REmote sensing-based Dss for Sustainable Drought-adapted Irrigation Management

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“Halting desertification in Europe”

European Commission DG-ENV – D1

Technical Report

Reporting date: September 2012
Covering the period: January 2011- June 2012
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Consortium: UPCT / IMIDA / CEBAS-CSIC / UCO / AFRE

Final version

REDSIM Technical Report

Halting desertification in Europe

Contents

0. Executive Summary

REDSIM is a pilot project carried out within the framework of the “Halting Desertification in Europe” programme, supporting EC – DG Environment in addressing problems in water management with particular emphasis on the implementation of the Water Framework Directive and the European Water Scarcity and Drought Policy. The full project title is “Remote-sensing based DSS for Sustainable drought-adapted Irrigation Management” (REDSIM). The project was coordinated by the Universidad Politécnica de Cartagena (UPCT), Spain.

The REDSIM project period was January 2011 to June 2012. The target basins were the Upper Guadiana River Basin and Segura River Basin, southeastern Spain. Practically all the key institutes and organizations acting in these basins were involved in the project as partner or stakeholder (basin authorities, irrigators' associations and research institutes).

Goals and objectives met

The objective of REDSIM was improving Irrigation Water Productivity (IWP) in these two water-stressed watersheds, by developing and validating an Information-Decision Support System (REDSIM-IS) based on remote sensing data and simplified water balance and crop models to assist growers in implementing and managing efficiently deficit irrigation (DI) techniques.

Key activities carried out were the (1) setting up and calibration of the REDSIM information system (REDSIM-IS) and derived farm advisory tools, (2) the mapping and prediction of soil and crop attributes, surface fluxes, rainfall, soil water balance and IWP, and (3) the implementation and monitoring of the irrigation treatments in pilot farms, on-farm evaluation of the acceptance of the REDSIM tools.

The REDSIM information system was successfully implemented during the project and farm-level evaluation has been done with a group of farmers. Deficit irrigation strategies were tested in various crops during the project period and results were synthesized for dissemination among farmers. The REDSIM trials showed that IWP can be increased by around 20% in citrus orchards and melons, 30% in Nectarines orchards and about 60% in vineyards, compared to conventional irrigation strategies.

Given the importance of these crops in the Mediterranean areas, and the fact that the level of knowledge and number of tools for DI are increasingly available to farmers, REDSIM confirms that there is a significant potential to increase the economic output of irrigation water in these areas, and to promote its sustainable use. Farmers should however have easy access to this knowledge (guidelines brochure of REDSIM, capacity building, demonstration projects), and should be supported through REDSIM-like information systems.

Key findings, results and recommendations:

- The potential to increase water productivity by changing irrigation practices is substantial, even in irrigation districts equipped with modern infrastructure (e.g. Campo de Cartagena, S-E Spain) where drip irrigation is fully implemented. Over-irrigation is common and deficit irrigation techniques are hardly practised due to the lack of proper crop-specific guidelines and information systems that provide the necessary information on crop water demands.

- Fine-tuned drip irrigation may, in combination with deficit irrigation techniques, ensure that these saving potentials are exploited. Water consumption can be reduced and IWP increased by up to 40% for different fruit crops. Farmer information and advisory systems are essential to support these water saving strategies.

- To this end, irrigators should become acquainted with the use of advanced irrigation management tools and become more familiar with deficit irrigation techniques, through better science communication, demonstration projects and capacity building. This is likely to have a beneficial impact on the water productivity and sustainability of irrigated agriculture in semi-arid European basins.
- Certainly, economic incentives are deemed necessary to motivate irrigators to adopt and successfully implement advanced irrigation methods and supporting tools. Also irrigators' associations can play a key role in fostering DI and its uptake by farmers.
- Combining and processing ground and RS-based spatial datasets of crop/soil indicators within integrated information/advisory systems is highly recommendable for optimizing irrigation management and increasing WP. In particular, there is scope to include radar-based rainfall mapping (QPE, quantitative precipitation mapping) in plot-level irrigation planning, especially in Mediterranean areas where rainfall is extremely variable in space and time.

Actual water savings

The water savings and economic advantages of applying regulated deficit irrigation (RDI) supported with REDSIM tools, can be summarized as follows:

1. The yield of the nectarine cultivar studied was insensitive to 25 % less irrigation, if programmed in the right growth period (regulated deficit irrigation), which means a significant increase in IWP.
2. The trials done at the mandarin pilot farm confirmed the feasibility of the RDI strategy during the second stage of mandarin fruit growth, potentially saving up to 30% of water.
3. For melons, RDI allows water savings of around 18% compared to plots conventionally irrigated, without affecting yields and fruit quality, increasing water productivity to 12.4 kg m-3.
4. For grapevines, RDI allows savings up to 60% compared to plots conventionally irrigated, without affecting yields or even sometimes increasing them, depending on the variety.

Sustainability and transferability

The REDSIM information system and the data- and tool-integrating approach, was warmly welcomed and positively evaluated by stakeholders in the study areas. Also, regional authorities have been positive about its development and see potential in its use. Unfortunately however, no funds have been secured yet for maintenance, further dissemination and future improvements. Nevertheless, until the end of 2012, the online components will be maintained and updated continuously from existing resources. In the meantime, new initiatives and proposals are being launched to regional and EU programmes to further enhance the tool and foster its uptake.

As argued before, fostering deficit irrigation techniques, supported by REDSIM outcomes (tools, information system, guidelines), holds the potential to increase irrigation water productivity significantly, especially in the Mediterranean basin. No major technical barriers are foreseen for transferring the REDSIM tools to other water-scarce regions in Europe. However, the following issues are considered important for successful uptake:

- Risk-adversity and lack of knowledge about deficit irrigation techniques by farmers is a key barrier for uptake. Nowadays, for many key crops, enough knowledge is available that is yet to be communicated to farmers, through for example the REDSIM guidelines (Annex VII), demonstration projects and other. Also, REDSIM confirmed that a participatory approach for the implementation of farm advisory support is recommended to adapt design to local preferences and knowledge

- Information on rainfall is currently scattered among different organizations and institutes within the same basin, as is the case in the Segura Basin, but also in several other drought-prone basins in Europe. A key outcome of REDSIM is the successful integration of all available networks, including remotely-sensed rainfall radar, providing a product that gives farmers plot-level information on the amount of rainfall during the latest hours and other data. The key barrier to be dealt with is the institutional setting in each basin, that may limit the exchange of data for other purposes than those that are supported by the organization itself.
- Even with low investment requirements, farmers will only adopt new irrigation techniques when they find some type of economical incentive, depending on the marginal financial benefits in optimizing their water use in each region.

1. Introduction

This final report summarizes the results and findings of the REDSIM project: one of the four pilot activities contributing to the exchange of good practices and innovation at the local level for halting desertification in Europe, funded by the European Commission, DG Environment. Outcomes of REDSIM should feed into the EU Policy Review of the Strategy for Water Scarcity and Droughts, and will be integrated in a "Blueprint to safeguard European waters", to be finalised by the end of 2012. REDSIM started in January 2011 and finished in June 2012.

The overall objective of REDSIM is to improve Irrigation Water Productivity (IWP) in water-stressed watersheds, by developing and validating an Information-Decision Support System (REDSIM-IS) based on Remote sensing (RS) information and simplified water balance and crop models to assist growers in implementing and managing efficiently deficit irrigation (DI) techniques. More details on the background and methodology can be found in the project proposal.

The following points summarize the project:

- Full project title: Remote-sensing based DSS for Sustainable drought-adapted Irrigation Management (REDSIM)
- Target country: Spain. Target regions: Upper Guadiana River Basin (UGRB) and Segura River Basin (SRB)
- Principal beneficiary: Universidad Politécnica de Cartagena (UPCT)
- Contact person: Alain Baille, Full Professor, Department of Food and Agricultural Engineering
- Involved partners:
    - IMIDA (Instituto Murciano de Investigación y Desarrollo Agrario)
    - CEBAS-CSIC (Centro de Edafología y Biología Aplicada del Segura - Centro Superior de Investigación Científica)
    - UCO (Universidad de Córdoba)
    - AFRE (Asociación de Fabricantes de Riego Españoles)
- Involved stakeholders:
    - CHS (Segura Basin Hydrological Confederation)
    - CAG (Consorcio del Alto Guadiana)
    - AEMET (Agencia Estatal de Meteorologia)
    - FENACORE(Federación Nacional de Comunidades de Regantes)
- Grant agreement number: 07.0316/2010/581763/SUB/D1

During the project period, each quarter a progress report was presented, including the planned deliverables as annexes (see Table 4 for overview). This final report summarizes the activities (Chapter 2), results (Chapter 3) and key findings (Chapter 4) of the entire project period (January 2011 - June 2012).

2. Activities

This chapter provides an overview of the activities carried out during the project, the corresponding deliverables and a description of their final status (Table 1). Figure 1 shows a graphical representation of the links and feedback between the issues/tasks addressed in REDSIM and the outputs corresponding to each issue/task. REDSIM is divided in eight tasks (A to H) that can be classified into three main groups (more details can be found in the project proposal):

- **Tasks A to E:** Tasks related to the design, elaboration and prototyping of the information system and management tool
- **Tasks F and G:** Tasks related to validation and valuation (Ground truth and irrigation performance assessment), and identification of gaps, drawbacks and improvements
- **Task H:** Tasks related to demonstration/dissemination/training

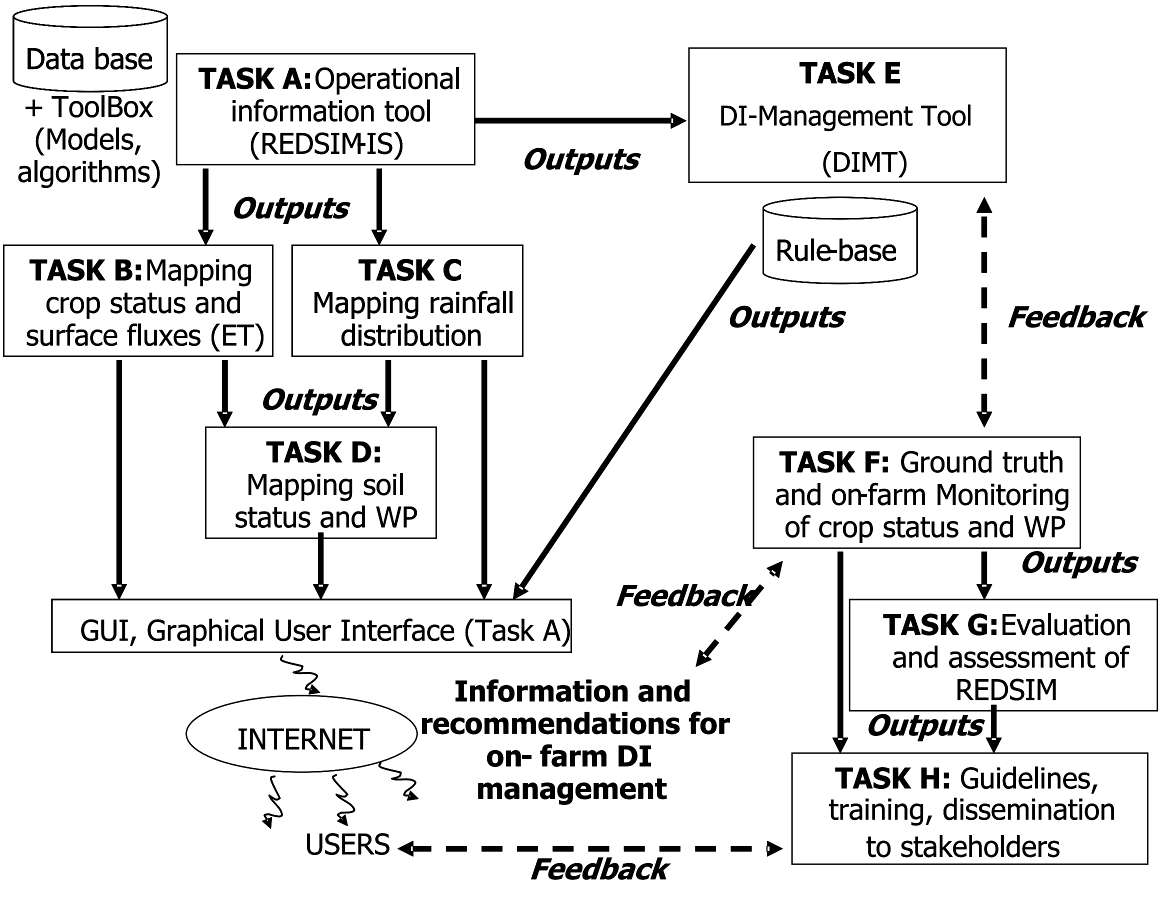


Figure 1. Graphical representation of links and feedback between the issues/tasks addressed in REDSIM and outputs corresponding to each issue/task (WP = Water productivity, ET = Evapotranspiration, DI = deficit irrigation).

Table 1 Activities undertaken during project period, REDSIM

Title	Brief description	Deliverables	Implementing body	Final status
A1. Assembling and coupling the different elements of REDSIM-IS A2. Development of a user's friendly interface (REDSIM-GUI) and alpha-tests of the information tool	A1: Communication protocols between servers will be implemented, the typology of spatio-temporal information and model outputs will be defined, UPCT Server Toolbox will be incorporated, protocols of answers to potential users will be defined A2: Graphical User Interfaces for UPCT and IMIDA servers will be made and specific queries from potential users will be defined	A-d1. Report on the architecture, components and prototyping of REDSIM-IS A-d2. Report on the alpha-tests of REDSIM-IS A-d3. Report on the Graphical User Interface (GUI) A-d4. REDSIM-IS and RDSIM-GUI prototypes are available	M. Erena, J.A. Lopez-Morales (IMIDA) S. Garcia (UPCT)	The REDSIM information system was successfully launched according planning and will remain operational after project, supported by REDSIM-partner IMIDA. Deliverables are finished, and reports were included in previous quarterly progress reports (see Table 4).
B1. Mapping of crop stress indicators B2. Mapping of land evapotranspiration (ET) fluxes	B1: Maps will be made of crop stress indicators (CWSI, WDI, TVDI, VTCI, etc.) derived from the analysis of the space LST-NDVI and from the ratio ET/ETc (ETc = standard crop evapotranspiration calculated by the FAO-56 Penman-Monteith method) B2: ET-maps and energy balance maps will be provided for the main irrigation schemes of the SRB.	B-d1. Report on methodological and practical issues in mapping crop stress indicators and surface fluxes B-d2. Report on algorithms and models used to mapping crop stress indicators and surface fluxes B-d3. Final synthesis report on mapping Soil/Crop Attributes and Surface Fluxes	Alain BAILLE, Sandra GARCIA (UPCT)	Building on previous research and applications, the tools that will deliver the maps of ET fluxes and crop stress are operational. Corresponding reports were included previously as annex (see Table 4).
C1 Real time precipitation data management C2 Automated Quality Control (QC) implementation for QPE C3 Multi-sensor Precipitation Estimates (MPE) implementation	C1: communication protocols between servers and adaptation of data formats as eventually required by the MPE processing system will be implemented C2: A software implementation to automate the QC protocols to prepare data sets to be integrated into the MPE algorithm (CMA-OAS). C3: The precipitation product will be integrated into the REDSIM-IS	C-d1. Implementation of communication protocols between servers. Development of queries for integration of multisource precipitation data C-d2. Report on the quality control. Implementation and tests of software for QC on IMIDA server. C-d3. Report on the algorithms to be implemented for MPE.	Gonzalo González (CSIC), Javier García (CSIC), Manuel Erena (IMIDA)	The deliverable is currently fully operational. MPE are available at hourly intervals. It is produced in a format and geographic projection available for the other tasks. The product is available for other applications different to those of REDSIM.

		Implementation of MPE software in the IMIDA/Ben Arabi server C-d4. Implementation of algorithms to map the Grid Topology of the vector radar MPE mesh into the data requirements of Task D		
D1 Mapping of soil water status over the Segura and Upper Guadiana Basins D2. Mapping of water productivity (WP) over the Segura and Upper Guadiana Basins	D1: Calibration and validation of soil water balance models and spatio-temporal evolution of soil moisture over irrigated zones of SRB and UGRB D2: Maps describing the spatial distribution of crop yield, water consumption and water productivity in the SRB and UGRB	D-d1. Report on methodological and practical issues in mapping soil water status (m3) D-d2. Report on algorithms and models used to mapping WP (m6) D-d3. Final synthesis report on mapping soil water status and WP (m9)	Alain BAILLE , Johannes Hunink, M. González-Real (UPCT), M. Garcia Vila, E. Fereres (UCO),	Soil water and water stress modelling and its integration within the information system was completed. The synthesis report (D-d3) is included as annex in this final report. The other reports were included in progress reports (see Table 4)
E1. Early-prototyping of the DI-Management Tool (REDSIM-DIMT) E2. Coupling REDSIM-DIMT to REDSIM-IS	E1: A prototype of the DI-management tool will be available to provide recommendations to farmers. E2: REDSIM-DIMT will be operational for providing recommendations to farmers through the users interface (GUI)	E-d1 Report on the architecture, components and prototyping of the DI-Management Tool (DIMT) E-d2. Report on the alpha-tests of REDSIM-DIMT E-d3, Prototype of REDSIM-DIMT is available	J.E. Hunink, G. Egea, B. Martin, A. Mertens, A. Baille (UPCT), Diana Sanchez (IMIDA))	Tests and evaluation has been finished. Reporting was included in previous progress reports (see Table 4).
F1. Design and implementation of crops and irrigation treatments in pilot-farms F2. On-farm monitoring of crop response to irrigation treatments	F1: - Implementation of the required experimental set-up and acquisition of the required ground data and performance indicators required to benchmarking of farm practices in the pilot areas, and direct demonstration of water savings on the farms F2: Reference ground data on crop behaviour and water use in different DI treatments, evaluation of the performance of the different irrigation strategies, yield, quality and water productivity assessment at the farm level	F-d1. Report on field implementation and monitoring of the irrigation treatments (m3) F-d2. First activity report on on-farm monitoring (m6) F-d3. Second activity report on on-farm monitoring (m12)	J. J. Alarcón, O. Mounzer (CEBAS - CSIC) and R. Domingo (UPCT) for the SRB pilot studies M. García-Vila and E. Fereres (UCO) for the UGRB pilot studies	Field implementation and monitoring reports were included in the previous progress reports (see Table 4).

G1. On-farm evaluation of REDSIM performances with respect to technical and economic criteria G2. Overall assessment of REDSIM in terms of viability, robustness and adoption by farmers	G1:advantages/shortcomings of REDSIM with respect to different criteria/indicators will be highlighted and gaps to be filled and recommendations for improvement will be identified G2:advantages/shortcomings of REDSIM with respect to farmers' perception and acceptance will be determined and gaps to be filled and recommendations for improvement will be identified	G-d1. Report on benchmarking and evaluation of REDSIM-IS against agronomic and economic criteria (m15)) G-d2. Report on overall assessment of REDSIM viability, usability and robustness for drought-adapted irrigation management based on remote sensing information (m15)	B. Martin, V. Martínez, R. Domingo (UPCT), F. Alcón, S. Tapsuwan, A. Mertens (UPCT)	Evaluation activities were successfully finished, reporting included as annex in this final report.
H1. REDSIM web-site maintenance and actualisation H2. Guidelines, manuals and brochures, demonstration field days	Dissemination products	H-d1. REDSIM web-site operational (m3) H-d2. Restitution workshops and demonstration days at Segura and Upper Guadiana pilot sites (m15) H-d3. REDSIM guidelines and brochures (m15)	P. González-Cebrían, R. Morcillo, M. López Estebaranz (AFRE)	The REDSIM website (www.redsim.net) has become operational in april 2011, a number of public documents and project flyers have been made available at that moment. During the last months of the project period, several dissemination events took place (see Annex 1). The REDSIM guidelines are also included as annex in this final report.

3. Results

This chapter provides an overview of the results obtained. These results are presented in 3 tables (similar to the REDSIM progress reports):

- Table 2: Main results
- Table 3: Outcomes
- Table 4: Deliverables

Besides, Key findings are presented in Chapter 4.

The overall aim of REDSIM was to provide insight in the potential of information systems that integrate remote sensing and other datasets for the wider adoption of good irrigation management practices and environmentally sound (deficit) irrigation strategies. Table 2 summarizes the main results of REDSIM and issues and conclusions on the potential of the REDSIM approach.

Table 2 Main results of REDSIM

Aim	Results
1. Know-how on enabling and limiting factors that determine the usefulness of the information provided and the adoption of good, environmentally sound irrigation management practices (deficit irrigation) through an information system like REDSIM-IS	The REDSIM information system was successfully implemented during the project and weekly farm-specific information bulletins have been shared with a group of farmers during the REDSIM evaluation period. Insight was obtained on the constraints and requirements of such a decision-supporting information system. The following points summarize the key issues for the implementation of this type of farmer decision support: - A participatory approach, in which the targeted farmers are involved in the design process of the information system. - Only a needs analysis is not sufficient as the adoption may be inhibited due to subtle issues related with presentation, design, definitions, etc. - Clarity and flexibility in design of decision support system are key principles - For full uptake of the tools, demonstration projects are deemed necessary; participatory approach is not sufficient for adoption - Assessment of the quality of tool-based decisions is crucial for uptake, during minimum one-year period and for different crops - Involvement of extension services and irrigator associations is crucial to disseminate the use of these type of information systems - Capacity building for deficit irrigation practices is highly recommended to overcome the knowledge gap and common scepticism on this type of practices
2. Insight in the enabling and limiting factors that determine the improvement of technical skills of the users, enabling them to adapt also to future enhancements and other DSS.	The strong stakeholder participation of the project allowed obtaining knowledge on how to tailor the system to the users' (farmers) needs and constraints. From the evaluation of REDSIM the following can be concluded on the learning by farmers: - Even if the presentation of the information is kept as simple as possible, it is necessary to ensure that the users are familiar with the concepts, needs and opportunities of the tool. Capacity building activities are necessary. - The REDSIM evaluation showed that even farmers using modern irrigation equipment, are not necessarily frequent users of computers, internet or email, causing a barrier for adoption - Users should already use to some extent technological tools within their daily work (computer, smartphone, or internet). If they manage their business purely on their intuition and experience, convincing farmers to adopt an external source of additional information is complex and requires further demonstration activities. - Farmers need convincing demonstration cases that show the potential for

	considerable financial savings in order to start using new tools, - Participation in the decision support development promotes learning and exchange of knowledge between farmer and developer
3. Insight in maintenance and supervision requirements (post-implementation) for REDSIM-IS.	For REDSIM to be successfully implemented, continuously updated information (remote sensing, model and expert input, etc) is required. Resources needed for the REDSIM-IS system to be operational (after implementation) are: - Hosting of website - Licenses for commercial geodatabases - For rainfall radar component: calculation time on supercomputer - 25 hours/month of technical staff for check of data processing - 25 hours/month of technical staff for monitoring communication with supercomputer for rainfall radar algorithm - Additional resources for the generation of weekly REDSIM advisory bulletins: 40 hours/month for supervision and data control (for around 100 farmers) Besides, continuous evaluation and updating with the latest knowledge on irrigation scheduling practices is recommended, requiring an adequate science-user interface. Given the positive evaluation and feedback from users and regional authorities, there is a strong will to secure funds for maintaining the system, reaching more users, and allow future updates and improvements. Regional programmes for agriculture as well as EU programmes are being evaluated to prepare proposals in this direction. The goal is to offer REDSIM-IS as the principal irrigation advisory platform to farmers and other stakeholders. Currently, the system is being maintained from existing resources, as no funds have been secured so far.
4. Determining factors for migrating REDSIM-IS or similar system to other water-stressed agricultural regions in Europe	The following requirements to transfer results from REDSIM, and implement the REDSIM tools in other water-stressed agricultural regions of Europe are highlighted, in terms of resources and other conditions: Resources: 1. Low-cost or free availability of data from agro-meteorological network, 2. Skilled staff in extension service to configure and maintain information system and for capacity building activities. 3. Pilot sites within the region for demonstration activities 4. For rainfall-radar component of REDSIM-IS: supercomputer required for resource-intensive data processing Other conditions: 1. It has become clear by discussing this with the 3 parallel projects within the Halting Desertification programme, that in many regions in Europe, the marginal financial benefits in optimizing water use are low, which limits the potential for successful uptake of innovative technologies. 2. Involvement and participation of irrigation associations and stakeholder organizations are crucial for adoption. However, in several agricultural areas, also in Spain, farmers are hardly organized within such an organization. This makes it difficult to reach the final users and involve them in the design of advisory systems (participatory approach) 3. Farmers are typically experience-based-learners, so local demonstration projects are deemed necessary.

During the project, several indicators were selected to monitor the progress. Table 3 provides a summary of the results in terms of these indicators, and the extent to which the objectives of REDSIM have been met. More details can be found in the deliverables included as Annex.

Table 3 Outcomes related to monitoring indicators, REDSIM

Results	Indicators	Source of data	Comments
Objectives			
Overall objective: Improve Irrigation Water Productivity (IWP) in water-stressed watersheds, by developing and validating an Information-Decision Support System (REDSIM-IS) based on Remote sensing (RS) information and simplified water balance and crop models to assist growers in implementing and managing efficiently DI strategies.	Indicators related to Irrigation Water Productivity (IWP) and similar	Data on Irrigation Water Productivity in pilot farms during implementation period. See project deliverables F-d3.	Field implementation of the DI strategies, and evaluation of the REDSIM tools, indicated that IWP can be increased by - around 20% in citrus orchards - about 30% in Nectarines orchards - about 60% in vineyards - about 20% in melons Other indicators (product quality-related, economical) can be found in deliverables F-d3
Specific objective 1: Development of a low-cost information-decision support system (REDSIM-IS) based on remote sensing information (satellites, ground meteorological radars, agrohydrological models (water productivity) and decision rules	Required resources (person-months)	Resources spent during set-up, testing and implementation	The following table summarizes the costs expressed in person-months for the set-up, testing and implementation of REDSIM. **Phase** — **Person-month** Needs analysis — 0.5 Design — 3 Implementation — 2 Capacity building — 0.3 Fostering uptake — 2 Monitoring and evaluation — 1.5 Maintenance — 0.3
Specific objective 2: to evaluate water savings and agronomic/economic advantages of using such a tool with respect to other irrigation strategies	Water saved compared to full irrigation in pilot plots (m3/ha)	Technical-economic evaluation and validation (task F), see corresponding deliverables	The water savings and economic advantages of using RDI supported with REDSIM tools, can be summarized as follows: - The yield of the nectarine cultivar studied was insensitive to 25 % less irrigation. Irrigation scheduling using trunk diameter sensors applied around 27% less water than current farmer practices, indicating considerable scope to save water. - The trials done at the mandarin pilot farm confirmed the feasibility of the RDI strategy during the second stage of mandarin fruit growth. Also it stressed the importance of continuous soil water monitoring when larger deficits are applied (50%Etc), saving up to 30% of water. - For melons, RDI allows water savings of around 18% compared to plots conventionally irrigated, without affecting yields and fruit quality, also water productivity increases considerably up to 12.4 kg m-3. It was confirmed that an increase of planting density has no significant effect on the irrigation water productivity. - For grapevines, RDI allows savings up to 60% compared to plots conventionally irrigated, without affecting yields or even sometimes increasing them,

Results	Indicators	Source of data	Comments
			depending on the variety.
Specific objective 3: To assess how farmers could use the elaborated information provided by the information system to derive reliable DI scheduling and decision rules, and their level of acceptance/participation in using recommendations provided by the information system	Level of confidence and adoption of REDSIM for decisions of farmers vs. output of REDSIM-IS	On-farm evaluation and benchmarking of the REDSIM information-management tool (activity G)	The surveys and evaluation carried out have revealed that there are many factors that influence the acceptance of better irrigation information by early adopters. Some factors can be improved or modified by the scientists providing the information to foster uptake. These factors include how easy the information is to understand, how realistic it appears to be, how specific is the information to each farm and how integrated is the information (water quality, quantity, climate, soil, land use, etc) with each other. Other factors are external to the bulletin but have shown to have an impact on acceptance or the bulletin, include the current financial stress driven by the economic situation in Europe and the level of water availability.
Specific objective 4: To identify constraints and gaps to be accounted for in case of the continuation of REDSIM	Required resources for continuation and gap filling	Technical-economic evaluation and validation (task F)	To increase the potential for the adoption of the DI-management tool, extension to other crop species than those addressed in this project should be envisioned. To make the information system more generic and widely applicable, further adjustments in the presentation and type of information, depending on the farmers´ objectives for each crop will be necessary. Also attention should be paid to capacity building to new users, both for the information provided as for the targeted technique (RDI).
Specific objective 5: After completion of objective 3, establishment and test of a capacity-development programme that will be tailored to the needs of the farmers, bringing together the expertise and experience of the REDSIM research and development teams.	Percentage of farmers capable and willing to incorporate the tool in their irrigation management strategies	Feedback from stakeholders and evaluation of capacity building activities (task H)	The percentage of farmers interested in implementing and using the REDSIM tool appears to be high (> 75%). The time span for evaluation was short, so a longer period of evaluation is recommended.

Table 4. is provided showing the timeline of the deliverables along the project period. The table shows also in which of the annexes of the previous progress the report deliverables can be found that are not included in this final report.

Table 4 Timeline of project as executed, and deliverables, June 2012, REDSIM

Report	Inception	Progr. #1	Progr. #2	Progr. #3	Final
Period	Jan-Mar ´11	Mar-Jun ´11	Jul-Sep ´11	Oct-Dec ´11	Jan ' 11 - Mar ´12
A-d1. Implementation of communication protocols between servers			Annex II		
A-d2. Report of identification of typology of expected spatiotemporal results from UPCT: spatial and time resolution			Annex II		
A-d3. Implementation of applications on UPCT Server			Annex II		
A-d4. Implementation of GUIs (Graphical User Interface)			Annex II		
B-d1. Report on methodological and practical issues in mapping crop stress indicators and surface fluxes			Annex III		
B-d2. Report on algorithms and models used to mapping crop stress indicators and surface fluxes.			Annex III		
B-d3. Final synthesis report on mapping Soil/Crop Attributes and Surface Fluxes.			Annex III		
C-d1. Implementation of communication protocols and synchronized data transfers between IMIDA-AEMET servers. Development of queries for automated integration of multisource precipitation data		Annex II			
C-d2. Report on the quality control (QC) protocols to be implemented for multisensor precipitation estimates (MPE). Implementation and tests of automation software for QC on IMIDA server.				Annex II	
C-d3. Report on the algorithms to be implemented for MPE and software performance tests. Operational implementation of the MPE software in the IMIDA/Ben Arabi server.					Annex VI
C-d4. Implementation of algorithms to map the Grid Topology of the vector radar MPE mesh into the data requirements established by Task D					Annex VI
D-d1. Report on methodological and practical issues in mapping soil water status		Annex III			
D-d2. Report on algorithms and models used to mapping WP.		Annex III			
D-d3. Final synthesis report on mapping soil water status and WP.					Annex II
E-d1 Report on the architecture, components and prototyping of the DI-Management Tool (DIMT)			Annex IV		
E-d2. Report on the alpha-tests of REDSIM-DIMT (m6)			Annex IV		
E-d3. Prototype of REDSIM-DIMT is available for on-farm tests and evaluation(m8)					
F-d1. Report on field implementation and monitoring of the irrigation treatments		Annex IV and V			
F-d2. First activity report on on-farm monitoring		Annex IV and V			
F-d3. Second activity report on on-farm monitoring				Annex III, IV & V	

Report Period	Inception Jan-Mar ´11	Progr. #1 Mar-Jun ´11	Progr. #2 Jul-Sep ´11	Progr. #3 Oct-Dec ´11	Final Jan ' 11 - Mar ´12
G-d1. Report on benchmarking and evaluation of REDSIM-IS against agronomic and economic criteria (m15)					Annex III
G-d2. Report on overall assessment of REDSIM viability, usability and robustness for drought-adapted irrigation management based on remote sensing information					Annex III
H-d1. REDSIM web-site operational (m3)					
H-d3. REDSIM guidelines and brochures (m15)		Annex VI			Annex VII
Meetings					
Kick off meeting					
Meeting with stakeholders Segura and UG basin					
Weekly individual meetings or communication by phone with users					
Restitution workshops and demonstration days at Segura and Upper Guadiana pilot sites					Annex I
Final meeting					Annex I

4. Key Findings

This chapter on key findings is structured in the following way:

- Overview of measures (Section 4.1);
- Inputs to the Blueprint to Safeguard European Waters (Section 4.2);
- Addressing possible indicators (Section 4.3);
- Recommendations regarding dissemination (Section 4.4).

4.1 Overview of measures

Table 5 provides an overview of effects, application, impacts and evidence base of the measures dealt with in REDSIM.

Table 5 , Overview of measures

Effect on Local Water Balance	Category of measure	Type of measure	Application / activity / process	Result	Impact	Preconditions or prerequisites (incl. governance issues)	Estimated cost	Side effects / comments	Up-scaling / transferability / sustainability	Evidence base
Decreasing demand	Improving Irrigation Practices	Deficit irrigation, Precision irrigation	Regulated deficit irrigation (RDI) and Partial Root Drying (PRD) for fruit trees	Reduction water consumption up to 40% , increased water productivity	HIGH, but depending on fruit species and variety, and on the farmers´ objective in terms of fruit quality, which is directly related with the market demand	Requires skills, and guidelines specific for each species and variety (see also REDSIM brochure), and continuous monitoring of the crop status by field visits, possibly supported with information system and sensoring to control risks. Requires also economical incentives (see section 4.2)	50-300 €/ha of irrigated land	Fertilizer use can also be optimized simultaneously with resulting environmental benefits. Besides: empowerment of irrigators and the increase of environmental awareness	- Very transferable to other areas of EU given the high fruit production in Mediterranean zone - Requires capacity building and tools to provide farmer with the relevant information and guidelines - Requires irrigation advisory service	REDSIM experimental farms and data from projects focused on this technology carried out by UPCT and CEBAS in Segura River basin, Spain.
Decreasing demand	Improving Irrigation Practices	Deficit irrigation, Precision irrigation	Regulated deficit irrigation (RDI) for melon and grapevines	Reduction of water consumption up to 18%. Increase of irrigation water productivity up to 11%	Idem	Idem	50-100 €/ha of irrigated land	Idem	Idem	REDSIM pilot farms in Upper Guadiana River Basin, Spain.
Decreasing demand	Improving Irrigation Practices	Irrigation practices	Best Irrigation Management Practices (BIMPs)	Conservation of farm's soil and water resources without sacrificing productivity	HIGH locally, dependent on baseline	Farmers open to new ideas, techniques and technologies, considering irrigation as a high priority	50-200 €/ha of irrigated land	Observation tools used depend on crop type and farmers´ expertise	- BIMPs are generally applicable - Impact dependent on baseline, i.e. current level of water conservation techniques applied - Capacity building crucial	Cartagena irrigation scheme, SE-Spain
Decreasing demand	Improving Irrigation Practices	Precision Agriculture	Optimize water use using ground-based sensors and modelling tools	Optimized scheduling of water provided to crop	Higher production and water productivity, possibly lower water use	Economically feasible for large farms with high-income crops. In other cases requires economic incentives	50-100 €/ha of irrigated land	Several companies already deliver services in this field especially for grapevines	- Viable for other areas where high-income crops are cultivated - Requires availability of agro-meteo network	Spain

Effect on Local Water Balance	Category of measure	Type of measure	Application / activity / process	Result	Impact	Preconditions or prerequisites (incl. governance issues)	Estimated cost	Side effects / comments	Up-scaling / transferability / sustainability	Evidence base
Decreasing Demand	Improving Irrigation Practices	Precision Agriculture	Optimize water use using low-cost remote sensing data and simulation tools	Optimized planning and scheduling of water provided to crop	Higher production, possibly lower water use	Feasible only for larger farms due to limited resolution of satellite imagery	5-30 €/ha of irrigated land	Accuracy is proportional to land areas, crop uniformity and resolution of remote sensing. A few research projects are developing tools in this direction.	- Transfer to other regions requires skilled extension service and infrastructure to set up information system - Potential for large uniformly cropped areas	Spain
Increasing water supply	Improving soil management	Increasing soil infiltration	Adding organic matter to improve soil structure and hence rainwater infiltration	Less rainwater is lost by runoff	Increasing water infiltrated 10-30% depending on plot characteristics	Availability of good quality organic matter; willingness of the farmer to improve soil quality; extension services support activity	100 €/ha – 1000 €/ha depending on organic matter quality and transport cost	The quality of organic matter is important, some sources can be high in heavy metals	Possible to upscale to farm association level reducing unitary cost. Well transferable to other regions. Depends on abundant source of reasonably priced organic matter like urban refuse, but quality is an issue	Scientific and pilot research by REDSIM partners
Increasing water supply	Reducing farm runoff	Implementin soil conservation measures	To implement soil conservation measures (walls, barriers, vegetation, etc)	Less rainwater is lost by runoff	Very dependent on farm characteristics .	Know-how on building soil conservation measures; willingness of the farmer to reduce soil erosion ; extension services support activity	Very dependent on farm characteristics	Abundant soil conservation measures can make difficult mechanization. On the positive side up-scaled application can reduce damage by floods downstream farms	To be fully effective at the landscape scale they should be implemented by farm association and/or extension services on large areas	Parallel research by REDSIM partners
Increasing water supply	Better information on spatiotemporal rainwater distribution	Increasing rain gauges	To increase number automatic rain gauges and integrate them on real time regional estimates of rain water	The rainwater available for crop is known with less error	Improving irrigation precision on deficit irrigation schemes	Know-how on installation, management and maintaining automatic weather stations	From 500 € per station including communication equipment	No side effects	Transferrable to other regions	REDSIM

Effect on Local Water Balance	Category of measure	Type of measure	Application / activity / process	Result	Impact	Preconditions or prerequisites (incl. governance issues)	Estimated cost	Side effects / comments	Up-scaling / transferability / sustainability	Evidence base
Increasing water supply	Better information on spatiotemporal rainwater distribution	Integrating rain gauges from different institutions and private people	To increase available information on rainwater by integrating unconnected networks of rain gauges	The rainwater available for crop is known with less error	Improving irrigation precision on deficit irrigation schemes	Know-how on integrating rain gauge networks; willingness of institutions private owners to share data on real time	If network is already set-up (like in REDSIM) cost of adding new networks is low, otherwise it maybe be evaluated from 20000 to 40000 € per region	No side effects	It is a measure to be implemented over regions transferable everywhere however long-term maintaining is an issue and it should be managed by institutions with experience	REDSIM

4.2 Inputs to the Blueprint to Safeguard European Waters

In this section the policy options providing inputs to the Blueprint to Safeguard European Waters are dealt with - policy option by policy option. For each sub-section the following issues are (where relevant):

- Technical issues;
- Institutional issues;
- Financial issues;
- Up-scaling (i.e. the extent to which it is possible to apply REDSIM in other regions taking);
- Sustainability and dissemination

4.2.1 Develop a positive role for land-use

The following key findings from REDSIM have been found relevant for this policy option:

Technical issues

- Modernization and use of advanced irrigation management tools in large irrigation schemes are likely to have a beneficial impact on water productivity and the sustainability of irrigated agriculture in semi arid countries.
- There is scope to increase the beneficial use of rainwater directly on the plot or to use this source as an integral part of the irrigation scheme water supply. Decision support tools like those in REDSIM have the potential to promote the strategic use of rainwater in the irrigation planning and scheduling and to wisely combine this source with irrigation water obtained from external sources.
- By providing more precise rainfall estimates to farmers (as in REDSIM) and motivating them to make better use of this water source, runoff will be reduced and more water will be retained on-farm, promoting sustainable drainage. European guidance could be given to promote the effective application of water retention and soil and water conservation measures by farmers and build mechanisms that stimulate them to meet water quantity and quality objectives.

Institutional issues

- Different institutes within a region (agro-extension service, weather service, scientific institutes, semi-professional meteorological associations) provide meteorological observations (meteorological stations and rainfall radar) but these networks and datasets tend to be disconnected. Nowadays, suitable technology is available to integrate these information sources (especially stations and radar), providing a useful tool to estimate rainfall and the water balance of the different land-uses in the basin (water accounting). Particularly there is scope to better quantify the role of upstream natural areas to buffer extreme weather events and to regulate water supply. More initiatives and collaborative projects to foster the integration of meteorological data sources (possibly through WISE) should be promoted.

Financial issues

- No findings

Up-scaling

- The disintegration of institutes maintaining weather information is not unique to the REDSIM study areas, and up-scaling the integrating activities as in REDSIM is recommended for more sustainable water management (reducing the impact of extreme events and increasing water supply)

Sustainability and dissemination

- Of the most productive agricultural area in the Segura Basin (Campo de Cartagena irrigation scheme), a water accounting study is currently being carried out by researchers of the UPCT. These activities take place currently within the academic programme. The reasons to start these research activities were:
    - This particular irrigation scheme is one of the most productive and intensively used agricultural areas in the EU with a very high level of adopted modern infrastructure. Therefore, a water accounting study of this region can serve as a guideline for other similar regions that have not yet reached the level of water use and economic and environmental pressures as in this area
    - The water accounting methodologies are becoming better defined and have been proven to be a strong and useful tool for regional water management in other areas. Also on a European level this type of studies are being promoted through the EU water accounting system which is currently being set up. The research group hopes to find collaboration on a European level for these activities.
    - REDSIM has provided key input into the water accounting methodology: rainfall (remotely sensed radar and ground observations) and evapotranspiration. Besides, information has been obtained on irrigation practices, which allows closing the key components of the regional water balance, and specifying them by land-use type (irrigated crops, tree crops, horticultural crops, urban areas, etc).

4.2.2 Economic incentives for a more efficient water resources management

The following key findings from REDSIM have been found relevant for this policy option:

Technical issues

- The Common Agricultural Policy should target direct support to farmers to adopt good practices that promote the improvement of soil quality and soil conservation measures on irrigated crops in order to increase the infiltration of rainwater and the reduction of runoff (for example through Payment for Ecosystem Services – PES). Other currently operating funds that focus on semi-natural areas should redirected to agricultural lands that produce much higher quantities of erosion and runoff when not managed properly.

Institutional issues

- From REDSIM and other projects dealing with water-driven issues in the REDSIM agricultural study area, it can be concluded that an institutional setup that allows tradable water permits in these water scarce areas could optimize the use of the available resources and increase water productivity. In fact, on a small scale, limited water trading occurs already in these areas, clearly benefiting the productivity of the area, but currently no legal framework exists.

Financial issues

- To increase the potential for adoption of deficit irrigation and precision agriculture, economic incentives are deemed necessary to motivate farmers and/or irrigators associations to adopt this practice and offer site and crop specific recommendations.
- A proper valuation of externalities related with the use of water in agriculture (positives and negatives) is considered necessary. This would provide better estimates as a guiding principle in

setting further policy, regulatory, and business decisions at the interface of agriculture with society and the environment.

- Experiences suggest that irrigation scheduling based on periodic sensing and monitoring coupled to information systems is viable for high-income crops and well-trained farmers. To obtain a more efficient use of the water resource for low-income crops with higher economic risks and more volatile markets, it is necessary to build a proper financial mechanism (e.g. PES) that supports the farmers in implementing the necessary infrastructure, technology and farmers training.

Up-scaling

- No findings

Sustainability and dissemination

- No findings

4.2.3 Water efficiency targets and measures to protect water resources

The following key findings from REDSIM have been found relevant for this policy option:

Technical issues

- Also in irrigation districts where drip irrigation is almost fully implemented, the potential to increase the water productivity by changing irrigation practices is noteworthy. Over-irrigation is common and deficit irrigation is hardly practised due to lack of proper crop-specific guidelines and information systems that provide the necessary information on crop water demands. Fine-tuned drip irrigation may, in combination with regulated deficit irrigation or partial root zone drying techniques, ensure that these potentials are exploited.

- A reliable source of water is crucial when irrigation scheduling (doses and frequency) should be optimized. Ponds managed by the farmer and located on the farm increase the reliability of the source and the resilience to short periods of lack of water supply. Losses by evaporation from the water surface of the ponds are significant and can be lowered when a few innovations are done to make evaporation-reducing techniques cost-effective.

- It should be stressed that water saving policies and techniques like those of REDSIM should be applied to increase sustainability of the system but not to expand the acreage of irrigated crops. What is often seen is that the adoption of more sophisticated technology caused a reduction of local water demand but also an intensification of crop cycles and acreage, principally due to economical incentives. This in fact increases the total demand at the basin scale, and therefore increasing the gap between supply and demand.

- Although not studied in REDSIM, it is stressed that downstream environmental and hydrological impacts of changes in on-farm irrigation management on the surface- and groundwater bodies on the watershed-scale should be of high significance for the Blueprint.

Institutional issues

- There is scope to optimize the use of rainwater by technically integrating this source in strategic irrigation planning by irrigation district authorities and on-farm irrigation scheduling by irrigators, as in REDSIM.

Financial issues

- No findings

Up-scaling

- Requirements for the implementation of the REDSIM tools in other water-stressed agricultural regions are (1) low-cost or free availability of data from agro-meteorological network, (2) skilled staff in extension service to configure and maintain information system (3) costs related to irrigation water should be significant compared to total production costs (4) a participatory approach is recommended to adapt design to local preferences and knowledge.

- Fostering uptake or the irrigation practices supported with REDSIM-like tools, through local demonstration projects are deemed necessary: farmers are typically experience-based-learners

Sustainability and dissemination

- The REDSIM outcomes on irrigation practices and decision support were converted in a brochure with guidelines, targeted to farmers. This brochure (see Annex) has been made available in Spanish and English and will be distributed among farmer organizations and during following events in the region.

- The integration of the agro-meteorological information sources within REDSIM-IS has been a major step forward in the provision of useful information for irrigation planning by farmers. Based on the evaluation performed within REDSIM, the bulletin and information system will be further adapted to the farmers´ preferences and uptake will be fostered during following demonstration projects in the region.

4.2.4 Governance

The following key findings from REDSIM have been found relevant for this policy option:

Technical issues

- Experiences of REDSIM confirm that there is still a significant lack of knowledge by farmers of innovative water management technologies, in spite of the efforts by extension services. Therefore, substantial efforts have to be put on technology transfer, especially from the academic environment to the irrigation advisory services in water-scarce areas.

- At national and basin scale better communication networks between stakeholders that facilitate the exchange of information is recommended to achieve a more efficient way of sharing good practices, new technologies and adoption experiences, throughout all levels involved. On the European scale this may be enhanced through the CAP Farm Advisory System.

- Using outcomes of REDSIM, water accounting activities have been started in the study areas. These results can be used to evaluate the actual impact of land use and management on the sustainability of water resources. It will also allow a better quantification of how land management affects the ecologic and socio-economic issues within a basin. Water accounting data can be used to build Payment for Ecosystem Services schemes linked to reduced negative impacts of water resource depletion or positive impacts of land management changes.

- Water accounting also allows mapping and quantifying irrigation sources, distinguishing between surface and groundwater sources (illegal abstractions, etc).

Institutional issues

- Officers of the Spanish Water Authorities are assigned by the state government, which make these positions highly political. Political motivations are therefore in some cases more important than technical criteria.

- In Spain different public agencies are responsible for processing meteorological data, depending on the region and its stakeholders. Policies that promote the integration and compatibility (f.e. by information systems like REDSIM) between the different data sources would allow a better use of the available data. Institutions managing weather stations (in the Segura basin at least 5) as well as private owners should be motivated to fully share their data.

Financial issues

- Currently there exists an imbalance between tariffs, taxes and transfers to finance measures promoting water efficiency in the basin because of complex and inefficient administrations dealing with water management. Currently, Basin Authorities are mainly financed by the state administration while more direct payment mechanisms from the main water users (irrigation schemes, etc) could give them more incentives to invest in efficient infrastructure and water saving measures that have an impact at the basin scale.

Up-scaling

- Water accounting frameworks provide a good tool to compare statistical information and quantify pressures on water resources. It can provide insight in how the different types of land uses, crops and land practices contributing to the water accounts. REDSIM outcomes and tools can support this water accounting analysis, also in other areas of the EU.

Sustainability and dissemination

- Water accounting based on REDSIM outcomes has started for mapping of irrigated areas and quantifying groundwater recharge and abstractions in Segura basin. Satellite observations and remote sensing are used to estimate evapotranspiration and form an effective source of information to support decision makers of river basin authorities in monitoring the water assets and impacts.

4.2.5 Knowledge base

The following key findings from REDSIM have been found relevant for this policy option:

Technical issues

- For irrigation schemes where large homogeneously cultivated surfaces exist, the use of low-cost satellite information to support irrigation planning, benchmarking and water accounting is very valuable. For this purpose it is of paramount importance that the European Union invests in new agriculture-focused satellite sensors and to stimulate the GMES programme.

- Further research on water-driven issues in agriculture on the following:

    - Impacts on yield and quality of deficit irrigation for tree crops

    - Precision agriculture and spatial variability within agricultural plots

    - Harmonization between on-farm water management and the irrigation distribution network

    - Off-farm downstream environmental impacts of irrigation management (groundwater, pollution, etc)

- The potential to improve the integration of rainwater for strategic and operational irrigation water management. Knowledge gaps exist on how to increase water infiltration and reduce runoff specifically in irrigated areas.
- The interaction between upstream and downstream land and water management, and the relation with financial mechanisms that enhance and optimize this interaction, as payment for ecosystem services.

- We suggest the use of the following policy relevant indicators, that can be determined at the scale of an irrigation district, or could possibly be averaged for all irrigation districts within a basin:
  - Allocated amount of water (m3/ha) and Distribution efficiency (%) = V(farms)/V(total)
  - Total cost of water per ha (€/ha), Labour cost per ha (€/ha) and Labour cost per m3 (€/m^3)
  - Energy cost per m^3 (€/m^3) and Total energy consumption (Kwh per ha)
  - Water-related costs to total operational costs per ha and crops (%)
  - Other indicators that can be derived from water accounting studies

Institutional issues

- The hydrological and socio-economic interactions between upstream land management and downstream water availability within a river basin should be better recognized and integrated in the river basin management, by better coordination and common policies of the different acting administrations: water authorities, forest services, extension services, etc.

Financial issues

- No findings

Up-scaling

- The REDSIM-IS platform and data- and tool-integrating approach could be transferred to other water scarce regions, adding value for irrigation management by farmers and planning of water resources by decision makers. Water-related costs should be significant to total production costs to ensure uptake and a participatory approach for implementation is recommended to adapt design to local preferences and knowledge.

Sustainability and dissemination

- REDSIM has provided a knowledge base that will remain at the disposal of farmers and decision makers, integrating the relevant remote sensing and other datasets for irrigation and land use planning. The system is set up following the EU Inspire standards. It provides policy-relevant indicators on the sustainability of water resources for river basin and local managers. These type of information platforms enables easier delivery of data to the stakeholders and allows, may allow compliance assessments and comparative analysis for a more sustainable and productive irrigated agriculture.

4.2.6 Innovation

The following recommendations for innovation from REDSIM have been found:

Technical issues

- Costs of soil moisture sensors have been reduced due to recent technological developments and several innovations that made it possible to incorporate them in low-cost wireless sensor networks. Several research groups in Europe are investigating currently the potential of this spatial real-time information for agro-hydrological purposes. Finally, this information source could be introduced in REDSIM-like information systems to provide high-res and more accurate information on soil moisture deficit and related soil-crop variables.

- Also, valuable information on the spatial variability within a plot can be obtained from medium-res and hi-res satellite imagery. This type of imagery is increasingly available at reasonable costs. Currently, innovation is taking place but should be further promoted, to incorporate this information in agro-supporting systems.

- Paradoxically, the massive adoption during the past decades of new farming techniques based on use of high energy inputs has caused a loss of know-how on soil and water conservation measures. These have a non-negligible impact on rainwater use and its potential is disregarded by most modern farmers especially on irrigated lands. Combining rainwater collection and soil conservation with modernized irrigation infrastructure is now a key challenge, and should be encouraged to allow the integration of these practices in modern high-tech irrigated agriculture.

Institutional issues

- Innovation and demonstration sites are crucial for the adoption of new innovative technologies, as farmers tend to be cautious, experience-based learners and reluctant to apply new strategies and techniques as they have to cope with many risk factors in their day-to-day business. Pilot and demonstration projects with the involvement of universities and SMEs assure a better technology transfer and a more competitive sector with enhanced economic water productivity.

Financial issues

- No findings

Up-scaling

- No findings

4.3 Addressing possible indicators

The following indicators are recommended based on the outcomes of the REDSIM project.

Title	Definition	Data	Comments
	Hydrological drought indicators		
Standardized Precipitation Index (SPI)	SPI is an indicator to reflect drought situations, in comparison to historical records, and will be hosted by the European Drought Observatory (EDO). This indicator can produce different time-related outputs, so meteorological drought evidence and evolution can be shown for the past month(s), season(s) and/or year(s), facilitating the establishment of links to other drought indicators. This indicator and an accompanying fact sheet have been agreed upon by the Water Scarcity and Drought Expert Group.	The indicator is based on monthly long-term rainfall time series. The principal rain-gauge networks in the Segura basin are maintained by AEMET National Meteorological Agency. Additionally, at the present time there is a high spatial resolution (20 km) dataset of gridded rainfall for peninsular Spain, for 1950-2007 time period. The dataset, named Spain02, was generated from more than 2000 rain-gauges station for Spain, by Herrera et al. (2010).	One of the principle outcomes of REDSIM: the rainfall product that combines weather station AND rainfall radar information to provide high-resolution and precise quantitative rainfall estimates, could be used to improve the estimation of SPI. This allows more accurate and detailed monitoring of drought in Mediterranean areas where the spatial variability of rainfall is extremely high.
Standardized Runoff Index (SRI)	The Standardized Runoff Index (SRI), which is similar to the SPI, is used to classify hydrological drought. The SRI can be computed the same way as the SPI, except for being based on the monthly-mean runoff time series (Shukla and Wood, 2008). This indicator have been agreed upon by the Water Scarcity and Drought Expert Group.	The stream gauges data needed (monthly runoff) for deriving SRI, are provided by Confederación Hidrográfica del Segura (CHS), Water Agency of the Region.	The indicator SRI can be combined with other locally used indicators based on a comparative study, as can be found in Annex V: "Some examples of indicators in the Segura Basin".
Ground water level	The monitoring of groundwater levels could be interesting for the evaluation of drought propagation through the water cycle, and the impacts on the main reserves of the basin.	There is a network of groundwater level managed by Confederación Hidrográfica del Segura (CHS), Water Agency of the Region.	Based on outcomes of REDSIM, water accounting studies have been started to assess the water balance of the basin and water abstractions.

Title	Definition	Data	Comments
Soil moisture	The JRC present Information on soil moisture in form of soil suction (pF) values of the top soil layer. Values show an instantaneous image of the top soil water content as modelled by LISFLOOD. The Water Scarcity and Drought Expert Group has agreed upon the use of this indicator	The data provided by JRC present a spatial resolution of 5 km, and daily temporal resolution.	Suitable data on soil hydraulic properties remains a limitiation for reliable soil moisture estimates. For this reason, REDSIM has provided regional soil texture maps, not available for this region before. This dataset allows better estimates of soil moisture using hydrological modelling
Water storage (St)	The streamflow is registered by stream gauges network for the basin. But, it is preferable to use an indicator based on monthly runoff such as SRI.	The water storage dataset is managed by Confederación Hidrográfica del Segura (CHS). The data are provided for different time scales: daily, monthly, etc. For a few reservoirs, the automatic monitoring system managed by the basin authority (SAIH) registers data every 5 minutes.	This indicator is related with the CHS index, as discussed in Annex V: “Some examples of indicators in the Segura Basin”.
Streamflow (Q)	The streamflow is registered by stream gauges network for the basin. But it is preferable to use an indicator based on monthly runoff such as SRI.	The stream gauges network is managed by Confederación Hidrográfica del Segura (CHS). The data are provided for different time scales: daily, monthly, etc. The automatic monitoring system managed by the basin authority (SAIH), has data available for time periods of 5 minutes for selected stations.	This indicator is related with the CHS index, as discussed in Annex V: “Some examples of indicators in the Segura Basin”.
Remote sensing-based indicators			
Fraction of Absorbed Photosynthetic	FAPAR is considered a good indicator to detect and assess drought impacts on vegetation	The FAPAR indicator can be extracted from MODIS satellite imagery	

Title	Definition	Data	Comments
Solar Radiation (FAPAR)	canopies. It represents the fraction of the solar energy which is absorbed by the vegetation canopy and is a biophysical variable directly correlated with the primary productivity of the vegetation. This indicator and an accompanying fact sheet have been agreed upon by the Water Scarcity and Drought Expert Group.	which provides a dataset for the last 10 years. Recently, FP7 geoland2 project published a dataset with a higher resolution (300m, 10-day intervals) based on the MERIS sensor.	
Temperature Vegetation Dryness Index (TDVI)	The remote sensing-based TVDI indicator is related with soil moisture, where high values indicate dry conditions and low values wet conditions. It is based on the key principles of the surface energy balance taking values of 1 for limited water availability and 0 for maximum evapotranspiration and thereby high soil water availability.	Its calculation requires multiple remote sensing observations of any type of satellite with a thermal band (MODIS, Landsat, etc) to accurately define the boundary conditions of the energy balance.	An example of the application of TVDI, using data from MODIS sensor (Terra satellite), is presented in Annex V: "Some examples of indicators in the Segura Basin".
Water Deficit Index (WDI)	The Water Deficit Index (WDI) quantifies the relative reduction of latent heat flux (evapotranspiration), where a value of 0 corresponds to a fully wet surface (evapotranspiration only limited by the atmospheric demand), and 1 for dry surfaces where there is no latent heat flux.	Its calculation requires multiple remote sensing observations of any type of satellite with a thermal band (MODIS, Landsat, etc) to accurately define the boundary conditions of the energy balance.	An example of the application of the Water Deficit index, using data from MODIS sensor (Terra satellite), is presented in Annex V: "Some examples of indicators in the Segura Basin".
Performance indicators for comparison and benchmarking			
Total annual volume of irrigation water delivery per unit irrigated area	Total volume of water delivered to water users over the year or season. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups.	Measurement should occur at the point of interface between the irrigation provider and the water user(s). For the REDSIM irrigation districts, this information has been made available.	An example application for the Campo de Cartagena irrigation district can be found in Annex IV: "Benchmarking indicators for the Cartagena irrigation district".

Title	**Definition**	**Data**	**Comments**
Energy consumption per unit irrigation delivery	This is the active energy consumed divided by the total volume of water supplied to users and provides information on the energy efficiency of the district.	Measurement should occur at the point of interface between the irrigation provider and the water user(s).	An example application for the Campo de Cartagena irrigation district can be found in Annex IV: "Benchmarking indicators for the Cartagena irrigation district".
Water price	The water price can be highly variable throughout the year for one particular district, and is a determining indicator to compare different irrigated areas	Data should be made available by the irrigation provider	An example application for the Campo de Cartagena irrigation district can be found in Annex IV: "Benchmarking indicators for the Cartagena irrigation district".
Main system water delivery efficiency	This is the *Total annual volume of irrigation water delivery* (=Total volume of water delivered to water users over the year) divided by the *Total annual volume of irrigation supply* (= Total annual volume of water diverted or pumped for irrigation).	Measurement should occur at the point of interface between the irrigation provider and the water user(s).	An example application for the Campo de Cartagena irrigation district can be found in Annex IV: "Benchmarking indicators for the Cartagena irrigation district".

4.4 Recommendations regarding dissemination

4.4.1 Dissemination to other regions

From REDSIM, the following recommendations are put forward for the transfer and dissemination of its results to other water-scarce regions in Europe:

- Regulated Deficit Irrigation (RDI): given the importance of tree crops in the Mediterranean areas, and the fact that the level of knowledge and number of tools for RDI are increasingly available to farmers, REDSIM shows that there is a significant potential to increase the economic output of irrigation water in these areas, and to promote its sustainable use. Farmers should however have easy access to this knowledge (guidelines brochure of REDSIM, capacity building, demonstration projects), and should be supported through REDSIM-like information systems.

- Information on rainfall is currently scattered among different organizations and institutes within the same basin: in the Segura Basin, but also in several other drought-prone basins in Europe. A key outcome of REDSIM is the successful integration of all available networks, including remotely-sensed rainfall radar, providing a product that gives farmers plot-level information on the amount of rainfall during the latest hours. The key barrier to be dealt with is the institutional setting in each basin, that may limit the exchange of data for other purposes than those that are supported by the organization itself.

- No major technical barriers exist to transfer the REDSIM-IS platform and data- and tool-integrating approach to other water scarce regions. However, REDSIM also showed that a participatory approach in the design of a farm advisory product is important. For this reason, a 'one-size-fits-all' information system focused on farmers is not feasible and adapting design and tailoring by involving the target users in the development process is highly recommendable.

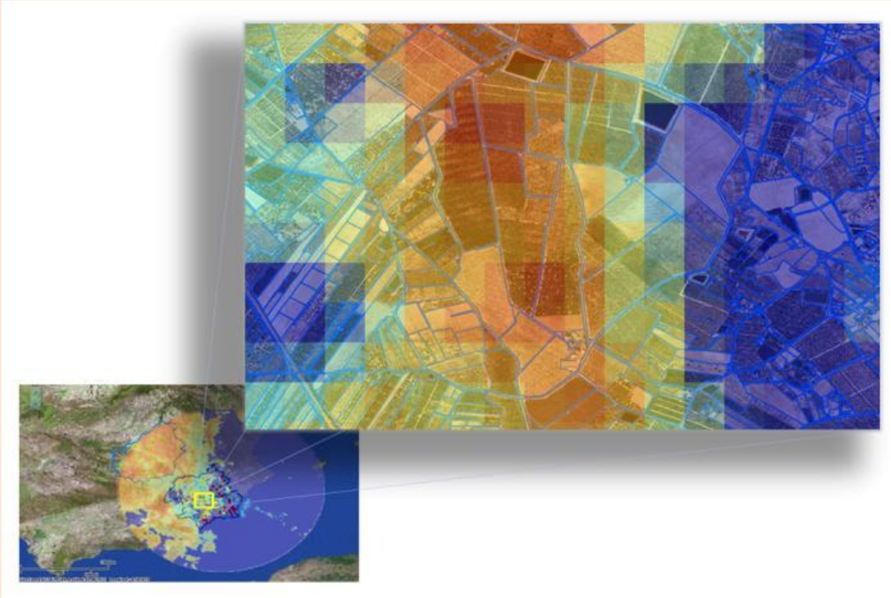
4.4.2 Main dissemination outcomes

The following inserts highlight the main dissemination outcomes of REDSIM:

- **How much rain received my plot? Integrating existing monitoring systems for enhanced precipitation estimates**
- **Agro-hydrological simulation tools: nowadays accessible to practitioners for decision support to assess impact of water stress on crops production.**
- **Regulated Deficit Irrigation: an irrigation practice that supports a more productive and sustainable management of scarce water resources.**
- **Farmers' information and advisory systems. The importance of a participatory approach by involving farmers in the tool development.**
- **REDSIM-IS has been tested; this web-based mapping service focuses on farmers, gathering relevant spatial and temporal data sets, and is compatible with the European INSPIRE standard**
- **Economic incentives matter to encourage the adoption of water use efficiency technologies**
- **Farmers' narratives on production inputs and costs, and sourcing alternative sources of irrigation water**

How much rain received my plot? Integrating existing monitoring systems for enhanced precipitation estimates

Especially in Mediterranean areas, rainfall is temporally and spatially extremely variable. At the same time, rainfall is a key factor to plan agricultural operations and for irrigation scheduling. So far, no precise plot-level estimates of rainfall are available to the farmer. On one hand, the weather station networks are not dense enough to provide the farmer reliable estimates for each plot. On the other hand, rainfall radar gives useful information on the spatial variability, but gives no useful quantitative estimates and only of the relative intensity.

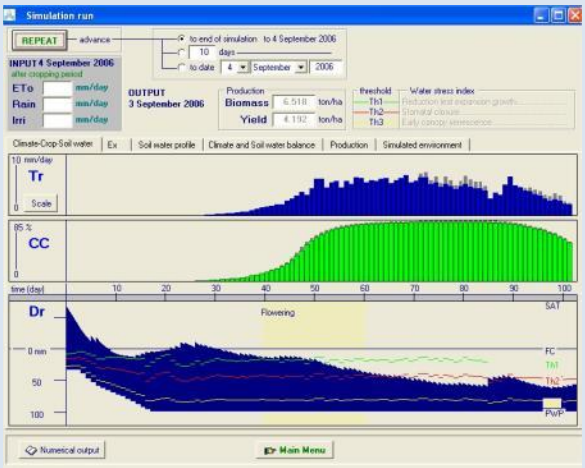


Merging both information sources (from rainfall radar and rainfall weather stations) has been subject of study in several projects, but implementation has been limited so far due to the complexity of the algorithms requiring intensive computing. Within the REDSIM project, an innovative product that uses state-of-the-art algorithms to combine information from weather station networks with rainfall radar in real time was implemented. Through a web-portal (REDSIM-IS), the farmer is able to assess with high accuracy the amount of rain that received his plot during the last hours and days.

Such tools can also serve other purposes (flood alerts, hazard analysis, etc) and can be useful for regional water resources planning, and be incorporated in River Basin Management plans for enhanced drought management.

Agro-hydrological simulation tools: nowadays accessible to practitioners for decision support to assess impact of water stress on crops production.

In situations of water scarcity, the focus must be placed on achieving efficient and equitable use of water as a limited resource. The economics and management of agricultural water demand and use require information on water productivity. This information has been typically obtained from empirical crop-water production functions.



However, dynamic crop-growth models by simulating the yield response to different amounts of applied water under a specific set of agronomic conditions, provides a more powerful and reliable tool. This type of crop-growth models are a flexible alternative to empirical production functions and produce a more realistic range of results.

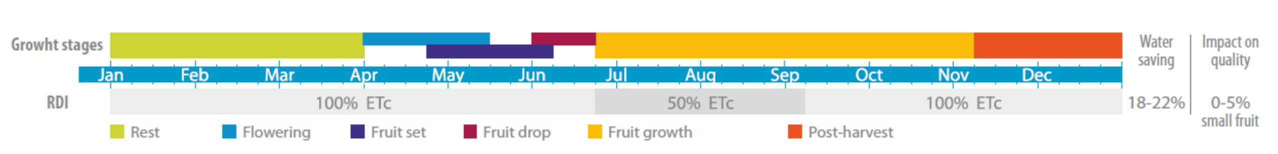
These types of tools become increasingly available for practitioners and are not unique to the academic environment anymore. Water productivity predictions are useful for farmers, extension specialists, field consultants, engineers, water planners, economists, policy analysts, and scientists.

The project REDSIM has demonstrated the value of the crop model developed by FAO called "AquaCrop", to schedule irrigation, to study the effects of irrigation practices on water productivity, and to carry out comparative evaluations. An example of the outputs of AquaCrop is showed in the Figure 1, which is a simulation of a regulated deficit irrigation scheduling for melon in The Upper Guadiana River Basin.

Regulated Deficit Irrigation: an irrigation practice that supports a more productive and sustainable management of scarce water resources.

Improving water productivity of irrigated land in semiarid areas in Spain and other countries of the Mediterranean Basin is considered a priority at European level. There is an urgent need to develop and implement practical measures and tools that support a more productive and sustainable management of scarce water resources.

There are several techniques that guarantee a high yield while saving water, thus increasing irrigation water productivity. One of them is Regulated Deficit Irrigation (RDI). This is an irrigation strategy that puts crops deliberately under a certain degree of water stress during ‘drought-tolerant’ growth stages while ample water is applied during ‘drought sensitive’ stages. Besides saving water, RDI allows to (i) save energy and fertilizers and (ii) obtain an optimal water productivity. The following diagram is taken from the REDSIM guidelines:



Several crops have been studied within REDSIM, applying RDI. This summarizes the key outcomes:

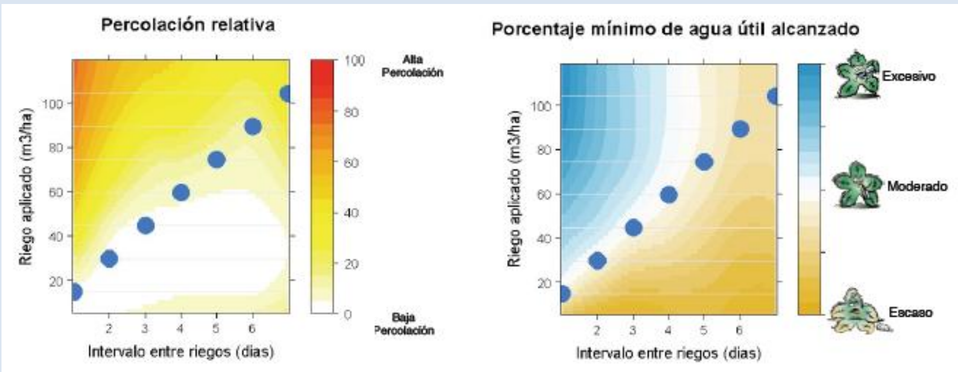
- The yield of the nectarine cultivar studied was insensitive to 25 % less irrigation.
- The trials done at the mandarin pilot farm confirmed the feasibility of the RDI strategy during the second stage of mandarin fruit growth, saving up to 30% of water.
- For melons, RDI allows water savings of around 18% compared to plots conventionally irrigated, without affecting yields and fruit quality, also water productivity increases considerably up to 12.4 kg m-3.
- For grapevines, RDI allows savings up to 60% compared to plots conventionally irrigated, without affecting yields or even sometimes increasing them, depending on the variety.

Farmers’ information and advisory systems. The importance of a participatory approach by involving farmers in the tool development.

Under water scarce conditions, the complexity of decisions on water management increases and farmers may increasingly lack the necessary information and capacity to make management decisions that integrate the range of issues involved. Thus appropriate advisory tools are needed to help farmers to consider new information and apply new ways of thinking to improve practices in farm water management.

	19 Mar	20 Mar	21 Mar	22 Mar	23 Mar	24 Mar	25 Mar
Lluvia (mm)	1.9	17	22	0	0	0	0.5
ETo (m3/Ha)	29	22	27	35	36	34	34
ETc (m3/Ha)	15	11	14	18	18	17	17

Traditional development of advisory services is a top down process, giving little consideration to the farmers' preferences for the type of information required and the ease of interpreting instructional information provided. In recent years, the importance has been stressed of a participatory approach during the development of decision support tools for farmers to improve the functionality of the design in relation to the objectives and conduct evaluative activities early in the process, integrated with design activities.



REDSIM involved a group of innovative farmers in the design process and undertook evaluation activities during the development of an informative irrigation bulletin that should allow them to better plan irrigation and save water. This was done by obtaining farmers’ feedback before and after they have used the advisory bulletin and assessing the usefulness, clarity and acceptance of the tool components during the design process to obtain feedback on how to adjust the tool to the user and encourage uptake.

The benefit of a participatory approach in decision support development is to both the irrigators and the service providers as maximum benefit is being gained from such services.

REDSIM-IS has been tested; this web-based mapping service focuses on farmers, gathering relevant spatial and temporal data sets, and is compatible with the European INSPIRE standard

Policymakers need to deal with an increasingly amount of information among different regions and coming from different networks and organizations. Providing policy-relevant indicators based on statistical and water accounting datasets to assess the sustainability and vulnerability of water resources is of paramount importance to river basin and local managers.

REDSIM-IS is a single web portal that integrates all available spatiotemporal information (meteorological networks, weather radar, satellite remote sensing, surveying, etc.) of the study basins, to provide updated information on soil and crops for better irrigation management, planning and scheduling by the farmer, but also other decision makers. This web-based mapping is compatible with the European INSPIRE standard and improves the sharing of data and other information in the line of the Water Information System for Europe (WISE) Implementation Plan.

Economic incentives matter to encourage the adoption of water use efficiency technologies

The sustainable use of water requires that the demand and supply of water are balanced with each other in the short and long term. Thus, in areas where water resources are scarce, this can be achieved through reducing demand or increasing water supply availability, or both. Among the available water demand management policies, improving water use efficiency is more socially acceptable (as compared to increasing water price) and is regarded as a good alternative for achieving sustainable water management. Thus, the adoption of modern water saving techniques or technologies that increases the efficiency of water use and reduces input requirements, while maintaining production levels, could be the key to long term sustainable water use in arid and drought-prone areas.

It has been demonstrated in Spain, Israel and California that higher water prices promote the adoption of modern irrigation technologies. Economic theory posits that the scarcity of natural resources leads to an increase in their shadow prices. Hence, the increasingly scarce water resources will lead to the increase adoption of water saving technologies in order to reduce the costs associated with purchasing water. The rate of adoption of water saving technology will depend on the level of scarcity and the price of water.

The financial savings achieved through reduced irrigation water requirements also provide an incentive to adopt modern irrigation technologies. However, the degree of savings depends on locality and local conditions.

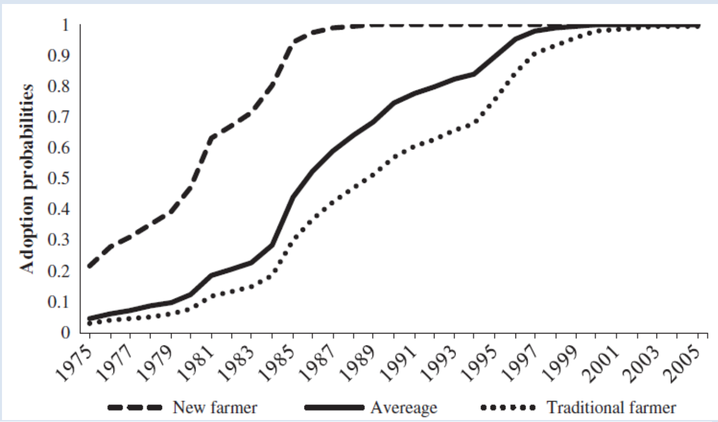


Figure 1. Drip irrigation adoption probabilities at mean values of time invariant variables. From: Alcon, F., M. D. de Miguel, and M. Burton

In the Campo de Cartagena Irrigation Scheme, in the south-eastern part of Spain, it has been proven that the speed of adoption of drip irrigation technology has been driven by economic factors. The hypothesis that new technologies will spread faster among those who have better access to capital resources and greater credit availability was proven true in this region. Also, the ongoing increase in the average price of water due to scarcity has influenced adoption.

Farmers' narratives on production inputs and costs, and sourcing alternative sources of irrigation water

The market price of water influences farm demand for water. Farmers have to balance the marginal cost of water with the marginal benefit (or profit) gained from the extra unit of water bought. If the marginal cost of water exceeds its marginal benefit, farmers would respond by reducing their water consumption level to the point where the marginal cost of buying the extra unit of water equals to its marginal benefit. Hence, the individual farm demand for water is dictated by the market price of water, among many other factors.

Responses in farm demand for water to changes in the market price of water vary between different irrigation areas due to the varying characteristics of the area and the crops grown. Extensive arable crops, which represent the majority of crops in Europe, are generally not profitable in the EU because the market price is lower than the production costs. For these crops, water demand becomes inelastic and inefficient at water prices higher than 0.09-0.15 €/m3. Hence, these crops are subsidized by the EU CAP.

When crops are intensive and more profitable, such as woody crops, the demand for water is more inelastic. That is because the opportunity cost of losing these crops due to water scarcity is higher as they require higher investment costs and longer return periods. Hence, the marginal benefit of an additional unit of water for these crops is higher than for extensive arable crops. For fruits and vegetables in the Mediterranean, the marginal cost of irrigation water can reach values greater than 0.5€/m3 and at times greater than 1€/m3 for specific crops in particularly water scarce situations. This argument supports the for the use of alternative (or non-conventional) water sources, such as desalinated water. However, the demand for high-priced water sources (0.5-1 €/m3) would depend on expected crop price and expected water availability. Particularly for woody crops, farmers would be willing to pay high prices for water if they expect that plantation survival is at risk in times of extreme and prolonged drought conditions.

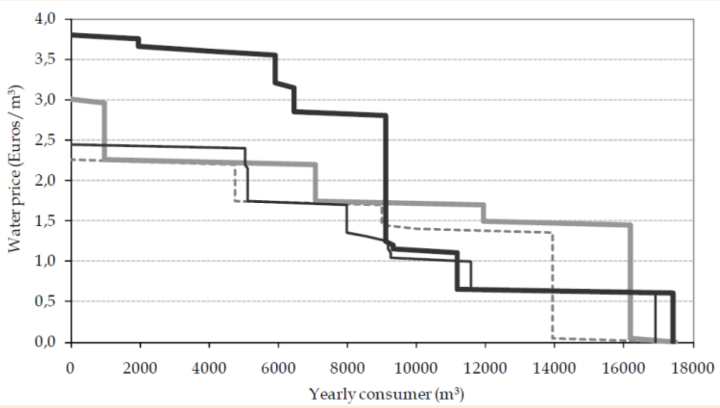


Figure 2. Irrigation water demand curves for Spanish grapes.

In the south-eastern part of Spain, where the irrigation water demand curve is usually inelastic, higher water prices would be valid only from the standpoint of cost recovery, but is not expected to be so from the water savings perspective. In this context, it is clear that water demand elasticity is influenced by the market price of water and expected farm profitability. Hence, farmers' willingness to pay for irrigation water will partly vary with the market price of the crops. Generally, farmers are more concerned about product prices than water prices. Unfortunately for farmers, the price of fruit and vegetables in the EU market is often variable. Nonetheless, as long as the marginal benefit of the water is higher than its marginal cost, farmers would be willing to pay for the water. However, in years when market prices of crops are low, farmers will reduce their demand for water to minimise loss.