SIXTH FRAMEWORK PROGRAMME
Food Quality and Safety

SAFIR
Safe and High Quality Food Production using Low Quality Waters and Improved Irrigation Systems and Management

1. Publishable final activity report

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Acronym of the project SAFIR		
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Revision		
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1 Project execution

The present proposal addresses two fundamental problems that over the past decade increasingly have become concerns of the general public: one problem being the jeopardizing of safety and quality of our food products, while the other being the increasing competition for clean fresh water. The proposed project has a multi-disciplinary approach, which integrate the European as well as the global dimension of the EU-policy on food quality and safety. The main driving force behind the project idea is new research results, which demonstrate that irrigation pattern can increase the water use efficiency as well as the quality of vegetable crops. Furthermore, recent innovations in the water treatment and irrigation industry have shown potential for the use of low quality water resources, such as rivers and other surface water, for irrigation of vegetable crops without jeopardizing food safety or quality.

The proposal includes three components:

I. The technological development of water saving irrigation systems and management for use of low quality water resources. Technological advances will be made in the field of cost effective tertiary water treatment technology for on-farm use. Irrigation equipment for sub-surface irrigation systems will be tested in the field and developed to facilitate a new water saving strategy, PRD-irrigation, which improves water use efficiency and the quality of the produce.
II. Impact of the technology on product quality and safety, production system and the environment as well as a risk assessment from farm to fork.
III. A component concerning the feasibility and application of the system. The financial and economic aspects will be investigated and institutional and consumer barriers will be identified. A Decision Support System will be developed for the on-farm management of water resources. A range of dissemination activities addressing national and EU authorities, commercial stakeholders from the food sector, and farmers' organizations is included.

1.1 Project objectives

To achieve this, eight ***specific objectives*** have been identified and addressed in corresponding work packages.

	WP	Specific Objectives
I	1	1) To develop a novel irrigation technology combining the use of small-scale on-farm modular water treatment plants and improved irrigation hardware, which enable the use of low quality water resources and increase water use efficiency
	2	2) To develop new irrigation single crop management schemes to ensure: safe and high quality vegetable production using low quality water resources, and improved water-use-efficiency
	3	3) To develop single crop models to take into account the effect of PRD-irrigation with low quality water on water use efficiency, plant water uptake, soil water distribution and crop yield.
II	4	4) To assess the impact of the improved irrigation systems on the properties of water, soil and vegetables produce (biological, chemical, and physical) in the irrigated/fertigated cropping systems
	5	5) To assess the risks of the improved irrigation system in terms of food safety and farmers' health
III	6	6a) To assess the financial and production economic impact of the improved irrigation systems at farm and national level
		6b) To identify and assess institutional barriers for implementation of the improved irrigation systems
	7	7) To develop a decision support system (DSS) for irrigation management at farm level by integrating aspects of existing dynamic models to take into account crop quality, irrigation water quality, irrigation techniques and environmental impacts of the improved irrigation systems
	8	8) To facilitate dissemination of project results and experience to relevant authorities, farmers organizations, food and irrigation industry and research institutions

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1.3 Overall state-of-the-art achievements

Partners in WP1 designed, tested and carried finally produced a White Book "User manual for farmers and water companies on suitable drip irrigation technology and waste water treatment technology for use in irrigation of vegetable crops, tomatoes and potatoes" (cf. Chapter 2, D1_4), available also from www.safir4eu.org.

In WP2 final conclusions were drawn from the experimental results achieved in China and Europe, and as well conclusions were made on how to apply various water saving irrigation strategies, Deficit (DI), Regulated Deficit (RDI) and Partial Root-zone Drying (PRD) in combination with various irrigation technologies, mainly focused on subsurface drip (cf. Chapter 2, D2_5), available also from www.safir4eu.org.

The main activities in WP3 were to develop and test improved SPAC models, SALTMED and Daisy. These activities as well as a complete documentation of the new code developments are presented in D3_2, Chapter 2, available also from www.safir4eu.org. In addition recommendations on relevant water saving irrigation strategies were assessed based on modelling activities carried out in collaboration with partners holding the various experimental sites (cf. Chapter 2, D3_1), available also from www.safir4eu.org.

In WP4 important conclusions were drawn on the impact on soil-crop-produce of using treated waste water for drip irrigation. Details are given in the deliverable reports Chapter 2, D4_3, D4_4 and D4_5, available also from www.safir4eu.org.

The overall conclusions from the Chinese sites (mainly CAU, Beijing) were that the main parameters, quality and safety of fresh tomato were not statistically different between waste water irrigation, SAFIR treated waste water irrigation, and groundwater irrigation. The quality of all irrigation water and safety of fresh tomato met the Chinese standard of cropland irrigation water and food safety. The accumulation of heavy metal in soil was hardly detected as the amount added through irrigation was much smaller comparing to the background. More consideration is needed on nitrate and heavy metal leaching at the CAU site as the groundwater table was only around 1.2m under ground. The overall conclusion on microbiology was that low quality water treated with the SAFIR WP1 technology can safely be used to irrigate tomatoes and potatoes. Low concentration of indicator organisms was found in treated water, and no detectable difference was found in subsurface and surface irrigation. Overall conclusion on the food quality data was that no significant links were found between irrigation water quality and fresh or processed food trace elements content or quality markers for tomato and potato. But three years of testing are not sufficient to exclude cumulative effects of heavy metals or other contaminants in soils, crops and finally in processed products.

From the analysis of the fresh and processed products from sites in Europe no significant links could be recognized between irrigation water quality and fresh or processed food trace elements content or quality markers in the selected crops. However, the first general comment from a quality viewpoint and, above all, from a safety viewpoint, is that three years of testing are not sufficient to exclude incontrovertibly cumulative effects of heavy metals or other contaminants in soils, crops and finally in processed products. All products were okay seen from a legislative point of view. There were no significant differences regarding content of heavy metal from tap water compared to treated waste water.

The overall conclusions on microbiology findings at sites in Europe were that SAFIR treated waste water can be used to irrigate tomatoes and potatoes and still have an acceptable hygienic food safety level. No detectable difference was found in E. Coli contamination of soil/produce following subsurface and surface irrigation.

Hence, the overall conclusion on chemistry/pathogens at EU and Chinese CAU sites was that no significant negative impact was found of irrigation water quality on soil, food and processed food in the investigated concentration range and over three years, on plot scale, compared to other factors.

In WP5 a literature review was carried out on transport of pathogens in soils, Chapter 2, D5_4. A health risk assessment and risk modelling of the SAFIR irrigation methods were published in Chapter 2, D5_5 and D5_6. The following conclusions were drawn: No association between contamination in irrigation water and contamination of soil or produce was found. Hence, no effect of SAFIR irrigation was found. Some peak E. Coli concentrations were identified. It indicated some risk but could not be attributed to SAFIR irrigation. From the components of health risk assessment were found that pathogens and inorganic contamination in supply water did not lead to contamination in soil and crops, which might pose risks to farmers. Crop samples did not indicate any contamination with potential health risks. And finally, typical levels of contamination from "normal" food supplies for the same crops culd be as bad or worse than in SAFIR samples.

In WP6 the final assessment of the cost structures of the new water saving irrigation technologies have been published in Chapter 2, D6_3 and as well institutional barriers and potentials for introducing new water saving irrigation technologies have been presented in Chapter 2, D6_4 and D6_5. Farm level conclusions were: New irrigation technologies and strategies have a potential of saving water. In case of scarce water, some of the potential is already exploited, as is the case on Crete. In most cases, however farmers have little economic incentives (just) to save water. Adaption of new technologies and strategies are mainly driven by labour, energy and capital costs - incidentally then saving water. In some cases PRD may increase quality of the products and mineralization of nitrogen. But there is no extra water saving potential of PRD compared to DI/RDI. Just in case of a high quality premium and cheep double-dripper lines PRD will become more profitable than DI/RDI.

As a part of D6_3 the economic potential of the new irrigation and water treatment technologies was assessed at the catchment scale. This study was based on a real situation representing a Mediterranean area: the western part of the Island Crete. Reuse of wastewater treated by MBR was compared to three baseline sanitation projects in several contrasted contexts of water scarcity.

The main activities in WP7 were to document and setup running prototypes of the DSS and management models handling guidance on the safe use of treated wastewater and water saving irrigation strategies at farm level. The DSS system NULIBAR and the management models are detailed described in Chapter 2, D7_1 and D7_2 and can as well be run from the SAFIR homepage, see Results at www.safir4eu.org.

In WP8 several important dissemination results have been achieved. A final public workshop was arranged in September 2009 in Brussels to present and further discuss the final outcome of SAFIR. To this workshop SAFIR was invited several guest speakers to give a talk and hereby putting the SAFIR results into a wider perspective. The workshop presentations are available from the SAFIR homepage www.safir4eu.org. Action were taken to provide the results from SAFIR to the broader audience, as present SAFIR results at conferences and scientific journal papers, a series of final stories were published in easy to read leaflets, see www.safir4eu.org. Finally, funding was allocated to publish a special issue in the scientific journal Agricultural Water Management, due Dec 2010.

1.4 Overall impact for industry or reserch sector

Safir has given important knowledge on water saving irrigation technologies and strategies, and as well developed technical solutions for treatment of municipal waste water to turn grey water to green water safe for irrigation of food crops. The new knowledge technologies may show important for SME, both those involved in SAFIR and a wider scale. For details cf. in this report section 1.5, WP1-3 and chapter 2.

1.5 Description of work packages

WP 1: Water Treatment and Irrigation Technology

Objectives

To develop a novel irrigation technology combining the use of small-scale modular water treatment plants on farm and improved irrigation hardware, which enable the use of low quality water resources and an increase in water use efficiency.
To improve the current knowledge of irrigation management for low quality raw water to design new irrigation and fertilisation systems enhancing crop quality and safety

Description of work

Task 1.1: Assessment of relevant technologies
The partners will combine new water treatment devices (prototype) and implement them into new irrigation systems *(1)*. The combined system will be flexible to fit the requirements according the raw water quality and to the risk of pollutants and pathogens bioaccumulation/contamination in the products. It includes the coverage of seasonal concentration changes (e.g. no nitrogen removal during the plant vegetative phases, strong reduction when nitrate accumulation might occur in the fruits) *(2)*. Thus, the new modular systems will couple new irrigation technologies with improved small-scale water treatments facilitating deficit irrigation strategies such as partial root zone drying irrigation and buried drip lines (link to WP2)*(3)*. The new system will produce a definite range of target water qualities, changing according to the growth season and the economical optimum (link to WP3 and WP4) *(4)*. Further the project will propose Best Available Technology (BAT) for municipal waste water treatment targeted to different subsequent agricultural reuses: the main focus for safe agricultural reuse is on pathogens, nutrients, contaminants and micropollutants according to quality requirements defined in WP2 and WP3. High and low technology solutions (e.g. wetland treatment or membrane bioreactor) are being discussed in terms of water quality upgrading potential and resource requirements (financial, human and energy) *(5)*.

Task 1.2: Implementation of technologies at the five field sites
The water treatment unit will be conceived as a mobile station at the five field sites able to serve the largest crop area, reducing the management costs (link with WP6) and making crop management and irrigation as flexible and dynamic as possible (link with WP7) *(1)*. The water treatment will focus mainly on faecal contamination, salt, nitrate and heavy metal (Cd, Cr, Ni) removal and pH adjustment *(2)*. The degree of treatment should be able to interact with the management DSS (WP7) in an intelligent way: for cost minimization the removal of salt, nitrate and heavy metals will be done only to defined thresholds (WP3, WP4, WP5) *(3)*.

Task 1.3: Adjustment and refinements of technologies
Stepwise over three experimental years (WP2) the configuration of will be optimised according to gained knowledge in WP2-4

Task 1.4: Reporting
The new systems will be documented with respect to partners confidentiality rights and a user manual will be released easy to understand for end users (farmers and water companies)

Deliverables, see Chapter 2 Dissemination

D1_3: Intelligent water treatment prototype and irrigation systems ready to operate at the five field-sites (Hard- and software running at the experimental sites).

D1_4: User manual for farmers and water companies finalized and published (Report).
D1_5 (extra) Evaluation of alternative water resources for irrigation in agriculture (Report).

State-of-the-art achievements

Task 1.1 Assessment of relevant technologies: WP1 partners identified and agreed the most relevant water treatment technologies to be implemented in the SAFIR field experiments. The process had several loop during the project lifespan, ending in two innovative water treatment technologies at small-scale: a prototype of a compact pressurised membrane biofilter (MBR) and a modular water treatment plants designed to refine poor quality water at field scale (FTS, Field Treatment System). The analysis of the existing technologies and their potentiality, of the boundary conditions, as well as the rationale of the WP1 water treatment are reported in the document "WP1 – Evaluation of alternative water resources for irrigation in agriculture V3.01" attached herewith. WP1 provided as well the selection of the most suitable irrigation system and its design, customised for each field site. A Sub-surface Drip Irrigation System provided suitable and reliable fertigation in five experimental field sites in Europe and in China. The irrigation system was designed to fulfil the requirements both of the WP2 experimental schema and of WP4 sampling and monitoring plan, and it was upgraded and improved in 2007 and 2008 following the partners' feedbacks. To manage correctly the PRD (Partial Rootzone Drying) irrigation strategy, a special coupled dripline was provided by Netafim to the field partners.

MBR water treatment: the MBR prototype is aimed to offer a viable option to replace conventional wastewater treatment for small communities, residential areas, scattered houses and factories. Hence it is an innovative solution for de-centralised water treatments, helping to solve problems of non point pollution like sewage floodways leacking, discharge from waste water treatment plants by-pass, and plants or sewage line breakdowns, which frequently affect surface irrigation water used as recipient for the urban or industrial treated or untreated waste water. The prototype put together membrane ultrafiltration technologies and enhanced activated sludge digestion, minimising the size of the treatment device and consuming energy amount comparable to a traditional water treatment process. In areas with high anthropogenic pressure and human footprint index MBR treatment provide high quality, filtered and disinfected, water for irrigation. Water produced with MBR doesn't require further filtration and can be safely used with every irrigation method. MBR prototype is designed without denitrification, but it is possible to add a de-nitro as well as a phosphour removal unit. To profit of the MBR water nitrate content, avoiding any pollution risk, fertilisation and fertigation schedule were managed by a DSS.

FTS water treatment: on site FTS treatment was developed, adapted and implemented in an advanced filter station downscaling and modifying urban and industrial waste water treatment technologies. The FTS doesn't aim to replace conventional wastewater treatment system, as for MBR, but merely to allow a safe use of poor quality water for irrigation purposes on a very small scale. The configuration of the prototype is flexible, changeable according to the raw water quality and to the risk of pollutants and pathogens bioaccumulation in the food chain or soil and water contamination. Till now available technologies don't allows to remove salt and/or nitrate at field scale in an economic way. For that reason FTS concentrate on two major issues: faecal contamination and heavy metal pollution. The configuration of the prototype range from a simple gravel filter adapted and managed to enhance its capability to partially remove particulate bound to a complete set up that includes a special filter able to remove the most harmful heavy metals (arsenic, cadmium, chromium), as well as excess of lead, zinc and copper, and an UV disinfection lamp. FTS components could work separately, being bypassed when raw water doesn't require inorganic pollutants removal or disinfection. Only the gravel filter couldn't be disconnected. As for the MBR, the management of nitrate supply via irrigation water was done by means of a precise fertigation coupled with water saving irrigation strategies aimed to reduce bioaccumulation and biomagnification of pollutants along the food chain or ground and surface water pollution.

SAFIR WP1 integrated water treatment: the treatment pathways are designed for the main reclaimed water sources: primary waste water from small communities, industrial or residential areas; secondary treated waste water, not filtered nor disinfected, produced by urban water treatment plant; secondary waste water, already disinfected and screened for main pollutants, that may require further on site refinement to avoid food contamination. Treated waste water is usually discharged into surface water, already polluted or not, hence most of the irrigation water sources in Mediterranean areas need to be treated on site, similarly to polluted groundwater. The SAFIR WP1 water treatment consist of three stages. Treatment phase 1 provides water which is treated with MBR or FTS technology in function of its pollutant loads (fig. 1). Properly treated SWW, although not filtered and disinfected, could be treated only with a simple gravel filter. Phase 2 provides a further refinement of water by means of a suitable irrigation method. Buried drip line (sub-surface drip irrigation, SDI) is considered the best option, however also drip irrigation, sprinkler and furrow were tested and compared with SDI. Irrigation strategy (phase 3) is considered as a part of the integrated water treatment. Impact of both soil humidity and suspension of irrigation on faecal contamination of soil and fruits is well documented in literature. A decision support system drives irrigation management aimed to save water and allows to keep soil humidity in the root zone at a suitable level for the plant, whilst not optimal for bacteria survival. Moreover, supplying strictly the water amount needed to obtain a good crop yield and quality also keeps the pollutant accumulation in the receiving soil in a tolerable range. Provided that the bioavailability of inorganic pollutants (e.g. arsenic or cadmium) is mainly a function of its concentration in the pore water, reducing plant available water can limit their uptake by roots.

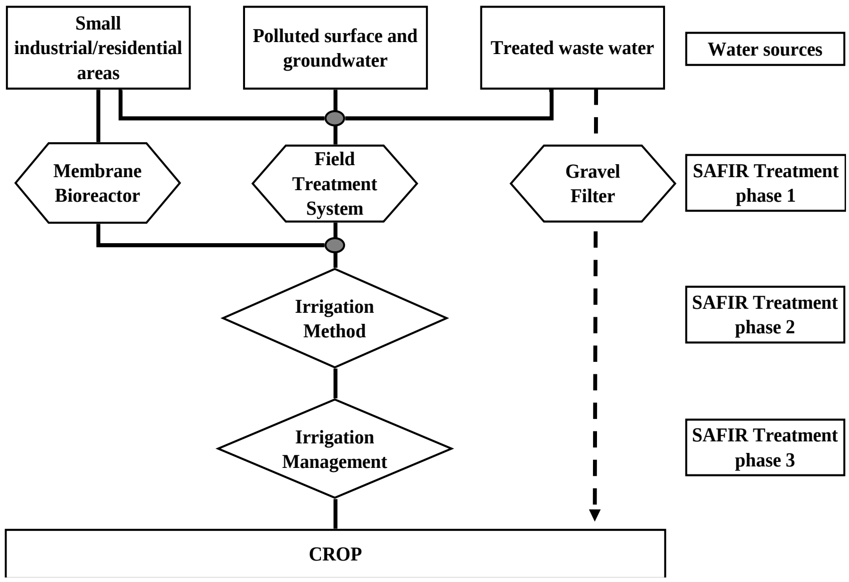

Figure 1. Safir water treatments pathways

Irrigation method and strategy as a part of the water treatment technology: the last barrier to food contamination in the SAFIR WP1 water treatment schema is the distribution of the water via subsurface drip coupled with a wise water supply aimed to reduce the irrigation volume and the irrigation period, the latter mainly close to harvest, reducing as well the pressure of the contaminants on the produced food. The effectiveness of the system is threatened by the difficulties in monitoring performance and measurement of uniformity, that are often cited as a disadvantage of subsurface drip systems. The use of reclaimed water or poor irrigation water quality has often been associated to emitters clogging and bio-fouling risks. The use of irrigation water which quality could damage the irrigation system at the end of the irrigation season or even worse during the cropping season is, of course, not a sustainable option. In order to check the impact of the SAFIR WP1 water treatments on the technical characteristics of the drippers utilised for three years in the field experiments a bench test was carried out on the brand new irrigation material and at the end of the project. The test results show that the SAFIR functional waters don't caused any damage to the drippers as the tap water utilised in the control plots.

New technologies supporting the research targets: the data collected during the first year of research clearly showed two main problems: inorganic pollutants load into the raw water sources was discontinuous; the forecast grab sampling of the inlet and outlet water don't allowed to extrapolate the real contaminants load entering the SAFIR WP1 treatment systems or delivered to the field. To add a defined amount of an element to a solution, in order to make it detectable, the so called spiking, is a commun practice in laboratory. The same practice was not applied before at field scale, due to the high amount of water, the rapid flow, the need to keep stable the enriched solution to be injected into the irrigation water flow, and to the difficulty to secure a correct homogenisation all over the irrigation time, lasting hours. SAFIR WP1 designed a Dosing system able to inject simultanuosly the desired amount of arsenic, cadmium, chromium, lead and copper into the inlet water, keeping them at the required concentration with an acceptable precision. In strict cooperation with WP4 was decided to integrate the water sampling along a period corresponding to the crop relevant phonological stages. To allows the field partners a sampling device was designed by the WP1 and adapted to the field site needs. The PLD (Proportional-Like Device) is a not expensive, easy to use, reliable device which allows to sample countinuosly the inlet water into the treatment systems as well as the irrigation water delivered to the field (fig. 2).

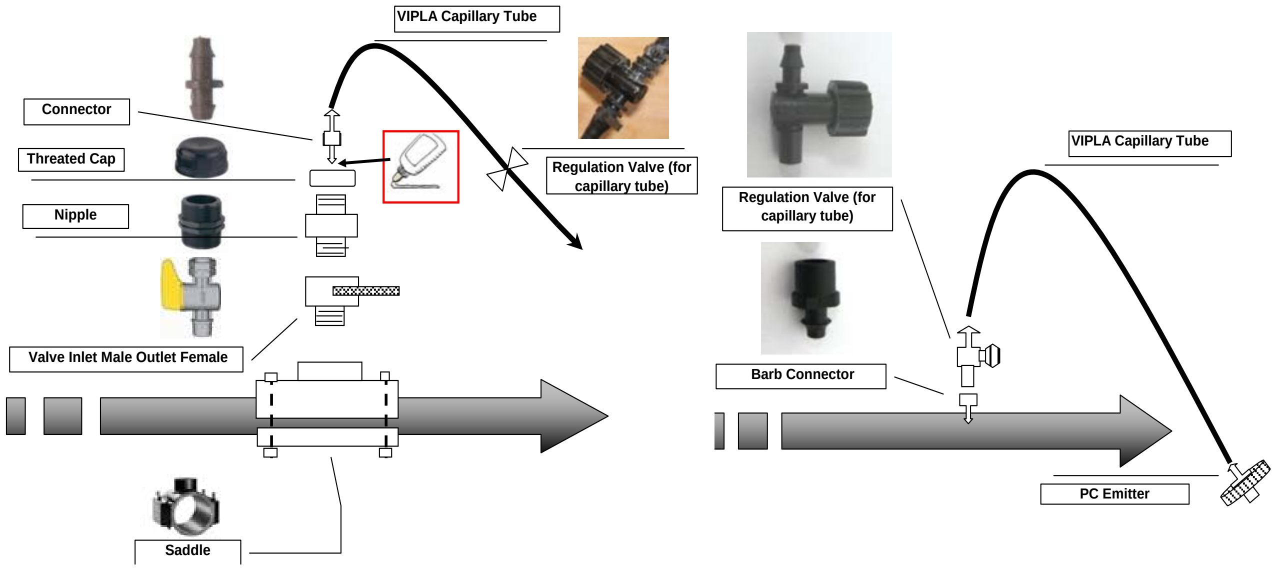

Figure 2. Safir Proportional-Like Devices (PLD)

The use of PLD allowed to integrate inorganic compounds concentration during an entire crop growth stage. It cannot be utilised to sample for microbial loads, being impossible preserve the sample for more than few hours. Grab samples were thus utilised to check the effectiveness and reliability of the PLD integrated sampling.

Task 1.2 Implementation of technologies at the five field sites: Every field site was equipped with an irrigation system specifically designed to fulfil the WP2 and WP4 requirements. The field experiments in Italy and in Greece were equipped with MBR prototypes. At the end of the first year was decided to concentrate the MBR prototype development in Italy, serving two experimental fields (potato and processing tomatoes). In Italy was tested the use of secondary treated waste water, not filtered nor disinfected, only filtered by a normal gravel filter. The complete FTS configuration was tested in Serbia, Greece and China.

Task 1.3 Adjustment and refinements of technologies: The technologies implemented at the field sites were continuosly monitored and further developed and adjusted in two successive loops: at the end of the first and of the second experimental year. Further refinements were done at the end of the third years, focused mainly on bench tests to improve aspects like maintenance, effectiveness and operational costs.

Task 1.4 Reporting: The WP1 results were presented to the Commission and to the partners in the project annual reports. The relevant internal documents were circulated among partners in the due time as forecast. Furthermore, the results and the proposal made by the WP1 team were presented and discussed at each project annual meeting and PMG meeting. A power point presentation was made available for the project partners at every meeting. WP1 provided a final document, the "User manual for decentralised functional water production for irrigation purposes", synthetising the results obtained (D1_4 Chapter 2 Dissemination). An extra deliverables was provided as well, the "WP1 – Evaluation of alternative water resources for irrigation in agriculture V3.01", (D1_5 Chapter 2 Dissemination). Moreover the WP1 presentations done during the SAFIR workshops are available for the Commission and for a wider audience (free downloads from the safir website – www.safir4eu.org)

Impact for industry or research sector

The test and further development of the compact pressurized MBR technology allowed the SME involved (Grundfos Biobooster) to patent the system, that is now available on the market.

The studies carried out on the assessment and improvement of the gravel filter effectiveness removing contaminants from irrigation water, are of pre-competitive value for the SME involved (Netafim) allowing to design the gravel filter, already produced by the company, for wide purposes and markets than before.

The development of an Heavy Metal Removal Device, as a component of the FTS system, allows the SME Netafim to utilise the existing filter body technology for a different purpose, enlarging the potential market.

The studies carried out on the PRD irrigation strategy provided to the Irrigation sector, and in particular to the SME Netafim, relevant know how about the technical and technological difficulties and problem to solve to produce a high quality PRD dedicated dripline.

The application of industrial adsorber matrix in the agricultural sector can boost the development of low cost and effective new products. EU industries can profit of the knowledge produced by WP1.

The SAFIR WP1 results concerning the compact pressurized MBR systems removal capability of faecal and inorganic contaminants are innovative and offer the opportunity to carrie out further researches in the field of the de-centralised water treatment aimed to produce functional water to be reused in agriculture, gardening or public green areas. On site refinement might be studied as well (FTS) starting from the SAFIR WP1 results.

The researches carried out about the gravel filter effects on irrigation water contaminants dynamics are innovative (almost no literature available). Further researches might be carried out to confirm the SAFIR WP1 results and to enhance the gravel filter design and management protocols. SAFIR WP1 studies on functional water production demonstrated that it is possible to convert grey water, instead of more valuable blue water, in green water and safe food. Starting from the SAFIR WP1 results, further researches on the relations between functional water production and food safety might be carried out, supporting the revision of local, national and EU regulations. The SAFIR WP1 water treatments and irrigation management were designed also to be utilised for the Disability Adjusted Life Year (DALYs) risk analysis, as requested by the new WHO standards (2006). The results obtained by the SAFIR WP1 can help to better understand the log removal capability of the steps from the raw water inlet till the crop harvest, allowing to correctly apply the DALYs criteria. This researches might have a positive effect also on the Global Gap standards.

WP 2: New Irrigation Management Schemes

Objectives
To develop new irrigation single crop management schemes to ensure: safe and high quality vegetable production using low quality water resources, and improved water-use-efficiency.

Description of work

Task 2.1: Design and conduct field/controlled environment experiment including physical-chemical measurements.
Three-year field experiments on potato and tomato will be set up at partner 2,9,12-14 in a factorial design with 3 replicates. The control treatment will be irrigation with conventional clean waters. Controlled environment studies will be conducted for two years at partner 1, 3 and 11 in order to develop management models that can handle PRD-irrigation with respect to uneven soil water distribution and hormonal effects on transpiration.

Task 2.2: Apply new developed irrigation technology from WP1 and irrigation management from WP3.
Water saving new irrigation schemes for potatoes and tomatoes will be developed by experiments with and analyses of partial root zone drying (PRD) irrigation strategies that optimise the water-use-efficiency by applying recent research on plant water relations including hormone-signalling effects on stomata. The use of low quality water coupled with appropriate water treatments (WP1) will further be demonstrated to save high-quality, fresh-water resources. The schemes will take into account the need for an increased food safety as related to the use of low quality water. This will be done by studying the impact of water treatments, delivery of water below ground (subsurface drip irrigation) and PRD on pathogen survival and pollutant uptake in crops (WP4). Finally, the impact on crop quality and productivity by reduced water supply in the PRD-irrigated/fertigated cropping systems will be investigated.

Task 2.3: Data control, simple data analysis, deposit in databases for WP3 and WP7, statistical analyses.
The obtained high quality data from these experiments will be stored in an efficient database structure available to all partners from the internet. The effects of the use of different waters, irrigation management will be assessed using standard statistic, however the importance of these results will be biased from the results (Impact) obtained in WP4.

Task 2.4: End-user visit at field site, reporting.
At all five sites mid-season end-user meetings will be arranged to discuss progress results, and final reports on main results from all sites will be produced.

Deliverables, see Chapter 2 Dissemination
D2_5: Statistical analysis of the field experiments and conclusion on the new irrigation/fertigation techniques and methods of growing potatoes and tomatoes (Report).

State-of-the-art achievements

Conclusion on the new irrigation/fertigation techniques and methods of growing potatoes and tomatoes.
Within the EU-project SAFIR new water saving irrigation strategies were developed based on pot, semi-field and field experiments with potatoes, fresh tomatoes and processing tomatoes as model plants. The field irrigation guidelines was developed under temperate, Mediterranean (Greece, Italy) and continental (Serbia, China) climatic conditions during summer. The field investigations on

processing tomatoes was undertaken only in the PO valley (Italy) on fine textures soil. The guidelines is based under the assumption that drought adaptation mechanisms of crop plants can be utilised for optimizing water saving irrigation scheduling. The investigations showed that gradual and partial soil drying implemented by deficit irrigation (DI) or partial root zone drying (PRD) induced hydraulic and chemical signals from the root system resulting in partial stomatal closure, increase in photosynthetic water use efficiency, slight reduction in top vegetative growth. Further PRD irrigation increased N-mineralization causing a stay green effect late in the growing season. In potatoes and tomatoes the water saving irrigation strategies DI and PRD were able to save about 20% of the water used in fully irrigated plants . Under the phase of establishment both potatoes and tomatoes should be fully irrigated. During the later phases the following water saving deficit irrigation can be undertaken
without causing significant yield reduction. The guidelines and quality effects are:

- Potatoes
  - DI/PRD irrigation can be undertaken from after end of tuber initiation applying 30% ater saving of FI. During the last 14 days 50% of FI can be applied without yield decrease.
  - PRD irrigation increases marketable yield by 15% due to improved size distribution.
  - Antioxidant content is increased by PRD treatment.
- Fresh tomatoes
  - DI/PRD irrigation can be undertaken from 1st truce is developed. For 2 weeks DI is applied to save 15 -20 % of FI. In the middle period DI/PRD is applied to save 30 % of FI . The last 14 days of growth period DI/PRD is applied to save 50% of FI.
  - Antioxidant content is increased by PRD irrigation
- Processing tomatoes
  - From transplanting to fruit setting at 4-5th cluster PRD and DI irrigation threshold for re-irrigation is when available soil water content, ASWC=0.7 (soil water potential, Ψ_{soil} =-90 kPa). During the late fruit development/ripening stage, from 10% of red fruits, threshold for re-irrigation is and for DI when ASWC= 0.5 (Ψ_{soil} = -185 kPa) and for PRD irrigation when ASWC (dry side) = 0.4 ($\Psi_{soil, dry side}$ = -270 kPa).

For tomatoes fully irrigation for cooling effects should be undertaken when night/day average temperature >26.5 ^{0}C or when air temperature > 40 ^{o}C to avoid flower dropping. For potatoes the high temperature threshold is less clear. Similar irrigation guidelines might be developed for other crops partly based on deficit irrigation experiments, for further details see Deliverable D2_5, Chapter 2 Dissemination.

Summary

During the four year SAFIR program physiological studies in potatoes and tomatoes have given further insight into the mechanisms of signalling, water saving, growth and yield maintenance in potatoes and tomatoes subjected so the water saving irrigation strategies PRD and DI. Some advantages have been obtained by PRD irrigation as compared to DI irrigation in respect to both quality and quantity of the produce of plants. Physiological models for ABA production and stomatal closure has been developed and are now implemented in the DAISY and SALT-med models (WP3) for further implementation in DSS models (WP7). Water saving irrigation guidelines has been developed using potatoes and tomatoes as model plants.

Impact for industry or research sector

The project have investigated the potential for water saving in potaoes and tomatoes using subsurface drip irrigation in both DI and PRD mode of irrigation. Further development of the drip irrigation equipment and software for DSS has the potential for industial development.

1) Irrigation equipment

The PRD subsurface irrigation tubes should be developed so they are able to irrigate as traditional DI irrigation or as PRD irrigation alterning the irrigation beteen left and right side of the plants. The latter can be obtained by using a douple tupe system where drippers are placed so they are able to irrigate on the right and left side of the plants in turn. This may be obtained more advanced by using two type of drippers which can open and close on preplanned stimulis, e.g. high pressure may open the drippers on the left side of the plants while low pressure drippers may open the drippers on the right side of the drippers. These possiblities are still to be exploited by the industry for low cost production of DI/PRD tube irrigation systems.

2) Decision support sytems (DSS) optimizing water saving without yield depression.

As clear from the above findings the greatest water saving is obtained under precision irrigation can be regulated in a dynamic way so that initial growth phases is fully watered for tomatoes, young stages have water savings of 15-20%, medium stages have savings of 30% while late stages has saving of 50% as compared to fully irrigated plants without yield depression. For potaoes also the initial growth phases is fully watered, after tuber initation until nearly maturity the savings can be 30% while for the last 14 days of the growth period the savings is 50% of fully irrigated plants. These results be used in commercial DSS regulating the irrigation level and may be based meteorological observations, soil moisture observarions and/or plant observations. The DSS may be further refined by including runnings of advanced models as DAISY and SALT-Med further developed with hormonal contral of leaf conductance (WP3). The advantage of such improved DSS is that different climatic and soil conditions can be taken into account for optimizing the the hormonal flow in the xylem system of root originated hormones mainly ABA.

3) Quality improvement

15% higher marketable yield can be obtained in PRD irrigated potatoes due to better size distribution (4-6 cmm diameter). Also the investigation showed that the antioxidant content was increased in both PRD irrigated potatoes and tomatoes in the range og 5-10%. These finding should be further investigated to elucidate the mechanisms behind.

4) Soil and plant nitrogen

PRD irrigation increased N-mineralization and N_{min} availability in the soil causing a stay green effect late in the growing season as clear from field investations in potaoes. This effect is now being further investigated using ^{15}N isotope labelling technique. Our recent results indicate that PRD not only stimulates organic N mineralization in the soil but also increases the root N uptake efficiency. The stimulated soil organic N mineralization under PRD may be interesting in improving crop N nutrition in low input organic farming systems where slow and low soil N supply during active growth season is often limiting yield.

WP 3: Single Crop Modelling

Objectives

To develop single crop models to take into account the effect of PRD-irrigation with low quality water on water use efficiency, plant water uptake, soil water distribution and crop yield.

Description of work

Task 3.1: To further develop existing models such as SALTMED and DAISY to bring them up to the level that they can be applied for PRD-irrigation using low quality water.

Data delivered by WP2 controlled environment experiments will be used to develop models for leaf photosynthesis and transpiration as affected by PRD-irrigation, soil and climate and these will be integrated in SALTMED and DAISY. The models will be partly based on concepts from the DanStress model partly on potato growth models from the FertOrgaNic and SALTMED projects. A 2D soil water and solute model will be developed, calibrated and included in DAISY.

Task 3.2: To implement and calibrate these models to analyse the effects of deficit irrigation such as PRD-irrigation when using low quality water on crop yield.

Data from the field experiments of WP2 will be used to calibrate the models and will further be modelled to analyse the effect of PRD-irrigation at crop level on water use efficiency, crop growth, yield and quality. This will be a re-current process where model results will be used to improve irrigation system, irrigation/fertigation management and scheduling during the three-year period of the field experiments taking into account characteristics of water quality.

Task 3.3: To develop the models as tools for managing irrigation water and nitrogen to the most important horticultural crops at various soils and climate regions in- and outside Europe.

The new DAISY and SALTMED modules for managing irrigation and fertigation of vegetables will be finally included in the model complexes. The user interface will be adapted to enable management of the new irrigation technologies for water treatment and PRD-irrigation including necessary input options.

Task 3.4: To test the models against experimental data of selected crops.

The finalized models will be tested on data from the field experiments and other datasets. One of the models will be run with “what if scenarios” depicting series of possible irrigation water management practices, and a set of guidelines and recommendation will be produced based on the successful test of the models and the results of “what if scenarios”.

Deliverables, see Chapter 2 Dissemination

D3_1: Guidelines and recommendation on best water management practices when using low quality water and PRD-irrigation systems (Report).

D3_2: Final version and documented models available (Report and software available from www.safir4eu.org).

State-of-the-art achievements

The main objective of this work was to develop single crop models to take into account the effect of PRD-irrigation with low quality water on water use efficiency, plant water uptake, soil water distribution and crop yield. The work included three tasks. The first was to further develop existing models such as SALTMED and DAISY to bring them up to the level that they can be applied for PRD-irrigation using low quality water**.** The second was to implement and calibrate these models to analyse the effects of deficit irrigation such as PRD-irrigation when using low quality water on crop yield. The third was to develop the models as tools for managing irrigation water and nitrogen to the most important horticultural crops at various soils and climate regions in- and outside Europe. The fourth was to test the models against experimental data of selected crops. Subsequently, SALTMED and Daisy models have been further developed to account for the subsurface irrigation, Partial Root Drying, PRD, dry matter, soil temperature, soil nitrogen dynamics, fertigation and Evapotranspiration using canopy conductance estimated by various methods (based on environmental variables, Absecic Acid, ABA, etc.). The modelling work was carried mainly by partner 3 (Copenhagen University, DK) and Partner 4 (NERC, UK) with also contribution from partner 1 (Aarhus University, DK), partner 2 (CER, Italy), Partner 12 (Belgrade University, Serbia), Partner 9 (NAGREF, Greece)

Data delivered by WP2 controlled environment experiments have been used to develop models for leaf photosynthesis and transpiration as affected by PRD-irrigation, soil and climate and these were integrated in SALTMED and DAISY. At the same time, data from the field experiments of WP2 were used to calibrate and test the models as well as to analyse the effect of PRD-irrigation at crop level on water use efficiency, crop growth and yield. The results aimed at improving the irrigation/ fertigation management and scheduling of the field experiments taking into account characteristics of water quality.

Two important deliverables were completed, first was report on guidelines and recommendation on best water management practices when using low quality water and PRD-irrigation systems, Deliverable D3_1, see Chapter 2 Dissemination. The second was a delivery of the final software versions and supporting documents of the two models, Deliverable D3_2, see Chapter 2 Dissemination. These models are available /downloadable from SAFIR website www.safir4eu.org

The models were presented in several workshops and partners were trained on using the two models.

Daisy model has been successfully applied on field experiments conducted in Crete (tomato) and Denmark (potato) while the SALTMED model has successfully been applied using field experiment data from Italy (tomato and potato), Crete (tomato) and Serbia (potato). SALTMED was tested against final yield, soil moisture and soil nitrogen field data collected from the field under different irrigation systems such as PRD subsurface drip, subsurface drip full irrigation, drip deficit irrigation, sprinkler and furrow irrigation systems. The results indicated that:

- SALTMED and Daisy models successfully simulated the biomass production, yield, soil moisture, soil nitrogen and crop growth under different climatic and field management conditions. Therefore we recommend these models as useful tools for agriculture water management.
- High quality data are essential for good model predictions. More frequent measurements and continuous records (no data gaps) are needed for better model application and prediction.

- The models were sensitive to the soil hydraulic parameters and these should be given more attention and resources to obtain these parameters from field measurements.

- The SALTMED model and field results of Serbia indicated that the average water productivity of drip treatment was 2.11 kg potato dry matter per m^3 of water while it was 1.69 for the furrow. The water productivity for deficit drip, full drip and PRD drip were very close, being 2.17, 2.14 and 2.04 kg potato dry matter respectively. The ratio of water productivity between furrow and Drip was 0.80. This is a 20% water saving. Therefore, the drip irrigation is highly recommended. The water productivity is calculated here as a ratio of yield to total seasonal amount of applied irrigation water and rainfall.

- The SALTMED model and field results of potato in Italy showed that on average the productivity under the sprinkler was 87.46 % of the PRD and the normal drip was very close to the PRD, 97.43%. The water productivity was 3.11, 3.03 and 2.72 Kg/m^3 for PRD, normal drip and sprinkler irrigation system, respectively. Water saving would be about 13% if the PRD is used instead of the sprinkler irrigation.

- The SALTMED model and field results of Italy on Tomato indicated that the PRD was the highest in water productivity followed by the normal drip followed by the sprinkler irrigation system being 2.53, 1.91, and 1.35 Kg/m^3 respectively. The water productivity of sprinkler was 53% of the PRD and the normal drip was 75 % of the PRD. This means that PRD would allow water saving of 25% and 47% when it is used instead of normal drip and sprinkler irrigation systems, respectively.

- The SALTMED model and field results of Crete on tomato indicated that the PRD productivity was 15% higher than normal drip irrigation.

Dissemination of the modelling results

In addition to the workshops where the models have been demonstrated, a plan has been drawn to publish the new models and the modelling results. A special issue of journal of Agriculture Water Management has been agreed with the publisher to publish the models and modelling results among other papers of SAFIR project. The special issue is planned to be in public domain in December 2010

Impact for industry or research sector

- The SALTMED modelling results recommend the use of subsurface drip-PRD as it could save up to 25% water when compared with normal drip irrigation system and about 50% when compared with surface irrigation such as furrow irrigation system.These results are in line with the experiments results. In terms of water saving, the modelling results are quite similar to those obtained from field, semi-field and pot experiments in WP2.

- Water saving in agriculture is significant as the agriculture sector consumes between 75% and 85% of fresh water resources. Any saving would results in a significant volume of water that can be used either to irrigate more lands and thus increasing food production and food security or to be directed to the industry or domestic use to meet the growing population demands for fresh water. In addition, the saved water has economic value that would improve the farmers income when using less water and get higher yields under better managed irrigation systems such as PRD.

WP 4: Impact on Food and Soil Properties

Objectives

WP4 will focus on transport and fate of a selection of trace pollutants and pathogens within the cycle waste water-treated waste water-soil and subsoil-plants-products-man. Main objectives are:

- To investigate the efficiency of treatment technology developed and prototyped in WP1 with respect to a list of major and trace elements and pathogens including indicator organisms for bacterial, viral and parasitic pathogens.
- To study the transport of these substances/micro-organisms within the root zone towards plants (bio-accumulation) and fresh products as well as processed products.
- To investigate and model the transfer of substances/micro-organisms in the root zone and the unsaturated zone. A special focus will be on changes of soil properties due to irrigation with low quality water.

Main outputs will be conceptual and numerical models of chemical/biological transfers at field scale that will give feedback to WP1 and WP2 on the minimum requirements for irrigation water and to WP5 on the potential risks of the novel subsurface soil and traditional soil surface irrigation systems. Modules of WP4 models will be included in the integrated analytical tools developed by WP7 (openMI approach).

Description of work

Task 4.1: Efficiency of combined treatment technology with respect to major and trace elements and pathogens (BRGM, UOC, CAU, CAAS)

Low quality raw waters and treated waters used for irrigation of the study sites will be characterised for their chemical and biological characteristics with a special focus on nutrients (N, P, K) heavy metals, boron, indicator organisms and selected pathogens. Standard methods, e.g. ISO standards, will be used for the analyses. This task gives analytical assistance to WP1 allowing optimisation of the developed treatment technology and defines the input function in the system soil-crop-man.

Task 4.2: Field experiments on water and solute transfer in soil, unsaturated and saturated zone (BRGM, CAAS, CAU, CER, AU-DJF, UB, UOC, NAGREF)

The in situ experiments on soil and circulating solutions will be completed by laboratory experiments on undisturbed soil columns so that the variability of soil properties and irrigation schemes of the different study sites can be addressed. The transport of natural occurring *E. coli* and bacteriophages in waste water and inoculated protozoan parasites in soil and ground water will be studied by standard enumeration methods and molecular detection methods. The data acquired by task 4.2 will provide input to the modelling of soil properties and of pollutant and nutrient transport as well as to the risk assessments in WP5.

Task 4.3: Fate and pathways of trace pollutants in root zone soil and groundwater (BRGM, CAU, CER, NAGREF, UB, CAAS, AU-DJF.)

The effects of poor water quality on the soil- and bioaccumulation of harmful compounds will be studied on the basis of the data acquired in task 4.2. A special focus will lie on the transfer of toxic or phytotoxic solutes (heavy metals, As, B…) to the food products and on long term effects related to their accumulation in soil and their potential transfer to groundwater.

The research is based on an experimental and numerical approach that integrates the dynamics of chemicals and microbes in the unsaturated zone and towards the saturated zone, with novel biogeochemical models and environmental tracers (state of the art isotopic fingerprinting techniques).

Task 4.4: Survival in soil of residual pathogens in treated low quality water (UOC, CAU)

Pathogen die-off and survival in soil is influenced by a number of environmental factors. Survival and viability of *E.* coli and inoculated test organisms in mainly subsurface soil but also soil surface waste water irrigated soil environments will be assessed together with important physico-chemical parameters affecting survival and viability. Survival studies of microbial indicators will be carried out at two selected sites using sealed-off cylinders. Parasite viability and where relevant also infectivity will be determined by viability colour staining assays (DAPI/PI for protozoan parasites) and hatch assays for helminth eggs.

Task 4.5: Impact of low quality water irrigation on food quality (SSICA, CAU, KLV)
Evaluation of the different water treatments upon the fresh and processed tomato and potato will be considered. The chemical and physical and microbiological characteristics of fresh material during the growing period and after ripeness will be determined. Processing into stabilised commercial products in semi-industrial scale pilot plants will allow evaluating the final quality characteristics of processed products. Microbial food safety of subsurface waste water irrigated crops will be assessed with a focus on test organism and high risks crops, e.g. root crops like potatoes and carrots. A thorough comparison between conventional water and low quality water will provide the base of food related risk analysis in WP5.

Deliverables, see Chapter 2 Dissemination

D4_3: Mobility and accumulation of selected toxic elements and test microorganisms in the system irrigation water-soil-subsoil-crop-food under irrigation with low quality water (Report).

D4_4: Survival in soil of residual pathogens in treated low quality water and their contamination of food products (Report)

D4_5: Impact of low quality water irrigation on food quality (Report)

State-of-the-art achievements

Treating wastewater up to drinking water quality before unrestricted use for irrigation is a solution that will eliminate or greatly reduce risks for soil, food, farm workers and consumers, even if some trace elements need to be below drinking water standards for sensitive crops, but will enhance treatment costs at a level not affordable neither by municipalities nor by the farmers. Using raw wastewater and relying on the attenuating capacity of soil as a bioreactor, reduces treatment costs to zero but maximises sanitary and ecological risks. Any agricultural water reuse project has therefore to find a reasonable balance between the two extremes making use of the available technological and management options. This was one of the overall objectives of the SAFIR project: To propose to farmers an economically viable and safe set of technological options and best management practices for the reuse of wastewater. In this aim, conventional secondary sewage treatment was combined with specifically developed tertiary treatments. **WP 4**, contributed to these objective by an extensive monitoring an research program focusing on the **chemical and microbiological impact** of water reuse on food and soil properties conducted on the SAFIR study sites.

The originality of the SAFIR approach in general and WP 4 in particular resides in the following specificities:

- •Relevant **quality parameters were monitored throughout the system**: from raw wastewater, treated effluents, over irrigation water, soil, to raw crop and up to semi-industrially processed food (potato flakes and tomato puree).
- Cropping was realised at **plot scale** simulating **real farm practices** (fertilisation, irrigation), whilst soil labourage was done at the **farm scale**. Each plot was irrigated for three years with the same water source, even if some quality shifts due to technological modifications were documented. The investigated crops are among the most widespread worldwide (potato, tomato, crop rotation was applied for Italy).

- The monitoring stretched over **3 irrigation seasons** (2006 to 2008) to allow assessment of both annual and inter-annual variations of HM contents in soil and crops and of cumulative effects in soils. Most previous studies under controlled conditions addressed shorter time scales and the few long-term impact studies (over decades up to one century) lack control of the input function and boundary conditions (irrigation water composition, agricultural practices).
- The **irrigation water quality** was such as can be realistically expected after appropriate treatment, which again distinguishes the SAFIR approach from "worst case" studies both at laboratory scale (crop uptake of heavy metals from highly contaminated soil solutions) and field scale (long term irrigation with raw wastewater, contaminated soils due to industrial pollution).

Inorganic pollutants

All four European studies presented yield coherent results and the conclusions converge: **In a normal farming context based on irrigation systems using tap water or tertiary treated waste water from small-scale treatment devices, the variations of inorganic compounds contents in soils and the edible parts of crops are not driven by the water composition even after three years of cropping.** Any such influence on the content of inorganic compound contents of soils and of raw food seems overridden by the impact of farming practices like fertilisation and pesticide use or external sources of heavy metal contamination of soils, for details see Deliverable D4_3, Chapter 2 Dissemination.

Even if a three years monitoring is long compared to similar previous studies, the duration of the SAFIR experiments does not allow any final conclusions on the **long term effects** of irrigation with treated wastewater. Cumulative effects of heavy metals in soils have been shown to operate over decades and extrapolation of our data on longer periods using the same cropping and irrigation practices would be hazardous. Independently of water quality, we observe **important variations for several major and trace elements over the three irrigation seasons and within each season**. These variations are systematic for a majority of fully irrigated plots, irrespectively of their irrigation regime (water type, technique). Soil accumulation of trace elements due to long term irrigation by waste waters is considered as a cumulative process, rather at the time scale of years than of months and has been documented for sites with a long history of raw wastewater irrigation (e.g. Paris Basin, Mezquital Valley). Obviously, short term variations over months within one irrigation season may superpose to such cumulative processes (if any) and the underlying mechanisms have to be understood when aiming to model trace metal behavior under irrigated sites. It has been previously shown that seasonal alternations of aerobic and anaerobic conditions induce important and rapid changes on metal mobility in forest soils or in paddy soils with alternative precipitation and dissolution of neoformed Fe-phases.

It can be furthermore supposed that surface or subsurface drip irrigation will lead to quite **localised trace element accumulation**, driven by geochemical processes in the zone of influence of the dripper. Such processes (sorption, (co-)precipitation…) will affect each trace element differently, in function of pH and other key parameters so that a distinct distribution can be expected for each compound. The applied global sampling procedure within the potential zone of influence of drip irrigation combined with bulk soil analysis may smooth out such small scale gradients and mask to some extent cumulative effects. In this approach, the processes occurring on minor mineral phases like adsorption-desorption of trace elements on clay minerals, dissolution-precipitation of iron oxi-hydroxides along with trace metals, cannot be addressed in detail. Small changes may indeed affect minor phases but are not necessarily visible in the bulk soil composition.

The bulk soil analyses were completed and refined through selective extraction techniques giving hints to the heavy metal carrier phases and the associated mechanisms of fixation-release at the spatial scale of a drip emitter. Such a study, focusing on a study on HM distribution on decimetric scale around a drip emitter, selective extraction of heavy metals and lead isotope fingerprinting, has been conducted on the Crete study site and allowed identifying airborne contamination by gasoline lead from a nearby motorway, as main source of lead contamination in the mobile lead fraction in the crete soil. The non-mobile residual fraction bears the typical fingerprint of natural, geogenic lead,

The **absence of any visible effect on the edible parts** of tomatoes and potatoes could either be explained by concentrations in all the applied waters and in soil staying below the compound- and crop-specific thresholds that would lead to cumulation either by the fact that the edible organs may not be the main sink for trace metals and therefore not representative of the total plant uptake. Contrasts of irrigation water quality need to be even more significant as soil acts as a buffer before plant uptake. In studies where links between heavy metals in soil and in plants edible parts were found, the concentrations in soils were higher than in this study. The concentration in the edible organs then depends on the inorganic compound mobility from the roots to the others organs. The similar evolution of trace element concentrations over the duration of the experiment in soils and crops on plots irrigated with different water types suggests that here again other factors than water quality prevail, namely pest treatment and fertigation.

Food processing will give rise to process specific and crop specific trace element depletions and enrichments, that can in some cases, especially for potato flakes, significantly increase the concentrations measured in the raw food but with enrichment factors that differ greatly from one element to the other. Those shifts mask further the influence of the irrigation water type.

WP4 findings have been integrated in the Decision Support System developed by WP7 in form of a heavy metal module. The need for simple **functions describing soil-water interaction for practical purposes** in the field of irrigation excludes in most cases the direct use of geochemical models even if combined to water flow and water management models. The use of such reactive transport models is mainly limited to research projects and implies involvement of specialists. Yet there is need to **model and predict the impact of certain agricultural practices including the use of non-conventional water on soil and crops at farm scale**. The methodology proposed byy WP4 mainly consists in degrading and condensing the information output from a stringent thermo-kinetic soil-water interaction model to come up with functions like the classical Freundlich sorption isotherms.

The complexity of soil mineral-water interactions investigated through a geochemical model for one contaminant (Pb) has been reduced to mainly two equations including the most significant soil parameters (pH and FeO) from a set of initially 13 parameters. These two functions enable to calculate the Freundlich constants for a given combination of pH and FeO contents and were be used as input to the DAISY model as component in a decision support system for the agricultural use of waste waters. This preliminary and limited study demonstrates the potential of the use of stringent geochemical models to determine soil functions widely used in the agronomical world.

Microbiology

In the microbiological part of the project, different types of low quality water, soil and produce samples were obtained from sites in Europe and China. The water, soil and crops (tomatoes and potatoes) were analysed for levels of faecal pollution using *E. coli* as an indicator. The presence of *E. coli* indicates that the water, soil or produce may contain other faecal bacterial contaminants, such as pathogens like salmonella or campylobacter, while if no *E. coli* bacteria are found then the probability of contamination with the other faecal bacterial pathogens is minimal. In addition, the samples were analysed for the presence of total coliform bacteria and total viable counts of bacteria able to grow at 36°C. Water and crops from two European sites were also analysed for parasitic helminth eggs. Protocols were prepared for analyses of soil, water and produce (tomatoes/potatoes) adjusted to each of the field sites all three years. The implementation of the microbiological studies were established during the first and second year and continued during the third year. Microbiological methods were standardized by using the same microbiological media for detection of selected indicator organisms at all field sites. All microbiological results received during the three years of the SAFIR project were quality assured and uploaded to the SAFIR database.

The initial level of faecal pollution in waste water before water treatment (Membrane Bio Reactor ("Bio Booster"), UV-light or sand filtration) was up to 60,000 *E. coli*/ml. The study had certain limitations in that the recycled water after the different treatments had quite a low level of faecal pollution (< 3000 CFU/ml) as further reductions as a result of die-off following application and environmental exposures are then difficult to assess. A similar situation existed in Serbia with low concentration of *E. coli* found in channel water that did not receive additional treatment. This meant that it was difficult to assess the magnitude of *E. coli* reduction in the chain from water source to agricultural crop in the field.

The results of the study showed that there does not seem to be any correlation between the level of faecal pollution in the water used for irrigation and the numbers of *E. coli* found on the irrigated crops. There were found a very low number of *E. coli* in the soil and on the crops. Only 2% of the crops samples were contaminated with *E. coli*. On the few potatoes (1) and tomatoes (2) that contained *E. coli*, the average number of *E. coli* was 71 CFU per potato and 190,000 CFU per tomato. In soil samples, the deviation in *E. coli* concentration was much wider, ranging from 0 to 480,000 *E. coli*/g soil with 79% of the soil samples containing less than 100 *E. coli*/g soil. A total of 31% of soil samples taken before recycled water was used for irrigation contained *E. coli*, while only 7% of soil samples analyzed during irrigation contained *E. coli*. In the control group, in which the tomatoes and potatoes were irrigated with tap water, similar low level of *E. coli* was found in the soil despite the fact that the tap water did not contain *E. coli*. This indicates an environmental origin of *E. coli* found in soil samples. No parasite eggs were found in recycled water after water treatment where as tomatoes on two occasions were found contaminated with helminth eggs, one of the cases when the tomatoes were irrigated with tap water. The low level of faecal contamination found on tomatoes and potatoes is considered to indicate only very low human health risks. Tomatoes have a slippery surface that is easy to wash and potatoes are usually either washed or peeled and normally cooked.

Studies in survival and transport of pathogens were conducted in large soil lysimeters. Plots containing clay soil and sandy soil, respectively, were irrigated by subsurface drip irrigation with selected pathogens (*Salmonella* Senftenberg, *Campylobacter jejuni*, *E. coli* O157:H7 and *Salmonella* Typhimurium phage) added to the irrigation water during four occasions during one month. During each of the 4 irrigations, the total number of the individual human bacterial pathogens and *Salmonella* phage contained in the water applied to each lysimeter were 3×10^8 cfu (colony forming units) and 6×10^{10} pfu (plaque forming units), respectively. The following six month the plots were only irrigated with tap water. Potato plants were growing in the plots. Drainage water were analysed for 7 month and potato samples were analysed at harvest time being the end of the first month. *Salmonella* Typhimurium phage were detected in only a few water samples two weeks after start of study with a concentration of 2 pfu/ml. None of the added bacterial pathogens were found in the drainage water. On potato samples all added pathogens were found at harvest time in low concentrations. Salmonella Typhimurium phage were found with a concentration of 6.5×10^3 pfu/cm^2 potato surface and the bacterial pathogens had a concentration range of 7-34 cfu/cm^2.

General conclusion on microbiology: The MBR technology has shown a great ability to reduce the concentration of *E. coli* in waste water to a very low level. Irrigation with water which contained low levels of *E. coli* was associated with only very few findings of soil samples containing *E. coli*, which was also the case for produce samples, although such produce contained higher *E. coli* concentrations than concentrations found in treated waste water used for irrigation. This suggests other possible faecal contamination sources than the irrigation water e.g. environmental sources like wild animals, birds, etc. If the concentration of bacterial pathogens in the irrigation water is sufficiently high, as shown in the soil lysimeter experiment, irrigated produce may contain pathogens that could posses a risk to the consumer, if the produce is eaten raw, for details see Deliverable D4_4 and D4_5, Chapter 2 Dissemination.

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Microbiological and chemical impact of low quality water irrigation in China (CAU site)

In the CAU site, primary and secondary treated waste water from small waste water treating plant was used as low quality water resource. Generally, this kind of waste water mostly came from residential quarters, which resulted in much lower concentrations of heavy metals than might have been expected if industrial wastewaters had contributed significantly to the sewage. Furthermore, the treatment and water saving irrigation strategy respectively, further improved the quality and reduced the quantity of waste water entering the soil system. As a result, Pb, Cd, Cr, Zn, and Cu did not show any clear tendency to accumulate in soil over the total duration of the experiment.

Among the 12 elements concerned by the study of fruit quality, Ca, Mg, Na, Fe, and B decreased significantly from 2006 to 2008, Mn, Zn, Mo, Si, and Cu kept constant, and Cd and Cr increased from 2007. These result indicated that waste water irrigation would result in a deficit for some elements, while others accumulated gradually in fruit.

There was no significant differences in juice pH, EC, Brix, total acids, and N, P, K content of tomato fruit between irrigation methods and water types.

The source of *E.coli* and *coli form* bacteria on mature tomato surface could not be directly attributed to irrigation water, even if, generally speaking, irrigation with waste water and treated waste water could be expected to increase the amount of *E.Coli* and *coli form* bacteria. UV disinfection had reductive effect on *E. coli* and c*oli form* bacteria amount on mature tomato surface in most cases.

In general, changes in tomato quality and safety parameters, such as heavy metal content and pathogen amount, was not measurable under the field experiment conditions. All tomato fruit produced from plots irrigated by SAFIR treated waste water reached the standard of food safety of China. Meanwhile, the environmental impact of waste water irrigation could not be detectable at the timescale of the study (3 years). The concept of farm-scale on-site treatment combined with water saving techniques and strategies leads to water qualities comparable to conventional surface waters. Those waters, when applied in lower quantity (due to water saving strategies) and directly to the root zone (through surface or subsurface drip irrigation) will lead to greatly reduced health and environmental risks (see conclusions of WP5).

WP 5: Risk assessment

Objectives

To assess the risks of the improved irrigation system in terms of food safety and farmers' health. Specific objectives are to:

- Protect consumers by providing a means of assuring product safety and freedom from water-borne contaminants, related to uptake from irrigation practice.
- Assess and prevent other health risks arising from exposures from use of these water supplies at all stages from farm to table, covering farmers and marketers of these products and neighbouring communities.

Food safety is an over-riding concern and the SAFIR consortium is committed to guaranteeing the safety of the novel irrigation technologies and management systems developed within SAFIR. Indeed given the existing inadequate infrastructure for water treatment in intervention areas, improvements in food safety are to be expected from this project, and are one of the stated goals. This work package is directed to the evaluation of sources of risks, demonstration of any such improvements and prevention of any such risks. This will involve input into the design of the monitoring and evaluation of each field trial, health risk assessments made of these monitoring measurements (microbiological and chemical contaminants) and assessment of potential risks to food growers and handlers.

This work package consists of two phases: the first phase would be the development of risk assessment models that provide a framework to evaluate the food safety and public health risk associated with SAFIR. This phase would be based in large part on a literature review. The second phase would use data collected in the different WP's and field sites to develop site specific models and provide where necessary recommendations to improve the implementation of SAFIR.

Task 5.1: Human health risk scoping and establishment of risk assessment model

Systemic and dermal diseases have been demonstrated in relation to irrigation and direct skin contact with contaminated water, and the relevance of that literature to the SAFIR methods will be assessed. This will involve updating and extending the review of the literature, which we have already conducted (Mara & Cairncross, 1989). Variables will include the type of crop and type of irrigation system. Reports employing Hazard Analysis and Critical Control Point (HACCP) methods to identify critical points for risk of health risk associated contamination will be included. These would include: irrigation and uptake, harvesting, washing crops, handling crops, storage and transport, sprinkling crops at market etc. Based on this review, a model would be developed for assessing the specific potential for contaminant uptake by characterising routes and extent of human exposure to pathogens and chemical contaminants. This model would allow comparison between sub-surface drip irrigation techniques and the control methods, particularly surface irrigation. A workshop would be held, jointly with WP4, to coordinate with them on their sample collection and analysis strategy, to provide data optimal for the WP5 model. The output would be a report and paper based on this review.

Task 5.2: Modelling the survival of pathogens and indicator organisms in the sub-surface soil relevant for assessing health risks

It is anticipated that a key route of exposure would be through pathogens surviving in the soil and potentially exposing people working in the fields; to assess this risk requires the development of a model for the survival of pathogens and indicator organisms in the sub-surface soil. In turn this will entail field measurements in the irrigated plots and specific soil inoculation experiments with indicator pathogens (described in WP4). Protocols will be agreed with teams in WP4. Data collected will be analysed to develop a survival model for these pathogens. The information on pathogen survival will be combined and analysed in relation to data concerning soil characteristics and dynamics obtained in WPs 2 and 4. Each season during the study period will yield data for further analysis and modelling. Interim reports would be prepared after each season and a full report and paper after the third season.

Task 5.3: Exposure and risk assessment to consumers from potential crop contamination in SAFIR field trials

The potential risk to consumers may be estimated from the measured contaminants in food samples collected in trial and control areas. The acute risk from pathogenic organisms and the chronic risk from chemical contamination will both be considered here, using the framework of models developed in 5.1 and 5.2. The risk models will require consideration of potential uncertainty, including considering alternative exposure scenarios and Monte Carlo simulations. Predictors for risk from measured contamination levels will be developed in relation to evaluated risk factors (irrigation, handling, washing etc) and soil/crop parameters. This would be repeated after each season, and then reanalysed for all seasons together. A workshop would review initial results from the first season. Inputs will be given on study design and preparation of protocols to be used in WP4 thereby assuring the generation of data, which are needed for the risk assessment.

Task 5.4: Exposure and risk assessment for farmers, food-handlers and communities

As is noted in the state of the art, significant risks of, in particular, nematode infections have been reported among agricultural workers exposed in waste water irrigated fields and this component will focus on assessing risks to them and others such as food handlers who may be at risk. It is expected that the risk would be lower from the sub-soil irrigation technologies and this task will assess this, through studies assessing the potential for exposure in the light of the models developed in 5.1 and 5.2. Data would be collected by observation and questionnaire, to characterise the exposure scenarios where uptake may occur. A workshop would review initial results from the first season. From these data a risk assessment of potential acute and chronic risks to these workers and communities may be made and proposals developed, if there is judged likely to be a measurable risk, for epidemiological or surveillance studies of these populations.

Deliverables, , see Chapter 2 Dissemination

D5_4: Modelling of pathogens in soil (Report).
D5_5: Risk assessment from crop contamination (Report).
D5_6: Risk assessment for farmers, food-handlers and communities (Report).

State-of-the-art achievements

This Work Package was conceived to assess whether or not there might be measurable or potential risks to health arising from the SAFIR irrigation methods.

As the SAFIR experimental plots were not large scale units with dedicated farmworkers there was no possibility of measuring uptake, exposure or disease in the technicians or fieldworkers that would allow any meaningful direct assessment of incidence of disease. We therefore planned a risk assessment based on contamination data collected in SAFIR (WP4), some additional data we collected, estimation of potential exposure to contaminants and published literature. Together these sources enabled us to assess the potential for harm to both consumers and farmworkers. Overall we can say that the picture is reassuring.

These were observational field measurements, and therefore there was some variability, and some sporadically high values of either microbial or heavy metal contamination of irrigation water, soil and crop. But in no case were these sporadically high values related to the use of (originally) contaminated waste streams. They were explicable by normal variation: a heterogeneity of contamination outdoors related to wildlife, precipitation and chance. Further the levels of contamination measured were in general low, within guideline values for crops and in the case of microbiological contamination consistent with sporadic contamination found in normal retail samples of the same product in this case tomatoes (ie food grown without any irrigated with partially treated waste water).

We could reach these conclusions by a systematic evaluation of the contaminant data collected and comparison with relevant health based guideline values.

Several aspects of our work represented novel state-of-the-art achievements:

- The risk assessment conducted within the SAFIR project represents one of the first uses of the by the WHO propagated QMRA approach for the calculation of risks to consumers and farm workers within the European setting.

- This application of QMRA has provided new insights and the LSHTM and Copenhagen University have been in an ongoing discussion with those people working in the WHO on the risk assessment models to help improve the QMRA models. The WHO QMRA risk assessment models are currently being updated and as a result of feed-back from the LSHTM, Copenhagen University and others the WHO will now start working with Norovirus as an indicator of viral disease within the models, thereby replacing Rotavirus, we consider this is a significant improvement.

- For estimating potential occupational exposure to contaminated soil field observation by an industrial hygienist at a SAFIR fields site was undertaken.

- To compare to real-world levels of microbial contamination of food samples, a random convenience sample of tomatoes in London retail outlets was carefully washed and the level of microbial contamination assessed.

Impact for industry or research sector

The fact that we can demonstrate an absence of a SAFIR-treatment related risk to farmers or consumers, has far reaching consequences, suggesting that this efficient and sustainable use of dwindling water resources can be used perhaps safely. We note “perhaps” as much dirtier water streams may represent a hazard, and a scaling up to industrial scales may introduce risks and some surveillance of exposure would be advised. Further it is recognized that in spite of an absence of quantifiable risks, there may be some consumer reluctance when measured against an abstract benchmark of “total cleanliness”, which will need to be addressed in presenting this technology.

WP 6: Economy

Objectives

- To assess the financial and economic impact of the improved irrigation systems at farm and national/regional level.
- To identify and assess institutional barriers for implementation of the improved irrigation systems.

Description of work

Task 6.1: Assessing the financial potential of new irrigation technologies at farm level.
The first step in this work package will be to conduct a system description and assess the production economy at farm level to assess whether it is profitable for farmers to invest in these new production systems. The profitability for farmers might be different between regions due to local differences, access to water and factor inputs. This activity will be based on case studies conducted at the farm level. Questionnaires will be sent to the participating institutions from 5 different sites to estimate the costs structure and gross margins for potato and tomato production.

Task 6.2: **Assessing the economic and environmental impact of alternative technologies at the catchment scale and regional level.**
This activity will (i) develop a framework for assessing costs and effectiveness of various irrigation technology scenarios and (ii) implement it in a selected number of case studies. The cost-effectiveness analysis (CEA) will take into account direct costs, environmental costs (due to increased / reduced nitrate leaching), health costs, and other indirect costs. By assessing the cost effectiveness for each technology we will compare with conventional fertilisation and irrigation practices to point out the most suitable management practices and technical solutions. These measures can be aggregated to some extent in order to assess the regional impacts of new fertigation and irrigation systems. To collect data about costs, prices, and factor inputs for the new irrigation systems, questionnaires will be distributed to the project partners at 5 different sites.

Task 6.3: Technology assessment and identification of sociological and institutional barriers
Due to regional differences in legislative, institutional and economic conditions, the adoption of the new technologies by farmers may vary slightly between regions. The traditional production economic analysis and CEA often neglects those non-economic/environmental bottlenecks that in practice prevent the technology/innovation from adoption. These bottlenecks could be local obstacles, legislation or caused by other market externalities. The third activity will address these issues through (i) a survey of existing national regulations which might represent a barrier for the adoption of the new technologies; and (ii) a participatory technology assessment (PTA) involving local stakeholders (institutional representatives and grass-root level farmers). The technology assessment should reveal those technologies that could be best suited for individual local regions.

Deliverables, , see Chapter 2 Dissemination

D6_3: Cost-Effectiveness Analysis (Report)

D6_4: Sociological and institutional barriers (Report)

D6_5: Potential of implementation of improved irrigation systems for use of low quality water resources (Report)

State-of-the-art achievements

As input to the deliverables and to reach the objectives of this work package, various information have been collected from the SAFIR partners. The following data has been used in the deliverables.

- Irrigation system costs.
  A questionnaire has been given to the partners about:
    1. The costs of the different systems in the countries
    2. The resource use of the systems (water, electricity and diesel)
    3. The costs of the water, electricity and diesel.

- Crop and labour price.
  On the SAFIR homepage a database have been constructed where the partners have uploaded information on:
    1. crop yield
    2. crop prices
    3. labour use
    4. labour prices
  For maize, winter wheat, potatoes and tomatoes from 2006 – 2009

- Wastewater treatment data:
    1. From Grundfos (a Danish company) information on costs and flow data from their Membrane Biological Reactor (MBR) system has been given.
    2. From Deliverable 1_4 data about the field treatment system has been collected.

- From Crete is collected data about wastewater among these are:
    1. treatment level
    2. treatment costs
    3. new wastewater treatment plant costs

- From literature is collected information about the SAFIR countries and institutional barriers which consisted of:
    1. agricultural practices
    2. irrigation systems
    3. water availability
    4. water administration
    5. wastewater reuse in each of the regions.

The collected data has been used in the three deliverables D6_3, D6_4 and D6_5.

Deliverables
D6_3, see Chapter 2 Dissemination: This deliverable include two reports. A Report on Cost-Effectiveness Analysis at farm level and a report on CBA at Crete has been conducted. The first report include data on various “Irrigation system costs” and “Crop and labour prices”. These systems have been used to compare new drip irrigation systems and strategies including full irrigation, deficit irrigation (PRD, Partial Root zone Drying) with conventional systems in tomatoes and potatoes. In addition the data from Grundfos was used to assess the potential economic application of using and treating waste water for irrigation at the various field sites in Europe and China. Findings from this study indicate that deficit and PRD drip irrigation can be a water saving alternative to conventional irrigation strategies. However, in many regions there is little incentive to use these systems due to higher initial investment costs for drip irrigation systems and low if any taxes on water for irrigation. This report also gives an indication of the potential reduction of nitrate leaching from drip irrigation systems.

In D6_3, see Chapter 2 Dissemination: The second part of this deliverable include a Report on the potential of implementing improved irrigation systems for use of low quality water resources based on data about wastewater from Crete and the data from Grundfos. The data was used to assess the economic value of decentralised treated wastewater used for irrigation in different contexts of water scarcity. A cost benefit analysis was conducted in order to find the most optional solution in different scenarios. The results of the study could justify for water planners to invest in such type of water reuse projects and to subsidize farmers. However, a sensitivity analysis of the CBA shows that the economic efficiency is very dependent on the cost of MBR implementation and wastewater conveyance system.

Further, the data on irrigation system costs was used In Boesen et al. (2009) to analyse if a tax on water may give Serbian farmers an incentive to shift to more water efficient irrigation systems and strategies. Two irrigation systems and three strategies for irrigation in potatoes were investigated. It was found that very high taxes on water would be needed to give incentives for the farmers to change to new systems and strategies. At that water price however, the Serbian farmers would properly give up the irrigation or grow other crops.

D6_4 (see Chapter 2 Dissemination) includes a report on the sociological and institutional barriers of implementing new irrigation systems. Data from literature has been used to summarise the institutional barriers for implementing new irrigation strategies and technology in Greece, Italy, China and Serbia. The potential of using treated wastewater is also investigated with the data from Grundfos (Membrane. Biological Reactor) and the more simple Field Treatment System. Findings from this study indicate that the incentives to save water are little in many of these regions. Moreover, wastewater treatment is likely to be a feasible solution to get water for irrigation.

Finally, D6_5 (see Chapter 2 Dissemination) summarises and discusses the potential of implementing improved irrigation systems for use of low quality water resources among the various regions.

Conclusions
The overall conclusions from work package 6 are:

- New irrigation technologies and strategies like drip irrigation, deficit irrigation, regulated deficit irrigation and partial root zone drying have the potential of saving water. In case of water scarcity, some of the potential is already exploited. In most cases, however, farmers have little economic incentives “just” to save water. Adaption of new technologies and strategies are mainly driven by labour, energy and capital costs “incidentally” saving water.

- Use of treated waste water could be a further option and is already used many places in China. The cost of a complete field treatment system with, UV-filter, gravel filter and heavy metal filter is about 0.08 € per m^3 which should be sufficient to bring the water quality from a first treatment stage to application for irrigation purposes. However, the field treatment system is primary concentrated on removing faecal contamination and heavy metal pollution whereas the technology does not allow removing salt and nitrate economic efficiently.

For a complete waste water treatment an MBR system for local waste water treatment was investigated. The cost of waste water treatment with MBR is between 0.55-1.35 € per m^3 depending on the size. The system will not be a solution for the individual farmer to clean waste water for own use but be a solution for a community to clean their wastewater localy and reuse the treated water for irrigation.

WP 7: Management model

Objectives

To develop a decision support system for irrigation management at farm level by integrating aspects of existing dynamic models to take into account crop quality, irrigation water quality, irrigation techniques and environmental impacts of the improved irrigation systems.

Description of work

The issues of interest – crop quality, crop production and environment – require analysis at different scales and with focus on different aspects (crop quality, water quantity and quality, single field irrigation, optimised water allocation on farm scale etc.). This requires a range of tools of different complexity and an efficient method of linking these is therefore required. In order for individual farmers to use relatively complex tools for decision making a decision support system (DSS) involving the above mentioned aspects as well as economy is proposed developed. The analytical layer of the DSS will be based on existing numerical and analytical models, which though needs further development and integration through an open modelling interface called openMI. This interface is being developed in the HarmonIT project supported under the 5th EU framework programme (Contract no: EVK1-CT-2001-00090) and facilitates linking of existing and new water software codes. Its main objective is to provide a standard interface for modelling components and other relevant tools, and the advantage of openMI compared to other standards is that a dynamic linking and exchange of data takes place during the simulations. The openMI standard is completed and documented (Gijsbers, (2004)) and currently several water models are developed into openMI compliant versions.

Task 7.1: Further development of tools

Existing model tools for such analyses have been developed for different purposes and scales. For instance the irrigation module in the MIKE SHE hydrological modelling system handles water demand using a maximum allowable water deficit approach but further development is foreseen e.g. to describe the solute fluxes between various water sources with different water quality. Other tools foreseen to be parts of the DSS require also minor developments to address the specific problems on field and farm scale.

Task 7.2: Step-by-step procedure

The description of the openMI standard will be tailored to issues relevant for field and farm scale modelling and the step-by-step procedure for implementation of the modelling interface will be modified accordingly. This procedure is necessary for other partners to allow them to develop openMI compliant versions of modelling tools to be part of the DSS.

Task 7.3: OpenMI compliant version of DAISY

The model for irrigation developed under WP3 (DAISY/IrrMod) will obviously be a part of the management model and the procedure will firstly be tested through the development of an openMI compliant version of the DAISY.

Task 7.4: Development of the management model

In WP4 detailed analyses of impact on soil, water and plants will be carried out. Analyses will be based on model tools capable of describing multi-species reactive transport in large detail. Thereby the controlling factors under different conditions will be identified and as such be used in the management models. The management model will include a tool that relate crop quality with irrigation water quality and a hydrological model that handle irrigation on crop and farm level with the aim of optimising use of water with various quality.

Task 7.5: Testing of the management model

The management model will be tested on one of the field sites using all existing and available data as well as data obtained through this project.

Task 7.6: Development of the DSS
A decision support system for the on-farm management of water resource using the new irrigation system will be developed.

Deliverables, see Chapter 2 Dissemination
D7_1: Platform developed for the DSS based on integration of existing models and databases and documented (Report).
D7_2: DSS-prototype available and documented (Report and software available at www.safir4eu.org).

State-of-the-art achievements
Many places on the globe water is a scares resource and in these areas are wastewater a potentially valuable resource of both water and nutrients for agricultural crops, required its usage is managed properly. Before farmers consider using wastewater in their crop production they must be convinced that it can be done without risks to themselves, their land or to the consumers purchaching their produce. To help farmers with this type of complex decisions the SAFIR project deliver on workpackage 7 a prototype decision support for considering the main farmer issues related to safe management of wastewater in irrigation of agricultural crops, Deliverables D7_1 and D7_2, see Chapter 2 Dissemination.

The SAFIR project commissioned by the European Commision during 2005-2009 have conducted substaintial research and development within the scope of safely utilizing wastewater for irrigation. The objective of workpackages 7 (WP7) has been to synthesize and integrate this information for the development of a decision support system (DSS) assisting safe wastewater irrigation management at farm level. The developed DSS is based on existing dynamic models, but the objective has been to expand them to take into account, crop quality, irrigation water quality, irrigation techniques and environmental impacts of the improved irrigation systems.

In meeting the work package objectives was developed a simple web-based and a more advanced desktop decision support system called simple NUtrient and water BALances IRrigating with treated wastewater (NUBALIR) and the prototype management model, respectively. Basis for both developed DSS platforms include general state of the are knowledge, research conducted on SAFIR workpackages including a variety of experiments from six SAFIR field test sites representing local conditions from China, Greece, Denmark, Italy and Serbia in potato and tomato crops.

The conducted research on work package 7 has been lead by DHI collaborating with the work package partners University of Århus (DJF), University of Copenhagen (OoC), Bureua de Reseaches Geologique et Minieres (BGRM), China Agricultural University (CAU) and Chinese Academy of Agricultural Sciences (CAAS). However, as the decision support tools integrate extensive amounts of information across the capabilities of several more SAFIR partners than those in the work package, took collaboration also place with SAFIR partners outside of this work package, so almost all partners have contributed, but in particular Food and Resource Economics Institute (FOI), Consorzio di Bonifica di secondo grado per il Canale Emilliano Romagnolo (CER) and London School of Hygiene and Tropical Medicine (LSHTM).

From project start objective was to develop one DDS integrating a number of modules mentioned above.However, during the work it became clear that to set up this model system, certain initial analyses was required and for performing these was the web-application NUBALIR developed.

In NUBALIR is included potato and processing and fresh tomato, which can be analysed for a wet, dry and normal climates at the SAFIR test field sites. The user also choose which fertilisation strategy to apply in reality or in the runs with the prototype management model. Calculations then provide an overview of required irrigations for the selected crop and irrigation system during different growth phases. It also calculates the expected fertiliser requirement, the need for initial fertilisation, the addition of N and P through the use of wastewater and it indicates the excess nutrients that may be present if wastewater is used towards the end of the growing season.

In addition to NUBALIR was also developed the more advanced prototype management model consisting of a range of modules. The work behind the main components in this and workpackage tasks has been elablorated on in the following.

The water administration module (WAM) was developed as a comprensive database and key module that hold information about the physical system that surround the farmers field. Meaning that the user can specify a range of available water sources, filters and purifiers and link them together and thereby defining the fields available irrigation water sources. Water sources are developed so they comprise information about flow and chemical constituents and priority rules can be given. All types of water can be routed through filters and therby undergo constituent specific decays, transformations or removal by fractions. The WAM communicate via the standard Open modeling interface with the irrigation fertigation module.

The developed irrigation fertigation module (IFM) function as the strategy component. It controls when and how much to supply of water and nutrients, by continuosly asking, the crop and soil (PSA) its demands and the water administrator (WAM) its available supply, using the developed standard OpenMI interface. As basis for the functioning of the IFM was substantial work allocated research into the irrigation and fertigation strategies for different irrigation methods in potato and tomato crops. This included crop specific mappings of soil moisture dependent trigger values signaling start and stop of irrigation for four dominating growth stage,. Triggers values was mapped in matrices comprising sprinkler, furrow and drip irrigations methods together with four irrigation strategies including full irrigation (FI), deficit irrigation (DI), regulated deficit irrigation and partial root drying (PRD) . The developed fertigation strategy is based on a continous monitoring of the actual N status in the crop in relation to a crop specific critical N content.

Daisy (PSA) plays a central role in the prototype management model simulating crop growth, water movement, temperature, carbon and nitrogen processes as well as heavy metals and bacteria if required. The conducted research on WP7 has transformed Daisy from a 1D to a 2D code, making it possible to simulate a spatial alternating irrigation from one side of the crop to the other as required when applying the irrigation strategy partial root drying. Additionally, has Daisy been made OpenMI compliant allowing exchange of nitrate, ammonium bacteria, and heavy metals. In order to handle heavy metals and bacteria have Daisy been developed on a number of points e.g. handling of a triple soil pore domain allowing transport of large particles such as bacteria, surface generation of colloids for transport of e.g. heavy metals and filtering functions for colloids and bacteria as wells as some kinetics for multiple domains. The descriptions of heavy metals and bacteria in Daisy was examplied and tested on lead (Pb) and E.Coli, respectively.

The main dataset used for testing the prototype management model was based on potato experiments from the Italian field test site CER and a Daisy potato crop calibrated in work package 3. Data collection for testing and initial model test setup was initiated during field test site visit in summer 2008.

Initially it was considered to OpenMI wrap the geochemical model PHREEQC in order to implement heavy metals in the prototype management model, but for a number of reasons, mainly complexity, considered not feasible. An alternative approach lead to deriving effective partition coefficients (K_d-values) and it showed to be relatively simple to implement a heavy metal module in Daisy using the K_d-values to determine transport and soil accumulation. An approach for deriving K_d-values was established based on modelling a large number water-soil interaction model runs based on test site data and batch experiments. A paper has on WP4 been prepared to demonstrate how to generalise such and approach in order to apply for a larger selection of soils and compounds.

Microbial risk assessments modules was developed in Excel as a postprocessing routine, calculating the risk of microbial contamination of consumers and farmers. E.Coli concentrations calculated with Daisy, between first irrigation and harvest has been used for assessing risk to farmers whereas concentrations at haverst indicate risk for consumers. E.Coli's description in Daisy include decay in soil. E.Coli was used as an an indicator organism, which also lets translate into risk for other organisms including Rotavirus, Camphylobacter, Cryptosporidium and Giardia.

WP6 conducted a collection of unit costs on water, nutrients, energy etc from each of experimental field test sites. Based on these unit costs was made a simple profit calculation in the prototype management model considering area size, fixed and variable costs related to each water source and fertilizer and crop prices considering three harvested crop qualities, although the project data cannot provide reliable quality classes. In the profit calculations is the water usage extracted from the WAM and the amounts of fertilizer from the IFM.

In order to run the prototype model has been developed a user interface for model execution and a Excel spreadsheet solution for extracting and presenting the main simulation results. Parameterization of the WAM and IFM take place through Microsoft Access and some additional time series files and Daisy are setup using a normal texteditor. Profit calculations and heavy metal assessements are being performed as a Excel post processing. Microbial risk assessment is also developed as a Excel postprocessing, but from it has been developed so is automatically excutes when results are being extracted.

SAFIR workpackage 7 was successfully in meeting its two objectives by having provided and documented two DSS platforms; a simple (NUBALIR) and a more advanced prototype management model. Together they enable the user to perform comprehensive dession support in irrigation management on farm level taking into account range of determining factors

More specifically WP7 end results include NUBALIR the simple DSS allowing the farmer to analyse the overall fertilizer and irrigation possibilities on his farm, using different water sources , under different climatic conditions applying different irrigation techniques.

The advanced prototype management mode descriebes the full irrigation system applied at farm level and can help the farmer to decide:

- if the use of treated waste water - as an additional or as the only water source - is an option,
- if further treatment of the recycled water is necessary
- which purification method to use e.g. sand filters, membranes technology and/or UV light,
- between different irrigation strategies,
- between various fertigation strategies.
- if wastewater use for irrigation pose health risk to farmers or consumers

The recommended choice is based on water availability, productivity, costs and benefits, product safety, safety for farm workers, and impact on the environment.

Although the developed SAFIR DSS platforms are prototypes, they mak**e** up not previously seen concepts for detailed decision support systems integrating complex and temporal cross sectorial information from water resources and water quality to crop production, environmental impact, risk assessment and economy. In the coming years will the SAFIR DSS hopefylly be subject for further developments and ideally used in projects around the world. Hopefully, it also contribute to the continued development and application of the standard OpenMI interface.

For farmers the SAFIR DSS gives the possibility to safely exploit sources of wastewater, optimizing crops yields while also assessing environment impact and risk for famers and consumers.

In the broader picture, applying SAFIR DSS can potentially help safely using waste water, maintaining agricultural crop production in areas of scares water resources, ensuring economical feasible crop production and hopefully save clean water for drinkning water puposes.

For access to the SAFIR DSS platforms go to the SAFIR homepage at http://www.safir4eu.org and for more information on the open modeling interface (the OpenMI) go to http://www.openmi.org

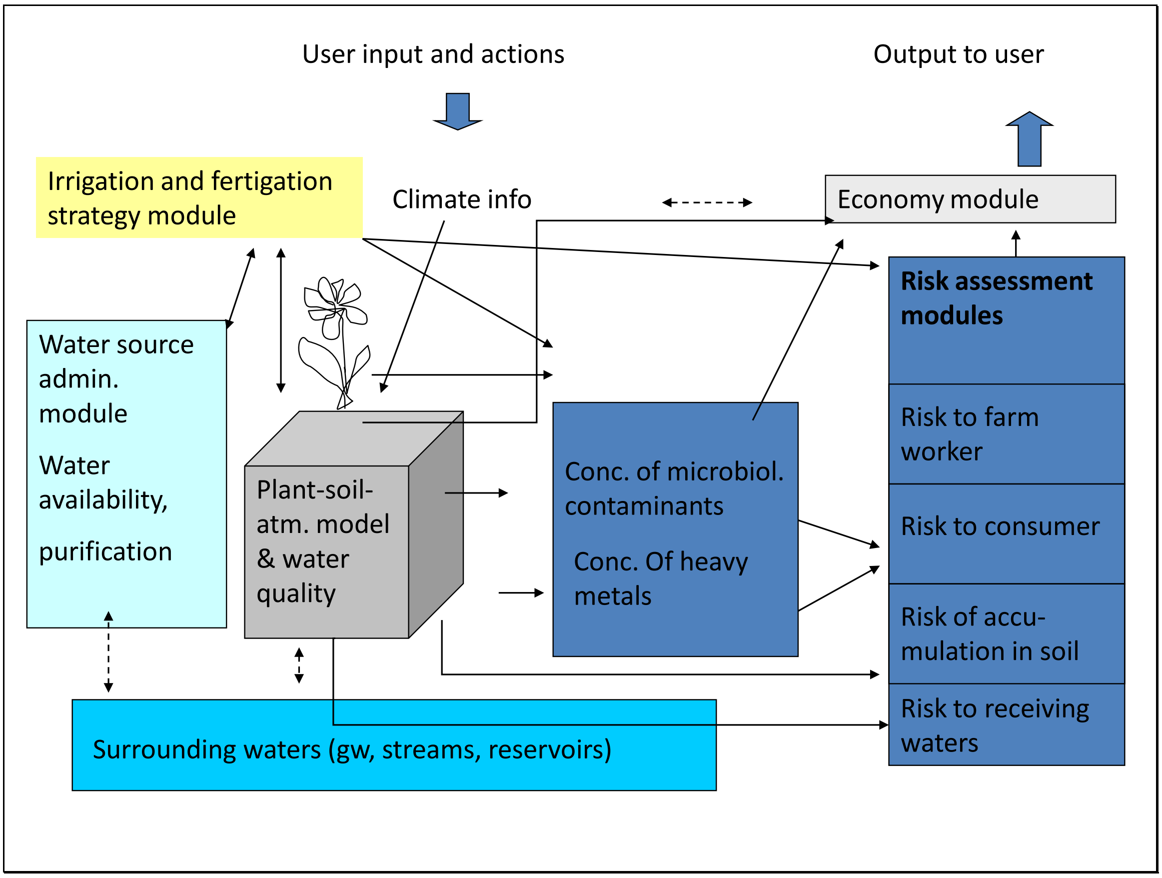

Figure 3 Overview of the SAFIR prototype management model

WP 8: Dissemination

Objectives
To facilitate dissemination of project results and experience to relevant authorities, farmers organizations, food and irrigation industry and research institutions.

Description of work

Task 8.1: Establishment and maintenance of an interactive website exclusively for SAFIR

A project web-site will be established where information about the project, project news, and project results will be published. The web-site will be an important tool for the communication with stakeholders, in terms of the provision of information on the project as well as feed-back and comments. The web-site will have a restricted area for which a login is needed. The restricted areas will contain the project management tool described in WP0.
(Task Manager: AU-DJF)

Task 8.2: Initiation and maintenance of communication with key stakeholders and end-users of project results at national and European level

The project will actively seek to establish communication with key stakeholders from relevant authorities, farmer's organisations, and food retail and irrigation industry. As one of the first steps a project information brochure will be distributed. The project will invite key stakeholders to participate in a Stakeholder Group who will be invited to participate in an annual meeting. The stakeholders will be informed on work plans and progress and invited to provide feedback and advise to ensure that the project activities are addressing the real issues and not overlooking important aspects. In relation to specific problem issues that may arise, the project will address such issues individually and seek advice and feed-back from relevant stakeholders.
(Task Manager: AU-DJF)

Task 8.3: Drafting and finalisation of a Technology Implementation Plan (TIP)

Based on the contact and communication with key stakeholders, the potential of the new irrigation system, the ambitions and capacity of the SME partners, and the directions of the Commissions the project will draft the principles and initial Technology Implementation Plan (TIP) and present it at the SG-meeting in month 25 of the project. The TIP will be finalised and initiated before the end of the project.
(Task Manager: AU-DJF)

Task 8.4: Publish reports and documentation of project results and experience

Project achievements (results and experience) will be documented in reports and scientific articles. The reports will be published at the project web-site, while scientific articles will be submitted to relevant scientific periodicals for evaluation and publication. The project will prepare a final report where a set of recommendation and guidelines for production of safe and high quality vegetable crops under irrigation based on low quality water resources. The recommendations and guidelines will be based on the experimental fieldwork and tested models for farmers when applying such water resources.
(Task Manager: AU-DJF)

Task 8.5: Organise workshops for discussion and dissemination of project results and experience

Local demonstration days at core experimental field sites are scheduled to take place during project implementation to discuss the applied technologies and results. In total 3 demonstration days have been scheduled at each of the experimental field sites. Planning of the demonstration days will be undertaken in cooperation with the partner responsible for the site and the PMG. Towards the end of the project key stakeholders will be invited to participate in a final workshop together with the

project participant to discuss the recommendations and guidelines that will be a result of the project. The feed-back from this workshop will be incorporated into the draft final report (D8_2).
(Task Manager: AU-DJF)

Deliverables, see Chapter 2 Dissemination

D8_1: Project information brochure.

D8_2: Final report with recommendation for the use of low quality water resources and improved irrigation systems addressing requirements of farmers, water and food safety authorities, and the food retail sector.

State-of-the-art achievements

SAFIR has successfully updated from its homepage www.safir4eu.org the scientific communities and other stakeholders on the progress and results of the project. The which will continuously be updated also after the project ending.

Impact for industry or research sector

The SAFIR project has disseminated its results through varios media, scientific papers, conference proeceedings, brochures etc., all available from the homepage. In addition the SAFIR project will give free to scientific communities an internet based database which holds all measured data collected during the project.

2 Dissemination

The major outcome of the SAFIR project is published in public available reports, see below, conference proceedings, scientific papers, etc., cf. the SAFIR hompage www.safir4eu.org.

D1_4 User manual for decentralised functional water production for irrigation purposes

D1_5 Evaluation of alternative water resources for irrigation in agriculture

D2_5 Statistical analysis of the field experiments and conclusion on the new irrigation/fertigation techniques and methods of growing potatoes and tomatoes
D3_1 Report on guidelines and recommendation on best water management practices when using low quality water and PRD-irrigation systems
D3_2 Final version and documented models available
D4_3 Mobility and accumulation of selected toxic elements in the system irrigation water-soil-subsoil-crop-food under irrigation with low quality water (report)
D4_4 Survival in soil of residual pathogens in treated low quality water and their contamination of food products (report)
D4_5 Impact of low quality water irrigation on food quality
D5_4 Report on modeling pathogens in soil
D6_3 Report on Cost-Effectiveness Analysis
D6_4 Report on sociological and institutional barriers
D6_5 Final report prepared on the potential of implementation of improved irrigation systems for use of low quality water resources
D7_1+
D7_2 Decision support system for irrigation with low quality water: system, underlying models and tests
D8_1 Project information brochure
D8_2 Final report with recommendation for the use of low quality water resources and improved irrigation systems addressing req. of farmers, water and food safety authorities, and the food retail sector