Water Allocation Planning for Vega Baja del Segura Spain

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Preface

This Climate-KIC awarded pathfinder project aims at identifying opportunities for innovative solutions that decrease local fresh water shortages in economic vulnerable regions under increasing water stress. It provides the foundation for innovation pilots, in which solutions 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.

FutureWater's role in this project was to develop an integrated land and water resource management (ILWRM) model for scenario development. The results of this work are described in this report and are used as input for a business model. Data collection for further fine-tuning can follow during operationalizing of the model.

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

The project partners are:

- Stichting Deltares, Delft, Netherlands (Lead Institution).
- Wageningen University, 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

There has been a rapid uptake of the term Climate Smart Agriculture (CSA) by the international innovation community in the past years. 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 demand integral considerations. Substantial efforts are required to develop the knowledge and capacities to make CSA a reality. This pathfinder project focusses on reducing these efforts considerably with respect to choosing and assessing the potential of local fresh water supply solutions. Solutions like climate adaptive drainage, aquifer storage and recovery and levee bank infiltration, in which the water storage capacity of the subsurface is utilized to the full, are considered innovations that may strengthen regional agricultural economy and reduce water stress due to climate change.

This project identifies opportunities for innovative solutions that decrease local fresh water shortages in economic vulnerable regions under increasing water stress (droughts, salinization). Solutions like climate adaptive drainage, aquifer storage and recovery and levee bank infiltration are considered innovations that strengthen regional agricultural economy and reduce water stress due to climate change. The project has three components:

1. Analysis of a drought and salinization prone region: what water shortages now and under climate change will occur in the region; what agricultural production is economically most vital to the region; how can geographical/climatological and soil characteristics support different adaptation measures.
2. Making maps for the region that define the potential success rate of various kinds of fresh water solutions.
3. Building business cases for the use of fresh water solutions, on a local scale, with and for farmers, private companies that manufacture and install technical infrastructure and regional governments (water management agency; agricultural agency).

This project builds upon more than 4 years of research and pilots within the Knowledge for Climate program in the Netherlands in which various measures to increase local fresh water availability were extensively investigated, tested in the field with several agricultural entrepreneurs and companies providing the technical infrastructure. In this project 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 this knowledge has been incorporated in a toolbox called the Fresh Water Options Optimizer (FWOO). The FWOO explores the potential for solutions that deal with water shortage, either caused by drought or limitations in fresh water supply. These solutions are primarily adaptive, but can also be used to create conditions for farming higher grade, more profitable crops. The project covers both a supply side and a demand side need. It is stimulating a portfolio of innovative technologies that improves freshwater.

The basis for the FWOO consists of a method to produce maps that pinpoint where conditions are less or more suitable for local fresh water solutions that secure the water supply of farmers and decrease their vulnerability to periods of drought or stalling water supply. Moreover, the

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

1.2 Aim

The project will demonstrate the business potential of fresh water solutions for a case study area with intensive agriculture within the Valencia region, Spain. Also, within the project knowledge and experiences are shared with stakeholders from Italy's Emilia Romagna region, where similar challenges are present and potential for local fresh water solutions exist. In this way this region is offered the occasion to prepare also for innovation pilots in a follow up stage.

For the purpose of this project it was decided to develop two new modelling frameworks for the Vega Baja del Segura region, using state-of-the-art models and the latest strategic plans. The Soil, Water, Atmosphere and Plant (SWAP[1]) model simulates transport of water, solutes and heat in unsaturated/saturated soils. The model is designed to simulate flow and transport processes at field scale level, during growing seasons and for long term time series. The model was used to analyse water flows and processes on a field scale level and are described in a report by Research Institute Alterra[2] (2015). This report describes the second modelling approach, using the Water Evaluation And Planning (WEAP[3]) 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 flood irrigation used nowadays, and the use of desalinated water upstream (50% and 75% desalinated).

2 Vega Baja del Segura

Vega Baja del Segura is a comarca (county) in the province of Alicante, Valencian Community, in the SouthEast of Spain.

To the North its neighbouring comarcas are the Baix Vinalopó and Vinalopó Mitjà. Its southern limits are also those of the Valencian Community as it meets a different autonomous community, the Region of Murcia.

Figure 1. Location of study area.

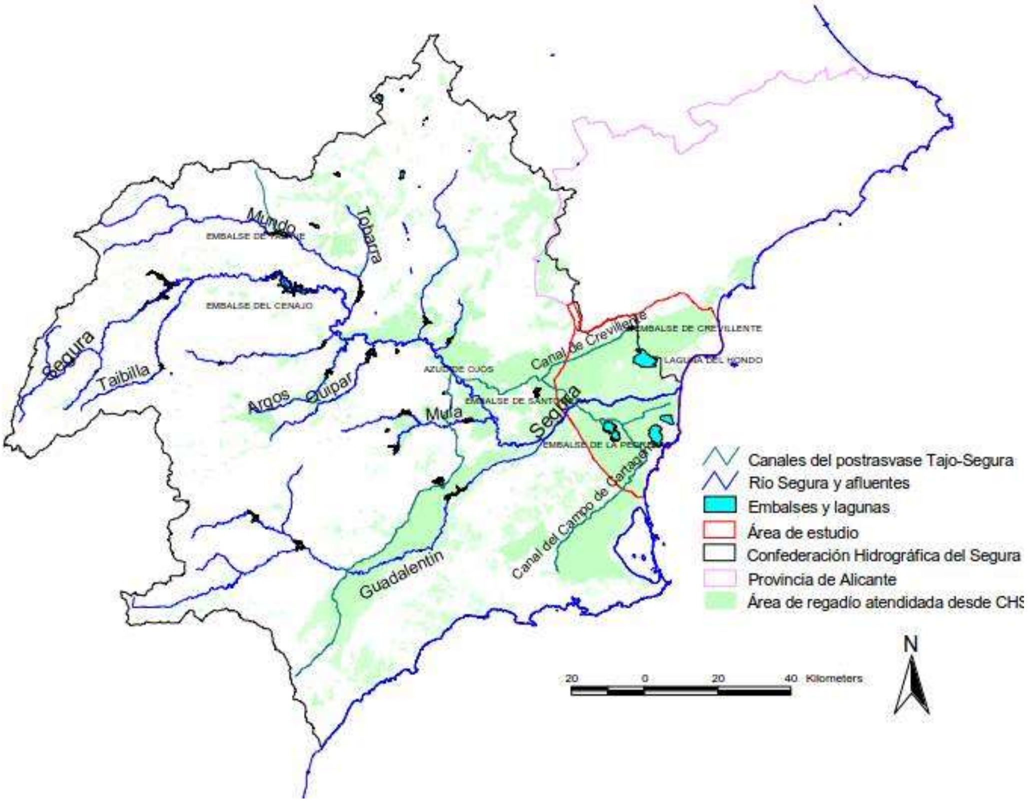


Figure 2. Detailed map of study area.

3 Methods and Tools

3.1 WEAP

3.1.1 Introduction

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 3). 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).

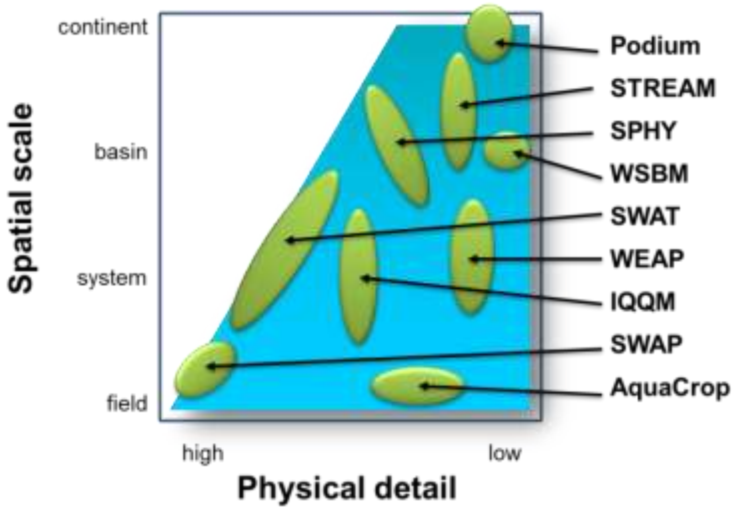


Figure 3. Relation between spatial scale and physical detail in water allocation tools. The green ellipses show the key strength of some well-known models (Droogers and Bouma, 2014).

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.

3.1.2 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[a]
        - Soils
        - Land cover
        - Headflow salt concentration
        - Evaporation and transpiration

    - Dynamic data
        - Climate (precipitation)
        - Irrigation water demands (water use rates and weekly variation)

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

▪ 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 the Spanish Ministry of Agriculture, Food and Environment[4]. The following sections will summarize the building of the model, details can be found in the model input data itself.

3.1.3 Model components

3.1.3.1 Boundary, area extent and background layers

Figure 4 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.

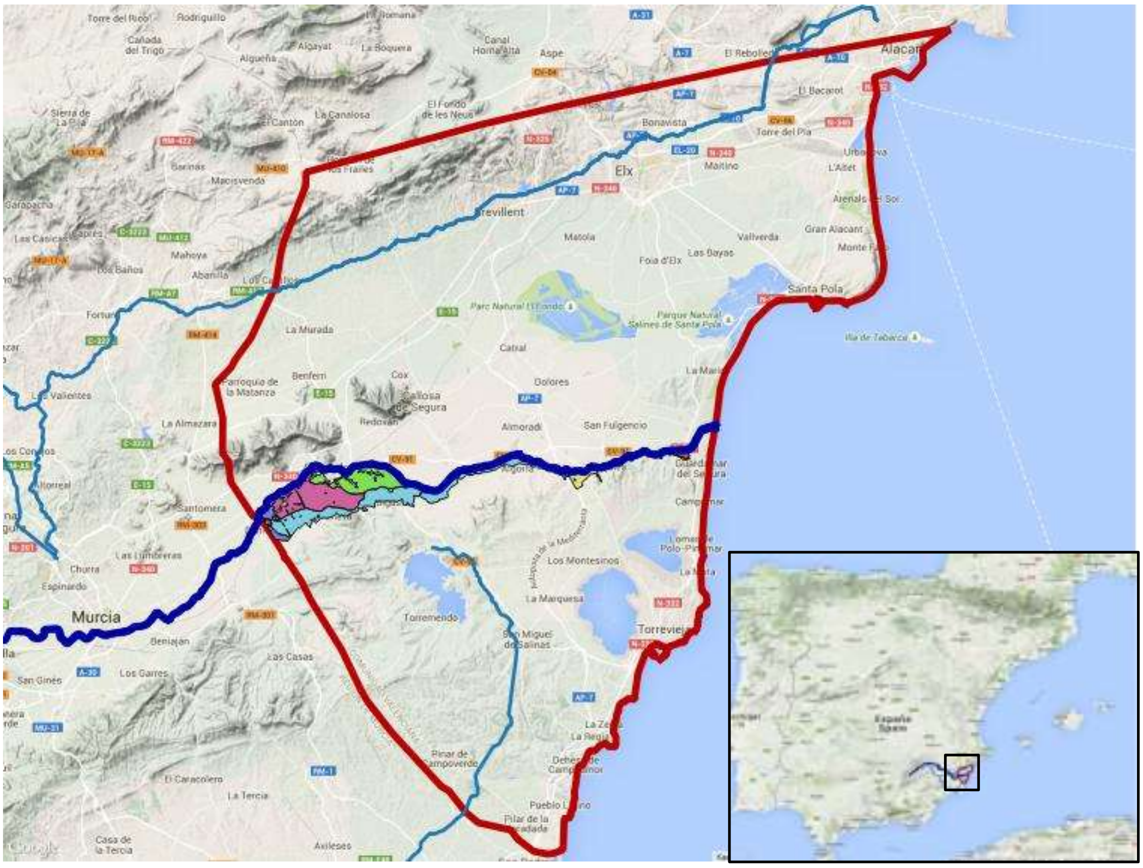


Figure 4. Pilot area extent.

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 5):

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

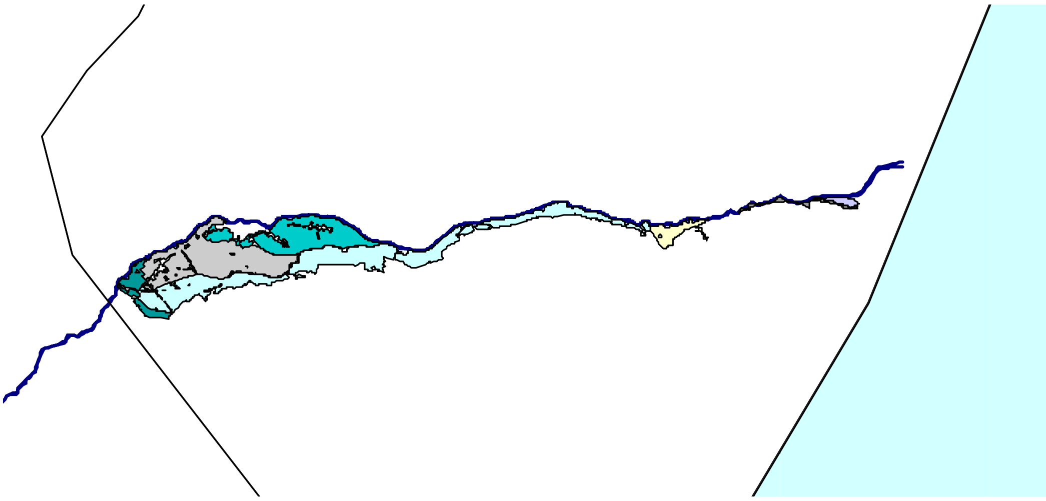


Figure 5. Various background layers used to support model building in WEAP.

This data was obtained from the Institut Valencia D'Investigacions Agraries[5].

3.1.3.2 Irrigation districts

A total of 7 irrigation districts have been identified. Table 1 shows the different areas including land cover.

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

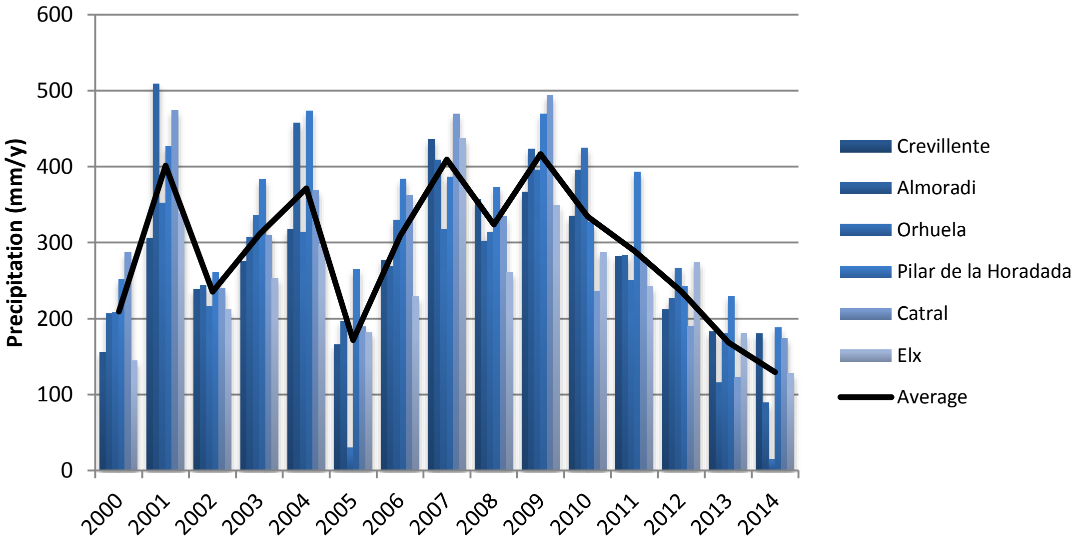
Name	Arable crops (ha)	Citrus (ha)	Pomegranate (ha)	Total agriculture (ha)	Total area (ha)
1. Moquita	42,9	117,1	0	160,0	164,7
2. Molina	307,4	634,8	0	942,2	946,3
3. Huertos	264,4	394,7	0	659,1	682,7
4. Alquibla	115,7	1151,9	0	1307,6	1370,4
5. Benijófar	55,6	75,7	0	131,2	133,8
6. Rojales	20,2	15,1	0,2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

3.1.3.3 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[6]. 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.



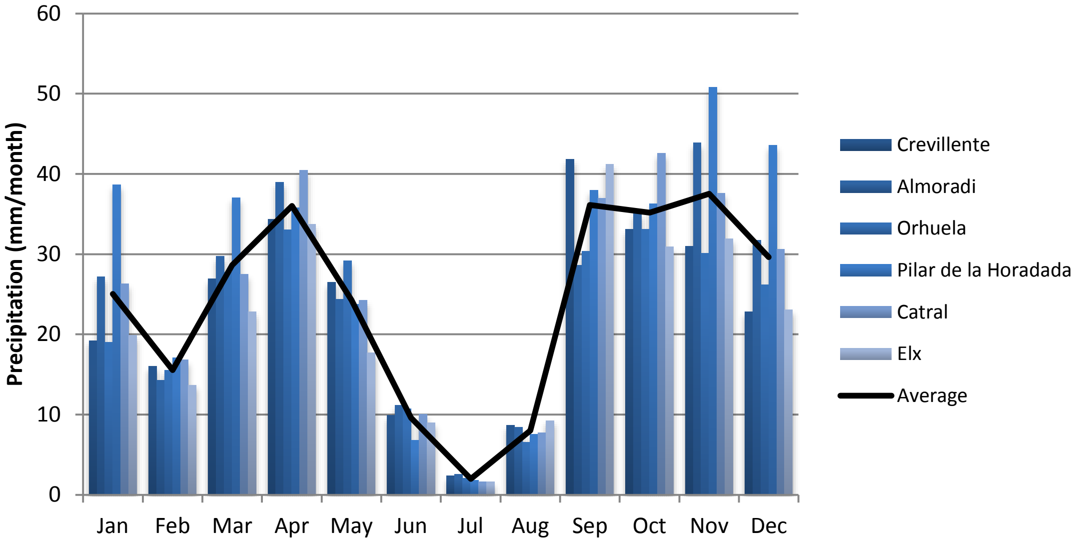


Figure 6. Precipitation data from 6 weather stations close to the pilot area (top: precipitation per year, bottom: 15-year average precipitation per month).

3.1.3.4 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 7). These values can easily be changed in the model.

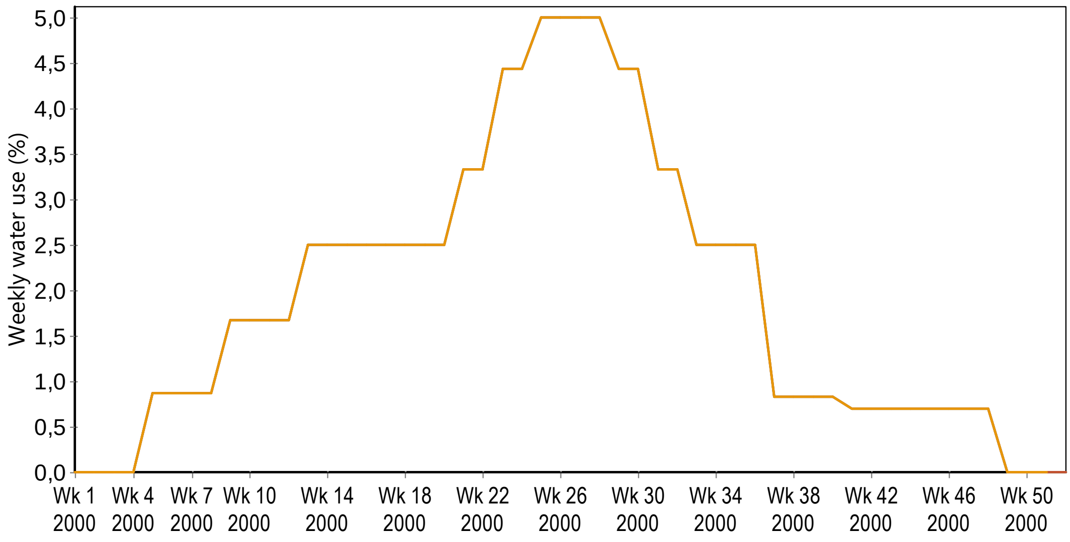


Figure 7. Weekly variation in water use.

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 (Research Institute 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.

3.1.3.5 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

3.1.3.6 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.

3.1.3.7 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[%])

3.1.3.8 Minimum outflow requirement

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

3.1.3.9 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).

3.1.4 Schematic overview

Figure 8 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)

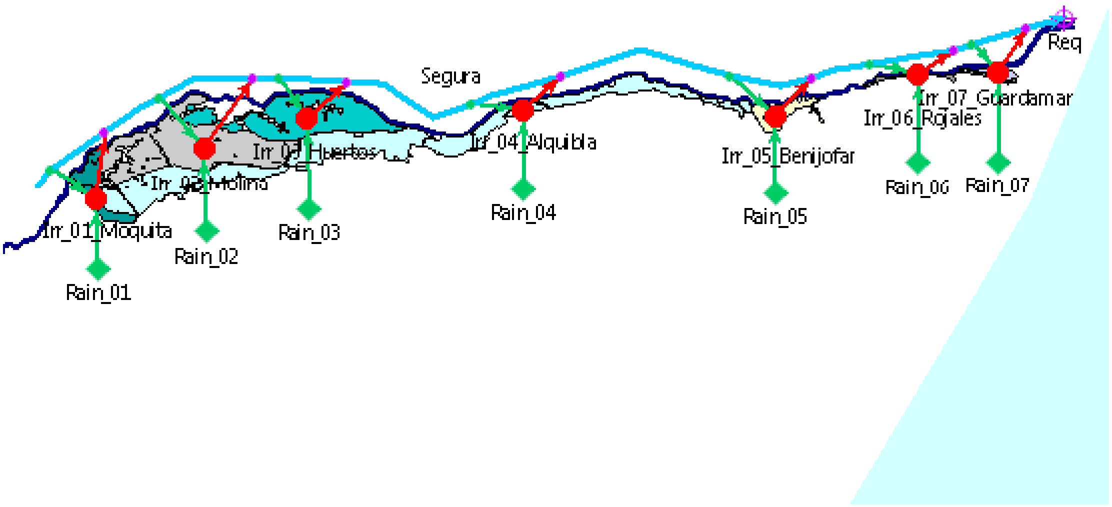


Figure 8. Schematization of the WEAP model.

3.1.5 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[7]. 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.

3.2 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 2. Variables used in business case calculations.

	Arable	Citrus	Pomegranate
Threshold Level (dS/m)[8,9,10]	2,0	1,5	1,3
Slope Salt Stress (% / dS/m)[9,10,11]	10	15,5	15
Potential Yield (kg/ha)[9,11]	20000	25000	30000
Crop Price (EUR/kg)[12,13,14, 15]	0,50	0,60	0,50
Average farmer area (ha)[16]	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 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 were calculated in EUR/ha were calculated.

4 Results

4.1 WEAP

4.1.1 Water quality

4.1.1.1 Inflow water quality

Figure 9 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.

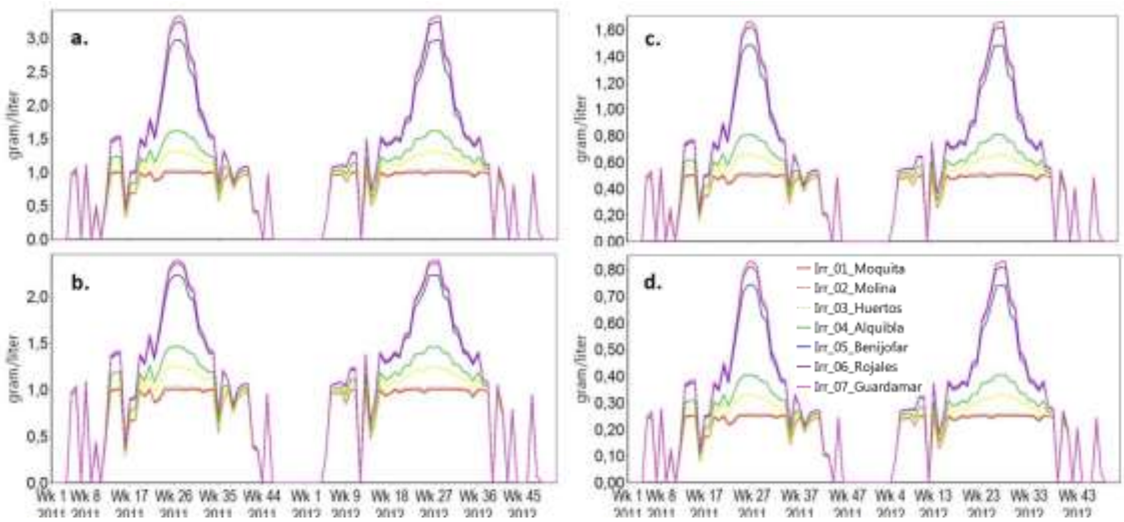


Figure 9. District inflow water quality (precipitation and irrigation water mixed) in different irrigation districts, in 2011 and 2012, for the a. reference, b. subsurface irrigation, c. 50% desalination and d. 75% desalination scenarios.

4.1.1.2 River water quality

Figure 10 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.

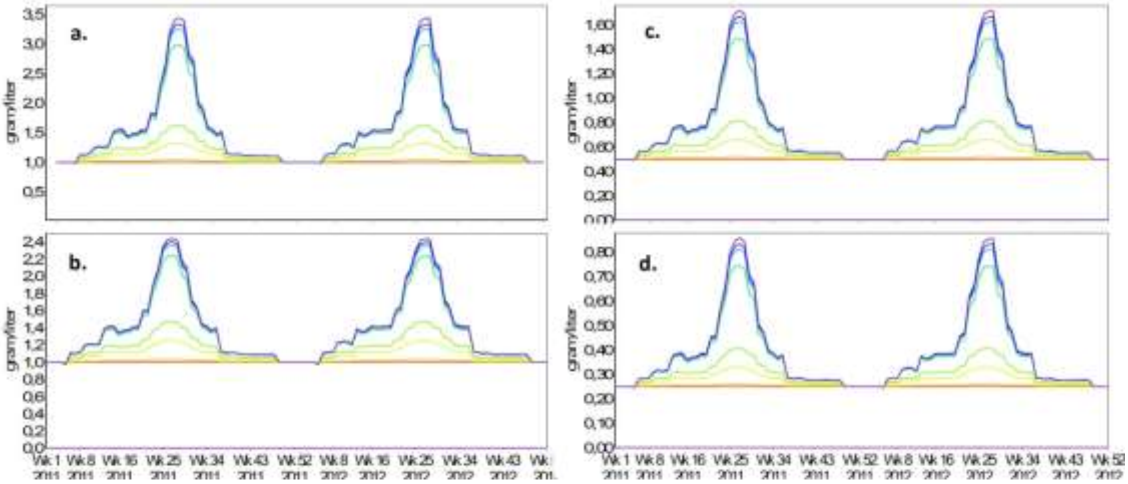


Figure 10. Segura river water quality from upstream (red) to downstream (blue), in 2011 and 2012, for the a. reference, b. subsurface irrigation, c. 50% desalination and d. 75% desalination scenarios.

4.1.2 Water supply

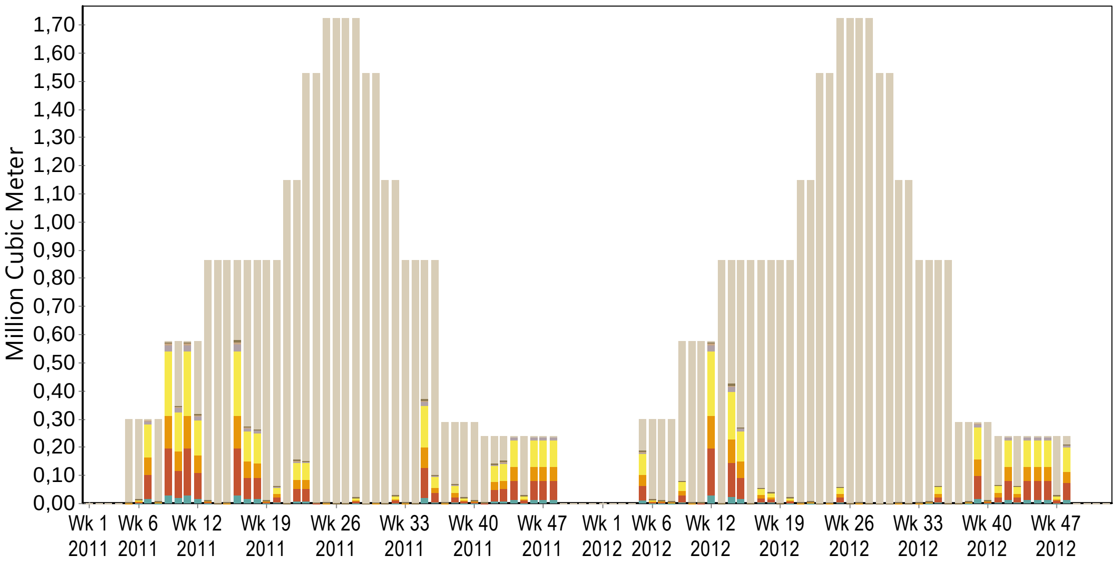


Figure 11 shows the total supply of irrigation water delivered to all districts in the reference scenario. The coloured bars show the amount of precipitation, which is different for each district because of the difference in area, and the grey bars represent the amount of additional water supplied from the Segura river for irrigation purposes

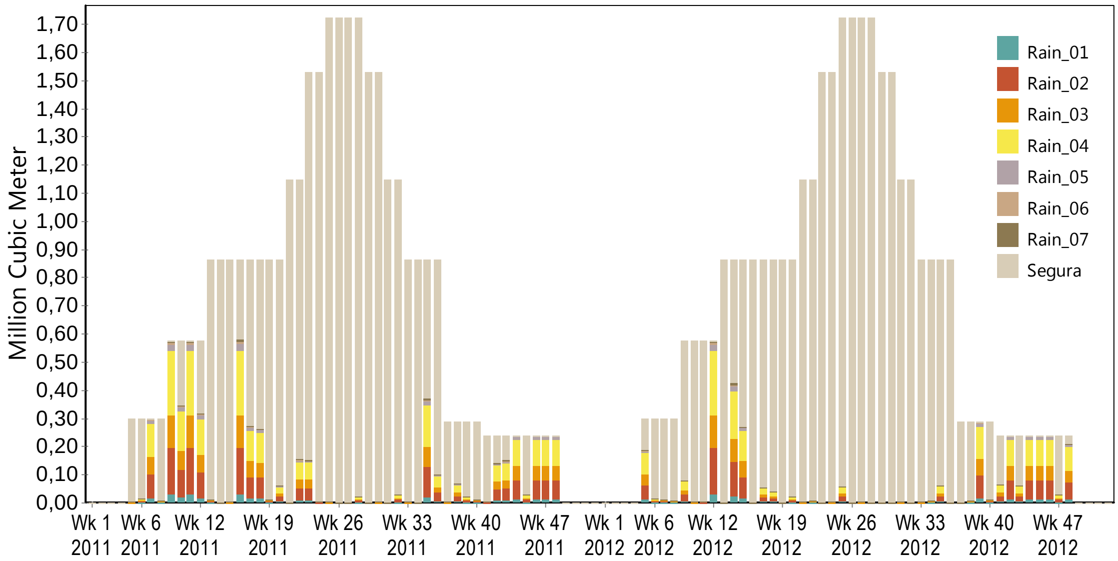


Figure 11. Total supply delivered to all demand sites by different sources (precipitation and irrigation), in 2011 and 2012, for the reference scenario.

For the subsurface irrigation scenario, the required amount of additional Segura water is around 6% less (Figure 12). For the desalination scenarios, the water supply is the same in the reference scenario.

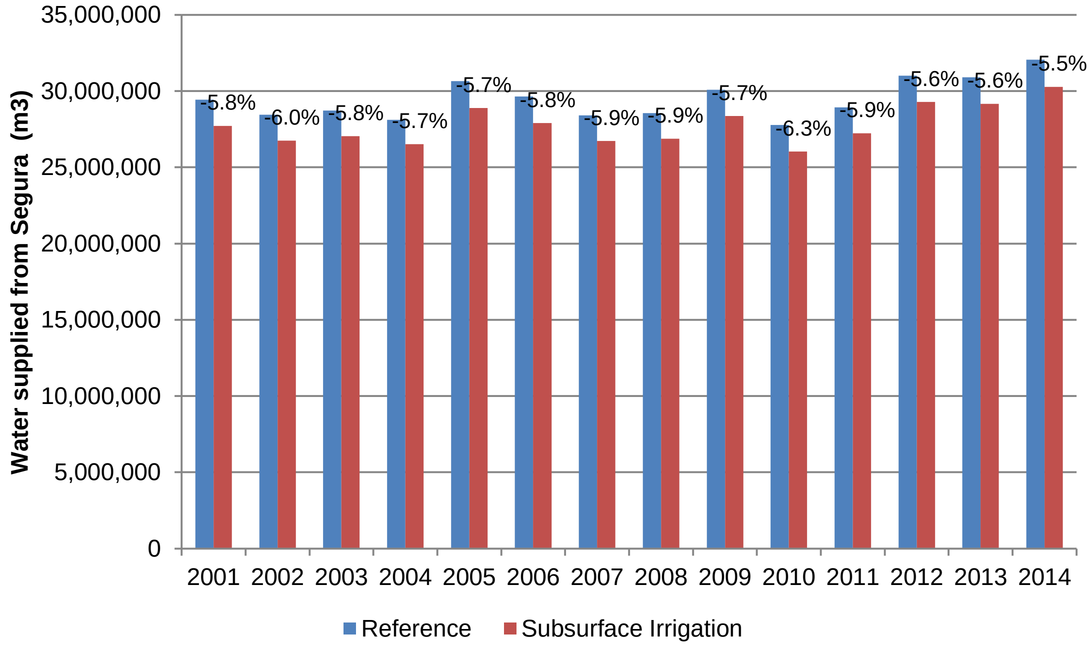


Figure 12. Yearly total water supply from the Segura River to the whole pilot area.

4.2 Business case

4.2.1 Crop benefits

Figure 13 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.

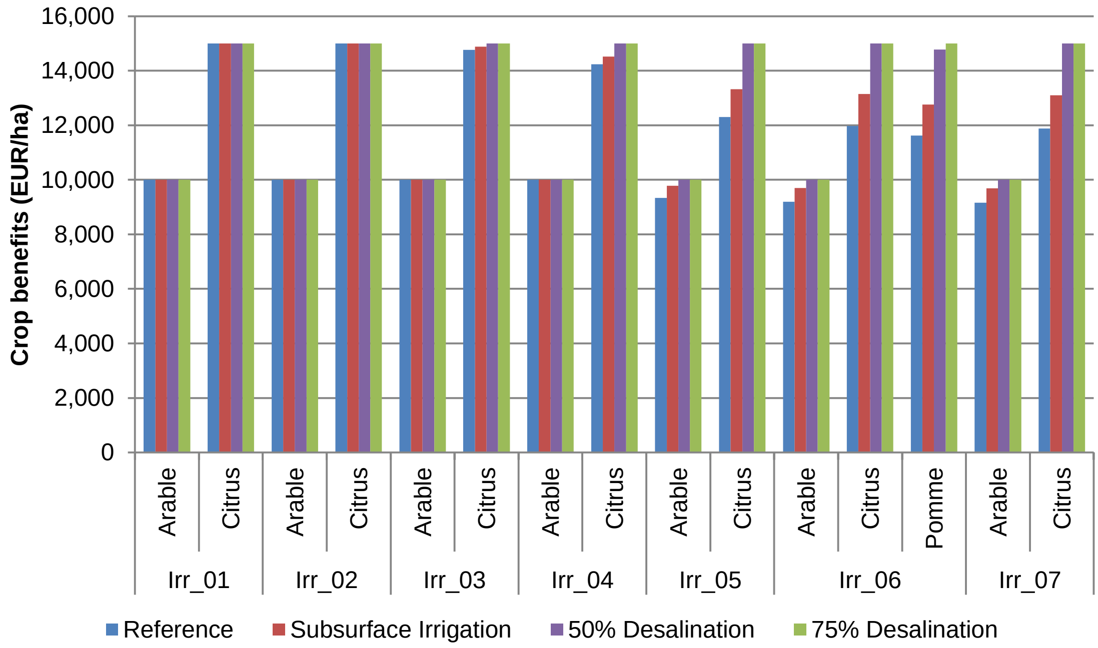


Figure 13. Crop benefits per area, 15-year average.

In the whole pilot area crop benefits for the subsurface irrigation and desalination scenarios increase with about 1,3% and 3%, respectively (Figure 14).

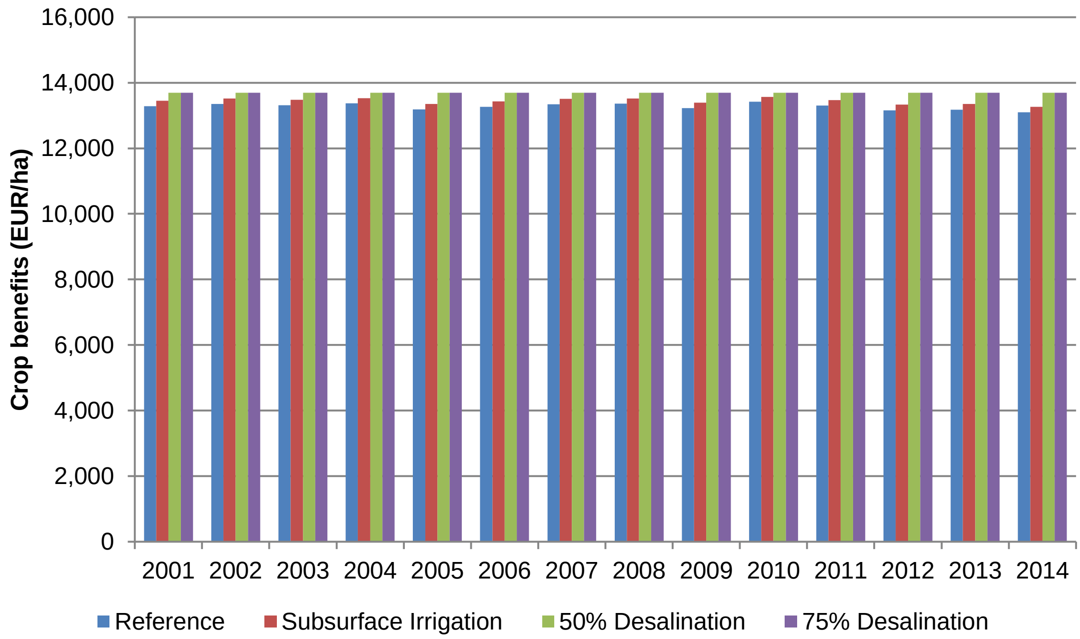


Figure 14. Average pilot area crop benefits per year.

4.2.2 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 15.

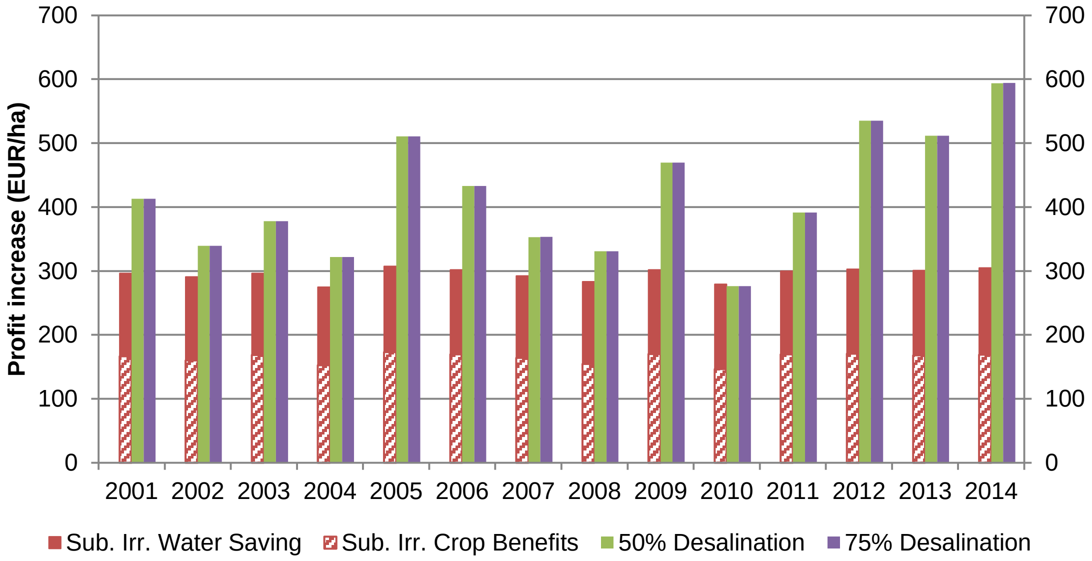


Figure 15. Profit increase due to increase in crop benefits and water savings.

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 3. 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

5 Conclusions and Recommendations

In this scoping study, SWAP model results were used 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.

6 References

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2 Wageningen University, Droevendaalsesteeg 4, 6708 PB Wageningen, The Netherlands

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

Appendices

Appendix A. Excel sheet: FWOO_InputData
Appendix B. Excel sheet: FWOO_WEAP_CalcYield