PROJECT FINAL REPORT

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1. EXECUTIVE SUMMARY

Effectively responding to water scarcity is among the key challenges that the Mediterranean region is facing in its quest for sustainable development. In many watersheds of the Mediterranean countries, water resources are presently fully or overcommitted and irrigated farms are using up to 80% of all allocated resources. Demand for water is likely to continue increasing due to population growth as well as increased demand from in-stream users. If supply driven approaches have prevailed for decades in most of the region's countries, on-going water policy reforms are increasingly looking into a better integration of Demand Side Management (DSM). This approach is increasingly proposed as a strategy for mitigating water-scarcity problems through a variety of participatory measures including technical, political, institutional, economic, training, awareness rising and communication tools intended to encourage better use of existing resources before considering increasing supply.

In this context SIRRIMED project addressed issues related to sustainable use of water in Mediterranean irrigated agricultural systems, with the overall aim of optimizing irrigation water use. The approach proposed in SIRRIMED for reaching this goal was based in an Integrated Water Irrigation Management (IWIM) where the improved water use efficiency was considered at farm, irrigation district and watershed scales. These strategies included innovative and more efficient irrigation techniques for improving water productivity and allowed savings in water consumption.

SIRRIMED considered the development, test and validation of new deficit irrigation strategies, the sustainable and safe use of poor quality waters and the improvement of precise irrigation scheduling using plant sensors. These new techniques were integrated with suitable husbandry irrigation practices.

At the district scale, efforts was directed towards an integrated policy of water allocation which accounts for the characteristics and specificity of each farm, requiring the availability of data bases and efficient management tools (decision support systems) specifically designed to fulfil the objectives of maximizing water use efficiency.

At the watershed scale, priority was devoted to the assessment of new models of water governance, and the definition of strategies and policies aimed at promoting a more responsible use of irrigation water.

Finally, SIRRIMED established a sound dissemination strategy for transfer of knowledge towards the end users, with a real participatory approach to facilitate an adequate involvement of stakeholders (farmers, association of irrigation users, water authorities and SMEs).

2. PROJECT CONTEXT AND OBJECTIVES

1. Introduction

In many watersheds of the Mediterranean Countries, water resources are presently fully or overcommitted. Demand for water is likely to continue increasing due to population growth as well as increased demand from in-stream users. Irrigated farms are the largest consumers of fresh water in Mediterranean Countries: either individually or as members of irrigation districts, using up to 80% of all allocated water in some regions. With the increasing water demand of other sectors and environmental constraints, water resources available for agriculture will decrease in the next decades. However maintaining or increasing the fraction of irrigated agriculture in the national food production is essential to reach or maintain food security and welfare in many countries of the World, and especially within the Mediterranean Basin. In this critical context, there is an urgent need to foster the adoption and implementation of alternative irrigation systems and management practices that will allow increased crop/water productivity.

2. Concepts and ideas behind SIRRIMED

The conceptual strength of SIRRIMED, derives firstly from its integrated approach to explicitly linking irrigation practices and management to crop physiological and yield response and to hydrological processes at multiple scales, and secondly from the implementation of a participatory approach involving stakeholders throughout the whole chain of water distribution and application. An additional strength of this research is that it advances our capabilities to link process-based field data with simulation modelling of the functioning of irrigation districts and watershed, and allow the development and validation of information, diagnostic and management tools which account for the high level of interaction and complexity of the systems to be managed.

The key concepts of SIRRIMED can be defined as (i) *integration*, (ii) *harmonisatio*n and (iii) *participation.*

(i) **Integration**. SIRRIMED will develop *an integrated approach to water use and management*, by giving more consideration to the management of water as a resource rather than just the provision of water as a service.

(ii) **Harmonisation.** The concept of *'system harmonisation'* relies on consensus and collective decision making based on a process of optimisation of a production chain. SIRRIMED will apply this concept at the district scale, involving farmers and water service providers as main stakeholders.

(iii) **Participation.** A basic working concept of SIRRIMED is the close involvement of researchers and stakeholders in a *participatory approach to build local capacity and support innovation in irrigated agriculture*.

3. Main objectives

The three concepts have been applied to achieve the following **key objectives**:

(i) Objective 1. Improvement of water productivity through sustainable Irrigation practices and management (farm and irrigation scheme scales). Testing, adapting, evaluating and proposing novel/alternative irrigation practices and management tools for improving water use and irrigation efficiencies (WP1-WP2). These new alternatives will be introduced and assessed with participation of stakeholders through integration in benchmarking activities (WP3) and harmonisation process (WP4).

(ii) **Objective 2. Assessment of the impact of irrigated agriculture on the regional water resources (watershed scale).** By quantifying the magnitude and direction of change of key components of the watershed hydrological cycle in response to irrigation activities — and, in turn, the relationship of these components to total watershed behaviour — it is possible to clearly identify the major drivers that determine the available water resources and how they are altered by irrigation activities. Biophysical models and remote sensing data will be the main tools supporting the **integrated modelling** of watershed balance (WP5). Such information at the watershed scale is required for issues related to water governance (WP6).

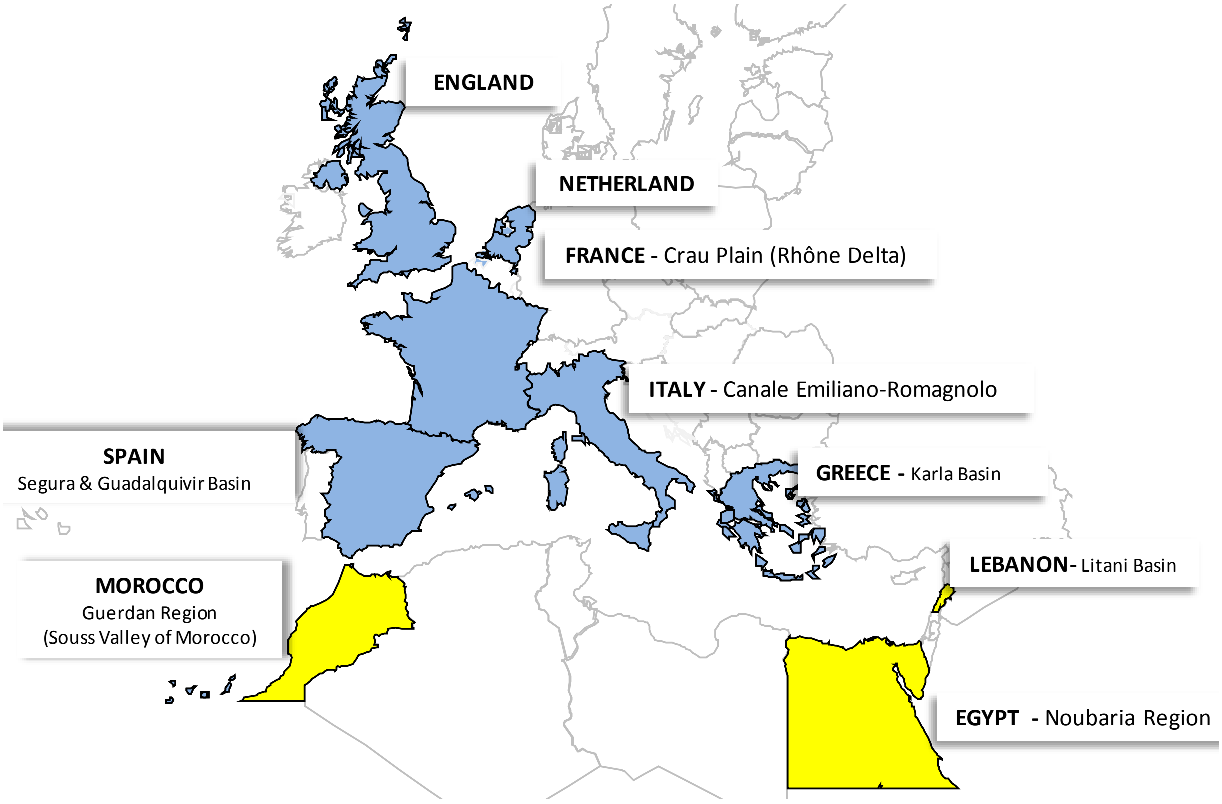
(iii) **Objective 3. Towards a new concept of water governance**. The focus on institutional issues has major implications for irrigation. Water governance is developed and managed differently in every country. Levels of governance and authority vary; responsibilities and mandates are somewhat confused, particularly between management of the resource and provision of services, and between the roles of the public and private sectors. SIRRIMED will dedicate a specific work-package to i**ntegrate** water governance issues in a **participative** approach (WP6).

(iv) **Objective 4. Fostering education and training in sustainable irrigation*.*** A relevant feature of SIRRIMED is the expected broader impacts that it will have within the educational and scientific realms. Through training of stakeholders, students and researchers in the rapidly evolving fields of irrigation technology, agro-physiology and hydrology, this project will contribute to strengthening the human resources needed to address in an **integrated way** increasingly complex global issues related to water and land use change in terrestrial ecosystems (WP5). Knowledge generated about current and potential future consequences of irrigated agriculture will provide sorely needed scientific documentation and tools for **harmonising** policy decisions related to protecting water resources and, at the same time, preserving or enhancing the food production capacity of Mediterranean Countries (WP7)

4. Relevance of crops and target areas considered in SIRRIMED

The previously described objectives and scientific/technological were adapted and validated in the 7 Mediterranean irrigation target areas:

- Spain: Segura and Guadalquivir basin.
- France: Crau Plane (Rhône Delta)
- Italy : Canale Emiliano-Romagnolo
- Greece : Karla basin
- Morocco : Guerdan Region (Souss Valley of Morocco)
- Lebanon: Litani basin
- Egypt: Noubaria Region.


ENGLAND
NETHERLAND
FRANCE - Crau Plain (Rhône Delta)
ITALY - Canale Emiliano-Romagnolo
SPAIN
Segura & Guadalquivir Basin
GREECE - Karla Basin
LEBANON- Litani Basin
MOROCCO
Guerdan Region
(Souss Valley of Morocco)
EGYPT - Noubaria Region

3. MAIN S&T RESULTS/FOREGROUNDS

3.1 KEY ON-FARM IRRIGATION TECHNIQUES TO SAVE WATER

3.1.1 *Problem Statement*

Dynamic variations of climatic water demands and soil-plant water status, along with the need to improve irrigation water productivity, impose an interactive irrigation scheduling procedure which is not always feasible for most irrigators. These days, scientific research on plant-environment interactions, the development of precise environmental sensors and enhanced computing capabilities are helping irrigators to more closely match their decisions to variations (both spatial and temporal) in crop water requirements.

3.1.2 *Objectives/Research Questions*

Optimise key irrigation technologies to save water at the farm scale. These key irrigation technologies are:

a) precise irrigation scheduling using plant/soil water sensors
b) deficit/partial root zone drying irrigation
c) improvement of water use efficiency in greenhouse crops,
d) use of poor quality waters

3.1.3 *Experimental Design*

- Cartagena-Spain, **Extra-early peach**: plant physiological performance and water productivity were compared under drip irrigation scheduling based on local farmer experience, well watered controls (according to micrometeorological calculations) and regulated deficit irrigation (RDI) applied with the aid of trunk diameter sensors.
- Mikrothives-Greece, **Vineyard**: Continuous monitoring of soil water content together with spatial maps of apparent soil electrical conductivity (VERIS and EM38), soil texture, soil physical properties, topographic and elevation and yield distribution were used to precisely determine spatial and temporal crop water requirements.
- Lancaster-UK, **Potato**: plant physiological performance, ABA signaling and water status indicators were compared between plants grown under control (well watered) conditions, sustained deficit irrigation and partial root zone drying (PRD).
- Murcia-Spain, **Citrus trees**: plant physiological performance and water productivity were compared in factorial combinations of two irrigation water quality (fresh water and saline reclaimed water) and two irrigation scheduling methods (Control and RDI).

- Murcia-Spain, **Lemon trees**: soil water content and plant physiological performance were assessed on potted trees subjected to PRD treatments using fresh or saline water.
- Murcia-Spain, **Citrus trees**: HYDRUS-2D/3D model assessed the long term effect of combining deficit irrigation and saline water quality on soil water content and salinity build up.
- Greece, **Tomato**: a decision support system (DSS) to control the Na concentration of the nutrient solution was tested in a semi-closed hydroponic system.

3.1.4 *Key Findings*

Nectarine trees (cv. Viowhite and cv Flanoba), UPCT Murcia-Spain:

- Applying regulated deficit irrigation based on trunk diameter fluctuations (TDF) saved 15 to 40 % (fluctuated with year and nectarine variety) of water when compared to farmer's experience, with no significant effects on fruit yield and quality.
- Farmer irrigation scheduling changed due to interactions with irrigation scientists: from applying 17% more water than well watered controls in the 1st year of the study, to 10% less in the last year of the study
- Trunk diameter fluctuations (TDF) were inversely correlated to soil water content and directly proportional to vapour pressure deficit. Maximum diameter shrinkage and signal intensity are feasible indicators for implementing precise irrigation scheduling.
- A new variable, termed early daily shrinkage (EDS), was derived from TDF, and was linearly related to plant water status throughout the year (unlike MDS).

Potato (cv Horizon and cv Maris Piper), Lancaster University-UK:

- Varietal differences in root vigour should be considered when applying water saving irrigation techniques to potato crops.
- Early application of water deficits can reduce the advantage of root vigorous varieties to maintain crop with less water applied.
- PRD generates a unique relationship between [ABA] and soil moisture but predicting [ABA} in the field is difficult due to vertical soil moisture gradients (2)

Citrus trees (Mandarin and Grapefruit), CEBAS-CSIC, Murcia-Spain:

- Applying RDI during the 2nd fruit growth stage (July-August) saved up to 18 % of tree seasonal water requirements. It affected the plant vegetative growth without reducing its final yield.
- Combining water deficit (RDI) with reduced quality water increased soil ECe (> 6 $dS.m^{-1}$) to very critical values and consequently reduced the final yield by 20 to 25 %, especially during years of heavy fruit load. Furthermore, mandarin trees irrigated at 100%ETc

with reclaimed saline water showed visible symptoms of Boron toxicity (after 5 years of application).

- Saline reclaimed water can substitute fresh irrigation water during periods of non-critical production conditions. 20 to 30% of fresh water can be saved without affecting final yield quantity and quality.

Tomatoes and vines, CERTH-Greece:

- Precision viticulture considering spatial field variation in soil / plant properties saved water (approx. 20%) and improved berry quality uniformity.

Closed & semi-closed irrigation system saved water (25% and 35%) using a DSS but achieved similar yield as open hydroponics system.

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3.2 FROM KNOWLEDGE TO ON-FARM SUITABLE PRACTICES

3.2.1 *Problem Statement*

In the agricultural sector, all farmers know how essential water is for crop production and that any shortage may have an impact on final yields. However, water is getting scarce while its efficient management remains a dynamic and complex process difficult to handle. This fact creates fear of potential water-related yield losses, encourages farmers to over-irrigate and keep them from adopting water saving practices especially when the cost of the amount of water to be saved does not outweigh the investment.

3.2.2 *Objectives/Research Questions*

Activities within this work package (WP2) were aimed to adapting new irrigation strategies and using new technologies to water demanding crops currently grown in the Mediterranean region, including cereals, fruit trees and vegetables, integrating these issues with husbandry practices applied in different Mediterranean studied cases located in Spain, Italy, Greece, Lebanon, Morocco and Egypt.

3.2.3 *Demonstration Fields*

- Cartagena-Spain, Extra-early **nectarine**: water productivity has been studied under drip irrigation scheduling based on local farmer experience, water balance and regulated deficit irrigation.
- Cordoba-Spain, **Olive** trees: the effect of different RDI schedules on growth and yield has been evaluated in two olive orchards of different plant densities (low and high plant density).
- Agadir-Morocco, **Tomato** under greenhouses: adaptation and tuning of PRD irrigation strategy to better rationalization of water supply.
- Agadir-Morocco, **Citrus** orchards**:** the effect of different irrigation regimes (precise scheduling and regulate deficit) has been assessed on fruit quality and size.
- Noubaria-Egypt, **Wheat**: regulated water deficit has been applied during different growth stages to identify the most appropriate means of irrigation scheduling and management strategies at the farm level. Brackish drainage water and seawater have also been tested as potential sources for irrigation of cereals crops in arid areas.
- Bekaa-Lebanon, **Potato**: mini-sprinklers and drip irrigation systems have been tested to evaluate the agronomic attributes of potato production at commercial scale.
- Cartagena-Spain, **Shade covers**: different porous shading materials have been evaluated for suspended shade cloth covers on evaporation mitigation.

3.2.4 *Key Findings*

Nectarine trees (cv Viowhite and cv Flanoba), UPCT Murcia-Spain:

- Plant based precision irrigation and regulated deficit irrigation on nectarine trees produced considerable water savings (20 to 40%) without significant effect on crop yield and quality
- Establishing the demonstration plots on a private commercial farm facilitated the adoption of new sophisticated environmental sensors and technology. It produced a progressive change in farmers' criteria regarding irrigation scheduling and improved its water productivity.

Olive trees, Cordoba-Spain:

- Fruit growth during summer is retarded by water deficits but recovers when water stress is relieved.
- Under low planting density, oil yield increased around 20 percent under an RDI regime as compared to the sustained DI, for the same amount of water applied (75 mm seasonal application).
- Increased application of water (150 mm, sustained) was limited by canopy size and did not increase production over the 75 mm application as RDI.
- Yields under high density were not affected by deficit irrigation in Spring and did not vary among treatments.

Tomato under greenhouse, Aghadir Morocco:

- Precisely managed water deficit (PRD and RDI) saved about 30% to that of the farmer
- Economic losses are quite limited after moderate stress (70% ETc) or after PRD alternating every 3 days;
- Level of affordable economic losses depends on the market pricing, the grower's will, the laws in force for sustainability and on the level of water scarcity in the region.

Citrus trees, Aghadir Morocco:

- Moderate water-restriction was applied on commercial Clementine orchards allowing water savings up to 25 % without any significant reduction neither in yield nor in the economic return.
- After 4 consecutive years, RDI did not affect citrus trees' bearing capacity nor commercial quality.

Wheat, Noubaria-Egypt:

- The use of recycled drainage water and diluted sea-water for irrigation of cereal crops significantly affect potential yield. Nonetheless, these options remain viable in arid areas with very limited water resources to be used on vey sandy soils.

Potato, Bekaa-Lebanon:

- Vertical PRD application wasn't efficient on potato plants (Spunta variety) cultivated on heavy soil.
- Irrigation using Mini-Sprinklers produced better potato crop with 20-30 % less than common farmers' application rates.

Shade-Cover, Cartagena-Spain:

- Shade covers can be economically feasible when water availability is the limiting factor in crop production.
- The shade-cloth structures require a high initial capital investment. Hence government subsidies, combined with technical demonstrations to farmers will speed the pace of investment until the price of water increases in the region.

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3.3 DISTRICT CHARACTERIZATION AND BENCHMARKING

3.3.1 *Problem Statement*

Irrigation performance is the result of a large number and variety of activities such as planning, design, construction, operation of facilities, maintenance and application of water to the land or agricultural production, irrigation, land settlement, maintenance, construction, water users' organization, etc. Assessment of irrigation water management "IWM" on heterogeneous irrigation schemes, particularly those in the Mediterranean countries, is not straightforward. These schemes typically have extensive systems of branched canals with numerous outlets along their length, distributing water over large areas with various soil types, for use by farmers with differing sizes of land holdings, growing a variety of crops. This heterogeneity is a major complication for IWM.

3.3.2 *Objectives/Research Questions*

The overall objective of WP3 is to provide stakeholders with a suitable method of irrigation performance assessment through the process of 'benchmarking', and to propose district best management practices.

3.3.3 *District Case Studies*

- Campo de Cartagena Irrigation District (CCID) - Spain, contains an irrigable area of 41,065 ha, although the irrigated area usually ranges between 30,000 and 34,000 ha depending on the annual water allocation. CCID has 33 irrigation sectors equipped with a highly sophisticated pressurized water distribution network. This is managed by local irrigators' association "comunidad de regantes".
- Canale Emiliano-Romagnolo (CER) – Italy, sub catchment basin Santerno: Selice and Tarabina. Both districts are equipped with pressurized and buried waterpipes. Selice district covers 1450 Ha, with 147 surface hydrants and Tarabina district covers 680 Ha, with 70 surface hydrants.
- El Guerdane district, Souss-Massa, Morocco. It covers a surface in the order of 10,000 ha taken up by mainly citrus fruit trees. It is equipped with a pressurized water distribution network to serve 670 farmers.
- Nubaria Scheme, Egypt. It serves newly claimed lands of about 900,000 feddans (378 000 hectares).
- Lake Karla schemes, Greece. Surface water networks and localized groundwater networks. In Surface Water Networks, consisting of earth made open ditches, the water comes from surface water resources (i.e. small reservoirs). Localised Groundwater Networks are designed as single farm irrigation infrastructures (individual network).

3.3.4 *Main Outputs*

- Data were collected in several pilot farms to complete the district-scale data. All data were quality-checked and stored in Excel files.
- District-scale data was treated, structured, and implemented in the web-based Analysis and Database tool (WAD).
- A Benchmarking tool has been developed and made available, upgraded and fully operational.

- The analysis at district scale makes clear that water supply restrictions contributed much more than the modernisation process or other circumstances to the performance changes observed over time.
- The perseverance of water scarcity situations in the study area entails environmental and economic drawbacks that could negatively affect to the economic and environmental sustainability at medium term.

Best management practices

- In semi-arid Mediterranean regions with limited water resources and reduced quality, the enhanced management practices should rely on implementing water saving techniques, introducing salt and deficit tolerant varieties and rootstocks and adopting precise irrigation scheduling technology while keeping an eye on water quality.
- Increase water scarcity resilience and economic and agronomic water productivity by introducing species and varieties of crops more adapted to local soil and climatic conditions and utilizing screen or greenhouses.
- Stimulate water reuse, mainly in arid and sub-arid areas and where there are no risks that fecal and inorganic contaminants affect food quality or threaten human health.

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3.4 DEVELOPMENT OF A DISTRICT INFORMATION SYSTEM

3.4.1 *Problem Statement*

For the sustainable management of irrigation schemes, it is crucial to have information on the variability —in time and space— of water flows, losses and resources and on the possible impact of this variability on crop productivity within the district. In the Mediterranean area, the organizations managing the irrigation district water often lack this type of information and the corresponding decision support tools. This may lead to sub-optimal management of the district, to potential conflicts among stakeholders, and to non-sustainable irrigated agriculture under scenarios of change in water resources and climate.

3.4.2 *Objectives/Research Questions*

To develop and test District Information Systems (DIS) in various Mediterranean irrigation districts facing a wide range of issues and having different information needs. These DIS are directed towards stakeholders for the district day-to-day management as well as for planning and strategic decision-making. The DIS is developed from a GIS-based modeling approach which integrates a generic crop model and a hydraulic model of the distribution system, and uses state-of-the-art remote sensing information and algorithms.

3.4.3 *Case Studies and DIS Features*

- The DIS for Campo de Cartagena Irrigation District –Spain:
  - Quantifies groundwater versus surface water use at the irrigation sector level
  - Estimates Irrigation Water Applied based on remote sensing
  - Provides an Irrigation Bulletin at Farm-level
- The DIS of Plaine de Crau – France :
  - Input to DIS from developed end-user-focused remote sensing tools EVASPA (evapotranspiration) and BV-NNET (LAI and fraction cover)
  - Statistical modelling of agricultural practices
  - Distributed application of crop model STICS using MultiSimLib
  - Quantifies water balance sensitivity under climate change for hay production
- Genil Cabra, Spain
  - Remote sensing-based regional yield gap analysis using crop model
  - AquaData: Tool developed to manage the AquaCrop inputs. applications.

    - AquaGIS: Tool developed to manage the AquaCrop outputs, including a GIS to facilitate spatial analysis of the results.
- Santerno & Selice – Italy
    - Integration of FAO crop model AquaCrop into already operational DIS, using NDVI-based parameterization scheme
- Karla Lake, Greece
    - Complex linking of CROPWAT (crop), WEAP (allocation) and hydraulic model
    - Wide range of future scenarios on land use change, infrastructure, measures
- Nubaria Scheme, Egypt.
    - Relating vegetation index with yield for spatial analysis of water productivity
    - Analysis of measures with various crop models for wheat

3.4.4 *Key Findings*

General

- In Mediterranean irrigation schemes, water managers often lack key information on the spatial and temporal variability of flows, losses, resources and/or yields.
- This information is of crucial importance for managing the schemes in a sustainable way and guaranteeing an optimal functioning and yields, with causing minimal impacts.
- Therefore, a major challenge in the Mediterranean basins is to equip the water managers of irrigation schemes with decision support tools that allow obtaining insight in the internal processes but also the external processes acting upon them.
- As the organizations in charge of managing these schemes generally have scarce resources, policies should promote the use of these type of decision support tools.
- A DIS for a certain scheme should always be a function of (i) local expertise and skills with existing tools (ii) Local problems and feasible solutions, and (iii) Local data.

SIRRIMED

- Irrigation districts in the Mediterranean basin cope with common issues, and more local problems. Within SIRRIMED, a representative selection of districts gives insight in these issues and their possible solutions.
- Common challenges are: (i) groundwater management, (ii) losses due to infrastructural deficiencies, (iii) vulnerability to climate change and adaptation, (iv) yield gaps, (v) water quality issues.

- District Information Systems were developed for several irrigation districts, each with district-specific objectives. All together, the DIS cover a wide range of issues, some of them common to various districts.
- The combination of remote sensing algorithms, crop models and hydraulic models into one DIS results in a strong tool for studying the current and future situation by district water managers.
- Spatial information which resulted especially relevant in the DIS implementations were: groundwater recharge and extractions, crop evapotranspiration, conveyance losses and crop yield (gaps).
- Stakeholder involvement from the start of the project promoted the possibility of final uptake of the tool.

Technical

- A major challenge in the development of DIS, using remote sensing information, is to cope with the differences in scales and resolutions among the datasets and satellite imagery. Significant efforts should be dedicated to these scale issues.
- NDVI-based approaches were found useful in several DIS to obtain information on crop variables and model parameters.

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3.5 DEVELOPMENT OF A WATERSHED INFORMATION SYSTEM

3.5.1 *Problem Statement*

There is an urgent need to quantify the impact of irrigation on the environment as well as to optimize irrigation management to minimize the risks carried on by irrigation (e.g. over exploitation of aquifer and surface water, degradation of water quality…). Environmental impact of irrigation depends on the hydrological condition at the watershed level, which is relatively difficult to measure, and may be affected by changes in climate, land use and water uses. Consequently, impact assessment tools for irrigated agriculture require a thorough understanding of the hydrological processes and spatial and temporal variations associated with hydrological factors such as rainfall, soils, and crops grown in different units of the considered region.

3.5.2 *Objectives/Research Questions*

Develop watershed information systems (WIS) to acquire and synthetize the information required for (i) environmental assessment of irrigation activities and (ii) regional planning of water resources, both on catchment scale.

The WIS are (i) to provide synthetic and quantitative outputs of the different components of the catchment hydrologic balance and (ii) to diagnose the impact of irrigation water use on the quantity and quality of water resources downstream of the irrigation schemes.

3.5.3 *Case Studies: Environmental Issues (EI) and WIS Features*

- Campo de Cartagena, Spain.

EI: possible overexploitation of water, contamination of groundwater and lagoon.

WIS-CC: develops a water accounting framework using (i) a soil water balance model and (ii) evapotranspiration monitoring from remote sensing (NDVI based or energy balance based) and rain monitoring by radar.

- Plaine de Crau, Crau Aquifer, France

EI: aquifer recharge (what is the contribution of irrigation? what are the impacts of changes in land use, climate and surface water availability?).

WIS-PC: combines (i) a surface simulation module (spatially distributed simulations of crop production, irrigation, drainage toward the aquifer and groundwater withdrawal), (ii) a remote sensing module (monitoring crop development and evapotranspiration with the BVNNET and EVASPA tools developed in WP4) and (iii) a groundwater model (MODFLOW).

- Genil Cabra, Spain

EI: water demand exceeds groundwater availability, diffuse pollution (fertilisers and pesticides).

WIS-GC: combines (in a small watershed) (i) the monitoring of runoff flow and the amounts of transported sediments, pesticide and fertilizer residues, (ii) the monitoring of irrigation, (iii) crop modeling and (iv) crop and evapotranspiration monitoring using remote sensing.

- Karla Lake, Greece

EI: overexploitation of ground and surface water, land use and water use planning for the restoration of Lake Karla.

WIS-UTH: combines (i) a water balance model (simulation of surface processes and groundwater recharge), (ii) a groundwater model

(MODFLOW), (iii) a reservoir model, (iv) a lake-aquifer interaction model, (v) the Water Evaluation and Planning (WEAP) software (providing outputs relevant to watershed management) and (vi) evapotranspiration monitoring with remote sensing data (METRIC software).

3.5.4 *Key Findings*

➢ Developed tools

- WIS combining various simulation modules, in situ and remote observation modules.
- Interface with GIS database and spatially distributed models.
- Calibration and evaluation of the hydrological models, the crop process models and the remote sensing mapping tools.

➢ Evaluation of remote sensing tools for mapping evapotranspiration (ET)

- ET monitoring with EVASPA (tool developed in WP4) are in close agreement with in situ long term measurements (0.7 to 0.9 mm day^{-1}).
- The variability in estimation of ET from various algorithms provides an indication on uncertainties in ET mapping (EVASPA, NDVI-based, MOD16).
- Albedo and net radiation (primary inputs for the estimation of ET) can be derived with uncertainty levels better than requirements for mapping ET.

➢ WIS outputs: evaluation of actual water fluxes (in quantitative and qualitative terms)

- Campo de Cartagena: 50% of evapotranspiration was met by irrigation inputs; on average, natural recharge seems to equilibrate groundwater abstractions, but they concern different aquifers (shallow and deep aquifers, respectively).
- Crau aquifer: traditional flooding irrigation of grassland contributes to 70% to 80% of the aquifer recharge.
- Genil Cabra: high runoff flows were observed in relation to unsuitable irrigation practices; they carried significant amount of sediment and large amount of pesticides and fertilizer residues.
- Lake Karla watershed: the water balance appeared negative even in wet years, which have resulted in the continuous drawdown of aquifer water table (up to 100 meters since 1960 in some areas).

➢ Water use and land use planning under future scenarios

- Climate projections indicate strong increases in reference ET (up to 5% in Crau in 2030 and up to 20% in Crau and Cartagena in 2090), promoting significant increases in actual ET and irrigation water needs, and a small decrease of percolation to aquifers.
- Forecasted reduction in surface water availability for irrigation and urbanisation in the irrigated area over the Crau aquifer might result in a strong decrease in aquifer recharge causing a drop in withdrawal potential between 10% and 100% depending on the location.

- The implementation of the new delivery network from the new Lake Karla would result in a significant reduction in withdrawals and an increase of the water table (also in relation with water seepage from the lake); other scenarios (reduction in canal losses, alteration of irrigation methods, introduction of greenhouse cultivation) would result in lower aquifer restorations.

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3.6 IRRIGATION ECONOMICS AND GOVERNANCE

3.6.1 *Problem Statement*

Pricing is usually seen as an economically efficient option to enhance the sustainability of irrigation water use as prices provide monetary incentives for users to save water. It has been argued though that the price elasticity of irrigation water pricing is low. Moreover, economic instruments often perform complementary roles, do not operate on their own, and are typically embedded in an institutional context. Whether centralization or decentralization is more effective in managing scarce water resources is furthermore still up for discussion in many countries. The need for multi-level governance approaches that effectively deal with local level challenges seems of critical importance. Although there is no governance panacea, understanding water governance in specific contexts may help identifying best practices and overall principles of institutional design.

3.6.2 *Objectives*

Evaluate relevant institutional-economic terms and conditions for farm household uptake of existing and new water saving approaches in irrigated agriculture and assess irrigation governance arrangements in order to offer recommendations for the (re)design of institutions for irrigation.

3.6.3 *Research Design*

- A common research protocol was developed for application in the case studies to ensure cross-case comparability and assess the transferability of best-practice experiences.
- Farm household surveys were carried out in Spain, Greece, Morocco and Lebanon with the aim to assess farmer perception of current water management issues in irrigated agriculture and the acceptance of new irrigation technology.
- Based on legal and policy documents and stakeholder interviews in Spain, Greece, Italy, Morocco and Lebanon the role and relevance of actors, rules, resources and discourses on the adoption of new irrigation technology to improve water productivity were identified and analysed.
- The cross-case study comparison allows the assessment of both common and context specific local factors driving farm household uptake of new irrigation technology and the performance of institutions to promote irrigation efficiency in order to identify best practice and policy recommendations.

3.6.4 *Key Findings*

The role of irrigation water pricing

Based on a meta-analysis of irrigation water pricing, the sensitivity of water demand to water pricing appears to depend on the price currently paid by farmers. If farmers already pay a high price, they are, as expected, more sensitive to additional price increases. Water use is less sensitive at lower average irrigation water price levels. Also a relationship exists between price elasticity and irrigation technology. Price sensitivity decreases if more advanced water saving technologies are in use.

Farmer uptake of new irrigation water technology

In the survey in the Spanish case study we find that farmers are willing to pay a premium to secure water supply and enhance water supply reliability. There also exists significant demand for improved irrigation water technology, but farmers often lack awareness and knowledge about alternative technologies, for instance deficit irrigation. Furthermore, no farmer preferences are found for institutional-economic changes to improve irrigation water supply efficiency such as water markets compared to current irrigation district allocation rules. In Lebanon we find that preferences for new irrigation technology are heterogeneous and farm household characteristics have to be accounted for when trying to modify existing irrigation methods. In Greece, we furthermore find evidence of farmer awareness of the ecological impacts of unlimited water resource extractions. Instead of drilling new or deeper boreholes in time of scarcity, farmers are willing to invest in improved (automated) drip irrigation to increase their yields and profits and at the same time restore the water ecology in the watershed. In Morocco a choice experiment was used to assess farmer demand for complementary ‘soft’ policy instruments such as drought insurance for citrus cultivation.

Critical factors hindering irrigation efficiency

- Institutional failures:
  - Fragmentation without much coordination of water institutions.
  - Absence of or ineffective conflict resolution mechanisms.
  - Slow and difficult implementation of (new) rules on the ground.
  - Insufficient enforcement of rules, violation of rules.
  - Lack of credibility and legitimacy of institutions.
- Insufficient knowledge and technology transfer from public agencies to farmers (private sector often takes over).
- Public agencies lack water monitoring data and/or capacity to use data for providing services to farmers.
- Unbalanced allocation of financial resources to different phases of irrigation development (from mobilization to in-farm support).
- Lack of full cost recovery.
- Illegal groundwater exploitation.

Key factors determining the success of institutions in promoting irrigation efficiency

- Capacity to mobilize and utilize resources (money, knowledge, power, influence).
- Ability to circulate innovative policy proposals into relevant policy circles by the existence of wide social networks and bridging organizations connecting farmers’ needs to different levels of policy making.

Best practices and policy recommendations

- Bridging organizations acting at the interface between farmers and policy-makers can foster the capacity to provide credible and salient information as they connect needs and develop knowledge useful to both groups.
- Regional and local conflict resolutions mechanisms embedded in water boards, regional administrations and irrigation management organizations may substantially increase the capacity to deal with stakeholders’ conflicts. Water allocation disputes at local level may be reduced and irrigation efficiency increased by water quota systems assigning a fixed amount of water to farmers to self-manage.
- Constructive participation of stakeholders in water and irrigation management decisions at different levels of government may substantively improve the capacity to induce rule compliance.

- A balanced distribution of financial resources may enhance the capacity to provide physical and technical infrastructure for irrigation. The mobilization of resources and the achievement of high level irrigation efficiency may be promoted by the use of a mix of policy instruments including public-private partnerships, subsidies, voluntary agreements and contracts.
- Knowledge and technology transfer could be made more effective through the establishment of public sponsored networks of experimental farms in the case study regions where farmers can check the results of experiments for example in relation to the efficiency of irrigation technology.
- Institutional design addressing the needs of small farmers may improve the capacity to provide institutional infrastructure, especially in countries where the agricultural landscape is highly fragmented. For example, the aggregation business model, a five year voluntary agreement between farmers and agricultural businesses, helps small farmers in Morocco to improve their farming activities.
- Support to policy implementation and institutional (re)organization may benefit institutional infrastructure. For instance, to assist (re)organizing offices, a step-by-step transition procedure to new regimes could be built in the re-design framework of institutions. In this process it is important to account for some transition time as institutional reorganization involves civil servants becoming acquainted to new routines and procedures and sometimes the need to develop new skills.

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4. POTENTIAL IMPACT AND MAIN DISSEMINATION ACTIVITIES

4.1 POTENTIAL IMPACT

4.1.1 *European and International Added Value*

The European (in the sense of the community) and international added value of SIRRIMED has consisted basically in mutual knowledge generation and in capability-building to confront the challenges of sustainable agriculture and conservation of natural resources (i.e. water). Its impact can be summarized into a significant contribution to EU policy objectives on these subjects and an increase in trade opportunities for European and ICPC companies.

The SIRRIMED contribution to the challenges of sustainable management of water resources, based on an integrated, state-of-the-art, demand-side management approach, has permitted EU member states and, more broadly, countries of the Mediterranean region, to start benefiting from a set of tools operating at farm, district and watershed scales.

With these tools, water-policy makers and agricultural planners can set priorities and define irrigation strategies that are sustainable for a particular region and thus contribute to the EU's objective of promoting sustainable agriculture within the Mediterranean region, in the EU and in other parts of the world.

In this sense, SIRRIMED represents an important asset for a central objective of the EU-Mediterranean partnership by promoting a long-term, sustainable development in agriculture around the Mediterranean region. The management tools should also be of great value also to regions outside the Mediterranean, for instance in developing countries. The project is relevant to ensure mutual interest and benefits between EU member states and neighbour countries of the Mediterranean region, aiming at improving productivity and sustainability of agricultural lands in the Mediterranean region.

By establishing a Mediterranean network of representative agro-systems, combined with research and development activities that are central to a rational implementation of sustainable irrigation practices and management, SIRRIMED has provided a scientifically sound platform for European and ICPC research and development on sustainable irrigated farming. In this respect, SIRRIMED may be seen as an important milestone to the successful implementation of sustainable irrigation strategies among the growers practices and skills.

Improving the irrigation technology implies more competitiveness of the European farmers, as one of the direct consequences is the increase in net revenues. The other spin-off is that the new irrigation management practices will render the farming system more flexible and adapted to European regulations and to changes in the socio-economic environment. Also the Mediterranean Partner Countries will profit of the technological innovations.

SIRRIMED project results are clearly useful into the context of Integrated Water Resources Management (IWRM). The coordination with national, regional or local projects and initiatives have been fostered through SIRRIMED. All countries and organizations participating in SIRRIMED were already involved in activities related to irrigation scheduling and management. Their integration into the SIRRIMED framework have strengthened their structure and coherence, and widened the impact and dissemination of their findings. The shared and collective use of data and knowledge bases through the SIRRIMED web-site ensures the diffusion of knowledge, techniques and know-how, and a more efficient integration and use by stakeholders and end users. Therefore, the high level of integration offered by SIRRIMED has a strong potential for enhancing the efficiency of local and regional agricultural water policies.

SIRRIMED has been structured under a cross-cutting perspective, integrating scientific, technological, social and economic objectives addressed to study a complex issue (water irrigation consumption efficiency) on both sides of the Mediterranean Basin. SIRRIMED has successfully enhanced the scientific and technological collaboration between the North and South Mediterranean countries in the following aspects:

- At the scientific level, SIRRIMED has implemented a new approach to irrigation studies based in the integration of results obtained on different Mediterranean agro-systems (different tree species, regions, social-economic contexts, water policy, etc.).
- At the technological level, SIRRIMED has developed performing irrigation strategies that increase significantly the agricultural water use efficiency, especially in the Mediterranean Countries where the extensive and traditional agriculture systems must be renewed.
- At the social, economic and political level, SIRRIMED constitutes a promising contribution to the sustainable development of the agriculture in the rural regions of the South-Mediterranean Countries, through the establishment of sustainable irrigation practices.
- From the point of view of transfer of technology and know-how, the project includes an “Stakeholder Panel” and also the participation, as partners, of several stakeholders associations and SME of the Mediterranean Countries that have played a valuable role in the development, validation and valuation of the new irrigation management tools and will continue fostering its implementation. It has also had the participation of education and training institutions (universities, agricultural schools and research institutes) that have disseminated its results through workshops, seminars and training courses on irrigation management.

4.1.2 *Contribution to the Reduction of Irrigation Water Use*

SIRRIMED has developed innovative, more efficient and water-saving irrigation systems, technologies and techniques. It represents a significant contribution to the reduction of irrigation water use.

Up to 80% of water resources are dedicated to irrigation in Mediterranean countries, implying that any increase in irrigation water use efficiency (WUE) will save a significant amount of water. This appears to be the most efficient and straightforward means to comply with the EU water policy, mainly in areas with high level of water stress on the aquifers, where it is compulsory to reduce and eliminate the gap between uptake and recharge. At a mean term horizon, part of the saved water could be available for other agricultural, industrial and domestic uses. On the other hand, the conservation and preservation of the water resources, and its better use by farmers will enhance the sustainability of irrigated farming systems (lower input farming systems).

SIRRIMED has produced different deliverables that will improve water use efficiency in the Mediterranean Countries. The most relevant are:

- Models (district and watersheds information systems) as tools to improve irrigation system design.
- Best irrigation management practices.
- Best practice recommendations for sustainable irrigation water governance.

All of them conform to the Environmental Technologies Action Plan (ETAP), because they are oriented to reduce pressure on an important natural resource (water) and to increase the life quality of European citizens (improving agricultural products quality and safety).

4.1.3 *Global Contribution on Natural Resources Management*

The Mediterranean region is a very vulnerable area where major climatic changes are expected, that is increasing mean temperature and CO_2 concentration and decreasing precipitation and number of rainy days. Land-use changes add to climatic changes, making it crucial to optimize water use in terms of quantity and quality.

Degradation of soil and water resources are major constraints to economic growth, contributing to massive poverty and food insecurity among rural inhabitants in the Mediterranean region. To combat these problems, EU wishes to promote a sustainable management of natural resources (especially water) and to improve the access by farmers to environmentally-sound technologies, as those delivered by SIRRIMED.

The reduction in water availability for agriculture leads to a decrease in irrigated areas, a decrease in irrigation volumes per unit of surface area, and generally a progressive deterioration of water quality caused by excessive exploitation in areas most at risk. The use of incorrect irrigation strategies may cause deterioration of cultivated areas, leading to desertification. This makes it crucial to optimize irrigation by avoiding loss of water resources and improving methods that allow reductions in water volumes and sustainable use of marginal-quality water by adopting appropriate irrigation strategies, as those delivered by SIRRIMED.

The better understanding of the impact of different irrigation strategies on soils and crops provided by SIRRIMED allows improving the current level of productivity in line with sustainable practices of land exploitation in the Mediterranean region. The impact of SIRRIMED project will be positive in the areas already affected by deterioration of soil and water quality while its results will help to avoid problems in the areas subjected to drought and salinity risks. The project has a clear potential to reduce ground- and river-water contamination, and combating desertification.

Contacts and effective collaboration have been established with other national and international projects addressing the same or similar issues, creating positive synergies.

4.2 MAIN DISSEMINATION ACTIVITIES

The project has been widely diffused. Dissemination activities can be categorized as follows:

- a specific web site;
- periodical workshops and meetings;
- demonstration an training in pilot farms;
- information on relevant SIRRIMED results;
- compilation and publication of manuals and handbooks on sustainable irrigation practices.

The supports used for these activities are:

- web site static and dynamic information, including periodic e-newsletters;
- scientific and technical publications;
- contributions submitted and presented in international scientific meetings, conferences and workshops, including a final conference held in Brussels;
- contributions submitted and presented in regional scientific meetings, conferences and workshops;
- regional presentations;
- training courses;
- open days in pilot farms.

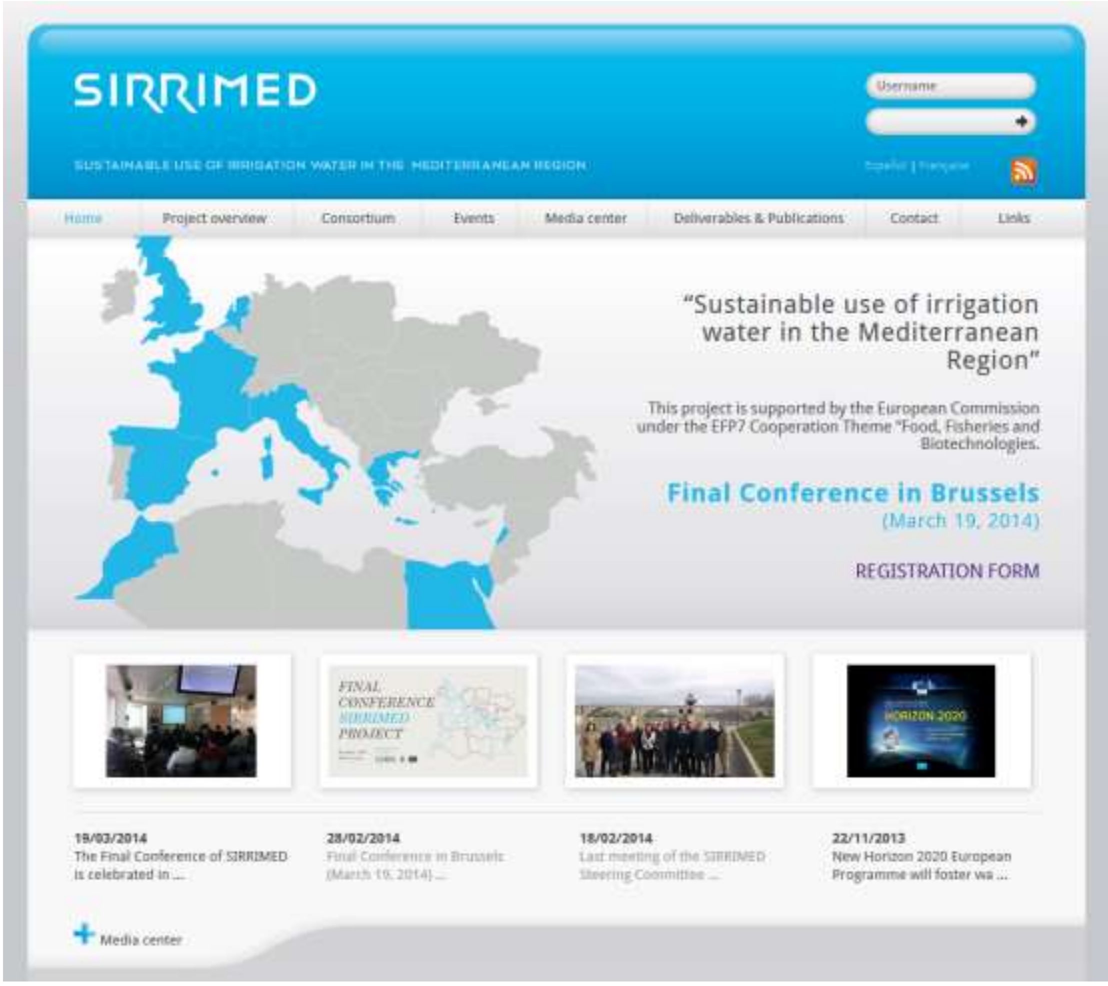
The objective of these activities was to ensure the proper visibility of the project in the scientific community and policy makers, as well as the diffusion and implementation of the project results towards the potential beneficiaries and the general public.

The initial plan has been successfully implemented without deviations. The project website is running and a leaflet containing the project presentation has been disseminated in English, French and Spanish. Furthermore, all project partners have disseminated the project and its results in many congresses and seminars. Also, many articles have been drawn up and published in well-known publications. On the whole, more than 300 dissemination activities have been produced among all the partners.

Detailed information on this activities can be found on the deliverable D7.7 Third and Final Report on “Dissemination activities”, which can be downloaded in the SIRRIMED website.

5. OTHER INFORMATION

Among its communication activities, SIRRIMED has developed a visual identity that is fully exploited in its web site: www.sirrimed.eu.



Keeping in contact with the project is easily done through the site by subscribing to its RSS flux or using its contact form. Interested people can also directly write to:

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