DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

www.dessin-project.eu

D33.2: Evaluation of the improvement of Ecosystem Services as a result of ASR/RO application

Final evaluation of the technological solution in terms of ESS and sustainability at the Westland Demo case

KWR Watercycle Research Institute, December 2017

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

D33.2 Evaluation of the improvement of Ecosystem Services as a result of ASR/RO application

FINAL EVALUATION OF THE TECHNOLOGICAL SOLUTION IN TERMS OF ESS AND SUSTAINABILITY AT THE WESTLAND DEMO CASE

SUMMARY

Water scarcity and quality issues form common concerns in many regions in and outside of Europe. Within the DESSIN project, innovative solutions are tested at five demo sites across Europe. This document contains the ESS evaluation the Westland demo case.

At the Westland demo site, aquifer storage and recovery technology (ASR) is used to inject fresh water into the first aquifer at horticultural greenhouse complexes. This technology partially compensates for the abstraction of brackish groundwater, which is used, after desalinization, for crop irrigation.

The technology creates value for three types of ecosystem services (ESS): Availability of groundwater for irrigation, chemical water conditions, and stormwater retention. Further upscaling of the technology could reduce sea water intrusion along the coastline as well.

Under current policy, this technology is not used at most horticultural complexes in the region. Planned policy revisions may however provide opportunities for wide scale application.

DELIVERABLE NUMBER	WORK PACKAGE
D33.2	WP33
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
KWR Water Research Institute	Dr. Sija Stofberg (KWR) Dr. Marcel Paalman (KWR) Dr. Koen Zuurbier (KWR)
QUALITY ASSURANCE	
Prof. dr. Pieter J. Stuyfzand (KWR)	Ester Vilanova Muset (Amphos 21)
PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
31/12/2017	31/12/2017
DISSEMINATION LEVEL	× PU = Public □ PP = Restricted to other programme participants □ RE = Restricted to a group specified by the consortium. Please specify: ________________________________ □ CO = Confidential, only for members of the consortium

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Table of contents

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Figures

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Tables

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

List of Acronyms and Abbreviations

ASR	Aquifer storage and recovery
ESS	Ecosystem services
RO	Reverse osmosis
ASRRO	Aquifer storage and recovery in combination with reverse osmosis

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Executive summary

Water scarcity and quality issues form common concerns in many regions in and outside of Europe. New technologies may provide solutions for these issues. If the benefits of technical solutions are clear, they are more likely to be implemented. Within the DESSIN project, innovative solutions are tested at five demo sites across Europe. This document contains the ESS evaluation report of the Westland demo case.

At this demo site, aquifer storage and recovery technology (ASR) is used to inject fresh water into the first aquifer at horticultural greenhouse complexes. This technology partially compensates for the abstraction of brackish groundwater, which is used, after desalinization, for crop irrigation. Furthermore, it reduces the salinization that results from the abstraction and from the injection of the concentrate that is created during the desalinization process.

The evaluation of this technology shows that the net groundwater abstraction has decreased and the groundwater salinity has decreased as well after implementation. However, small concentrations of contaminants were observed in the injected water. Furthermore, additional volume is created in the rainwater basins, which can be used as retention volume during peak precipitation events.

The technology creates value for three types of ecosystem services (ESS):

- Availability of groundwater for irrigation (provisioning)
- Chemical water conditions (regulation and maintenance)
- Stormwater retention (regulation and maintenance)

If only the production is considered, the ASR technology makes the production of irrigation water more expensive. However, if environmental effects are taken into account as well, ASR becomes a more competitive option, even when measures are needed to filter out contaminants from the water that is injected.

Under current policy, mitigation of environmental effects is not required, which is a reason why this technology is not used at most horticultural complexes in the region. Planned policy revisions (2022) may however provide opportunities for wide scale application of this technology, although subsurface spatial planning issues still need to be resolved.

Further upscaling of the technology could be beneficial, especially if all groundwater abstraction is compensated for by injection of fresh water, because it could also reduce sea water intrusion that takes place along the coastline. At a larger scale, complete compensation would be possible if companies with a low water demand inject more water than they abstract, to compensate for companies with a high water demand that abstract more than they inject. As such a system needs incentives; a water bank system is proposed as a measure to make the water use in the whole region more sustainable.

1 General introduction

Water scarcity and quality issues form common concerns in many regions in and outside of Europe. New technologies may provide solutions for these issues. If the benefits of technical solutions are clear, they are more likely to be implemented.

The European water research project DESSIN demonstrates and promotes innovative solutions for water scarcity and water quality related challenges, and demonstrates a methodology for the evaluation of ecosystem services (ESS). Innovative solutions are tested at five demo sites across Europe.

Within the DESSIN project, a framework has been developed for the evaluation of changes in ecosystem services (ESS) and sustainability as a result of the implementation of new technical or management solutions (D11.2). This framework is based on several methods, including the DPSIR framework (Kristensen, 2004). The DESSIN framework is applied on the five European demo cases. It is one of the first times that an evaluation framework has been applied on several international cases all together.

This document contains the ESS evaluation report of one of the demo cases. The evaluations have been conducted with the help of the specially developed ESS toolkit for the MIKE Workbench software (D23.3).

The objective of this report is to show how the technical solution(s) affect ecosystem services, and to perform an (economic) evaluation of the changes in ESS provision and use. Furthermore, the sustainability of the measure(s) is assessed and implications regarding governance and policy are discussed. After that, opportunities and challenges related to governance and policy are discussed, and novel financing mechanisms are proposed.

2 ASRRO Westland Demo site

In this report, an evaluation is made of the ESS and sustainability of the Westland demo case, where an innovative system, consisting of combined aquifer storage and recovery (ASR) and reverse osmosis (RO) (the acronym ASRRO is used for the combination of both techniques), is tested with the purpose to provide fresh irrigation water for greenhouse horticulture and to decrease groundwater salinization.

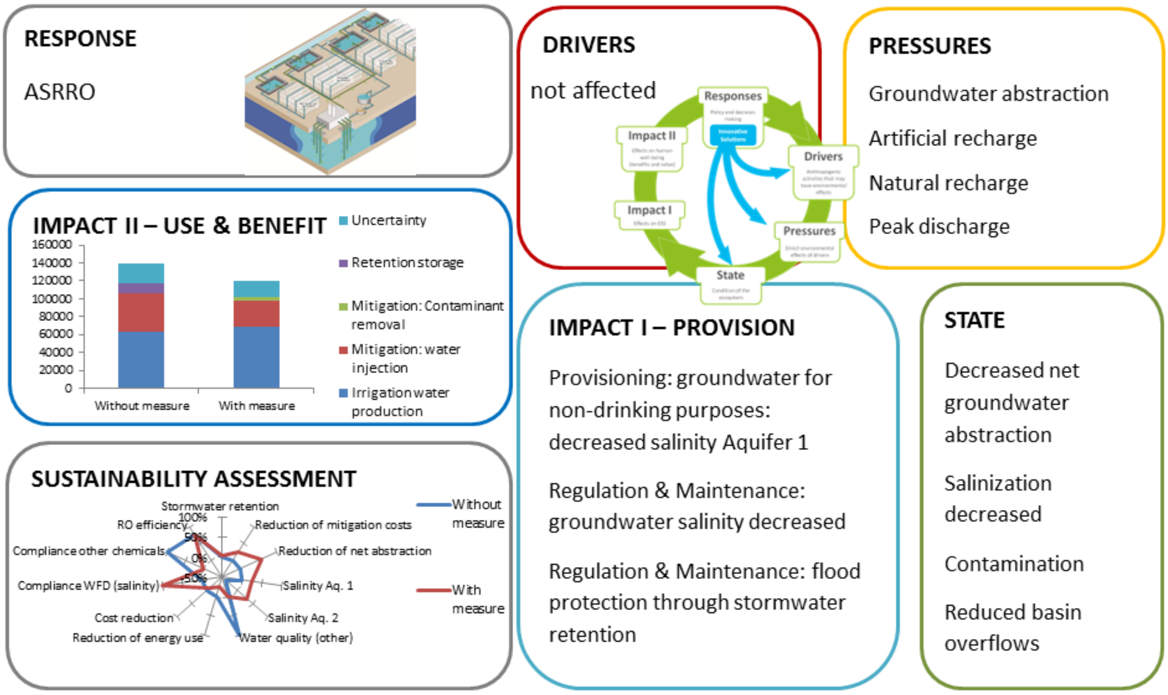


Figure 2-1. **Overview graphic of the ESS evaluation of the Westland demo case.**

2.1 Part I: Study description

2.1.1 SETTING THE SCENE

2.1.1.1 Administrative details

This assessment is carried out by KWR Watercycle Research institute and is part of the DESSIN project which is funded by the European Union Seventh Framework Programme (FP7). Information that was needed for this assessment was received from the horticultural companies at the Westland demo site and from previous DESSIN reports.

2.1.1.2 Objectives of assessment

The intended readers of this report are policy makers that are interested in improving irrigation water provision and mitigating groundwater salinization.

The assessment is conducted with the aim of (i) identifying and quantifying the effects of the implementation of the ASRRO system on water-related ecosystem services, and (ii) assessing the sustainability. The assessment will focus on the actual effects at the local scale of the ASRRO system, and it will extrapolate potential effects to the regional scale.

2.1.1.3 Overview of study area

The study area is located in the Netherlands, which is part of Western Europe. This region has a temperate maritime climate. The Westland region is located in the municipality ‘Westland’, which is part of the coastal, western part of the Netherlands (Figure 2-2). The municipality has 100,000 inhabitants. Most of the total area (9074 hectares) of the municipality is used for agricultural purposes (53%), of which 80% consists of greenhouse horticulture (Figure 2-3). The remaining area mostly consists of buildings, roads and recreational areas [CBS, 2017]. The region is especially known for its greenhouse horticulture, which is mostly focused on flower crops (51% of the greenhouse area) and vegetables. The horticultural sector of the Westland is important for the national economy as it provides about 60,000 jobs and contributes largely to the € 4.1 billion gross municipal product [Westland, 2017]. For comparison, the gross national product was € 702 billion in 2016 and the GDP of agriculture, forestry and fishery was € 11.5 billion (CBS, 2017).

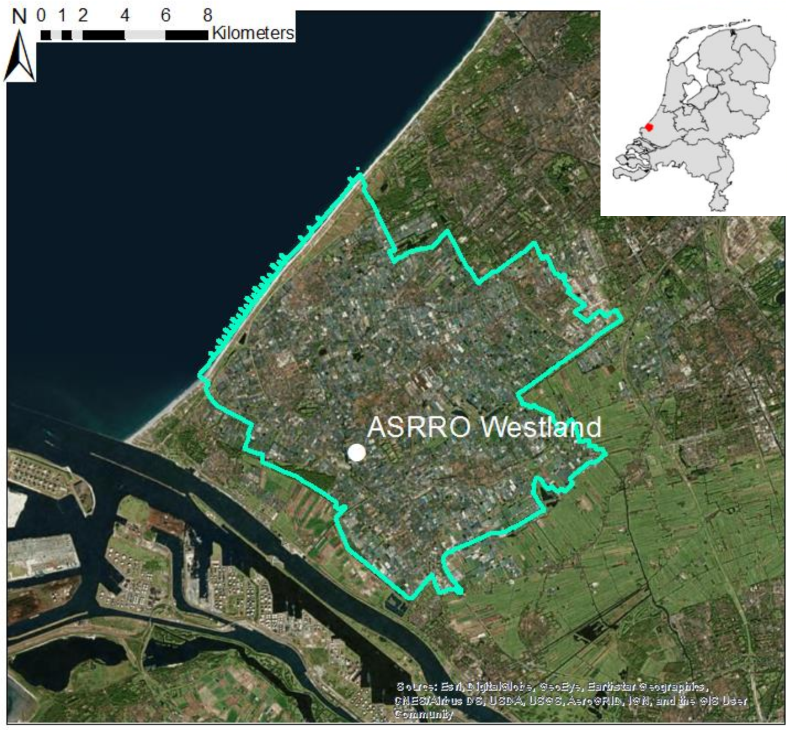


Figure 2-2. The ASRRO Westland demo site, the municipality of Westland and its location within the Netherlands.

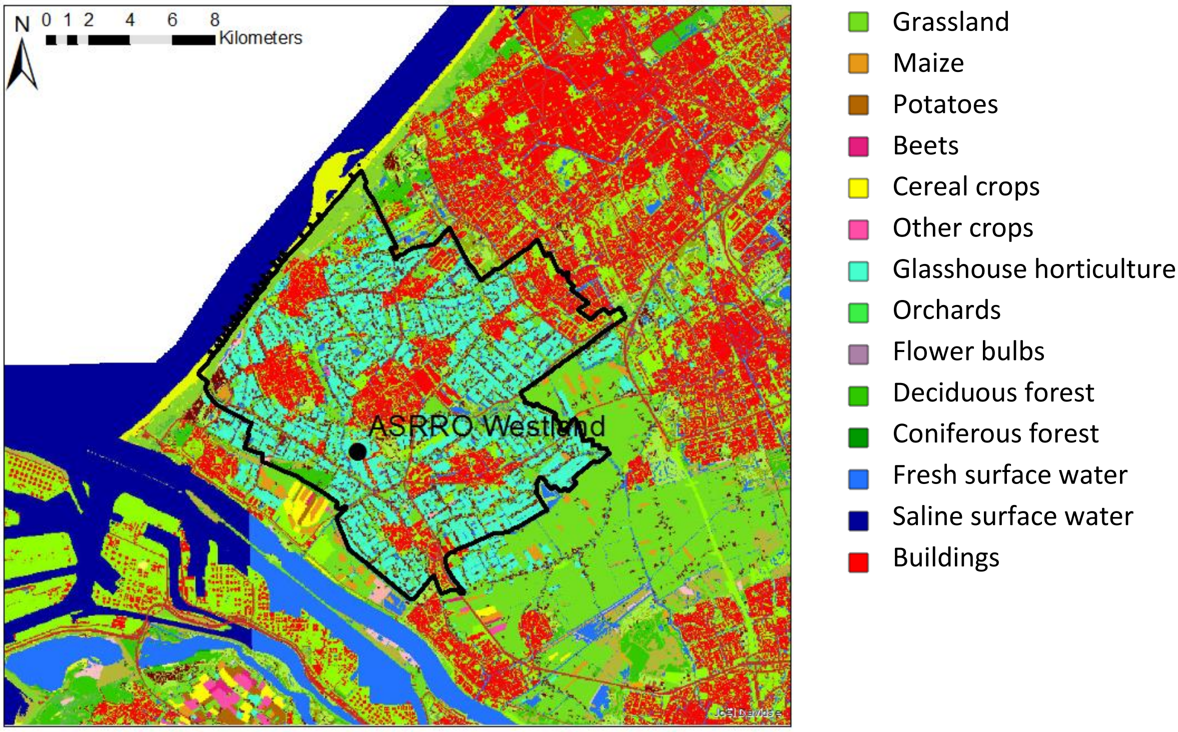


Figure 2-3. Land use map of the Westland area with the main types of land uses (Source: LGN7 (Alterra, 2012)).

The hydrological system of the Westland area consists of a polder, in which the ditch water levels are maintained at levels below mean sea level. The regional water authority Hoogheemraadschap Delfland pumps water out of the polders during times of precipitation surplus. To maintain sufficient water quality, the water authority 'flushes' the polder when needed, by supplying river water to the polder and pumping it out from the other side of the polder. The subsurface consists of aquitards and aquifers that contain brackish to saline groundwater. The first aquifer (approximately 23 - 37 m below surface) is brackish and the second aquifer (approximately >47 m below surface) is saline. As a result of the low surface water levels (Figure 2-4), salinization takes place as saline groundwater (intruded North Sea water) flows inland and upwards (saline seepage).

It is expected that climate change will put increasing pressure on these polder systems, as sea level rise and summer droughts will lead to increasing salinization (increased seepage pressure and seawater intrusion via rivers), while wintertime precipitation is expected to increase (Barends et al., 1995; Intergovernmental Panel on Climate Change (IPCC), 2007; Kooi, 2000; Kwadijk et al., 2010; Oude Essink et al., 2010; Post, 2003; Royal Netherlands Meteorological Institute, 2014; Schothorst, 1977; Zuurbier and Ros, 2017).

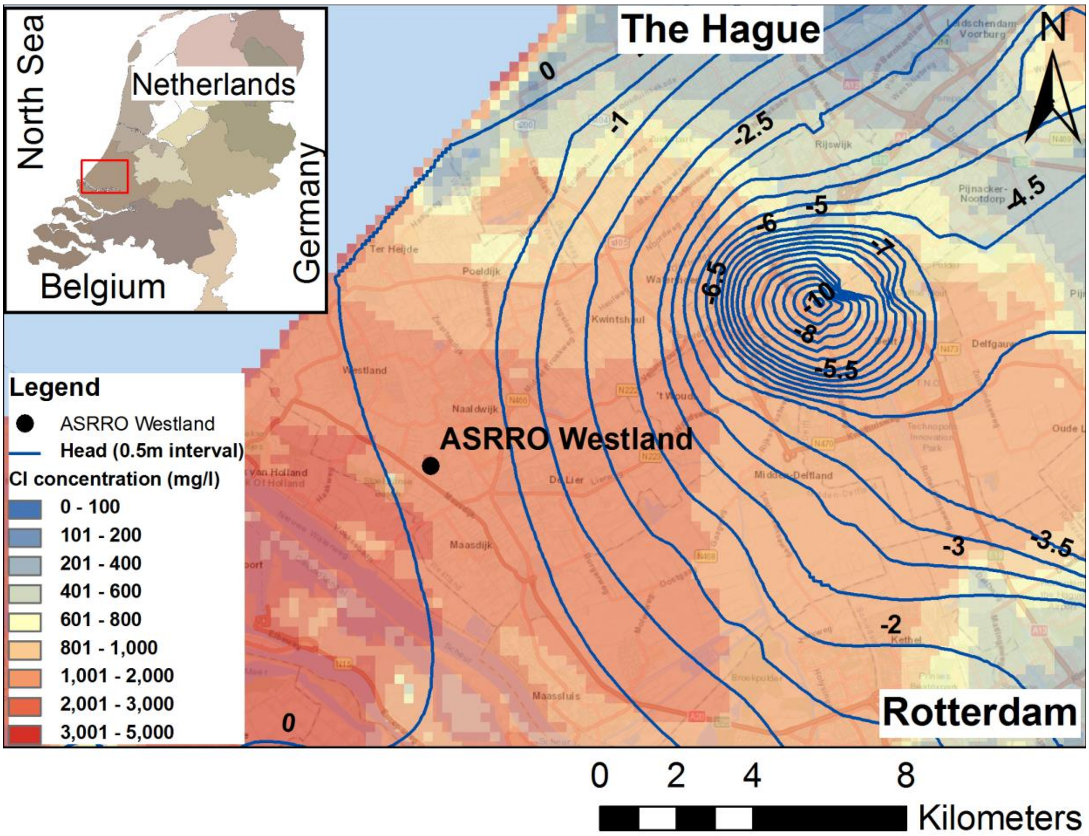


Figure 2-4. Hydraulic heads and groundwater chloride concentrations in the upper aquifer system of the Westland region.

2.1.1.4 Stakeholders

The stakeholders of the implementation of the innovative solution at the Westland demo case are those who use or maintain the (ground) water system. In this region, they include:

- Horticultural companies, as they use groundwater for the production of irrigation water. Furthermore, these companies are the ones that decide on the implementation of measures such as the ASRRO system.
- Hoogheemraadschap Delfland (Water Authority), which is responsible for the water system quantity and quality.
- Province of Zuid Holland, which is responsible for strategic management regarding (regional) groundwater quality.

2.2 Part II: Problem characterization

2.2.1 DRIVERS

In the densely populated Westland area, many human activities coexist, including housing, industry and agriculture. To make this possible, surface water levels are strongly managed through a system of dykes, drainage ditches and pumping stations.

The driver that is considered here, is the greenhouse horticulture, which is the dominant type of land use in the region. In the glasshouses, many types of crops, including vegetable crops (mainly tomatoes, cucumbers and peppers) and flowers, are cultivated.

2.2.2 PRESSURES

There are several water-related pressures that are attributed to greenhouse horticulture (Table 2-1).

Most horticultural crops that are grown in the greenhouses have a high water demand. The salinity requirements of the irrigation water in this area are exceptionally strict; drinking water (tap water) is already too saline for many of the crops. Only irrigation water with low salinities can be reused multiple times. Precipitation is a primary source of irrigation water, which is collected from the greenhouse roofs, and stored in basins or tanks. When insufficient precipitation is available, mainly desalinized brackish groundwater is used for irrigation (Stuyfzand and Raat, 2010). Surface water could be used as well, but often it is too brackish and unsuitable for desalination (RO) due to suspended solids.

During winter there is a freshwater surplus, as the crop water demand is relatively low. Due to limited storage volumes, part of the surplus is discharged into the surface water (ditches in a polder system) from where it is discharged into the sea. During the summer, the water demand is relatively high, and precipitation is often not sufficient to meet the irrigation demands. During summer, the surface water is often not suitable for irrigation, due to increased salinity levels that result from seepage of brackish groundwater (De Louw et al., 2010).

Due to the lack of available freshwater resources, brackish groundwater is abstracted and desalinized using reverse osmosis (RO). In this process, the brackish water is separated into two components: demineralized fresh water (permeate) and saline concentrate. The fresh water contains very little salts and can be readily used as irrigation water. The saline concentrate is considered waste. As it is not allowed to discharge the concentrate into sewage systems or surface waters, it is disposed into deeper aquifers.

As much of the region consists of paved area (buildings, roads), most precipitation is discharged into the surface water (network of drainage ditches) very quickly. As surface and groundwater water levels are relatively low, seepage takes place instead of recharge. Horticulture contributes to this pressure, as the storage basins can suddenly overflow during intense or long precipitation events. Since many horticultural companies are scaling up, with larger water basins, the overflow can result in large, sudden discharge peaks (Jouwersma, 2016). This requires many efforts by the regional water authority (Hoogheemraadschap Delfland) to pump out excess water from the polders. In some parts of the Westland region, intense precipitation events have led to flooding in the past (Gemeente Westland and Hoogheemraadschap van Delfland, 2012). In 2010, the Hoogheemraadschap formulated the objective to create 450,000 m^3 of water storage (retention) within their area (Hoogheemraadschap van Delfland, as cited in Van der Schans et al. (2014)).

Table 2-1. Overview of water-related pressures (according to the terminology of D11.2) that are attributed to greenhouse horticulture (before measure).

Pressure	Specification
Abstraction	Abstraction of brackish groundwater
Artificial recharge	Injection of RO concentrate into deeper aquifer
Natural recharge	Precipitation is collected from roofs, to be used for irrigation, surplus is discharged, and surface water levels are low, leading to reduced natural recharge
Peak discharge	Overflow of basins to surface water, increased flood risk

2.3 Part III: Response capabilities & potential beneficiaries

2.3.1 Response capabilities

The proposed measure consists of a combination of aquifer storage and recovery (ASR) and brackish water reverse osmosis (BWRO).

ASR is a technique that has been used in this region on a small scale since the 1980s. Surplus precipitation is injected by wells in the upper aquifer (10-50 m below surface). Later on, the stored fresh water is recovered by the same well. The percentage of stored water that can be recovered depends on dispersion in the aquifer, in-well mixing, bubble drift and buoyancy. Due to the density difference between the stored fresh water and the (brackish) groundwater, the injected water will flow upwards, leading to salinization of the bottom of the ASR well (Figure 2-5). In the Westland area, with its brackish groundwater, this means that the recovery efficiency is limited (Zuurbier et al., 2013).

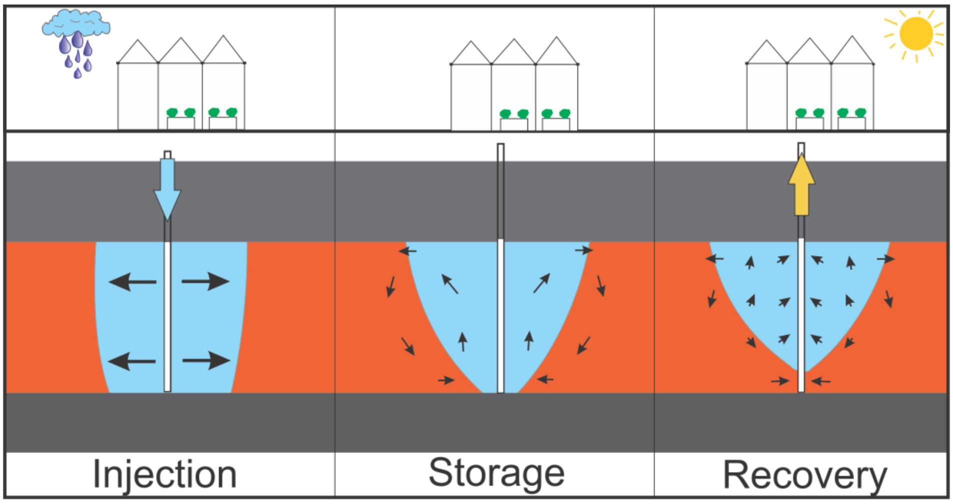


Figure 2-5. Freshwater loss during ASR in brackish and saltwater aquifers due to buoyancy effects.

To improve the performance of the ASR system, it is combined with a Freshkeeper and a RO system. Using multiple partially penetrating wells (MPPWs), the fresh water surplus is injected into deeper layers of the aquifer, and recovered from the upper layers. Salinization is further postponed by simultaneously abstracting brackish water from the deeper part of the aquifer (Freshkeeper, Figure 2-6). The abstracted brackish water is treated by RO, after which the permeate can be used for irrigation.

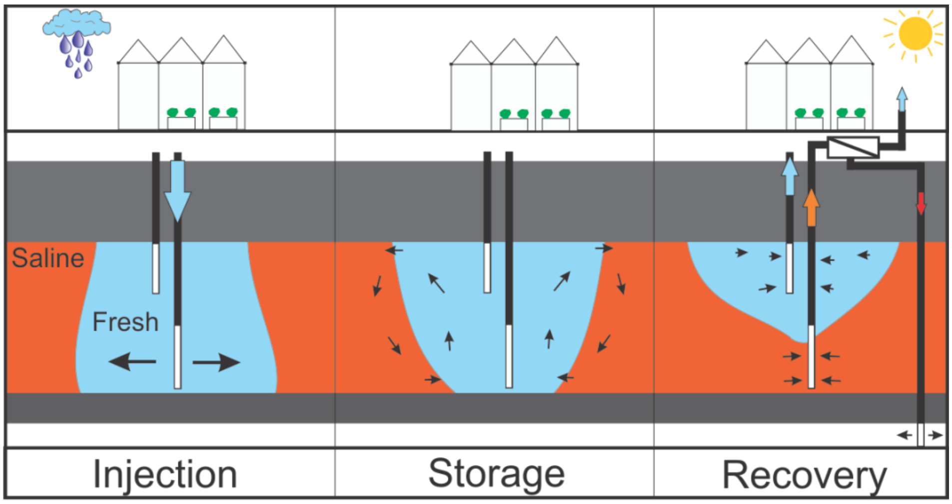


Figure 2-6. The introduction of the MPPW for deep injection and shallow recovery in combination with a Freshkeeper and optional RO-treatment for a maximal recovery of freshwater (ASRRO).

The combined ASR and RO system (ASRRO system) is expected to increase the amount of fresh groundwater, while reducing the abstraction of brackish water. This also means that less RO concentrate will be disposed into deeper aquifers. As a result, the salinity of the groundwater is expected to decrease.

Furthermore, storing surplus precipitation into the subsurface also means that less fresh water is discharged into the surface water.

2.3.2 Potential beneficiaries

In this study, two types of beneficiaries can be identified, the horticultural companies and the authorities that are responsible for water management (Table 2-2).

The horticultural companies need irrigation water for their crops. They may benefit from the measure as it allows them to abstract fresh water from the subsurface directly. Furthermore, it mitigates the salinization that can make it more difficult to desalinize brackish groundwater in the future.

Table 2-2. Potential beneficiaries and their classification.

Stakeholder Name	Beneficiary Type	Beneficiary Sub-Type
Horticultural companies	AGRICULTURE, FORESTRY AND FISHING	Irrigators
Hoogheemraadschap Delfland (water authority)	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Water management, water collection, treatment and supply
Provincie Zuid Holland	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Water management, water collection, treatment and supply

Several levels of government are responsible for water management (Table 2-3). The province of Zuid Holland is responsible for the strategic management of the water system, which includes the groundwater quality. In this case, the province is responsible for the groundwater quality. In other (larger) municipalities, the municipality may be responsible for the groundwater quality. The regional water authority Hoogheemraadschap Delfland is responsible for the operational management of the water system, which includes groundwater quantity. The Hoogheemraadschap Delfland is also responsible for issuing permits and exemptions that are related to groundwater activities (abstraction and injection). Prevention of flood events is one of their priorities (Hoogheemraadschap van Delfland, 2014).

Table 2-3. Government levels and their responsibilities regarding the pressures that are specified in Table 2-1 (Helpdesk Water, 2017).

Government level	Scale	Responsibilities regarding specified pressures: groundwater infiltration and abstraction and surface water management
Rijkswaterstaat	National	-
Provincie Zuid Holland	Province	Strategic management of (ground)water system: groundwater quality
Hoogheemraadschap Delfland	Regional water authority	Operational management of water system, including groundwater quantity
Municipality Westland	Municipality	-

2.4 Part IV: Impact evaluation

2.4.1 Relevant DRIVERS

As the proposed measure is a technical measure, no drivers are affected.

2.4.2 Relevant PRESSURES

As a result of the proposed measure, some of the identified pressures are affected (Table 2-4). Although the same volume of irrigation water will be abstracted from the subsurface, some of it will be produced directly, without the use of reverse osmosis. This means that less brackish water needs to be desalinized and therefore less concentrate will be injected into the subsurface (2nd aquifer). Furthermore, some of the abstraction is compensated for by the injection (artificial recharge) of collected precipitation into the subsurface. As basin levels decrease, less overflow of basin water into the surface water is expected.

Table 2-4. Expected effects of measure (ASRRO system) on pressures.

Pressure	Specification	Change
Groundwater abstraction	Abstraction of groundwater for irrigation	Same production volume, but less from brackish origin (RO), which implies less abstraction
Artificial recharge	Fresh water is injected into the upper aquifer	Increase of injected volumes
Artificial recharge	Disposal of RO concentrate into deeper aquifer	Smaller volume, but less brackish (as abstracted water is less brackish)
Peak discharge	Overflow of basin water into surface water	Decrease

2.4.3 STATE

Table 2-5 provides an overview of the state variables that are used in this ESS evaluation. The main state variable that is affected by the measure is water flow, in particular the volume of water that is infiltrated into the first aquifer and the volume of concentrate that is injected into the second aquifer. These variables directly affect the change in groundwater salinity. The data that was used for the state variables can be found in D33.1 (Zuurbier and Ros, 2017).

Salinization of groundwater cannot be directly calculated as the effects vary locally. However, the net amounts of water that are injected or abstracted and their concentrations can provide insight into salinization. Although with and without the measure, the same amount of water is needed for irrigation, the net abstraction (abstracted minus injected) from the first aquifer has become less than would be abstracted without the ASRRO installation (Table 2-5). The amount of concentrate that is injected into the second aquifer has decreased as well. For both aquifers together, the total water balance results in net abstraction. With the measure, the net abstraction is less than half of what it would be without the abstraction.

Before implementation of the measure, the salinity of the first aquifer was between 3,800 to 4,650 mg/l Cl- (density differences often result in stratification). The abstracted water would have this salinity as well, which means that locally, the abstraction would not result in direct salinity changes. However, as the abstracted water would be replaced by surrounding groundwater from horizontal direction (assumed to have same salinity) and vertical direction (from the aquifer below, which has a higher salinity) salinization was taking place.

Assuming that the RO recovery efficiency would be the same as with the measure (for which measurements are available), the injected concentrate into the second aquifer would be close to 7,000 mg/l Cl-. As this is higher than the ambient salinity (5,000 mg/l), salinization is occurring in the second aquifer.

With the measure, the salinity of the first aquifer decreased to between 2037 and 2222 mg/l Cl-. The net extracted salinity (total change in salt load divided by total change in water volume) was higher than the ambient salinity, showing that locally a net freshening was taking place (compared to the ambient concentration, more salt than water is net abstracted). This effect was confirmed by a model study, simulating the abstraction and injections (Ros and Zuurbier, 2017; Zuurbier and Ros, 2017).

As the RO feed water had become fresher compared to the situation without ASRRO, the RO concentrate had a lower salinity as well, between 3305 and 3966 mg/l Cl-. As this is lower than the ambient salinity of the second aquifer, freshening was also occurring here as a result of the measure. In D33.1, groundwater modelling results of the ASRRO system are shown. These results confirm freshening of the first and second aquifer (Figure 2-7) (Ros and Zuurbier, 2017; Zuurbier and Ros, 2017).

Throughout this report, the salinity of the injected water is considered. However, other components have been monitored as well. These measurements showed occasional exceedance of pesticide standards, as well as more regular exceedance of zinc standards (Zuurbier and Ros, 2017). These observations reveal a potential threat to the groundwater quality, and should therefore also be addressed.

The overflow from the rain water storage basin has not been measured and is therefore difficult to quantify. This effect has been previously addressed by Van der Schans et al. (2014), which is shown in Figure 2-8 and Figure 2-9. Implementation of the ASR system leads to lower basin levels, which reduces the number of overflow events during precipitation. The actual reduction depends on many factors, including the temporal distribution of (intense) precipitation events, the dimensions of the basin and the operational scheme of the ASR system. The modelling results from Figure 2-9 have been used to estimate the available retention volume in the storage basin. As the model was not made for this specific case, the results should be treated as rough estimates.

Table 2-5. Change of state parameters (variables) as a result of the measure. The retention in the storage basin is roughly estimated with a model for a comparable system.

State parameters	Type	Parameter	Unit	Without measure	With measure
Quantity and dynamics of water flow	Flow in and out of groundwater	Groundwater abstracted (1st aquifer)	m^3/y	255,609	232,179
Quantity and dynamics of water flow	Flow in and out of groundwater	Water injected (1st aquifer)	m^3/y	0	56,031
Quantity and dynamics of water flow	Flow in and out of groundwater	Net groundwater abstraction (1st aquifer)	m^3/y	255,609	176,148
Quantity and dynamics of water flow	Flow into groundwater	Concentrate injection (2nd aquifer)	m^3/y	157,538	134,109
Quantity and dynamics of water flow	Net water balance	Both aquifers (positive is into groundwater)	m^3/y	-98,071	-42,039
Salinity	Net extracted from 1st aquifer	Net abstracted Cl-/net abstracted water	mg/l Cl-	4222	2544
Salinity	Injected into 2nd aquifer	Salinity of concentrate	mg/l Cl-	6850	3344
Pollution	Injected into 1st aquifer	Zn	µg/l	n.a.	172
Pollution	Injected into 1st aquifer	Pesticides	µg/l	n.a.	0 – 0.6
Pollution	Injected into 2nd aquifer	Zn	µg/l	6	36
Quantity and dynamics of water flow	Discharge into surface water	Available retention volume in storage basin	m^3/ha	*296*	*542*

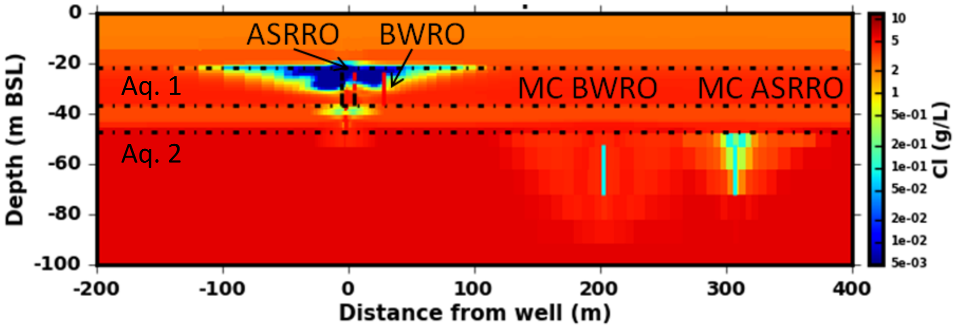


Figure 2-7. Modelled chloride concentrations for the ASRRO system and the brackish water RO (BWRO) after 4.5 years of operation after the measure is implemented. In the first aquifer, water is abstracted and injected. In the second aquifer, the membrane concentrate (MC) is injected for both systems.

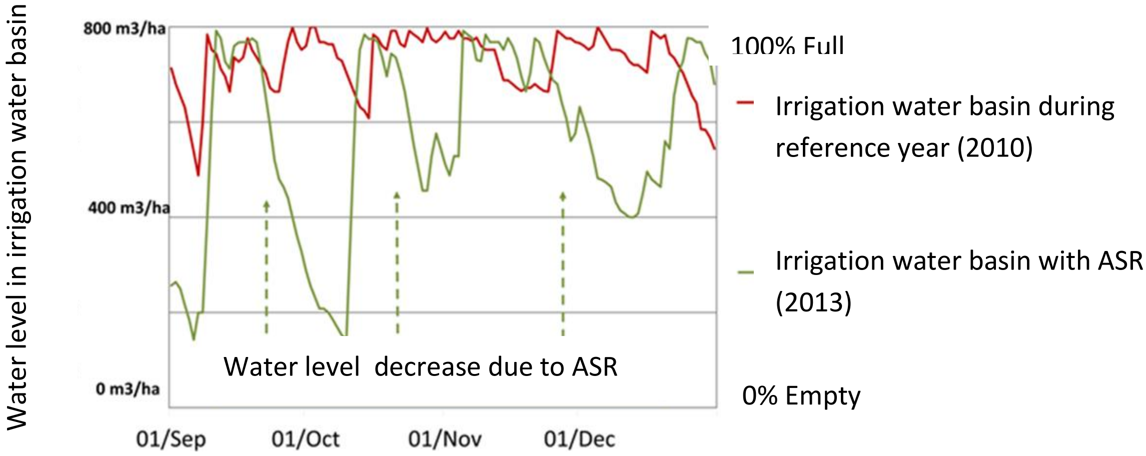


Figure 2-8. Effect of ASR on the amount of water that is stored in a roof water collection basin at the Westland demo case location (red: measured level in reference year 2010, green: measured level in 2013 after implementation of ASR system (Van der Schans et al., 2014).

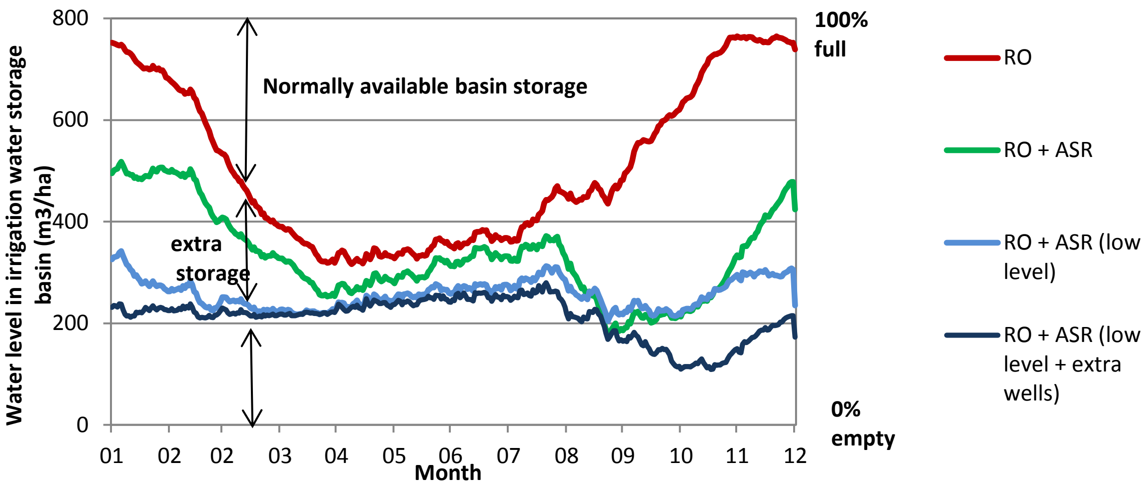
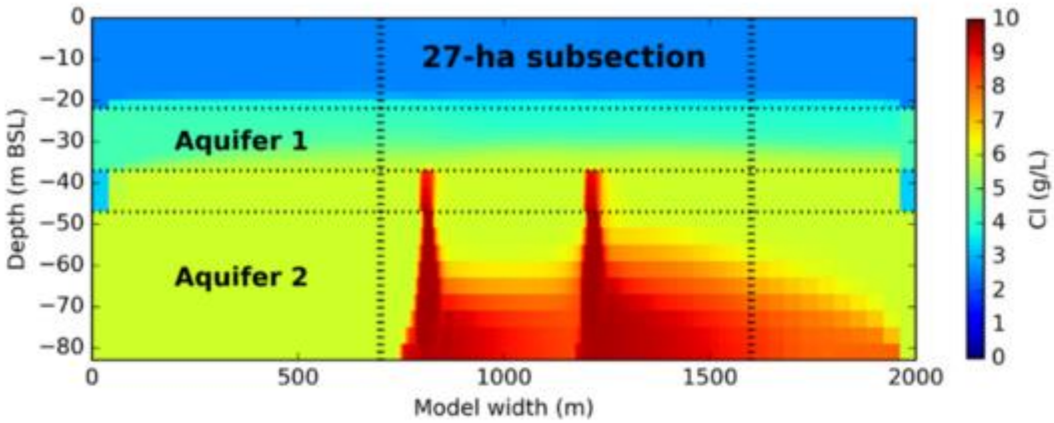


Figure 2-9. Basin levels with only RO (without the measure) and in combination with ASR. Optionally, one can aim for a low basin level by infiltrating more water or add more wells. These results are based on a modeling study which is described in Van der Schans et al. (2014). The RO+ASR (low level) type (light blue line) is expected to be similar to the ASRRO system at the Westland demo case.

Upscaling

Besides the local effects of abstraction and injection of groundwater, it should also be considered that net abstraction leads to supply of groundwater from elsewhere. Net abstraction from the first aquifer leads to salinization as water from the second aquifer flows upward (Figure 2-10), or, on a larger scale, more saline groundwater from the coastline is supplied laterally. When the abstracted water is compensated for by the infiltration of fresh water, the aquifers become more fresh. This effect is enhanced when more of these systems are implemented at a short distance from each other.



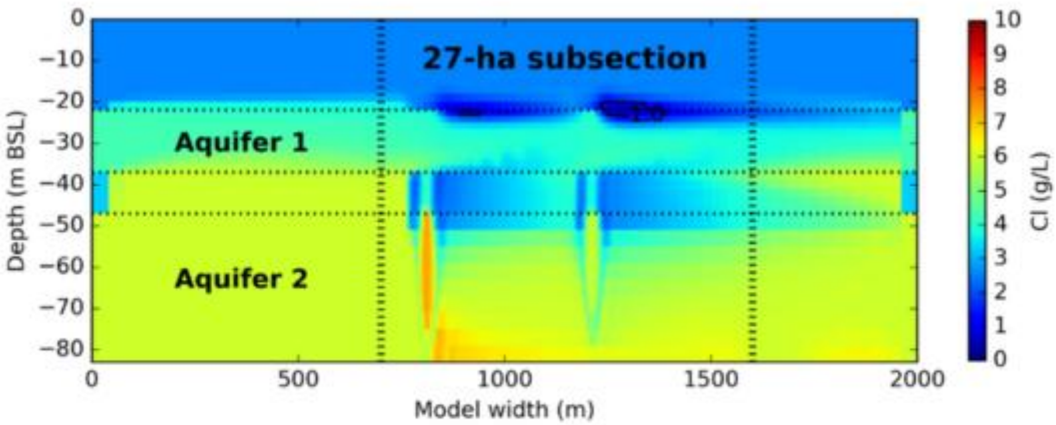


Figure 2-10. Cross section of the groundwater salinity in Aquifer 1 and Aquifer 2, with RO (upper figure) and ASRRO (lower figure). Source: (Ros and Zuurbier, 2017). Background flow of groundwater (from left to right) results in cumulative effects downstream.

As most greenhouse companies in the region abstract groundwater as feed water for RO by, it can also be assessed what the effects would be if ASRRO is applied regionally. In the Westland demo case, balance between net abstraction and injection is not attained, as the crops (tomatoes) require more water (>1000 mm/y) than is available from precipitation (850 mm/y minus the amount that is retained and evaporated from the roofs, up to 1 mm per rain event). However, with regional implementation for greenhouses with high and low water demands (Figure 2-11), it may in theory be possible to attain such a balance, as other crops require less irrigation. Such a situation was studied by Ros and Zuurbier (2017), which is included in D33.1. Their results show that applying this measure at a regional scale for 30 years results not only in a decreased salinity at a local scale, but also in decreased sea water intrusion along the coastline (Figure 2-12).

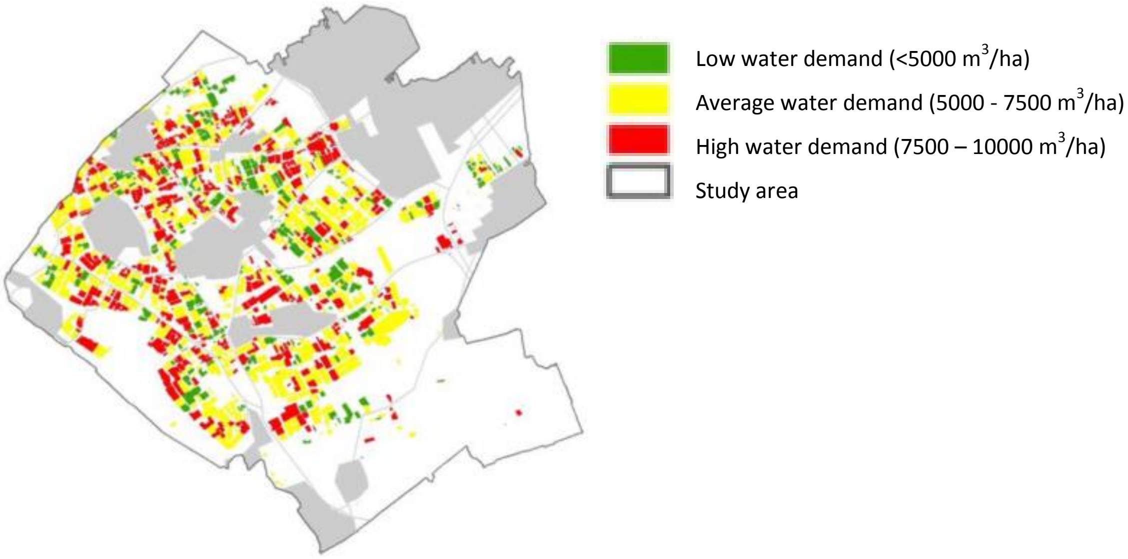


Figure 2-11. Distribution of low, average and high irrigation water demands in the Westland region and surroundings (Van der Schans et al., 2014).

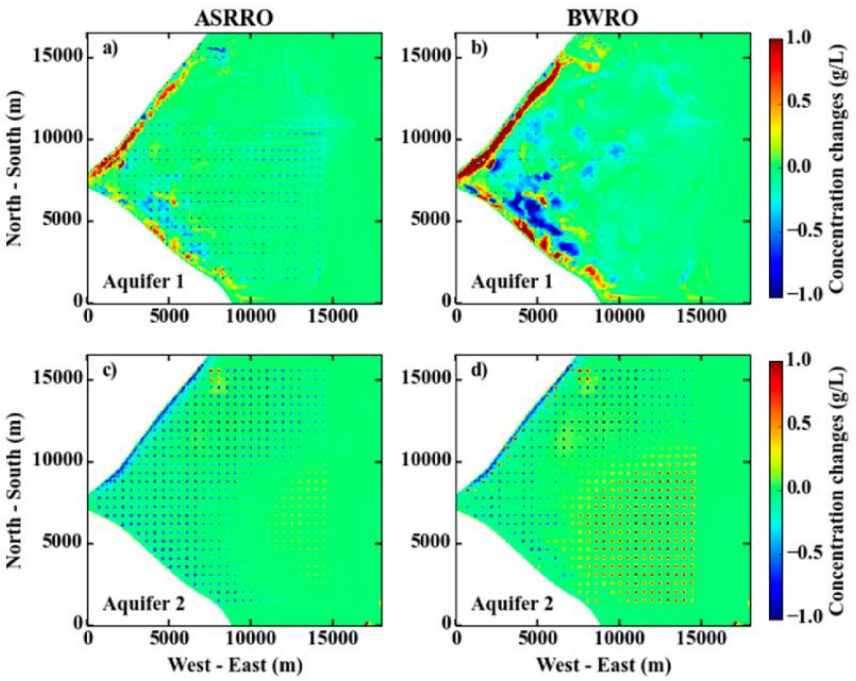


Figure 2-12. Relative chloride concentration changes (g/L) between ASRRO and autonomous processes, and between BWRO and autonomous processes, both after 30 years in Aquifer 1 (a,b) and Aquifer 2 (c,d) (Ros and Zuurbier, 2017). Each dot represents a location where either ASRRO or RO takes place.

Uncertainty

Several factors contribute to the uncertainty of the mentioned numbers:

- The volumes of water that are abstracted and injected will be different each year, and will differ for each company. Factors such as weather and crop type have strong effects on these volumes.
- Groundwater salinity differs strongly per location and may change over time. On some locations, net salinization may even occur (for example at the northwest part of Figure 2-12).
- Complicating processes may occur, such as short-circuit flow, which may cause unwanted mixing of groundwater and may result in decreased recovery efficiency and increased salinity of the first aquifer (Zuurbier and Stuyfzand, 2017).
- Contamination of the injected water with zinc and pesticides is observed. Zinc concentrations varied between 29 and 324 µg/l. On average, the pesticide concentrations were low (<0.1 µg/l carbendazim, pyrimethanil, fluopyram, spiromesifen, triflumizole, chloorprofam, indoxacarb and propyzamide), but peaks up to 0.6 µg/l pyrimethanil have occurred as well.
- Injection of rain water may change the redox conditions within the aquifer, leading to potential mobilization of compounds that could be considered contaminants. Such effects have not been investigated.
- Stormwater retention is quantified as the average storage capacity over the year, although it greatly fluctuates over time. As the storage is particularly needed during intense precipitation events, the differences may be larger or smaller, depending on weather events and infiltration capacity.

2.4.4 IMPACT I (ESS Provision)

The ecosystem services that are provided can be divided into three groups of CICES (Common International Classification of Ecosystem Services) classes (Table 2-6). As the described ESS are of use to humans, they are not quantified in this section, but in the next one (2.4.5).

The first one is a provisioning ESS, which is groundwater for non-drinking purposes. In this case, the availability of groundwater for irrigation does not depend on the amount or level or groundwater, as this is not a limiting factor in the Westland region. However, it depends on the salinity of the groundwater: if the salinity is extremely low, it can be directly used for irrigation water. If the salinity is higher, RO will be applied to desalinize the water, which is less preferable as it results in concentrate.

The other two ecosystem services are from the CICES section 'Regulation & Maintenance. The salinization and possible contamination of the aquifers affects the ecosystem service 'chemical condition of freshwaters'. Furthermore, the increased stormwater retention contributes to flood protection.

Table 2-6. Ecosystem services (ESS) provided by the measure (ASRRO implementation), the applicable CICES classification and relevant indicators of impact.

ESS	CICES Section	CICES Class	Impact I indicator	Impact I without measure	Impact I with measure
Availability of groundwater for irrigation that can be used directly or after desalination (RO)	Provisioning	Groundwater for non-drinking purposes	Change of salinity of Aquifer 1	Increase	Decrease
Chemical water conditions	Regulation & maintenance ESS	Chemical condition of freshwaters	Groundwater quality Aq. 1 and 2	Increase of salinity -	Decrease of salinity (Irregular) exceedence of standards for Zn and pesticides
Stormwater retention	Regulation & maintenance ESS	Flood protection	Retained stormwater	No change	Increase

Upscaling

If the measure (ASRRO) would be implemented throughout the Westland region, the impacts would be summed for each location. Upscaling could also have synergetic effects, as ASR systems downstream from other ASR systems may benefit from each other (Figure 2-10). Additionally, strong groundwater salinization along the coastline could be mitigated, as sea water intrusion would decrease (Figure 2-12, (Ros and Zuurbier, 2017)).

After many years, it may be possible that other ecosystem services may benefit as well. For example, coastal drinking water production plants may benefit from the reduced sea water intrusion(managed aquifer recharge for drinking water production is already applied at a large scale near the coastline near the town of Monster). Furthermore, ditch water quality could improve, due to decreased salinity of the seepage water.

2.4.5 IMPACT II (ESS Use and resulting benefits)

Each of the identified ecosystem services has direct use value to beneficiaries, that are identified in Table 2-7. The impact on the ESS is quantified in Table 2-8.

The irrigators (horticultural companies) have direct benefit from the availability of groundwater for irrigation. If the groundwater is of high enough quality (extremely low salinity), it can be used directly for irrigation. If the salinity is higher, reverse osmosis (RO) will be applied. The use (Impact II indicator) is quantified by the number of cubic meters of water that are abstracted for direct use (fresh water) and desalination (RO).

Groundwater quality is the administrative responsibility of the Province of Zuid Holland. For its protection, the European Water Framework Directive (WFD) and the Groundwater Daughter Directive (2006/118/EC) are applied. For groundwater, the purpose is to ensure good water quality. The regulations state that at least the quality should not decrease (standstill principle), which implies that (further) salinization or contamination should be avoided. Implementation of the measure leads to improved groundwater quality regarding salinity, but additionally introduces the risk of heavy metal (zinc) and pesticide contamination.

Flood protection is the responsibility of the regional water authority, Hoogheemraadschap Delfland. In the polder system, the surface water levels are managed continuously. During runoff peaks, water is pumped out of the polders. High peak runoff may occur as a result of the large paved areas (buildings and glasshouses), which means that the pumping capacity of the polders needs to be very large to avoid floods.

Table 2-7. Beneficiaries and Impact II indicators for each affected ecosystem service.

ESS	Beneficiary	Impact II indicator
Availability of groundwater for irrigation that can be used directly or desalinized (RO)	Irrigators (horticultural companies)	Volumes of abstraction for direct use and desalinized (RO) use.
Chemical water conditions	Province Zuid Holland	Change in concentrations in Aquifers 1 and 2
Stormwater retention	Hoogheemraadschap Delfland	Volume of peak runoff

Table 2-8. Quantification of Impact II indicators. Stormwater retention is roughly estimated with a model for a comparable system.

ESS	Impact II indicator	Without measure	With measure
Availability of groundwater for irrigation that can be used directly or after desalination (RO)	Volumes of irrigation water that are directly abstracted or desalinized (RO) (m^3/y)	Direct: 0 RO: 98,071	Direct: 13,317 RO: 84,754
Chemical water conditions	Concentration differences between injected or abstracted water in Aquifers 1 and 2 compared to ambient concentration	Chloride(mg/l): Aq 1: 0 Aq 2: +1850	Chloride(mg/l): Aq 1: -507 Aq 2: -1656
	Concentration compared to ambient concentration	Zn (µg/l): 0 Pesticides (µg/l): 0	Zn(µg/l): +166 Pesticides (µg/l): >0
Stormwater retention	Retention volume (m^3/ha)	*296*	*542*

Upscaling

Upscaling the measure by implementing ASRRO systems throughout the Westland region will mostly multiply the effects. However, several emergent benefits may be inferred as well:

- In case several ASRRO systems are implemented at short distances from each other, the systems that are located downstream (in the local groundwater flow system) may benefit from the 'freshening' effect of the upstream ASRRO systems, resulting in (slightly) lower salinity levels (Ros and Zuurbier, 2017). Furthermore, regional implementation may mitigate longer term sea water intrusion, which means that companies that are located near the coast could have access to groundwater which is not as saline as it otherwise would be or become.
- While implementation at one company has little effect on runoff, large scale implementation may result in a reduction in necessary pumping capacity in the polder systems. This effect may become more valuable in the future, as climate change scenarios predict more intense rainstorms (KNMI, 2014).

2.4.6 Economic valuation

Table 2-9 provides an overview of the economic valuation methods that are applied to estimate the value of each ESS change as a result of the applied measure. Table 2-10 provides the costs that have been estimated for each ESS using the methods that are described below. Table 2-11 shows the total yearly costs for the Westland demo case (4 greenhouse companies, 27 hectares in total).

Table 2-9. Economic valuation type and method that is applied for each ecosystem service.

ESS	Impact II indicator	Valuation type	Valuation method
Availability of groundwater for irrigation that can be used directly or after desalination (RO)	Volumes of abstraction for direct use and desalinized (RO) use	Production function	Costs of irrigation water production
Chemical water conditions	Change in concentrations in Aquifers 1 and 2	Restoration costs	Costs of mitigating environmental effects
Stormwater retention	Volume of peak runoff	Market valuation	Costs of alternative retention storage

The availability of groundwater for irrigation can be monetized by comparing the production costs of irrigation water. In D33.1 (Zuurbier and Ros, 2017), the production price per m^3 is quantified based on several assumptions. The estimation includes investment and operational expenditures (CAPEX + OPEX) over a lifetime of 20 years. When only CAPEX and OPEX are included, ASRRO (0.98 €/m^3) is 11% more expensive than conventional RO systems (0.88 €/m^3). When all potential discounts (discount rates, tax shields and subsidies) are included, applying the measure (ASRRO) results in 9% higher costs per cubic metre of irrigation water compared to the original activities (RO).

The decrease of groundwater quality can be monetized by the restoration costs that are needed to mitigate the environmental effects and to be able to meet the legal requirements. The most obvious way to mitigate salinization is to dilute by injecting fresh water. For this purpose, precipitation is an obvious choice, as it contains few solutes and contaminations compared to other water sources (surface water) and it is relatively cheap (compared to e.g. drinking water). It can be collected from roofs, temporarily stored in a basin or container and then be injected into the subsurface. The restoration costs are estimated using the assumptions that an ASR system is used, that is similar to the one that is implemented in the ASRRO system. Assuming that a suitable roof and basin would be available somewhere, the costs of such a system would be based on the CAPEX (approximately € 160,000 for an ASR system) and the OPEX (energy, maintenance and monitoring, approximately € 0.09/m^3). The mitigation costs for complete compensation of the abstracted groundwater (Table 2-10) are lower for the ASRRO system, as a smaller volume of rain water needs to be injected.

Regarding mitigation of environmental effects, groundwater contamination should be addressed as well. It is possible to use filtering techniques to remove contaminants from the precipitation water. Active coal filtration can remove pesticides. The costs of this technique depend strongly on the size of the installation. Assuming filter area sizes varying of 3 - 4 m^2, the costs are estimated as 0.32 to 0.40€ per cubic metre of infiltrated water in the Westland case (based on a cost calculator tool for small scale water purification systems (RHDHV, 2017)). Another option may be the use of the UV/ozone disinfection units that may already be available in many greenhouses (for disinfection of their recirculation water). These techniques may remove several types of pesticides as well. The costs of UV disinfection may vary from 0.07-0.12 € per cubic metre, depending on the flow rate (20-40 m^3/h was assumed here). For ozone, 0.33-0.36 € per cubic metre should be added. If these installations would be already present at the site, the investment costs do not need to be taken into account, which would reduce the costs significantly (up to less than 0.01 €/m^3 if the flow rate would be sufficient).

The zinc contamination is most likely caused by the presence of zinc in the materials that are used on the greenhouse roofs or gutters. It is possible that the use of different materials, or the application of a (polymer) coating on the gutters can prevent zinc contamination. Another way in which zinc can be removed from the precipitation is by adding a material such as shell grit to the sand filter (which is already present), which would increase the pH. The costs of this latter option would be practically nil.

The creation of stormwater retention volume in the basins will lead to a reduction of peak runoff in the polder water system. As part of their responsibility to prevent flooding, Hoogheemraadschap Delfland has been actively searching for additional stormwater retention volume to deal with intense precipitation events. They have explored options such as additional (volume in) open water, cellars under glasshouses and temporarily flooding areas such as roads and sport fields (Gemeente Westland and Hoogheemraadschap van Delfland, 2012; Hoogheemraadschap van Delfland, 2010; Jouwersma, 2016). As storage volume is something that can be traded, a market based approach is used here to valuate this ESS. Depending on which option is considered, the costs of the alternative options may vary.

If (temporary) storage would be created on land or by enlarging open water, the property price within the region should be considered. This price may vary between €6/m^2 for grassland (Boerderij, 2017) to € 40/m^2 for horticultural property (Gemeente Westland, 2016). If it is assumed that on each square metre, a storage between 0.1 and 0.4 m can be realized, the cost for retention volume may start from 15-60 €/m^3, although Jouwersma (2016) mentions that the price of retention volume in open water is much more than €20/m^3. Other options may be more expensive.

The costs of a water cellar below a glasshouse are for example are estimated at € 125/m^3 (TNO, 2007). Currently, the Hoogheemraadschap Delfland is testing the option of creating additional storage on the roofs of the glasshouses and in the rain water basins, by partially emptying them into the surface water before a precipitation event is expected (Gemeente Westland and Hoogheemraadschap van Delfland, 2012; Jouwersma, 2016). This project is called DIG (‘dynamische inzet gietwaterbassins’, dynamic effort irrigation water basins). An on-line system is implemented that makes a request to the horticulturists to lower their basin levels when intense precipitation events are expected. The investment costs of this option are estimated at €20/m^3 and the operational costs around € 4/m^3 (€ 3/m^3 with upscaling). In the calculation of costs per year, a lifetime of 20 years is assumed. Furthermore, as the increased storage volume is considered a very rough estimate, the comparison is also made with a storage difference of 10 mm, which is the storage volume that is attained with the DIG project.

The costs of stormwater retention volume creation with the measure are considered nil, as the investments and operational costs have already been taken into account in the irrigation water production costs. However, if this system were to be improved to have the same capabilities as the DIG option (on-line management), higher costs can be expected.

Table 2-10. Economic valuation (with and without measure) for each ecosystem service. Mitigation costs for abstraction have been roughly estimated.

ESS	Valuation method	Unit	Without measure	With measure
Availability of groundwater for irrigation that can be used directly or desalinized (RO)	Costs of irrigation water production	€/m^3 irr. water	0.64	0.70
Chemical water conditions	Costs of compensating abstraction per m^3 produced irrigation water	€/m^3 irr. water	*0.44*	*0.30*
	Costs of mitigating contamination	€/m^3 inj. water	n.a.	0.07-0.40
Stormwater retention	Investment costs of alternative retention storage CAPEX	€/m^3	20	Nil (now) ? (with on-line management)
	Operational costs of alternative retention storage	€/m^3/y	3-4	Nil (now) ? (with on-line management)

The results show that at this moment, irrigation water can be produced more cheaply if the measure is not applied. However, if mitigation of the environmental effects is taken into account, which is necessary to comply to European regulations, the price differences per cubic metre become very small. Furthermore, if the increase in retention storage is considered, the measure becomes economically more feasible (Table 2-11 and Figure 2-13).

Table 2-11. Total annual costs of RO (without measure) comparison with ASRRO (with measure).

ESS	Valuation method	Without measure (€/y)	With measure (€/y)
Availability of groundwater for irrigation that can be used directly or desalinized (RO)	Costs of irrigation water production	62,765	68,649
Chemical water conditions	Costs of compensating abstraction per m^3 produced irrigation water	43,151	29,421
	Costs of mitigating contamination	0	3,922 - 22,413
Stormwater retention	Costs of alternative retention storage CAPEX	10,800 – 33,210	0
Total yearly costs	(€/y)	116,716 – 139,126	101,993 – 107,596

Upscaling

It is expected that spatial upscaling will not significantly affect the costs that are described in Table 2-10. However, several aspects need consideration:

- Over time, ASR and filtration techniques, as well as their maintenance, may become cheaper as they will be developed further.
- Desalinization (without and with measure) may be more expensive at locations with higher salinities. Without the measure, desalinization using RO may become more expensive due to increasing groundwater salinity (as higher pressure is needed to desalinize the water and more regular maintenance may be needed).

- Coastal salinization as a result of sea water intrusion could cause problems in the far future, as polders become more saline. Mitigation of this process at the source, through large scale implementation of measures may result in avoidance or reduction of future costs.
- Reduced salinization and sustainable groundwater use may lead to an improved business settlement climate, which may lead to an increase in property value.
- In this particular (isolated) case, only part of the abstracted water can be replaced with rainwater, because much water is needed for the crops. If this type of technology would be implemented at other greenhouses with a lower water demand, it may be possible that more water can be injected than is abstracted. Combining the effects over the whole region, it should be possible to compensate for the overall abstraction with overall infiltration. In that case, the mitigation costs may be reduced.

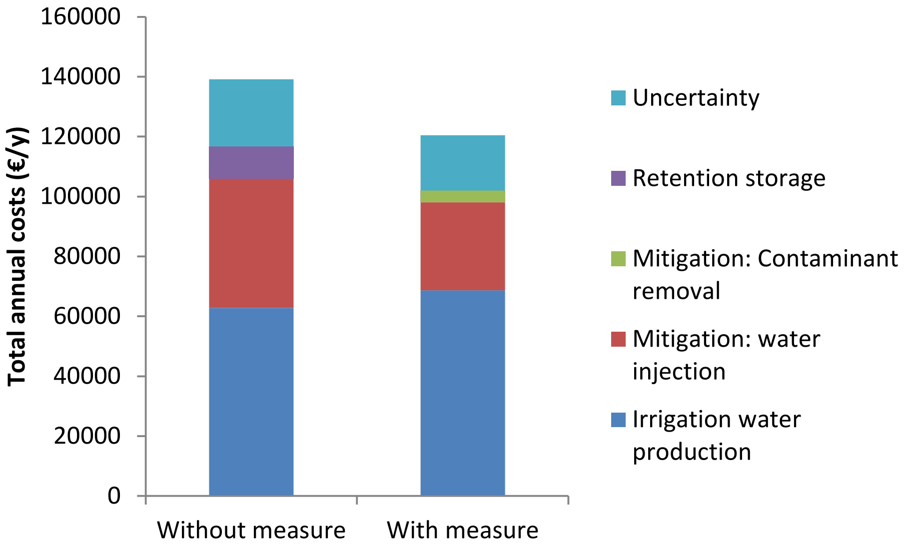


Figure 2-13. Comparison of total costs per year with and without the measure for irrigation water production at the Westland demo site, and potential costs of mitigation of environmental effects, as well as the additional costs to create retention storage without if the measure is not implemented. Uncertain costs include the value of retention storage (without measure) and the costs of contaminant removal which may differ for the chosen method and dimensions (with measure).

Uncertainty

In the economic valuation of the ESS, several uncertainties need to be taken into account. These include:

- Costs are strongly scale-dependent. Large systems are more cost effective than small systems.
- Local variations may occur due to differences in salinity and other substances that are found in the groundwater. Salinity differences may lead to different costs of RO. Other

substances may play a role in scaling of RO membranes (in which case extra maintenance is needed) and in the risk of well clogging.

- Costs of the considered alternatives (mitigation or retention volume alternatives) depend strongly on the chosen technology and may vary for each location.

2.5 Part V: Sustainability Assessment

2.5.1 Purpose and scale

This sustainability assessment follows the ecosystem services assessment of the ASRRO system implementation at the Westland demo site. The purpose of this assessment is to compare results on different dimensions of sustainability for the implemented measure (ASRRO) and the situation without the measure (use of desalinized groundwater without injection of fresh water).

The scale on which this analysis takes place is the Westland region that was identified in section 2.1.1.

2.5.2 Identifying sustainability indicators

In this step, the sustainability indicators for each sustainability dimension are identified according to the list that was compiled in D11.2. Table 2-12 provides an overview of the used sustainability indicators.

Social

Implementation of the ASRRO technology does not involve (significant) changes in health, safety, jobs, equity or cultural services. However, some economic impact on society can be identified. If the measure is upscaled, the reduction of high discharge peaks as a result of average basin level decrease will decrease the costs of water level maintenance for water authority Hoogheemraadschap Delfland. Furthermore, if it would be decided that the salinization effects should be mitigated, the mitigation costs can also be seen as an economic impact for society.

Environmental

The environmental dimension of this assessment consists of the change in water resources availability (net abstraction of groundwater leading to coastal salinization) and the local change in water quality (salinity and other chemicals) that results from abstractions and injections. Furthermore, energy use should be taken into account as well, which can be taken as a proxy for CO_2 emissions if fossil fuels are used.

Financial

The financial dimension is covered by the total costs of irrigation water for the horticultural company.

Governance

For the governance dimension, compliance to European and Dutch regulations is assessed. Regarding stakeholder involvement and transparency, no differences between the reference situation and the measure are expected.

Assets

Although implementation of the ASRRO measure requires additional assets compared to the reference situation, few indicators are expected to be different between the two types of technology.

Table 2-12. Sustainability criteria and indicators that are applied to the Westland demo case.

Dimension	Criteria	Metric or indicator
Social	Economic impact	Flood risk reduction
		Costs of mitigation
Environmental	Water resources availability	Net abstraction/injection
		Salinity difference with ambient Aq. 1
		Salinity difference with ambient Aq. 2
	Contamination	Other chemicals
	Energy consumed	Energy
Financial	Cost coverage	CAPEX+OPEX irrigation water
Governance	Compliance (WFD)	Stand still requirement
Assets	Technology efficiency	RO efficiency

2.5.3 Scoring of indicators

For the most part, the sustainability indicators correspond to the ESS indicators that have been identified and quantified in section 2.4.4 and 2.4.5. It is assumed that these indicators do not need additional explanation. Additionally, threshold or target values have been identified for each indicator. In most cases, the target value does not need additional explanation. For example, regarding change in salinity, the target is <0, which implies no change or reduction in salinity.

For the other cases, explanations are provided below:

- Energy use is based on technical data from D33.1 (Zuurbier and Ros, 2017).
- RO efficiency is based on technical data from D33.1 (Zuurbier and Ros, 2017).

Table 2-13. Scoring of sustainability indicators for the Westland demo case. Stormwater retention is roughly estimated.

Dimension	Metric or indicator	Unit	Threshold or target value	Without measure	With measure
Social	Stormwater retention	m^3	450,000	*7,992*	*14,634*
	Costs of mitigation	€/m^3	0	0.44	0.30
Environmental	Net injection/abstraction	m^3/y	>0	-98,071	-42,039
	Salinity difference with ambient Aq. 1	Δ mg/l	<0	0	-507
	Salinity difference with ambient Aq. 2	Δ mg/l	<0	1850	-1656
	Other chemicals	Δ µg/l	0	0	+
	Energy use	kWh/m^3	0	2.27	2.88
Financial	CAPEX+OPEX irrigation water	€/m^3	0	0.64	0.70
Governance	Stand still requirement (WFD)	Salinity	Yes	No	Yes
	Water Act	Zn µg/l Aq. 1	65	-	172
	Water Act	Zn µg/l Aq. 2	65	6.2	36
	Water Act	Pesticides µg/l	0.1	0	Irregular exceedance
Assets	RO efficiency	%	50%	38%	39%

2.5.4 Comparison and interpretation

To be able to compare the sustainability indicators, they must be normalized. As many target values are ‘0’, those indicators are normalized as ‘% of objective reached’. In the case of ‘yes’ or ‘no’ (logical variable), the percentages are either 100% or 0%. Figure 2-14 shows the normalized results for each sustainability indicator.

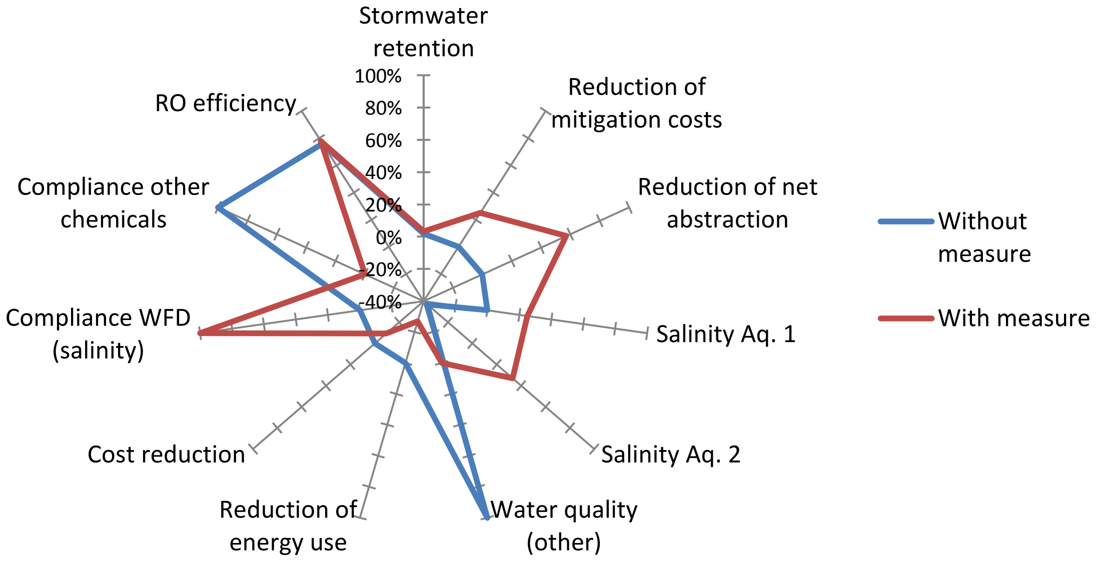


Figure 2-14. Radar plot comparison for sustainability indicators (% of objectives reached).

The results show that the measure (ASRRO) performs well regarding water quantity and salinity-related aspects: abstraction of groundwater is reduced, and salinization is mitigated. For other water quality related aspects, it performs less well, as increased concentrations of zinc and pesticides end up in the subsurface. Furthermore, it is more expensive and uses more energy than the conventional technology (RO).

For a complete evaluation, the different indicators should be weighted. As such a weighing would introduce additional subjectivity, this is not done quantitatively. However, some considerations are discussed:

- The effect of stormwater retention seems rather small, but is considered relatively valuable by the Hoogheemraadschap Delfland, as they have experienced some problems after intense precipitation events in economically valuable areas during the past decades.
- The effects of salinization may become larger over time. If upscaled, the measure may reduce coastal salinization as well.
- The impact of water quality decrease (pesticides and zinc) should be evaluated against the impact of salinization.
- The energy use of ASR is relatively small. Over time, with salinization, the energy use of RO (conventional technology) is expected to increase, as higher pressures are needed to produce fresh water. If salinization is mitigated, future energy consumption may decrease.
- The sustainability of energy use depends on the source of the energy. Solar or wind power can provide electricity with low environmental impact.

2.6 Opportunities and challenges for implementation

2.6.1 Governance & policy (incl. legislation and market issues)

Desalinized brackish groundwater is currently a commonly used source of irrigation water for horticulture in the Westland region, besides the primary source of precipitation that is collected in basins. The concentrate that results from desalination using RO technology is injected into deeper aquifers, as it is not allowed to discharge it onto the surface water or sewage system. However, injecting concentrate into the groundwater does not comply with the general Dutch and European regulations (Water Framework Directive, WFD) either, as the concentrations are often higher than found in the ambient groundwater (not complying with the stand-still principle). In case alternative ways to obtain irrigation water are not available or feasible (according to a preference order, Table 2-14), the authorities grant exemptions for the injection of concentrate into the subsurface. The authorities that are responsible for these activities are the water authority Hoogheemraadschap Delfland, which is responsible for granting licences to abstract groundwater, and the municipality Gemeente Westland, that is responsible for the injection of concentrate. The Province of Zuid-Holland advises the local authorities that for new cases, storage of precipitation water in the first aquifer should be preferred (Provincie Zuid-Holland, 2017).

The current exemptions are valid until 2022, after which new policy will probably become effective.

Table 2-14. Preference order for glasshouse irrigation water which is used by authorities to decide on exemptions for the use of brackish groundwater (Infomil, 2012).

Preference order for glasshouse irrigation water
1. Collective use of waste water
2. Collective production by drinking water company
3. Collective or individual provision of precipitation water
4. Fresh groundwater
5. Drinking water
6. Brackish groundwater with concentrate disposal in subsurface
7. Surface water with unknown destination of concentrate

Implementing the ASRRO system, which is the evaluated technology in this report, can mitigate the salinization that results from the current activities. Regarding local salinization, the described measure improves the compliance to legislation (WFD) as it results in an improvement of groundwater quality. Regarding other chemicals, the injection of precipitation may lead to contamination with pesticide residues, while concentrate injection may lead to exceedance of the standards for Zn (as a result of different background concentrations of this heavy metal in the first and second aquifers), but these contaminations can be avoided by using additional techniques (see section 2.4.6).

The main reason why the technology is not being implemented is that the production of irrigation water becomes more expensive. If however, mitigation would be taken into account, the costs of producing irrigation water with ASRRO would become comparable or lower. This observation reveals the main opportunity for this technology: if the policy would change in such a way that groundwater abstraction with concentrate disposal would only be allowed if the environmental effects would be mitigated, it would probably become the best option.

Implementation on a large scale, as was described in section 2.4.3, in which each company would completely balance their groundwater abstractions with precipitation injections, would not be possible for many individual companies as their water requirements are higher than the amount of precipitation that can be collected from the greenhouse roofs. Some crops, like tomato, require irrigation that may exceed 1000 mm/y, while the annual precipitation in the Westland region averages around 850-900 mm/y (KNMI, 2017). To fully compensate for abstracted groundwater, collaboration with parties that have a precipitation surplus (horticultural companies or other roof owners) would be necessary.

Large scale implementation would require incentives for all parties involved. Policy and legislation could theoretically provide such incentives, such as conditional exemptions for concentrate injections or higher quality standards for injected water.

In the next section (2.6.2), a novel financing mechanism is proposed, which is currently being explored by a consortium of research institutes, governments and horticultural interest organisations (COASTAR project, (Allied Waters, 2017)). Such a financing mechanism would likely require new policy concepts and embedding in legislation, as well as (active) participation of governmental institutions. Finding new solutions to deal with salinization, that focus on regional self-sufficiency would possibly fit in the philosophy of the Dutch national 'Delta programme' (Deltaprogramma Zoetwater, 2017).

Furthermore, large scale implementation would provide water retention, which would reduce peak discharges and would contribute to polder water management. For the regional water authority (Hoogheemraadschap Delfland), such a development would reduce the (re)investments and efforts that are needed to prevent flooding. Additionally, one of the objectives of recent policy of the regional water authority is to promote self-sufficiency within the region (pers. comm. Hoogheemraadschap Delfland).

One of the other challenges for implementation of ASRRO systems is subsurface spatial planning: the subsurface can be used for other purposes as well, for example the storage of heat (aquifer thermal energy storage, ATES). For such purposes, the province is the responsible authority. ATES and ASR systems can interfere with each other, as they may reduce recovery efficiency due to interfering flow patterns. Neighbouring ASR systems could affect each other as well, but in general the interaction would lead to improved recovery efficiency downstream due to decreased salinization (Figure 2-10).

Table 2-15. Summary of governance and policy related opportunities and challenges. The opportunities and challenges in *italics* only apply to large scale implementation.

Opportunities	Challenges
Current policies regarding brine injection will be revised in coming years , province has preference for storage of precipitation	Current policy results in situation in which RO is cheaper for horticulturists than ASRRO
Measure allows improved compliance to WFD regarding salinity	Subsurface spatial planning: competition with other uses of subsurface
Improved business settlement climate	*Requires large changes in administration and policy*
Reduced effort for polder level management	

2.6.2 Novel financing mechanisms

At this moment, groundwater users have little incentive to implement mitigation measures, such as the ASRRO system. The only reason for them to implement it, would be to avoid increased (future) salinization, which would increase the costs for desalination.

For large scale implementation with full compensation for groundwater abstraction, potential precipitation suppliers currently have no incentive to inject collected rain water into the subsurface. The 'Waterbank Westland' is a novel concept that is currently being explored within the COASTAR project (Allied Waters, 2017).

The concept of a 'water bank' is derived from international examples (Hanak and Stryjewski, 2012; Megdal et al., 2014; Montginoul et al., 2016; Montilla-López et al., 2016; O'Geen et al., 2015). The report that explores a water bank for the Westland region is currently in preparation (Stofberg & Zuurbier, *in preparation*). The idea is summarized as follows:

- The subsurface is considered the physical component of the water bank. The subsurface can be used for storage (injection) and withdrawal (abstraction) of water.
- The water bank, as an organization, makes sure that abstraction of groundwater is (regionally) compensated for by injection of fresh water.
- Participants receive credits or euros for the injection of fresh water, while abstraction of water (not necessarily at the same location) will be subject to a fee (credits or euros). The water bank oversees this form of trade.

In practice, this could mean that:

- Horticulturists and other groundwater abstracters can continue using RO for their irrigation water production (no need to replace technology they invested in)
- Groundwater abstracters pay a fee for each m^3 that is abstracted.
- For each injected m^3 of fresh water, a subsidy is provided (in kind or in euros).
- This fee could be (partially) paid in kind by injecting fresh water or by paying for someone else to inject fresh water

The water bank itself could be a public or public-private initiative. It should be noted that many technical, governance-oriented and practical questions still need to be explored and addressed. Furthermore, many conditions need to be met in order to reach successful implementation. However, the system provides an incentive for the reduction of salinization, while still providing enough irrigation water for horticultural companies.

2.7 Conclusion

2.7.1 Impact and sustainability

The ESS evaluation and sustainability assessment showed that the implementation of the ASRRO system at the Westland demo case has resulted in strong mitigation of the salinization of the subsurface. The availability of groundwater for irrigation (provisioning ESS) and chemical water conditions (regulation and maintenance ESS) are improved. Furthermore, it can contribute to the reduction of flood risks in the region by providing stormwater retention volume in the rainwater collection basins, which improves the stormwater retention ESS (regulation and maintenance). Contamination of the injected water with pesticides and zinc is, however, an adverse effect, reducing the chemical water conditions ESS (regulation and maintenance). This contamination can be prevented by adding other technological solutions.

If the measure would be scaled up to the whole region, the intrusion of sea water in coastal regions could be mitigated as well.

The economic valuation showed that RO (the original technology) allows cheaper production of irrigation water. However, when mitigation of environmental effects is taken into account, ASRRO will become competitive. As the increase of retention storage is valuable as well, the overall costs of ASRRO would become lower than for RO.

2.7.2 Implementation

Current policy allows RO to be applied cheaply, which makes ASRRO uncompetitive. In 2022, the policy will be revised. It is likely that new policy will aim for more sustainable use of groundwater and better compliance to the European WFD, which means that it may create an opportunity for ASRRO to be used by more companies, as it may become a cheaper option.

To allow for full compensation of the abstracted water, some sort of trading should take place between horticultural companies with a low water demand (surplus of precipitation water) and a high water demand. For this purpose, a water bank is proposed as a structure to manage and regulate groundwater abstractions and injections. Such an organization could guarantee the provision of enough irrigation water to the horticultural sector as well as sustainability

3 References

Allied Waters, 2017, COASTAR. Robuuste zoetwatervoorziening voor laag Nederland schuilt in de ondergrond: Allied Waters.

Alterra, 2012, Landgebruik LGN7: Wageningen, Alterra WUR.

Barends, B. J., Brouwer, F. J. J., and Schröder, F. H., 1995, Land subsidence, natural causes, measuring techniques, the Groningen gasfields., Rotterdam, The Netherlands, Balkema, 409 p.:

Boerderij, 2017, Gemiddelde prijzen landbouwgrond.

CBS, 2017, Statline, http://statline.cbs.nl.

De Louw, P. G. B., Oude Essink, G. H. P., Stuyfzand, P. J., and Van Der Zee, S. E. A. T. M., 2010, Upward groundwater flow in boils as the dominant mechanism of salinization in deep polders, The Netherlands: Journal of Hydrology, v. 394, p. 494-506.

Deltaprogramma Zoetwater, 2017, Kennisagenda Zoetwater 2017.

Gemeente Westland, 2016, Nota grondprijzen 2017.

Gemeente Westland, and Hoogheemraadschap van Delfland, 2012, Proeftuin Oranjepolder.

Hanak, E., and Stryjewski, E., 2012, California's water market, by the numbers: Update 2012: San Francisco, CA, Public Policy Institute of California.

Helpdesk Water, 2017, Verantwoordelijkheden grondwaterbeheer, Volume 2017, Rijkswaterstaat.

Hoogheemraadschap van Delfland, 2010, Demonstratieproject meervoudig ruimtegebruik voor waterberging in glastuinbouw: Hoogheemraadschap van Delfland.

-, 2014, Beleidsnota Beperken en voorkomen wateroverlast: Hoogheemraadschap van Delfland.

Infomil, 2012, Goed gietwater glastuinbouw, p. 1-15.

Intergovernmental Panel on Climate Change (IPCC), 2007, Climate Change 2007 - The Physical Science Basis

Jouwersma, S., 2016, Dynamische inzet van gietwaterbassins.

KNMI, 2014, KNMI Klimaatscenarios.

-, 2017, Klimaatatlas, Volume 2017: De Bilt, KNMI.

Kooi, H., 2000, Land subsidence due to compaction in the coastal area of The Netherlands: the role of lateral fluid flow and constraints from well-log data: Global and Planetary Change, v. 27, no. 1-4, p. 207-222.

Kristensen, P., 2004, The DPSIR framework: National Environmental Research Institute, Denmark, v. 10.

Kwadijk, J. C. J., Haasnoot, M., Mulder, J. P. M., Hoogvliet, M. M. C., Jeuken, A. B. M., van der Krogt, R. A. A., van Oostrom, N. G. C., Schelfhout, H. A., van Velzen, E. H., van Waveren, H., and de Wit, M. J. M., 2010, Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands: Wiley Interdisciplinary Reviews: Climate Change, v. 1, no. 5, p. 729-740.

Megdal, S. B., Dillon, P., and Seasholes, K., 2014, Water banks: Using managed aquifer recharge to meet water policy objectives: Water, v. 6, p. 1500-1514.

Montginoul, M., Rinaudo, J.-D., Brozovic, N., and Donoso, G., 2016, Integrated Groundwater Management, Integrated Groundwater Management, p. 693-710.

Montilla-López, N. M., Gutiérrez-Martín, C., and Gómez-Limón, J. A., 2016, Water banks: What have we learnt from the international experience?: Water, v. 8.

O'Geen, A., Saal, M., Dahlke, H., Doll, D., Elkins, R., Fulton, A., Fogg, G., Harter, T., Hopmans, J., Ingels, C., Niederholzer, F., Solis, S., Verdegaal, P., and Walkinshaw, M., 2015, Soil suitability

index identifies potential areas for groundwater banking on agricultural inlands: California Agriculture, v. 69, p. 75-84.
Oude Essink, G. H. P., van Baaren, E. S., and de Louw, P. G. B., 2010, Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands: Water Resources Research, v. 46, p. W00F04.
Post, V. E. A., 2003, Groundwater salinization processes in the coastal area of the Netherlands due to transgressions during the Holocene [PhD Thesis: Vrije Universiteit.
Provincie Zuid-Holland, 2017, Goed Gietwater: https://www.zuid-holland.nl/onderwerpen/landschap/water/schoon-zoetwater/goedgietwater/.
RHDHV, 2017, Kostenstandaard, www.kostenstandaard.nl.
Ros, S. E. M., and Zuurbier, K. G., 2017, The Impact of Integrated Aquifer Storage and Recovery and Brackish Water Reverse Osmosis (ASRRO) on a Coastal Groundwater System: Water, v. 9, no. 4, p. 273.
Royal Netherlands Meteorological Institute, 2014, KNMI'14 climate scenarios for The Netherlands; guideline for professionals in climate adaptation: KNMI.
Schothorst, C. J., 1977, Subsidence of low moor peat soils in the western Netherlands: Geoderma, v. 17, no. 4, p. 265-291.
Stuyfzand, P. J., and Raat, K. J., 2010, Benefits and hurdles of using brackish groundwater as a drinking water source in the Netherlands: Hydrogeology Journal, v. 18, no. 1, p. 117-130.
TNO, 2007, Kansrijke scenario's Waalblok: TNO, 2007-U-R1090/B.
Van der Schans, M. L., Paalman, M. A. A., and Zuurbier, K., 2014, Potenties ondergrondse waterberging in het Westland: KWR.
Zuurbier, K. G., Bakker, M., Zaadnoordijk, W. J., and Stuyfzand, P. J., 2013, Identification of potential sites for aquifer storage and recovery (ASR) in coastal areas using ASR performance estimation methods: Hydrogeology Journal, v. 21, no. 6, p. 1373-1383.
Zuurbier, K. G., and Ros, S. E. M., 2017, Valorisation and demonstration of an ASRRO application in a field application: KWR Watercycle Research Institute.
Zuurbier, K. G., and Stuyfzand, P. J., 2017, Consequences and mitigation of saltwater intrusion induced by short-circuiting during aquifer storage and recovery in a coastal subsurface: Hydrology and Earth System Sciences, v. 21, no. 2, p. 1173.

ANNEX A: Output of MIKE ESS tool

Objectives	To evaluate the ecosystem services of the DESSIN Westland demo case
TargetAudience	Policy makers, researchers
CarryingOut	KWR Watercycle Research Institute
ProvidingInformation	DESSIN Westland Demo site, KWR Watercycle Research Institute
FundingAssessment	DESSIN project, EU FP7
NUTS3 Codes	NL333
Population Data Update	31-8-2017 15:22
Economic Data Update	31-8-2017 15:22
Employment Data Update	31-8-2017 15:22

Environment	The Netherlands has a temperate maritime climate. The Westland ASRRO site is situated in the low-lying, western coastal zone of the Netherlands, which is marked by presence of brackish to saline groundwater almost up to surface levels.
Economic	The Westland region is known for its many horticultural companies, which is easily observed as greenhouses dominate the landscape. Of the municipality Westland, 80% of the agricultural area consists of greenhouse agriculture (CBS, 2017). Furthermore, there are many companies providing services that are related to agri- and horticulture.
Socio-Economic	Income: more than Dutch average Employment: more than Dutch average.
Socio-cultral	Greenhouse horticulture

Stakeholder name
Horticultural companies
Hoogheemraadschap Delfland (water authority)
Province of Zuid Holland

Driver name	Specification
Agriculture	Greenhouse horticulture

Driver name	Pressure name	Specification
Agriculture	Abstraction	Brackish groundwater abstraction
Agriculture	Artificial recharge	Disposal of RO concentrate in deeper aquifer
Agriculture	Natural recharge	Reduced natural recharge due to surface cover
Agriculture	Point source	Overflow of basin water to surface water

Measure name	Measure Type	Lifetime (Years)
ASR/RO system	Technical	20

Measure name	Capability name	Capability Type	Specification
ASR/RO system	Decrease salinization	Theoretical	Decrease salinization by infiltration of fresh water (abstracted water less brackish, injected brine less saline)
ASR/RO system	Reduce basin overflow	Theoretical	Reduce basin overflow

Measure Name	Pressure Name	Specification
ASR/RO system	Abstraction	Brackish groundwater abstraction
ASR/RO system	Point source	Overflow of basin water to surface water
ASR/RO system	Artificial recharge	Disposal of RO concentrate in deeper aquifer
ASR/RO system	Natural recharge	Reduced natural recharge due to surface cover

Measure Name	State Parameter Name	State Parameter Category	State Parameter SubCategory	State Parameter Description	State Parameter IsAdditional
ASR/RO system	Net abstraction Aq 1 (m3/y)			Net abstraction Aq 1 (m3/y)	TRUE
ASR/RO system	Net injection Aq 2 (m3/y)			Net injection Aq 2 (m3/y)	TRUE

ASR/RO system	Net injection both aquifers (m3/y)			Net injection both aquifers (m3/y)	TRUE
ASR/RO system	Net extracted salinity Aq 1 (mg/l)			Total extracted Chloride (mg) / total extracted water (l)	TRUE
ASR/RO system	Injected salinity Aq 2 (mg/l)			Injected salinity Aq 2 (mg/l)	TRUE
ASR/RO system	Basin overflow (m3/y)			Basin overflow (m3/y)	TRUE
ASR/RO system	Pollution by other substances identified as being discharged in significant quantities into the body of water	Physiochemical	Other pollutants		FALSE

ESS Name	**CICES Class**	**CICES Section**	**Beneficiary Type**	**Beneficiary Sub-Type**
Aq 1 groundwater	Ground water for non-drinking purposes	Provisioning	AGRICULTURE, FORESTRY AND FISHING	Irrigators
Aq 1 salinity	Ground water for non-drinking purposes	Provisioning	AGRICULTURE, FORESTRY AND FISHING	Irrigators
Aq 2 groundwater	Ground water for non-drinking purposes	Provisioning	AGRICULTURE, FORESTRY AND FISHING	Irrigators
Aq 1 salinity (2)	Chemical condition of freshwaters	Regulation & Maintenance	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Sewerage
Aq 2 salinity	Chemical condition of freshwaters	Regulation & Maintenance	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Sewerage
Surface water level regulation	Flood protection	Regulation & Maintenance	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Sewerage

Stakeholder Name	Beneficiary Type	Beneficiary Sub-Type
Horticultural companies	AGRICULTURE, FORESTRY AND FISHING	Irrigators
Province of Zuid Holland	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Water collection, treatment and supply
Hoogheemraadschap Delfland (water authority)	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Water collection, treatment and supply

Measure	ESS Name	CICES Class	CICES Section	State Indicator Name	StateParameter Name
ASR/RO system	Surface water level regulation	Flood protection	Regulation & Maintenance	Basin overflow m3/y	Basin overflow (m3/y)
ASR/RO system	Aq 1 salinity	Ground water for non-drinking purposes	Provisioning	Net abstracted salinity Aq 1 (mg/l)	Net extracted salinity Aq 1 (mg/l)
ASR/RO system	Aq 1 salinity (2)	Chemical condition of freshwaters	Regulation & Maintenance	Net abstracted salinity Aq 1 (mg/l)	Net extracted salinity Aq 1 (mg/l)
ASR/RO system	Aq 2 salinity	Chemical condition of freshwaters	Regulation & Maintenance	Salinity of injected concentrate Aq 2 (mg/l)	Injected salinity Aq 2 (mg/l)

Measure Name	ESS Name	CICES Class	CICES Section	Impact I Indicator Name
ASR/RO system	Surface water level regulation	Flood protection	Regulation & Maintenance	Volume of water that can potentially be retained
ASR/RO system	Aq 1 salinity	Ground water for non-drinking purposes	Provisioning	Salinity of Aq 1
ASR/RO system	Aq 1 salinity (2)	Chemical condition of freshwaters	Regulation & Maintenance	Salinity of Aq 1
ASR/RO system	Aq 2 salinity	Chemical condition of freshwaters	Regulation & Maintenance	Salinity of Aq 2

Measure Name	ESS Name	CICES Class	CICES Section	Impact II Indicator Name
ASR/RO system	Aq 1 salinity	Ground water for non-drinking purposes	Provisioning	Directly abstracted irrigation water (m3)
ASR/RO system	Aq 1 salinity	Ground water for non-drinking purposes	Provisioning	Irrigation water treated with RO
ASR/RO system	Aq 1 salinity (2)	Chemical condition of freshwaters	Regulation & Maintenance	Reduction of salinization
ASR/RO system	Aq 2 salinity	Chemical condition of freshwaters	Regulation & Maintenance	Reduction of salinization
ASR/RO system	Surface water level regulation	Flood protection	Regulation & Maintenance	Retention capacity (m3)

ESS Name	Measure Name	Beneficiary Type	Beneficiary Sub-Type	Valuation Method	Assumptions/comments/references
Aq 1 salinity	ASR/RO system	AGRICULTURE, FORESTRY AND FISHING	Irrigators	Cost of irrigation water abstraction (including desalination) now	
Aq 1 salinity	ASR/RO system	AGRICULTURE, FORESTRY AND FISHING	Irrigators	Cost of irrigation water abstraction (including desalination) future	
Surface water level regulation	ASR/RO system	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Sewerage	Avoidance costs	Less costs for pumping stations or alternative measures
Aq 1 salinity (2)	ASR/RO system	WATER MANAGEMENT; WATER SUPPLY; SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	Sewerage	Improved business climate	Region becomes more attractive to agricultural businesses

Comparison Name	Change of salinity Aquifer 1			
Indicator type	**Indicator**	**Unit**	**Value, baseline**	**Value, ASR/RO system**
State	Net abstracted salinity Aq 1 (mg/l)			

Impact I	Salinity of Aq 1			
Impact II	Directly abstracted irrigation water (m3)			
Impact II	Irrigation water treated with RO			
Economic valuation	Cost of irrigation water abstraction (including desalination) future			
Economic valuation	Cost of irrigation water abstraction (including desalination) now			

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

www.dessin-project.eu

DESSIN
DEMONSTRATE ECOSYSTEM
SERVICES ENABLING INNOVATION
IN THE WATER SECTOR