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Application of the FWOO method in the Vega Baja Segura catchment

Potential for local solutions to optimize fresh water supply in European regions under increasing water stress

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Freshwater availability, climate smart agriculture, business case, climate adaptation, measures, Spain

Summary
This project identifies opportunities for innovative measures that decrease freshwater shortages in economic vulnerable regions that are under increasing water stress (drought, salinization), and aims at demonstrating that:

1 Local scale innovative measures for freshwater supply have the potential to boost agricultural production, today and under climate change. This is demonstrated by building positive business cases for such measures.
2 The Fresh Water Options Optimizer is a suitable method to investigate the spatially varying potential of freshwater measures and to stimulate climate smart agriculture throughout Europe.

Business cases were composed for measures Subsurface irrigation, Drip irrigation, Local desalinisation (Fource) and Monitoring irrigation water salinity. All business cases are positive. Furthermore, a common strategy was developed for the Carrizales area, centred around marketing the Carrizales melon as a quality product, allowing for higher salinities in irrigation water, and increased investment opportunities for climate adaptation measures.

The FWOO-NL method was as yet unfit for application in Spain. For European-wide application, the FWOO method requires: (1) inclusion of more freshwater measures than the seven currently included, from a wider variety of geographies, (2) definition of all factors that determine the suitability of measures, including those that are always met in the original area of implementation of a measure, (3) definition of factors for ‘new’ measures, (4) assessment of suitability of measures using data that is more commonly available (e.g. European-wide datasets), or can be entered by a particular user for local evaluation, (5) ease-of-use can be enhanced by making such an expanded FWOO methodology available via the internet or through a smartphone app.

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Version	**Date**	**Author**	**Initials**	**Review**	**Initials**	**Approval**	**Initials**
	dec. 2015	Joost Delsman		Marco Hoogvliet		Harm Duel	
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Preface

This Climate-KIC awarded Pathfinder project aims at identifying opportunities for innovative measures that decrease local fresh water shortages in economic vulnerable regions under increasing water stress. It provides the foundation for innovation pilots, in which measures are actually realised and tested in practice. The focus of this project is on the Vega Baja del Segura region, which is an arable area between Elche and Murcia, in the Alicante province in the southeast of Spain.

The project was granted by Climate-KIC on 2 December 2014 and ran from 1 January 2015 to 31 December 2015.

The project partners are:

- Stichting Deltares, Delft, Netherlands (Lead Institution).
- Wageningen University and Research Centre, Wageningen, Netherlands
- Instituto Valenciano de Investigationes Adrarias (IVIA), Monacada, Spain
- Agenzia Regionale Prevenzione e Ambiente dell' Emilia-Romagna (ARPA), Bologna, Italy
- FutureWater, Wageningen, Netherlands

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1 Introduction

1.1 Background and rationale

In the recent past, the term Climate Smart Agriculture (CSA) has been adopted rapidly by the international innovation community.. However, implementing this approach is challenging, partly due to a lack of tools and experience with farmers and water managers. Climate-smart interventions are location-specific, sometimes knowledge-intensive and require integral consideration. Substantial efforts are required to develop the knowledge and capacities to make CSA work. This pathfinder project focusses on reducing these efforts considerably with respect to choosing and assessing the potential of local freshwater supply measures. Innovative concepts like climate adaptive drainage, aquifer storage and -recovery, in which the water storage capacity of the subsurface is utilized to the full, may strengthen regional agricultural economy and reduce water stress caused by climate change.

This project identifies opportunities for innovative measures that decrease freshwater shortages in economic vulnerable regions that are under increasing water stress (drought, salinization). The project has three components:

1. Analysis of a drought and salinization prone region: what water shortages will occur in the region today, and under climate change; what agricultural production is economically most vital to the region; how can geographical/climatological and soil characteristics support different adaptation measures.
2. Test the applicability of the Freshwater Options Optimizer method, developed for the Netherlands, in the arid to semi-arid region of Vega Baja Segura.
3. Building business cases for freshwater measures, on a local scale, with and for farmers, private companies that market the technical infrastructure and regional governments (water management agency; agricultural agency).

This project builds upon more than four years of research and pilots within the ‘Knowledge for Climate’ research programme in the Netherlands, in which various options to increase local freshwater availability were investigated extensively, tested in the field with several innovative farmers and companies providing the technical infrastructure. For upscaling purposes this knowledge has been incorporated in a toolbox called the Freshwater Options Optimizer (FWOO). The FWOO explores the potential for measures that deal with water shortage, either caused by drought or limitations in freshwater supply. These measures are primarily adaptive, but can also be used to create conditions for growing higher grade, more profitable crops.

1.2 Project partners

Deltares

Deltares is an independent, not-for-profit, institute for applied research in the field of water and the subsurface. Throughout the world, Deltares works on smart measures, innovations and applications for people, environment and society. In this project, Deltares brings in expertise on soil and (ground)water system management, adaptation to climate change effects, data analyses and business case development. Deltares is also responsible for overall project management.

Wageningen UR Alterra
Alterra is a scientific research institute belonging to the Environmental Sciences Group (ESG) of Wageningen University and Research Centra, that gives advice to policy institutions, business and societal organisations. Alterra offers a combination of innovative, practical and interdisciplinary scientific research across many disciplines related to the green world around us and the sustainable use of our living environment. Alterra contributes expertise on the soil and (ground)water system, farm management and economics, crop science and climate change effects.

FutureWater
FutureWater is a research and consulting organization that works throughout the world to combine scientific research with practical measures for water management. FutureWater works with partners at both global, national and local levels. FutureWater contributes expertise on water management, climate adaptive freshwater measures, data collection and analysis, and drought and water shortage analysis in Spain. Furthermore, FutureWater acts as a liaison with Water2Invest KIC Climate project.

Instituto Valenciano de Investigaciones Agrarias (IVIA)
The Valencian Institute of Agricultural Research (IVIA) is an autonomous agency of the Generalitat Valenciana. IVIA is responsible for the aims of the Generalitat Valenciana to promote scientific research and technological development in the Valencian food industry and integrate this contribution to the progress of agricultural science. IVIA acts as the local partner for the Veja Baja Segura pilot area, and as intermediary with local farmers and industry. IVIA contributes expertise on soil science, local agricultural practice, sustainable agriculture and optimization of water use.

ARPA-Emilia Romagna
Arpa stands for "Agenzia Regionale per la Prevenzione e l´Ambiente dell´Emilia-Romagna" (Regional Agency for Environmental Protection in the Emilia-Romagna region, Italy). Arpa operates an environmental management and control system which integrates activities pertaining to the verification of and the compliance with regulations and standards by studying and analysing the causes of environmental degradation and their relative effects. Arpa is the primary contact for the region Emilia Romagna in Italy and responsible for knowledge transfer with this region.

1.3 Climate KIC

The mission outline of Climate KIC nicely summarizes the scope and goals of the Climate KIC public-private partnership:

Climate-KIC creates opportunities for innovators to address climate change and shape the world's next economy. We accelerate the innovation required for a climate resilient low-carbon future, and ensure that Europe benefits from new technologies, company growth and jobs.

This project is part of the Innovation Pillar, one of the pillars along which Climate KIC aims to fulfil the above goals. The Innovation Pillar facilitates cooperation between research, private and public partners, to ultimately support a self-sustaining economic activity that delivers climate impact. The Innovation Pillar uses a two-step approach, implemented in two project types: (1) Pathfinder project, to investigate whether an Innovation opportunity exists, and (2) Innovation project, in which climate-relevant solutions are developed and brought to market.

1.4 Project goals

This Pathfinder project aims at demonstrating that:

1. Local scale innovative measures for freshwater supply have the potential to boost agricultural production, today and under climate change. This is demonstrated by building positive business cases for such measures.
2. The Fresh Water Options Optimizer is a suitable method to investigate the spatially varying potential of freshwater measures and to stimulate climate smart agriculture throughout Europe.

As a Pathfinder project, this project aims to investigate whether the possibility for a self-sustained economic activity exists, that delivers climate impact. Climate impact translates here to climate smart agriculture and more specifically to a reduction of agriculture's dependence on freshwater.

This project will demonstrate the business potential of freshwater measures for a case study area with intensive agriculture in the Vega Baja Segura, Valencia province, Spain. Expertise and experience are shared with stakeholders from Italy's Emilia Romagna region, where similar challenges exist and local freshwater measures are called for. In this way, this region may be involved in innovation pilots in a follow up stage, cooperating closely in the dedicated partnership that gradually developed in this project. As a secondary objective, this project will identify hiatuses in knowledge and /or available information, and advise on follow-up steps.

1.5 Report outline

The report is outlines as follows: chapter 2 presents an overview of the FWOO methodology, as it was developed in the Netherlands. Chapter 3 describes the study area. Chapters 4 and 5 evaluate the FWOO-NL methodology for the study area, and outline suitable freshwater measures. Business cases for selected measures are outlined in chapter 6. Chapter 7 presents an integrated climate adaptation vision for part of the study area. Chapter 8 reports on knowledge exchanged between project partners. Conclusions and recommendations are given in chapter 9. Appendices contain field visit reports and report on quick scan modelling efforts.

2 Fresh Water Options Optimizer methodology in the Netherlands

2.1 Introduction

In The Netherlands a number of successful (in terms of effectiveness and economic feasibility) pilots have been carried out with local technologies and much practical knowledge has been gained on the costs and benefits of these innovations. For up scaling purposes (i.e. under what conditions can technologies be applied elsewhere, what will be the economic potential on a larger scale?) this knowledge has been incorporated in a toolbox called the Fresh Water Options Optimizer (FWOO).

The FWOO-NL was developed for The Netherlands, with government support, for farmers, water boards and water technology companies, and both the fresh water measures themselves and the FWOO-NL approach appear to have international potential. This chapter first introduces the FWOO methodology for suitability mapping, then describes the various FWOO-NL freshwater measures, and finally reflects on the entire FWOO-NL approach.

2.2 Methodology

The core of the FWOO-NL consists of a method to produce maps that pinpoint where physical conditions are more or less suitable for local fresh water measures that secure the water supply of farmers and decrease their vulnerability to periods of drought and/or stalling water supply.

Furthermore, the FWOO-NL hands a procedure to asses other physical factors that determine the success and quantitative potential of local measures, like interference between measures, the interaction with surface water quality, the current or future water management strategy and seasonal aspects.

The FWOO-NL method was applied for seven ‘candidate’ freshwater measures based on their innovative character and assumed effectiveness. The measures are:

1. Controlled drainage
2. Drains2buffer
3. Creek ridge infiltration
4. Vertical Aquifer Storage and Recovery
5. Freshmaker
6. Water conservation with weirs
7. Water conservation by raising ditch / canal bottom.

These measures will be described briefly in the next section.

In the following, a short example is given of producing a National suitability map for one of the freshwater measures, i.e. creek ridge infiltration, the infiltration of freshwater in sandy palaeo-channel deposits in a saline environment.

Method for producing suitable map for measure creek ridge infiltration
Based on knowledge about the application of creek ridge infiltration by modelling and field experiments (Pauw et al., 2015), various physical factors were selected that appeared dominant in determining the suitability of this measure. The factors are summarized in Table 2.1. Based on expert judgment, a score of 1 and 0 is given to each factor. Table 2.2 shows how combinations of these scores result in a suitability class.

Table 2.1 Factors controlling the suitability of creek ridge infiltration

	Criteria	**Score**	**Criteria**	**Score**
Factor A	Creek ridge or other elevated sandy geomorphological feature	1	absent	0
Factor B	In area with shallow saline groundwater	1	Not in saline area	0
Factor C	Infiltration situation	1	Seepage situation	0
Factor D	Soil suitable for active infiltration	1	Soil not suitable for active infiltration	0
Factor E	Average high water table (GHG) > 0.85 m below ground level	1	GHG < 0.85 m below ground level	0
Factor F	Cum. thickness of low permeable layers (within depth interval 2-20 m) ≤ 2.5 m	1	rest	0

Table 2.2 Conditional scores evaluation to determine the suitability of creek ridge infiltration.

Suitability / potential	**Score**
High	If A = 1 & C = 1 & D + E + F = 3
Normal	If A = 1 & C = 1 & D + E + F = 1 or 2
Low / possible	If A = 1 & C = 1 & D + E + F = 0
Not suitable	If A = 0 or C = 0

As an example, the parameter values of factor B and C and the resulting scores are shown in Figure 2.1 and Figure 2.2.

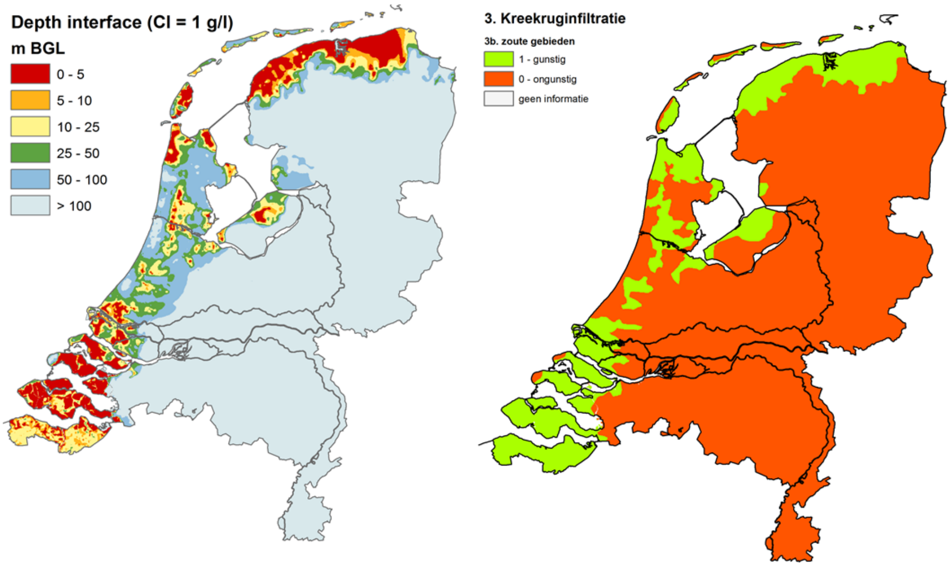

Figure 2.1 The parameter value of factor B (depth of the fresh-brackish interface) and the resulting score of this factor .In the factor score, green is favourable, red unfavourable.

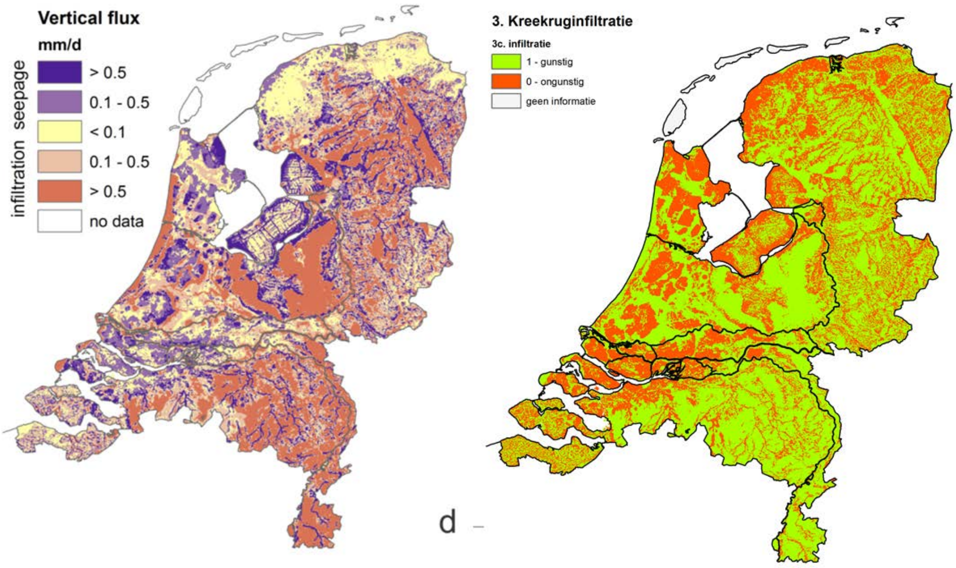

Figure 2.2 The parameter value of factor C (vertical flux: infiltration / seepage) and the resulting score of this factor. In the factor score, green is favourable, red unfavourable.

Figure 2.3 shows the scores of all factors controlling creek ridge infiltration and figure # shows the resulting suitability map (applying Table 2.2).

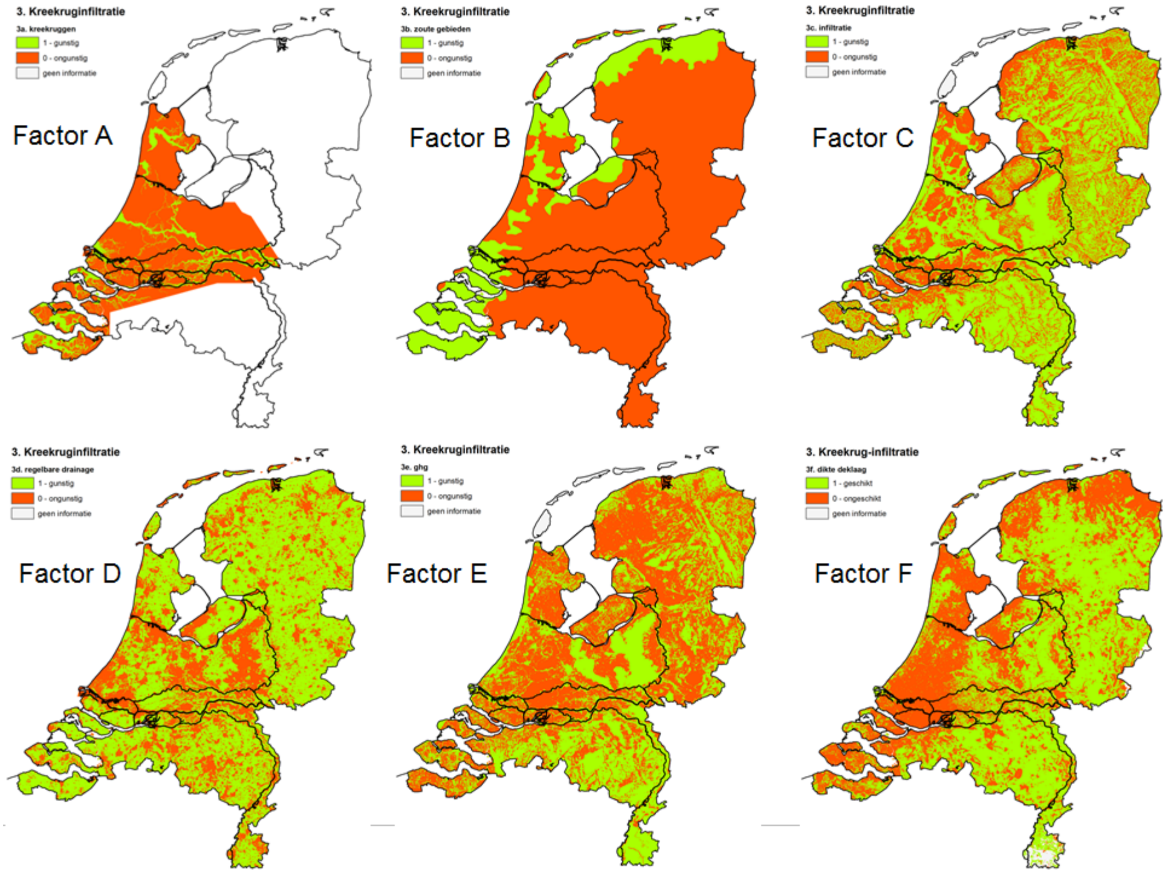

Figure 2.3 Scores of all factors included in the suitability assessment for measure creek ridge infiltration; green is favourable, red unfavourable.

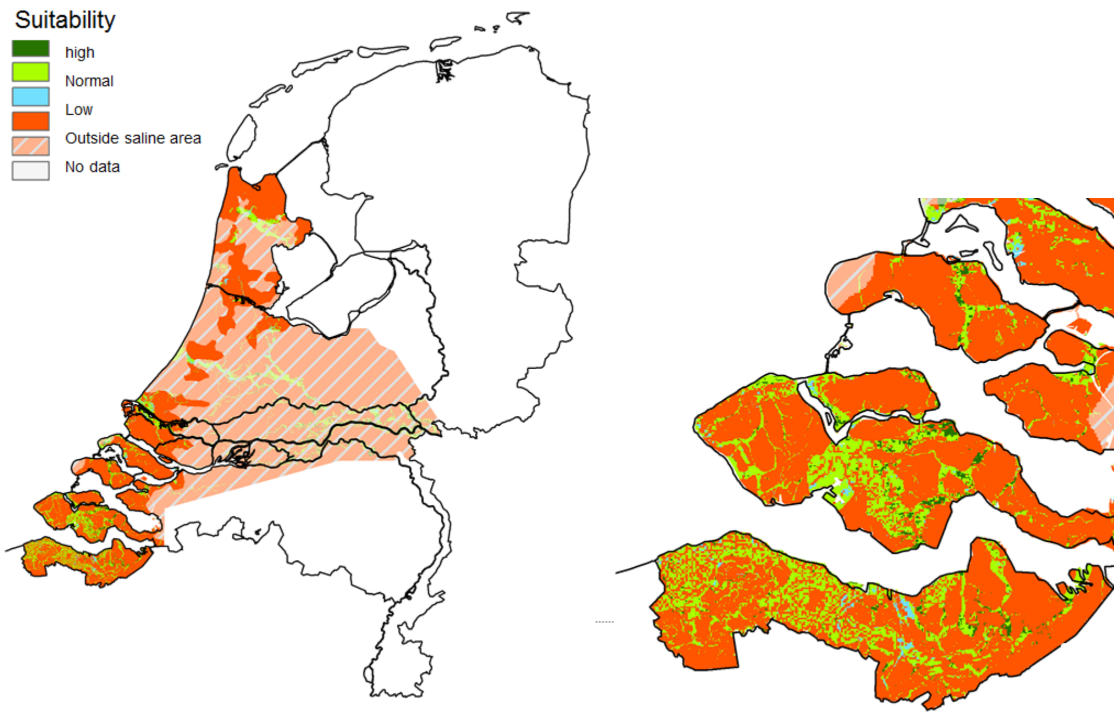

Figure 2.4 Suitability map of freshwater measure creek ridge infiltration.

In phase 1, suitability maps were constructed for all mentioned measures on a national scale. In phase 2, the suitability maps were scaled down to a regional scale for a pilot area called Wieringermeerpolder. Usually, more detailed information is available at a regional scale than at a national scale. In Figure 2.5, the suitability map is shown for the pilot area for freshwater measure Freshmaker based on data available on a national scale (left) and a regional scale (right).

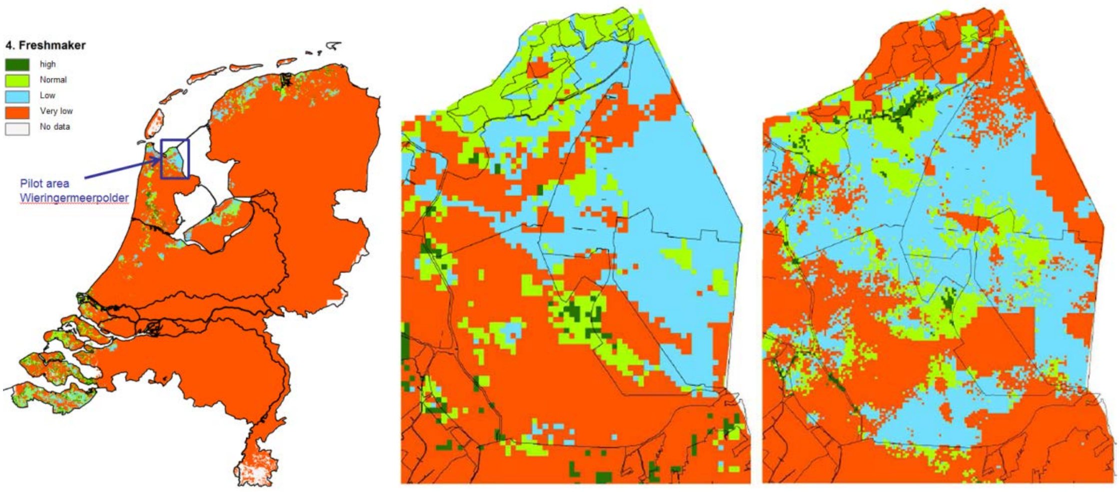

Figure 2.5 Suitability maps of freshwater measure Freshmaker based on data available on a national scale (left, centre) and a regional scale (right), for pilot are Wieringermeerpolder. See for legend suitability, Figure 2.4.

For this pilot area, the most effective freshwater measure was determined, and displayed on a map (see Figure 2.6).

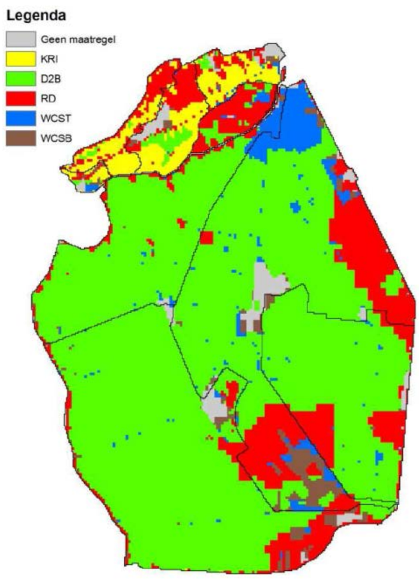

Figure 2.6 Map of pilot area Wieringermeerpolder with the most effective freshwater measure indicated. KRI = creek ridge infiltration, D2B = drains2buffer, RD = controlled drainage, WCST water conservation weirs, WCSB = water conservation raising ditch bottom.

2.3 Selected measures in FWOO-NL

2.3.1 Controlled drainage and climate-adaptive drainage

Drain tubes are connected to a collector drain which discharges into a control unit. The drainage level can be controlled in the control unit: low during wet periods when agricultural activities are planned and intensive drainage is imperative, and high levels to increase the water table and store water for dry periods. With controlled drainage, a farmer is much more in control of the water management of his fields than with a conventional system . The term 'climate-adaptive drainage' is used when the control of the drainage-level is done automatically, based on monitoring data of water tables, soil moisture and the weather forecast.

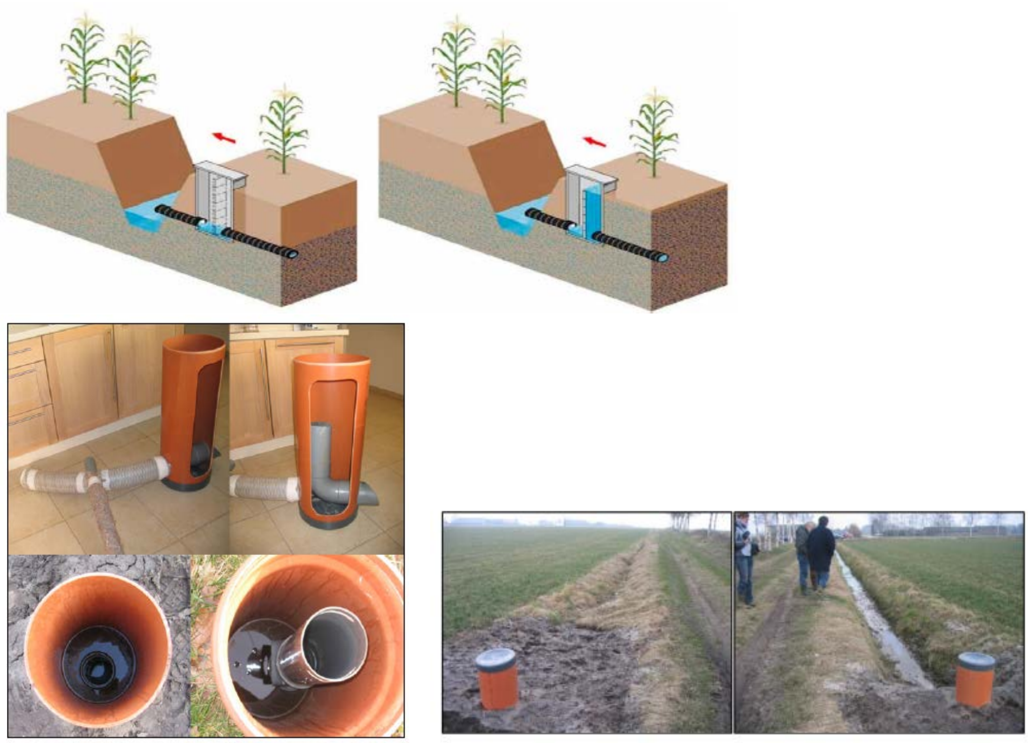

Figure 2.7 Principles of controlled drainage (above) and pictures of the control unit (below). Source: L.C.P.M. Stuyt

2.3.2 Drains2buffer

In areas with saline seepage (upward flow of saline groundwater) saline groundwater may reach the root zone by capillary rise. Drains2buffer involves a controlled drainage system to increase the vertical extension of the rainwater lens in order to prevent capillary rise of saline groundwater. Installation of deeper drain tiles than current systems allows the discharge of deeper and more saline groundwater during rain events. This causes the rainwater lens to grow until a new equilibrium is reached. It is important that the deeper drainage system is controlled to allow for increasing the drainage level (see freshwater measure 'Controlled drainage', paragraph 2.3.1). A video of the application of Drains2buffer can be seen at the following link:
https://www.youtube.com/watch?v=2vha9wYEt2Q

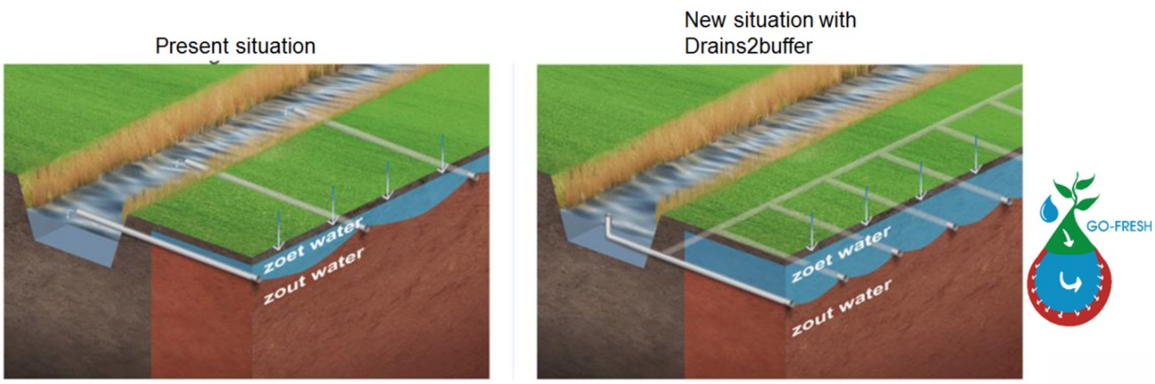

Figure 2.8 Principle of Drains2buffer using controlled drainage for increasing the rainwater lens (blue), saline groundwater is colored reddish brown.

2.3.3 Creek ridge infiltration

The purpose of creek ridge infiltration is to increase a freshwater lens in a saline environment below sandy creek ridges by artificial freshwater recharge. During winter, the precipitation surplus (surface water from canals) is made to infiltrate in higher elevated sandy creek ridges (or in other elevated sandy geomorphological features like dunes) using a dedicated controlled drainage / infiltration system. The freshwater lens can only grow when the average water table is made shallower, preventing saline groundwater pushes it in upward direction. The extra stored fresh groundwater in the lens is available for irrigation when required.

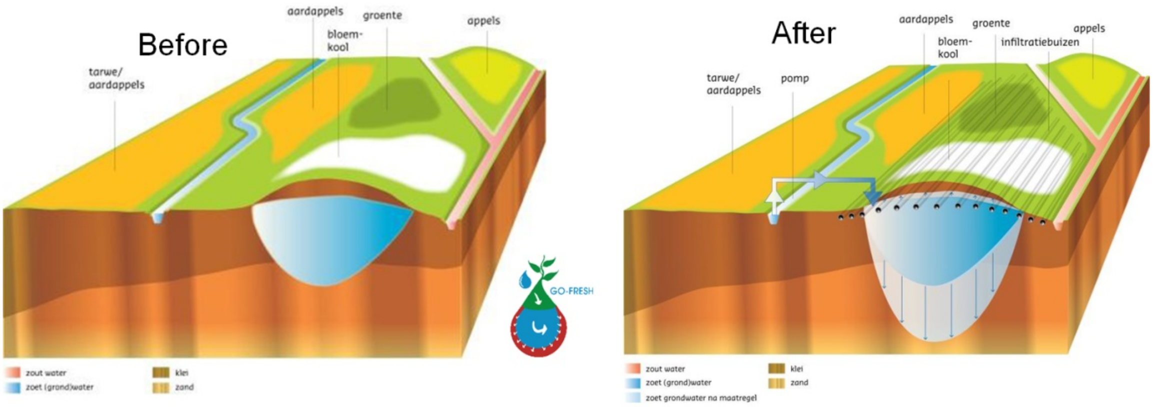

Figure 2.9 Principle of creek ridge infiltration using subsurface drainage pipes for infiltration of fresh surface water pumped out of a ditch in order to increase the rainwater lens (blue), saline groundwater is colored brownish-red.

During the Netherlands field excursion (16 April 2015, Appendix A.1), the creek ridge infiltration pilot project was visited and explanations were given by the farmer. The farmer is very enthusiastic about this way of conserving fresh water to irrigate his crops in periods of droughts. More information of this field experiment is given in Pauw et al. (2015).

Figure 2.10 Visit of Creek ridge infiltration pilot project, Serooskerke, Netherlands – 16 April 2015

2.3.4 Freshmaker

The Freshmaker (Zuurbier at al., 2014) is an aquifer storage and recovery method specifically suitable in shallow aquifers with saline groundwater with annual precipitation surplus. Aquifer storage and recovery of freshwater is applied using shallow horizontal directional drilled wells (HDDW) where fresh surface water is infiltrated in periods of precipitation surplus. From the deep HDDW brackish groundwater is extracted to keep the freshwater lens in place. Fresh groundwater can be pumped from the shallow HDDW to irrigate crops.

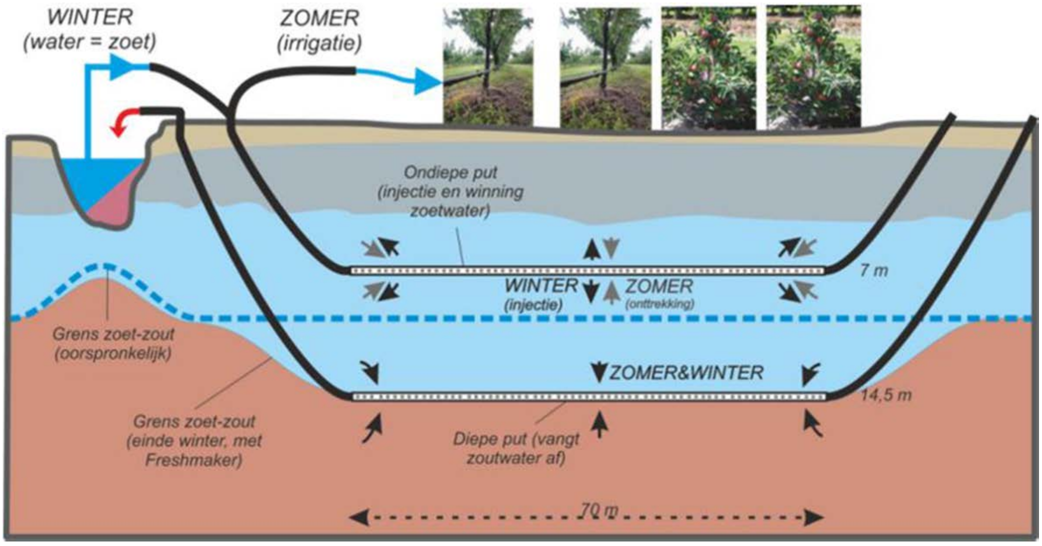

Figure 2.11 Principle of the Freshmaker using horizontal directional drilled wells (HDDW) for infiltration and extraction of fresh water. From a deep HDDW brackish water is pumped to keep the freshwater lens at place. The freshwater lens is blue, saline groundwater is colored brownish-red.

During the Netherlands field excursion (16 April 2015, Appendix A.1), the Freshmaker pilot project was visited and explanations were given by the installer of this technical measure. At this location, fruit (apple, pear) is grown that is very salt intolerant. The farmer is very enthusiastic about this way of conserving fresh water to irrigate the trees in periods of droughts. More information of this field experiment is given in Zuurbier et al. (2014).

Figure 2.12 Visit of Freshmaker pilot project, Ovezande, Netherlands, 16 April 2015

2.3.5 Vertical Aquifer Storage and Recovery

The principle of vertical aquifer storage and recovery is to recharge the aquifer with freshwater via vertical well(s) and to recover the freshwater from the same wells at a later stage. Multiple well configurations can be used to optimize injection and recovery fresh groundwater (Zuurbier et al., 2014). This measure is not suitable in aquifers in which the groundwater is too saline (EC > 15 mS/cm).

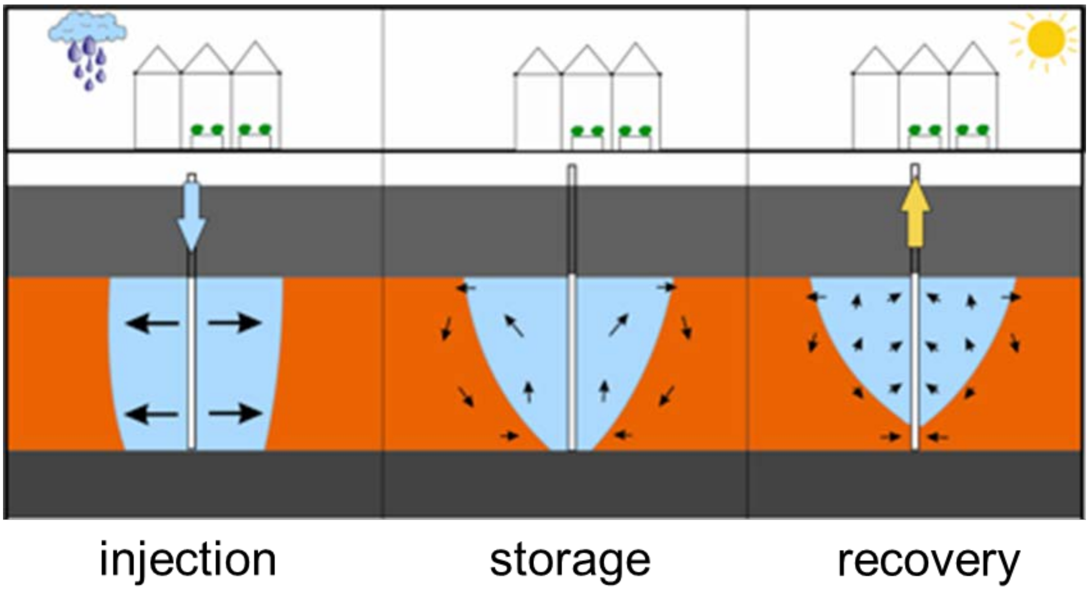

Figure 2.13 Principle of the Vertical aquifer storage and recovery using vertical wells for infiltration and extraction of fresh water.

2.3.6 Water conservation with weirs

Water conservation with weirs is a procedure for storing water in the subsoil by raising surface water levels in ditches using weirs. By increasing the surface water level, the groundwater level is increased, providing more soil moisture to the crops (Figure 2.14, Figure 2.15). The success of water conservation is very much dependent upon the availability of surface water to raise the water level (period, volume), the permeability of the subsoil and the overall relief, as the area of influence of a particular weir decreases with increasing slope of the terrain (Figure 2.16).

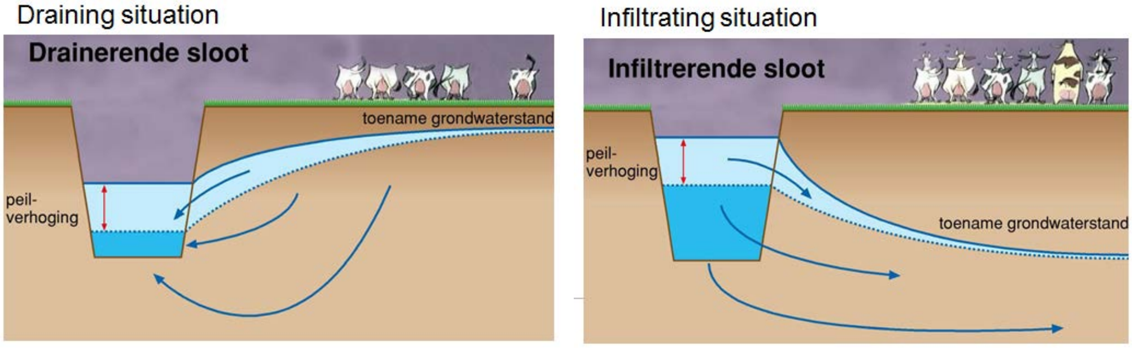

Figure 2.14 Principles of the water conservation by weirs. The surface water level is made shallower to delay the drainage of groundwater towards the ditch (drainage situation, left) or to infiltrate surface water into the soil (infiltration situation, right).

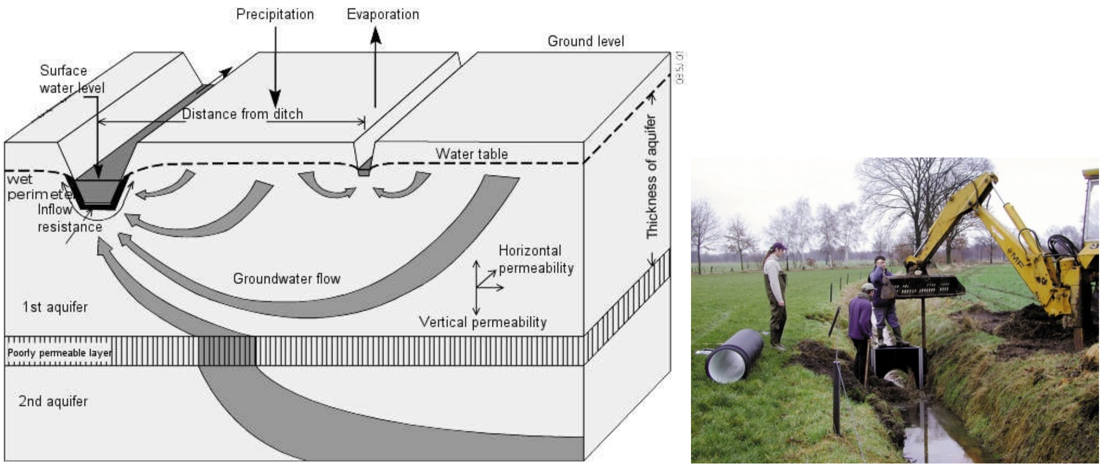

Figure 2.15 Groundwater flow to ditches and the most important parameters controlling groundwater flow (left). Installing a small weir in a ditch to locally increase the water table (right).

2.3.7 Water conservation by raising a ditch / canal bottom

Another way of water conservation is raising the ditch or canal bottom. By raising ditch bottoms, ditch water levels also increase. Higher average groundwater tables can thereby be achieved to support capillary rise from the water table to the root zone to provide enough soil moisture for crops during the growing season. This method is independent on the availability of surface water and slope of ditches / canals (see pictures). However, this measure is permanent and control of the water table as is facilitated with weirs or controlled drainage systems is not possible.

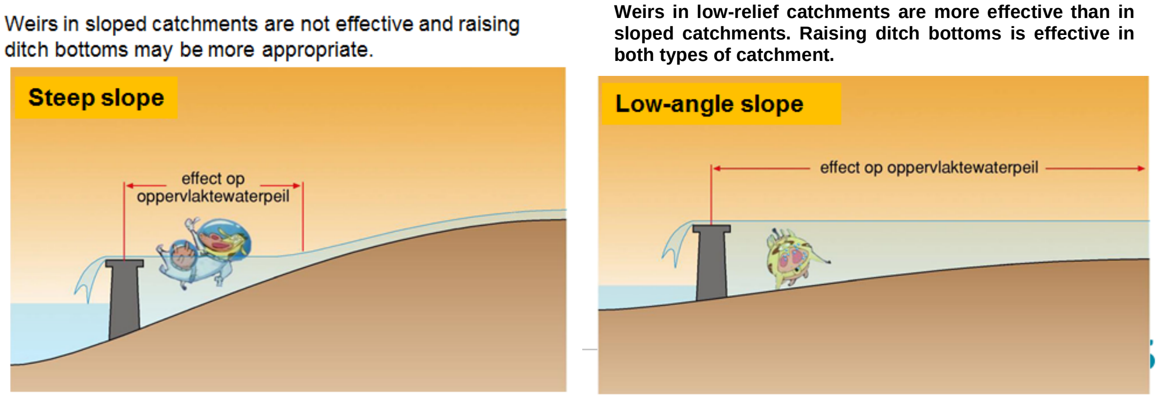

Figure 2.16 Water conservation by weirs in a ditch with a steep slope (left) and low-angle slope (right) (above). Raising ditch bottoms may be applied in either situation.

2.4 Conclusions

The FWOO-NL method was successfully applied at a national scale in the Netherlands. In addition, a pilot study was done on a regional scale (Wieringermeerpolder, Netherlands). To optimize the water availability of a certain area, application of the FWOO method on a regional scale (e.g. catchment or irrigation area) with regional data is essential. In principle, the seven freshwater conservation measures described in this chapter can be applied elsewhere. The FWOO-NL methodology is not limited to these seven measures, the methodology could equally well be applied to other measures. Applying the methodology requires insight in factors (geological, water management et cetera) determining successful implementation of a particular measure, and requires the availability of data to map these factors.

3 Study area: Vega Baja Segura and Vinalopo river basin

3.1 Introduction

This chapter presents an overview of climate, hydrology, water management and agricultural practices in the study area. These physiographic factors form the background for subsequent analyses and will be revisited in following chapters.

The Vega baja of Segura river and bajo Vinalopo are located at the Mediterranean southeast of Spain (Figure 3.1). This area covers more than 74 000 hectares, in which conventional flood irrigation is dominant. Since water shortage is the main limitation for crop production, farmers are organized in several associations for water management. In several cases, irrigation water is reused up to five times before being discharged into the sea.

The water shortage in this arid to semiarid area is linked to bad water quality for irrigation, with high salt contents. According to the Spanish Ministry of Agriculture, > 75% of the irrigated area is salt-affected (MAPA, 2002). Several irrigated areas can be differentiated depending on the water source: (1) the Segura river, (2) the Tajo-Segura transfer, (3) groundwater, and (4) agricultural return flows. These sources of irrigation water have widely different salinities, ranging from the Tajo-Segura river transfer with an average electrical conductivity (EC_{25}) of 1.1 dS m^{-1}, to the Segura river, with an average EC_{25} of 3.9 dS m^{-1}, to groundwater, with a variable EC_{25} between 4 and 8 dS m^{-1}, and to agricultural return flows, with highly variable EC_{25} between 5 and 14 dS m^{-1} (Visconti, 2009).

Soils of the irrigated areas are calcareous (FLc) and hyposalic Fluvisols (FLszw) (Ortiz et al., 2008). The soils in the area are characterised by a low horizon development, high equivalent calcium carbonate content, low organic matter content, low stone content, a pH about 7.8, are medium to fine-textured and are base-saturated (Visconti, 2009).

Figure 3.1 Location of the study area.

3.2 Climate

The climate is (semi)arid, with annual precipitation 280 mm and annual evapotranspiration 1200 mm. The mean annual temperature is 18 ºC, with warm summers (27ºC), and mild winters (10 ºC) (figure 2) and intensive rainfalls are frequent during the autumn. These climatic conditions necessitate irrigated agriculture.

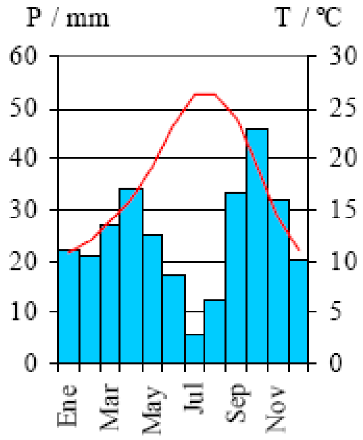

Figure 3.2 Precipitation-temperature diagram for Elche weather station.

3.3 The Carrizales water system

3.3.1 Main data

Carrizales is located at the end and lower part of the “Regadio Tradicional vega baja Segura and bajo Vinalopó”, inbetween two natural parks, “El hondo de Elche” and “Lagunas Santa Pola” included in the Ramsar and “Natura 2000” network. (figure 3). The historic irrigation association of Carrizales, founded in 1748, groups more than 400 farmers that cultivate 1160 ha.

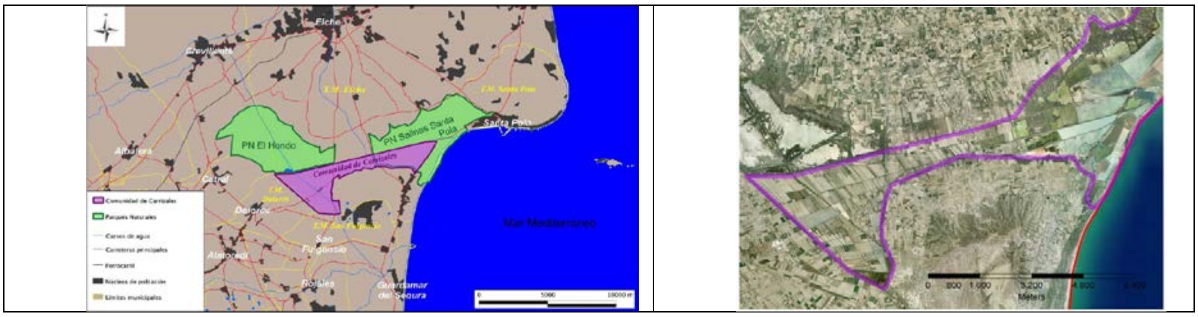

Figure 3.3 Carrizales location map (a) and aerial photograph (b)

The main function of this association is water supply and -management for irrigation. This entails the operational distribution of water as well as the maintenance of the infrastructure, consisting of more than 200 kilometres of irrigation channels. The irrigation association promotes ecological crop management considering the impact in the nearby Natural parks, and trying to integrate the agricultural activities in this special agro-natural ecosystem. A small part of the Carrizales area (aprox. 300 has) is included in the Natura2000 network.

In Carrizales, very active ecological associations (Associació per al Desenvolupament Rural del Camp d'Elx, Amigos de los Humedales del Sureste de Alicante and Asociación de

Naturalistas del Sureste) are involved in the environment conservation. They organize several workshops and other environmental activities to educate the population living in the area about the importance of integrating wetland conservation and crop production. This indicates the high social concern of the local population to conserve the Carrizales and the surrounding natural areas of "El Hondo de Elche" and "Salinas de Santa Pola".

The alluvial soils in this area tend to be silty clay, piezometric levels are shallow and can be found within 0.6 to 1 meter below the soil surface. These conditions of high salinity water, silty-clay soil texture, shallow groundwater and semiarid climate enhance the risk of soil salinization. In fact, in this area the measured electrical conductivity of soil saturation extract is always higher than 3 dS/m, locally reaching 12 dS/m at the top soil layer.

The main crops that are grown in Carrizales area are: melon, pomegranate, artichoke, broccoli, alfalfa and cereal (Table 3.1). Since the salinity is a principal factor in the crop production, all these crops are adapted to moderate salinity conditions.

Table 3.1 Main crops cultivated in Carrizales.

Crop	% area	Yield (t/ha)	Price (€/kg)
Melon	2.3%, 25 has	10-16	0.65 - 1.3
Pomegranate	10-15%	15-20	0.05 (for juice) 0.4 - 0.80 (fresh). Average 0.64
Artichoke	2-5%	12-20	0.4 - 1
Broccoli	2-5%	20	0.45
Alfalfa	20-25%	30	0.14
Cereal (wheat and barley)	20%	4.7	0.20

The prices for the different crops vary depending on the quality and the market demand. The highest yielding product in the region is the "Carrizales" Melon. The Carrizales association is promoting this high quality melon as "gourmet" product that is grown in moderately saline conditions. This saline conditions permit to produce a sweeter melon (15º Brix) well appreciated by the market. For this reason Carrizales is promoting a specific trade mark of "Melon de Carrizales", and farmers that want to sell this melon as such have to pay the association a special fee.

The second highest yielding crop after melon is pomegranate. The "Mollar" pomegranate variety grown in Carrizales is the most frequent variety produced in the Elche area (Alicante). This variety is well appreciated because of its sweet taste and the small seed size. The artichoke from "Vega baja del Segura" is also well appreciated in the national market; usually, the price is 15% higher than in other production areas. Although alfalfa and cereals are not high valuable crops, they are grown frequently in Carrizales. Both in crop rotation, and because of ease-of-cultivation. This production provides food to more than 5,000 goats and sheep living in Carrizales. Broccoli is another high valuable crop.

The irrigation water used in Carrizales is supplied through (cf. Figure 3.4):
- Dalt Channel
- Junction of channels-Dulce channel

Figure 3.4 Dalt channel (left) and channel junction-Dulce channel (right).

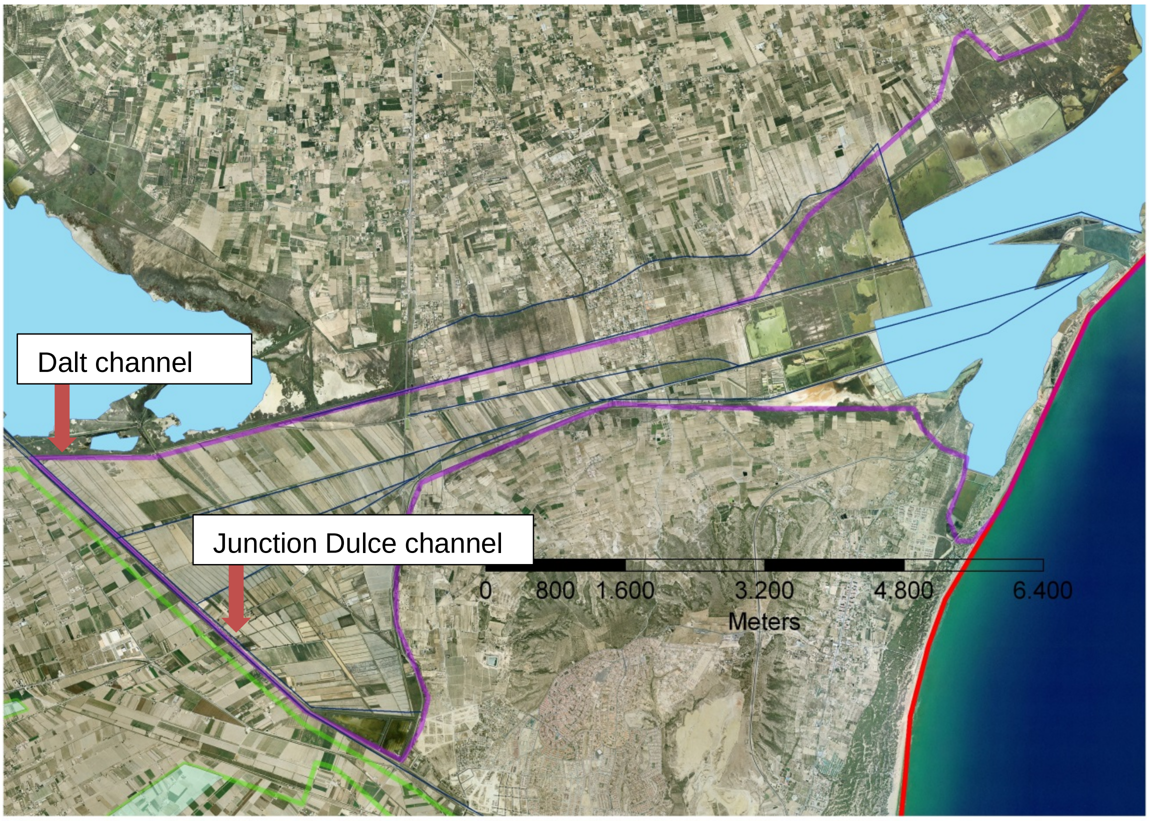

Figure 3.5 Location of photograps Figure 3.4

The main irrigation channel (Dalt channel) is supplied with reused water from Dolores irrigation area by the “Cebadas” channel and from “Catral” irrigation area. The dimensions of this main channel are: water height 1.07 m, width 4 m, the design discharge is 0.87 m^3/s.

The total amount of irrigation water assigned by law to Carrizales is 7.8 hm^3/year, yet only 50-60% (3.9 hm^3/year to 4.68 hm^3/year) is generally used by the farmers. The amount of water supplied is not enough to irrigate the 1160 ha cropped area. Carrizales farmers do not have any structure (dam, pool) to store water, so in case of occasional excess supply, this water cannot be stored. The general irrigation dose applied by farmers is 1 hour/ha with a water flow of 200 l/s, which corresponds to a 72 l/m^2 dose. Farmers and irrigation advisors are not aware of irrigation water salinity. For quick assessment, two electrical conductivity (EC) sensors have been provisionally installed in the both major water inlet points (Figure 3.6).

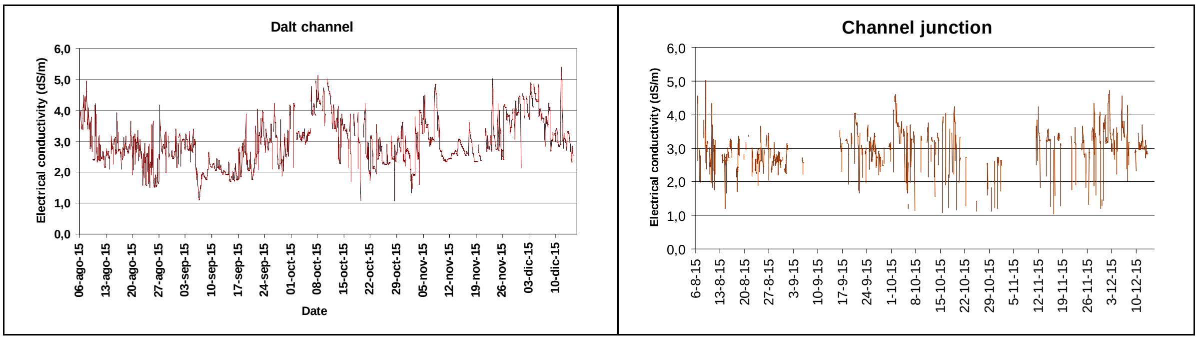

Figure 3.6 Electrical Conductivity of Dalt channel (left) and Channel junction (right).

The EC of the irrigation water used by the Carrizales farmers is highly variable (Figure 3.6). The EC typically ranges from 2 to 4 dS/m, but may peak at 5 dS/m. The spatial variability of irrigation water EC is very high, with areas irrigated with lower EC_{25} waters (2 dS/m) and other irrigated with very high EC_{25} waters (6 dS/m).

The irrigation cycle is seven days. The Carrizales area is split into two parts that correspond with the two water supply sources (Dalt channel and Dulce Channel), and each part is subdivided in seven areas, corresponding with the seven day cycle. The water is generally applied by surface irrigation. In one area (“El Maestre”) the water needs to be pumped since the surface water level in the irrigation channel is below field level. Some farmers have recently switched to drip irrigation for their melons by. They adapted a portable irrigation header (water distribution unit that connects a water pump to different drip lines) to be installed in a tractor. During 2015, 5 ha of melon were irrigated by drip irrigation with excellent results: the harvest was increased from 10 to 16 t/ha. They are considering buying a new irrigation header to increase drip irrigation possibilities.

3.3.2 Water costs and requirements

Farmers in Carrizales pay two fees for water use.. The first one, paid to the “Confederacion Hidrográfica Segura” is to maintain the main infrastructures: dam, main irrigation channels etc (€34-40 /ha/year). The second fee is paid to irrigation association (Carrizales) is to maintain drainage ditches and irrigation channels (€35-40 /ha/year). In total, the farmers pay €70 to 80 /ha/year.

3.3.3 Water sources and reservoir storage

The irrigation water in the area mainly comes from the Segura river. Water supply is managed through two dams located upstream, Cenajo and Fuensanta. water supply. Figure 3.7 shows water storage in these dams that provide water to “Regadio tradicional Vega Baja del Segura”. The potential storage capacity of these dams are, 437 hm^3 for Cenajo, and 210 hm^3 for Fuensanta. In figure 6 a 10 year drought period from 1999 to 2009 may be noticed, and a wet period from 2009 to 2015.

During the last 3 years, annual rainfall was lower than 180 mm/year, indicating a new drought period (Figure 3.8). The low rainfall rate during last three years lead to an intensively reduction of the water stored as observed in the figures specified below. This fact, combined with climate change, with higher temperatures and lower precipitation, will increase drought effects in agriculture.
At the time of writing, we appear to enter a new drought period as the volume of water stored has decreased dramatically during 2015. In December 2015 the total amount of stored water is 242 hm^3, corresponding to 37% of the available capacity.

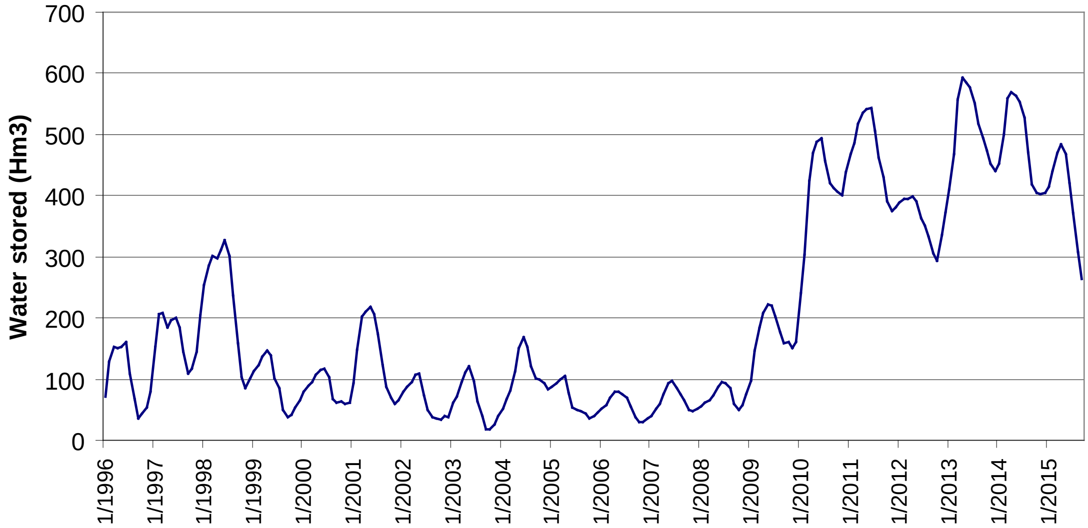

Figure 3.7 Water stored in the Cenajo and Fuensanta dams to provide irrigation water to "regadio tradicional vega baja segura".

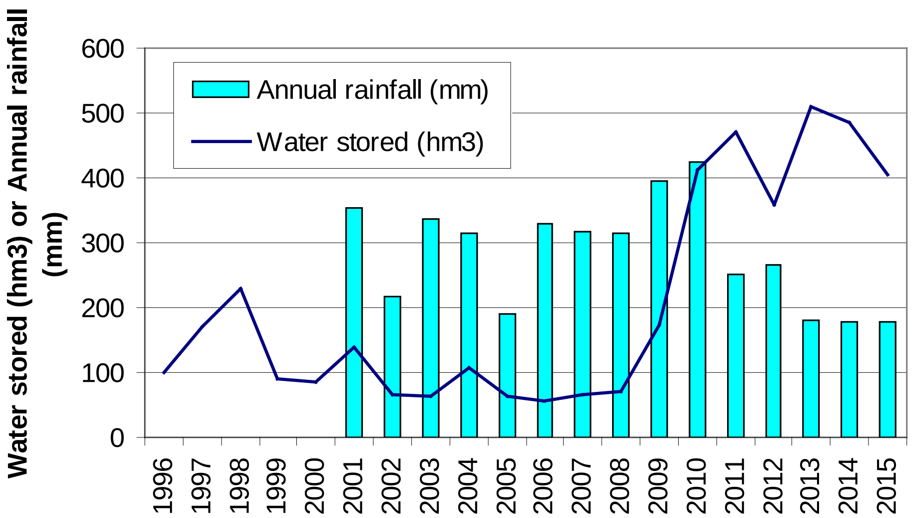

Figure 3.8 Annual average of water stored in the Cenajo and Fuensanta dams versus the annual rainfall for Orihuela weather station.

3.4 Agriculture

Irrigated agriculture of the Vega baja del Segura covers 71,000 ha, 47% ofthe area. Citrus (orange and lemon) is the most important crop (53%) of the area, fruit trees, particularly almond, and pomegranate, (16%) and vegetables like broccoli, artichoke, melon, and alfalfa (15%). Irrigation water salinity prompted the introduction of more salinity tolerant crops (artichoke, broccoli, pomegranate, alfalfa, wheat, palms, citrus grafted on tolerant rootstock), and crops like melon where fruit quality is favourably affected by brackish irrigation water.

The map produced from the map of crops and land use MARM updated to 2008 (Figure 3.9) shows that the spatial distribution of crops in the "Vega Baja del Segura and bajo Vinalopó" is determined by topography and irrigation water quality. On higher grounds and areas irrigated with good quality water (water transfer mainly) citrus is cultivated, beyond effects of the shallow groundwater tables and associated salt accumulation. Arable crops are grown in the alluvial river Segura area surrounding the reservoir of the “Hondo de Elche” area where growing conditions are more challenging.

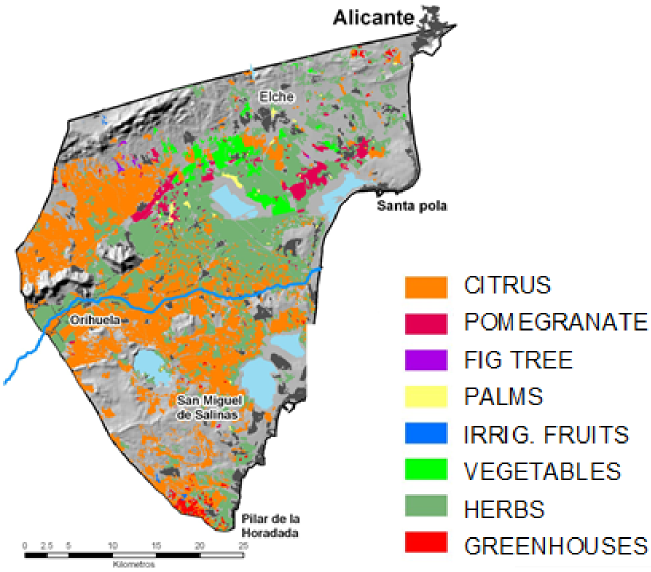

Figure 3.9 Land use map of the “Vega Baja del Segura y Bajo Vinalopó”.

3.5 Economy

The gross domestic product for agriculture in Alicante province represents 1.4% of the total, tourism activity amounts to 26.9%. Although tourism is the main economic activity, agriculture plays an important role to structure the territory and to conserve the environment. The coastal areas, more devoted to tourism, are in contrast to the inland areas where the agriculture, generally as secondary activity, supports the socio-economic activity. Therefore, agriculture is an important activity to avoid abandonment of the fields, prevent depopulation and reduce the risk of desertification process of these areas**.**

3.6 Governance

Water shortage is the main limitation for agriculture in the “Vega baja del Segura and bajo Vinalopó”. Therefore farmers are organized in more than 37 irrigation associations that are responsible for distributing and managing irrigation water. In the area, two types of irrigation can be distinguished: drip irrigation and surface irrigation. The traditional irrigation area of Segura river (located in the alluvial area of the Segura river) mainly uses surface irrigation, but the farmer can achieve high water use efficiencies because the water drained from an irrigation association is used as irrigation water in another irrigation association. In several cases, water can be reused up to 5 times before being discharged into the sea. A highly structured system of irrigation shifts, where, on average, farmers can irrigate every 15 days, (varying from 4 to 24 days), is the basis for irrigation water management in the area.

Farmers pay two fees for water use, one to the “Confederación Hidrográfica Segura” to maintain the main infrastructures: dam, main irrigation channels etc. (34-50 €/ha), the second fee is paid to the irrigation association is to maintain drainage ditches and irrigation channels (35-50 €/ha). In total, the farmers paid pay for the water provision from 70 to -100 €/ha, for their irrigation water supply, depending on the field location.

The public authority responsible to supply water to each irrigation association of the “Vega Baja del Segura and Bajo Vinalopó” is the “Confederación Hidrográfica del Segura”. This public institution decides about water use and its redistribution, depending on demand. Because of the 2015 drought, several conflicts have arisen between the Confederación on the one hand, and the irrigation associations on the other. The decline of water quality provided by Confederación in 2015, has prompted farmer to claim a better water quality for irrigation.

4 Evaluation of FWOO measures and method

4.1 Evaluation of FWOO – NL measures

The FWOO-NL measures that were suggested for applicability assessment in the Vega Baja Segura region were (chapter 2):

- Drains2buffer
- Controlled drainage and climate-adaptive drainage
- Creek ridge infiltration
- Freshmaker
- Vertical Aquifer Storage and Recovery
- Water conservation with weirs
- Water conservation by raising ditch / canal bottom

These measures were evaluated in a two-stage process: first, the measures were evaluated in consultation with local experts. Second, promising measures were evaluated using a quick-scan modelling approach to assess their effectiveness in local climatic and geographic conditions. We did not apply the FWOO suitability mapping approach, and evaluated the possible suitability from the resulting suitability maps, even though this might, at first glance, sound like a logical course of action. As further elaborated in chapter 4.2, suitability criteria are specific for the situation in the Netherlands. Criteria that are crucial for successful implementation of a measure and are always met in the Netherlands (e.g. climatic conditions), are excluded from the evaluation.

In the initial expert consultation, three possible measures were discarded by group consensus, as they were deemed not feasible due to local conditions:

- Creek ridge infiltration: this measure was discarded, as it relies on the presence of old marine creeks that serve as very local stores of infiltrated fresh rainwater in a saline groundwater environment. Both the geography and climatic conditions (annual precipitation deficit instead of surplus) do not allow for this measure.
- Freshmaker: this measure was discarded, as it was deemed too expensive for local farmers. In addition, climatic conditions (annual precipitation deficit instead of surplus) do not allow for this measure.
- Vertical Aquifer Storage and Recovery: this measure was discarded, as it was deemed too expensive for local farmers. In addition, climatic conditions (annual precipitation deficit instead of surplus) do not allow for this measure.

In a second stage, the applicability of the remaining measures was assessed using a quick scan modelling approach with the SWAP model of Alterra (Wageningen UR, The Netherlands) (Appendix B). Data on local climatic, soil, drainage, groundwater and crop conditions were provided by IVIA.

The quick scan modelling approach clearly indicated that the use of shallow groundwater as a buffer for plant growth was nearly impossible in the Vega Baja Segura conditions. Climatic conditions result in a large annual precipitation deficit. Even when including the available irrigation water, there is not enough water available to prevent drought stress in the crops. There is simply no water available to be stored in the soil. In addition, groundwater flow is generally downward, complicating any effort to retain shallow groundwater. And, finally, extreme care must be taken to prevent evaporation from the soil, as this leads to soil salinization problems already experienced in the region. The remaining measures all rely on the assumption that fresh groundwater can be stored in the shallow subsurface during periods of excess, and this water is directly available to plants during periods of scarcity. Due to the abovementioned issues, the remaining measures were deemed not feasible for the Vega Baja Segura region. We therefore continued this project with different measures that are further elaborated in chapter 5.

4.2 Evaluation of FWOO suitability mapping method

The FWOO suitability mapping method was preliminarily tested for the Vega Baja Segura region for the measure Controlled drainage. Following the suitability criteria from FWOO-NL, data was needed of: soil permeability, presence of boulder clay, presence of iron in the soil profile and/or seepage water, direction of regional groundwater flow, local drainage base. Available data was obtained from IVIA.

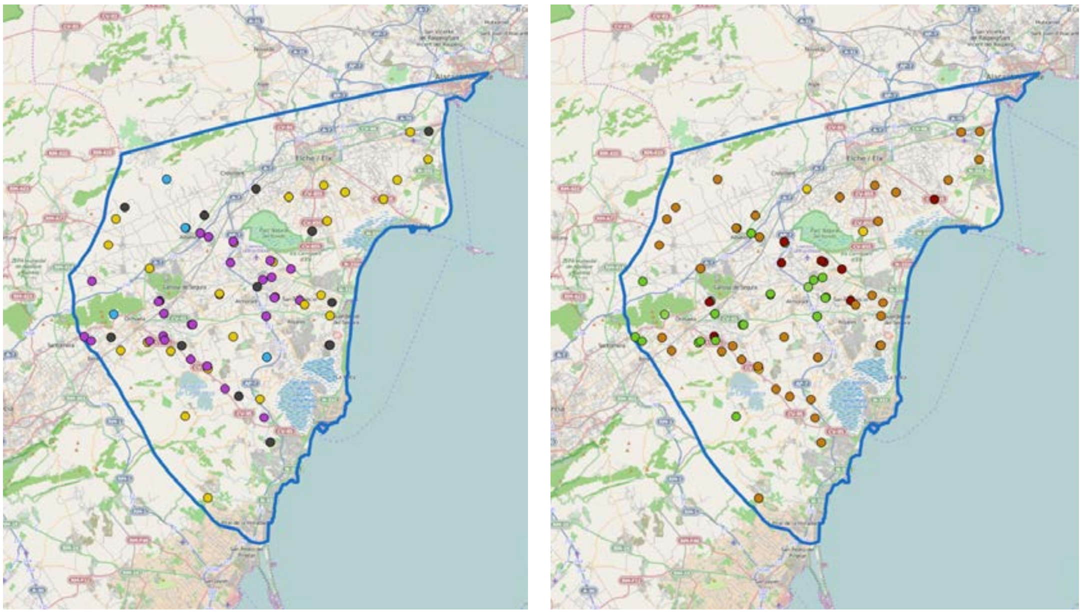

Figure 4.1 Soil permeability (left) and soil texture (right) in the Vega Baja Segura

It was not possible to do a full analysis of this measure as not all required data was available. Information was lacking on the local groundwater flow conditions, local drainage base and presence of iron in the soil profile. Furthermore, data was only available at selected points.

Even though the suitability mapping method was not tested further, it was immediately apparent that the method in its present form was lacking criteria to discriminate between ‘normal’ conditions in the Netherlands, and the situation in Vega Baja Segura, Spain. The method requires additional criteria, that should at least include some criteria on climatic conditions (e.g. precipitation excess), drainage system layout, surface water availability and crop type(s).

FWOO suitability mapping was not further investigated, as the different FWOO measures were deemed not suitable for the Vega Baja Segura region. No attempt was made to apply FWOO suitability mapping for the newly introduced measures (chapter 5). This was due to time constraints and the small size of the region we decided to focus on, the Carrizales irrigation district, a subregion of the Vega Baja Segura region. The FWOO suitability mapping approach is not applicable at this scale without the availability of data with a high spatial resolution (Hoogvliet et al., 2014). Collecting the necessary data at the required scale was impossible within the project duration.

4.3 European scale suitability mapping

Next to specific suitability mapping for the study area, work has been done on developing an FWOO mapping method for entire Europe. This work was carried out by MSc student Antoine Cardon (Université Pierre et Marie Curie, Paris) in the form of an MSc internship, part of the Climate KIC Education pillar. The internship was performed at Deltares, Utrecht, Netherlands. The internship is reported in a separate report (Cardon, 2015), a brief summary is repeated here.

The goal of the internship was to map suitability, based on physical parameters, and need, based on projected climate change effects on the water-limited crop yield, for four technologies across Europe, using a GIS application. The methodology included several steps:

- characterization of the different techniques,
- definition, acquisition and quantification of the parameters used to build the maps,
- calibration and weighting of parameters in order to combine them.

These steps were carried out based on previous assessments and new empirical work. As especially the weighting method on a European scale requires much more calibration with local data, the final results should be considered as a first step.

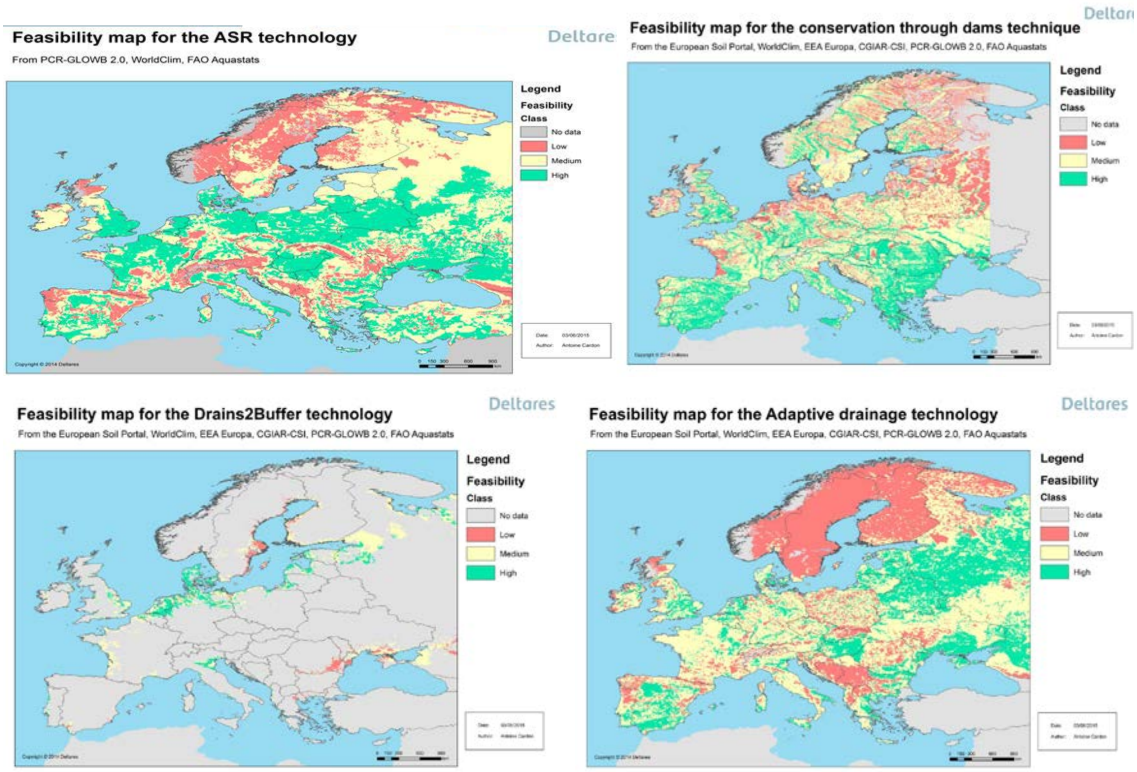

Figure 4.2 Suitability maps for techniques Aquifer Storage and Recovery, Conservation through dams, Drains2buffer and Adaptive Drainage

Four suitability maps were created for the techniques Aquifer Storage and Recovery, Conservation through dams, Drains2buffer and Adaptive Drainage, using at the maximum eleven datasets (Figure 4.2). The need map (Figure 4.3) is based on a single dataset, and used for each technique. The final suitability maps show logical and understandable results, demonstrating that the methodology is promising. The combination with the need map shows logical results as well, and gives good first indication of the potential for the four fresh water supply technologies in Europe. Some areas already experiencing well-known water problems with irrigation show good potential on the maps. Instead of combining the two kinds of maps into a third one, we preferred to interpret them alongside of each other. A combination can be made based on some of the recommendations found in Cardon (2015). The need map used here presents only climate change effects on water crop yield. Recommendations are given to use other information concerning water availability in agriculture as well as some economic parameters to improve the maps in the future.

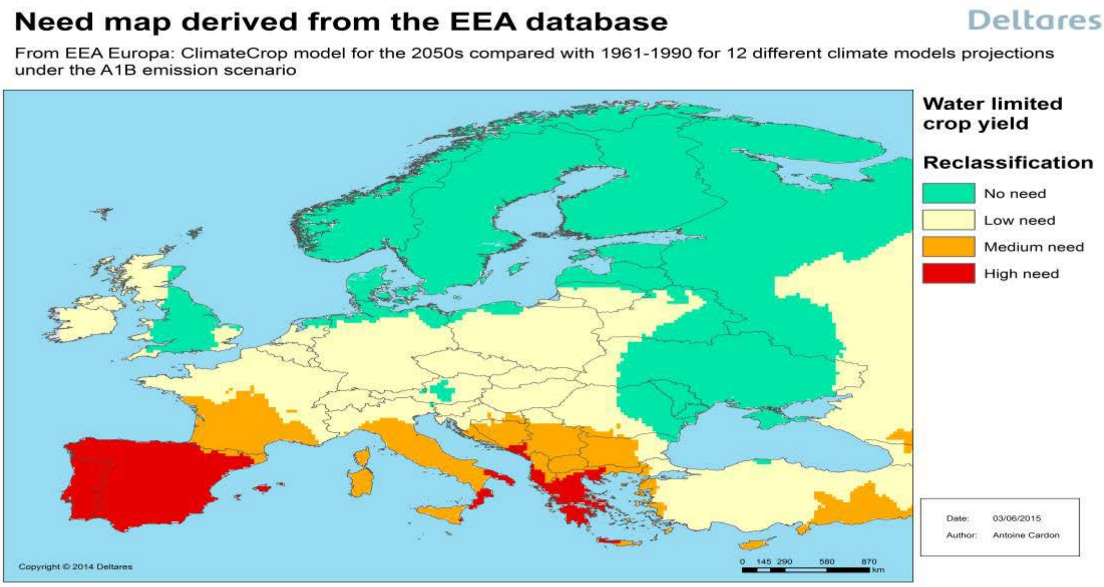

Figure 4.3 Need map (Cardon, 2015)

In conclusion, the methodology produced interesting results but needs to be improved by expert knowledge and more local data when it comes to the parameters used for the mapping. These local data and maps could be used as a verification test for potential areas indicated by our maps. Then, a general map of Europe for each technique from the FWOO could be built and used as more than an insight.

5 Alternatively selected measures

An alternative selection of three promising measures was made on the basis of expert discussions and the results of preliminary modelling using SWAP. The following measures were proposed:

- Subsurface irrigation / drip irrigation
- Local desalinisation using FOURCE
- Monitoring irrigation water salinity based on salinity measurements

5.1 Subsurface irrigation

This measure entails replacing the common practice of surface (flooding) irrigation with a system where irrigation is more or less continuous, and takes place using narrowly spaced subsurface drain pipes. Indicative SWAP calculations show a potential 15% increase in crop yield, given the same amount of irrigation water. The increase is caused by a more efficient use of irrigation water, as less water is lost to soil evaporation (60% less), or as deep percolation to the groundwater. The plant transpiration increased with 12-14%. Moreover, also due to the decrease in soil evaporation, soil salinity decreases by about 30%, compared to surface irrigation.

Figure 5.1 Installation of subsurface irrigation pipes

5.2 Drip irrigation

Although drip irrigation has found widespread use in areas prone to water scarcity, drip irrigation is only used sparingly in the Vega Baja Segura. This is mostly due to fear amongst farmers that drip irrigation will lead to an accumulation of salts in the soil. Using conventional drip irrigation, the salts present in irrigation water (2 – 4 dS/m in the region) are not flushed from the soil and tend to accumulate around the drip nozzles. High crop yield improvements are reported by local users of drip irrigation.

Figure 5.2 Drip irrigation applied in a broccoli field in Carrizales

5.3 Local desalinization (Fource)

Fource is a very interesting deal for farmers living in areas where agricultural crop yields are challenged by (rising) salinity. A user can reduce the salinity of his agricultural waters to a tolerable level for crop irrigation to the level he wants, taking into account the salt tolerances of his crops. At times of scarcity of fresh irrigation water, Fource is the farmer's affordable, flexible and durable fresh water source. It enables him to create fresh water supply safety and -independence. He optimizes his profits (i.e. crop yields), given limited water availability. Fource upgrades the available brackish irrigation water to durable resources, reducing the water footprint of crop production (70% of global water use).

Figure 5.3 Installation of Fource prototype in Zeeland, Netherlands

5.4 Monitoring irrigation water salinity

In the irrigation area of "Vega Baja del Segura y Bajo vinalopo, Alicante-Spain", the water quality and the quantity is one of the main problems in crop production. In this area, the irrigation associations are responsible of water management, and the "Confederación Hidrográfica del Segura" the public authority that provides irrigation water to the associations. A water quality monitoring irrigation system entails providing to farmers and irrigation associations with real-time information on salinity levels in irrigation water. This information could be useful for the irrigation associations to prompt the water supplier ("Confederación hidrográfica del Segura") to supply irrigation water having lower salinity. Additionally, this system gives farmers the opportunity to manage their irrigation water on the basis of salinity.

The sensors installed in the irrigation channels provide information about the electrical conductivity of irrigation water. At a first approach carried out in Carrizales during August to October 2015 period, the EC measured in the main water inlet, varied generally from 2 to 4 dS/m. Some crops irrigated in the area are tolerant to the highest salinity (artichoke, palm, alfalfa, and pomegranate) but other crops are affected by this salinity (melon, broccoli etc.), and the yield is reduced.

Figure 5.4 Monitoring irrigation water salinity system installed in Dalt channel

6 Business cases

6.1 Introduction

In this chapter, we first describe components of a successful business case, and the approach we followed to outline business cases. We then present business cases for the four measures deemed suitable for the study area: (1) drip irrigation, (2) subsurface irrigation, (3) local desalinization / Fource, (4) monitoring irrigation water quality. This chapter finally describes regional scale effects of various freshwater adaptation measures.

6.2 Components of a successful business case

Apart from a thorough costs/benefit analysis, any successful business case must include information on key resources, key partners, key activities, value propositions, industry overview, critical success factors, (in)tangible assets, scalability, sourcing, pricing, customer relationships, revenue streams, and various kinds of risks, e.g. market risk, sales volume risk and price risk, transfer pricing (if applicable) etc.

For the three innovative measures that are proposed in this project, the following topics have been subject to discussion, each of them on the basis of a few very basic questions:-

1. a product / service description,
2. the competitive environment of the product,
3. an analysis of the market, i.e. the target customers,
4. the development of a business model,
5. a description of the current, and
6. the future business position and a series of references that support the business plan (Appendix).

The discussion, leading to answering the questions was supported by a simple school of thought:

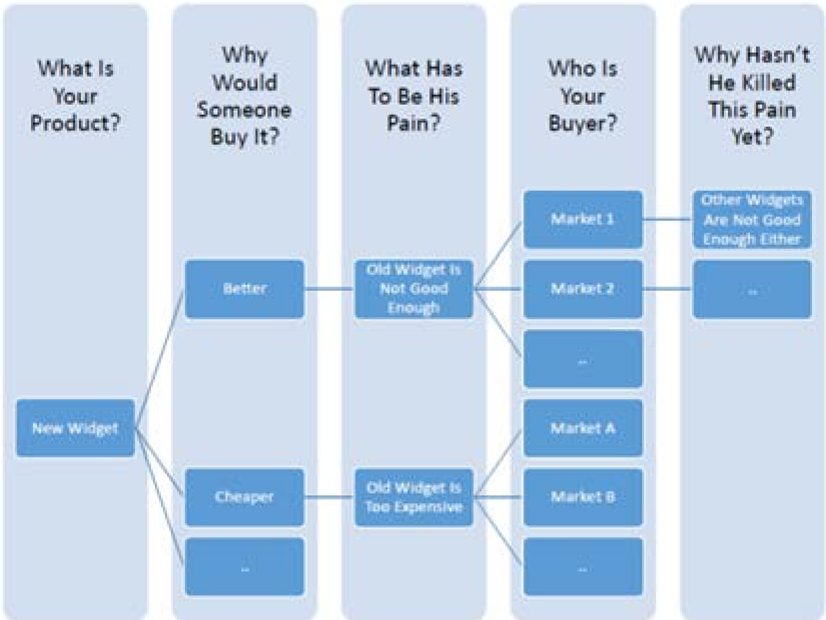

Figure 6.1 'The pain of the customer' is key

1. Product / service description
   - Describe the product / service.
   - Briefly describe the state of the art. What is novel / unique about your product / service? Are there any underlying patents / prototypes / unique facilities supporting your product / service?
   - Which opportunity / market problem is addressed with the product / service?
   - Describe how you are going to produce the product.
2. Competitive environment of the product
   - Why is your product / service better than others?
   - What is your competitive advantage and who are your competitors?
3. Market / target customers
   - Describe the market / target customers for your product / service
   - Why will these customers buy from you instead of others?
   - To how many different customers are you going to sell your product? Will they be the same customers each year (repeat customers), or will they be different customers every year?
   - How will you market your product / service?
   - When do you expect to sell your product/service for the first time?
4. Business model
   - Describe how the business will make money through a business model
   - What's the expected level of income in the next years (say till the end of 2017)?
   - How many of the products / services do you need to sell in a year to reach this level of income?
   - What's the (average) price of your product / service and how does this compare with products / services of competitors?
5. Current / future business position
   - Describe the (legal) entity offering the products / services
   - When was (will) your entity (be) established?
   - Describe the executive team
   - Who are the key persons for success?

6.3 Drip irrigation

Drip irrigation is a more efficient way of irrigation compared to the common practice of flooding irrigation. Although drip irrigation has found widespread use in areas prone to water scarcity, drip irrigation is only used sparingly in the Vega Baja Segura. This is mostly due to fear amongst farmers that drip irrigation will lead to an accumulation of salts in the soil. Using conventional drip irrigation, the salts present in irrigation water (2 – 4 dS/m in the region) are not flushed from the soil and tend to accumulate around the drip nozzles. Some melon growers in Carizales (in total 3 ha) switched in 2015 from the traditional flooding to drip irrigation. To overcome the problem of salt accumulation around the nozzles, they combine the drip irrigation with regularly flooding of the field. During the summer period, drip irrigation is applied every day for about 1-2 hour with a water flux of 8000 l/h. For the experiment, they used water directly out of the irrigation channel with no notable change in water height in the irrigation channel. However, when more farmers switch to drip irrigation a small buffer basin is needed for not disturbing the traditional flooding irrigation of other farmers.
A basin to store water for 3 days is enough which should have a storing capacity of about 48 m^3 (2 hour daily irrigation with 8000 l/h water pump).

Benefits
- Increase in crop yield

No SWAP-calculations were done for this type of irrigation. Therefore, the observed melon crop yield increases (3 ha in 2015) are used to calculate the benefits for this type of irrigation. Table 6.2 shows the increased crops yields and benefits for different crops where melon is taking representative for the other crops.

Table 6.1 Table benefits per ha (specified for Carrizales)

Crop	% area	Average price (€/kg)	Average current crop yield (t/ha)	Average increase of crop yield (t/ha)	Average benefits (€/ha)
Melon	2.3%	1	14	8.4	8400
Pomegranate	10-15%	0.64	17	10.2	6528
Artichoke	2-5%	0.7	16	9.6	6720
Broccoli	2-5%	0.45	20	12	5400
Alfalfa	20-25%	0.14	30	18	2520
cereal	20%	0.20	5	3	600

Other benefits are:
- no waterlogging risk
- possible introduction of different crop types
- higher water efficiency, more water available for other fields (water requirement for drip is 1.6 mm/d and flooding irrigation requires 4.8 mm/d).
- improvement of downstream water quality (see paragraph 6.7)

Costs
Costs for implementation of this measure (per hectare):
- Purchase and installation of drip irrigation header: €2.500
- Purchase of water pump (8 m^3/hr): €2.500
- Purchase and installation of drip irrigation tubes: €500 every 2 year.
- Construction of small storage basin (48m^3: 4x4x3m): €1.000
- Yearly costs of gasoline: €900 (1,19 € per 1 hour of irrigation)
- Total costs for period of 10 years: **€17.500**

The total costs of the installation of drip irrigation for a period of 10 years are about €17.500 per hectare**.** Drip irrigation is profitable when growing the following crops:
Melon: benefits from crop yield increase due to drip irrigation are €84.000.
Artichoke: benefits from crop yield increase due to drip irrigation are €67.000.
Pomegranate: benefits from crop yield increase due to drip irrigation are €65.000.
Broccoli: benefits from crop yield increase due to drip irrigation are €54.000.

Risks
- Increase of soil salinization; common practice to overcome this problem is to flush it regularly by flooding. By monitoring the water salinity, low salinity water can be used for drip irrigation (1-3 mS/cm) and higher salinities can be used for flushing (3-5 mS/cm).
- Drip irrigation requires a different way of operating: instead of bi-weekly, every 1 or 2 days.
- Low willingness to innovate, ‘keep things as they were’-mentality.
- Innovative farmers held back by strong agricultural lobby.

Opportunities
- Climate change: surface irrigation is not sustainable due to large water use
- Positive media exposure of irrigation authorities and innovative farmers
- Downstream benefits may convince irrigation authorities to support this innovation
- Applicable in many semi-arid regions worldwide.

Business model canvas

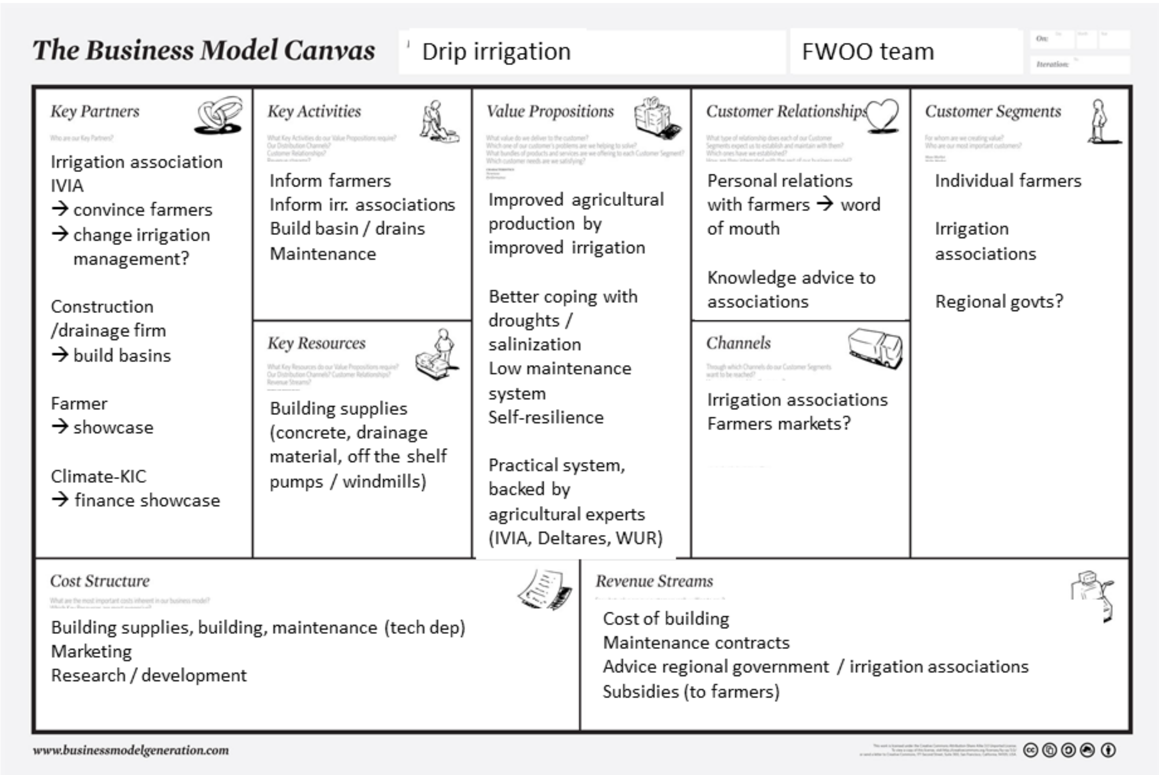

Figure 6.2 Business model canvas for Drip Irrigation.

6.4 Subsurface irrigation using pipe drains

This measure entails replacing the common practice of surface irrigation with a system where irrigation is more or less continuous, and is effectuated through narrowly spaced subsurface drains. In Dutch systems, a drain spacing of 7 m is common, with a typical drain depth of 1m below soil surface. Modelling the crop growth of mandarin with the Dutch SWAP (=Soil Water Atmosphere Plant) simulation software indicates that, using subsurface irrigation, a 12-14% increase in crop transpiration is likely compared to surface irrigation, applying the same amount of irrigation water. Crop transpiration is strongly correlated with dry matter production and – as a result – crop yield. Infiltration using subsurface drains promotes a more efficient use of irrigation water because less water is lost through soil evaporation and/or percolation to groundwater.

Benefits
- Increase in crop yield

Although SWAP calculations are done for the crop mandarin only, we use the calculated crop yield increase as representative for other crops. Table 6.2 shows the increased crops yields and benefits for different crops.

Table 6.2 Table benefits per ha (specified for Carrizales)

Crop	% area	Average price (€/kg)	Average current crop yield (t/ha)	Average increase of crop yield (t/ha)	Average benefits (€/ha)
Melon	2.3	1.00	14	2.1	2100
Pomegranate	10-15	0.64	17	2.6	1664
Artichoke	2-5	0.70	16	2.4	1680
Broccoli	2-5	0.45	20	3.0	1350
Alfalfa	20-25	0.14	30	4.5	630
cereal	20	0.20	5	0.8	160

Other benefits are:
- no waterlogging risk
- possible introduction of different crop types
- improvement of downstream water quality (see paragraph 6.7)
- lower maintenance requirement, compared to drip irrigation.

Costs
Costs for implementation of this measure differ significantly between the Netherlands and Spain.
Netherlands:
- Purchase and installation of 1500 m of wrapped ø60mm corrugated drain pipe, at €2/m = €3000
- Purchase and installation of collector drain pipe, manholes, connection to main drain channel: €5000
- Total: €8000/ha: profitable after three years (sooner in case of severe drought periods)

Spain
- Purchase 3000m ø 60mm corrugated drain pipe: €10275
- Installation of drains: €16150
- Installation 105 m collector drain: €1248
- Various parts: €265
- Pump €6611 (330m^3/hr, only 2 m^3/hr is necessary)
- Total: €35000/ ha

Having the infiltration system installed by a Spanish contractor renders this measure not profitable for any of the listed crops. In The Netherlands, installing such a system is considerably cheaper. Taking €8000 as installation costs, it would make the measure profitable within 3 years.

Risks
- subsurface irrigation requires a different way of operating: instead of bi-weekly, based on time, to continuous
- low willingness to innovate, ‘keep things as they were’-mentality
- innovative farmers held back by strong agricultural lobby

Opportunities
- Climate change: surface irrigation is not sustainable due to large water use
- Positive media exposure of irrigation authorities and innovative farmers
- Downstream benefits may convince irrigation authorities to support this innovation
- Applicable in many semi-arid regions worldwide.

Business model canvas

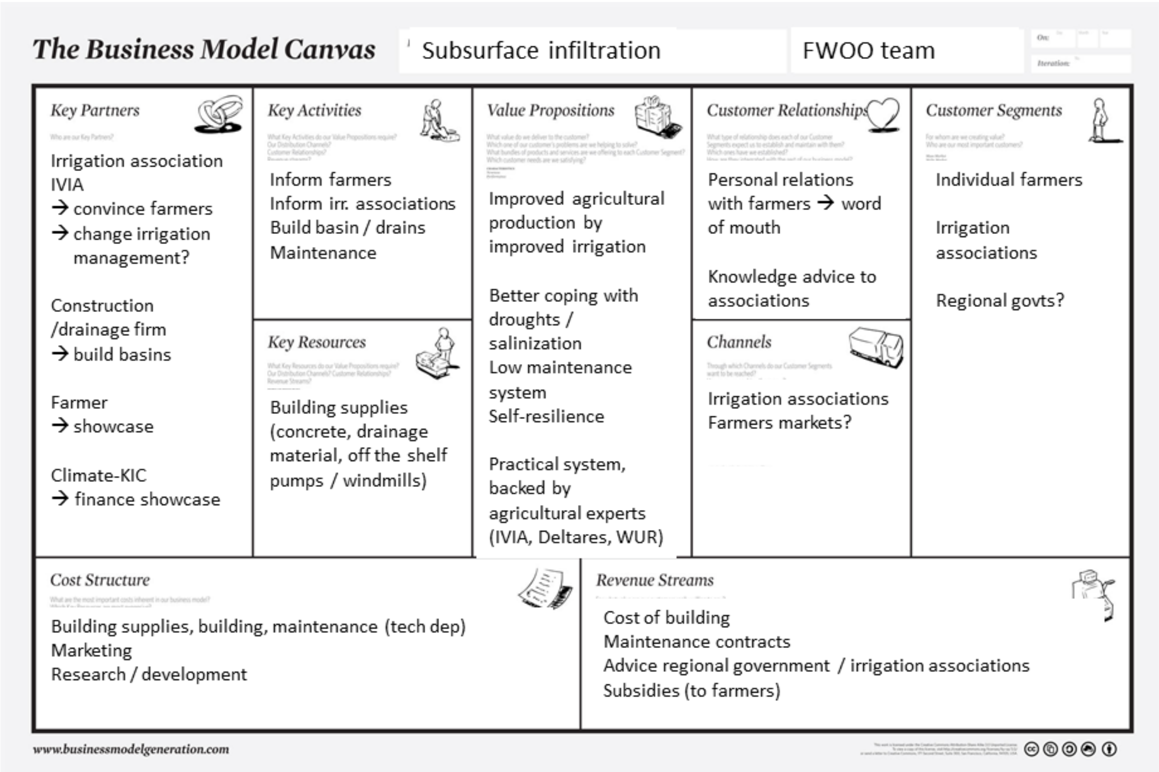

Figure 6.3 Business model canvas for Subsurface Irrigation.

6.5 Local desalinisation Fource

Operation of a standalone desalinisation plant (‘salinity trimmer’) to provide water of good quality (i.e. reduced EC) to farmers.

Costs
- Installation experimental prototype of standalone desalinisation plant; approx. €17.500
- An irrigation water demand of 6mm/day during 180 days/year equals an irrigation water demand of 10000 m^3 / ha /year. The proposed installation will desalinate 40 m^3 / day = 14 600 m^3 / year, and could serve 1,4 ha at maximum. So cost is €12500 /ha.
- The life expectancy of a desalination plant is at least 5 years, hence 1 m^3 of desalinated water costs €0,24 or less, depending on the running costs (energy) / maintenance of the desalinisation plant, and the service life of the installation.
- Water supply infrastructure (pipes, pump, power supply) from plant to irrigation canals: depending on location.

Benefits

- Increased selling price of harvested agricultural crops: assuming that the salinity trimmer will reduce the EC of the irrigation water from 4-5 dS/m to 1.5-2 dS/m, the selling price of harvested agricultural crops will be comparable to figures, proposed by business case ‘Monitoring irrigation water salinity’ (Table 6.3).
- Local desalination creates the potential perspective of the introduction of less-salt tolerant and more capital intensive crops
- Assuming a crop yield increase of €5000 /ha /year, the investment will be paid off in approximately 4 years.

Risks

- Stakeholders’ resistance to change
- Varying demand versus continuous supply
- Discharge of brine residue

Opportunities

- Financial support opportunities due to large scale application potential

Business model canvas

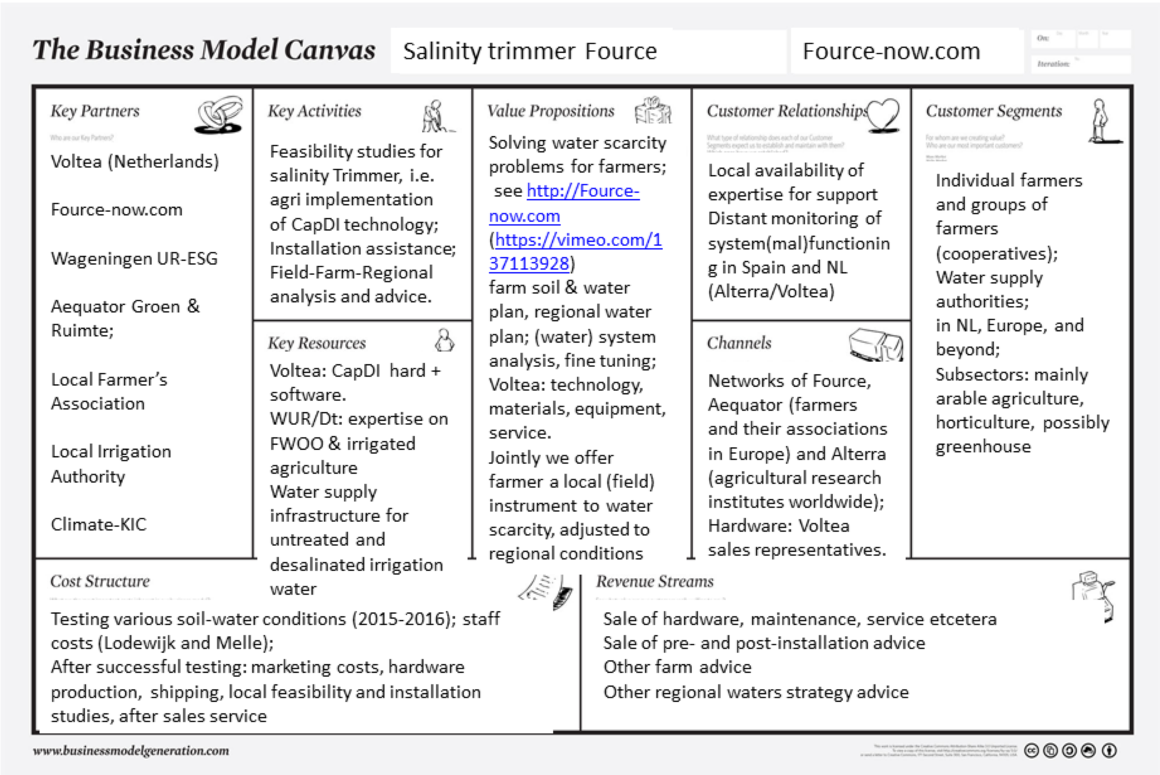

Figure 6.4 Business model canvas for Salinity trimmer Fource

6.6 Monitoring irrigation water salinity

Benefits

- In “Vega baja del Segura y bajo vinalopo” irrigation area, water salinity control is carried out manually by several irrigation associations. With this measure implemented, the monitoring can be done more efficiently with a lower cost, while the information can be provided easily to each farmer.
- Farmers with water storage facilities could use this information to manage the water depending on water quality.
- In the case of farmers of the Carrizales irrigation association, with more flexible water availability for farmers, they could manage the irrigation time depending on the water quality.
- The water dose can be adapted to the water quality and salt tolerance of the crop, leading to increased production and reduced water dose.
- It may be possible to introduce less salt tolerant yet more profitable crops.

Table 6.3 shows the simulated benefits for crops grown in Carrizales using two irrigation water salinities: 2,15 dS/m and 4,33 dS/m. The DSS-SALTIRSOIL model (www.agrosal.ivia.es) was used to perform simulations for the two scenarios considered. Salt tolerant crops like artichoke and wheat can be irrigated with higher EC’s without yield reduction, while for crops like melon and broccoli the potential yield reduction is close to 20%. In this case the benefit of good water quality is used is €2940/ha and €1710/ha respectively. Pomegrate is also a moderate tolerant crop and the yield reduction by salinity is just 6%. A moderate benefit of €653/ha for pomegranate was estimated if good water quality was used for irrigation.

Table 6.3 Benefit margins per hectare for the different crops grown in Carrizales, irrigated with two different water qualities.

Crop	Irrigation (mm)	Production at EC 2 dS/m (%)	Production at EC 4 dS/m (%)	Potential production (t/ha)	Price (€/kg)	Benefit increase (€/ha)
Artichoke	305.6	100	100	16	0,7	0
Pomegranate	337.8	100	94	17	0.64	653
Melon	309.6	85	64	14	1.0	2940
Broccoli	161.0	100	81	20	0.45	1710
Wheat	484.9	100	100	5	0.2	0

Costs

The total cost of the sensors and data logger installation per irrigation association, included the maintenance during 3 years is €2.717 as given in Table 6.4. This cost is a fair assessment for each irrigation association.

Table 6.4 Costs to install and maintain the sensors system.

Type	**Installation costs €**	**Yearly costs €**
Installation of 1 sensor to measure EC and water level.	654	
Installation of 1 logger including GSM data transmission	1214	
GSM data transmission (6 times per day) and web hosting		65
Replace sensor every 3 years		218
SUM for 3 years	**2717**	

Risks

Farmers in this area usually resist innovations and new technology. Only irrigation consultants and technical personnel of the irrigation association may convince them to change their irrigation practices. Continuous information of farmers on the beneficial effects of new technologies on their businesses is imperative to change their mind about irrigation water management.

Opportunities

- During drought periods or for climate change conditions, the information about the water quality to irrigation association is relevant since a more specific water management is required.
- In case of high water salinity, irrigation associations can demand the public authority to improve the quality of the irrigation water that they supply. Acquired monitoring data backs up such a claim.
- With a better knowledge of water quality, farmers can be stimulated to replace their conventional surface irrigation system to drip irrigation, requiring less water.
- Irrigation with a better quality water reduces salinity damage to crops and increase crop yield accordingly.
- This system could be applicable in many arid to semi-arid regions worldwide, so it is possible to export the knowledge acquired.

Business model canvas

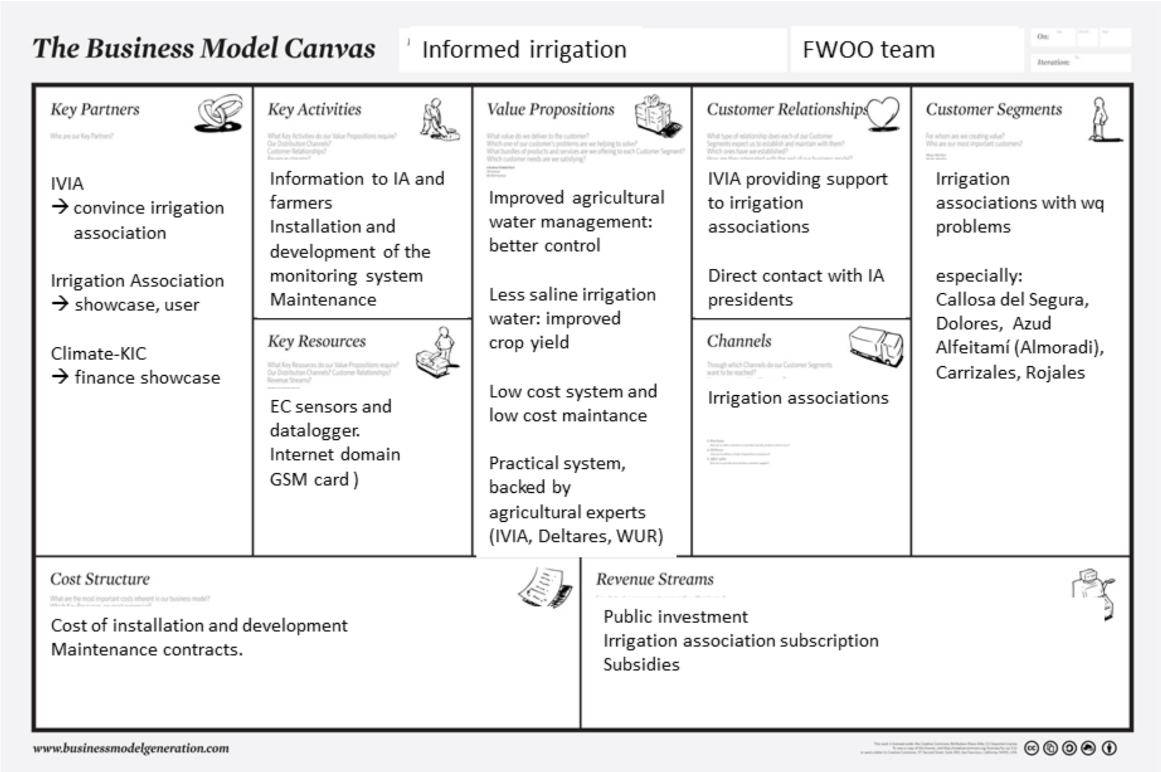

Figure 6.5 Business model canvas for Monitoring irrigation water salinity

6.7 Adaptation on a regional scale: downstream effects of measures

Local measures implemented by farmers can have regional effects. Especially in the Vega baja Segura, where irrigation water is reused multiple times. Upstream water quality improvement or degradation will have a downstream effect. Regional effects of locally implemented measures were investigated using a WEAP model of the Vega baja Segura. The model calculates effects of measures on water efficiency, salinity and crop yields in the cascade of use and reuse of irrigation water in the Vega baja Segura. The model is explained in detail in Appendix C-1.

Crop benefits

Figure 6.6 shows the difference in crop benefits per area, averaged over the past 15 years. The decrease in water quality causes crop benefits to decrease with about 10% in the downstream irrigation districts. Implementation of subsurface irrigation drains half this effect, decreasing crop benefits with about 5% downstream. When desalinated water is used (either 50% or 75% desalinated), crop benefits are equal in downstream areas compared to upstream.

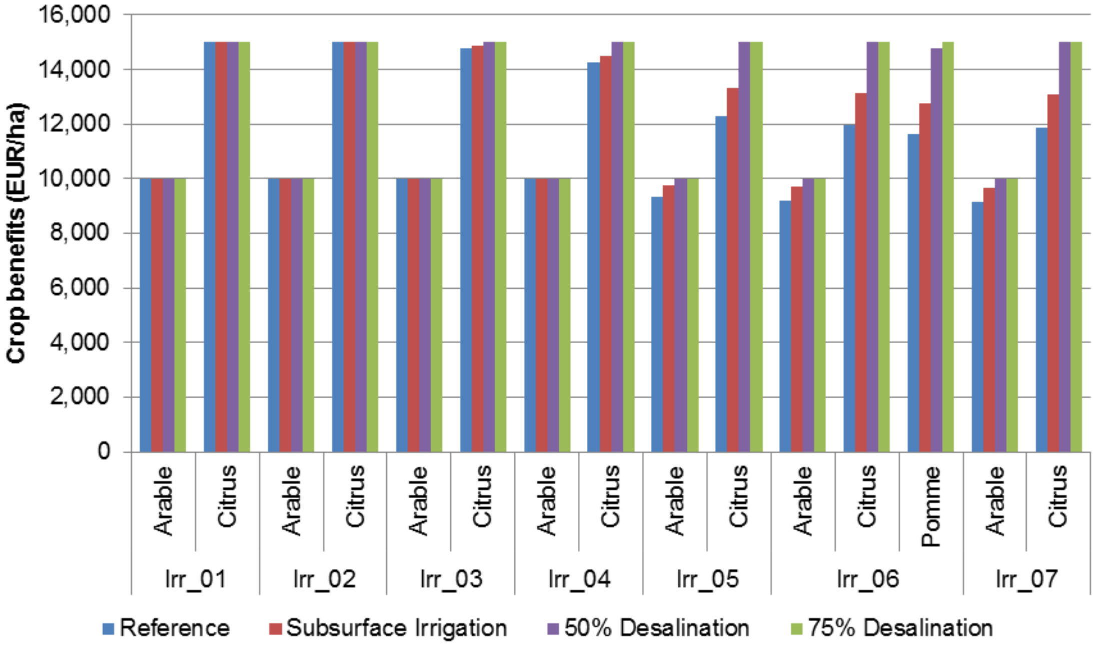

Figure 6.6. Crop benefits per area, 15-year average.

In the whole pilot area crop benefits for the subsurface irrigation and desalination scenarios increase with about 1,3% and 3%, respectively (Figure 6.7).

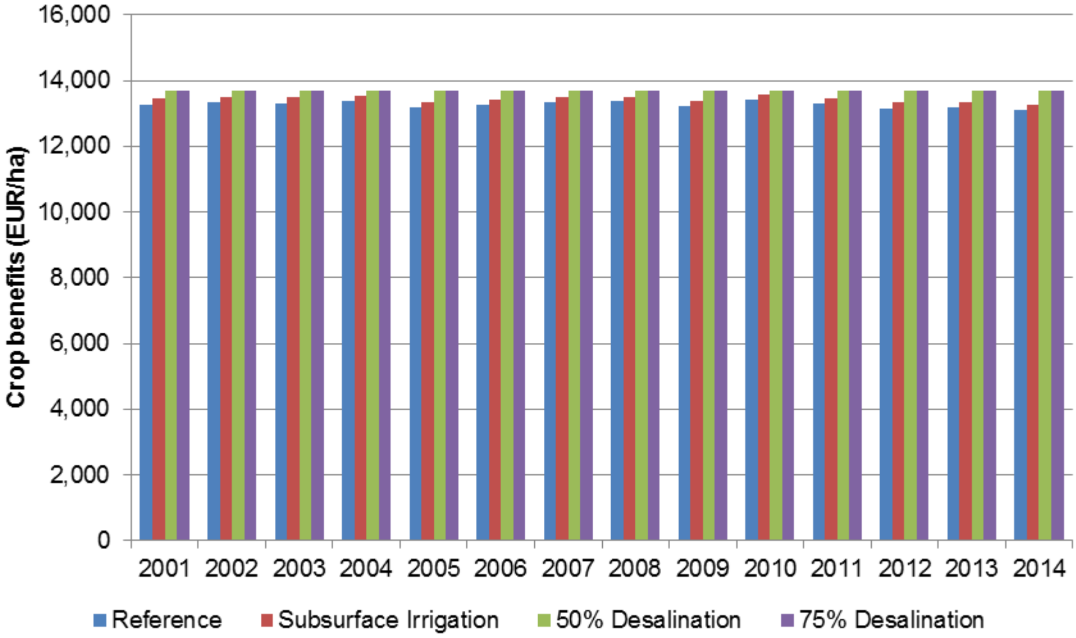

Figure 6.7. Average pilot area crop benefits per year.

Profit
Due to the increase in crop benefits, without an increase in variable costs, the net profit increases. When the subsurface irrigation measure is implemented, less irrigation water is required. The overall result per hectare is shown in Figure 6.8.

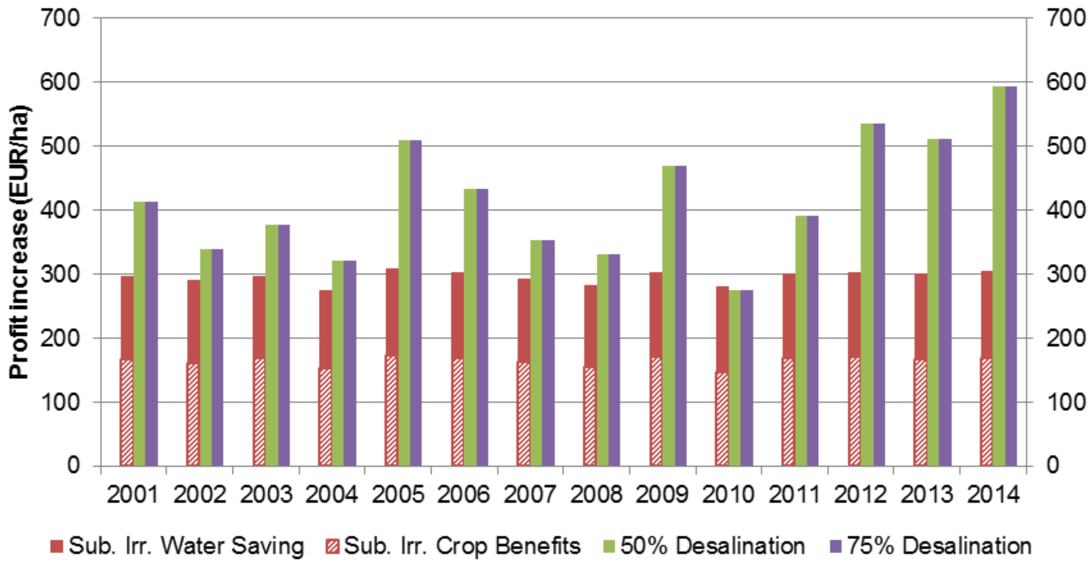

Figure 6.8. Profit increase due to increase in crop benefits and water savings.

The average size of a farm in the area is 7,5 ha. This means that the profit per farmer can yearly increase with € 2.214 (+/- 152), € 3.138 (+/- 1.315) or € 3.138 (+/- 1.317) when subsurface irrigation, 50% desalination or 75% desalination is implemented, respectively. For the whole area this yearly profit increase comes down to € 966.481 (+/- 66.527), € 1.369.968 (+/- 574.120) or € 1.370.077 (+/- 574.982) (Table 3).

Table 6.5. Average yearly profit increase in pilot area.

Measure	**Subsurface Irr. (€)**	**50% Desalination (€)**	**75% Desalination (€)**
Yearly profit per hectare	295	418	418
Yearly profit per farmer	2.214	3.138	3.138
Yearly total profit	966.481	1.369.968	1.370.077

7 A way forward for the Carrizales irrigation district

Each of the four investigated measures increases climate resilience of agriculture in the Vega baja Segura region. Measures were investigated separately based on the premise that it is easier for farmers to implement measures individually, without having to seek consensus with all farmers in a given region. More progressive farmers will then not be held back by more conservative colleagues. During stakeholder discussions it became quickly apparent, however, that the efficiency of the investigated measures would increase when they are jointly implemented. A coherent vision for a 2050, climate resilient, Carrizales region was therefore developed.

The dominant threat in the Carrizales region is the lack of freshwater. The region is ‘the end of the pipe’, receiving irrigation water already used and reused several times in upstream irrigation districts. Irrigation water is therefore brackish, and limits crop yields in the Carrizales. In addition, groundwater in the region is saline and therefore currently remains unused. The majority of farmers operate small-scale farms, and grow salt-tolerant but low- to medium yielding crops such as alfalfa, cereal and pomegranate. These crops are almost exclusively irrigated by surface irrigation.

Some farmers have, however, tried to create an advantage from this disadvantage. They have started to grow limited amounts of melons (Piel de Sapo variety), and irrigate them with brackish to saline water. The melons yield less tonnage, but the sugar content and hence the quality of the melons is superior to those irrigated with freshwater. Farmers have started to brand these melons ‘Carrizales melon’ and sell them locally, mostly to quality restaurants, for higher prices. In addition, new drip-irrigation approaches have increased melon yields considerably.

This bottom-up development is, in our view, crucial to a sustainable, climate resilient, agriculture in the Carrizales and bordering irrigation associations. All over Europe, a clear transition is apparent that moves away from mass-produced products and food items, and back to locally produced products with a clear connection between the consumer and manufacturer. People are increasingly willing to pay more for quality products, produced with care for people and planet. The quality brand of the Carrizales melon, ecologically produced with respect for the surrounding nature areas, fits in perfectly with this on-going transition.

Carrizales melons are currently only sold locally. A clear potential therefore exists to market these melons across Spain and even Europe. In the Carrizales, only about 2-3% of the area is now in use to grow melons. Due to crop rotation requirements (melon is grown in a two- to four-year crop rotation), the potential area for growing melons is limited to about 30%. A tenfold increase of current production is therefore possible in the Carrizales region alone, amounting to a potential annual sales increase of about 3 M€.

Water management should accommodate this change in crop types, enabling a more continuous drip irrigation of melons. As the melons are not just tolerant to, but in fact require higher salinity levels, more water can be used for irrigation than in the current situation. Groundwater is a potential source of irrigation water. This is a sustainable water source, as the area experiences upwards groundwater flow. Moreover, drainage water from Carrizales parcels (growing alfalfa or wheat in crop rotation with melon) can be reused to irrigate melons. The ‘monitoring irrigation water salinity’ plays a vital part, as continuous salinity measurements will enable farmers to make flexible use of the different available water types, dependent on salinity conditions of irrigation water.

With this described change in agricultural practice, a better financial position enables farmers to invest in measures to further improve water efficiency on their lands. The FOURCE technology enables farmers to be less dependent on upstream irrigation water, by trimming the salinity of groundwater or local drainage water to acceptable (hence quite high) levels for the melons. The implementation of subsurface irrigation may provide a viable alternative to maintenance-intensive drip irrigation.

Such a described transition must, for it to be a success, be supported by:
1. local stakeholders (who have already started this transition),
2. market research on the potential market for the Carrizales melon, providing an improved cost-benefit analysis on such a transition,
3. knowledge institutes with a strong link to local agriculture, providing knowledge on: (1) the optimal salinity levels for melons, thereby balancing quality and yield, (2) agrohydrology, optimizing irrigation practices, (3) water management

8 Knowledge exchange

An integral part of this FWOO project was to exchange knowledge on agricultural climate change adaptation between the different participating regions (Netherlands; Valencia, Spain; Emilia-Romagna, Italy). Knowledge exchange was primarily facilitated by three consortium-wide meetings. The first meeting, in Renesse, Netherlands, was attended by all consortium members, as was the third meeting in Elche, Spain. The second meeting was not attended by ARPA-ER, as this meeting was not in the original proposal for WP 5 (Knowledge Exchange).

Reports of the different field visits and stakeholder meetings are in Appendix A. During the first meeting, in Renesse, Netherlands, all regions presented their regions and their specific challenges. For the Zeeland region in the Netherlands, salinization is caused by upward flow of saline groundwater, reaching upward to within 2m from the surface. Thin rainwater lenses exist above the saline groundwater, providing crops with fresh water, but these are vulnerable to climate change. Different measures are proposed and tested to increase the availability and hence the resilience of agriculture in the area. We visited two of these measures: creek ridge infiltration and the freshmaker. Both aim to store freshwater surpluses in the soil, for later use during dry periods. Participating farmers are enthusiastic about these measures.

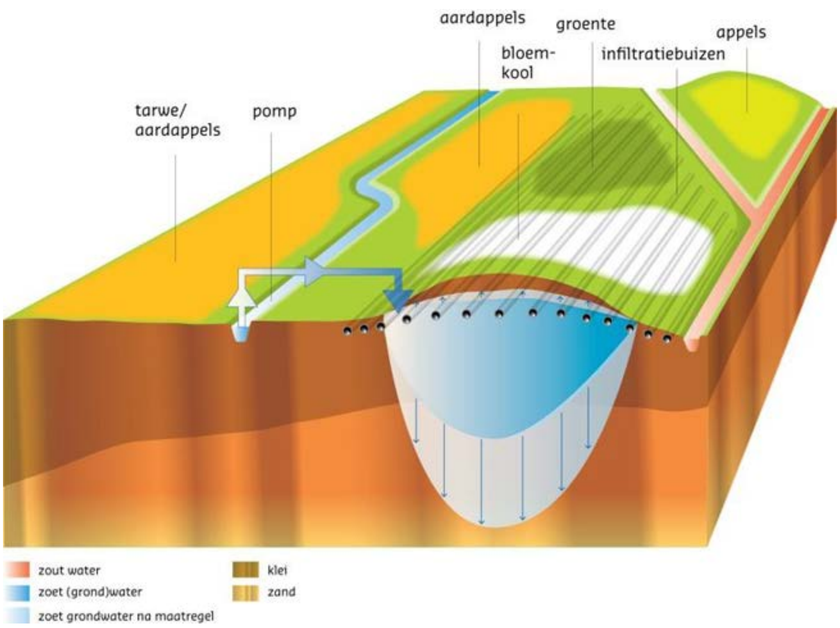

Figure 8.1 Creek ridge infiltration

The Vega baja Segura region, in the south of the Valencia province, experiences an arid to semi-arid climate. Agriculture is completely reliant on irrigation water, diverted from the river and stored in large dams. This irrigation water is used and reused several times by different irrigation associations. Surface irrigation is the most common (Figure 8.2). The layout of this system dates back several centuries. Salinity is a big problem, caused by evaporation of irrigation water. Also the availability of water is a problem, in dry years the dams run dry and there is not enough water for irrigation.

Figure 8.2 Surface irrigation in Vega baja Segura

The Po delta in the Emilia-Romagna region is a low-lying area, that experiences salinization from seawater intrusion in the Po river (Figure 8.3). Climate change is affecting the region, both in droughts (climate projections show a significant increase in the number of dry days (Figure 8.4)), as in floods.

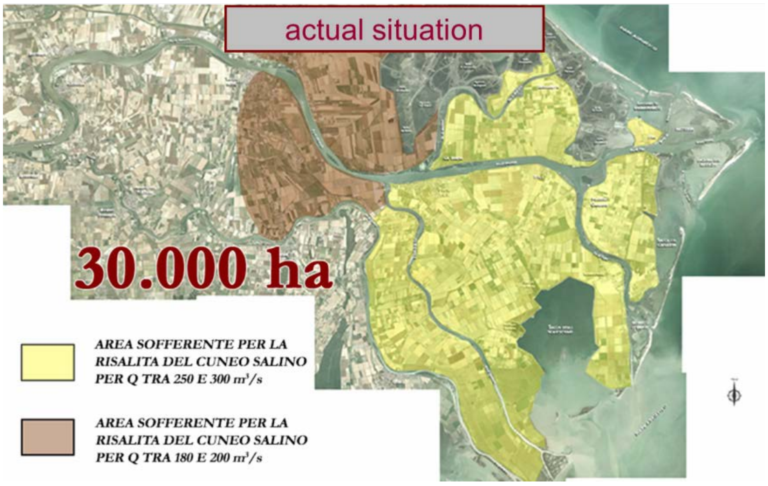

Figure 8.3 Salinization in the Po delta

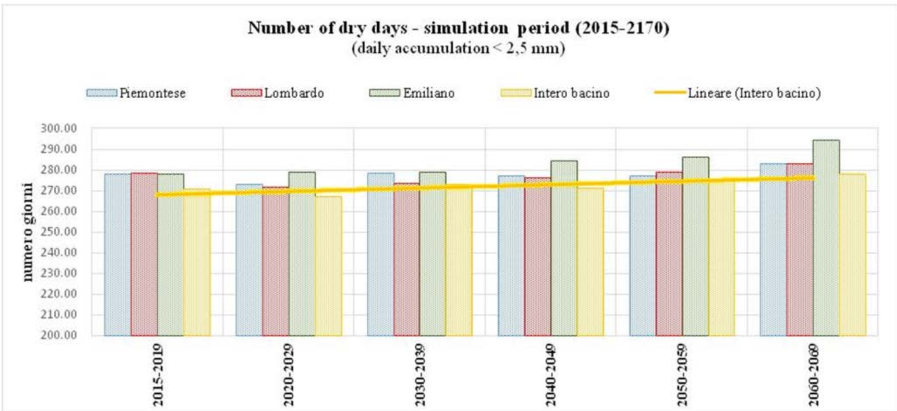

Figure 8.4 Projection of number of dry days in the Po basin

9 Conclusions and outlook

9.1 Application FWOO Netherlands to Spain

We tested the applicability of both the methodology and the measures of FWOO-NL in the study area of Vega baja Segura, Spain. It was concluded that:

- FWOO-NL measures were as yet deemed unfit for Vega baja Segura. This is caused by the lack of a water surplus during some part of the year, climatic conditions preventing the use of shallow groundwater as a freshwater buffer, the threat of soil salinization by evaporation, a rigid biweekly irrigation cycle that necessitate large storage basins and therefore high costs.
- Different measures were therefore selected for further investigation: Subsurface irrigation, Drip irrigation, Local desalinisation (Fource), Monitoring irrigation water salinity.
- The FWOO-NL suitability mapping methodology could not be performed due to a lack of data.
- The FWOO methodology lacks criteria that discriminate between the Netherlands and Spain; it only includes criteria that differ within the Netherlands. Due to the absence of e.g. climatic factors in the methodology, measures that are unfit for the Spanish situation were not considered unfit by FWOO.

9.2 European-wide application of the FWOO methodology

From the presented case study we conclude that European-wide application of the FWOO methodology requires:

- Inclusion of more freshwater measures than the seven currently included, from a wider variety of geographies,
- Definition of all factors that determine the suitability of measures, including those that are always met in the original area of implementation of a measure. Such additional criteria should at least include some criteria on climatic conditions (e.g. precipitation excess), drainage system layout, surface water availability and crop type(s),
- Definition of factors for ‘new’ measures
- Assessment of suitability of measures using data that is more commonly available (e.g. European-wide datasets), or can be entered by a particular user for local evaluation
- Ease-of-use can be enhanced by making such an expanded FWOO methodology available via the internet or through a smartphone app
- Necessary first steps were taken in a MSc internship (Cardon, 2015). Results show that the methodology produced interesting results, but needs to be improved by expert knowledge and more local data when it comes to the parameters used for the mapping.

9.3 Business cases of climate adaptation measures

Business cases were composed for measures Subsurface irrigation, Drip irrigation, Local desalinisation (Fource) and Monitoring irrigation water salinity. It was concluded that:

- Subsurface irrigation was not feasible with local, Spanish, installation costs. Contractors in the Netherlands, however, can install such systems for considerably lower costs. Adoption of technology used in the Netherlands could provide a clear business opportunity for Spanish contractors. With lower costs, subsurface irrigation can be profitable within 5 years for high-yielding crops.

- Drip irrigation is feasible for the high productive crops like melon, pomegranate, broccoli and artichoke. However, drip irrigation should always be accompanied with regularly flooding (2-4 times / year) of the fields to flush the accumulated salts.
- Local desalinisation (Fource) is still in a development stage, and costs will likely decrease in coming years. Fource can be profitable in four years for high-yielding crops.
- Monitoring irrigation water salinity is a very low-cost option. Benefits are difficult to monetarise, but, through improved water management, are expected to outweigh costs.
- Although more difficult, as this requires farmers to reach a common strategy, a common strategy, with water management geared to a more innovative irrigation practice, would improve the effectiveness of separate local measures.
- Such a common strategy was developed for the Carrizales area, centred around marketing the Carrizales melon as a quality product, allowing for higher salinities in irrigation water, and increased investment opportunities for climate adaptation measures.
- Marketing a salt-resistant melon as a quality, niche product has already started as a bottom-up development in the area. This development is, in our view, crucial to a sustainable, climate resilient, agriculture in the Carrizales and bordering irrigation associations

9.4 Outlook

From the current project, two important trajectories can be distinguished:

FWOO Europe app

While this project concluded that the FWOO-NL methodology was as yet unable to designate appropriate and feasible measures for farmers in the Veg baja Segura region, a need for farmer access to information on innovative measures still clearly exists. A farmer or other local stakeholder requires information on what measures are feasible given his local conditions, and what benefits do these measures entail against what costs? This information is now buried in technical reports, spread across different European knowledge institutes and climate start-ups. Utilising European-wide data could give an easy-to-use first impression of possible measures, but this must be accompanied by the possibility to include local, better, information. In the Climate KIC portfolio, an overall project to easily disseminate climate innovations to end-users appears to be currently lacking. A FWOO Europe app project, creating a common platform for easy end-user communication could fill this gap.

The Carrizales melon as a driver for climate resilience in the Vega baja Segura

For the study area, a common vision has been outlined for the Carrizales region within the Vega baja Segura. This vision encompasses a clearly positive business case for the region, that includes an annual income increase of 3 M€, while at the same time decreasing the region’s dependence on freshwater. The latter clearly increases the climate resilience of the area, as freshwater scarcity is the main threat to sustainable agriculture in the area. The vision is centred around increasing the production and marketing of the *Carrizales melon*, a melon that acquired better taste through irrigation with high-salinity water. For this vision to become reality, local stakeholders must come together with knowledge institutes, improving the water management and irrigation practices in the area and making sure climate resilience is indeed achieved, and marketing specialists, to aid the market development of the Carrizales melon.

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A Field visit reports

A.1 Visit Renesse, Netherlands, 16 – 17 April 2015

During the field trip, we first visited an agricultural parcel that was illustrative for the very heterogeneous distribution of saline groundwater. Measurements with the Deltares TEC-probe showed that the depth of saline groundwater varied significantly (from 1 -> 20m) as a result of slight elevation differences. Salinity in surface water reflects this heterogeneity in groundwater salinity. After lunch, we visited several ‘FWOO-measures’. We talked to a farmer in the ‘WaterFarm’, a cooperation of farmers to more effectively use freshwater. He used very simple end-pipes to store more water in his drainage system. We then visited the controlled artificial recharge and drainage system ‘Creek ridge infiltration’, where the farmer explained that this system provided him with more freshwater, enabling the growth of higher yielding-crops. We finally visited the ‘Freshmaker’, where horizontally drilled saltwater drainage- and freshwater infiltration tubes enabled the storage of more freshwater.

Figure A.1 Impression of field visit Renesse, Netherlands

A.2 Field visit Elche, 18 – 19 May 2015

The meeting was attended by Joost Delsman (Deltares), Perry de Louw (Deltares), Lodewijk Stuyt (Wageningen-Alterra), Martijn de Klerk (Future Water), José Miguel de Paz (IVIA), and Fernando Visconti (IVIA). During the first day we visited a pilot zone in the area, which as a whole, represents the irrigation and drainage management in the entire traditional irrigation area of the “Vega Baja del Segura” River. Specifically we visited the Almoradí, Dolores, and Carrizales irrigation areas in this order. These three areas are featured by the scarcity of irrigation water and existence of salinity problems due to the poor quality of the irrigation water and the high water table.

The visit to the Alfeitamí irrigation area was guided by Daniel, who is the water manager of this area. He showed us where the water is taken from the Segura River, i.e. at the Alfeitamí diversion dam. A water electrical conductivity (EC_{25}) measurement taken there showed a value of 2.0 dS/m. Then we move to a point where a farmer was irrigating a lemon orchard by surface. At this point, the organization of the drainage system was explained. In this point the salinity of irrigation water was that of the Segura River at the Alfeitamí diversion dam, i.e. 2.0 dS/m of EC_{25}, and for the drainage from the plot was 4.9 dS/m. As a consequence of the mixing of the irrigation surpluses with the drainage from the plots, in the Mayayo drainage ditch the water EC_{25} presented an intermediate value between 2.0 and 4.9, which was 3.7 dS/m.

Following the Mayayo drainage ditch we entered the next irrigation area, and started our second visit of the day. This visit was to the area of Dolores, where we were guided by the secretary of the Dolores irrigators association, and also by its irrigation manager. Specifically, we visited the final part of the Dolores system of drainage ditches. In the Dolores area irrigators use the drainage waters from the previous irrigation areas to irrigate in turn. The drainage waters reach their area through the Mayayo and also through the Abanilla drainage ditches. The Dolores irrigators association discharges its own drainage waters to various ditches in which the EC_{25} ranged between 3 and 4 dS/m. Part of this water is discharged to the sea and another part is brought to the next irrigation area, i.e. the Carrizales irrigation area. In the same place we also visited a pumping station where the water from the mouth of the Segura River is pumped into the “Hondo de Elche” reservoirs where it is stored until use in the “Campo de Elche”. We were informed about the spacing between drain pipes, which was 20 to 30 m. A spontaneous discussion arises at that point amongst us about the likely measures to enhance the draining of the fields.

During the afternoon the Carrizales irrigation area was visited. In this area farmers use the drainage waters coming from the Dolores area to irrigate in turn. In this area therefore the water originally diverted from the Alfeitamí diversion dam is used for the third time. This fact makes the area to be the most affected by water scarcity and salinization. Various different plots in the area were visited. Huge differences in soil salinity were observed in short distances. The factor which can explain these differences is the drainage management. In plots where the farmer has achieved control over the water table, crops such as pomegranates and sweet melons are grown. In plots where the farmer has not been able to keep the water table away enough from the soil surface, soil is heavily salinized, and even almost permanently waterlogged as we could appreciate in the “Charca” plot. The EC_{25} of the irrigation water ranged between 4 and 5 dS/m, while the drainage water taken directly from the plots ranged between 13 and 14 dS/m. The water in the drainage ditches ranged again between the previous values, i.e. between 6 and 7 dS/m due to mixing between both.

Finally we visited the Santa Pola Natural Park, where the drainage water from the Carrizales irrigation area is used again and for the last time. There the water is used to fill the wetland lagoons where some bird, fish and plant species keen on brackish waters find at their best. Further away the drainage ditches reach the sea where the drainage effluents are finally disposed. They have a system of gates in the drainage ditches which they close or open depending on the water flow direction. This is to avoid the sea water from flowing landwards. It is an important control measurement since in drought times farmers are sometimes forced to use the water from the drainage ditches to irrigate again their fields in the Carrizales area. This action constitutes a fourth use of the same water for irrigation.

Figure A.2 Impression of field visit Elche, Spain, May 2015

A.3 Field visit Elche, 26 - 27 November 2015

The concluding Climate KIC FWOO meeting again took place in Elche, Spain, 26 – 27 November 2015. Participants were José Miguel de Paz (IVIA), Fernando Visconti (IVIA), Joost Delsman (Deltares), Perry de Louw (Deltares), Lodewijk Stuyt (WUR Alterra), Marijn de Klerk (FutureWater), Silvano Pecora (ARPA-ER), Mauro del Longo (ARPA-ER). The first day of the meeting we were joined by Fernando Antón, president of the Irrigation Association of Carrizales.

During the first morning session, business cases for the different local measures were discussed together with Sr Antón, who provided valuable extra feedback on the measures and knowledge about the water system and agricultural practices in Carrizales. During the afternoon session, we visited the Carrizales irrigation district, and met with a local farmer. This farmer was one of the larger farmers in the region, and he was experimenting with using drip irrigation to grow melon and broccoli. The melons are of some local fame, and are branded as 'Carrizales melon'. Due to the brackish irrigation water used for crop irrigation, melon yields are lower, but the melons have an increased sugar content. They are therefore highly appreciated. Drip irrigation boosted melon yields by >200%!

Figure A.3 Impression of field visit Elche, Spain, November 2015

The second morning session was spent re-evaluating the business cases given the information provided on the first day. The business cases were incorporated into a vision for the Carrizales area, to make agriculture in the region more sustainable, climate-robust, and less reliant on freshwater. This vision is summarized in Figure A.4. In the evening of the second day, a meeting was organized for local farmers and irrigation associations. In the meeting the measures were explained to and discussed with the local farmers. A report is included as Appendix A.4.

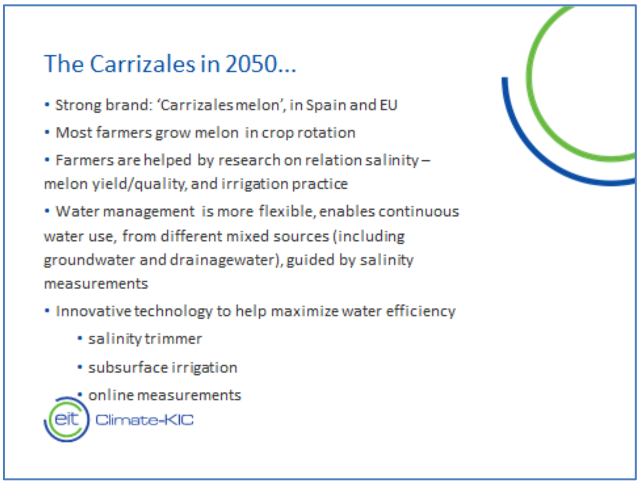


Figure A.4 Vision for the Carrizales region, a climate-robust, profitable future

A.4 Report of meeting with farmers, Elche agricultural experimental facility, November 27, 2015

José Miguel de Paz presented to the farmers the fresh water optimization measures discussed by the team of researchers. He did so within a speech entitled Opciones para la optimización del manejo del agua de riego en la Vega Baja del Segura y Bajo Vinalopó, i.e. Options to optimize the irrigation water management in Vega Baja del Segura and Bajo Vinalopó. Pepe talked for about 20 minutes. Once the speech was finished, he opened the floor for discussion of each option in order: i) combined drip and surface irrigation, ii) the subsurface irrigation, iii) the monitoring system for water flow and salinity, and iv) the use of the Fource's Salinity Trimmer. The discussion lasted about 40 minutes, and here is an extract of the most important issues raised.

1. Combined drip and surface irrigation and subsurface irrigation
One farmer (Manuel) spoke first, he strongly advocated for the use of surface irrigation in the area. He explained that flooding allows farmers to keep soil salinity under control, and that he was afraid of the consequences of not flooding. He added that the consequences of no flooding had to be investigated before any change could be done because of the high hazards involved. He indicated that recently the valley authority had made a meeting with the farmers about the change from flood to drip irrigation. He added that he irrigates once a month and even once in three months sometimes. Another farmer prompted another problem to change from flood to drip irrigation, this is that drip irrigation demands the availability of water storing facilities, something rare in the Vega Baja del Segura. Another man (Aitor) spoke next. He indicated that drip irrigation saves 30% of water regarding flooding. He further said that the burial of the irrigation line saves an additional 20% of water because of low evaporation. A controversy arose at this point between both farmers. The farmer that spoke first (Manuel) eventually indicated that Aitor was from another different area where drip irrigation is more likely to work. This is true, Manuel owns fields in the middle of the Vega Baja where the water table is within 1 m of the soil surface, while Aitor works in the Campo de Elche where he besides owns a company for the installation of irrigation systems, and where the water table is deeper. Another man intervened, he prompted that the globe artichoke cultivated under surface irrigation has better taste, and as a consequence it is worth 0.40 € more per kilogram, therefore 50% more revenues. Another farmer from the Vega Baja del

Segura (Joaquín) indicated that drip could be used in alternative fashion with flood, that this is not much trouble, and moreover that this would save 20% water. Another farmer (Jose Manuel) asked Aitor how he can manage buried drip irrigation with horticultural crops. He responded that there are short cycle hoses and long cycle hoses, and that the former is recommended for horticultural crops, and the latter for tree crops. The long cycle hoses can last several years he indicated. Inquired by Pepe, Aitor added that the drip irrigation line can be buried just to 10 cm depth with the use of a machine. Another farmer says that the use of drip irrigation for high added value crops in rotation with surface irrigation for low value crops is a feasible option. Daniel said that there is an increasing number or farmers in the area that feel drip irrigation as an adequate alternative to flooding.

Figure A.5 José Miguel de Paz (IVIA) presents the project to local farmers and other stakeholders – 27 November 2015

2. Monitoring system for water flow and salinity
The man from San Felipe Neri was the one for whom the system for monitoring was more interesting. This was because in San Felipe Neri the farmers have more flexibility for water use. The man from Dolores (Joaquin) indicated that the system could have utility for them too. To have information on flows and salinity seems to have utility for other farmers too. However, Daniel from the Azud de Alfeitamí pointed out that although the system is useful to be aware, to furthermore be of use to complain about water quantities delivered by the valley authority, the system must be standardized. Another farmer besides indicated that this system could be useful for irrigators associations with few water inlets and outlets, but of no use otherwise.

3. Salinity Trimmer
The man from San Felipe Neri indicated that now in the Vega Baja there are scarce problems of water availability, but that if this discussion took place in another time, like the 90s and early 00s he remembered, the outcome would be different. He indicated that there are some few springs in the area giving water with EC between 6-7 dS/m, and asked why these had not been exploited for water production with the use of desalination plants. He found interesting the salinity trimmer in these cases, and also in other instances, for example, with crops of high value. He indicated that the water from the Tajo transfer is worth more of less the same money, i.e. 0.26 €/m3. Aitor asked how the machine works. We tried to explain the functioning, and indicated him that it was not based on a membrane technology. Aitor asked if

users have the ability to tune the salinity of the water produced by the trimmer. We answered yes. Aitor asked how much was the fraction of water produced regarding the water fed to the machine. We answered that 85%, plus 15% of brine. Aitor asked how these quantities would change if the user wanted to trim the salinity by more than a half, e.g. to one sixth. We translated the question to Lodewijk. Lodewijk answered that the percentages would keep the same, but that the machine would work more slowly, i.e. it would not produce 48 m3/day but less. Aitor asked how much the machine costed. We answered that it was worth 17500 €. Lodewijk later added that the machine is a prototype and its price is expected to decrease with the onset of sales. Aitor asked why it had just 5 years of life. We translated this question to Lodewijk again. Lodewijk answered that after five years more or less the user must replace the desalination units which are worth 1000 € more or less. Some other farmers intervened asking about the brine disposal. They saw this as a problem because of strict legal constraints for polluted water disposal in the area. This last point was stressed by Daniel. Lodewijk prompted that brine disposal is a problem everywhere, but this did not seem to convince them. Manuel asked if the salinity trimmer acts also on the nitrate in addition to sodium and chloride. We answered yes. He saw this as a problem because in order to schedule the fertilization of his fields, he subtracts the irrigation water nitrate contents from his crops nitrogen requirements. Farmers were in general willing to collaborate.

With these last issues the meeting was finished. Informal conversations unfolded having a snack.

B SWAP modelling

B.1 Introduction

SWAP calculations for Fresh Water Optimizer Options (FWOO)
Calculation period: 01-0-2011–31-12-2012.

Evaluated scenarios:
Situation 1: overland flow irrigation
Situation 2: irrigation through subsurface pipe drains ('subsurface irrigation')

B.2 Observed data

Meteorology

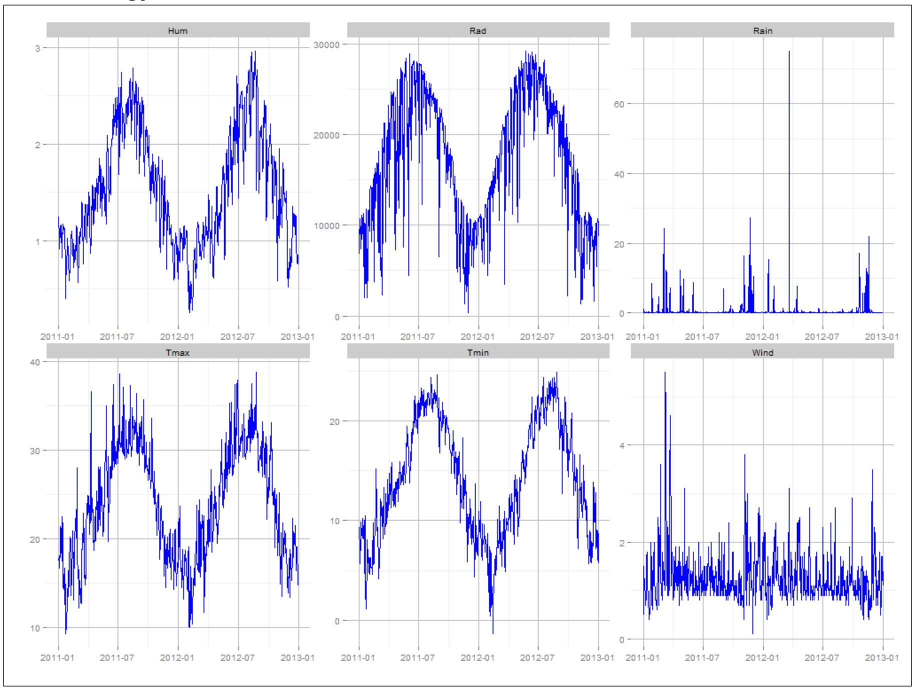


Figure B.1 Meteo input of station number 10.

Precipitation in 2011 and 2012 was 283 mm and 227mm, respectively.

Soil

Table B.1 shows the soil characteristics, from the surface to 120cm depth.

Table B.1 Soil characteristics, measured from the surface to 120cm depth

Top (cm)	**Bottom (cm)**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**W_{sat} (g g-1)**	**θ_{fc} (-)**	**θ_{wp} (-)**	**BD (g cm^{-3})**
0	10	21.01	43.48	35.50	0.51	0.38	0.20	1.371
10	30	22.34	38.75	38.91	0.52	0.40	0.23	1.540
30	60	16.79	42.60	40.60	0.52	0.41	0.27	1.691
60	90	6.14	42.76	51.11	0.63	0.44	0.32	1.691
90	120	1.75	40.15	58.10	0.74	0.46	0.35	1.691
120	150	2.27	43.57	54.16	0.74	0.45	0.34	1.691

Irrigation scheme
Every month there is an irrigation gift of 84mm, except for January and December. Table B.2 specifies the supply dates in 2011 and 2012.

Table B.2 Irrigation scheme

Date	Gift (mm)
2011-07-19	84
2011-08-20	84
2011-09-18	84
2011-10-18	84
2011-11-24	84
2012-02-15	84
2012-03-15	84
2012-05-16	84
2012-06-30	84
2012-07-31	84
2012-08-29	84
2012-09-29	84
2012-10-31	84
2012-11-29	84

Soil water content
During the period July 2011 - December 2012 measurements of the groundwater level and the water content at depths of 15 and 45cm below surface are available, see Figure B.2. In total there are 25 measurements of the groundwater level. The water content of the soil is measured on an hourly basis.

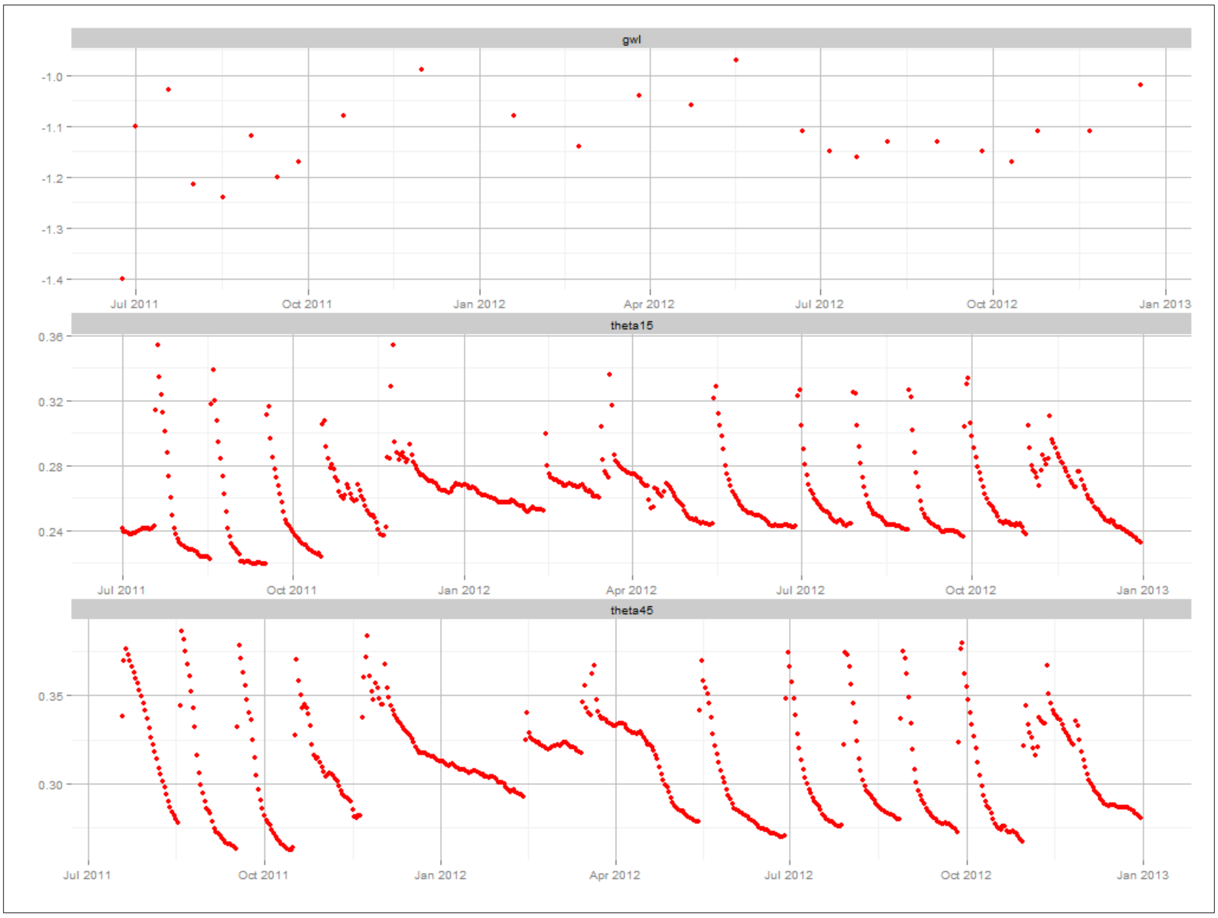


Figure B.2 Observed depth of shallow groundwater (top panel) and water content in the upper soil layer at 15 cm (middle panel) and 45 cm (bottom panel).

B.3 Scenario 1: overland flow irrigation

B.3.1 Setup of SWAP model

<u>Soil schematisation</u>
A 'SWAP-profile' of 2m depth is defined, consisting of compartment-layers of 1cm. Table B.3 shows the characteristics of the three different soil layers.

Table B.3 Soil schematisation

Top (cm)	Bottom (cm)	ORES	OSAT	ALFA	NPAR	KSAT	Code
0	30	0.01	0.42	0.0051	1.305	0.80	B13
30	60	0.01	0.42	0.0191	1.152	13.79	O11
60	200	0.01	0.56	0.0095	1.158	1.02	O12

<u>Drainage</u>
A 2m deep open channel is defined with drainage and infiltration resistance of 750d. Drain spacing is set to 750m. The water level in this channel is set to 0.80m (1.2m below soil surface).

Bottom boundary
The bottom flux is calculated from the hydraulic head of the deep aquifer. The hydraulic head of the aquifer is set to 0.8m depth, with a vertical resistance of the aquitard of 500d.

Crop
The crop type is Mandarin. Maximum rooting depth is set to 0.80m. Figures 3a and 3b show the rooting of the crop during the growing season.

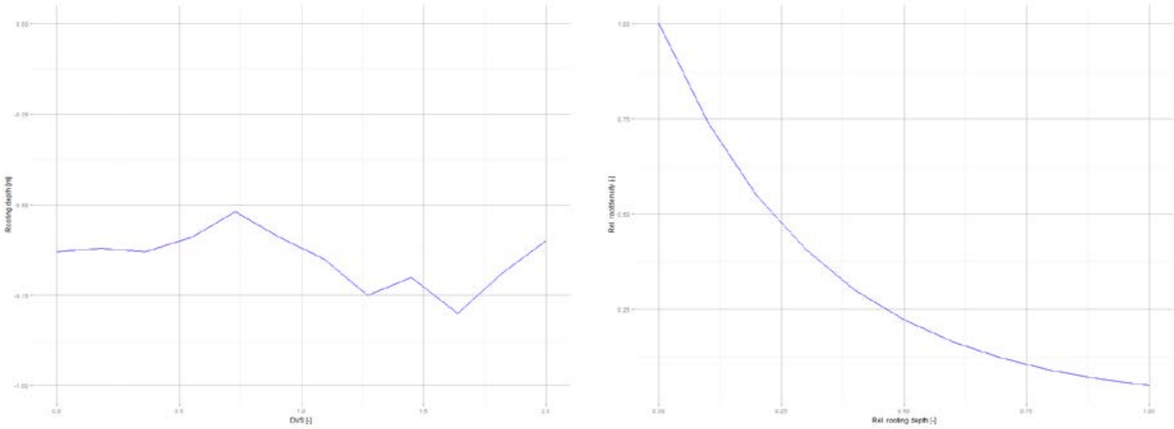


Figure B.3 Rooting depth at given stage of development during the growing season [m] (a), and Relative root-density at given relative rooting depth (b).

Irrigation scheme
Every month there is an irrigation gift of 84mm, except for January and December. Table 2 shows the time of irrigation gift in 2011 and 2012. In the first half of 2011, no information about irrigation is known. During this period an irrigation gift of 84mm on the 25th of the month is assumed. In order to prevent runoff, the ponding level at the soil surface is set to 0.2m.

Salinity
The salinity of the initial condition, irrigation water, drain water and seepage are all set to 2000 mg/litre.

B.3.2 Results

Water balance

Table B.4 Water balance of scenario 1; all data specified in mm.

In		**Out**	
2011			
Precipitation	283.1	Plant Transpiration	552.0
Irrigation	840.0	Soil Evaporation	446.2
		Interception	41.9
Infiltration (open)	0.0	Drainage (open)	142.6
Upward seepage	115.0	Downward seepage	56.8
Total	1238.1	Total	1238.6
2012			

Precipitation	227.0	Plant Transpiration	533.3
Irrigation	756.0	Soil Evaporation	371.6
		Interception	31.3
Infiltration (open)	0.5	Drainage (open)	129.0
Upward seepage	128.7	Downward seepage	55.6
Total	1112.2	Total	1120.8

Simulated ground water depth (m below soil surface)

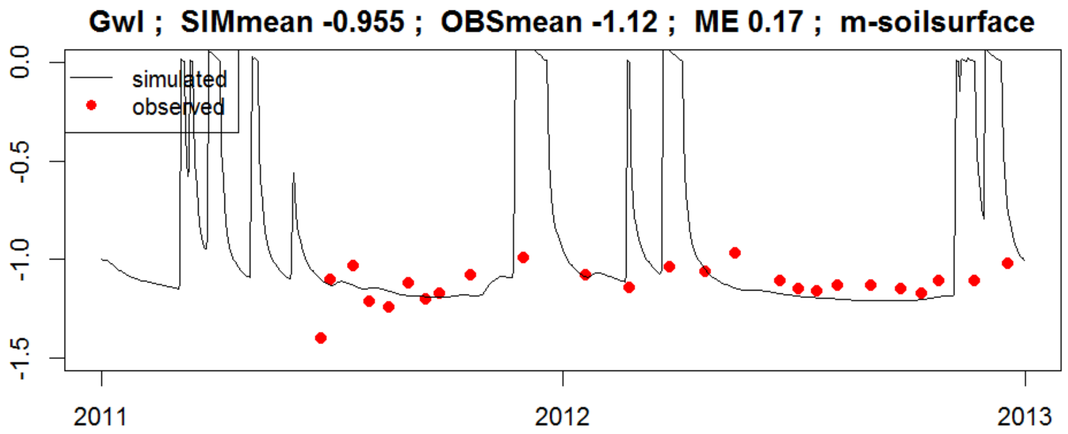


Figure B.4 Calculated and measured groundwater water depths. The model-performance is given at the top of the figure.

Water-content
Figure 5 shows the calculated soil pressure head.

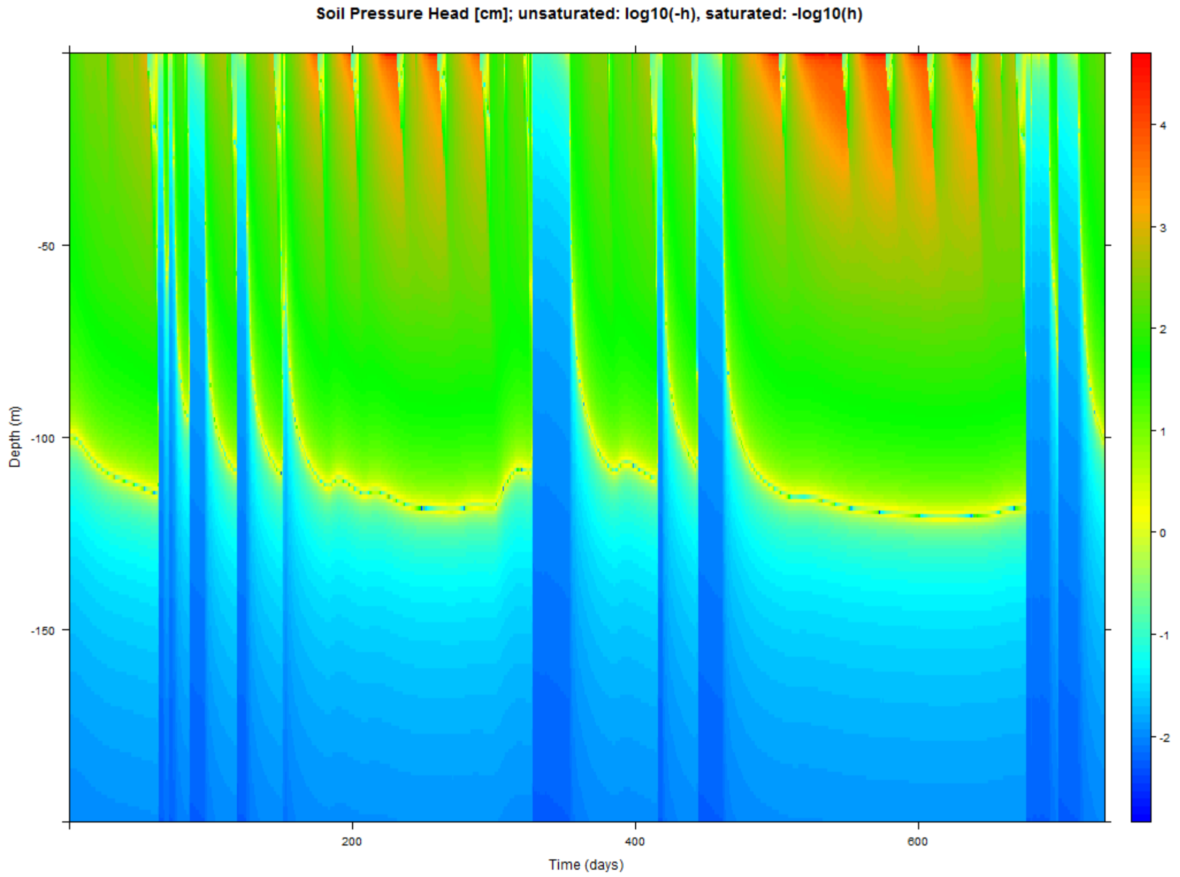


Figure B.5 Contour of calculated water content, with depth and time [-]

The model performance is shown in more detail in Figure B.6.

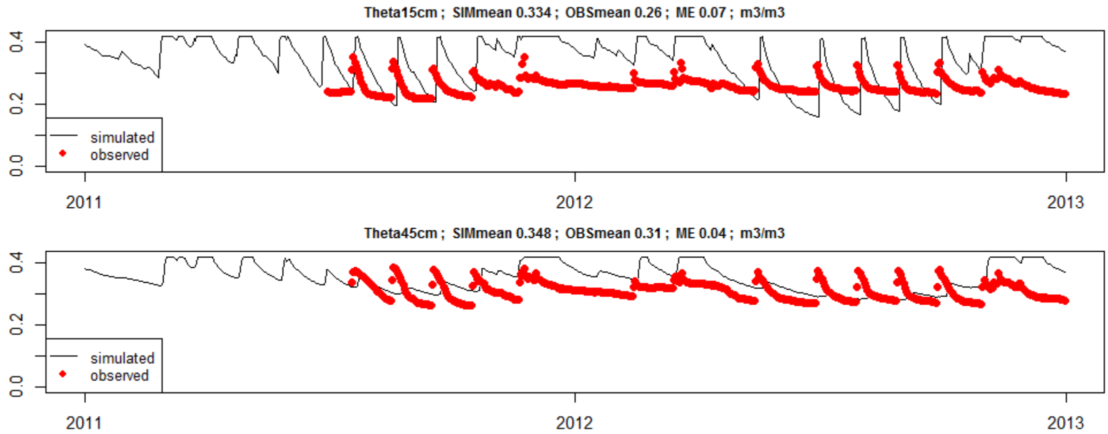


Figure B.6 Calculated and measured water content at of 15 and 45cm depths. The model-performance is specified numerically at the top of the figures.

<u>Salinity</u>

Figure B.7 shows a colourized impression of the calculated salinity concentration with soil profile depth and time.

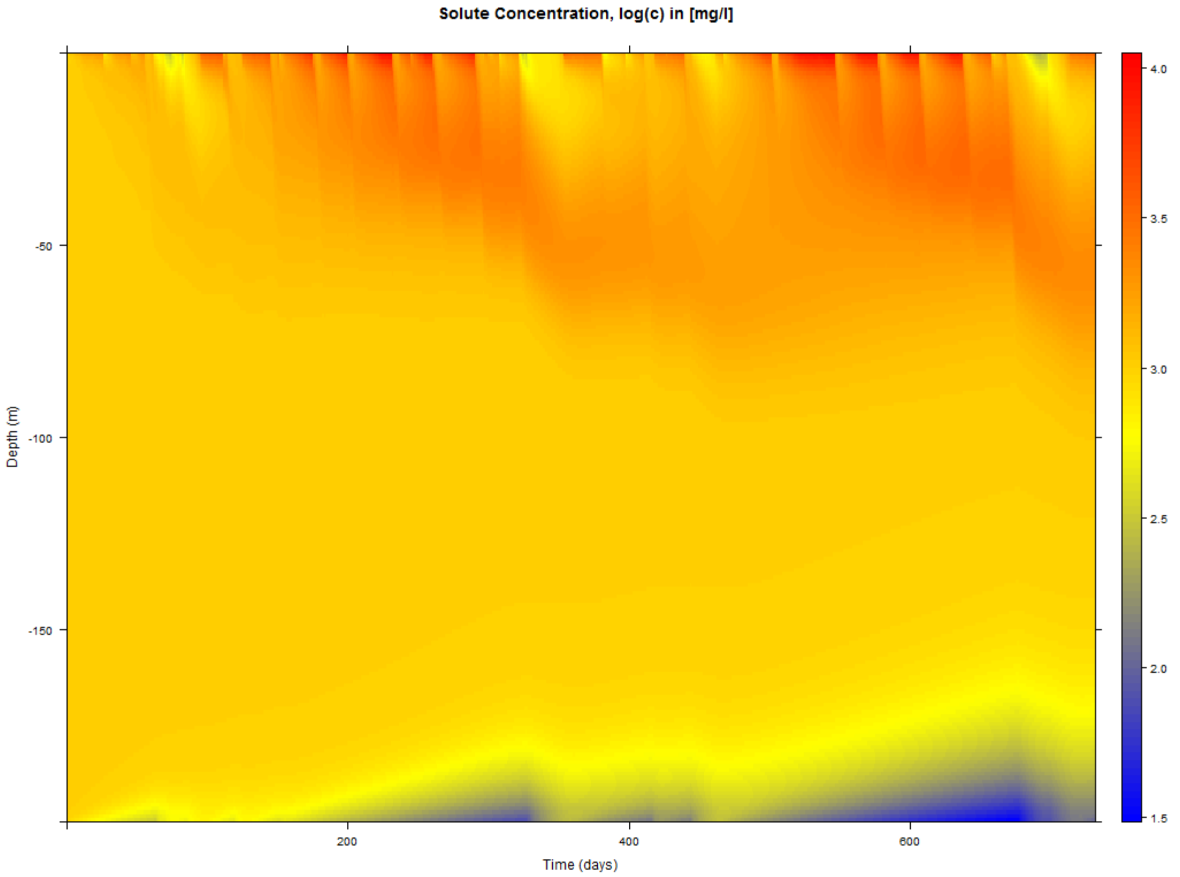


Figure B.7 Contour of the calculated salinity concentration in groundwater, with soil profile depth and time.

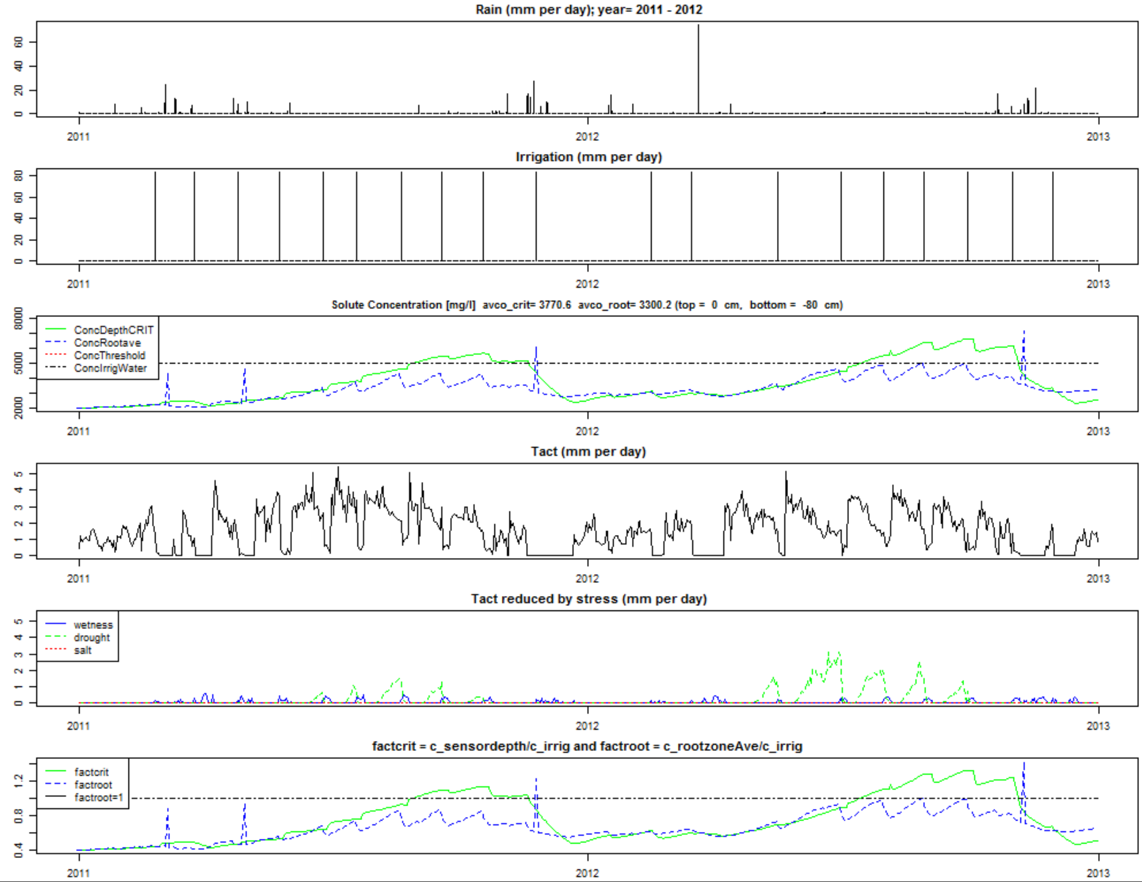


Figure B.8 Salinity concentration and crop stresses. 'ConcRootave' is the average salinity concentration in the root zone (0-0.80m depth). 'ConcDepthCRIT' is the concentration at 0.30m depth.

B.4 Scenario 2: irrigation through subsurface pipe drains

B.4.1 Setup of SWAP model

In the following paragraph, only changes compared to scenario 1 are described.

Drainage
A second drainage system is introduced, viz. a pipe drain at 0.30m below soil surface with an infiltration resistance of 75d. Drain spacing is set to 75m.

Irrigation scheme
The irrigation scheme is disabled.

B.4.2 Results

Water balance

Table B.5 Water balance of scenario 2.

In		**Out**	
2011			
Precipitation	283.1	Plant Transpiration	617.0
		Soil Evaporation	159.4
		Interception	41.9
Infiltration (drain)	876.1	Drainage (drain)	0.0
Infiltration (open)	0.0	Drainage (open)	268.0
Upward seepage	0.0	Downward seepage	68.3
Total	1159.2	Total	1154.6
2012			
Precipitation	227.0	Plant Transpiration	616.5
		Soil Evaporation	133.2
		Interception	31.3
Infiltration (drain)	885.0	Drainage (drain)	0.0
Infiltration (open)	0.0	Drainage (open)	264.6
Upward seepage	0.0	Downward seepage	64.8
Total	1112.0	Total	1110.4

<u>Salinity</u>

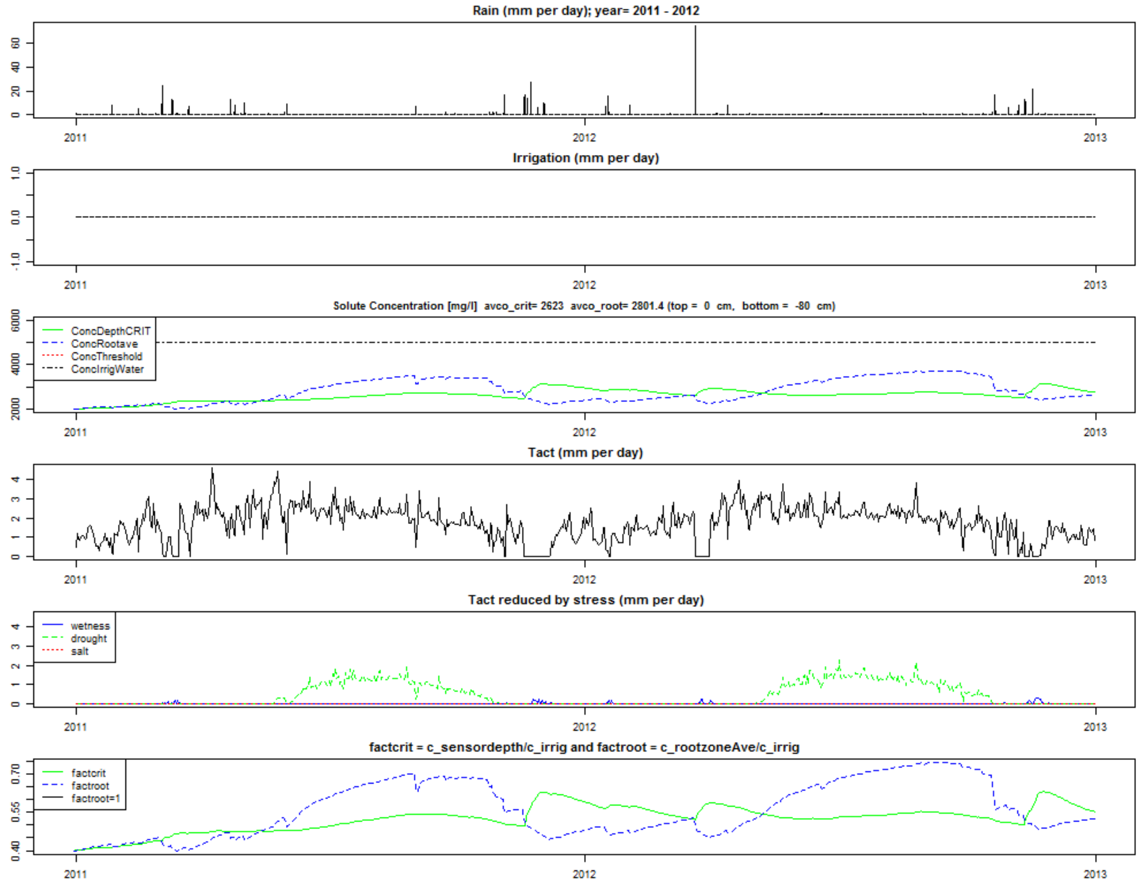


Figure B.9 Salinity concentration and crop stresses. 'ConcRootave' is the average salinity concentration in the root zone (0-0.80m depth). 'ConcDepthCRIT' is the ' concentration at 0.30m depth.

B.5 Comparison of scenarios 1 and 2

Waterbalance

With draintube-irrigation (scenario 2) the soil evaporation decreases with approximately 60% compared to the regular irrigation method (scenario 1). Due to this reduction of water-losses there's an increase in plant transpiration (12 – 14%), and also an increases in water availability downstream (due to increase of drainage and downward seepage), see Table B.6.

Table B.6 Waterbalance of scenario 1 versus scenario 2.

In	Scenario 1	Scenario 2	Out	Scenario 1	Scenario 2
2011					
Precipitation	283.1	283.1	Plant Transpiration	552.0	617.0
Irrigation	840.0		Soil Evaporation	446.2	159.4
			Interception	41.9	41.9
Infiltration (drain)		876.1	Drainage (drain)		0.0
Infiltration (open)	0.0	0.0	Drainage (open)	142.6	268.0
Upward seepage	115.0	0.0	Downward seepage	56.8	68.3
Total	1238.1	1159.2	Total	1238.6	1154.6
2012					
Precipitation	227.0	227.0	Plant Transpiration	533.3	616.5
Irrigation	756.0		Soil Evaporation	371.6	133.2
			Interception	31.3	31.3
Infiltration (drain)		885.0	Drainage (drain)		0.0
Infiltration (open)	0.5	0.0	Drainage (open)	129.0	264.6
Upward seepage	128.7	0.0	Downward seepage	55.6	64.8
Total	1112.2	1112.0	Total	1120.8	1110.4

C WEAP modelling of Vega Baja del Segura

This appendix describes the modelling approach, using the Water Evaluation And Planning (WEAP) model, focusing on water demand, supply and quality for the current situation as well as under some development scenarios. These scenarios include the implementation of subsurface irrigation drains, instead of surface irrigation currently used, and the use of desalinated water upstream (50% and 75% desalinated).

C.1 Model description

C.1.1 WEAP

The model used for the Vega Baja del Segura region is built using the WEAP framework. WEAP is selected as it is designed to work at basin scales and the amount of physical detail needed for this project (Figure C.1). A detailed discussion on WEAP can be found in the WEAP manual which can be freely downloaded from the WEAP website (http://www.weap21.org/). A summary of WEAP's capabilities is provided here.

An easy-to-use tool is needed to match water supplies and competing demands, and to assess the upstream–downstream links for different management options in terms of their resulting water sufficiency or un-met demands, costs, and benefits. The Water Evaluation and Planning tool (WEAP) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Delphi Studio programming language and MapObjects software are employed to spatially reference catchment attributes such as river and groundwater systems, demand sites, wastewater treatment plants, catchment and administrative political boundaries (Yates *et al.* 2005).

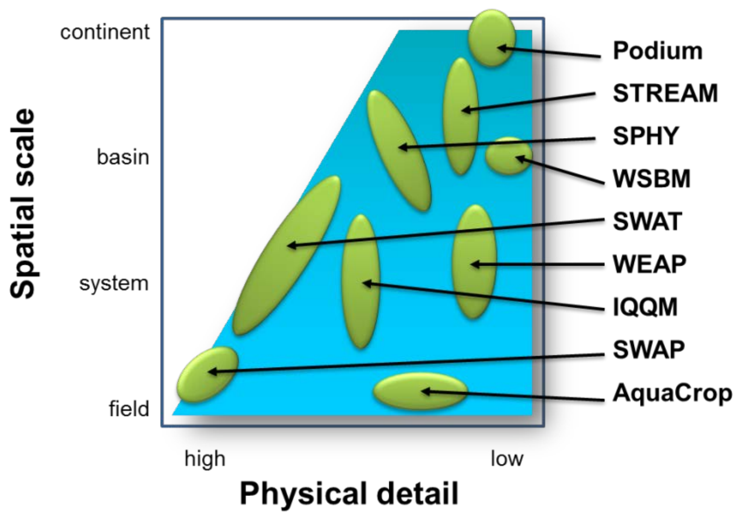


Figure C.1 Relation between spatial scale and physical detail in water allocation tools. The green ellipses show the key strength of some well-known models (Droogers and Bouma, 2014).

Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are mutable, both in space and time. WEAP then employs a priority-based optimisation algorithm and the concept of “equity groups” to allocate water in times of shortage.

In order to undertake these water resources assessments the following operational steps can be distinguished:

- The study definition sets up the time frame, spatial boundary, system components and configuration. The model can be run over any time span where routing is not a consideration, a monthly period is used quite commonly.
- System management is represented in terms of supply sources (surface water, groundwater, inter-basin transfer, and water re-use elements); withdrawal, transmission and wastewater treatment facilities; water demands; and pollution generated by these activities. The baseline dataset summarises actual water demand, pollution loads, resources and supplies for the system during the current year, or for another baseline year.
- Scenarios are developed, based on assumptions about climate change, demography, development policies, costs and other factors that affect demand, supply and hydrology. The drivers may change at varying rates over the planning horizon. The time horizon for these scenarios can be set by the user.
- Scenarios are then evaluated in respect of desired outcomes such as water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Water supply: Using the hydrological function within WEAP, the water supply from rainfall is depleted according to the water demands of the vegetation, or transmitted as runoff and infiltration to soil water reserves, the river network and aquifers, following a semi-distributed, parsimonious hydrologic model. These elements are linked by the user-defined water allocation components inserted into the model through the WEAP interface.

Water allocation: The challenge is to distribute the supply remaining after satisfaction of catchment demand the objective of maximizing water delivered to various demand elements, and in-stream flow requirements - according to their ranked priority. This is accomplished using an iterative, linear programming algorithm. The demands of the same priority are referred to as “equity groups”. These equity groups are indicated in the interface by a number in parentheses (from 1, having the highest priority, to 99, the lowest). WEAP is formulated to allocate equal percentages of water to the members of the same equity group when the system is supply-limited.

The concept-based representation of WEAP means that different scenarios can be quickly set up and compared, and it can be operated after a brief training period. WEAP is being developed as a standard tool in strategic planning and scenario assessment and has been applied in many regions around the world.

C.1.2 Data sets

Building the WEAP model for Vega Baja del Segura requires various sets of data. Data can be divided into the following main categories:

- Model building

- Static data[1]
  - Soils
  - Land cover
  - Headflow salt concentration
  - Evaporation and transpiration

- Dynamic data
  - Climate (precipitation)
  - Irrigation water demands (water use rates and weekly variation)
  - Flow requirements
- Scenarios
  - A. Reference
  - B. Subsurface irrigation
  - C. Desalination plant upstream (50% desalination)
  - D. Desalination plant upstream (75% desalination)
- Model validation/calibration
  - River headflow
  - Downstream river salt concentration

Data were obtained from various sources and combined into a consistent set of input for WEAP. Climate data was obtained from the Spanish Ministry of Agriculture, Food and Environment[i]. The following sections will summarize the building of the model, details can be found in the model input data itself.

C.1.3 Model components

Boundary, area extent and background layers

Figure C.2 shows the boundary of the study area (red border). For this WEAP simulation, a pilot area south of the Segura River (dark blue) was chosen. In this area 7 irrigation districts are situated, from west (upstream) to east (downstream): Moquita, Molina, Huertos, Alquibla, Benijofar, Rojales and Guadamar. The area is around 5 km from north to south and 40 km from east to west, with a total area of 3382 ha.

[1] Note that static data can still vary over longer time frames, but are fairly constant over days/weeks.

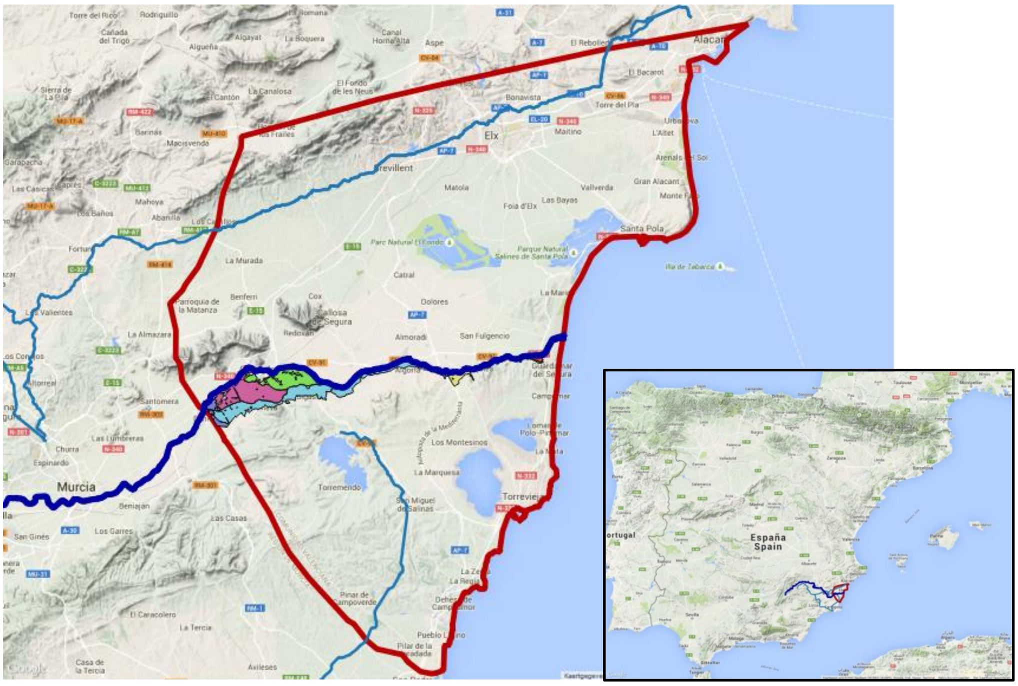


Figure C.2 Pilot area extent.

Within WEAP various background layers were added to support the development of the model. These layers were created using a GIS tool such as for example ArcMap or QGIS. The most relevant layers that were added are (Figure C.3):

- Countries, states and oceans
- River flow network
- Irrigation districts within the area

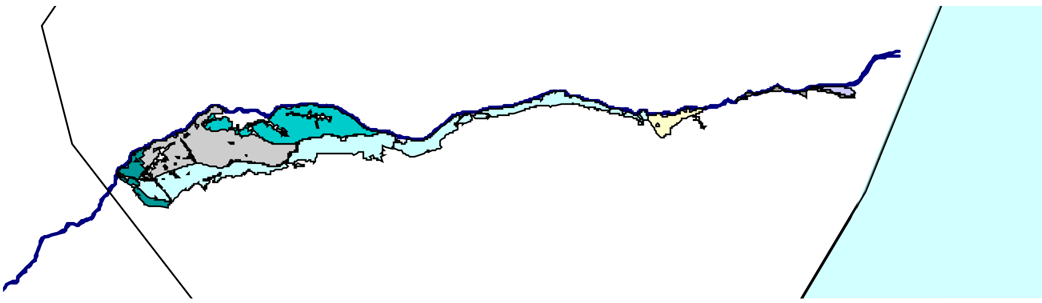


Figure C.3 Various background layers used to support model building in WEAP.

This data was obtained from the Institut Valencia D'Investigacions Agraries[ii].

Irrigation districts
A total of 7 irrigation districts have been identified. Table 4 shows the different areas including land cover.

Table C.1 Land cover areas of the 7 irrigation districts as applied in WEAP.

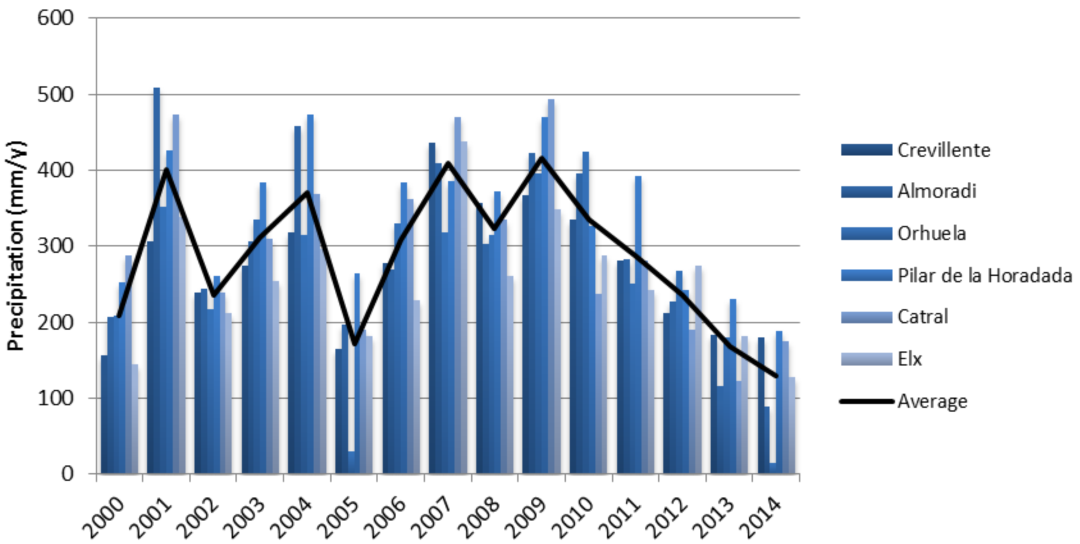
Name	Arable crops (ha)	Citrus (ha)	Pomegranate (ha)	Total agriculture (ha)	Total area (ha)
1. Moquita	42,9	117,1	0	160,0	164,7
2. Molina	307,4	634,8	0	942,2	946,3
3. Huertos	264,4	394,7	0	659,1	682,7
4. Alquibla	115,7	1151,9	0	1307,6	1370,4
5. Benijófar	55,6	75,7	0	131,2	133,8
6. Rojales	20,2	15,1	0,2	35,6	44,2
7. Guardamar	9,9	28,6	0	38,5	40,3

Further refinement in terms of area as well as number of land classes can be implemented rather easily within WEAP in case more detailed information will become available.

Climate

Only the precipitation in the area was used as input for the WEAP model. This data was obtained from the Spanish Ministry of Agriculture, Food and Environment[iii]. Daily precipitation was calculated by taking the average from 6 weather stations: Crevillente, Elx, Catral, Orihuela, Almoradí and Pilar de La Horadada. These weather stations are all located in the south part of the province of Alicante. Since the pilot area is relatively small, precipitation was considered to be equal in all 7 irrigation districts.

This climate data was converted from Excel into text files. These text files can be read by WEAP. In this way, changing climate information requires only a change in text file and not in the entire WEAP model.



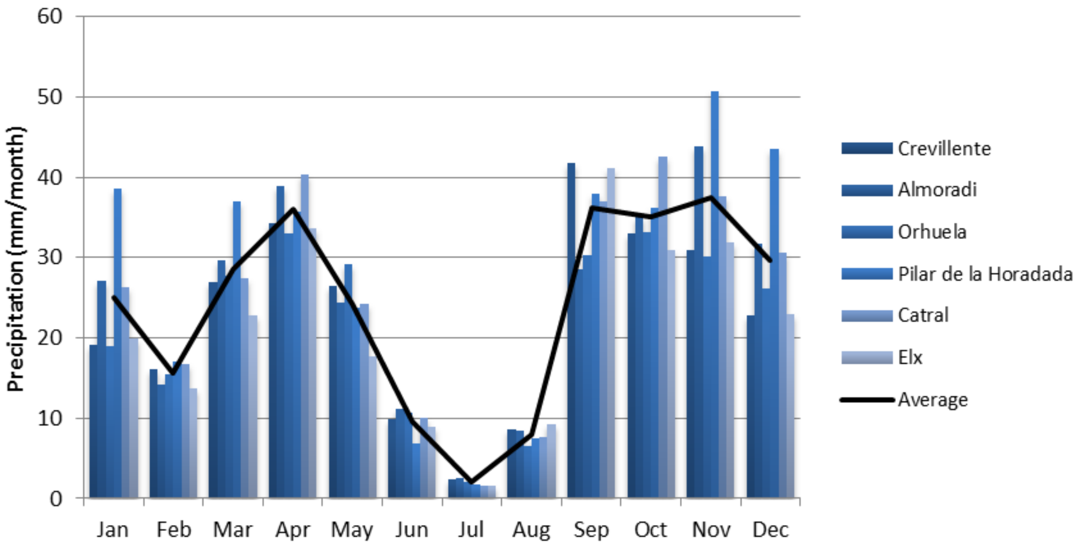


Figure C.4 Precipitation data from 6 weather stations close to the pilot area (top: precipitation per year, bottom: 15-year average precipitation per month).

Agricultural demand

The agricultural water demand has been set at 1050 mm/year for all crops. Since the demand is higher during summer months, a weekly demand variation was used in the model (Figure C.5). These values can easily be changed in the model.

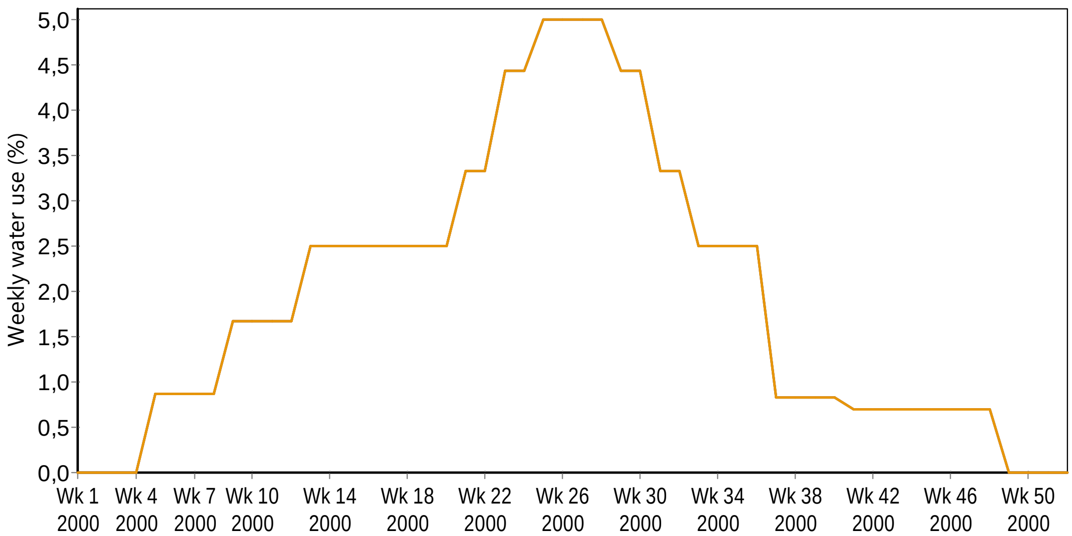


Figure C.5 Weekly variation in water use.

The agricultural water demand was multiplied with a water use factor. This factor was 1 for the reference and desalination scenarios and 0,947 for the subsurface irrigation scenario. This number was derived from the SWAP model results (Alterra, 2015, for calculations see Appendix B). These results showed that 5,3% less water was required to achieve the same plant transpiration when using subsurface irrigation.

Evaporation and transpiration losses
Since the current irrigation method is by flooding the area, a large part of the irrigation water is lost by evaporation. To investigate the amount of evaporation and plant transpiration, Research Institute Alterra conducted a field-scale study by using the SWAP model (Soil-Water-Athmosphere-Plant). The results of this studied showed that evaporation is around 400 mm and plant transpiration around 540 mm per year, leaving around 135 mm flowing out of the field through the drains, in the reference scenario. The outflow equals 12,9% of total inflow into the field, giving a consumption of 87,1%.

In the subsurface irrigation scenario, evaporation decreased to around 130 mm, with the same plant transpiration, leaving around 235 mm flowing out through drains. The outflow equals 23,5% of total inflow into the field, giving a consumption of 76,5%. For detailed calculations see Appendix B.

Headflow salt concentration
The salt concentration of the headflow was set to 1000 mg/l for the reference situation. For the scenario with 50% desalination upstream this concentration was 500 mg/l and for the scenario with 75% desalination 250 mg/l.

Outflow salt concentration
Since the total amount of salt in the inflow and outflow need to be equal, the outflow salt concentration was determined by multiplying the inflow salt concentration with the change in inflow and outflow (inflow/outflow). Overall this gives the following formula:

Inflow salt concentration x 100 / (100-Consumption[%])

Minimum outflow requirement
So far the environmental flow requirement for downstream has been set to zero as no information was available.

Other assumptions
Evaporation in the transmission links, as well as the river itself was assumed to be 0. Furthermore, the headflow was set in such a way that the demand could be completely supplied (i.e. there was no unmet demand).

C.1.4 Schematic overview

Figure C.6 shows the schematization of the WEAP model and the location of the 7 irrigation districts. The model was setup based on the available data, using the following schematization (in brackets the number of nodes):

- River (1)
- Other Supply (7)
- Demand Site (7)
- Transmission Link (14)
- Return Flow (7)
- Flow Requirement (1)

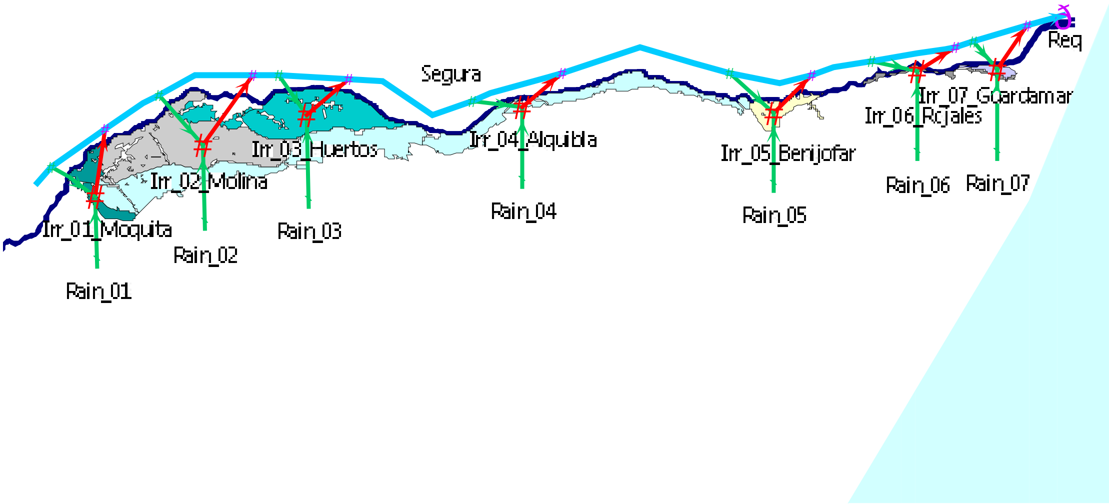


Figure C.6 Schematization of the WEAP model.

C.1.5 Validation and calibration

The salt concentration in the river depends strongly on the average weekly inflow into the river. This number was adjusted so that the downstream salt concentration (i.e. below the return link of irrigation district 7) was around 5,5 dS/m (3,5 g/l), as was reported[iv]. This was the case with an inflow of 3,5 m^3/s, which comes down to around 110 million m^3 per year. This is 9 times lower than the actual headflow[7]. This difference can be explained by the lower demand in the model, since only the south side of the river was modelled, and the neglected evaporation and run-off.

C.1.6 Business case

To evaluate the effect of any of the 3 measures, the difference in crop benefits and water savings were calculated. This was done by using the variables below.

Table C.2 Variables used in business case calculations.

	Arable	Citrus	Pomegranate
Threshold Level (dS/m)[v,vi,vii]	2,0	1,5	1,3
Slope Salt Stress (% / dS/m)[9,10,11]	10	15,5	15
Potential Yield (kg/ha)[9,viii]	20000	25000	30000
Crop Price (EUR/kg)[ix,x,xi,xii]	0,50	0,60	0,50
Average farmer area (ha)[xiii]	7,5	7,5	7,5
Water price (EUR/m^3)[6]	0,25	0,25	0,25

The weighted average yearly inflow water quality was used to assess the amount of crop stress. This stress reduces crop benefits. The inflow salt concentration was converted from mg/l to dS/m by using the following formula:

EC in dS/m = TDS in mg/L or ppm / 640

If the EC is above the threshold level, the salt stress was calculated by using the slope described in Table C.2. The salt stress reduces the potential crop yield by the same amount, giving the final crop yield in kg/ha. By multiplying with the crop price, the crop benefits in EUR/ha were calculated.

C.2 Results

C.2.1 Water quality

Inflow water quality
Figure C.1 shows the effect of different measures on the inflow water quality of the 7 different irrigation districts. The highest peaks are observed during the summer months, when most of the irrigation water is used and precipitation is low. When the amount of precipitation is high (like around week 8), the salt concentration drops to 0. This has to do with the fact that no additional irrigation from the Segura river is required in these relatively wet periods. Desalination of water upstream has a much more positive effect on the water quality than subsurface irrigation drains.

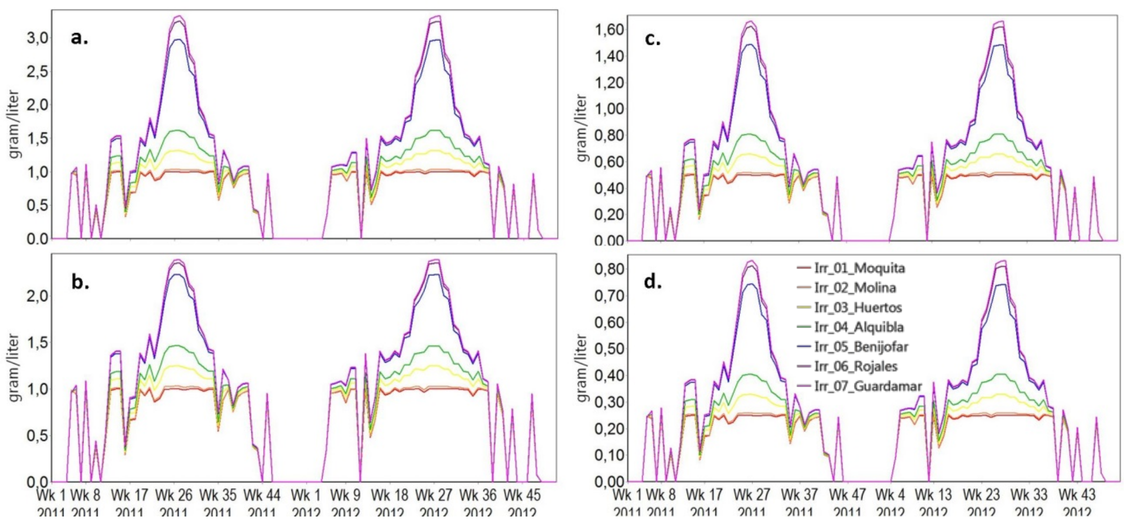


Figure C.1 District inflow water quality (precipitation and irrigation water mixed) in different irrigation districts, in 2011 and 2012, for the a. reference, b. subsurface irrigation, c. 50% desalination and d. 75% desalination scenarios.

River water quality
Figure C.2 shows the effect of different measures on the water quality in the Segura river. Desalination of water upstream has a much more positive effect on the water quality than subsurface irrigation drains. The subsurface drains lead to a downstream decrease in salt concentration of around 30% during summer months.

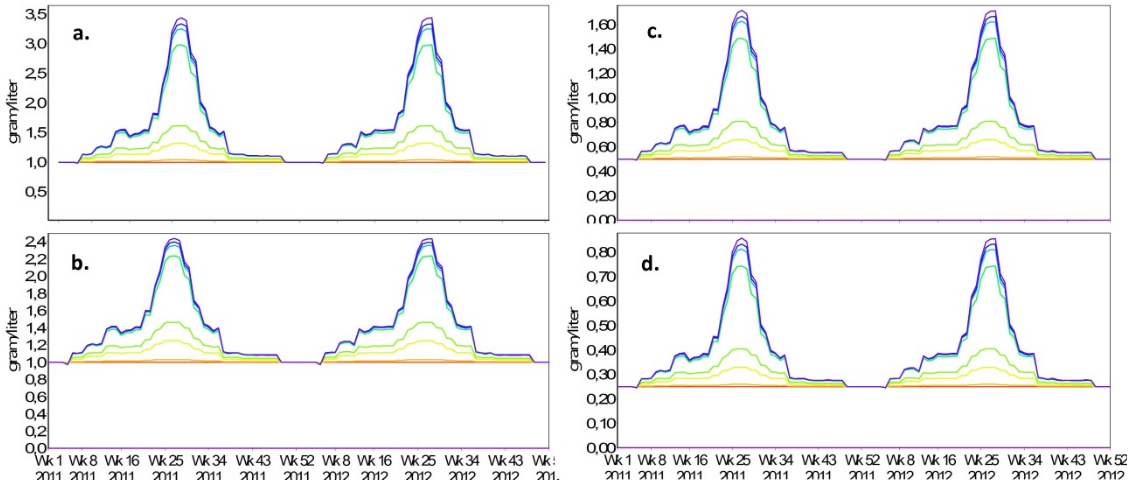


Figure C.2 Segura river water quality from upstream (red) to downstream (blue), in 2011 and 2012, for the a. reference, b. subsurface irrigation, c. 50% desalination and d. 75% desalination scenarios.

C.2.2 Water supply

Figure C.3 shows the total supply of irrigation water delivered to all districts in the reference scenario. The coloured bars show the amount of precipitation, which is different for each district because of the difference in area, and the grey bars represent the amount of additional water supplied from the Segura river for irrigation purposes

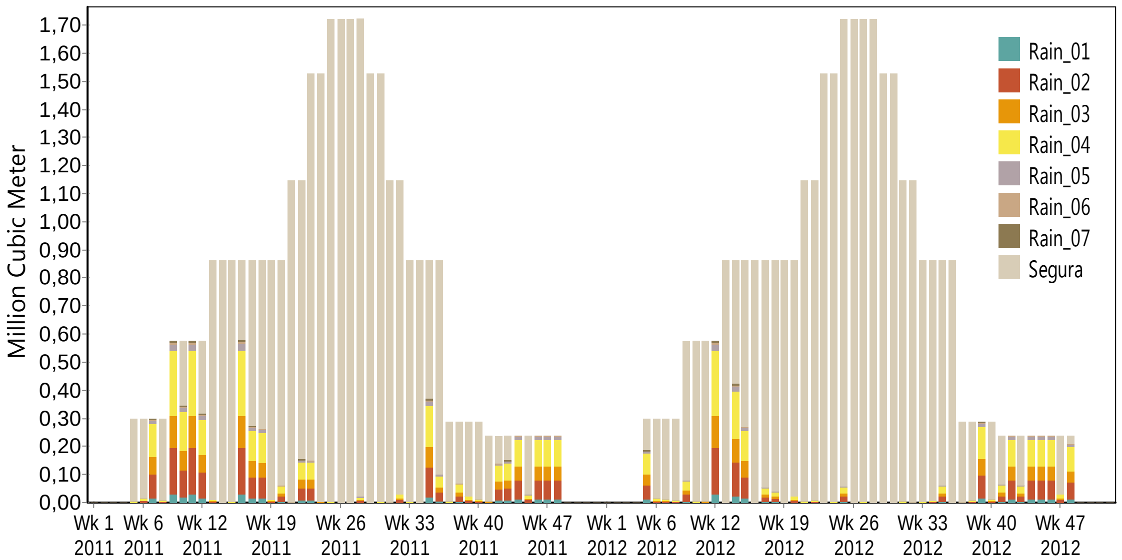


Figure C.3 Total supply delivered to all demand sites by different sources (precipitation and irrigation), in 2011 and 2012, for the reference scenario.

For the subsurface irrigation scenario, the required amount of additional Segura water is around 6% less (Figure C.4). For the desalination scenarios, the water supply is the same in the reference scenario.

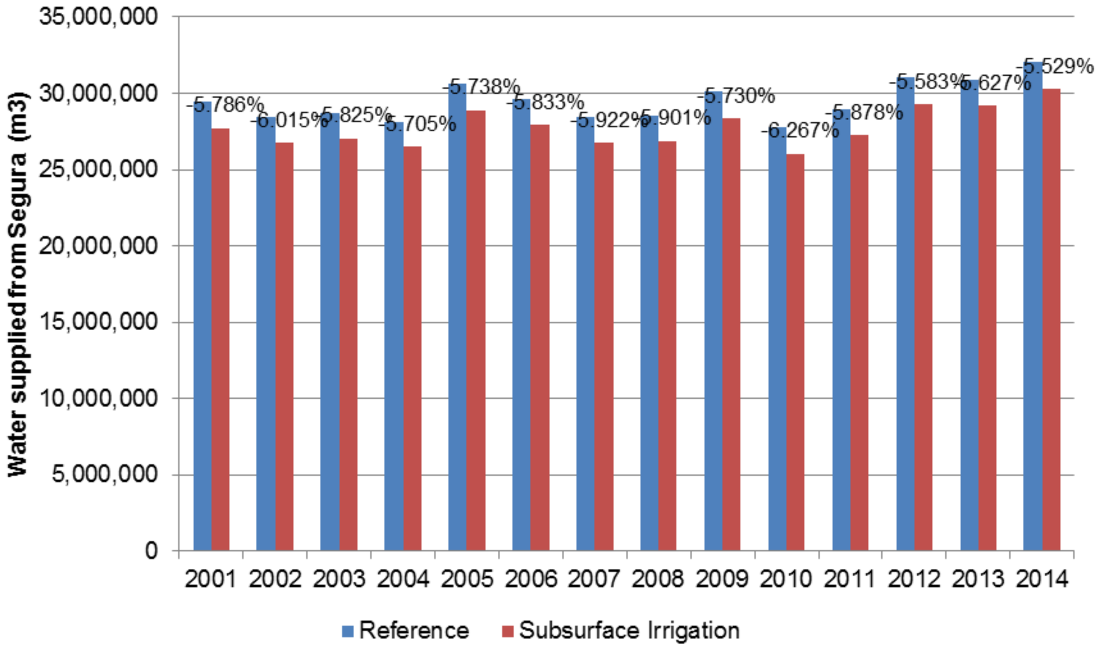


Figure C.4 Yearly total water supply from the Segura River to the whole pilot area.

C.3 Business case

C.3.1 Crop benefits

Figure C.5 shows the difference in crop benefits per area, averaged over the past 15 years. The decrease in water quality causes crop benefits to decrease with about 10% in the downstream irrigation districts. Implementation of subsurface irrigation drains half this effect, decreasing crop benefits with about 5% downstream. When desalinated water is user (either 50% or 75% desalinated), crop benefits are equal in downstream areas compared to upstream.

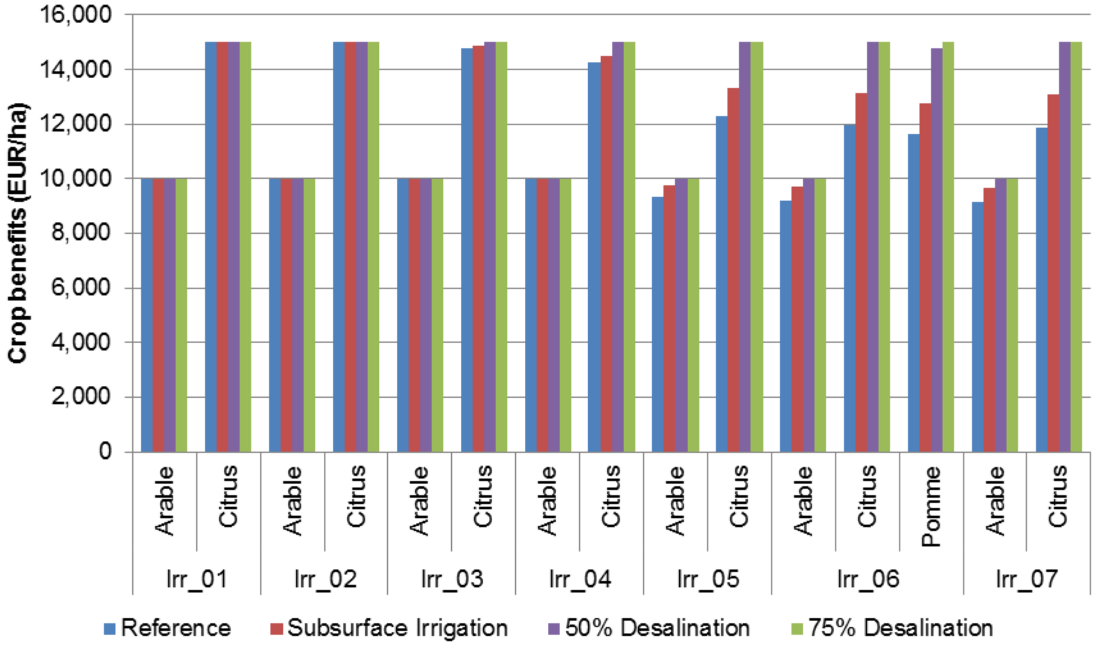


Figure C.5 Crop benefits per area, 15-year average.

In the whole pilot area crop benefits for the subsurface irrigation and desalination scenarios increase with about 1,3% and 3%, respectively (Figure C.6).

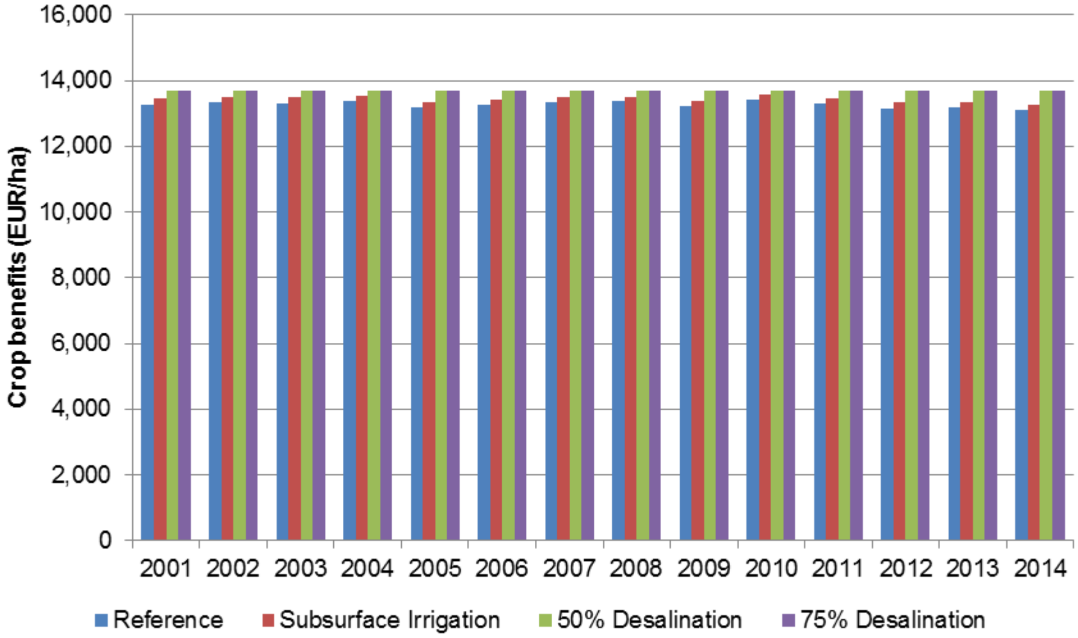


Figure C.6 Average pilot area crop benefits per year.

C.3.2 Profit

Due to the increase in crop benefits, without an increase in variable costs, the net profit increases. When the subsurface irrigation measure is implemented, less irrigation water is required. The overall result per hectare is shown in Figure C.7.

Figure C.7 Profit increase due to increase in crop benefits and water savings.

The average size of a farm in the area is 7,5 ha. This means that the profit per farmer can yearly increase with € 2.214 (+/- 152), € 3.138 (+/- 1.315) or € 3.138 (+/- 1.317) when subsurface irrigation, 50% desalination or 75% desalination is implemented, respectively. For the whole area this yearly profit increase comes down to € 966.481 (+/- 66.527), € 1.369.968 (+/- 574.120) or € 1.370.077 (+/- 574.982) (Table C.1).

Table C.1 Average yearly profit increase in pilot area.

Measure	Subsurface Irr. (EUR)	50% Desalination (EUR)	75% Desalination (EUR)
Yearly profit per hectare	295	418	418
Yearly profit per farmer	2.214	3.138	3.138
Yearly total profit	966.481	1.369.968	1.370.077

C.4 Conclusions and Recommendations

In this scoping study, SWAP model results were used in a WEAP model to determine the effect of subsurface irrigation and desalination measures downstream.

The river water quality increased with 30% downstream when subsurface irrigation was used and 50 to 75% when desalinated water was used. Crop benefits increased 10% with subsurface irrigation and 25% with desalination measures, in the downstream irrigation district. Water saving in the whole area due to subsurface irrigation was around 6%.

Due to this increase in crop benefits and decrease in water demand, the yearly profit of the whole region increases by almost € 1 million when subsurface irrigation is implemented. Desalinating the water upstream increases the yearly profit by around € 1,4 million.

Further study on the costs and willingness of farmers to invest in any of these measures is needed. From this the investment return period can be calculated and the most suitable measure can be determined. Moreover, other models (like e.g. SaltIrSoil) could be used to study the effects of salt concentrations in demand sites.

C.5 References

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[i] http://eportal.magrama.gob.es/

[ii] Institut Valencia D'Investigacions Agraries (IVIA), Carretera Moncada-Náquera, Km. 4.5, 46113 Moncada, Valencia, Spain

[iii] http://eportal.magrama.gob.es/

[iv] IVIA-CDAS, CIDE-CSIC, CIDE-UV, Informe técnico sobre la sostenibilidad de la agricultura de regadio en la vega baja del segura y bajo vinalopo (alicante) desde el punto de vista de la salinización de los suelos (2011).

[v] http://www.fao.org/nr/water/cropinfo_citrus.html

[vi] http://www.wyomingextension.org/agpubs/pubs/WY988.PDF

[vii] http://www.fao.org/docrep/005/y4263e/y4263e0e.htm

[viii] http://www2.spi.pt/euromedcitrusnet/Documents/Sector%20Analysis%20Report/EuroMed CitrusNet%20Sector%20 Analysis%20Report-Spain.pdf

[ix] http://www.freshplaza.com/article/142005/Spain-Citrus-exporters-overcome-Russian-veto-with-record-sales

[x] http://www.freshplaza.com/article/141030/Spain-High-artichoke-prices,-small-production

[xi] http://www.freshplaza.com/article/103440/Spain-Pomegranate-demand-rising-every-year

[xii] http://www.freshplaza.com/article/139203/Spanish-oranges-dominate-the-German-markets

[xiii] http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/es/factsheet-comunidad-valenciana_en.pdf