and salt was mined, causing the elevation difference to increase even more. The nowadays elevated parts are called the creek ridges (figure 1.2) (van Baaren & Harezlak, 2011).

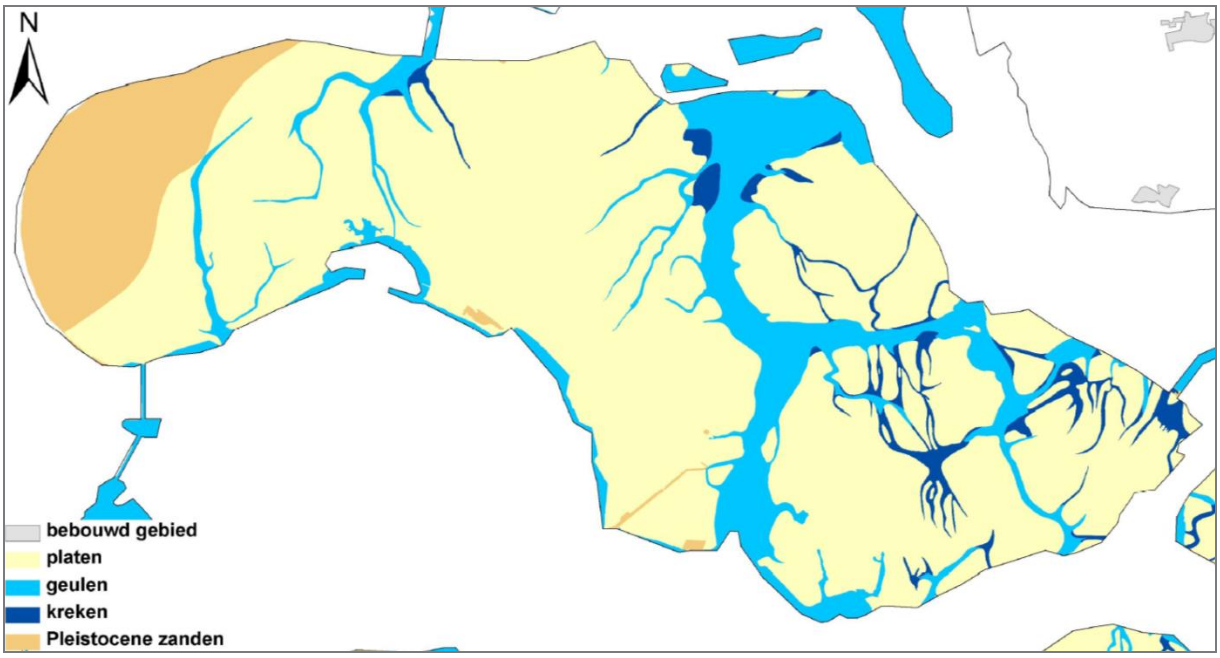

Figure 1.2 Creek ridges, trenches, plates and Pleistocene sand deposits (van Baaren & Harezlak, 2011)

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[1] Crops have suffered from salinity in relative low areas, where there are thin water lenses (van Baaren et. al, 2012)

The creek ridge measure

The creek ridge measure increases the thickness of the fresh water lens by storing water in the subsurface (figure 1.3). Storing the fresh water is achieved by decreasing the outflow of water by adjusting the drainage system. These drainage measures are small dams in draining ditches around the parcel. Another way of increasing the thickness of the fresh water lens, is by infiltration of fresh water through controllable drainage in the winter. The infiltration of water can be achieved by a controllable drainage system that is connected to drains. The drains are connected to a fresh water source, for example a basin, well or ditch and the fresh water source is required to have a higher water level to enable water to infiltrate into the creek ridge (van Baaren *et al.*, 2012).

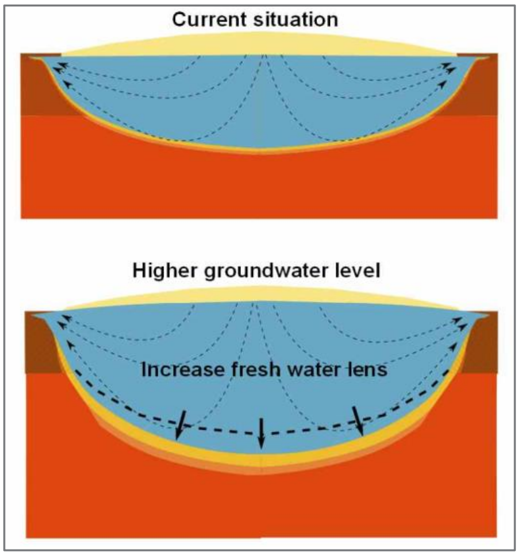


Figure 1.3 Creek ridge infiltration experiment (Oude Essink, 2014)

The creek ridge measure could serve as a solution to the changing environment. Instead of allowing water to run off to ditches, the creek ridge measure actively stores fresh water in sandy and slightly elevated soils adding fresh water to already existing fresh water lenses. By doing so, larger fresh water lenses are created. With the creek ridge measure is in place where possible, the volume of fresh water in those areas should increase, creating a fresh water buffer that could be used to prevent crop damage during dry spells. Figure 1.4 and 1.5 show how a creek ridge looks in today's land scape.

Approximately 18% of the agricultural land on Schouwen-Duiveland is suitable for applying the creek ridge measure at creek ridges with a relative thick water lens. This is based on an internship research by Sommeijer (2013) on feasible areas for applying the creek ridge measures on Walcheren. By repeating her method of selecting creek ridges on Schouwen-Duiveland 18% of the agricultural area should be feasible (subchapter 4.2). The 18% refers to areas above sea level and with a fresh (brackish)/saline interface at 5 meters below ground level. Thus these creek ridges are different from the shallow rain rainwater lenses.

When the creek ridge measure is applied at suitable areas, it should lead to an increase in fresh water that could theoretically be used for different parts on the island. Lower parts that are not suitable for the creek ridge measure are more susceptive to salinization processes, because fresh water lenses are thinner. These lower parts might profit from fresh water if it could be transported from the creek ridge area.

To calculate the extra available water from the creek ridge, an analytical method is used. Using the analytical method, an estimation is made on the thickness of a fresh water lens in a creek ridge area. The parameters of this method include ground recharge, width of the creek ridge, permeability, porosity and depth of lens in relation to ground surface. For detailed calculations see tab 'Darcy CR' in 1.Rapid_asessment_tool_SD.xlsx (subsection 4.2).

To enable all areas to benefit from the creek ridge measure, fresh water must be able to flow from one area to another and create a more equal distribution of water. Therefore the island is divided in areas (figure 1.4). To enable this water flow water distribution by pipes is selected to base distribution costs on. The distribution per ditches is ruled out, because ditches can become brackish in summer (Visser, 2012). During interviews, a farmer stated distribution per trucks appeared not to be cost effective and labour intensive.

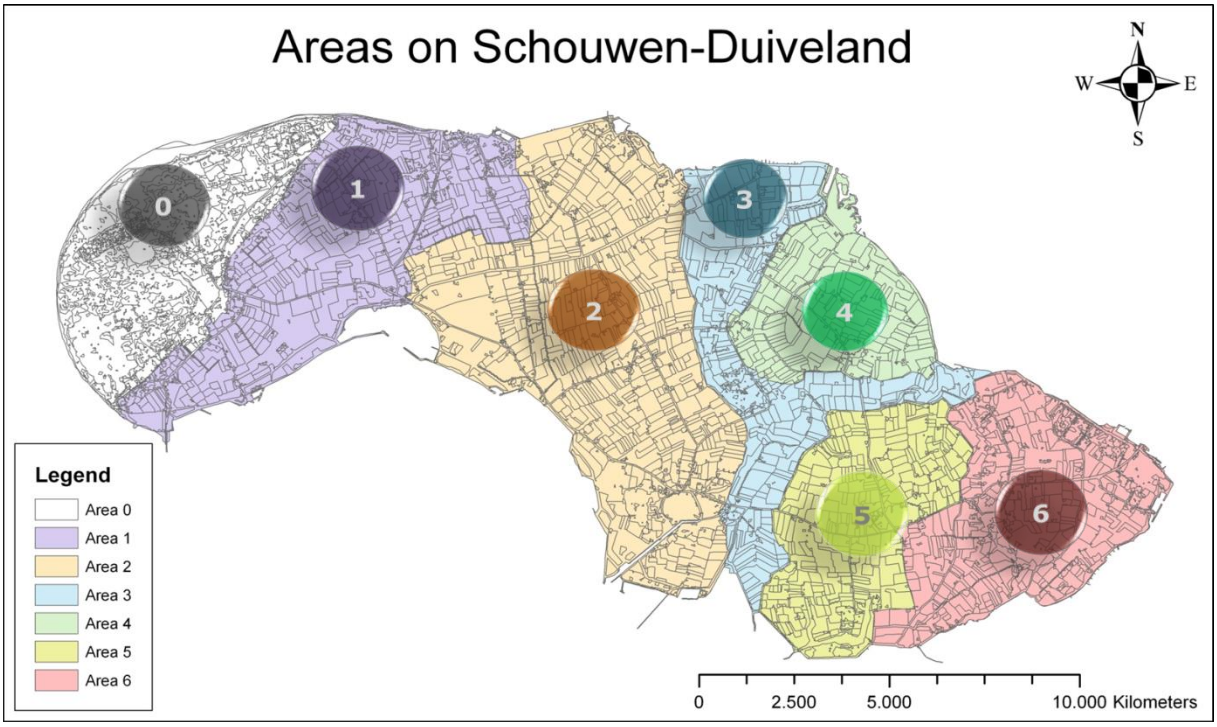
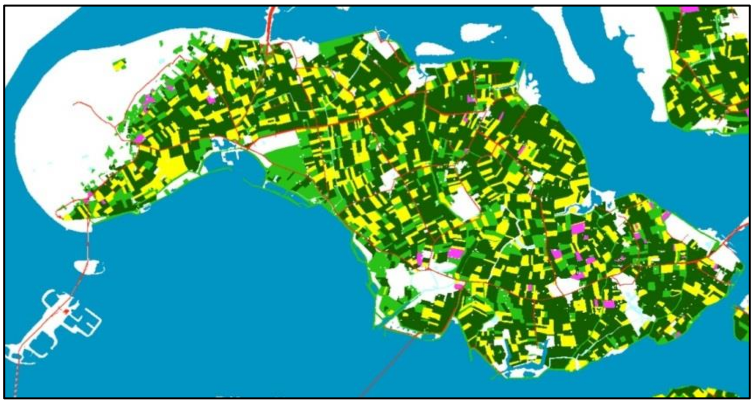


Figure 1.4 Areas on Schouwen-Duiveland (LGN4)

The borders of the areas are a fusion of the maps, ‘Water areas from the water plan of the municipality Schouwen-Duiveland’ and the map, ‘Water drain areas from the Water Board Scheldestromen’ (appendix I). The areas are there to determine a water flow from one area to another, and to see the effect of the creek ridge measure per area. The surface area of creek ridges with the relatively thick lenses is different in each region. The creek ridges, where the measure can be applied are most common in ‘area 3’ (figure 1.4). Area ‘0’, the non-coloured region on the map in figure 1.4, is not taken into account as there is very little agricultural compared to the other six regions.



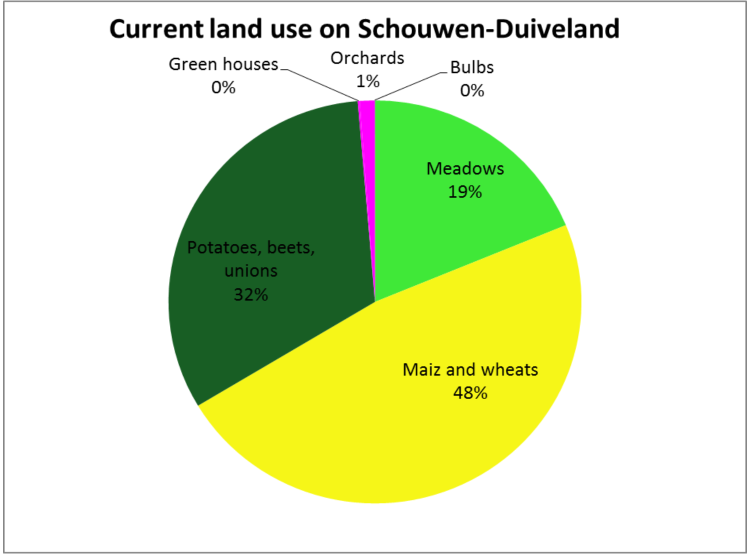


Figure 1.3 a: Land use (LGN4)
Figure 1.3 b: Percentage of land use (percentages are rounded, hence green houses and bulbs 0%)

Land use

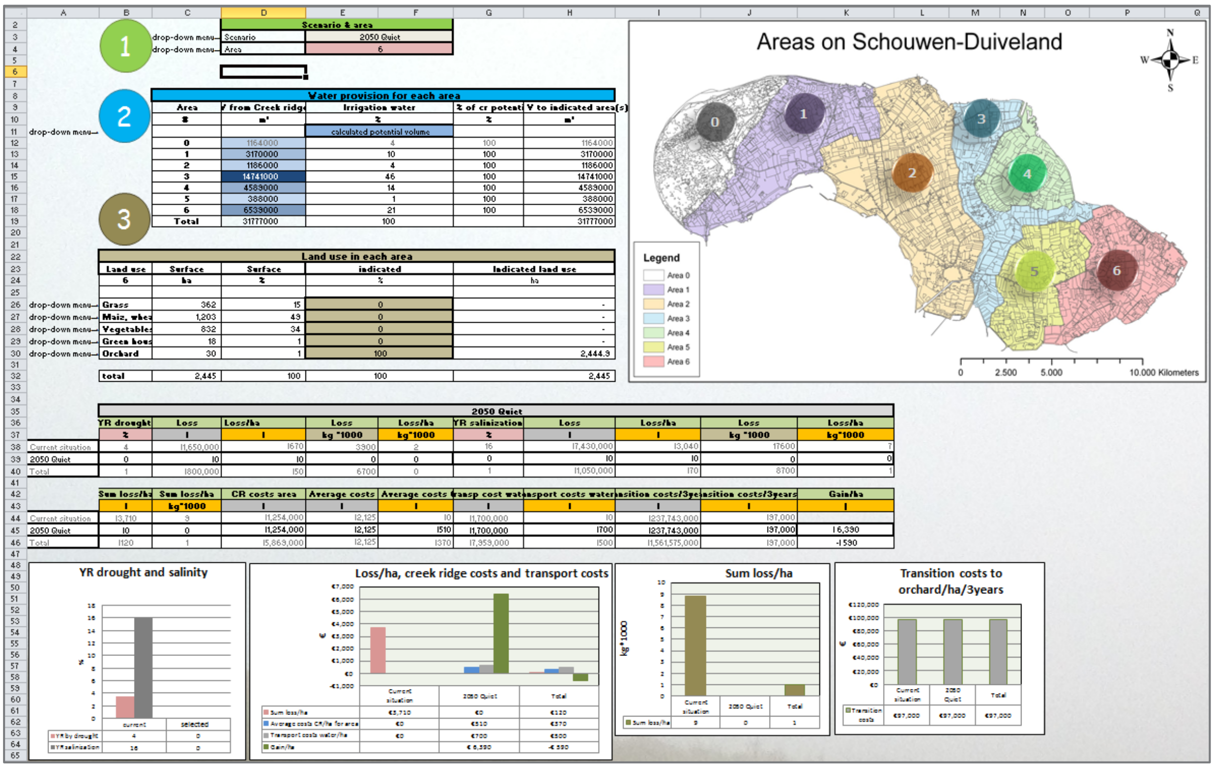
Currently, the main agricultural practices on Schouwen-Duiveland produce vegetable crops like unions, potatoes, green vegetables and meadows. To a small extent there are flowers, green houses and fruit is also cultivated (Visser, 2012). Visser (2012) further explains that fresh water lenses are the only fresh water sources for agriculture on Schouwen-Duiveland. They are on top of brackish/saline ground water layers and are replenished by precipitation, mainly during the winter season. In dry years there is less fresh water available and the interface between fresh and saline water rises towards the root zone. During the growing season in the summer, water in the ditches becomes brackish. Fresh water comes from the fresh water lenses but only limited use is possible and the availability depends on the amount of precipitation.

The tool (introduced below) will also enable to assess future scenarios with different type of land use. Since there might be extra available water after applying the creek ridge measure, it is interesting to see to what extend high value crops can be cultivated. In the tool orchards (or fruit trees) are selected as high value crop.

Rapid assessment tool and the user

To understand what a potential extra availability of fresh water does for the agriculture, considering the changing climate and the land use, a rapid assessment tool is constructed. This tool is constructed in Microsoft Excel and allows the user to 'play' with these inputs. By doing so, the user can see whether the creek ridge measure is a robust and feasible solution (read next page) to the increasing pressure on fresh water supply on Schouwen-Duiveland.

The tool (figure 1.4, repeated in chapter 4) makes calculations for a regional scale and are given per area, 1 until 6. After providing an input, an output is given that shows the loss in euro and kg per hectare, in comparison to the 'Current' climate scenario. The inputs of the tool are, climate scenarios, land use and water use. The output helps to better understand the consequences of different future scenarios, taking the creek ridge measure into consideration, for the agriculture on Schouwen-Duiveland. The 'Current' climate scenario is an average of the weather from 1980 until 2010. The future scenarios are based on KNMI'06 scenarios and are later explained.



Scenario & area	
Scenario	2050 Quiet
Area	6

Water provision for each area				
Area	V from Creek ridge	Irrigation water	% of cr potenti	V to indicated area(s)
#	m³	%	%	m³
		calculated potential volume		
0	1164000	4	100	1164000
1	3170000	10	100	3170000
2	1186000	4	100	1186000
3	14741000	46	100	14741000
4	4589000	14	100	4589000
5	388000	1	100	388000
6	6539000	21	100	6539000
Total	31777000	100		31777000

Land use in each area				
Land use	Surface	Surface	indicated	Indicated land use
6	ha	%	%	ha
Grass	362	15	0	-
Maiz, whea	1,203	49	0	-
Vegetable	832	34	0	-
Green hous	18	1	0	-
Orchard	30	1	100	2,444.9
total	2,445	100	100	2,445

	2050 Quiet									
	YR drought	Loss	Loss/ha	Loss	Loss/ha	YR salinization	Loss	Loss/ha	Loss	Loss/ha
	%	€	€	kg *1000	kg*1000	%	€	€	kg *1000	kg*1000
Current situation	4	€1,650,000	€670	3900	2	16	€7,430,000	€3,040	17600	7
2050 Quiet	0	€0	€0	0	0	0	€0	€0	0	0
Total	1	€800,000	€50	6700	0	1	€1,050,000	€70	8700	1

	Sum loss/ha	Sum loss/ha	CR costs area	Average costs	Average costs	ransp cost wat	nsport costs water	nsition costs/3ye	nsition costs/3years	Gain/ha
	€	kg*1000	€	€	€	€	€	€	€	€
Current situation	€3,710	9	€1,254,000	€2,125	€0	€1,700,000	€0	€237,743,000	€97,000	
2050 Quiet	€0	0	€1,254,000	€2,125	€510	€1,700,000	€700	€237,743,000	€97,000	€6,390
Total	€120	1	€5,869,000	€2,125	€370	€7,959,000	€500	€1,561,575,000	€97,000	-€590

	current	selected
YR by drought	4	0
YR salinization	16	0

	Current situation	2050 Quiet	Total
Sum loss/ha	€3,710	€0	€120
Average costs CR/ha for area	€0	€510	€370
Transport costs water/ha	€0	€700	€500
Gain/ha		€ 6,390	-€ 590

	Current situation	2050 Quiet	Total
Sum loss/ha	9	0	1

	Current situation	2050 Quiet	Total
Transition costs	€97,000	€97,000	€97,000

Figure 1.4 Print screen of the rapid assessment tool ('1.Rapid_Assessment_Tool_SD.xlsx')

The tool can be run for one of six areas on Schouwen-Duiveland. These areas are numbered 1 to 6. The tool is based on different types of input. These are KNMI'06 climate scenarios, water storage capacity of the creek ridges, land use, water use by crops, transport costs by pipes and transition costs. Based on the input, different scenarios are created.

It is possible to select water distribution options in the tool. Area 3 provides the largest quantity of available fresh water from the subsurface storage. The reason is that area 3 has the largest surface area available to apply the creek ridge measure. To possibly benefit other regions from this larger availability of fresh water, the distribution options from area 3 are chosen. All the distribution options are:

- All areas receive water from area 3,
- Areas that are adjacent to area 3 receive water (not area 6),
- All areas receive calculated potential from the same area,
- No water is provided as there is no creek ridge.

The rapid assessment tool estimates, based on the parameters mentioned above, the yield reduction of a crop class for a specific area. The output of the rapid assessment tool is given in € and kg per hectare and is an average of an area. Because the tool is built for use on a regional scale, the tool is more useful for policy makers rather than farmers. Users of the tool could include the water board or the province of Zeeland.

Pictures (1.5 and 1.6) show how a creek ridges' sandy deposits look in todays landscape.

Figure 1.5 Picture of creek ridge (2012)

Figure 1.6 Picture of creek ridge (2012)

Selection of Schouwen-Duiveland

Schouwen-Duiveland is an island of 231 km² and is located in the Southwest Delta of the Netherlands. The island is surrounded by saline water. Agriculture on the island is rain fed and fresh water is stored in fresh water lenses in the dunes, creek ridges (below) and in shallow water lenses. Agriculture is reliant on the fresh water lenses that are replenished by a yearly surplus of rainwater.

The island is completely surrounded by salt water and has not got any supply of fresh water from outside its boundaries. This makes the island completely dependent on shallow water lenses. In the future rainfall patterns will change and temperatures will rises. The replenishment of fresh water lenses during winter is threatened by these changes. As a result there is a need for adaptation measures, such as the creek ridge measure, to ensure the agricultural future of Schouwen-Duiveland (Stuyt *et al.*, 2006).

The island is selected because it is independent of external fresh water. Because the replenishment of rain water lenses are threatened by climate change, it is interesting to investigate whether the creek ridge measure is able to provide sufficient quantities of water. If the creek ridge measure is effective by providing sufficient quantities of water, it can be considered robust. When the costs of construction and distribution of fresh water are lower than the prevented potential loss of yield in €, the measure can be considered feasible (subchapter 4.2).

By investigating the contribution of fresh water from the creek ridges with relatively thick water lenses, it can be estimation if agriculture can sustainable in different areas of Schouwen-Duiveland. Farmers are interested to know to what extent they can rely on the creek ridge and rely on an increased availability of fresh water (subsection 5.1.2).

Aim of this research

The aim of this research is to contributes to the research that is being done within the GO-FRESH project, by assessing the robustness and feasibility of the creek ridge measure. This is formulated in to the following two aims:

1. To assess the long-term robustness* of the fresh water supply (resource) for the agricultural sector, using fresh water from the creek ridge under different climate scenarios.
2. To assess the economic feasibility** for farmers (resource users) to invest in the creek ridge measure with different land uses in different climate scenarios.

* The creek ridge is considered robust when it can meet the agricultural demand for fresh water in the climate scenarios. The robustness of creek ridge measure (or resource) is assessed by making use of the rapid assessment tool.
The creek ridge measure is a component of the water system of Schouwen-Duiveland. This complete system is complex as many components and actors that are part of this system. This system is referred to as a Social Ecological System (SES) (Anderies, 2004). In such a system components and actors influence and interact with each other. More on robustness, closely related concepts and the Social Ecological System (SES) can be read in chapter 3.2.
** The feasibility of investing in the creek ridge measure is determined by the investment and distribution costs of the creek ridge measure versus a decrease in the yield reduction below the threshold level. In this research this is set at a loss of 25% yield reduction of the turnover under normal circumstances retrieved from LEI (2012). The 25% of yield loss is indicated by farmers. Under the current land use this is €900/ha and for orchards the threshold is €5000/ha of yield reduction (these numbers are rounded up).

Analyses

In chapter 5 the results and analyses of the outputs of the tool are shown. An overview is given of fresh water supply and demand for agriculture on Schouwen-Duiveland, the results of the interviews and different output of the rapid assessment tool. To visualize the outcomes of the supply and demand of fresh water for agriculture, tables are used.

In the tool a high number of outcomes are possible, because of the high number of outputs possible, it is impossible to show all outputs. Therefore the outputs of different possibilities are shown that are most relevant or interesting.

In the €ureyeopener project (Stuyt *et al.,* 2012) a rapid assessment tool is also been used. In subsection 5.2.2 a short comparison is made between the two tools.

2. Problem statement & research questions

The availability of fresh water lenses is very likely declining due to climate change, rising sea level and a higher demand from agriculture, causing an increase in pressure on the fresh water reserves in the sub soils and salinization (van Baaren & Harezlak, 2011; Tolk, 2012). These kinds of developments demand for measures to ensure a more secure fresh water supply for the future.

Research question

In 2050, based on climate scenarios from the KNMI (2006), periods of drought are likely to become longer as weather is becoming more extreme, resulting in higher temperatures, more intense rainfall and higher sea levels, which in turn will create higher pressure on the current fresh water supply. This will probably result in crop damage as a result of droughts and salinization (van Baaren & Harzelak, 2011). As farming becomes more difficult the urge for a more reliable water supply could become more urgent in the long-term. With the assessment of different water demands and land use in different areas in different climate scenarios, the following research questions are asked:

1. What is the long-term robustness of the fresh water supply for the agricultural sector with water from the creek ridge under different climate scenarios?
2. What is the feasibility of investing in the creek ridge measure with different land uses in different climate scenarios?

Sub questions:

- Would the creek ridge measure in current climate conditions be robust?
- Would the current land use be able to sustain in the future scenarios?
- Could there be orchards on Schouwen-Duiveland in the future scenarios?
- Can the creek ridge measure be considered robust in the future?

To be able to answer the first research questions a clear description of the concept robustness has to be given. When describing robustness, an overlap with other concepts is found. These concepts are resilience and vulnerability[2] and they are closely related to robustness (chapter 3.2).

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[2] Resilience and vulnerability are not further used in the conclusions. Still value is given to explain the interlinks between the concepts to better understand them.

3. Theoretical Framework and used theory

Concepts such as ‘scenarios’ and ‘robustness’ were used earlier in this report. In this chapter these concepts and other concepts, terminology and theories are described from different scientific literature, to set the outline in which this research is conducted.

3.1 Method

Scenarios

Bruggeman (2011) and Mens (2012) describe scenarios as ‘consistent descriptions of possible futures, that can serve as a bases for strategic decisions’. Bruggeman (2011) adds three conceptual layers to scenarios:

- The external context: this context develops autonomously or is hardly affected by water management, as the external context describes sea level rise, climate change, European policy. Water management itself is influenced by the developments in this context.
- Transactional environment: in this context are the actors that can be affected indirectly and over which there is no direct control. These are farmers, people in the recreation sector, and civilians.
- National water management: This context imbeds the government, water boards and municipalities, or in other words, institutions that directly influence water management.

The KNMI’06 scenarios (next paragraph) only describe the external context that is mentioned above. These are possiblities 50 or 100 years on from the year 2000. The scenarios are within the external context as Bruggeman (2011) explains, and therefore cannot be influenced by national water management.

KNMI’06 scenarios

In the KNMI’06 scenarios, an indication was given for changing precipitation, temperature, potential evaporation, wind and sea levels (van den Hurk, 2006). These are known as the KNMI’06 scenarios. Besides season averages, different types of extremes are quantified, such as the temperature on the coldest day of the year. The KNMI’06 scenarios exist out of four climate scenarios (figure 3.1). They are based on worldwide climate models that indicate that by 2050 average worldwide temperatures will have risen by somewhere between +1°C and +2°C. These temperature rises form the starting point for the moderate; G, and warm climate scenarios; W. For the Netherlands not only is the worldwide temperature important, but also the average wind direction. The winters will possibly be influenced by an increase in Western wind flow. These winds would cause milder and wetter winters. The wind flow in the summer is likely to be come from the East more often, causing higher temperatures and longer periods of drought. The scenarios with changing wind patterns are described with G+ and W+ (appendix II).

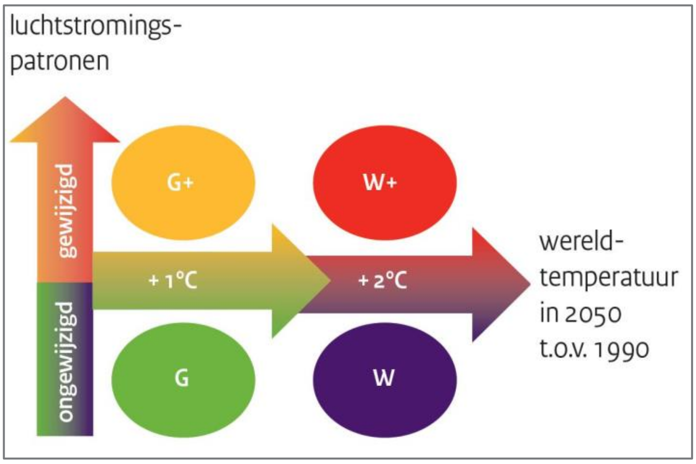

Figure 3.1 KNMI’06 Scenarios (KNMI, 2006)

Delta Scenarios
The Delta Scenarios describe a possible physical development and social economic development. They are formulated based on the report ‘Klimaat in de 21e eeuw’ by the KNMI (2006) and the report ‘Welvaart en leefomgeving’ by CPB, MNP and RPB (2006) (figure 3.2). In the next paragraphs the consequences for agriculture for each scenario are described based on on the report ‘Deltascenario’s: integrale verhaallijnen’ (2012).

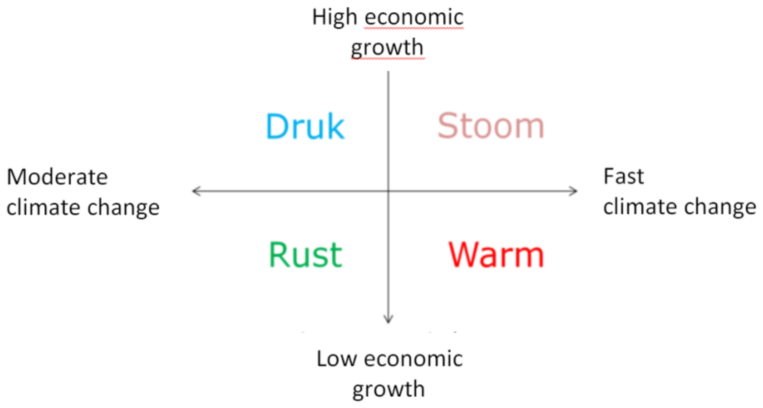

Figure 3.2 Delta scenarios (Deltascenario’s: integrale verhaallijnen, 2012)

- Busy (druk)
  High economic and population growth, together with a moderate temperature rise mark this scenario. The Netherlands’ power to compete and its innovativeness will cause the agro business to play a larger role in the global market, enhanced by the liberalization of food production and European agricultural policy.

  The agricultural sector will decrease due to a strong increase in urban areas. Rising food prices will lead to extensive intensification and a stronger integration of livestock farming and agricultural practices. The increase in wealth will also give an impulse to organic farming, that will lead to the local and regional chains that focus on high quality products, causing higher pressure on the ground prices. Farming in general will become more self-sufficient as farmers more often take measures themselves.
- Steam (stoom)
  The growth in population and wealth will lead to an increasing and changing demand to agricultural produce. Because of this there will be a dichotomy between large scale industrial companies and multifunctional companies that focus on local consumption. In the primary agricultural sector a strong intensification and up-scaling will take place, because of the increased demand for different products. Multifunctional agriculture will also increase, putting high pressure on the land, increasing prices leading to more efficient land use.

  To reduce damage by extreme weather conditions, the agricultural sector is increasingly willing to take measures. Intensified agriculture is becoming more willing to buy water for high value crops or to grow crops that are less water demanding. Less intensive agriculture is more willing to accept damage.
- Quiet (rust)
  Because of limited global trade agro-logistics will become less important. Renewal within the agricultural sector is therefore mainly focusses on regional production, close to the consumer, with short production chains. The dependence on importing raw materials is therefore decreasing.

The agricultural sector will remain the same, while the ability to compete and innovativeness will decrease. Spatial pressure will not be large since the urban areas will not increase, as agricultural land will remain large and no extreme weather conditions will occur. The crops cultivated will remain as they are now and extensive livestock farms will suffer from a decrease in competition for power, as energy prices go up.

The climate sensitivity in the primary sector will remains limited, as climate change is limited too. Due to limited technological developments, fresh water demand will become larger. The sector is counting on the ability to irrigate in the future and holds the government responsible for a large part in providing and sharing the water. Due to low profits, the sector will choose to grow less vulnerable crops.

- Hot (warm)
  Like in the scenario ‘quiet’ a limited global trade causes agro-logistics to become less important. Renewal within the agricultural sector will mainly focus on regional production with short production chains.

  In the primary sector regionalization takes place. This focuses less on global markets and more on the regional markets of northwest Europe. Eventually agricultural production will stagnating and decrease. This is because of a decrease in competition in the agricultural sector and the salinization of agricultural soils in certain areas as a result of climate change. Vegetables on open soils and tree crops will experience growth, while intensive livestock farming will have to shrink as energy prices rise and global energy competition is limited.

  The risk of drought damage will increase, since agriculture is susceptive to extreme weather conditions and is capable of limited adaptation. Especially on the sandy soils, the availability of water will create bottlenecks. In the southwest delta salinization will increase in coastal and reclaimed land areas. The bottlenecks will be larger in areas without an external water supply, where irrigation possibilities are limited and where soil has become saline. Also in this scenario the sector is expecting that water will remain available and that the government will take care of this. Farmers will be prepared to grow fewer vulnerable crops, and will be able to pay for a higher service level for fresh water, as they will have earned more with intensified crops.

Scenarios

The word ‘scenario’ is encountered in different literature. Every time when operating the tool, it can be said that, a new scenario is created, because an estimation is created that can be a possible future reality. Therefore, in this research the term scenario refers to an output of the tool. Throughout the report the word ‘scenario’ is referring to an outcome of the tool, unless explicitly mentioned differently.

Land use in 2050

According to the Delta Scenarios (Bruggeman, 2011) social economic change is included causing land use to change. Agriculture will focus on a more regional market resulting in a shorter food chain with larger varieties of crops or it could shift to intensified production, depending on the scenario (Polman *et al.*, 2012).

Only the physical climate changes described by the KNMI’06 are taken in to consideration as future scenarios. The tool makes it possible for the user to select different types of land use per area on Schouwen-Duiveland. It is not the aim of this research to compare the effects of agricultural land use that are currently not in place. For that reason land use in 2050 (when not manually changed in the tool) is based on current land use (LGN4: Landgebruik Nederland).

3.2 Concepts

Gallopín (2006) describes how the concepts robustness, resilience and vulnerability relate to each other. In this research not the whole SES system is assessed on its robustness, only a component of the system, being the resource. The complexity of a social-ecological system is explained by Anderies (2004).

Robustness

In relation to this research, the resource (creek ridge) is considered robust when it can meet the agricultural demand for fresh water in different outputs of the tool. The demand is the difference between the water deficit in climate scenario ‘Currrent’ and the climate scenarios for the future, ‘2050 Quiet’ and ‘2050 Steam’.

The concept robustness is described in literature as a system that can deal with an impact and still remain in the same state. For example throwing a rock to a bunker will not damage it; the bunker remains in the same state and can be used for the purpose it was designed for. This example directly shows the importance of the scale of the disturber or perturbation. A rock might not do harm, a very large rock or bomb might.

The dictionary describes robustness as:
ro·bust’ ness noun.

1. Strong and healthy; hardy; vigorous: a robust young man; a robust faith; a robust mind.
2. Strongly or stoutly built: his robust frame.
3. Suited to or requiring bodily strength or endurance: robust exercise.
4. Rough, rude, or boisterous: robust drinkers and dancers.
5. Rich and full-bodied: the robust flavour of freshly brewed coffee.

Robustness can be a property of a system or a policy and refers to the level in which the performance of the system or the output of a policy reacts to varieties or changing circumstances (Mens *et al.*, 2012). To further explain robustness a distinction is made between the robustness of a system and robustness of a policy, however the robustness of a policy is not further elaborated on.

A system that is robust entails the following variations:

- Only when there are big distortions will damage occur.
- The consequences of distortion are relative small.
- The consequences are relative insensitive to the scale of the distortion.
- The consequences of distortion are short-lived, due to the capacity of quick recovery of the system.

The outcome of robustness in practice will depend on the type of system and to what scale robustness is analysed. The level of a system’s robustness also depends on how the ‘functioning of the system’ is defined, judged, and under which circumstances it should be robust (Mens *et al.*, 2012). Anderies (2004) uses a comparable definition in relation to a Social-Ecological System and describes robustness as ‘the maintenance of some desired system characteristics despite fluctuations in behaviour of its component parts or its environment.’ For example airplane parts should maintain their function independently of weather conditions or other components of the airplane (page 13).

Resilience

The level to which a system can undergo change and maintain its structure is called resilience. Therefore resilience has some similarities with robustness, as it explains how a system keeps functioning while it undergoes change. But there are differences (Mens *et al.*, 2012).

Gaillard (2010) explains that the most recent description of resilience is the capacity of a system to absorb and recover from the occurrence of a hazardous event. This description has also been adopted by the United Nations International Strategy for Disaster Reduction as 'the capacity of a system, community or society to resist or change in order that it may obtain an acceptable level of functioning and structure'. Folke (2006) adds that resilience is not only about being robust to disturbance; it also implies the opportunities that disturbance opens up, such as evolved structures, processes and renewal of the system. So resilience provides an adaptive capacity that allows for development.

Resilience is about:

- The amount of change a system can undergo, while the same functions and the same structure remain.
- The level in which a system can organise itself.
- The capacity to build and expand knowledge and adaptive capacity.

Vulnerability

According to Hinkel (2011) vulnerability is a central concept in climate change research and policy. The term causes confusion as the meaning of it is described in many ways and overlaps with other terms such as resilience and adaptability. Hinkel explains that the IPCC describes vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity". It is difficult to measure concepts like this, as its components are not measurable. The concept has to be made operational to provide observable concepts (Hinkel, 2011). O'Brien (2004) and Smith & Wandel (2006) explain that vulnerability can be characterized as a function of three components (adaptive capacity, sensitivity, and exposure, also mentioned in the definition above):

- Adaptive capacity describes the ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences. It is considered as a function of wealth, technology, education, information, skills and infrastructure, access to resources and stability and management capabilities.
- Sensitivity refers to the degree to which a system will respond to a change in climate.
- Exposure relates to the degree of climate stress upon a particular unit of analysis; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events.

Mens *et al.* (2012) describes vulnerability as a system character that describes to what extent a system can be harmed by change. Vulnerability depends on the different variables and the type of change that is being considered. There is a difference between vulnerability for variables and vulnerability for change. In the case of vulnerability for variables, vulnerability can be seen as the inverse of robustness. In the picture below the situation on Schouwen-Duiveland is visualised in relation to the vulnerability assessment (figure 3.3).

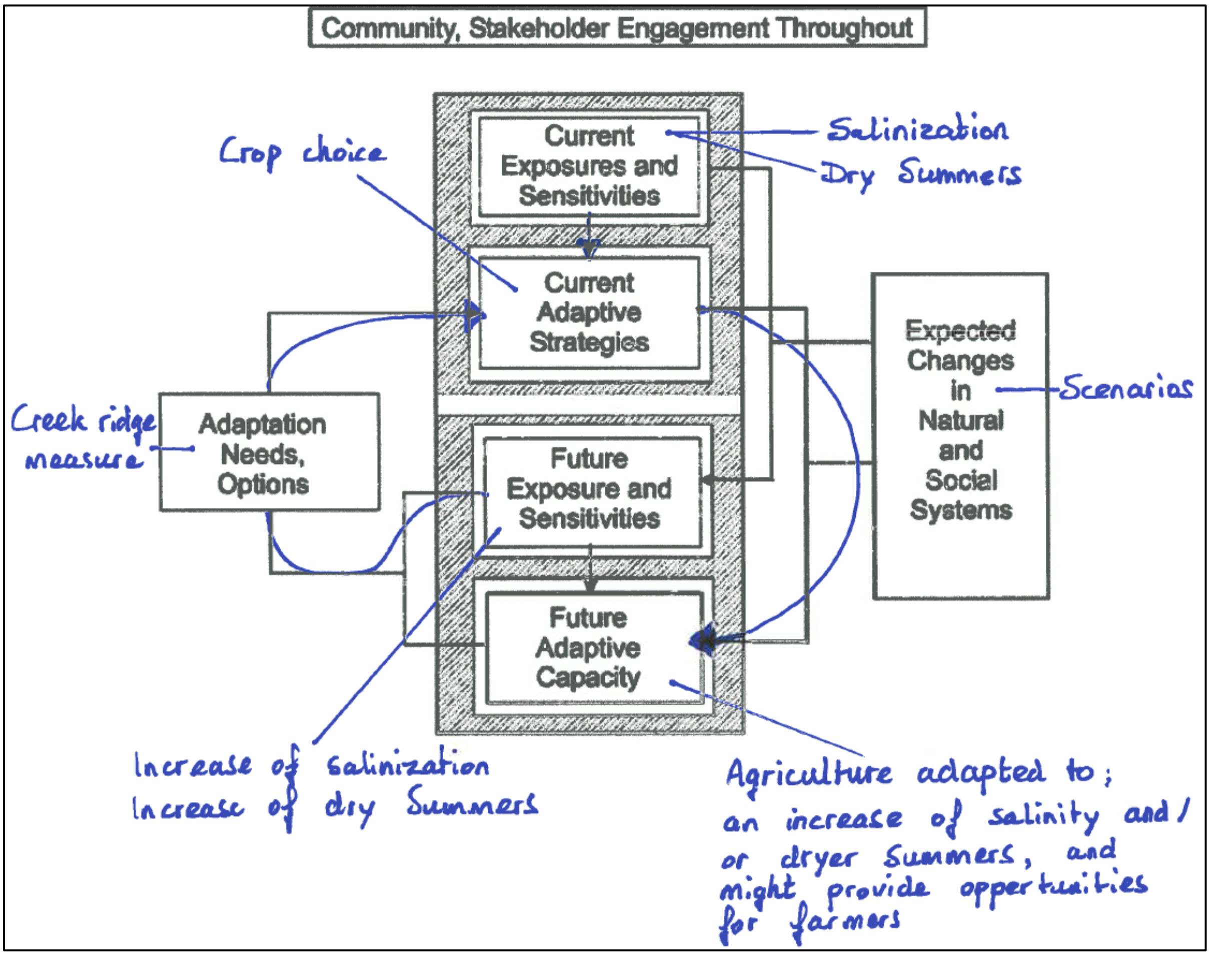

Figure 3.3 Conceptual framework for vulnerability asessment and mainstreaming with personal notes (Smith and Wandel, 2006)

Gallopín (2006) explains that vulnerability and resilience relate to a perturbation that impinge or disturb a system. That means a certain system is sensitive to a certain perturbation and not to other perturbations. This has to do with the type of perturbation, as it can be defined as perturbations, stress, hazard or shock. Hazards are threats to a system that exist out of perturbations or stress. Perturbations are spikes in pressure such as a tidal wave or a hurricane, beyond the normal range of variables in which the system operates and they commonly originate beyond the system's location. Stress is a continuous or slowly developing pressure, such as soil degradation, and is commonly within the range of normal variability. An increase in droughts as we head towards 2050 can therefore be seen as stress. It is a continuous and slowly increasing pressure that acts within the ranges of normal variability and within the boundaries of the system (Gallopín, 2006).

Social-ecological System

To judge robustness, a framework described by Anderies (2004) is used. The framework describes the interaction in a SES and highlights the key drivers and the interactions between them. The key drivers in the framework are the resources, the governance system and the infrastructure. Using this framework helps to judge the robustness of the key drivers in the system that is being assessed: 'the maintenance of some desired system characteristics despite fluctuation in the behaviour of its component parts or its environment' (Anderies *et al.*, 2004).

The SES can be thought of as interdependent systems of organisms. Thus, both social and ecological systems contain units that interact independently and each may contain interactive subsystems. It refers to a subset of social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units (Anderies *et al.*, 2004) (figure 3.4).

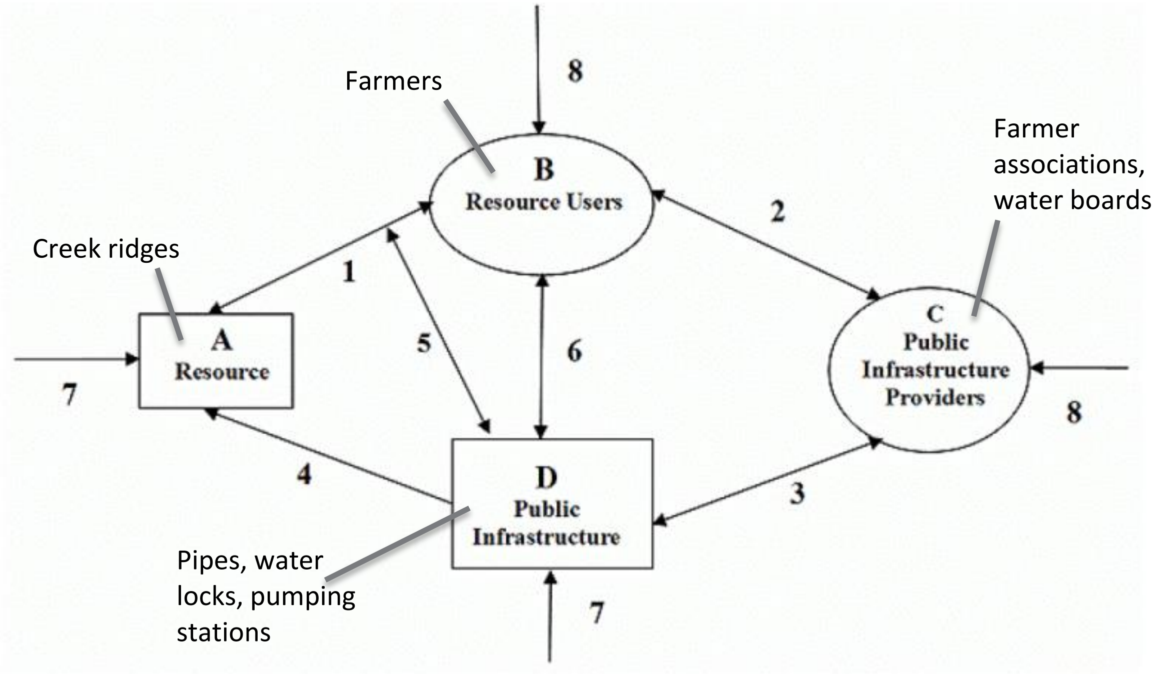

Figure 3.4 Conceptual model of a social-ecological system (Anderies *et al.*, 2004)

In the tables below the components of the conceptual model are listed, together with examples and potential problems. They show the potential relations that can exist and supports earlier statements on the complexity of a SES. The components of interest in this research are highlighted in bold.

Table 3.1 Entities involved in social ecological structures. The components that are relevant to this research are given in bold.

Entities	Examples	Potential problems
A. Resource	**Rain water** **Water lenses**	**Drought, climate change** **Uncertainty factor**
B. Resource users	Farmers	Stealing water
C. Public infrastructure providers	Farmer association Resource manager	Internal conflict or indecision
D. Public infrastructure	Engineering works	Wear out over time
Institutional rules	Memory loss, deliberate cheating	
External environment	Weather, economy, political system	Sudden and slow changes that are not noticed

Table 3.2 The links involved in social-ecological systems. The components that are relevant to this research are given in bold.

Link	Example	Potential problems
(1) Between resource and resource users	**Availability of water at time of need**	**Too much or too little water**
(2) Between users and public infrastructure providers	Monitoring performance of provides	Lack of information/free riding
(3) Between public infrastructure providers and public infrastructure	Building initial structure Regular maintenance Monitoring and enforcing rules	Disruption of temporal and spatial patterns of resource use Cost/corruption
(4) Between public infrastructure and resource	Impact of infrastructure on the resource level	Ineffective
(5) Between public infrastructure and resource dynamics	Impact of infrastructure on the feedback structure of the resource-harvest	Ineffective, unintended consequences

	dynamics	
(6) Between resource users and public infrastructure	Maintenance of work, monitoring and sanctioning	No incentives/ free riding
(7) External forces on resources and infrastructure	Drought	Destroys/disrupts resource and infrastructure
(8) External forces on social actors	Commodity prices and regulation	Conflict, uncertainty, greatly increased demand

The level of robustness of a system also depends on how the 'functioning of the system' is defined, judged, and under which circumstances it should be robust (Mens *et al.*, 2012). This research explicitly focuses on the resource. A distinction is made between the collapse or undesirable transformation of a resource (e.g. when a water source is no longer productive, or when costs vs. benefits are undesirable) and the loss of robustness of the entire system. In other words when controllable drainage, transition costs and transportation costs are not worth investing in or when a resource is not sufficient enough, then the component is not considered robust. However the component is part of the SES and the SES contains more components and drivers. When a resource is not robust it does not mean the whole SES is not robust.

Conclusions

The output of the tool can be considered as a newly created scenario. It is a scenario that is based on the different input variables that the user of the tool can influence. One of the input variables is the climate scenarios from the KNMI (2006). These scenarios are used in the tool to base crop yield reduction calculations on. When talking about a scenario, it refers to the output unless explicitly mentioned otherwise.

The term robustness is easy to relate to in terms as resilience and vulnerability. Robustness is a concept that is described in relation to a physical or management system. This system is robust when it maintains its functions after change has occurred or when the system has a backup to cope with a physical or management failure. If a perturbation causes change, it can be described as a stress that slowly comes from within a system and operates within the boundaries of a system. Perturbations that come from outside the system are described as a shock and are sudden and operate outside the normal boundaries of a system.

A system that is resilient has similarities to robustness. A resilient system has the ability to bounce back to its original or a comparable state, with the opportunity for development. On the other hand a system that is vulnerable cannot resist the impact from a perturbation, since it does not have the capacity to bounce back, or there is no capital or knowledge to be resistant to the perturbation.

In this research Schouwen-Duiveland is taken as a physical unit. Because the whole system is very complex it is hard to judge its robustness. Therefore the robustness of a component from the Social-ecological System of Schouwen-Duiveland is assessed. The political structures of the SES remain outside of the scope of this research.

The creek ridge is considered robust when it can meet the agricultural demand for fresh water in the climate scenarios. The demand is the difference between the water deficit in the 'Currrent' climate scenario and in the future scenarios, '2050 Quiet' and '2050 Steam'.

4. Methodology

In this chapter the parameters used to calculate the output in the main page of the tool are discussed. These parameters are estimations and calculations based on different reports, such as the invoice of the company Rutten, 'Vraag en aanbod van zoetwater in de Zuidwestelijke Delta' (2009), Selection criteria of creek ridges by Sommijer (2013), and more. Therefore sometimes the preciseness is debatable, as detailed in chapter 6.

The tool is built in a spreadsheet system, namely Microsoft Excel. Two separate files are used and calculate the average costs per hectare. It is not the aim to divide the cost between the water boards, farmers or other stakeholders in the region, but it could be interesting for the water boards to take note of these averages.

In chapter 4.1 a practical overview of the rapid assessment tool files are described and how to use them. In 4.2 an overview and explanation of the inputs and costs of the rapid assessment tool are given. In chapter 4.3 a description of how the tool works and how the outputs should interpreted is given. In chapter 4.4 theories on physics are given, chapter 4.5 describes the calculations that support the tool and finally in chapter 4.5, the interviews that help validate this research are summarized.

4.1 Files

Two important Excel files are provided with this report (or can be obtained on request (js.jansnel@gmail.com). The first is named '1.Rapid_Assessment_Tool_SD.xlsx' and can be seen as the main file, hence number '1'. The second file provides many of the calculations required in the main file and is named '2.Backdoor_Tool.xlsx'. The separation of the calculations in to two separate files was for practical purposes. The number of tabs is large and having two separate files allows a clear overview. In both files not all of the tabs might be visible. To make them visible click 'unhide' and select the desired tab (figure 4.1).

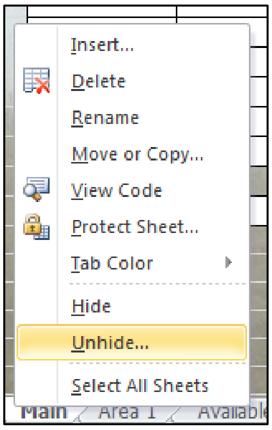

Figure 4.1 Unhide tabs

The first file contains the rapid assessment tool. The tool can be found in the 'main' tab, and can operated from here. No other tabs are needed to operate the tool. The choices made on this main page are connected to calculations in other tabs in the same file and in the second Excel-file. For that reason it is suggested to keep the files together. In case the files have a new directory, for example, if after copying to a new directory, the programme Excel might demand the links be refreshed in the current file. Answer by clinking 'refresh' or 'select file' and select the opposite file. Alternatively ignore the message, since the tool will still work without updating the links.

The rapid assessment tool links the information from the backdoor tool file and presents it on the main page. Below, the tabs that can be seen in the file are presented (figure 4.2). These tabs include the output of the calculations described in chapter 4.3.2.

Figure 4.2 Representation of the tabs in the '1.Rapid_Assessment_Tool_SD.xlsx' file.

The name of the ‘2.Backdoor_Tool.xlsx’ file is based on the characteristics of the file. It provides the input for the results in the ‘main’ file. In this file the calculations of crop water requirements and the yield reduction by drought are described. In chapter 4.5.1 each calculation step is described. These steps don’t necessarily synchronise with the tabs shown in the file for practical purposes, as the order in which calculations were done are not the same. Most of the tabs represented in the second file are presented below (figure 4.3). The calculation steps were taken following the calculation steps by the FAO paper 56 chapter 1 until 8 (1998). Chapter 7 of FAO paper 56 describes the calculations for dual crops and is therefore not included.

Figure 4.3

4.2 Method for estimating costs

After selecting (1) an area, (2) the use of the creek ridge measure and (3) land use, the user can see how his selections effect the average yield in €/ha and in kg/ha, as well as the possible transition cost to the orchard (fruit crops). In addition, the costs of controllable drainage and the distribution of possible extra available water are presented. Crop damage is calculated based on the water deficit and salinization (chapter 4.5.2). The decisions made by the user enables him to assess the feasibility of the creek ridge measure under circumstances determined by the user. By ‘playing’ with the tool different outputs can be generated. The output generated is given in loss/ha (in € and kg), therefore is not a profit.

Climate scenario

The climate scenario that is described as ‘Current’ in the tool is an average of the weather over 30 years, from 1990 until 2010. In chapter 3, four climate scenarios are presented; G, G+, W and W+. In this tool, two out of the four possible KNMI’06 scenarios are used: G and W+. These scenarios were selected because they represent the mildest and the most extreme scenario of the KNMI’06 scenarios. G is the KNMI’06 scenario in which the least amount of change occurs compared to 1990 and is considered mildest. In W+ the most amount of change occurs compared to the climate in 1990 and is considered most extreme. G+ and W are not taken in to account for reasons of simplicity.

In the tool the user can select two (other than ‘Current’) scenarios; ‘2050 Quiet’ (based on G scenario) and ‘2050 Steam’ (based on W+ scenario). These scenarios represent a change in temperature, precipitation, humidity and wind speed. The names of the scenarios are different than the original scenarios because estimations had to be made for a variety of factors, like humidity, and thus are not exactly the same. The calculations can be seen in the tab ‘climate data’ in ‘1.rapid_assessment_tool_SD.xlxs’ and in the tab ‘ETo’ in ‘2.Backdoor_Tool.xlxs’.

Water storage capacity and availability

To calculate the possible available water in the creek ridge, an analytical method is used (figure 4.4). To determine creek ridge areas the MSc internship research by Sommeijer (2013) on feasible areas for applying the creek ridge measures on Walcheren is used. The criteria that determine suitable surface area described in this report are applied on Schouwen-Duiveland. Five out of seven criteria are used to determine the feasibility for the creek ridge measure, in this research and these can be seen below[3]:

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[3] The two other criterias are: (1) ‘the unsaturated zone should be at least 0.85 m thick’ and (2) ‘There should be no confining layers within the first 20 m of the surface. They are left out to have a surface are available for the creek ridge measure that are large enough to base the estimations on in this report.

1. Infiltration/seepage fluxes in the area: infiltration>=0 (NO seepage!) (WINTER)
2. Suitable soil types are classified as: sand, light sabulous clay, heavy clay, light clay.
3. Ground surface should be at least 0 m +NAP or higher.
4. The depth of the fresh (brackish) / saline interface should at least be at 5 m below ground level (NO rainwater lenses)
5. Land use type is considered agricultural (classified as grass, maize, potatoes, beets, cereals, fruit trees, bulbs and other agricultural crops).

Based on the criteria of the research of Sommijer (2013) the surfaces that are suitable for creek ridges in all areas on Schouwen-Duiveland are determined. Understanding the creek ridge surface enables an estimation the volume of the fresh water lenses using the analytical method. See tab 'Darcy CR' in the 1.Rapid_Assessment_Tool_SD.xlxs file (figure 4.5).

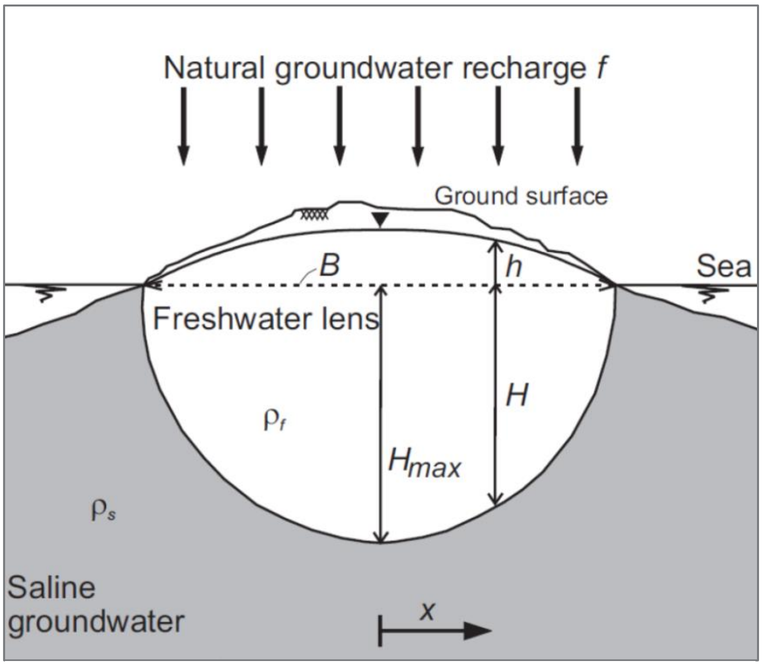


Figure 4.4 Fresh water lens in Dune area (Oude Essink, 2001)

The Badon Ghyben-Herzberg principle is used to describe the position of an interface between fresh and saline water (Oude Essink, 2001) (figure 4.4).

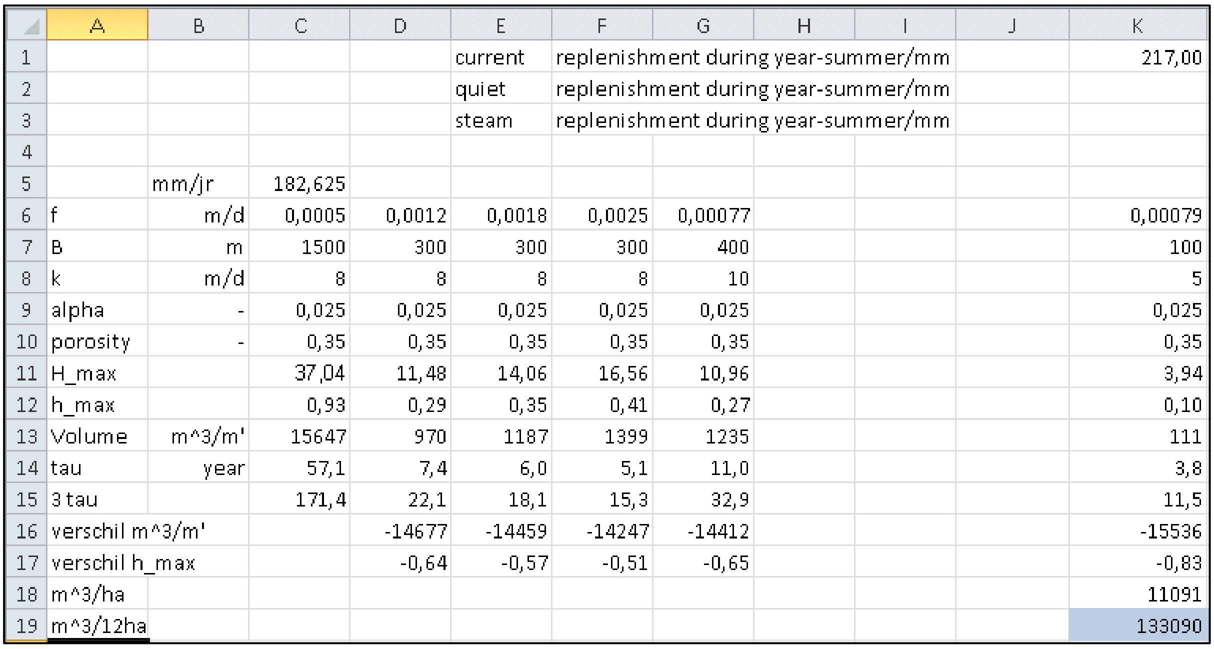
$$h = \frac{\rho_s - \rho_f}{\rho_f} H$$

Where h is the phreatic groundwater level in relation to mean sea level, ρ_s is the density of salt water, ρ_f is the density of fresh waters$_5$ and H is the depth of the fresh-saline interface (Oude Essink, 2001) (figure 4.4).

Using this method it is estimated that the following quantities of fresh water are available for each area. These quantities are distributes over the agricultural land in the selected area. Here it is visible that area 3 has the largest volume of fresh water lenses in creek ridges, and area 5 the smallest volume.

Table 4.1 Water volume from creek ridges

Area	V from Creek ridge
#	m³
0	1164000
1	3170000
2	1186000
3	14741000
4	4589000
5	388000
6	6539000
Total	31777000



	A	B	C	D	E	F	G	H	I	J	K
1					current	replenishment during year-summer/mm					217,00
2					quiet	replenishment during year-summer/mm					
3					steam	replenishment during year-summer/mm					
4											
5		mm/jr	182,625								
6	f	m/d	0,0005	0,0012	0,0018	0,0025	0,00077				0,00079
7	B	m	1500	300	300	300	400				100
8	k	m/d	8	8	8	8	10				5
9	alpha	-	0,025	0,025	0,025	0,025	0,025				0,025
10	porosity	-	0,35	0,35	0,35	0,35	0,35				0,35
11	H_max		37,04	11,48	14,06	16,56	10,96				3,94
12	h_max		0,93	0,29	0,35	0,41	0,27				0,10
13	Volume	m^3/m'	15647	970	1187	1399	1235				111
14	tau	year	57,1	7,4	6,0	5,1	11,0				3,8
15	3 tau		171,4	22,1	18,1	15,3	32,9				11,5
16	verschil m^3/m'			-14677	-14459	-14247	-14412				-15536
17	verschil h_max			-0,64	-0,57	-0,51	-0,65				-0,83
18	m^3/ha										11091
19	m^3/12ha										133090

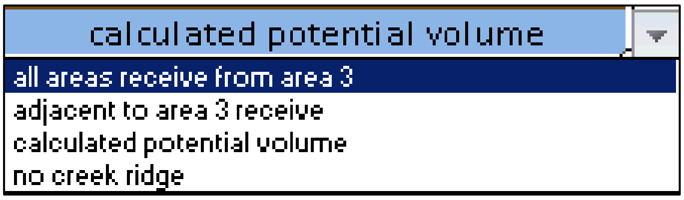
Figure 4.5 Spreadsheet of Darcy calculations (2.Backdoor_Tool.xlsx)

The dimensions of the surface areas for the creek ridge measure can vary. The calculated potential volume is larger, in a non-linear fashion, when the dimensions of the surface area are larger. Since all available surfaces for creek ridges vary, small dimensions are chosen. The calculations are made based on one hectare of surface area.

With the rapid assessment tool it is possible to select water distribution options (figure 4.5). These options are limited to four possibilities; (1) All areas receive water from area 3, (2) Areas that are adjacent to area 3 receive water (apart from area 6), (3) All areas receive calculated potential from their own area and (4) no water is provided as there is no creek ridge.

Area 3 provides the largest quantity of available fresh water from the subsurface storage. The reason is that area 3 has the largest surface area available to apply the creek ridge measure. To possibly benefit other regions from this larger fresh water lens, the distribution options from area 3 are chosen. These are options 1 and 2 as mentioned above.

After selecting one of the options (figure 4.6), the potential stored water in the creek ridges is shown. If desired the user can select a percentage from this available water, as it can be preferable to using less water than the amount potentially available. This can be decided by the user. A reason to reduce available water is to reduce distribution costs.



calculated potential volume

all areas receive from area 3
adjacent to area 3 receive
calculated potential volume
no creek ridge

Figure 4.6 Options of water distribution in step 1 of the rapid assessment tool (1. Rapid_assessment_tool_SD.xlsx)

Cost of creek ridge measure

The estimation of the costs for the creek ridge is based on an invoice from the drainage company Rutten. They charged €25.500 for the construction of a drainage system over twelve hectares, see tab 'costs' in '1.Rapid_Assessment_Tool_SD.xlxs'. The construction costs are a large investment, and does not need to be repeated yearly.

Water transport costs

When water is available from the creek ridge, it needs to be distributed over the agricultural area so that the area can benefit from it. To do so there are some costs involved, which depend on the type of distribution. Distribution can occur by truck, pipes or ditches. Ideally ditches should be used as the infrastructure already exists, but the ditches are often saline (van Baaren *et al.*, 2011) and thus are not an option for fresh water distribution[4]. The farmers indicated that water distribution by truck is not cost effective and labour intensive. For those reasons it is not considered in this research. Pipes are currently not an option as they are not in place. Pipes require energy to create pressure to enable a water flow, making distribution possible. In weighing up the three options mentioned above an estimation is made based on the costs for distribution by water by pipes. In the report 'Vraag en aanbod van zoetwater in de Zuidwestelijke Delta' (2009) a table is provided with the costs for water distribution by pipes, presented in tab 'costs' in the file '1.Rapid_Assessment_Tool_SD.xlxs'. These costs are divided in €0,50/m^3 for the water provision and €0,02/m^3 for maintenance. These costs are multiplied by the amount of fresh water available in each area in m^3. In other words, the distribution costs are influenced by the quantities distributed.

Land use

There is another type of agricultural land use on Schouwen-Duiveland. Crop classes are identified to simplify the tool and this is more time efficient when constructing it. In the tabs 'area 1', 'area 2', etc., and in file '1.Rapid_assassment_tool_SD.xlxs' the crops are presented in column 'G' . These crops represent a number of different crops. By grouping different crops together based on growth periods and other similarities, water demand per crop class in each hydrological area is determined. 'Landbouw in een veranderende delta' by Polman *et al.* (2012) and figures on K_y values are used to determine which crops can be classified.

K_y is a factor that describes the reduction in relative yield. They are crop specific and vary over growing season. In general, the decrease in yield due to water deficit during the vegetative and ripening period is relatively small, while during the flowering and yield formation periods it will be large (Doorenbosch & Kassam, 1979). Values for K_y for individual growth periods are included in 2.Backdoor_Tool.xlxs, tab 'K_y values'(chapter 4.5).

GIS software is used to calculate the surface areas of the crop classes and visualizes the surfaces as presented on the main page of the tool. The table below presents the scenario current and is repeated for the scenarios quiet and steam 2050 (figure 4.7). The crop classes are:

- Grass
- Maize (2 types of maize and 1 type of wheat
- Potato and green vegetable (various green vegetable data used, such as broccoli, cabbages, sprouts, spinach).
- Green houses (tomato data used)
- Orchards

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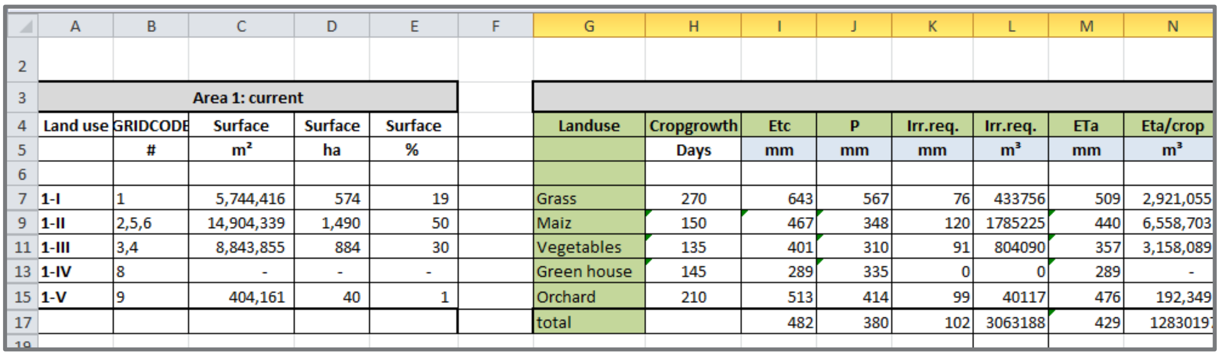
[4] According to the farmers desalinisation of the ditches is too costly and it therefore not taken into consideration. It is not further investigated in this research.

There are bulbs growing on Schouwen-Duiveland and it is interesting to know if bulbs could be cultivated when a more reliable water source is in place, as bulbs are salt intolerant. Unfortunately some crucial data on the K_y factor could not be found in the FAO data (1998). For this reason, the same method of calculating crop water requirements and yield reduction was not possible. Orchards are used to replace bulbs as a high value crop, but one large difference is that trees root very differently and therefore a comparison or estimation between bulbs cannot be made.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2														
3	Area 1: current													
4	Land use	GRIDCODE	Surface	Surface	Surface		Landuse	Cropgrowth	Etc	P	Irr.req.	Irr.req.	ETa	Eta/crop
5		#	m²	ha	%			Days	mm	mm	mm	m³	mm	m³
6														
7	1-I	1	5,744,416	574	19		Grass	270	643	567	76	433756	509	2,921,055
9	1-II	2,5,6	14,904,339	1,490	50		Maiz	150	467	348	120	1785225	440	6,558,703
11	1-III	3,4	8,843,855	884	30		Vegetables	135	401	310	91	804090	357	3,158,089
13	1-IV	8	-	-	-		Green house	145	289	335	0	0	289	-
15	1-V	9	404,161	40	1		Orchard	210	513	414	99	40117	476	192,349
17							total		482	380	102	3063188	429	1283019

Figure 4.7 Table showing outcomes of calculations per crop class (1.Rapid-assessment_tool.xlxs)

Turnover in € and kg/ha

The turnover does not represent profit/hectare, but represents income/hectare, from which farm operation costs have to be subtracted. Based on figures from LEI (LEI, 2012), the sales volumes for different crop classes are determined. The turnover is calculated by the Agricultural Economic Institute (LEI) and the WUR and represents the turnover per hectare under normal circumstances. The turnover per crop class is used to estimate the turnover per area on Schouwen-Duiveland.

In addition, interviewed farmers provide numbers on turnover, and these numbers were close or equal to the information presented by the LEI. But farmers remarked that these numbers varied a lot, because they are dependent on the market. For example when yield is low scarcity occurs on the market, which leads to a rise in prices (chapter 5.1.2).

Although this remark is made, €/hectare is still used in the output tables as it makes comparisons possible between the turnover/hectare from the output of the tool and LEI, or other sources.

Feasibility

The feasibility of investing in the creek ridge measure is determined by the investment and distribution costs of the creek ridge measure versus a decrease in the yield reduction below the threshold level. In this research this is set at 25% of the turnover under normal circumstances retrieved from LEI (2012). The 25% of yield loss is indicated by farmers. Under the current land use the 25% is €900/ha and for orchards the threshold is €5000/ha of yield reduction (these numbers are rounded up). The following formula is used for that: “(loss[€]/ha ‘no creek ridge’ – loss[€]/ha ‘with measure’)-costs creek ridge costs[€]/ha in and transport costs[€]/ha”. The outcome of this formula should be below the €900/ha to be considered feasible (or €5000/ha in case of orchards).

Transition costs

When water is available and a farmer has access to fresh water, he can consider changing[5] to a high value crop. Orchards (or fruit trees) are examples of high value crops. When changing to orchards a farmer has to change almost all of his practises. The advantage is that orchards have a higher €/kg ratio than most other conventional crops (LEI, 2012). Peppelman & Groot (2004) explained all the

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[5] Changing farmer practices demand many drivers. The possibility to do so is a requirement (Peppelman & Groot, 2004).

costs involved for different kinds of orchards. In this research the transition costs are based on the transition to apple trees. Transition costs are as high as €100.000/ha per 3 years. These costs are presented in tab 'costs' of the '1.Rapid_Assessment_Tool_SD.xlxs' file.

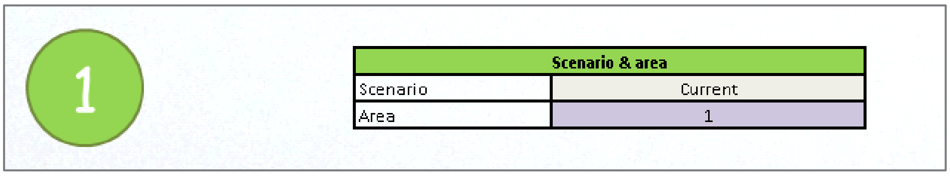
4.3 How to use the rapid assessment tool

The output depends on the combination of choices made by the user. This chapter provides an overview of all the possible choices. In figure 4.11 the map of Schouwen-Duiveland, steps '1', '2' and '3', and tables and graphs can be seen.

The numbers '1', '2', and '3' represent the three steps at which the user has to make certain choices to achieve an output. These choices can be made by using the drop down menu at each number. Schouwen-Duiveland is divided in to seven areas, areas '0' to '6', to enable assessment per area. This is desirable since the availability of the creek ridges vary over the island. The output counts for one specific area chosen at step '1'. At the bottom of the screen the output is presented in numbers and tables.

4.3.1 Tool step by step

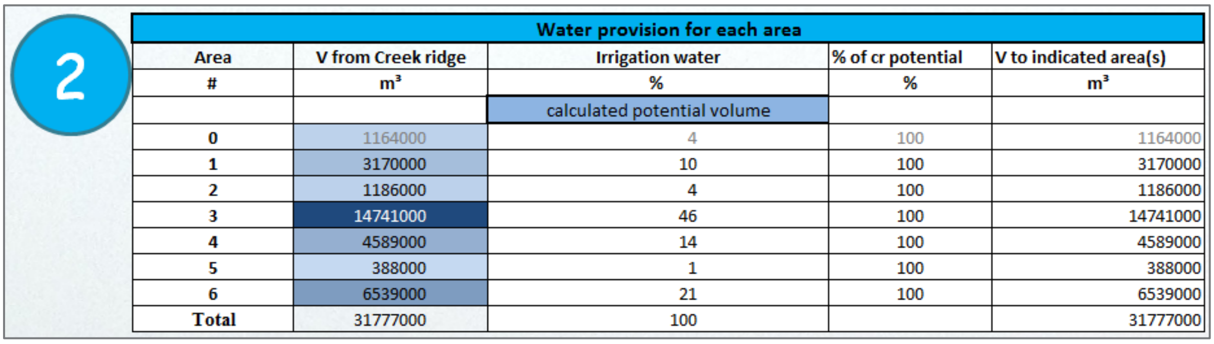
To use the tool, the user should adjust dropdown menus at all three steps, starting at 'step 1' (figure 4.8). In this table there are two drop down menus in which the user selects a scenario: 'Current', '2050 Quiet' or 2050 Steam', and one out of the six areas on the island, which are represented on the map ('0' is not an option, because the area has got no agricultural land use). Each area has a different potential water delivery volume, which affects the output of the tool. This depends on surface of suitable land for the creek ridge measure in that area and the choices made in step 2.



Scenario & area	
Scenario	Current
Area	1

Figure 4.8 Print screen of step 1 of the rapid assessment tool ('1.Rapid_Assessment_Tool_SD.xlsx')

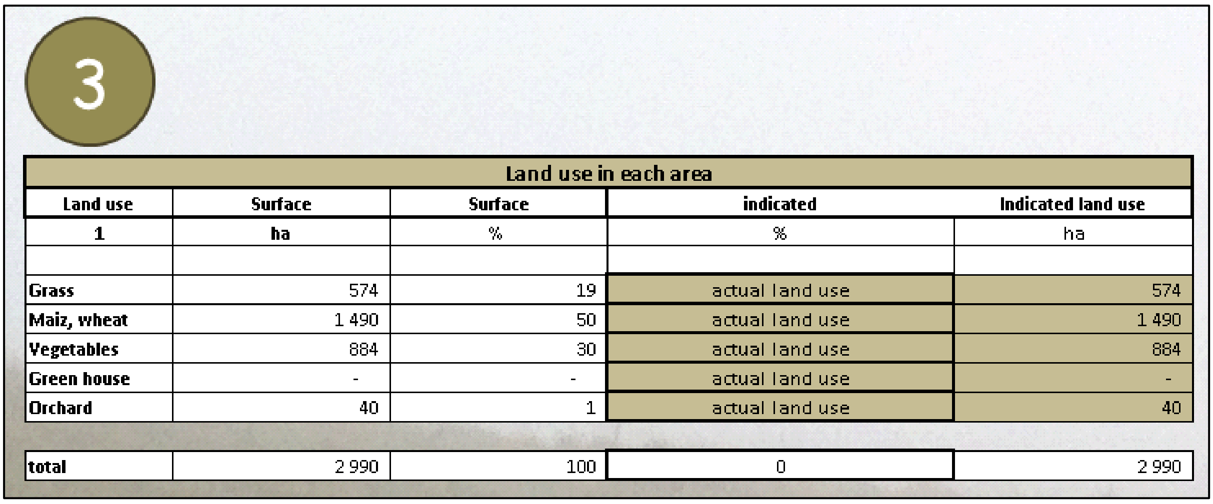
When selections are made, the user moves on to 'step 2' (figure 4.9). At step 2 the potential water from the creek ridge in the selected area can be chosen. As 'area 3' provides almost half of the total potential water availability the option is givin to provide water from 'area 3'. The options are; 'all areas receive water from area 3', areas 'ajdacent to area 3 receive water', 'calculated potential volume of selected area' and 'no creek ridge measure' (figure 4.6). By selecting one of the options given, the available water from creek ridges in the chosen area is calculated. The output of this selection is linked to the 5th colum on the right. The water availability given in the 5th column connects to the tables on other work sheets, that calculate yield reduction.



Water provision for each area				
Area	V from Creek ridge	Irrigation water	% of cr potential	V to indicated area(s)
#	m³	%	%	m³
		calculated potential volume		
0	1164000	4	100	1164000
1	3170000	10	100	3170000
2	1186000	4	100	1186000
3	14741000	46	100	14741000
4	4589000	14	100	4589000
5	388000	1	100	388000
6	6539000	21	100	6539000
Total	31777000	100		31777000

Figure 4.9 Print screen of step 2 of the rapid assessment tool (‘1.Rapid_Assessment_Tool_SD.xlsx’)

As a final step, before the user can see the results, selections in table 3 can be made (figure 4.10). Now the current landuse of the area that selected at ‘step 1’is shown. To estimate the possibility of farmers shifting to a higher value crop, it is possible to change the land use at ‘step 3’. The high value crop that is chosen is orchards as they have a higher turnover and a lower salt tolerance compared to conventional crops on Schouwen-Duiveland. The user can change the surface land use in an area by selecting a percentage that can be chosen from the drop down menu, such as ‘0%’, ‘10%’ or ‘20%’ of the chosen area. If the user decides to select a different surface area for one crop class, he should do the same for all crop classes, because the sum of all surface area must be 100%.



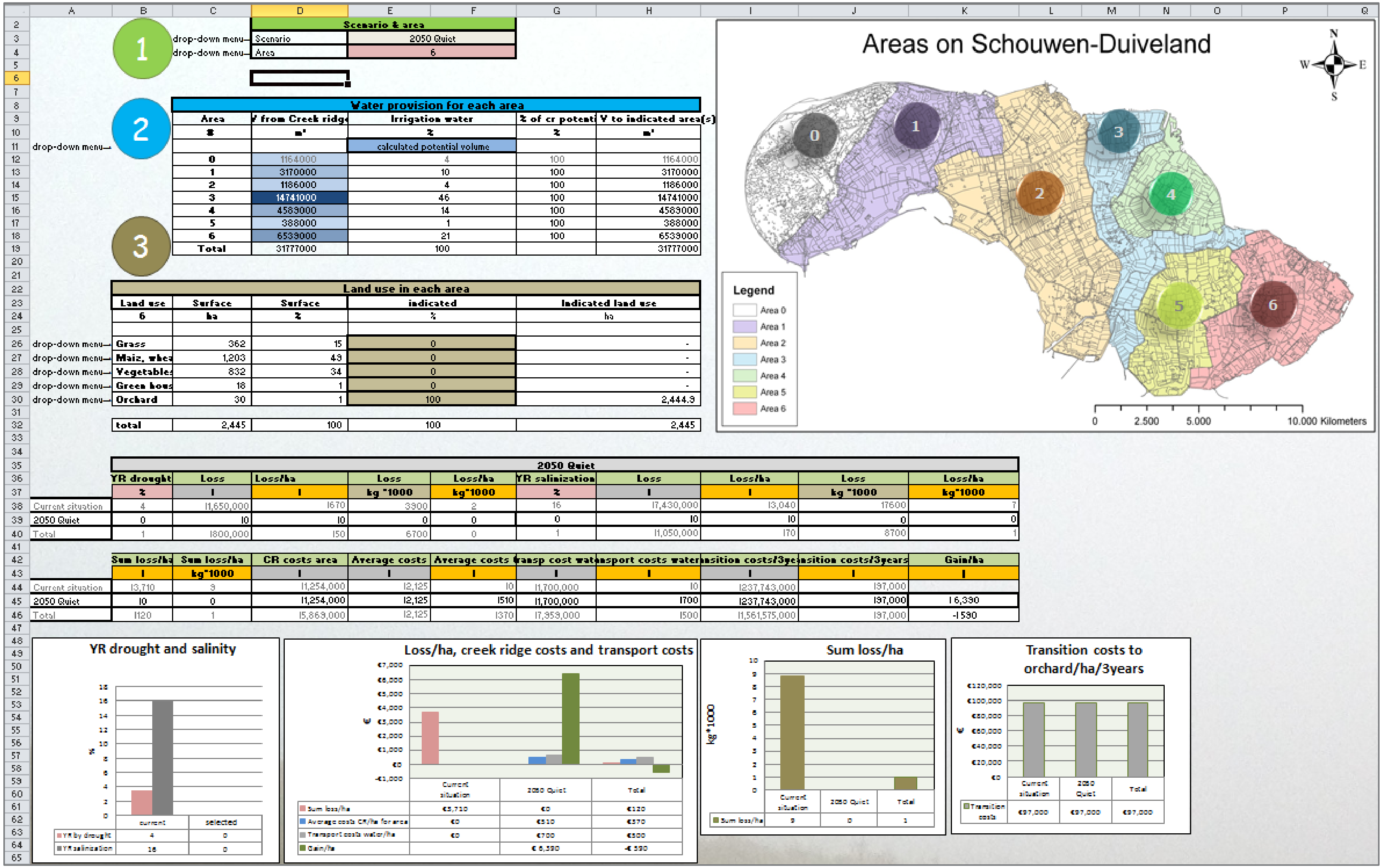
Land use in each area				
Land use	Surface	Surface	indicated	Indicated land use
1	ha	%	%	ha
Grass	574	19	actual land use	574
Maiz, wheat	1 490	50	actual land use	1 490
Vegetables	884	30	actual land use	884
Green house	-	-	actual land use	-
Orchard	40	1	actual land use	40
total	2 990	100	0	2 990

Figure 4.10 Print screen of step 3 of the rapid assessment tool (‘1.Rapid_Assessment_Tool_SD.xlsx’)

When the selections at all three steps have been completed, the output will be shown in the lower table on the screen (figure 4.11). From left to right it will show:

- the yield reduction (YR) by water deficit and salinity;
- an estimation of turnover loss in €/ha, the construction costs/ha and distribution costs/ha;
- an estimation on turnover loss in kg/ha;
- and transition costs to orchards.

Based on the output the user can decide if the created scenario is desirable.



drop-down menu— Scenario: 2050 Quiet
drop-down menu— Area: 6

Scenario & area	
Scenario	2050 Quiet
Area	6

drop-down menu—

Water provision for each area				
Area	V from Creek ridg	Irrigation water	% of cr potenti	V to indicated area(s)
#	m^3	%	%	m^3
		calculated potential volume		
0	1164000	4	100	1164000
1	3170000	10	100	3170000
2	1186000	4	100	1186000
3	14741000	46	100	14741000
4	4589000	14	100	4589000
5	388000	1	100	388000
6	6539000	21	100	6539000
Total	31777000	100		31777000

	Land use in each area				
	Land use	Surface	Surface	indicated	Indicated land use
	6	ha	%	%	ha
drop-down menu—	Grass	362	15	0	-
drop-down menu—	Maiz, whea	1,203	49	0	-
drop-down menu—	Vegetable:	832	34	0	-
drop-down menu—	Green hous	18	1	0	-
drop-down menu—	Orchard	30	1	100	2,444.9
	total	2,445	100	100	2,445

2050 Quiet

	YR drought	Loss	Loss/ha	Loss	Loss/ha	YR salinization	Loss	Loss/ha	Loss	Loss/ha
	%	€	€	kg *1000	kg*1000	%	€	€	kg *1000	kg*1000
Current situation	4	€1,650,000	€670	3900	2	16	€7,430,000	€3,040	17600	7
2050 Quiet	0	€0	€0	0	0	0	€0	€0	0	0
Total	1	€800,000	€50	6700	0	1	€1,050,000	€70	8700	1

	Sum loss/h	Sum loss/ha	CR costs area	Average costs	Average costs	ransp cost wat	nsport costs water	nsition costs/3ye	nsition costs/3years	Gain/ha
	€	kg*1000	€	€	€	€	€	€	€	€
Current situation	€3,710	9	€1,254,000	€2,125	€0	€1,700,000	€0	€237,743,000	€97,000	
2050 Quiet	€0	0	€1,254,000	€2,125	€510	€1,700,000	€700	€237,743,000	€97,000	€ 6,390
Total	€120	1	€5,869,000	€2,125	€370	€7,959,000	€500	€1,561,575,000	€97,000	-€ 590

	current	selected
YR by drought	4	0
YR salinization	16	0

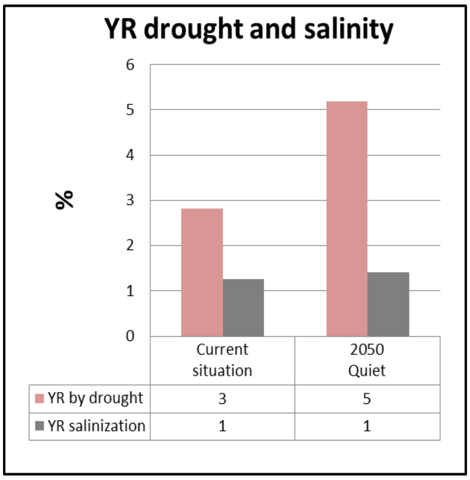
	Current situation	2050 Quiet	Total
Sum loss/ha	€3,710	€0	€120
Average costs CR/ha for area	€0	€510	€370
Transport costs water/ha	€0	€700	€500
Gain/ha		€ 6,390	-€ 590

	Current situation	2050 Quiet	Total
Sum loss/ha	9	0	1

	Current situation	2050 Quiet	Total
Transition costs	€97,000	€97,000	€97,000

Figure 4.11 Print screen of the rapid assessment tool ('1.Rapid_Assessment_Tool_SD.xlsx')

4.3.2 Output of the tool

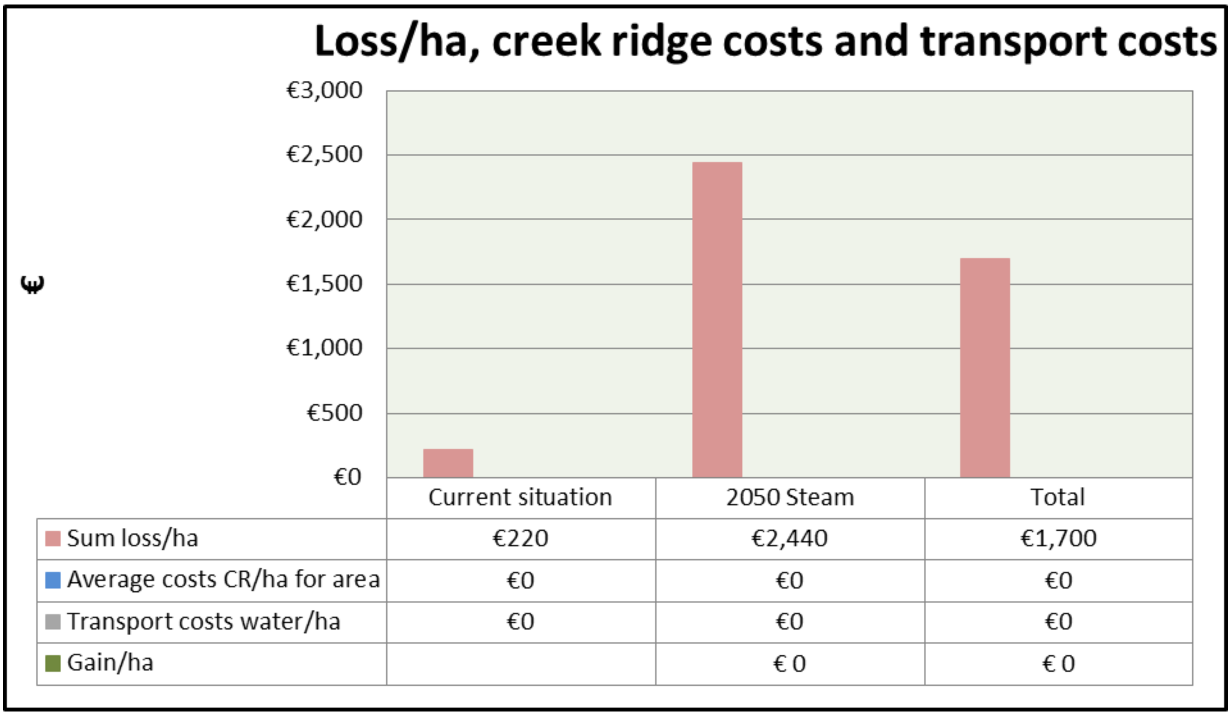


	Current situation	2050 Quiet
🟥 YR by drought	3	5
■ YR salinization	1	1

Figure 4.12 Yield Reduction by drought and salinity ('1.Rapid_Assessment_Tool_SD.xlsx')

The first table of on the bottom of the main page (figure 4.12) indicates the yield reduction by a water deficit and the salinity reduction. The first set of bars indicate the yield reductions in the current situation for a specific area. The second set of bars indicate the yield reduction for the selected area and the selected climate scenario.

The table below (figure 4.13) provides yield reduction for the selected area, this can be area 1 until 6, during the summer growth stage (the sum of yield reduction by drought and yield reduction by salinization). The first bar (left) shows the loss of yield in relation to the full potential yield per hectare for the climate scenario 'Current' in the selected area. The second bar (middle) shows the loss of yield the selected climate scenario . The third bar (right side) is an average of loss of yield, for the whole island for the selected climate scenario.



	Current situation	2050 Steam	Total
🟥 Sum loss/ha	€220	€2,440	€1,700
🟦 Average costs CR/ha for area	€0	€0	€0
■ Transport costs water/ha	€0	€0	€0
🟩 Gain/ha		€ 0	€ 0

Figure 4.13 Yield Reduction by drought and salinity expressed in loss/ha in € ('1.Rapid_Assessment_Tool_SD.xlsx')

Figure 4.14 is the same table as in figure 4.13, however in 4.14 the creek ridge measure has been applied and therefore also shows construction and distribution costs. The green bar in the middle of the graph (selected climate scenario, in this case; 2050 Quiet), shows the positive or negative output based on the selections made. This tells the user whether it is worthwhile investing in the creek ridge. In this example the gain/ha is €770, and thus is considered feasible.

'Total' is average of all the areas with 'actual land use' with the selected water distribution. Therefore 'actual land use' of an area can be compared to the effects on average for all the areas.

When selecting any other land use, the total will show the average of the selected area with different land use and all the other areas, with the ‘actual land use’. For this reason, the outcome cannot be compared with the average of the island.

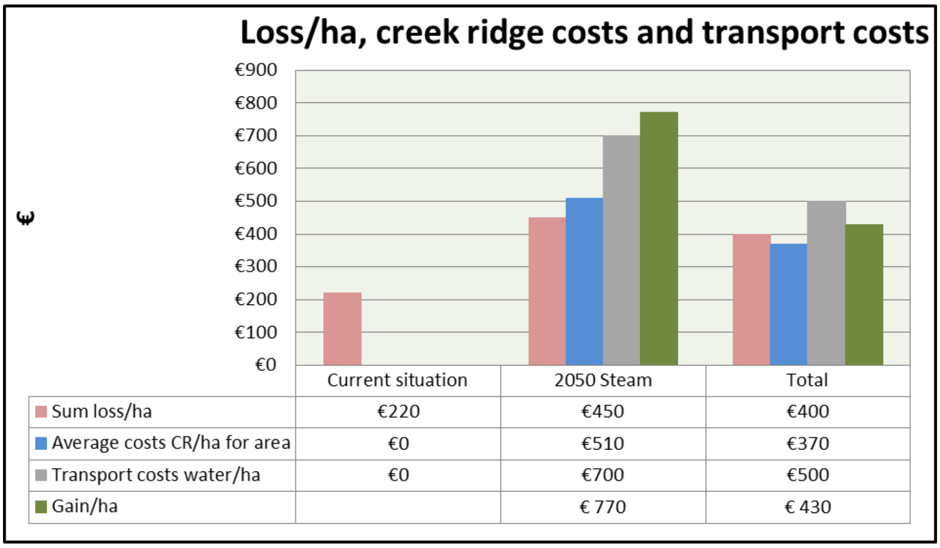


Figure 4.14 Yield Reduction in drought and salinity, construction costs, transport costs per hectare in € and the benefit per hectare when applying the creek ridge measure per hectare in € (‘1.Rapid_Assessment_Tool_SD.xlsx’)

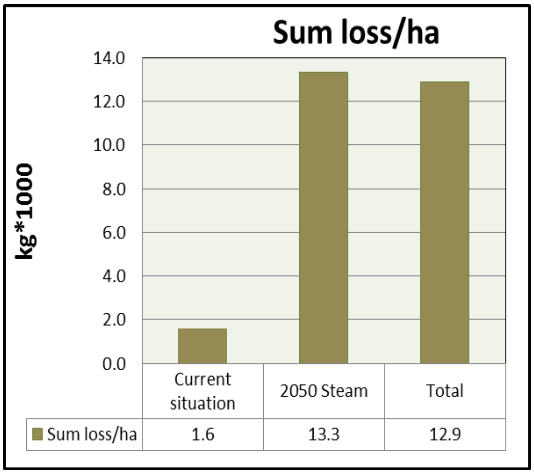


Figure 4.15 Loss in kg per hectare

In figure 4.13 and 4.14 loss/ha is expressed in €. Farmers do not express yield in euros because the agricultural product is market dependant. This means the price can vary between seasons, without being dependant on the quality, but on supply and demand. Expressing the yield in kilograms says much more about the quality, therefore a graph is added that shows the loss in kg/ha (figure 4.15). The output in euros/ha is a conversion from the loss in kg/ha calculated using figures from LEI (2012).

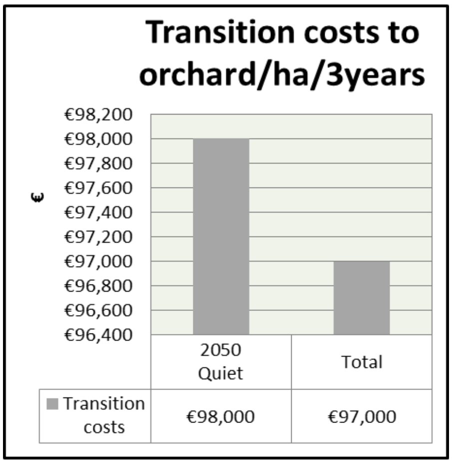


Figure 4.16 Transition cost

The graph on the left (figure 4.16) shows the transition costs based on Peppelman & Groot (2004) and represent all costs involved for the transition to fruit trees. These costs are roughly €100.000 for a period of three years per hectare. This graph is only produced when crop classes orchard is changed (higher than 0%) in step 3. The difference in cost occur, because there is already orchard land use in some other areas. Here no transition costs are made, therefore the average of the transition costs for the whole island are less.

Note: that the scale in the graph is small.

4.4 Theory of physics

To estimate the water use in agriculture on Schouwen-Duiveland the Penman-Monteith equation is used. This equation estimates the evapotranspiration rate of water through plants. Calculations are made for different crops, resulting in different water uses for each different land use in different climate scenarios.

Salinization has a significant effect on the transpiration of plants and the wellbeing of plants. Therefore the salinization of soils influences water use by plants significantly. Transpiration and salinization is explained below.

Transpiration

Transpiration is the release of water vapour and oxygen though the stomata. When moisture is limited, the stomata close to slow transpiration and conserve water. In the case of saline water the stomata close, preventing the crop from up taking saline water. When the stomata of the plant close, it transpires less. Water vapour is known as actual transpiration and equals crop water use. Photosynthesis cannot occur when the stomata are closed, and thus growth stops (Polman *et al.*, 2012). You can read more on the calculation of the crop water use in the methodology chapter 4.5.1.

Stomata play a crucial role in crop transpiration as they are opened by the adjacent cells that have enough ‘strength’ to open the stomata to a certain (crop dependant) potential. When this potential increases owing to a higher atmospheric demand, dehydration of the soil, or salinization occur. The stomata close as the adjacent cells become flaccid causing the resistance of the plant to increase and the transpiration to decrease. The potential transpiration of a crop equals the maximum evapotranspiration of a crop. (Roest *et al.*, 2003; Polman *et al.*, 2012). In this research the transpiration of a crop is described as the crop water requirement.

There is different meteorological and physiological data required for estimating the potential crop transpiration, such as temperature, humidity, radiation, wind speed and crop specific properties. As most of these vary throughout the year, an average over 30 years is used, and predictions are made by the KNMI using the KNMI’06 scenarios.

To water demand of a crop depends on the soil moisture in the root zone. To subtract water from the soil, plants have to create negative pressure in relation to the pressure of the water in the soil. The maximum negative pressure a plant can create is called the wilting point. If the pressure of the moisture drops below the maximum negative pressure point a plant has, it cannot uptake anymore water from root zone. So the moisture that is available for the plant is the moisture at field capacity minus the moisture at wilting point. Every soil type has different water holding capacities. In general sandy soils have a low water holding capacity and are more sensitive to droughts (FAO, auteurs 1998; Polman *et al.*, 2012).

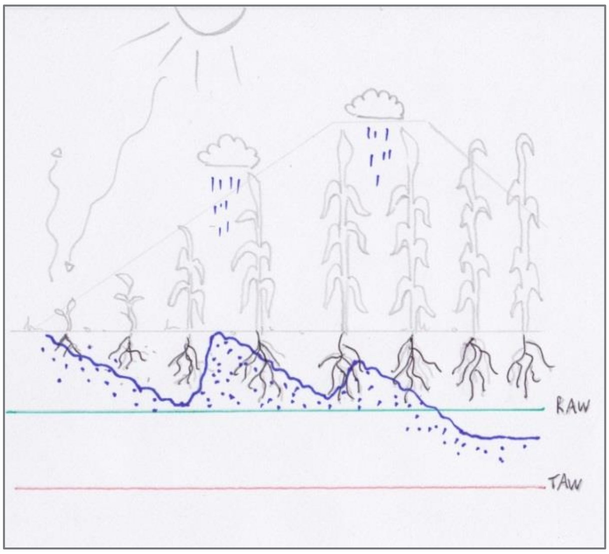


Figure 4.17 Visualisation of crop growth stages and available water (FAO, 1998)

A shortage of water leads to crop damage, but different crops have different responses to water deficit. Sensitivity of crops also differs within a growing season depending on the stage of growth a crop is in and this differs for each crop. For example grains are more sensitive to drought at the initial stage, while in the late season their sensitivity lessens. (figure 4.17 visualises growth stages) (Polman *et al.*, 2012).

Salinization

Salinization occurs when the level of chloride in ground water or surface water increases. In the southwestern delta groundwater is saline because of past seawater intrusion and marine transgression. Some areas lie below the mean sea level, and in these areas saline water can reach the surface by upward ground water flow. This is called seepage. Seepage leads to salinization of the surface water and shallow fresh groundwater bodies and makes the water unsuitable for agricultural purposes. A future rise in sea level is expected to increase seepage and salt load amounts in surface water and reduce the availability of both fresh surface water and ground water (de Louw *et al.*, 2011).

Roest *et al.*, explains (2003) that crop damage by salinization occurs when crops come in to contact with water that is brackish of saline. The saline water, as mentioned above, comes from the upward ground flow of water. Sometimes a crops are irrigated with brackish water. In general, damage by salinization is caused by an osmotic effect. Because the presence of chloride in soil has an osmotic effect, it reduces the availability of moisture that is ready for uptake by roots in the root zone (figure 4.18)

The sensitivity of crops to chloride in the root zone differs per crop and may vary depending on environmental factors. First of all the climate is important as it determines transpiration and growth. When transpiration and thus water absorption is higher, it becomes more difficult for the plant to exclude Cl-iones. The chloride tolerance of crops is lower when transpiration (determined by temperature, radiation and humidity) is higher. Also the aeration of the soil is of importance. The active exclusion of salts by the roots requires energy from the plant, obtained by the respiration of the plant. There needs to be enough oxygen for this respiration to occur (van Dam *et al.*, 2007; Roest *et al.*, 2003).

If soil becomes too saline, cultivating certain current produced crops becomes impossible. To prevent this different measures can be taken. One of the solutions to salinization could be switching to a salt tolerant crop, such as sea kale, different types of beet, quinoa or asparagus, (Stuyt *et al.*, 2006). Another option is to irrigate with fresh water. Schouwen-Duiveland has a lower precipitation surplus compared to other parts of the Netherlands and it is hardly possible to irrigate on Schouwen-Duiveland. The resulting crop damage leads to economic damage (van Baaren & Harezlak, 2011). In the tool the irrigation is assumed to be fresh because water is flowing from the creek ridge area that have relative thick lenses and contain fresh water. In this research crop damage by salinization occurs when there is a water deficit.

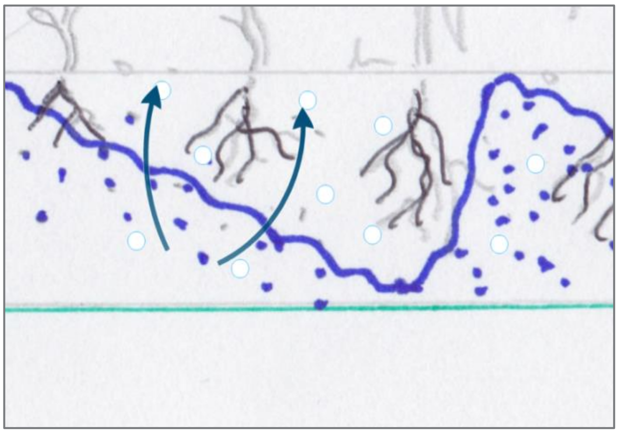


Figure 4.18 Salinisation reduces the availability of moisture ready for uptake by the roots (Roest *et al.*, 2003)

4.5 Calculations for yield reduction

There is a relation between yield reduction and water shortage of a crop (FAO, 1998). To determine the water shortage the water availability and the water use needs to be estimated. The water use of a crop is calculated according to the calculation steps that can be read in this chapter. Below the process of evaporation is explained based on the calculation method of the FAO (1998)[6]. Further down in subsection 4.5.1 a relation with yield reduction by salinization is made.

4.5.1 Calculations for yield reduction by a water deficit from FAO

Evapotranspiration
Evapotranspiration (ET) is the combination of two different processes, (1) evaporation and (2) transpiration. Evaporation is water that evaporates from the soil into the atmosphere, while transpiration is water that evaporates from the leafs of the plant. When water is evaporating, liquid water is converted to water vapour and removed from the evaporating surface. Energy is required to change the state of the molecules of water from liquid to vapour. Direct solar radiation and to a lesser extent, the ambient temperature of dry air provide this energy. The driving force of removing water vapour from a surface is the difference in pressure between the atmosphere and the surface. When the atmosphere is becoming saturated, evaporation slows down. The replacement of saturated air by dryer air depends on solar radiation, wind speed, air temperature and air humidity. All these parameters are included in calculating the evaporating process (FAO, 1998).

Transpiration consists of the vaporization of liquid water contained in the plant tissues and the vapour removal to the atmosphere. Crops lose their water through stomata, small openings on the plant leafs through which gasses and water vapour pass. Water together with nutrients is taken up from the soil by the roots, and is transported through the plant. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant. Like evaporation, transpiration depends on energy supply, vapour pressure and wind. Hence radiation, air temperature, air humidity. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate. The plant characteristics, environmental aspects and cultivation practices also influence the transpiration rate (FAO, 1998).

Evaporation and transpiration is happening simultaneously. Evaporation from a soil where a crop is planted is mainly determined by solar radiation reaching the soil surface. When a crop is small, water is lost predominately by evaporation, but once a crop is well developed and completely covers the soil, water is mainly lost by transpiration (FAO, 1998).

Calculations
The output of the calculations, to determine the yield reduction due to water deficit, are described in this chapter and is shown in tables for each climate scenario ('Current', '2050 Quiet' and '2050 Steam', figure 4.19). These calculations are repeated twice for each crop class in each scenario, once without water from the creek ridge and once with water provided by the creek ridge measures.

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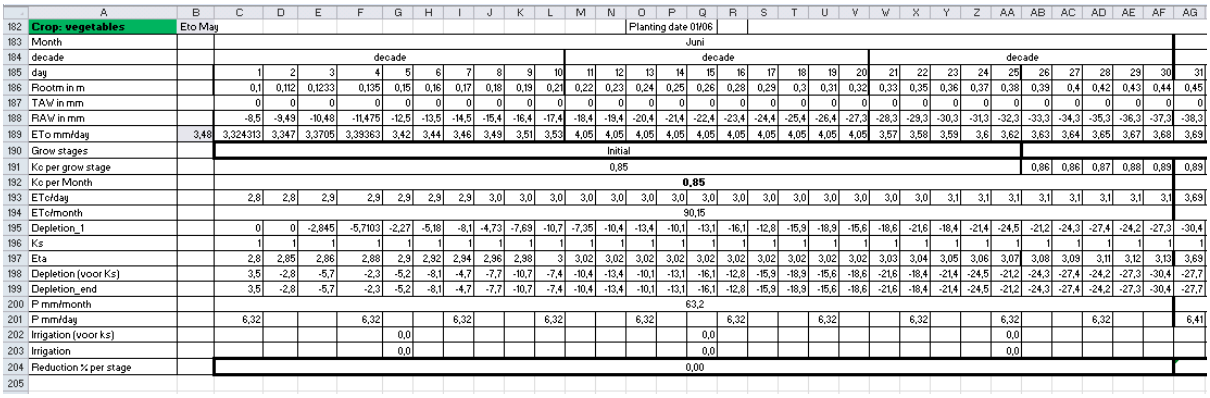
[6] This literature is relatively old, and new methods do exist, such as AQUACROP (FAO). Because the calculation method needed to be built in the spreadsheet, the Irrigation and drainage paper 56 from the FAO (1998) is chosen, since all the calculation steps are seperate from any program, and therefore could be implemented in the spreadsheet.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
182	**Crop: vegetables**	Eto May													Planting date 01/06																		
183	Month		Juni																														
184	decade		decade										decade										decade										
185	day		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
186	Rootm in m		0,1	0,112	0,1233	0,135	0,15	0,16	0,17	0,18	0,19	0,21	0,22	0,23	0,24	0,25	0,26	0,28	0,29	0,3	0,31	0,32	0,33	0,35	0,36	0,37	0,38	0,39	0,4	0,42	0,43	0,44	0,45
187	TAW in mm		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
188	RAW in mm		-8,5	-9,49	-10,48	-11,475	-12,5	-13,5	-14,5	-15,4	-16,4	-17,4	-18,4	-19,4	-20,4	-21,4	-22,4	-23,4	-24,4	-25,4	-26,4	-27,3	-28,3	-29,3	-30,3	-31,3	-32,3	-33,3	-34,3	-35,3	-36,3	-37,3	-38,3
189	ETo mm/day	3,48	3,324313	3,347	3,3705	3,39363	3,42	3,44	3,46	3,49	3,51	3,53	4,05	4,05	4,05	4,05	4,05	4,05	4,05	4,05	4,05	4,05	3,57	3,58	3,59	3,6	3,62	3,63	3,64	3,65	3,67	3,68	3,69
190	Grow stages		Initial																														
191	Kc per grow stage		0,85																									0,86	0,86	0,87	0,88	0,89	0,89
192	Kc per Month		**0,85**																														
193	ETc/day		2,8	2,8	2,9	2,9	2,9	2,9	2,9	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,69
194	ETc/month		90,15																														
195	Depletion_1		0	0	-2,845	-5,7103	-2,27	-5,18	-8,1	-4,73	-7,69	-10,7	-7,35	-10,4	-13,4	-10,1	-13,1	-16,1	-12,8	-15,9	-18,9	-15,6	-18,6	-21,6	-18,4	-21,4	-24,5	-21,2	-24,3	-27,4	-24,2	-27,3	-30,4
196	Ks		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
197	Eta		2,8	2,85	2,86	2,88	2,9	2,92	2,94	2,96	2,98	3	3,02	3,02	3,02	3,02	3,02	3,02	3,02	3,02	3,02	3,02	3,03	3,04	3,05	3,06	3,07	3,08	3,09	3,11	3,12	3,13	3,69
198	Depletion (voor Ks)		3,5	-2,8	-5,7	-2,3	-5,2	-8,1	-4,7	-7,7	-10,7	-7,4	-10,4	-13,4	-10,1	-13,1	-16,1	-12,8	-15,9	-18,9	-15,6	-18,6	-21,6	-18,4	-21,4	-24,5	-21,2	-24,3	-27,4	-24,2	-27,3	-30,4	-27,7
199	Depletion_end		3,5	-2,8	-5,7	-2,3	-5,2	-8,1	-4,7	-7,7	-10,7	-7,4	-10,4	-13,4	-10,1	-13,1	-16,1	-12,8	-15,9	-18,9	-15,6	-18,6	-21,6	-18,4	-21,4	-24,5	-21,2	-24,3	-27,4	-24,2	-27,3	-30,4	-27,7
200	P mm/month		63,2																														
201	P mm/day		6,32			6,32			6,32			6,32			6,32			6,32			6,32			6,32			6,32			6,32			6,41
202	Irrigation (voor ks)						0,0										0,0										0,0						
203	Irrigation						0,0										0,0										0,0						
204	Reduction % per stage		0,00																														
205																																	

Figure 4.19 Tables that combine outcome of the calculations (1.Rapid_Assessment-Tool_SD.xlxs)

Climate data for ETo

In 1948 Penman combined the energy balance with mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This combination method was further developed by many researchers and extended to cropped surfaces (surface with a planted crop) by introducing resistance factors (figure 4.20) (FAO, 1998).

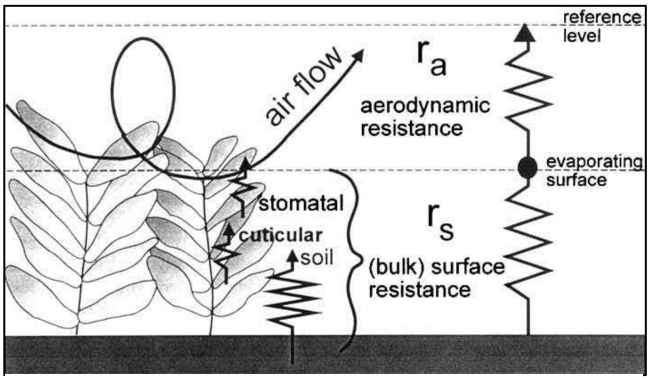


Figure 4.20 Evapotranspiration formula (FAO, 1998)

A distinction is made between aerodynamic resistance (r_a) and surface resistance (r_s). The surface resistance parameters are often combined into one parameter. The surface resistance describes the vapour flow through the stomata openings, total leave area and soil surface. The aerodynamic resistance describes the resistance from the vegetation upward and involves friction from air flow over vegetative surface. The exchange process in a vegetation layer is too complex to be fully described by two resistance factors. Good correlations can be obtained between measured and calculated evapotranspiration rates. This is done for a uniform grass reference surface and this standardized evapotranspiration for grass is referred to as ET_o (figure 4.21) (FAO, 1998).

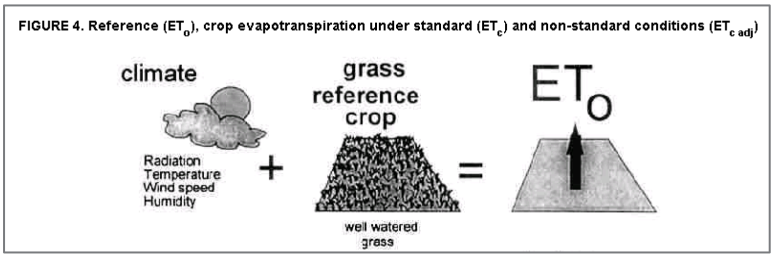


Figure 4.21 Evapotranspiration for reference crop (FAO, 1998)

From the original Penman-Monteith (FAO equation 3), the equation of the aerodynamic (FAO equation 4), and the surface resistance (FAO equation 5), the FAO Penman-Monteith method to estimate ET_o can be derived (FAO, 1998). The ET_o calculates different evapotranspiration rates at different periods in year or regions and the evapotranspiration of different crops can be related to it (equation 4.1)[7].

---

[7] At each formula below, a number is given between brackets on the right side. In case of equation 4.1 this is number 6. This number refers to the equation number in the Irrigation and drainage paper 56 from the FAO (1998). Also these number correspondent with the equation number tab 'ETo' of 2.Backdoor_Tool.xlxs (figure 4.23)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (6)$$

Equation 4.1

ET_o	reference evapotranspiration	mm day^{-1}
R_n	net radiation at the crop surface	MJ m^{-2-} day^{-1}
G	soil heat flux density	MJ m^{-2-} day^{-1}
T	mean daily air temperature at 2 m height	°C
u_2	wind speed at 2m height	m s^{-1}
e_s	saturation vapour pressure	kPa
e_a	actual vapour pressure	kPa
e_s-e_a	saturation vapour pressure deficit	kPa
Δ	slope vapour pressure curve	kPa $°C^{-1}$
ᵞ	psychometric constant	kPa $°C^{-1}$

The FAO Penman-Monteith equation also requires air temperature, humidity, radiation and wind speed data. Most of these parameters is obtained from the KNMI (2006) (figure 4.22). The data is used for the scenarios in present time and for the 2050 scenarios. The scenarios '2050 Quiet' and '2050 Steam' are based on the KNMI'06 (2006) climate scenarios. The climate data is represented in the tab 'climate data' of the 1.Rapid_Assessment-Tool_SD.xlxs. The climate data for the scenario 'Current' is retrieved from 30 year averages from the KNMI (2012).

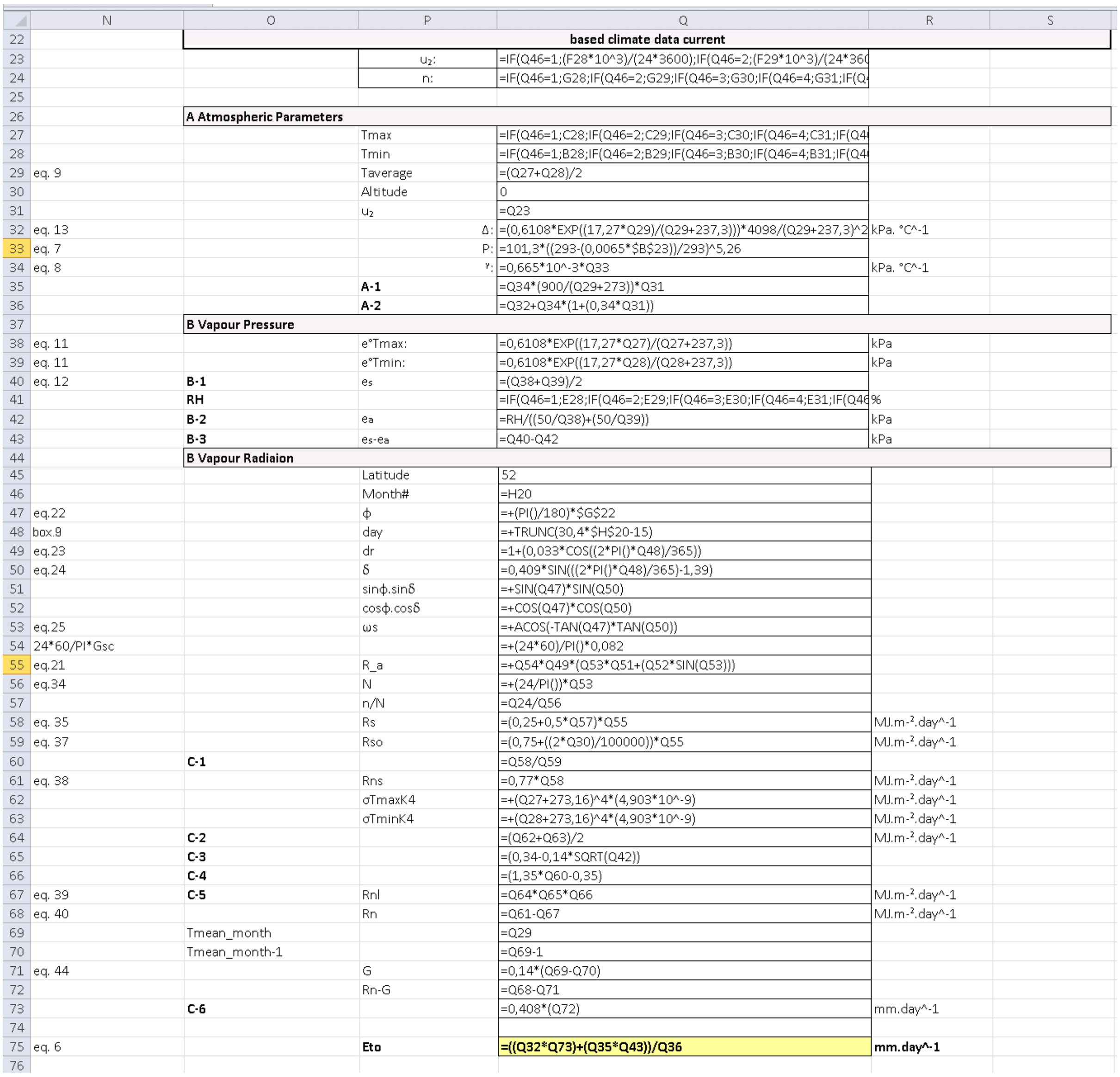
Vlissingen, langjarige gemiddelden, tijdvak 1981-2010

310	Temperatuur(℃)	Relatieve vochtig-heid %	Neerslag	Ver-dam-ping	Globale Straling	Zonneschijn	Lucht druk	Wind			
								Pot. wind	Gem. wind	Wind-vector	Aantal dagen met windkracht

Figure 4.22

Overview of calculations

Below (figure 4.23) a print screen is added from the Excel file ‘2.Backdoor_Tool.xlxs’. This sheet presents the calculations explained above and from appendix III. For more detail see the Excel file, tab ET_o. In the 1st column the number of the equation can be read, that correspondent with the numbers given in the calculation steps.



	N	O	P	Q	R	S
22		**based climate data current**				
23			u_2:	=IF(Q46=1;(F28*10^3)/(24*3600);IF(Q46=2;(F29*10^3)/(24*36		
24			n:	=IF(Q46=1;G28;IF(Q46=2;G29;IF(Q46=3;G30;IF(Q46=4;G31;IF(Q		
25						
26		**A Atmospheric Parameters**				
27			Tmax	=IF(Q46=1;C28;IF(Q46=2;C29;IF(Q46=3;C30;IF(Q46=4;C31;IF(Q4		
28			Tmin	=IF(Q46=1;B28;IF(Q46=2;B29;IF(Q46=3;B30;IF(Q46=4;B31;IF(Q4		
29	eq. 9		Taverage	=(Q27+Q28)/2		
30			Altitude	0		
31			u_2	=Q23		
32	eq. 13		Δ:	=(0,6108*EXP((17,27*Q29)/(Q29+237,3)))*4098/(Q29+237,3)^2	kPa. °C^-1	
33	eq. 7		P:	=101,3*((293-(0,0065*$B$23))/293)^5,26		
34	eq. 8		γ:	=0,665*10^-3*Q33	kPa. °C^-1	
35			**A-1**	=Q34*(900/(Q29+273))*Q31		
36			**A-2**	=Q32+Q34*(1+(0,34*Q31))		
37		**B Vapour Pressure**				
38	eq. 11		e°Tmax:	=0,6108*EXP((17,27*Q27)/(Q27+237,3))	kPa	
39	eq. 11		e°Tmin:	=0,6108*EXP((17,27*Q28)/(Q28+237,3))	kPa	
40	eq. 12	**B-1**	es	=(Q38+Q39)/2		
41		**RH**		=IF(Q46=1;E28;IF(Q46=2;E29;IF(Q46=3;E30;IF(Q46=4;E31;IF(Q46	%	
42		**B-2**	ea	=RH/((50/Q38)+(50/Q39))	kPa	
43		**B-3**	es-ea	=Q40-Q42	kPa	
44		**B Vapour Radiaion**				
45			Latitude	52		
46			Month#	=H20		
47	eq.22		ϕ	=+(PI()/180)*$G$22		
48	box.9		day	=+TRUNC(30,4*$H$20-15)		
49	eq.23		dr	=1+(0,033*COS((2*PI()*Q48)/365))		
50	eq.24		δ	=0,409*SIN(((2*PI()*Q48)/365)-1,39)		
51			sinϕ.sinδ	=+SIN(Q47)*SIN(Q50)		
52			cosϕ.cosδ	=+COS(Q47)*COS(Q50)		
53	eq.25		ωs	=+ACOS(-TAN(Q47)*TAN(Q50))		
54	24*60/PI*Gsc			=+(24*60)/PI()*0,082		
55	eq.21		R_a	=+Q54*Q49*(Q53*Q51+(Q52*SIN(Q53)))		
56	eq.34		N	=+(24/PI())*Q53		
57			n/N	=Q24/Q56		
58	eq. 35		Rs	=(0,25+0,5*Q57)*Q55	MJ.m-^{2}.day^-1	
59	eq. 37		Rso	=(0,75+((2*Q30)/100000))*Q55	MJ.m-^{2}.day^-1	
60		**C-1**		=Q58/Q59		
61	eq. 38		Rns	=0,77*Q58	MJ.m-^{2}.day^-1	
62			σTmaxK4	=+(Q27+273,16)^4*(4,903*10^-9)	MJ.m-^{2}.day^-1	
63			σTminK4	=+(Q28+273,16)^4*(4,903*10^-9)	MJ.m-^{2}.day^-1	
64		**C-2**		=(Q62+Q63)/2	MJ.m-^{2}.day^-1	
65		**C-3**		=(0,34-0,14*SQRT(Q42))		
66		**C-4**		=(1,35*Q60-0,35)		
67	eq. 39	**C-5**	Rnl	=Q64*Q65*Q66	MJ.m-^{2}.day^-1	
68	eq. 40		Rn	=Q61-Q67	MJ.m-^{2}.day^-1	
69		Tmean_month		=Q29		
70		Tmean_month-1		=Q69-1		
71	eq. 44		G	=0,14*(Q69-Q70)		
72			Rn-G	=Q68-Q71		
73		**C-6**		=0,408*(Q72)	mm.day^-1	
74						
75	eq. 6		**Eto**	**=((Q32*Q73)+(Q35*Q43))/Q36**	**mm.day^-1**	
76						

Figure 4.23 Print screen of calculation sheet in tab ‘ET_o’ (2.Backdoor_Tool.xlxs)

The calculations are elaborate, therefore continue in the appendix III.

4.5.2 Yield reduction by salinization

Chloride can cause damage in different ways (chapter 4.4). It can cause a reduction of moist by the roots of a plant reducing growth. And it has more effects, i.e. toxicity. Bakel & Stuyt (2011) explain that it is impossible to catch the relation of chloride and its effects in the root zone in a theory, as there is no sufficient knowledge on this.
In this research a yield reduction by chloride is assumed based on yield reduction figures. The yield reduction by salinity in the rapid assessment tool is linked to a water deficit. The crop damage by salinity is assumed to happen due to saline seepage. However the figures obtained to estimate this show a direct relations between chloride levels in irrigation water and yield reduction by the crop. These reduction figures are presented in the 'expert table' (appendix VI). The table is produced in the €ureyeopener project and is a second version in prep (L.C.P.M. Stuyt *et al.*, 2013).

Van Baaren *et al.* (2011) describe in 'zoetwatervoorziening Schouwen Duiveland' that different levels of chloride are present within five meters from the surface over the whole island, except for the dune area, ('area 0', page 1). These values are 500, 1000 and 1500 mg/l. As explained above, literature describes it is impossible to catch a theory describing the relation between levels of chloride and the yield reduction (Bakel & Stuyt ,2011), therefore an estimation is made[8]:

A crop has got a percentage of yield reduction by drought which is always the highest in scenario 'Steam 2050' (chapter 5). This percentage is divided in three ranges, e.g. a crop has a 10% yield reduction by a water deficit in scenario Steam 2050 without fresh water from the creek ridge, the following three ranges of yield reduction by chloride are determined.

>0 - 3.33% reduction by drought equals yield reduction by salinity for 500 mg/l
3.34 - 6.66% reduction by drought equals yield reduction by salinity for 1000 mg/l
6.67 - 10% reduction by drought equals yield reduction by salinity for 1500 mg/l

When fresh water is applied in the same scenario it can be expected the yield reduction by drought will decrease, consequently decreasing the yield reduction by salinity.

4.6 Interviews

During the research four farmers were interviewed on Schouwen-Duiveland (figure 4.26) with the aim to validate the data. All the farmers that were visited had different types of farms and different land uses, included in the whole range of crop classes that are described in the rapid assessment tool. The farmers and their practices were: (1) Giles Klompe; vegetables, wheats, and more (2) Senny Capelle; orchards and packing of fruit from abroad (3) Dick van Noord; Tomatoes in green houses, (4) Huub Remijn; vegetables and wheat (appendices IV and V). The interviews were conducted together with Thomas Boerman, student of the University of Utrecht. The guidelines for the questions can be found in appendix IV and a summary of the interviews can be found in appendix V.

The interviews were based on the semi-structured interview technique. Semi-structured interviews are conducted with a fairly open framework, which allows for focused conversation and a two-way discussion. Relevant topics with related questions formed the base of the interviews. During the interviews there was the opportunity for questions that arose during the interview, allowing both the interviewer and the interviewee, the flexibility to go into details or discuss issues. (Gilham, B.,

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[8] Chloride in the root zone causes higher crop stress compared to irrigation water. Therefor the estimation are on the low (safe) side.

2005). Gilham (2005) states that semi-structured interviews are an important way of conducting research, as they provide both flexibility and structure, and a high quality of data can be obtained. The disadvantages are the costs involved, as it takes time for preparation and the level of analyses, interpretations and presentation of the interview material.

Semi-structured interviews have the following properties:

- The same questions are asked of all those involved.
- The kind and form of questions go through a process of development to ensure their topic focus.
- Interviewees are prompted with questions about certain topics if they have not dealt with the topic of interest spontaneously.
- The duration of different interviews are approximately equal.
- Questions are open, for example, ‘what do you think of…’,’what is your point of view on…’.
- Hints are used according to whether the interviewer judges there is more to be disclosed at a particular point in the interview.

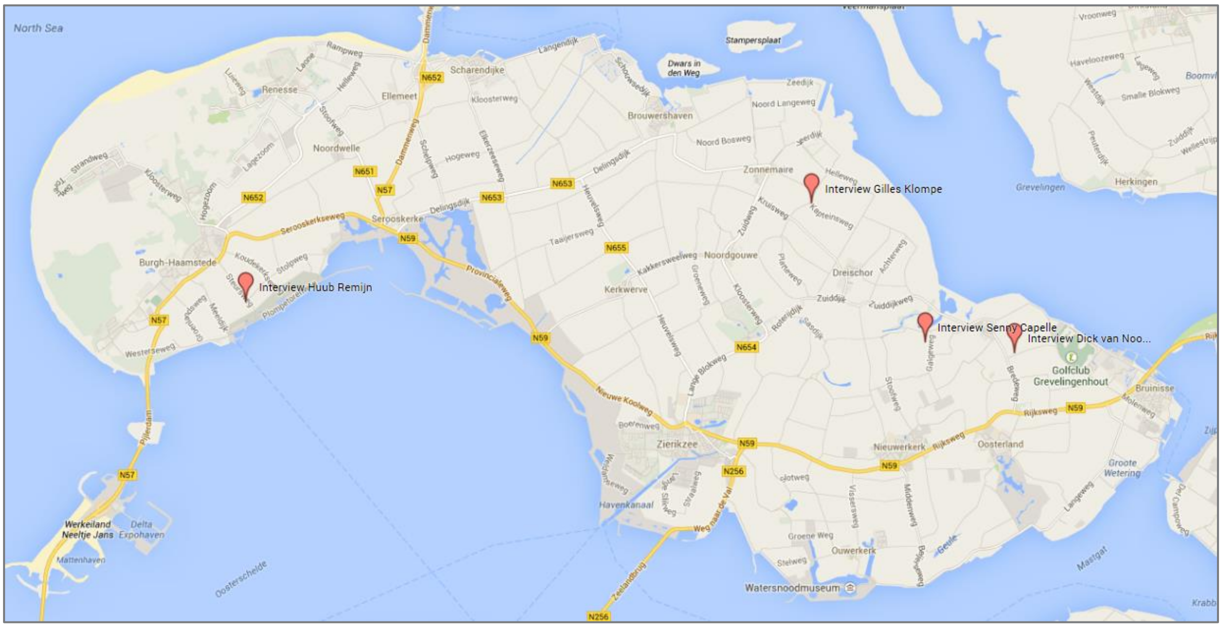


Figure 4.26 Location of interviews on Schouwen-Duiveland (Google Maps, 2014)

The goal of the interviews was to gather information from the farmers on different farming practices on Schouwen-Duiveland, touching on issues such as water use and the growth stages. This is used for the validation of data, for example the turnover per hectare, and yield/hectare.

5. Results and analyses

In this chapter the results and analyses are shown. In subsection 5.1 an overview is given of fresh water supply and demand for agriculture on Schouwen-Duiveland, the results of the interviews and e different output of the rapid assessment tool. To visualize the outcomes of the supply and demand of fresh water for agriculture, tables are used (table 5.1 and 5.2). The output of the rapid assessment tool is shown in the tool itself. In the tool a high number of outcomes are possible (subsection 5.1.3). Because of the high number of possible outcome it is impossible to show them all, therefore the output of different possibilities are shown that are most relevant or interesting. More options are provided in tables 5.3 to 5.8 in subsection 5.2. In subsection 5.3 a comparison is made with the €ureyeopener project.

5.1 Results

An overview of the fresh water supply and demand for agriculture is given in this subsection. These figures are not retrieved from the main page in the rapid assessment tool and are not a result of the selections that are made in steps 1, 2 and 3. The supply demand are given in the tabs 'area 1', 'area 2', etc. in 1.rapid_rapid_assessment_tool_SD.xlxs and are found under evapotranspiration (ET_c), precipitation , irrigation requirement, and precipitation (P).

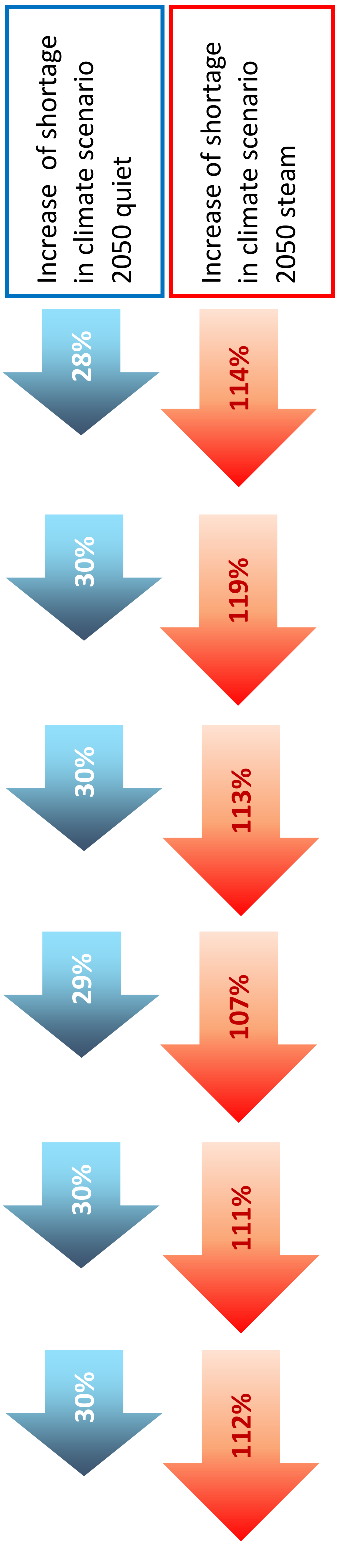
Table 5.1, on the next page, shows the fresh water demand, precipitation, shortage and available fresh water from the creek ridge in different climate scenarios. The arrows in blue and red on the right hand side of the table indicate the increase in shortage as a percentage. This excludes the available water from the creek ridge.

5.1.1 Water supply demand

In the table below the water demand, precipitation, shortage and available fresh water from the creek ridge is given per area and scenario, with the 'actual land use'. From here it can be read what the increase of shortage is for each climate scenario per area.

Table 5.1 Water supply and demand and the increase of water shortage in climate scenario 2050 Quiet and 2050 Steam compared to Current with current land use. The arrows on the right side represent the % increase and correspond with the blue and red aligned cells.

Area	Climate scenario	Water demand current	precipitation[9]	Shortage	Available from creek ridge
	mm	mm	mm	mm	mm
1	Current	482	380	102	53
	Quiet	521	391	130	53
	Steam	565	346	218	53
2	Current	494	394	99	12
	Quiet	535	406	129	12
	Steam	581	364	217	12
3	Current	475	373	102	383
	Quiet	518	385	133	383
	Steam	557	339	217	383
4	Current	456	352	105	144
	Quiet	497	362	135	144
	Steam	531	314	217	144
5	Current	472	370	103	10
	Quiet	514	381	134	10
	Steam	553	336	217	10
6	Current	470	368	102	134
	Quiet	511	379	133	134
	Steam	549	333	216	134



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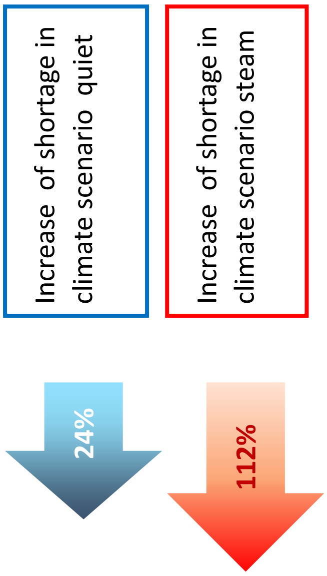
[9] Precipitation data is from different months that correspond with growth stages. Therefore precipitation is different per area.

In the table below the same information is given as in the previous, ecept the land use is now completely changed to orchards.

Table 5.2[10] Water supply and demand and the increase of water shortages in climate scenario 2050 Quiet and 2050 Steam in relation to the Current situation with orchards as the chosen land use. The arrows on the right side represent the % increase and correspond with the blue and red aligned cells.

Area	Climate scenario	Water demand current	precipitation	Shortage	Available from creek ridge[11]
	mm	mm	mm	mm	mm
Same for all areas	Current	513	414	99	
	Quiet	550	426	123	
	Steam	624	414	210	



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[10] Water demand, precipitation, shortage and availability are the same for all regions, since all land use is set on orchard in this table.

[11] Water availability per areas is different for each area. See table 5.1 for water availability from the creek ridge per area.

5.1.2 Results interviews

From the interviews was learned that a yield reduction by water deficit or a fresh water shortage is one factor, while there are many other factors that a farmer has to deal with when practising his profession. Climate wise there are also other factors like temperature and sun hours that can have positive and/or negative effect on yield. On a practical level there are things such as labour, machinery, crop choices, market, drainage, etc., all kinds of factors that influence the farmer daily practices running the company. Or as Mr Klompe said: “there is never one cause”.

From Mr Capelle and Mr van Noord was learned that farmers already use water storage in the form of basins. For green houses, logically, the water has to come from another source rather than the soil. In case orchards, a fresh water basin is used for drip irrigation. In both cases mentioned, the basins can be insufficient to provide water for the irrigation during dry spells. For orchard fresh water can also be used for another purpose during frost periods; by spraying water on the trees during sub-zero temperatures it prevents the buds from frost damage.

Mr Remijn stated that farmers accept a certain scarcity and appreciate 70%-80% they get from the optimal yield. Remijn seemed to be an exception to the other comparable farmers as he invests in water security himself. It takes a higher labour intensity to get extra fresh water availability and increase yield. For example, Remijn was the only farmer that uses the wastewater from a recreational area nearby. The fresh water is not useful for everything, for example green leaved vegetables such as spinach. In a dry spring in 2011 other farmers used trucks to distribute water, while Remijn did not need to do that. Klompe said distributing trucks is not cost effective.

The farmers could not exactly tell how much water a crop requires in mm, per growth stage or season, but they do mention €/kg. These figures come close to what is mentioned by LEI. For example, a famer mentions his farm has a €3500/ha gross turnover, including crops like wheat’s potatoes and unions. This is about the average from the figures that LEI (2012) provide on their website.

One thing that is important and that all interviewed farmers emphasize on, is that the price it not such an important indicator, as it can fluctuate because of the market. When all farmers have a good yield, the supply goes up, leading to a lower price and visa versa. Therefore the kg/ha say much more about a yield quality, rather than a high price.

Finally, all farmers were interested in the creek ridge measure. Only Remijn added, that also the creek ridge measure will most likely have its restrictions, for example an impermeable layer or no available fresh water nearby to contain. Every situation will be different, and therefore all options should be taken in to account. He explains there are more strategies to think of, such as fresh water provision from the Volkerak Zoommeer, the East part of the Haringvliet, run off from dunes, or deep subsurface fresh water aquifers below saline subsurface aquifers.

High lights from the interview:

- There is never one cause for yield reduction.
- Scarcity of fresh water for agriculture is happening in certain summers.
- Certain farm practices have fresh water reservoirs.
- Farmers usually express yield in kg/ha, rather than €/ha.
- Farmers excepts a certain degree of yield reduction.
- On average there is a turnover of approximately €3500/ha.

5.1.3 Outputs of the rapid assessment tool

In the rapid assessment tool there are different options that can be chosen that will lead to an output. Below all options possible are schematized (figure 5.1). When multiplying all options the number of different output is known; 3*6*4*10*1*11 equals 7920 options[12]. In this chapter the output of the tool will be assessed, but not for all possible output options. In chapter 5.2 a more elaborate output is given.

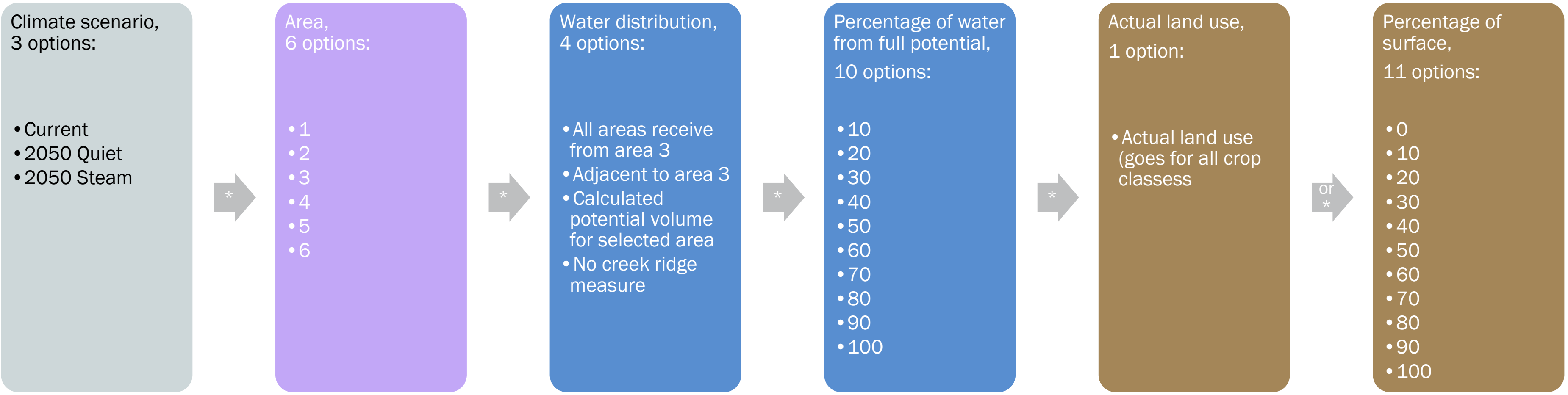

Figure 5.1 Options possible in the rapid assessment tool

Water distribution:

- All areas receive from area 3: water is distributed from the creek ridges in area 3, to all areas.
- Adjacent to area 3: water is distributed from the creek ridges in area to adjacent areas (not area 6).
- Calculated potential volume for selected area: water from the creek ridges is used in the same area.
- No creek ridge measure: no extra water is available

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[12] The number can be larger. When choosing a percentage of surfaces of the chosen area, at the final step, it has to be repeated five times for all crop classes. These selections have to add up to a total of 100%. Selecting a percentage for one crop class might, or might not, rule out the options for the other crop classes, e.g. selecting 100% for one crop class, consequently forces the user to select 0% for all the other crop classes, etc.

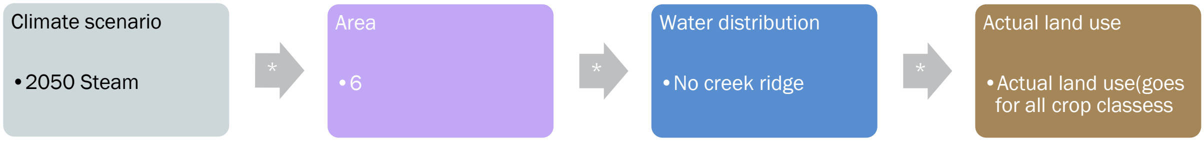
Below, one of the output tables is shown of two area as an example. All areas have a different surface area suitable for the creek ridge measure. Some areas have a relative small surface area suitable (area 5 followed by 2), while other areas can have a relative large suitable surface area (area 3, followed by 6). Below the output is given from area 6. And output tables are shown with orchard as land use in area 1.

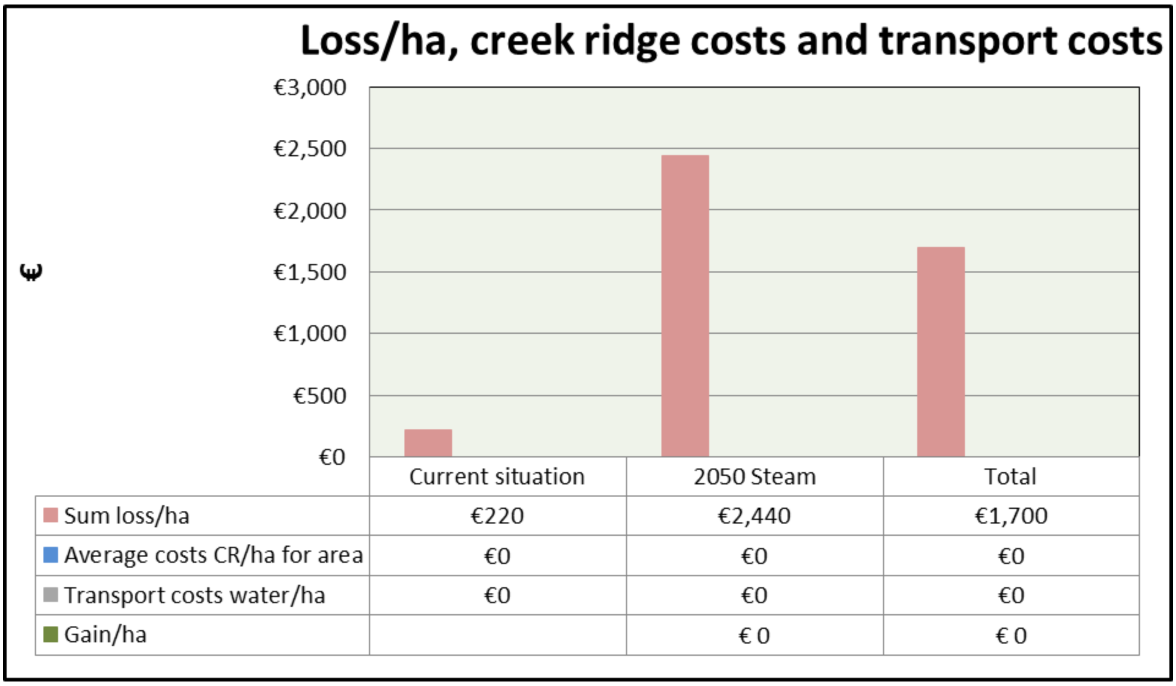
In chapter 5.2, tables show more output possibilities for all areas, with a more systematic approach. Based on these conclusions are drawn on the feasibility of the creek ridge measure, in different climate scenarios, with different water distribution types. This is done for other land use too; in all areas 100% orchards[13], replacing the current land use.

In the figures below examples of output of area 6 and 1 are given. For more output see tables in chapter 5.2 or file: 1.Rapid_assessment_Tool.xlsx.

The flowchart above each output describes the choices made in the rapid assessment tool. On the previous page all options are shown, with a short explanation of the water distribution options. In subsection 4.3.2 is explained what the different bars in the table represent.

Example 1, area 6:





	Current situation	2050 Steam	Total
🟥 Sum loss/ha	€220	€2,440	€1,700
🟦 Average costs CR/ha for area	€0	€0	€0
◼ Transport costs water/ha	€0	€0	€0
🟩 Gain/ha		€ 0	€ 0

Figure 5.2 Output table of tool (1.rapid_assessment_tool.xlsx)

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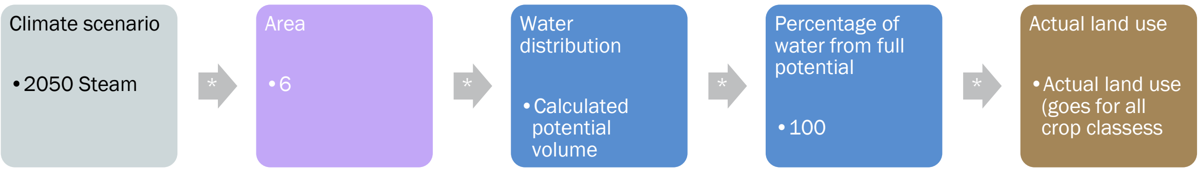
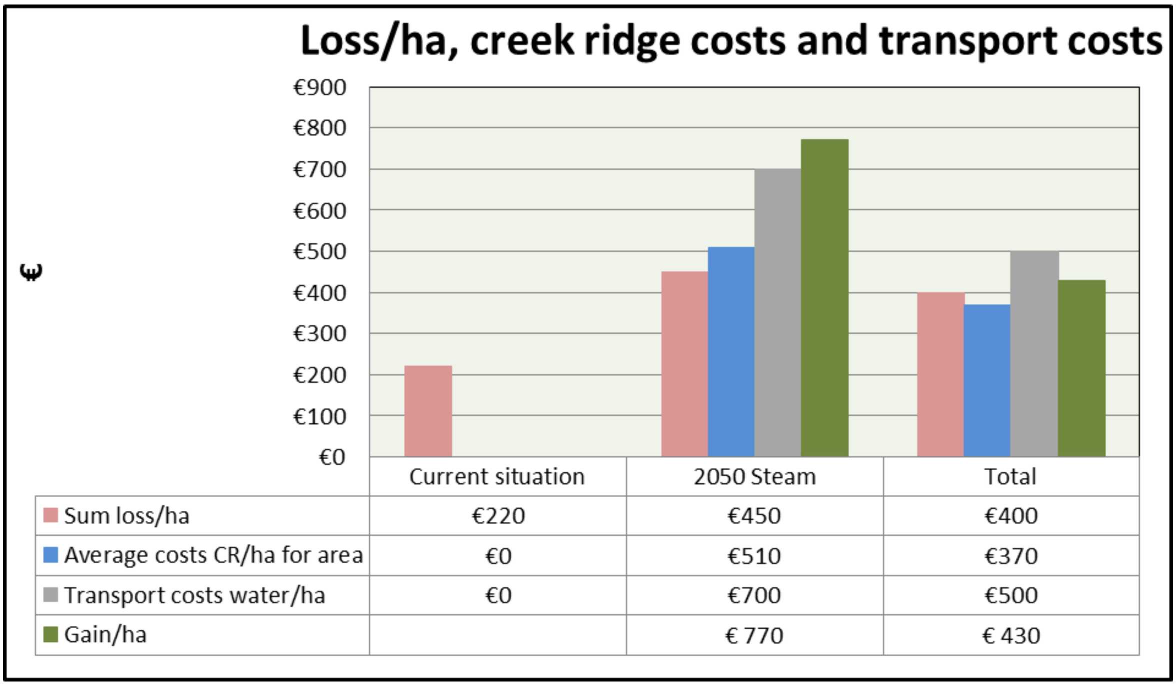
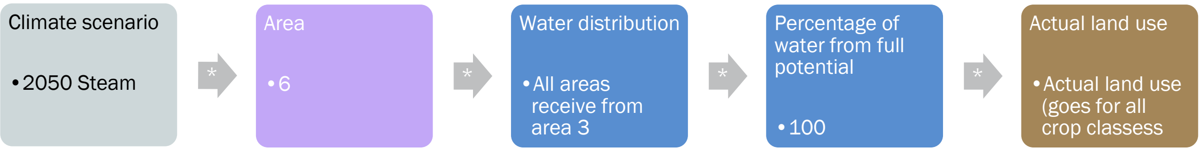
[13] 100% orchard as a land use is not realistic. It is assessed to assess whether the water supply is sufficient for this high value crop.

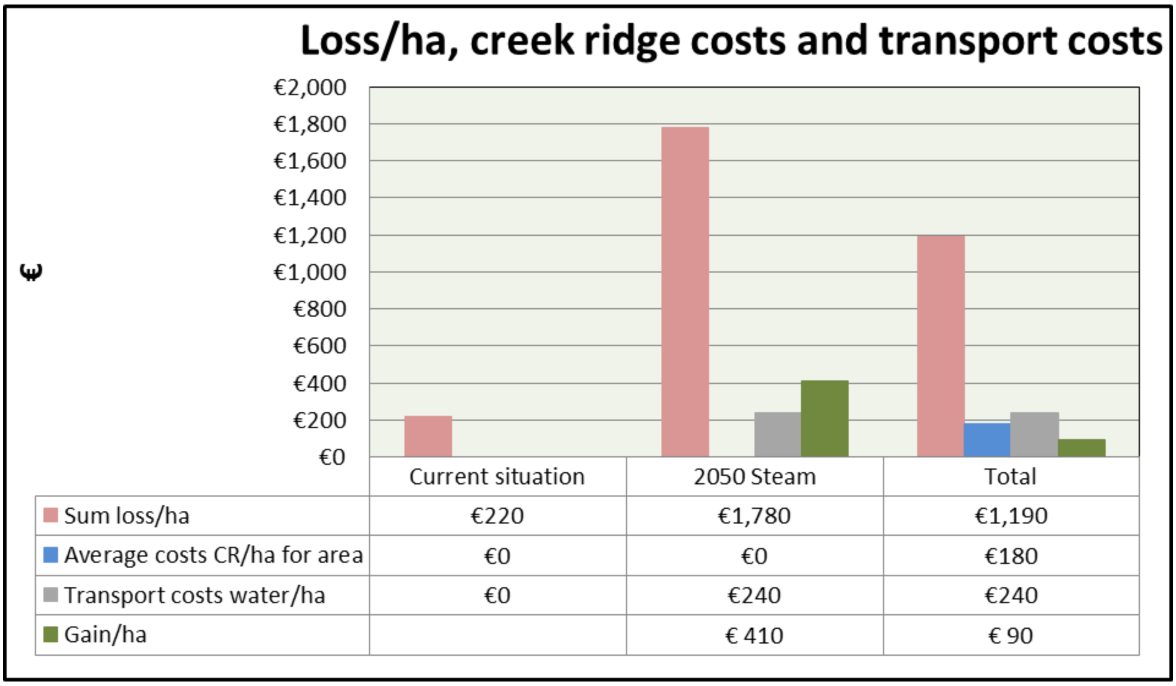




	Current situation	2050 Steam	Total
🟥 Sum loss/ha	€220	€450	€400
🟦 Average costs CR/ha for area	€0	€510	€370
⬜ Transport costs water/ha	€0	€700	€500
🟩 Gain/ha		€ 770	€ 430

Figure 5.3 Output table of tool (1.rapid_assessment_tool.xlxs)

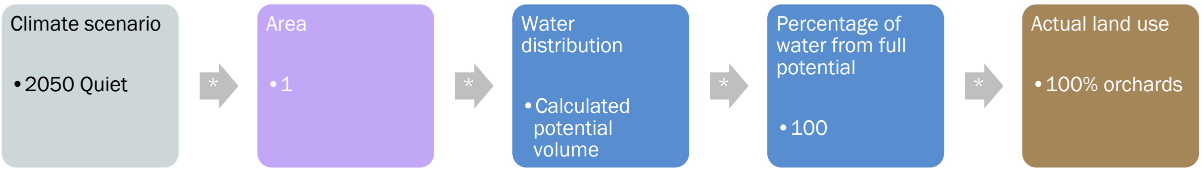


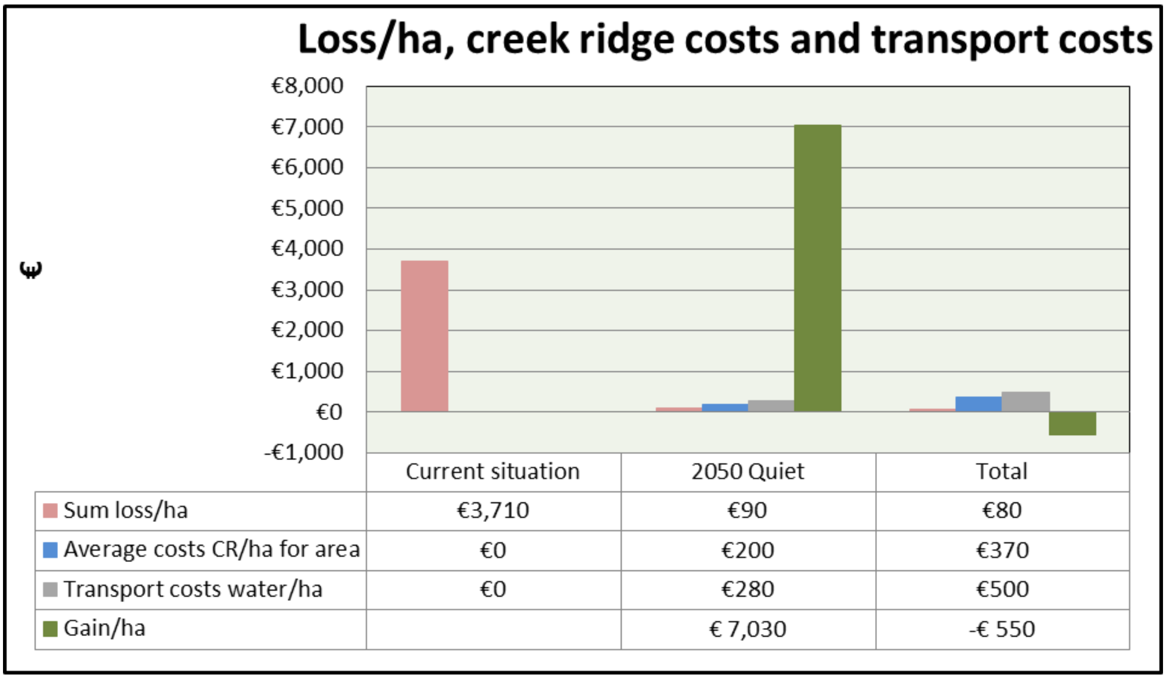


	Current situation	2050 Steam	Total
🟥 Sum loss/ha	€220	€1,780	€1,190
🟦 Average costs CR/ha for area	€0	€0	€180
⬜ Transport costs water/ha	€0	€240	€240
🟩 Gain/ha		€ 410	€ 90

Figure 5.4 Output table of tool (1.rapid_assessment_tool.xlxs)

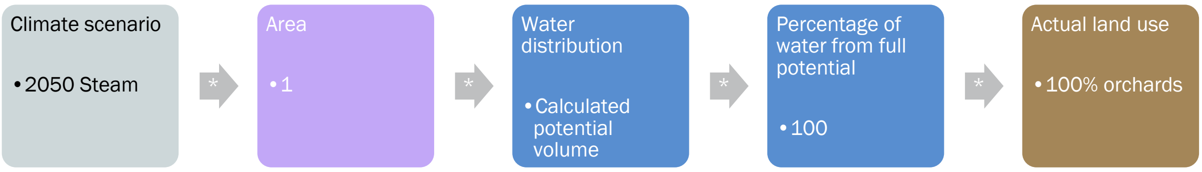
Example 2, area 1 with a land use of 100% orchards

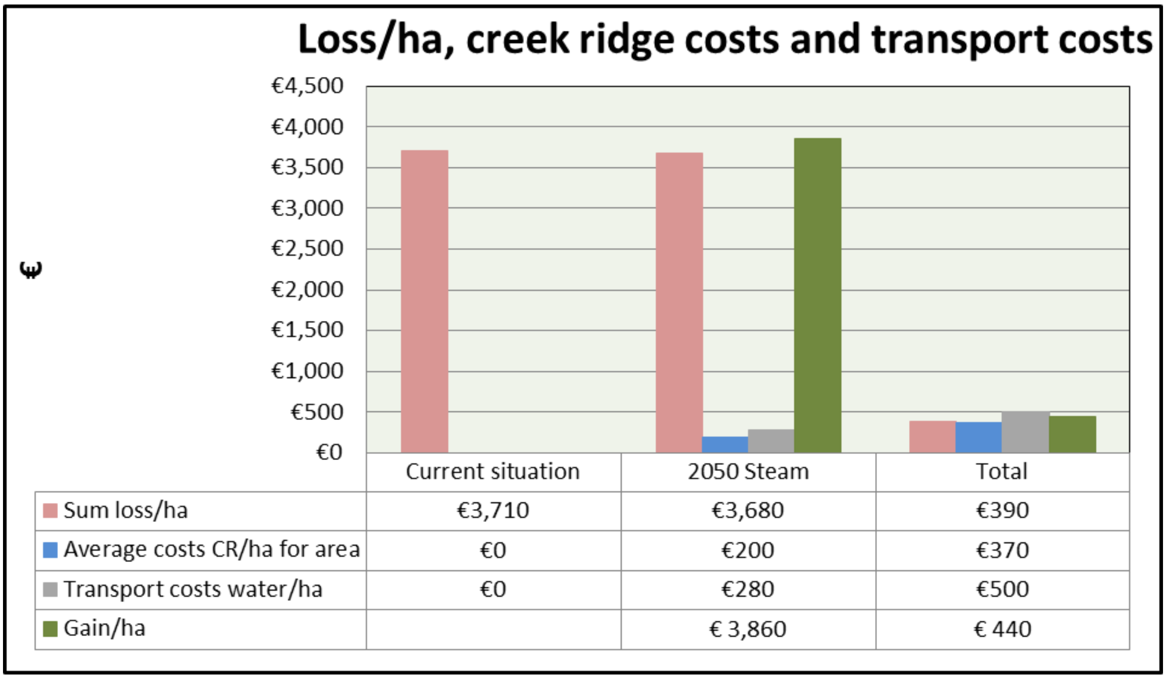




	Current situation	2050 Quiet	Total
🟥 Sum loss/ha	€3,710	€90	€80
🟦 Average costs CR/ha for area	€0	€200	€370
⬜ Transport costs water/ha	€0	€280	€500
🟩 Gain/ha		€ 7,030	-€ 550

Figure 5.5 Output table of tool (1.rapid_assessment_tool.xlxs)





	Current situation	2050 Steam	Total
🟥 Sum loss/ha	€3,710	€3,680	€390
🟦 Average costs CR/ha for area	€0	€200	€370
⬜ Transport costs water/ha	€0	€280	€500
🟩 Gain/ha		€ 3,860	€ 440

Figure 5.6 Output table of tool (1.rapid_assessment_tool.xlxs)

To get a better understanding of the columns in the tables on the following pages, they are explained below (figure 5.17):

Loss/ha	Loss/ha	Cr ridge costs/ha	Distribution costs/ha	Gain/ha	Figure

Figure 5.7 Explanation of headers of tables 5.3 until 5.8

- Loss/ha (first column): loss per hectare in different climate scenarios without the creek ridge measure.
- Loss/ha (second column): loss per hectare in different climate scenarios with the creek ridge measure and distribution costs. E.g. the calculated potential available water from the area or from water from the creek ridge in area 3.
- Cr costs/ha: average costs per hectare for construction of the creek ridge measure in the area of selection. This is different per area, because areas diver in size.
- Distribution costs/ha: average costs per hectare for distributing the fresh water from the creek ridge in the area or to another area. This is dependent on m^3 distributed.
- Gain/ha: this column shows the yield reduction after implementing the creek ridge with reduction of the transport and construction costs (loss/ha ‘no creek ridge’ – loss/ha ‘with measure), minus the costs (creek ridge costs/ha and transport costs/ha). E.g. in case of area 1 in table 5.3 Quiet: (330-140)-200-280 = -290.
- Figure: this refers to the figures represented in chapter 5.1.3.

Table 5.3 Overview feasibility of implementing creek ridge with current land in €

		No creek ridge	Potential volume (100%)				
Area	Scenario	Loss/ha	Loss/ha	Cr ridge costs/ha	Transport costs/ha	Gain/ha	Figure
1	Current	160	160				
	Quiet	330	140	200	280	-290	
	Steam	1450	820	200	280	150	
2	Current	190	190				
	Quiet	310	180	50	60	20	
	Steam	1410	1320	50	60	-20	
3	Current	180	180				
	Quiet	360	0	1290	1760	-2690	
	Steam	1560	0	1290	1760	-1490	
4	Current	190	190				
	Quiet	360	0	550	750	-940	
	Steam	1950	240	550	750	410	
5	Current	180	180				
	Quiet	450	240	40	50	120	
	Steam	1800	1720	40	50	-10	
6	Current	180	180				
	Quiet	370	0	510	700	-840	
	Steam	2430	450	510	700	770	5.2 & 5.3

Table 5.4 Overview feasibility of implementing creek ridge with current land use in €

		No creek ridge	Adjacent to area 3				
Area	Scenario	Loss/ha	Loss/ha	Cr costs/ha	Transport costs/ha	Gain/ha	Figure
2	Current	190	190				
	Quiet	310	120	0	360	-170	
	Steam	1410	650	0	360	400	
3	Current	180	180				
	Quiet	360	140	1290	360	-1430	
	Steam	1560	710	1290	360	-800	
4	Current	190	190				
	Quiet	360	160	0	360	-160	
	Steam	1950	980	0	360	610	
5	Current	180	180				
	Quiet	450	150	0	360	-60	
	Steam	1800	740	0	360	700	

Table 5.5 Overview feasibility of implementing creek ridge with current land use in €

		No creek ridge	The whole island from area 3				
Area	Scenario	Loss/ha	Loss/ha	Cr costs/ha	Transport costs/ha	Gain/ha	
1	Current	160	160				
	Quiet	330	150	0	240	-60	
	Steam	1450	1000	0	240	210	
2	Current	190	190				
	Quiet	310	150	0	240	-80	
	Steam	1410	1000	0	240	170	
3	Current	180	180				
	Quiet	360	170	1290	240	-1340	
	Steam	1560	1100	1290	240	-1070	
4	Current	190	190				
	Quiet	360	190	240	240	-310	
	Steam	1950	1410	240	240	60	
5	Current	180	180				
	Quiet	450	180	0	240	30	
	Steam	1800	1220	0	240	340	
6	Current	180	180				
	Quiet	370	170	0	240	-40	
	Steam	2430	1780	0	240	410	5.2 & 5.4

Output in case of orchards

Table 5.6 Overview feasibility of implementing creek ridge with orchard land use in €

		No creek ridge	Potential volume (100%)				
Area	Scenario	Loss/ha	Loss/ha	Cr costs/ha	Transport costs/ha	Gain/ha	Figure
1	Current	3710					
	Quiet	7610	90	200	280	7040	5.5
	Steam	8030	3680	200	280	3870	5.6
2	Current	3710					
	Quiet	7610	3660	50	60	3840	
	Steam	8030	7900	50	60	20	
3	Current	3710					
	Quiet	7600	0	1290	1760	4550	
	Steam	8030	0	1290	1760	4980	
4	Current	3710					
	Quiet	7610	0	550	750	6310	
	Steam	8030	0	550	750	6730	
5	Current	3710					
	Quiet	7610	3690	40	50	3830	
	Steam	8030	7930	40	50	10	
6	Current	3710					
	Quiet	7600	0	510	700	6390	
	Steam	8030	0	510	700	6820	

Table 5.7 Overview feasibility of implementing creek ridge with orchard land use in €

		No creek ridge	Adjacent to area 3			
Area	Scenario	Loss/ha	Loss/ha	Cr costs/ha	Transport costs/ha	Gain/ha
2	Current	3710				
	Quiet	7610	0	0	360	7250
	Steam	8030	3500	0	360	4170
3	Current	3710				
	Quiet	7600	0	1290	360	5950
	Steam	8030	3500	1290	360	2880
4	Current	3710				
	Quiet	7610	0	0	360	7250
	Steam	8030	3500	0	360	4170
5	Current	3710				
	Quiet	7610	0	0	360	7250
	Steam	8030	3510	0	360	4160

Table 5.8 Overview feasibility of implementing creek ridge with orchard land use in €

		No creek ridge	The whole island from area 3			
Area	Scenario	Loss/ha	Loss/ha	Cr costs/ha	Transport costs/ha	Gain/ha
1	Current	3710				
	Quiet	7610	190	0	240	7180
	Steam	8030	3750	0	240	4040
2	Current	3710				
	Quiet	7610	190	0	240	7180
	Steam	8030	3750	0	240	4040
3	Current	3710				
	Quiet	7600	190	1290	240	5880
	Steam	8030	3750	1290	240	2750
4	Current	3710				
	Quiet	7610	190	240	240	6940
	Steam	8030	3750	240	240	3800
5	Current	3710				
	Quiet	7610	190	0	240	7180
	Steam	8030	3750	0	240	4040
6	Current	3710				
	Quiet	7600	190	0	240	7170
	Steam	8030	3750	0	240	4040

5.2 Analyses

In this chapter the analyses of the results chapter are given

5.2.1 water supply and demand

In table 5.1 and 5.2 it is visible that in both climate scenarios the shortage of fresh water is increasing in each area of Schouwen-Duiveland. From the climate scenario ‘Current’ up to ‘2050 Quiet’ there is an increase of approximately 30% of fresh water shortage, and up approximately 110% in climate scenario ‘2050 Steam’. There is a difference per area, because there are different crops growing with different growing stages.

5.2.2 Interviews

Based on the interview, farmers explain that in general a yield loss of about 25% is accepted. This can be caused by a water deficit, salinity, sun hours, too wet conditions, etc. The 25% is therefore set as a threshold for feasibility. When in the future scenarios the turnover is reduces more than 25%, due to a water deficit and salinity, the investment in the creek ridge measure is not feasible. The farmers indicated that there turnover is on average €3500/ha. Based on this the rounded number €900/ha turnover reduction is set as a threshold.

5.2.3 Outputs of the rapid assessment tool

Examples figure 5.2 until 5.6
In these figures the outputs of the tool show, a feasible creek ridge measure. This can be seen by the reduces yield reduction (red bar) and the relatively large green bar (gain/ha). More outputs are shown in the tables 5.3 until 5.8 and are more closely looked at below.

tables 5.3 until 5.8
In case the number is negative in the column gain/ha of table 5.3 until 5.8, the investment is larger (construction and distribution costs) than the yield reduction in €. This is compared to the yield reduction that is taking place without any measure. A negative or low outcome is not desired, the measure is not feasible.

In case when the yield reduction is reduced significantly, the measure can be considered robust, this is not related to the number in the column gain/ha. Thus the measure can be robust and not feasible at the same time.

No creek ridge
When looking to tables 5.3 until 5.8, it is clear that in the left columns ‘no creek ridge’ that the increased water shortage in climate scenario ‘2050 Steam’ has a large effect on yield loss per hectare in all areas. The losses would be higher than the losses the farmers indicated as acceptable. These losses were indicated around 25%, which would be up to €900/ha maximum (rounded up). In the tables in all areas the losses are higher than €900/ha in climate scenario ‘2050 Steam’. Yield reduction in all areas in climate scenario ‘2050 Quiet’ are around €350/ha. This yield reduction is a little higher than ‘Current’ and within the range of what farmers would call ‘acceptable’ (table 5.3, 5.4 and 5.5, left column).

Potential calculated volume from creek ridge in area

The possible extra available water can lead to a yield reduction in climate scenario '2050 Steam'. But this relies on how the water is distributed. The reason for this is the availability of areas where the creek ridges measure is applicable. There is hardly any locations available for the creek ridge measure in area 2 and 5. As a result, yield losses are estimated higher than the indicated threshold. This is also the case in area 1, but to a lesser extent. Area 3, 4 and 6 would be able to reduce yield losses significantly with the additional fresh water from the creek ridge (table 5.3).

Water distribution from area 3 that are adjacent to area 3

Because area 3 has the largest surface for the creek ridge measure, it could potentially store most fresh water. Therefore options are considered transporting water from this area to adjacent areas and to the whole island. This potentially could lead to a decrease in yield reduction.
The option to distribute from area 3 to adjacent areas does not clearly benefit the region, simply because the area is becoming too large, and thus the quantity of water too low. Losses are now in between €600 up to €1000/ha, that can be considered within and outside the range of what is acceptable by farmers (table 5.4).

Water distribution to all areas from area 3

This way of distribution the fresh water has to provide the largest surface area with the same quantities, lowering the available water per hectare. The loss/ha is passing the threshold of €900/ha and is not feasible. This scenario describes adaptation and investment, with no return (table 5.4).

High value crop

In case of transition to orchard the following can be said. The turnover per hectare is about €19.000/hectare (LEI, 2012). Taking in to consideration the 25% yield loss as acceptable, a loss of €5000/ha, should be permissible. Orchard could be grown in the climate scenario current, because the losses are about 3700/ha under current average climate condition. This makes sense as there are orchards on Schouwen-Duiveland currently and apparently profitable. In the climate scenarios '2050 Quiet' and '2050 Steam' however, losses would increase and when there is no alternative water supply provided, orchards are estimated not to be feasible, due to climate conditions (table 5.6, 5.7 and 5.8 left column).

When applying the creek ridge in scenario '2050 Quiet', it does allow orchard in all areas. In climate scenario '2050 Steam', it does allow orchards in areas where water from the creek ridge is most abundant after applying the creek ridge measure. These areas are 3, 4 and 6 and even in area 1. The losses in area 2 and 5 go up to €8000/ha and thus considered not feasible (5.6).

Finally when choosing fresh water distribution from area 3 to adjacent areas and to all areas it would allow orchards in both the climate scenario 2050 Quiet and 2050 Steam. Yield reduction in 2050 Quiet would be close to €0/ha and up to €3500 and €3750/ha in 2050 Steam (5.7 and 5.8).

5.3 Comparable tool

€ureyeopener (2012) is a tool that is built with the aim to get better insight in the possibilities for salinization management and contribute solving fresh water problems (Stuyt *et al.*, 2012). The model simulates water flow in the mid-west of the Netherlands at the 'Hoogheemraadschap' of 'Rijnland' (figure 5.13).

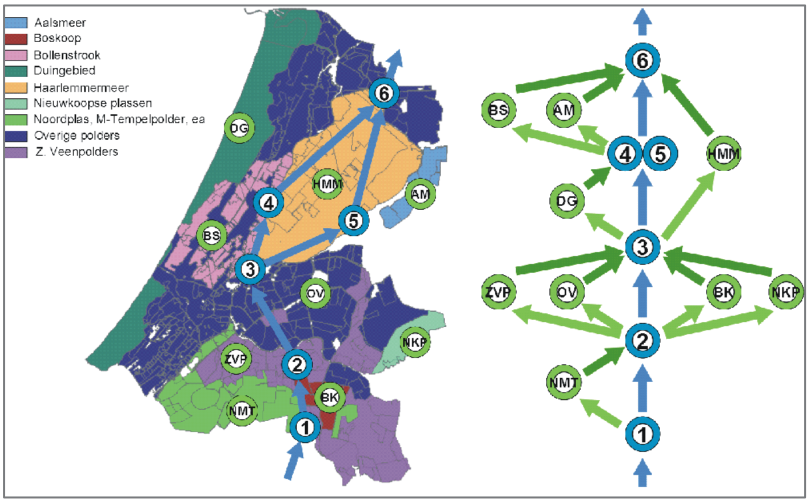


Figure 5.13 Schematic view of water flow of model (public wiki, 2012)

Comparisons can be made between the rapid assessment tool used for Schouwen-Duiveland and the flow model used in 'Hoogheemraadschap'. Both assess a fresh water demand in relation to agriculture. By changing water flows in the region, the area deals strategically with water scarcity to minimalize damage by salinity. A difference in the €ureyeopener tool is, that it has the aim to also assess the impact of salinity on nature. This is not done in the rapid assessment tool for Schouwen-Duiveland.

Other similar characteristics are that both tools simulate a situation, or create a 'scenario'. The user can 'play' with the tool to see what the possible effect of the choices are, and show the costs and benefits in €.

Another difference is the technical background and the linkages between calculations. In the rapid assessment tool for Schouwen-Duiveland these tend to get long and complex, a weakness of the tool (discussion). The formula used to link calculations in €ureyeopener are less complex, therefore less sensitive for errors[14].

Most interesting to see is how both tools (or projects) can learn from each other. I.e. what steps should be taken to make the rapid assessment tool for Schouwen-Duiveland (more) implementable?

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[14] The latest €ureyeopener is built in a Fortran/Python environment

6. Discussion

Software

In the initial stage of the research a program needed to be selected for building the tool in. Ribasim is a software program developed by Deltares, and support the process of planning and resource analysis. It can be very useful for simulating the behaviour of river basins under various hydrological conditions. Ribasim could be very useful for the distribution part of irrigation water in the rapid assessment tool, although this is not the main focus of result. Other software programs like WEAP and SWAT were considered, but for similar reasons not serving the purpose of this research. Therefore Excel was selected as it able to support and link formula.

The downside of using Excel is that codes or formula used to link to different output of e.g. an area and climate scenario to a yield reduction, become complex. Due to the complexity it can be confusing for an outsider. Another downside is, that when an error occurs, it is hard to track back the location of the error. The code below is an example of the complexity:

```
=IF(AND($E$6="current",$E$7=1),'Area 1'!$AX$17, IF(AND($E$6="current",$E$7=2),'Area 2'!$AX$17,
IF(AND($E$6="current",$E$7=3),'Area 3'!$AX$17, IF(AND($E$6="current",$E$7=4),'Area 4'!$AX$17, IF(AND($E$6="current",$E$7=5),'Area
5'!$AX$17, IF(AND($E$6="current",$E$7=6),'Area 6'!$AX$17,IF(AND($E$6="2050 quiet",$E$7=1),'Area 1'!$AX$35, IF(AND($E$6="2050
quiet",$E$7=2),'Area 2'!$AX$35, IF(AND($E$6="2050 quiet",$E$7=3),'Area 3'!$AX$35, IF(AND($E$6="2050 quiet",$E$7=4),'Area
4'!$AX$35, IF(AND($E$6="2050 quiet",$E$7=5),'Area 5'!$AX$35,IF(AND($E$6="2050 quiet",$E$7=6),'Area 6'!$AX$35,IF(AND($E$6="2050
steam",$E$7=1),'Area 1'!$AX$53, IF(AND($E$6="2050 steam",$E$7=2),'Area 2'!$AX$53, IF(AND($E$6="2050 steam",$E$7=3),'Area
3'!$AX$53, IF(AND($E$6="2050 steam",$E$7=4),'Area 4'!$AX$53, IF(AND($E$6="2050 steam",$E$7=5),'Area 5'!$AX$53,
IF(AND($E$6="2050 steam",$E$7=6),'Area 6'!$AX$53,0))))))))))))))))))
```

Accuracy

The rapid assessment tool is based on different types of calculations, like estimations of crop water requirement and cost for water distribution. It is difficult to calculate accurate estimation of the input without field experience. In this research estimations are based on literature calculations and expert knowledge. For this reason the output is debatable. Although this comment, the satisfaction of the work is high, as the tool does what it needs to do, making a ‘rapid’ assessment, and thus inaccuracy is accepted. In addition, different elements of input can be improved, resulting in a more accurate rapid assessment.

Functionality

The rapid assessment tool allows the user to ‘play’ with the tool and learn what climate change and a potential water shortage can do to a farmer’s turnover on average. By selecting the input, an output is given, but the difference with other selections or the benefits cannot be directly seen. The difference can be assessed after running the tool a second time. The tool can be seen as version 1.0, and is susceptible for improvement.

CO_2 pressure

During the colloquium, somebody from the audience referred to the method of calculation of crop water requirement and asked whether CO_2 pressure was taken into account. For calculating crop water requirement no direct relation between CO_2 pressure and crop water requirement is made. The FAO, irrigation & drainage paper 56 (1998) is used, here CO_2 is a parameter that influences the net long wave radiation (R_{nl}) and is impeded in this formula (appendix III). The comment is welcome as it shows the complexity of the content. Many parameters are linked and all those parameters can be discussed. This discussion can lead to a more accurate tool.

Feasibility
Some assumptions made are unlikely to be compared to real situation, such as the distribution of fresh water by pipes, because they are not there. When fresh water distribution is considered a viable option, this could be research in the future.

Ability to replace
The tool is specifically built for Schouwen-Duiveland. The land use is based on Schouwen-Duiveland as well as surface areas of crop classes within areas. Thus, the rapid assessment tool, can in the state it currently is, only be used for Schouwen-Duiveland. To enable the tool for another region, new crop classes (if necessary) have to be made for the new region. The surfaces of regions and surface of crop classes will be different and have to be changed too. If only the surface areas have to change adaption is easy. If new crop classes have to be added, changing the tool becomes more complex because yield reduction have to be added for this crop class, and existing codes need to be changed.

Yield reduction by a water deficit
This research investigates a yield reduction by a water deficit and salinity. The link between those is debatable as there is no clear scientific proof how these two parameters influence each other. In addition to that, farmers say that there is never one cause. There are many other parameters that influence the crop stages, e.g. sun light, clouds, temperature, etc. While using this tool the user should be aware of these other parameters, and for that reason it is virtually impossible to make 100% accurate predictions.

7. Conclusions

Farmers, nowadays practice rain fed agriculture, with some exceptions. In the future, due to different reasons the rain fed agriculture will get under more pressure. The creek ridge measure, storing fresh water actively in sandy deposits or the creek ridges, potentially creates a larger fresh water lens that could be used to prevent crop damage or yield reduction in the future.

The creek ridge measure, or the resource, would be constructed on places where this is possible, being (in short) the slightly alleviated more sandy soils, with the fresh (brackish / saline interface on at least 5 meter depth. Because the availability of locations for the creek ridge measure varies, the island of Schouwen-Duiveland is divided into area. This enables different output for different areas. Area 3 is estimated to have far more available water from the creek ridge then others (14,741,000 m^3). Area 6 has got less than half compared to area 3 (6,539,000 m^3), but has got compared to the other regions a relative high availability. Area 5 has got the lowest availability (388,000 m^3) followed by are 1 (1,186,000 m3). Area 4 (4,589,000 m3) and area 1 (3,170,000 m3) are in between.

Robustness and feasibility are assessed. A creek ridge is determined robust when it can meet the demand of fresh water by agriculture in the climate scenarios. In other words, the resource should provide sufficient fresh water for the agricultural fresh water demand in 2050 in different climate scenarios. This determined by the percentage of yield loss. When the yield loss remains within the acceptable range of 25% the water resource can be considered robust.
Feasibility is determined when the investment of the creek ridge is worthwhile. This is determined by the investment costs versus the money saved by a decrease of yield reduction.

In climate scenario '2050 Quiet' agriculture is likely to be comparable to the situation as it is currently. The yield losses are estimated a bit higher in relation the climate scenario 'Current' but farmer practices might be similar as today's farm practices as yield reduction does not increase very much.
In climate scenario '2050 Steam' the current agricultural practices could not sustain. The impact from the changing environment is too large. The current agricultural practices do not resist drought and/or salinity and are therefore not profitable. This can be seen in table 5.3, 5.4 or 5.5 in the first column, under 'no creek ridge'. The numbers in red are below the threshold and not considered feasible.

7.1 Reflection on research questions

1. What is the long-term robustness for the fresh water supply for the agricultural sector, under different climate scenarios?

- It is clearly shown that the fresh water supply of Schouwen-Duiveland will be under increased pressure, in both climate scenarios, '2050 Quiet' and '2050 Steam'.
- In climate scenario '2050 Quiet', it is in most cases (on average!) not interesting to invest in adaptation measure, except for area 5. When not investing in the creek ridge measure, the farmer can sustain his practices. In most of the areas investing in the creek ridge measure, is too expensive.
- In the climate scenario '2050 Steam', the creek ridge measure is robust in certain areas, like 1, 4 and 6. In different areas the creek ridge investment will have a larger return than others. Area 3 is considered robust, as it pushes back yield reduction, but is not feasible, since it has relatively

high construction costs for the creek ridges in the area. Over time this can be feasible, since the investment costs are not yearly returning costs.

- In case no creek ridge measure is applied to ensure fresh water provision, orchard is not profitable, under any climate scenario (table 5.6, 5.7 and 5.8, left column, ‘no creek ridge’). In case the investments in creek ridges are done, it can be profitable, but is than dependant on area and climate scenario. Orchard could viable in in climate scenario ‘2050 Steam’ in area 3, 4, 6 and possibly in area 1.

2. What is the feasibility to invest in the creek ridge measure with different land use in different climate scenarios?

- In climate scenario ‘2050 Quiet’, the creek ridge measure is not feasible, due to the relatively low increase of yield reduction in this scenario. The costs of implementing are too high to be paid back by the decrease of yield reduction.
- When the available area for implementation of the creek ridge measure is low, the creek ridge measure is not feasible in climate scenario ‘2050 Steam’ These areas are 2, 5 and to a lower extent, area 1. The average available water for the area is too low to decrease the yield losses significantly enough to be feasible in these areas.
- In the climate scenario ‘2050 Steam’, the creek ridge measure is robust in certain areas, like 1, 4 and 6. In different areas the creek ridge investment will have a larger return than others. Area 3 is considered robust, as it pushes back yield reduction, but is not feasible, since it has relatively high construction costs for the creek ridges in the area. Over time this can be feasible, since the investment costs are not yearly returning costs.

7.2 Recommendation

When no investment is done in the creek ridge measure, farmers might not maintain their practices in the future, due to the changing environment. The rapid assessment tool constructed for this research shows that the creek ridge measure can prevent large yield damages when applied in areas suited for the creek ridge measure. Taken that in to consideration, research and field tests are in the benefit of the agriculture on Schouwen-Duiveland. Measures to ensure fresh water supply for agriculture in different types of areas on Schouwen-Duiveland are recommended to be continued to be further explored and researched.

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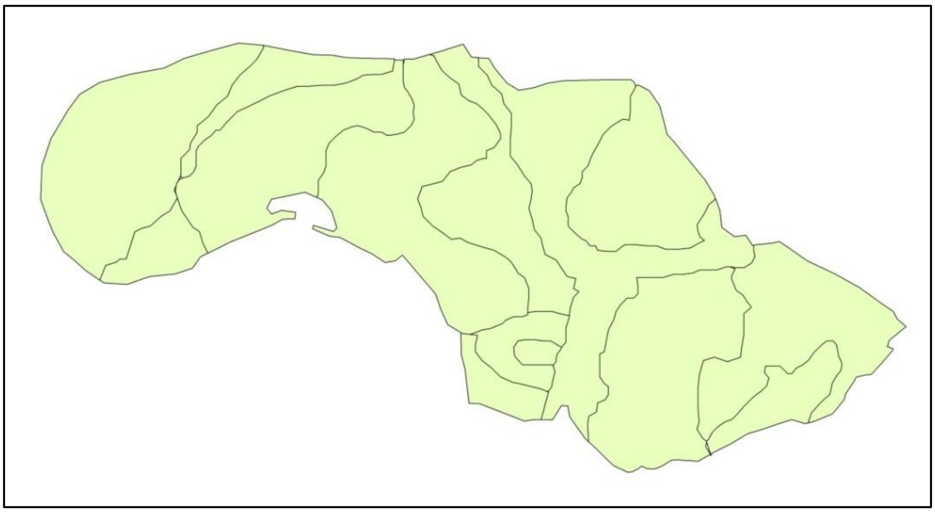
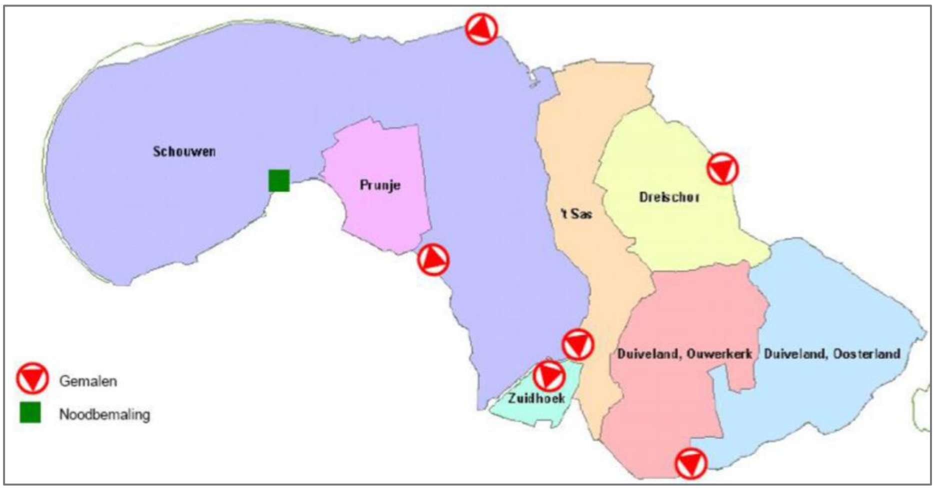
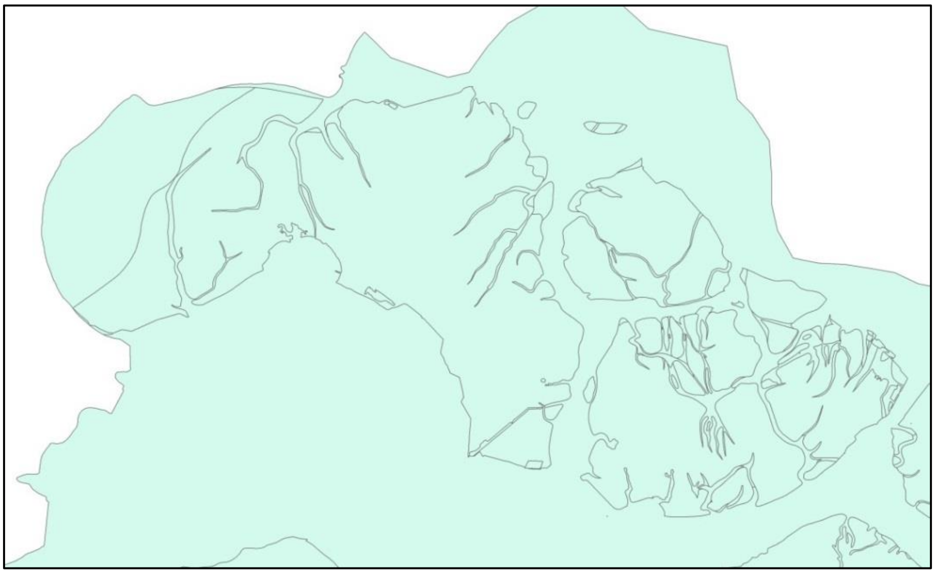
Appendix I



Water areas from the water plan of the municipality Schouwen-Duiveland (van Baaren & Harezlak, 2011)

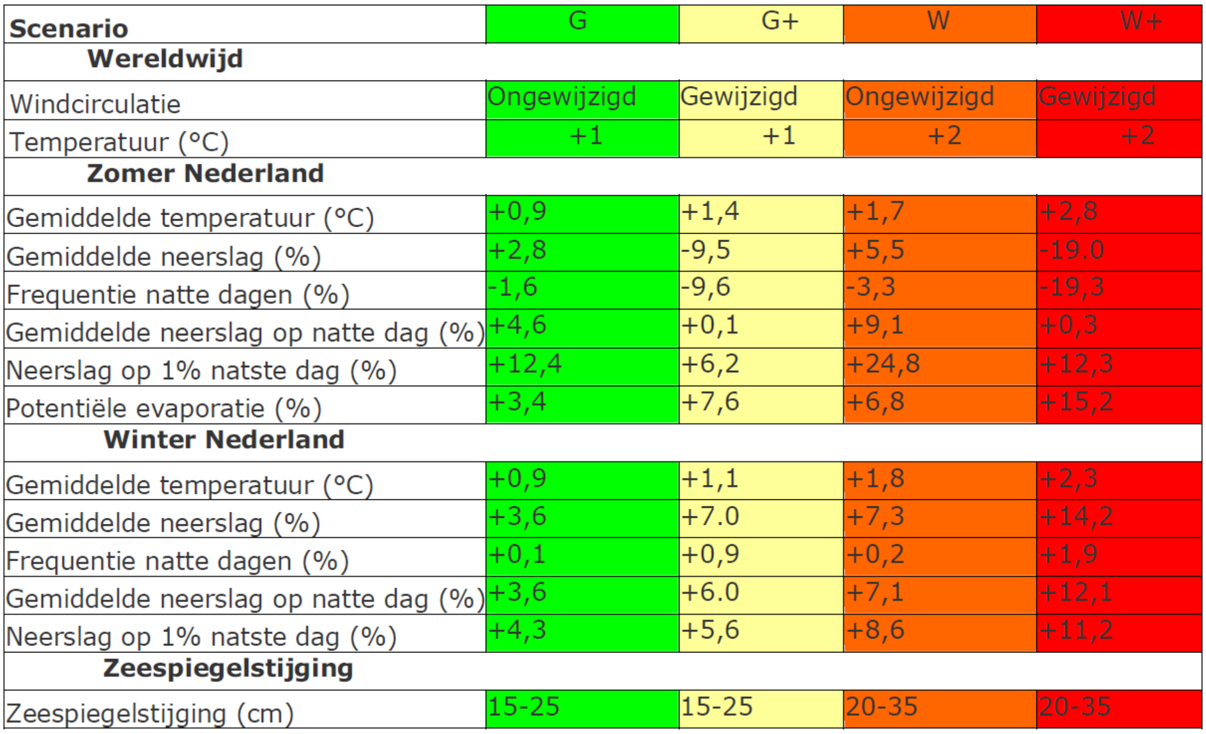


Water drain areas from the Water Board Scheldestromen (van Baaren & Harezlak, 2011)



Borders of creek ridges and trenches (REGIS)

Appendix II



Scenario	G	G+	W	W+
Wereldwijd				
Windcirculatie	Ongewijzigd	Gewijzigd	Ongewijzigd	Gewijzigd
Temperatuur (°C)	+1	+1	+2	+2
Zomer Nederland				
Gemiddelde temperatuur (°C)	+0,9	+1,4	+1,7	+2,8
Gemiddelde neerslag (%)	+2,8	-9,5	+5,5	-19.0
Frequentie natte dagen (%)	-1,6	-9,6	-3,3	-19,3
Gemiddelde neerslag op natte dag (%)	+4,6	+0,1	+9,1	+0,3
Neerslag op 1% natste dag (%)	+12,4	+6,2	+24,8	+12,3
Potentiële evaporatie (%)	+3,4	+7,6	+6,8	+15,2
Winter Nederland				
Gemiddelde temperatuur (°C)	+0,9	+1,1	+1,8	+2,3
Gemiddelde neerslag (%)	+3,6	+7.0	+7,3	+14,2
Frequentie natte dagen (%)	+0,1	+0,9	+0,2	+1,9
Gemiddelde neerslag op natte dag (%)	+3,6	+6.0	+7,1	+12,1
Neerslag op 1% natste dag (%)	+4,3	+5,6	+8,6	+11,2
Zeespiegelstijging				
Zeespiegelstijging (cm)	15-25	15-25	20-35	20-35

Climate scenarios (KNMI, 2006)

Appendix III

The continuation of calculation for yield reduction by a water deficit:

Air temperature T

Solar radiation absorbed by the atmosphere and the heat emitted from the earth surface increases the air temperature. The air surrounding a crop influences the evapotranspiration. In warm sunny weather, the evapotranspiration is higher, than in cloudy cool weather.

Air humidity (RH)

Energy from the sun and surrounding air is the main driving force for vaporization of water, the difference between the water vapour pressure at the evapotranspiring surface and the surrounding air is the determining factor for the vapour removal. E.g. well watered crops in a warm and arid region evapotranspire a lot of water, while a crop in humid tropical regions evapotranspire less water as the high humidity of the air will reduce the evapotranspiration demand.

Wind speed U_2

The process of water vapour removal depends to a large extent on wind speed and air turbulence, which transport large quantities of air over the evaporating surface. When vaporizing water the air above the evaporating surface becomes gradually saturated with water vapour, reducing the evapotranspiration rate. Unless the air is replaced by dryer air.

Atmospheric parameters (ETo)

In addition to climate date, atmospheric parameters are used. Below different parameters are described used in the FAO Penman-Monteith equation.

Atmospheric pressure (P)

The atmospheric pressure is the pressure exerted by the weight of the earth's atmosphere. The higher the altitude, the higher the evapotranspiration, due to lower atmospheric pressure. The effect to the calculation of the ET_o is small and an average value for a location is sufficient (equation 4.2).

$$P=101.3\left(\frac{293-0.0065z}{293}\right)^{5.26} \quad (7)$$

Equation 4.2

P	atmospheric pressure	kPa
z	elevation above sea level	m

Latent heat of vaporization (λ)

The latent heat of vaporization expresses the energy required to change a unit mass of water from liquid to water vapour in a constant pressure and constant temperature process. The value varies as a function of temperature and thus at high temperatures a less energy is required than at lower temperatures. As λ varies slightly over normal temperature ranges a single value of 2.45 MJ kg_{-1} is taken.

Psychometric constant (γ)
The specific heat at constant pressure is the amount of energy required to increase the temperature od a unit mass of air by one degree at constant pressure. Its value depends on the composition of air, i.e. one being humidy (equation 4.3).

$$\gamma=\frac{c_p P}{\varepsilon \lambda}=0.665\times 10^{-3} P \quad (8)$$

Equation 4.3

γ	psychometric constant	kPa $°C^{-1}$
P	atmospheric pressure	kPa
λ	latent heat of vaporization	2.45 MJ kg^{-1}
c_p	specific heat at constant pressure	1.013 MJ kg^{-1} $°C^{-1}$
ε	ratio molecular weight of water vapour/dry air	0.622

Air temperature (T)
Vapour pressure for a certain period should be computed as the mean between the vapour pressure at the daily maximum and minimum air temperatures of that period. The daily maximum (T_{max}) and the daily minimum (T_{min}) are the maximum and minimum air temperatures observed during 24 hours (equation 4.4).

$$T_{mean}=\frac{T_{max}-T_{min}}{2} \quad (9)$$

Equation 4.4

Relative humidity (RH)
The relative humidy expresses the degree of saturation of the air as a ratio of the actual (e_a) to the saturation ($e°(T)$) vapour pressure at the same temperature (T). It is the ratio between the amount of water the surrounding air actually holds and the amount it could hold at the same temperature. As RH is given by the KNMI this formula is not applied (equation 4.5).

$$RH=100\frac{e_a}{e°(T)} \quad (10)$$

Equation 4.5

Mean saturation vapour pressure (es)
Saturation vapour pressure is related to air temperature, so it can be calculated from the temperature (equation 4.6).

$$e°(T)=0.6108\exp\left[\frac{17.27T}{T+237.3}\right] \quad (11)$$

Equation 4.6

$e°(T)$	saturation pressure at the air temperature T	kPa
T	air temperature	°C
Exp	2.7183 raised to the power	[...]

The vapour pressure is calculated as the mean between the saturation vapour pressure at both the daily maximum and minimum air temperature (equation 4.7).

$$e_s = \frac{e^{\circ}(T_{max}) + e^{\circ}(T_{min})}{2} \quad (12)$$

Equation 4.7

Slope of saturation vapour pressure curve (Δ)

For the calculation of evapotranspiration, the slope of the relation between saturation vapour pressure and temperature is required (equation 4.8).

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \quad (13)$$

Equation 4.8

Extra-terrestrial radiation (Ra)

Radiation striking a surface perpendicular to the sun’s rays at the top of the earth’s atmosphere is about 0.082 MJ m^{-2} min^{-1}. The local intensity of radiation is determined by the angle between the direction of the sun’s rays and the surface of the atmosphere. This angle will change during the day and will be different at different latitudes and in different seasons. The solar radiation received at the top of the earth’s atmosphere on a horizontal surface is called extra-terrestrial radiation (R_a). R_a is a function of latitude, date and time of day.

Shortwave radiation (Ra)

Some of the radiation that enters the atmosphere is scattered, reflected or absorbed by the atmosphere gasses, clouds and dust. The amount of solar radiation reaching a horizontal surface is known as solar radiation. It is also referred at as shortwave radiation.

Relative sunshine duration (n/N)

The relative sunshine duration is another ratio that expresses the cloudiness of the atmosphere. It is the ratio of the actual duration of sunshine, to the maximum possible duration of sunshine or daylight in hours. As with extra-terrestrial radiation, it depends on the position of the sun and is a function of latitude and date.

Albedo (α) and net solar radiation (Rns)

Part of the solar radiation is reflected by the earth’s surface. The fraction of the solar radiation reflected by the surface is known as the albedo. The albedo is highly variable for different surfaces and for the angle at which the suns ray’s reach a surface. It can be as large as 0.95 for snow and 0.05 for a wet bare soil. A green grass cover is assumed to have an albedo of 0.23. Then et solar radiation is the fraction of the solar radiation that is not reflected from the surface.

Net longwave radiation (Rnl)

The solar radiation absorbed by the earth is converted into heat energy. The earth is at a much lower temperature than the sun emits radiative energy with wavelength longer than those from the sun. Therefore terrestrial radiation is referred to as long wave radiation. The emitted long wave radiation is absorbed by the atmosphere or lost into space. Part of the radiation finds its way back to the earth’s surface. Consequently, the earth both emits and receives long wave radiation. The difference between outgoing and incoming radiation is called the net long wave radiation, R_{nl}. It represents an energy loss as most, as the outgoing radiation is almost always greater than the incoming radiation.

Net Radiation (Rn)

The net radiation is the difference between incoming and outgoing radiation of both short and long wavelengths. It is the balance between the energy absorbed, reflected and emitted by the earth's surface. It is expressed as the difference between the incoming net short wave (R_{ns}) and the net outgoing long wave (R_{nl}) radiation. During daytime it is positive and at night is it negative, except under extreme conditions and at high altitudes.

Soil heat flux (G)

The soil heat flux is the energy that is utilized in heating the soil. G is positive when the soil is warming and negative when the soil cooling (equation 4.9).

Extra-terrestrial radiation for daily periods (R_a)

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \quad (21)$$

Equation 4.9

R_a	extraterrestrial radiation	MJ m^{-2} day^{-1}
G_{sc}	solar constant	0.082 MJ m^{-2} min^{-1}
d_r	inverse relative distance Earth-Sun	see equation 23 below
ω_s	sunset hour angle	see equation 25 below
φ	latitude	see equation 22 below
δ	solar decimation	see equation 24 below

The conversion from decimal degrees to radians is given in equation 4.10.

$$[\text{Radians}] = \frac{\pi}{180}[\text{decimaldegrees}] \quad (22)$$

Equation 4.10

The inverse relative distance Earth-Sun, dr, and the solar declination, δ, are given in equation 4.11.

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \quad (23)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \quad (24)$$

Equation(s) 4.11

The sunset hour angle is given in equation 4.12:

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right] \quad (25)$$

Equation 4.12

Daylight hours (N)

The daylight hours are given in equation 4.13

$$N = \frac{24}{\pi}\omega_s \quad (34)$$

Equation 4.13

Solar radiation (Rs)

If solar radiation is not measured, it can be calculated with the Angstrom formula which relates solar radiation to extra-terrestrial radiation and relative sunshine duration (equation 4.14).

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (35)$$

Equation 4.14

R_s	solar or shortwave radiation	MJ m^{-2} day^{-1}
n	actual duration of sunshine	hour
N	Maximum possible duration of sunshine or daylight hours	hour
n/N	relative sunshine duration	-
R_a	extra-terrestrial radiation	MJ m^{-2} day^{-1}
a_s	regression constant, expressing the fraction of extra-terrestrial radiation reaching the earth on overcast days	n=0
a_s+b_s	fraction of extra-terrestrail radiation reaching the earth on clear days	n=N

Depending on the atmospheric conditions and solar declinations (latitude and month), the Angstrom values a_s and b_s will vary. Where no actual solar radiation data are available and no calibration has been carried out, a_s =0.25 and b_s =0.5 are recommended.

Clear sky radiation (Rso)

The calculation of clear sky radiation when n=N, is required for computing net long wave radiation (equation 4.15).

$$R_{so} = (0.75 + 2\ 10^{-5} z) R_a \quad (37)$$

Equation 4.15

z	elevation above sea level	m

Net solar or net shortwave radiation (Rns)

$$R_{ns} = (1-\alpha) R_s \quad (38)$$

Equation 4.16

R_{ns}	net solar or shortwave radiation	MJ m^{-2} day^{-1}
α	albedo reflection coefficient	0.23 for hypothetical grass reference crop
R_s	the incoming solar radiation	MJ m^{-2} day^{-1}

Long wave radiation (Rnl)

The rate of longwae energy emission is proportional to the absolutwe temperature of the surafce raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law (equation 4.17).

$$R_{nl} = \sigma\left[\frac{T_{maxK^4} + T_{minK^4}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad (39)$$

Equation 4.17

R_{nl}	net outgoing long wave radiation	MJ m^{-2} day^{-1}
σ	Stefan-Boltzmann constant	4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}
$T_{max, K}$	maximum absolute temperature during the 24-hour period	K = °C + 273.16
$T_{min, K}$	minimum absolute temperature during the 24-hour period	K = °C + 273.16
e_a	actual vapour pressure	kPa
R_s/R_{so}	relative shortwave radiation	limited to ⍰ 1.0
R_s		see equation 4.14
R_{so}		see equation 4.15

Net radiation (Rn)

The net radiation is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net long wave radiation (R_{nl}) (equation 4.18).

$$R_n = R_{ns} - R_{nl} \quad (40)$$

Equation 4.18

Soil heat flux (G)

$$G_{month,\, i} = 0.14\,(T_{month,\, i} - T_{month,\, i-1}) \quad (44)$$

Equation 4.19

$T_{month, i}$	Mean air temperature of month°C	
$T_{month, i-1}$	Mean air temperature of previous month	°C

Wind speed

Wind speed is slowest at the surface and increases with height. For this reasons anemometers (wind speed measure device) are placed at a chosen standard height. For the calculation of evapotranspiration, wind speed is measured at 2 meters above the surface. This formula is not applied in these calculations as wind speed is given by the KNMI (equation 4.20).

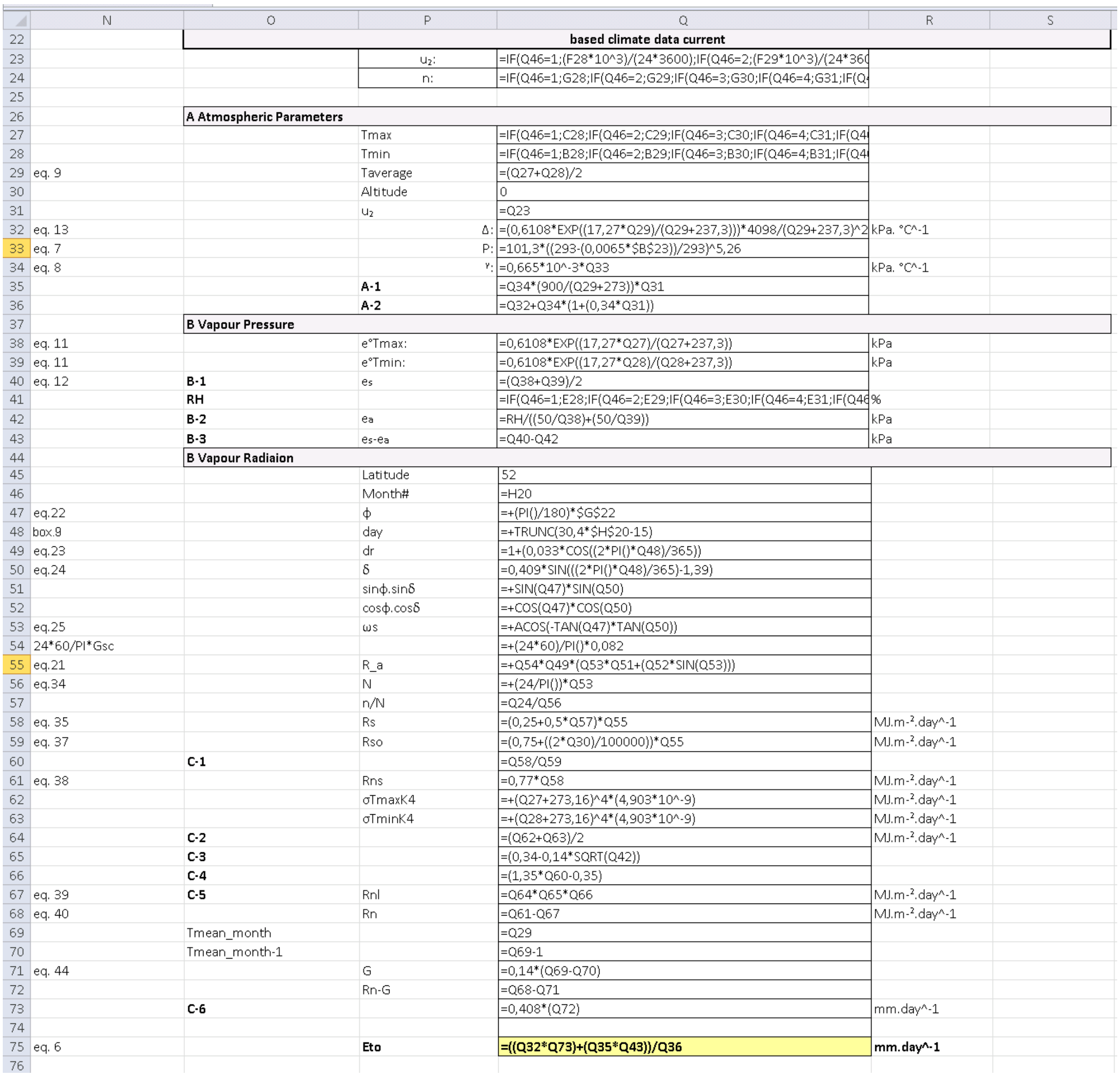
$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (47)$$

Equation 4.20

u_2	wind speed at 2 m above ground surface	m s^{-1}
u_z	measured wind speed at z m above ground surface	m s^{-1}
z	height of measurement above ground surface	m

Calculations

Below (figure 4.23) a print screen is added from the Excel file '2.Backdoor_Tool.xlxs'. This sheet presents the calculations explained above. For more detail see the Excel file, tab ET_o.



	N	O	P	Q	R	S
22		**based climate data current**				
23			u₂:	=IF(Q46=1;(F28*10^3)/(24*3600);IF(Q46=2;(F29*10^3)/(24*36		
24			n:	=IF(Q46=1;G28;IF(Q46=2;G29;IF(Q46=3;G30;IF(Q46=4;G31;IF(Q		
25						
26		**A Atmospheric Parameters**				
27			Tmax	=IF(Q46=1;C28;IF(Q46=2;C29;IF(Q46=3;C30;IF(Q46=4;C31;IF(Q4		
28			Tmin	=IF(Q46=1;B28;IF(Q46=2;B29;IF(Q46=3;B30;IF(Q46=4;B31;IF(Q4		
29	eq. 9		Taverage	=(Q27+Q28)/2		
30			Altitude	0		
31			u₂	=Q23		
32	eq. 13		Δ:	=(0,6108*EXP((17,27*Q29)/(Q29+237,3)))*4098/(Q29+237,3)^2	kPa. °C^-1	
33	eq. 7		P:	=101,3*((293-(0,0065*$B$23))/293)^5,26		
34	eq. 8		γ:	=0,665*10^-3*Q33	kPa. °C^-1	
35			**A-1**	=Q34*(900/(Q29+273))*Q31		
36			**A-2**	=Q32+Q34*(1+(0,34*Q31))		
37		**B Vapour Pressure**				
38	eq. 11		e°Tmax:	=0,6108*EXP((17,27*Q27)/(Q27+237,3))	kPa	
39	eq. 11		e°Tmin:	=0,6108*EXP((17,27*Q28)/(Q28+237,3))	kPa	
40	eq. 12	**B-1**	es	=(Q38+Q39)/2		
41		**RH**		=IF(Q46=1;E28;IF(Q46=2;E29;IF(Q46=3;E30;IF(Q46=4;E31;IF(Q4	%	
42		**B-2**	ea	=RH/((50/Q38)+(50/Q39))	kPa	
43		**B-3**	es-ea	=Q40-Q42	kPa	
44		**B Vapour Radiaion**				
45			Latitude	52		
46			Month#	=H20		
47	eq.22		ϕ	=+(PI()/180)*$G$22		
48	box.9		day	=+TRUNC(30,4*$H$20-15)		
49	eq.23		dr	=1+(0,033*COS((2*PI()*Q48)/365))		
50	eq.24		δ	=0,409*SIN(((2*PI()*Q48)/365)-1,39)		
51			sinϕ.sinδ	=+SIN(Q47)*SIN(Q50)		
52			cosϕ.cosδ	=+COS(Q47)*COS(Q50)		
53	eq.25		ωs	=+ACOS(-TAN(Q47)*TAN(Q50))		
54	24*60/PI*Gsc			=+(24*60)/PI()*0,082		
55	eq.21		R_a	=+Q54*Q49*(Q53*Q51+(Q52*SIN(Q53)))		
56	eq.34		N	=+(24/PI())*Q53		
57			n/N	=Q24/Q56		
58	eq. 35		Rs	=(0,25+0,5*Q57)*Q55	MJ.m-².day^-1	
59	eq. 37		Rso	=(0,75+((2*Q30)/100000))*Q55	MJ.m-².day^-1	
60		**C-1**		=Q58/Q59		
61	eq. 38		Rns	=0,77*Q58	MJ.m-².day^-1	
62			σTmaxK4	=+(Q27+273,16)^4*(4,903*10^-9)	MJ.m-².day^-1	
63			σTminK4	=+(Q28+273,16)^4*(4,903*10^-9)	MJ.m-².day^-1	
64		**C-2**		=(Q62+Q63)/2	MJ.m-².day^-1	
65		**C-3**		=(0,34-0,14*SQRT(Q42))		
66		**C-4**		=(1,35*Q60-0,35)		
67	eq. 39	**C-5**	Rnl	=Q64*Q65*Q66	MJ.m-².day^-1	
68	eq. 40		Rn	=Q61-Q67	MJ.m-².day^-1	
69		Tmean_month		=Q29		
70		Tmean_month-1		=Q69-1		
71	eq. 44		G	=0,14*(Q69-Q70)		
72			Rn-G	=Q68-Q71		
73		**C-6**		=0,408*(Q72)	mm.day^-1	
74						
75	eq. 6		**Eto**	**=((Q32*Q73)+(Q35*Q43))/Q36**	**mm.day^-1**	
76						

Figure 4.23 Print screen of calculation sheet in tab ‘ET$_o$’ (2.Backdoor_Tool.xlxs)

Crop evapotranspiration ETc

Differences in evaporation and transpiration between field crops and the reference grass surface are integrated in a single crop coefficient (K_c) (equation 4.21).

$$ET_c = K_c\, ET_o \quad (58)$$

Equation 4.21

ET_c	crop evapotranspiration	mm d^{-1}
K_c	crop coefficient	
ET_o	reference crop evapotranspiration	mm d^{-1}

Crop growth stages

As the crop develops, ground cover, crop height, and leaf area changes. The K_c of a crop varies over the growing period, due to differences in evapotranspiration during the various crop stages. The growth period is divided into four different growth stages; (1) initial, (2) development, (3) mid-season and (4) late season. The length of these stages are provided by the FAO Irrigation and drainage paper No. 25 and represented in chapter 6 of the FAO paper No 56 (FAO, 1998). Crops that have similar crop growth stages are grouped as one crop class (tab ‘K_c adjusted’, 2.Backdoor_Tool.xlxs).

Single crop coefficient

In the single crop coefficient approach, the effect of crop transpiration and soil evaporation are combined into a single K_c coefficient. The coefficient integrates differences in soil evaporation and crop transpiration rate between the crop and the grass reference surface. As soil evaporation may fluctuate daily as a result of rainfall or irrigation, the single crop coefficient expresses only the time-averaged effects of crop evapotranspiration. Also K_c values are provided in tables and are derived from this in the same manner as stage lengths. They are represented in the same file 2.Backdoor_Tool.xlxs, ‘K_c adjusted’.

The K_c values from the table (figure 4.24) represent values for specific climate. For different climates, more humid and less windy condition, the crop coefficient has to be modified for each growth stage.

K_c ini is derived from table 29, FAO paper 56.

FIGURE 29. Average $K_{c\ ini}$ as related to the level of ET_o and the interval between irrigations and/or significant rain during the initial growth stage for all soil types when wetting events are light to medium (3-10 mm per event)

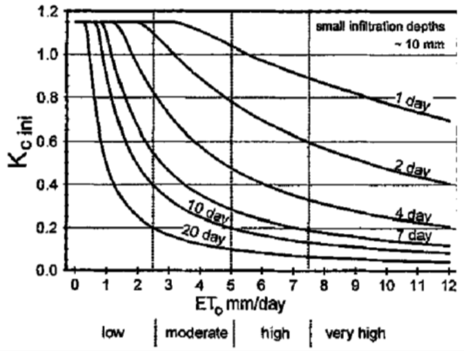


Figure 4.24 Kc Initial stage (FAO, 1998)

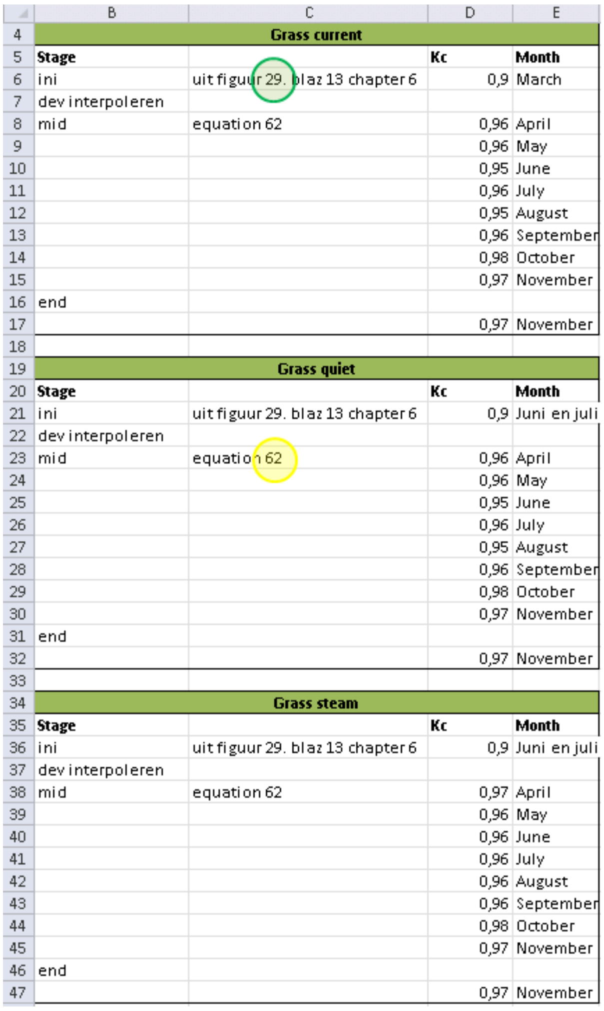
K_c mid and K_c end are derived by equation 4.22.

$$K_{cmid} = K_{cmid(Tab)} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (62)$$

Equation 4.22

K_c mid (tab)	value for K_c mid from table 12	
U_2	mean value for daily wind speed over grass during the mid-stage	m s-1
RH_{min}	mean value for daily minimum relative humidity during the mid-season growth stage	%
h	mean plant height	

The results for each crop and climate scenario are put in tables that are presented in 2.Backdoor_Tool.xlxs. In the figure below an example is given for grass (figure 4.25).



	B	C	D	E
4	**Grass current**			
5	**Stage**		**Kc**	**Month**
6	ini	uit figuur 29. blaz 13 chapter 6	0,9	March
7	dev interpoleren			
8	mid	equation 62	0,96	April
9			0,96	May
10			0,95	June
11			0,96	July
12			0,95	August
13			0,96	September
14			0,98	October
15			0,97	November
16	end			
17			0,97	November
18				
19	**Grass quiet**			
20	**Stage**		**Kc**	**Month**
21	ini	uit figuur 29. blaz 13 chapter 6	0,9	Juni en juli
22	dev interpoleren			
23	mid	equation 62	0,96	April
24			0,96	May
25			0,95	June
26			0,96	July
27			0,95	August
28			0,96	September
29			0,98	October
30			0,97	November
31	end			
32			0,97	November
33				
34	**Grass steam**			
35	**Stage**		**Kc**	**Month**
36	ini	uit figuur 29. blaz 13 chapter 6	0,9	Juni en juli
37	dev interpoleren			
38	mid	equation 62	0,97	April
39			0,96	May
40			0,96	June
41			0,96	July
42			0,96	August
43			0,96	September
44			0,98	October
45			0,97	November
46	end			
47			0,97	November

Figure 4.25

ETc under soil water stress conditions

In chapter 8 of the FAO Irrigation and drainage paper 56 by Allen *et al.* (1998) Soil water availability is described as following:

Total available water (TAW)

Soil water availability refers to the capacity of a soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased. In the absence of water supply, the water content in the root zone decreases as a result of water uptake by the crop. As water uptake progresses, the remaining water is held to the soil particles with greater force, lowering its potential energy and making it more difficult for the plant to extract it. Eventually, a point is reached where the crop can no longer extract the remaining water. The water uptake becomes zero when wilting point is reached. Wilting point is the water content at which plants will permanently wilt.

As the water content above field capacity will drain and as plant roots cannot extract the water content below wilting point, the total available water in the root zone is the difference between the water content at field capacity and wilting point (equation 4.23)

$$TAW = 1000(\theta_{FC} - \theta_{WP})\, Z_r \quad (82)$$

Equation 4.23

TAW	the total available soil water in the root zone	mm
θ_{FC}	the water content at field capacity	$m^3\ m^{-3}$
θ_{WP}	the water content at wilting point	$m^3\ m^{-3}$
Z_r	the rooting depth	m

TAW is the amount of water that a crop can extract from its root zone depends on the type of soil and the rooting depth. Ranges for field capacity and wilting point are listed in Table 19 for different soil texture classes. Ranges of the maximum effective rooting depth for various crops are given in Table 22.” These are represented in the file 2.Backdoor_Tool.xlxs, tab ‘TAW’ and tab ‘rootm and depletion fraction’. On Schouwen Duiveland there are different soils. From clay to sandy soils. All calculations done for crops in different areas are based on the field capacity and wilting point of one soil type. Silt is chosen, since silt represents an estimated average on Schouwen-Duiveland.

Readily available water (RAW)

As the soil water content decreases by uptake of the water by a crop, water becomes more strongly bound to the soil particles and is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress. The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water (equation 4.24).

$$RAW = p\ TAW \quad (83)$$

Equation 4.24

RAW	readily available soil water in the root zone	mm
p	average fraction of TAW that can be depleted from the root zone before moisture stress (reduction in ET) occurs	0-1

The fraction p is a function of the evaporation power of the atmosphere. At low rates of ET_c, the p values listed in Table 22 are higher than at high rates of ET_c.

Water stress coefficient (Ks)

The effects of soil water stress on ET are described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient (equation 4.25).

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW} \quad (84)$$

Equation 4.25

K_s	is a dimensionless transpiration reduction factor dependent on available soil water	0 – 1
D_r	root zone depletion	mm
TAW	total available soil water in the root zone	mm
p	fraction of TAW that a crop can extract from the root zone without suffering water stress	

Yield moisture stress relation

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_{c\,adj}}{ET_c}\right) \quad (90)$$

Equation 4.26

K_y	a yield response factor	
$ET_{c\ adj}$	adjusted (actual) crop evapotranspiration	mm d^{-1}
ET_c	crop evapotranspiration for standard conditions (no water stress)	mm d^{-1}

K_y is a factor that describes the reduction in relative yield according to the reduction in ET_c caused by soil water shortage (equation 4.26). K_y values are crop specific and vary over growing season. In general, the decrease in yield due to water deficit during the vegetative and ripening period is relatively small, while during the flowering and yield formation periods it will be large. Values for K_y for individual growth periods are derived from FAO Irrigation and Drainage Paper N°33. They are included in 2.Backdoor_Tool.xlxs, tab ‘K_y values’.

Appendix IV

Guideline for interview questions in Dutch

Respondent
Bedrijfsprofiel
Naam van de boer:
e-mailadres:
telefoonnummer:

Verleden

1. Hoe heeft het bedrijf zich de afgelopen 10(+) jaar ontwikkeld?

....

2. Hoe was de zoetwatervoorziening geregeld en hoe is deze nu?

....

3. Is uw waterverbruik en waterwens nu ten opzichte van 10(+) jaar geleden meer, minder of gelijk gebleven op uw bedrijf?

....

4. Kunt u iets vertellen over uw bouwplan en de wijzigingen daarin de afgelopen 10(+) jaar?

....

Heden

5. Hoe werkt uw huidige zoetwateraanvoer?

6. Hoe zou u uw zoetwaterschaarste omschrijven?

a). ernstig tekort b). tekort c). geen d). overschot e). ruim overschot

6-a). Kunt u een indicatie geven hoe groot het tekort of overschot van het zoete water is en in welke periode van het jaar?

....

6-b). Op welke wijze bepaalt u dit?

....

7. Heeft u wel eens tegenvallende gewasopbrengsten? Zo ja: wat is over het algemeen de oorzaak hiervan?

....

8. Hoe drukt u uw gewasopbrengst het liefst uit? Is dit kg per ha, € per kg € per ha?

....

9. Ik begrijp dat ieder jaar anders is.
Wat beschouwt u als een normaal jaar wat betreft uw gewasopbrengst? Welk jaar en waarom?

....

9-a). Kunt u ook een top jaar en een slecht jaar noemen? Welke jaren en waarom?

....

9-b).Welke percentages gewasreductie heeft u zo ongeveer in die jaren gehad? Wat was het effect op uw opbrengst in euro (Jan: omdat het voorkomt dat bij droogte en weinig opbrengst de boer toch meer verdient omdat de euro per kilo toe is genomen (vraag en aanbod))

....

10. Kunt u vertellen over collega's in uw omgeving die geen, minder of meer problemen ervaren?

....
....
....

Toekomst

11. Indien de zoetwaterschaarste in een groeiseizoen toeneemt, zou uw bedrijf daar dan mee om kunnen gaan?

a). nee, grote schade en dus kwetsbaar
b). matig, kleine schade en dus licht kwetsbaar
c). zoetwaterschade is geen probleem
d). ja, bij klein beetje schaarste geen schade
e). ja, bij grote schaarste geen schade

11-a). Waardoor komt het dat u wel of niet kwetsbaar bent? Heeft u maatregelen getroffen? Aan welke termijn denkt u dit te realiseren?

....

12. Stel dat u buiten uw huidige watergebruik een grote hoeveelheid extra water krijgt. Hoe ziet u uw bedrijf dan over 10 jaar?

....
....

13. Vindt u dat er wat gedaan moet worden aan de zoetwatervoorziening op Schouwen-Duiveland?

13-a). Zo ja; wat zou volgens u moeten gebeuren?

....

13-b). En; wie zou hier verantwoordelijk voor zijn?

....

14. *De kreekrugproef (zie afbeelding in begeleidende brief) is een wijze om de zoetwater voorziening op Schouwen-Duiveland te verbeteren. Welke kansen en barrières ziet u bij deze proef?

....
....

15. Kent u nog andere strategieën/welke mogelijkehden ziet u?

....

16. Heeft u bedrijfsopvolging? Zo ja wat is de bedrijfsstrategie van deze persoon?

....
....

17. Wie zou ik nog meer kunnen interviewen over hetgeen dat we net hebben besproken?

Appendix V

Summary of interviews conducted on Schouwen-Duiveland

Interview 1:

Gilles Klompe
Kapteinsweg 14, 4315 PN, Dreischor
e-mail adres: gjklompe@live.nl
telefoonnummer: 0031(0)651028764

The farm exist for 200 years and has been past on from father to son for generations. Recently Mr Klompe fused with his neighbour increasing the land from 60 to 250 hectare. In principle there is no water from irrigation and thus crops rely on precipitation. In dry years, water from the Volkerakzoom lake can be taken and distributed with trucks, this is not desirable as it turned out not to be cost effective. Mr Klompe explained he is expecting yield reduction by drought from time to time. Farmers base their crop choice on this and it determines farmer practices he explained.

In the past decades intensification of agriculture is the trend on Schouwen-Duiveland, It has led to the decrease of crop variety. Mr Klompe started with the cultivation of bulbs as the Gevelingen Lake was supposed to become a fresh water body. It turned out this never happened and Mr Klompe stopped the cultivation of bulbs. Nowadays he is cultivating a variety of crops, i.e. potatoes, beets, wheat, unions and more.

About water scarcity Mr Klompe explains that there is a shortage in theory, but in practice he experiences that farmers adapt. And apart from yield reduction by drought there are many more other factors to be taken into account. It is for example very important how a crop germinates, if this doesn't go well, the rest of the season can be as good as it can be, the crop will never reach full potential anymore. Than there is the factor of less light, lower temperature., etc. So there is never 1 cause.

A good year depends on how it is expressed. A year in kg/ha does not equal a good year in €/ha, as the supply demand is imbalanced by the supply and a low price/ha is the result. Mr Klompe explains no measures are needed as farmers have adapted and will always adapt.
If there would be any water available he would not change his cropping pattern or company to another high value crop, but instead he would want to irrigate when needed in periods of drought. He also adds to that that the water provision needs be taken into account while at the drawing table. It is difficult to implement a whole new fresh water provision while the farm is already equipped. Fresh water provision by flushing all ditches to get them fresh is the only way to enforce the fresh water provision according to Mr Klompe. But he thinks this will not happen because of the costs. Buffering water in subsurface aquifers or basins is not taken as a serious option by Mr Klompe, as it would be too small scaled and includes too high logistical costs. Agriculture can continue as it currently does and farmers except the losses they have due to drought or other causes.

Interview 2:

Senny Capelle fruitteler te Nieuwerkerk
Galgeweg 5, 4306 NJ, Nieuwerkerk
e-mail adres: sjcapelle@gmail.com
telefoonnummer: 0031(0)651361597

In the past the farm of Mr Capelle were agricultural practices, while now a days it is mainly fruit trees and packing and transhipment of fruit from abroad to distribution centres elsewhere in the Netherlands. Packing is done for several other fruit companies and fruit for transhipment is coming from different places over the world i.e. New Zealand and Italy.

Yearly precipitation is not sufficient for his fruit trees and therefore Mr Capelle has got a basin from which the trees are irrigated by drip irrigation. In case of a dry summer, the capacity of the basin might be insufficient. A shortage of water determines the quality of the fruit. Too little water results in a smaller diameter of the fruit and a lower price too. The water use of a tree is determined by the growth phase a tree is in, as young trees consume relative more water.

The biggest cause of a reduced yield is not a water shortage, but frost in October. Due to the unavailability of water he can't use sprinklers to prevent damage from this, while other fruit farmers more inland ca. But the advantage of the location of Schouwen-Duiveland, much less frost occurs, as the climate is milder by the influence of the sea.

A good harvest for one farmer is a good harvest for the other, causing prices to drop. But it works the other way around as well, with a bad harvest a good price is paid for the product. There were many more fruit growers on Schouwen-Duiveland in the past, especially on the West of the island. Many farmers have switched to recreational activities.

The company does not rely on its own harvest, as it has other activities regarding the transhipment and packaging. A drought would cause some trouble for the harvest as the basin is used to its full capacity already. Next to the basin there is no back up, except for piped water.
In case of an extra fresh water provision it would be a welcome insurance against frost. But it would not lead to an extension of the current agricultural practices, more likely the transhipment and packaging of fruit would be expanded.

Mr Capelle further explains that the creek ridge measure is possibly the only feasible option for an increase of fresh water security. But there are many problems before implementing such measures as the sub soil needs to be known and it requires cooperation between farmers. In some cases the cooperation can be improved. When getting involved in such projects, there needs be unity among the farmers and in addition to that it really depends on the crops of the farmers. As they all got different water demands and growing seasons.

Interview 3:

Uitwerking interview 19-12-2012

Dick van Noord glastuinder te Sirjansland
Noord Hogeweg 1A, 4308 NW Sirjansland
e-mail adres: dick@dtvannoord.nl
telefoonnummer: 0031(0)65156713

Van Noord started with 1 hectare on Schouwen-Duiveland and has expanded the greenhouse surface to 3.5 hectare. Currently 4.7 hectare is being build in addition to the existing 3.5 hectare. There is a 12.000m^3 basin for 3.5 hectare of tomatoes. Drain water is being recycled and yearly there is a demand of approximately 13.000m^3 of irrigation water. Currently van Noord 1.2 m^3/m^2 of which 30 -35% is recycled. The other part is rainwater stored in the basin.
Water use has been the same. The main reason for this is that a green house is a closed system, however scarcity occurs depending on the precipitation that falls in a year.

Van Noord explains the crop cannot suffer from water shortage at all, since the plants grow in a green house and not in an actual soil, no water buffer is present. In case the basin is not sufficient in fresh water supply, water has to get from another source. In case this situation occurs, tap water is used, but this is not desirable because the water is ‘to clean’ for the plant and lacks nutrients. And the water is more expensive.

A good year in yield is different from a good in year financially. 2010-2011 was a good year, while 2011-2012 was a bad year in terms of yield. Financially speaking it can be the other way around. A good yield is largely dependant on sun hours. The company has a yearly turnover of approximately €8.000.000.

The company copes with scarcity by buying fresh water. Next to the tap water there is no other buffer to deal with possible water scarcity. If there is the ambition to create another buffer strategy, investments have to be done. Van Noord is now collecting water from his green house roof surface area and stores this in his basin. According to him there a lot of potential to use roof surface area in urbanized areas. Now this water is not collected and flushes away. There is a potential to collect and store this water too. Another option is to transport fresh water from the Biesbosch area. The municipality will play a large role in decision-making on alternative fresh water provision.

The creek ridge is a nice alternative. Van Noord explains that he would like to store water that would not fit his basin, in subsurface water basins and pump it up when needed. But research on the soil types on his land has to be executed. In case possibilities exist the measure can count on the support of adjacent farmers. It could be a project that together can be realized, as it would be a good alternative to tap water. Van Noord would like to know more on subsurface water storage for practical use for his green house.

Interview 4:

Uitwerking interview 20-12-2012

Huub Remijn
Steursweg 2, 4328 NH, Burgh-Haamstede
e-mail adres: oudbrabers@zeelandnet.nl
telefoonnummer: 0031(0)620133220

In 1994 Remijn started farming. The farm had 70 hectares of land, but has expand thoughout the years up to 120 hectares. In recent years he is focussing on and interested in the presents of fresh water. By influence of the Oosterschelde and the North Sea, groundwater and ditch water is saline. The nearby dunes contain fresh water. Water that flows from here mixes with saline water bodies and is therefore not useful.
The water holding capacity of the soil is high in which rainwater is stored for a long period of time, making the soil useful for agriculture. But in times of drought the water holding capacity is not sufficient enough.

Surrounding farmers accept a certain scarcity and appreciate the 70- 80% of the optimal yield they have got. Remijn does not want to suffer from ‘unnecessary’ yield reduction and invests in fresh water security, but has a higher labour input to achieve his extra water availability. Remijn obtained a permit for a drain to get water from a fresh water source of 5 meters thick. And Remijn is the only one that has got access to waste water from recreational area, although this water can be used for limited purposes. Throughout the years Remijn cultivates potatoes, beets, celery, unions and wheat.

Drainage of fresh water is as important as the supply of fresh water, hence the fact that the bigger part of the year is rather too wet then too dry. Remijn explains he has a water shortage even though the measure he took. For the majority of Schouwen-Duiveland he thinks the situation is more urgent, since it is more difficult to get alternative sources of fresh water, compared to the alternatives Remijn has got.

Shortage is dependant of seasons and cop type. One crop can cope better with drought then the other, e.g. wheat versus potatoes. In addition to that is mentioned that a year of drought is financially often a good year. The cause of a disappointing yield in kg is not only because of drought. A wet year causes problems too such ass fungus. And the timing of different causes can have different effects. A drought specifically in the growth phase of potato causes a yield reduction of 30% in kg, easily. Other factors such as salinization are a threat too.

Dry years are financially the best years. The turnover of the farm is approximately €400.000 or €3500/ha. Colleagues of Remijn have a lower water availability, but because of that less labour. Remijn has to provide extra labour input to arrange his water supply.
Through the investments Remijn has done he can cope with extra drought, without having a yield reduction. He took precautions that he things are necessary for the whole island. As an example he explains that in the 2011 when there was a dry Spring, other farmers were distributing water by tankers, while he didn’t needed to.

In case of additional available fresh water his farm would most likely operate in the same way as it is doing now. Although Remijn adds it will create favourable conditions and might provide opportunities later. In the opinion of Remijn it all comes down to: ‘what is a farmer willing to pay?’ It has to be accessible for a farmer to motivate the farmer to invest. As an example Remijn tells that thirty years ago there was a chance to create fresh water ditches, that would require a higher levy from the water boards. Because of the higher tax the farmers themselves declined the proposition.

According to Remijn agricultural organizations have responsibility for fresh water provision, because it concerns food production. Government as there is an interest from society. And there are different opposing interests, making it impossible that everybody is a winner, e.g. the development of nature: economic versus ecologic interests. Developing nature decreases the availability of fresh water for agriculture.

Restrictions of the creek ridge measure are costs and soil dependant. Every situation will be different. Other strategies are water provision from the Volkerak Zoommeer, the East part of the Haringvliet, run off from the dunes, or from the deep subsurface water aquifers, below the saline waterbodies.

Appendix IV

Opbrengstreductie in % dertigjarig gemiddelde

			geen bereg	beregening met concentratie chloride in gietwater mg/l													
		UC	-1	0	50	100	150	250	500	750	1000	1250	1500	2000	3000	4000	5000
Zavel	Aardappel	11	1	0	0	0	0	0	0	0	0	1	1	1	3	4	5
	Gevoelige aardappel	12	1	0	0	0	0	1	1	2	3	3	5	7	9	10	15
	Tulp	13	0	0	0	0	0	0	0	1	1	2	2	3	6	7	8
	Biet	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fruitteelt	15		0	0	0	0	0	0	6	16	26	36	56	96	100	100
	Vollegr. Groenten	16		0	0	0	0	0	16	36	56	76	96	100	100	100	100
	Boom-/sierteelt	17		0	0	0	0	16	56	96	100	100	100	100	100	100	100
	Glastuinbouw	18		0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gras	19	2		0	0	0	0	0	0	0	0	0	0	1	1	2
Klei	Aardappel	21	5	0	0	0	0	0	0	0	1	2	3	5	7	12	16
	Gevoelige aardappel	22	5	0	0	0	0	1	3	7	9	12	15	19	26	31	34
	Tulp	23															
	Biet	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fruitteelt	25		0	0	0	0	0	0	6	16	26	36	56	96	100	100
	Vollegr. Groenten	26		0	0	0	0	0	16	36	56	76	96	100	100	100	100
	Boom-/sierteelt	27		0	0	0	0	16	56	96	100	100	100	100	100	100	100
	Glastuinbouw	28		0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gras	29	4	0	0	0	0	0	0	0	0	0	0	0	2	3	5
Klei op zand	Aardappel	31	2	0	0	0	0	0	0	1	1	2	3	5	9	12	15
	Gevoelige aardappel	32	2	0	0	0	0	0	2	5	7	9	11	15	21	24	28
	Tulp	33															
	Biet	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fruitteelt	35		0	0	0	0	0	0	6	16	26	36	56	96	100	100
	Vollegr. Groenten	36		0	0	0	0	0	16	36	56	76	96	100	100	100	100
	Boom-/sierteelt	37		0	0	0	0	16	56	96	100	100	100	100	100	100	100
	Glastuinbouw	38		0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gras	39	4	0	0	0	0	0	0	0	0	0	0	0	1	2	3