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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes

IRMA

WP5, Action 3

Deliverable 5.3.1. Detailed plan regarding the information system setup

Development of an Irrigation Information System for the plain of Arta (IRMA_SYS Arta)

IRMA_SYS

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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes (IRMA)

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Development of an Irrigation Information System for the plain of Arta

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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes (IRMA)

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RAW =TAW × MAD with TAW = FC – PWP (1) 63

IRn = ETc – (ER + GW + RAW) + LR (2) 66

IRg = IRn / IE (3) 67

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)}$$ (4) 69

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{37}{T_{hr}+273} u_2 (e_o(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)}$$
$$e_a = e_o(T_{hr}) \frac{RH_{hr}}{100}$$ (5) 69

$$ET_0 = 0{,}0023(T_{mean} + 17{,}8)(T_{max} - T_{min})^{0,5} R_a$$ (6 70

$ET_{c\ adj} = K_S \times K_c \times ET_0$ (7) 70

Ks = (TAW – D_r)/(TAW – RAW) (8) 70

$ET_c = K_c \times ET_0$ (9) 70

$K_L = k_s \times k_d \times k_{mc}$ (10) 71

ER = $\Theta_2 - \Theta_1 + ET_0$ (11) 73

LR(fraction) = $ECw2\ Max\ ECe \times 1Le$ (12) 73

LR = $ETc1 - LR(fraction) - ETc$ (13) 73

MF = RAW / ET_c (14) 74

Bias, $B = \frac{A+B}{A+C}$ (15) 86

Probability Of Detection, $POD = \frac{A}{A+C}$ (16) 86

False Alarm Ratio, $FAR = \frac{B}{A+B}$ (17) 86

Critical Success Index, $CSI = \frac{A}{A+B+C}$ (18) 86

$D_{r,i} = D_{r,i-1} - (P_i - RO_i) - IR_{n,i} - CR_i + ET_{c,i} + DP_i$ (19) 91

$\Theta_s <= D_{r,i} <=$ TAW (20) 91

$TAW = FC - PWP$ (21) 91

$RO_i = P_i + \Theta_{i-1} - \Theta_s$ when $(P_i + \Theta_{i-1} - \Theta_s) > 0$ (22) 91

$D_{r,i} = D_{r,i-1} - P_i - IR_{n,i} + ET_{c,i} + RO_i$ (23) 91

$\Theta_i = \Theta_0 - D_{r,i} + IR_{n,i}$ (24) 91

$D_{r,i} \geq RAW$, $RAW = MAD \times TAW$ (25) 91

$RAW = MAD \times TAW$ (26) 91

$IR_{n,i} = D_{r,i-1}$ (27) 92

$D_{r,i} = P_i + ET_{c,i} + RO_i$ (28) 92

$MF = RAW / ET_c$ (29) 92

$IRT = PF / MF$, with $0.1 \leq IRT \leq 1$ (30) 92

$IR_{n,i} = IRT \times D_{r,i-1}$ (31) 92

$D_{r,0} = FC - \Theta_0$ (32) 93

$\Theta_0 = FC - IRT \times RAW$ from the 1st of April until the 30th of September (33) 93

$\Theta_0 = FC$ from the 1st of October until the 31th of March (34) 93

$D_{r,0} = 0$ (35) 93

$D_{r,0} = FC - \Theta_0$ (36) 93

$\Theta_0 = FC - IRT \times RAW$ from the 1st of April until the 30th of September (37) 93

$\Theta_0 = FC$ from the 1st of October until the 31th of March (38) 93

$ET_c = K_c \times ET_0$ (39) 94

$ET_{c\ adj} = K_S \times K_c \times ET_0$ (40) 94

$Ks = (TAW - D_r)/(TAW - RAW)$ (41) 94

Acronyms

PM	Penman-Monteith
K_c	crop coefficient
K_L	landscape coefficient
k_{mc}	microclimate factor
k_s	species factor
k_d	density factor
FC	field capacity
PWP	permanent wilting point
TAW	Total available water
RAW	Readily available water
Ks	Water stress factor
Dr	Water depletion
PET, ET_0	Potential evapotranspiration
ET_c	Crop evapotranspiration
$ET_{c\ adj}$	Crop evapotranspiration adjusted by Ks

ASAF	Agricultural Cooperation of Arta and Filipiada
CAP	Common Agricultural Policy
CGAP	Code of Good Agricultural Practices
ELOT	Greek Standards Organisation
EU	European Union
GG	Greek Governamental Gazette
GOLR, LOLR	General, Local Organization of Land Reclamation
GSPW	General Secretariat for Public Works
JMD	Joint Ministerial Decision
OPEKEPE	Greek Payment Authority

Introduction

According to EU Water Framework Directive (WFD) 2000/60/EC (EU, 2000), action is needed to protect waters in both qualitative and quantitative terms. In the framework of the UN Environment Program (UNEP, 2005) it was concluded that a challenge of water-related issues for Mediterranean countries is to integrate water demand management in agriculture and to develop added value tools to optimize efficiency in irrigation. European Landscape Convention (which was adopted by the Greek state in 2010) promotes protection, management and planning of natural, rural, urban and peri-urban areas including land, inland water and marine areas. FAO-AQUASTAT states that in Greece and Italy about 70% and 40% of the available water resources are used for irrigation purposes respectively. In 2012, the EU-report on identifying water saving potentials in the EU countries mentioned that improving water application efficiency would save 15 to 60 % of water use (BIO Intelligent Service, 2012).

Finally CMMC (2013) predicts a -40% to -60 changes in water availability for irrigation in extended Mediterranean areas of EU countries (Fig. 1). These facts make the optimum irrigation water managements a top priority goal.

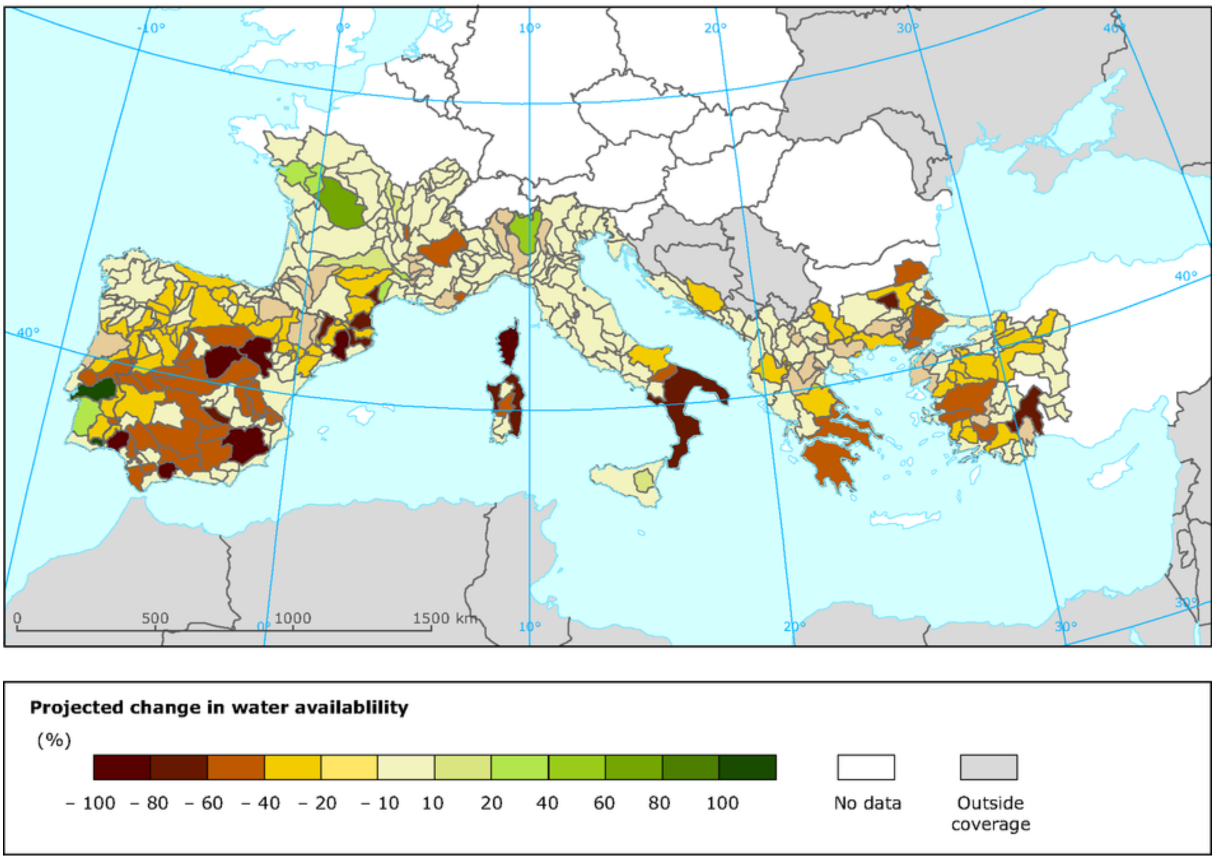


Fig. 1 Projected change in water availability for irrigation in the Mediterranean region. (CMMC, 2013)

Adequate supply of water results in better irrigation efficiency helps plants to avoid stress situations and boosts yield. Irrigation control involves the determination of both timing-frequency and duration of each watering event.

The IRMA project concept states that with the given infrastructure, irrigation systems efficiency in both farm and irrigation scheme level could almost immediately increase if more reasonable water management was applied. In this framework the development of tools for real time data based cultivations water needs estimation and automatic generation of recommendations for improved irrigation schedules is of great importance.

Fig. 2 The IRMA project area (source: Google Maps)

Static or web based practical software has already been developed in order to assist agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies. Good examples are CropWat (FAO) and CIMIS (CDWR, 2008). Also irrigation companies have introduced evapotranspiration (ET) controllers for use in agricultural and landscape systems (Davis et al. 2009; McCready and Dukes, 2011).

In Greece relevant attempts have until now produced mainly static software (Charthoulakis et al. 2006, 2007 and 2010; Samaras 2008; Arabatzis and Malitsidou, 2009). Evaluation of these tools showed impressive results as it is reported reduction on water consumption for irrigation at levels of 20% (olives at the island of Crete –Chartzoulakis et al., 2007) and of 45% (landscape irrigation – CDWR, 2008; Davis et al. 2009). In every case these tools should be adjusted for local conditions and this presupposes the knowledge of the special characteristics of the cultivations for each region and of the local irrigation practice (Papazafiriou 1984; Maton et. al. 2005).

Operating examples of "real time" meteorological data, web based irrigation scheduling systems in the IRMA project area (Fig. 2) are ProBioSis (2008) and Agrometeopuglia (AssocodiPuglia, 2008).

In the framework of WP5 (Actions 5.3, 5.4 and 5.5) of the ETCP GREECE-ITALY 2007-2013, IRMA project, a new integrated irrigation scheduling support web service will be developed and adjusted for the area of Arta / Region of Epirus, Greece and an existing one (AgrometeometeoPuglia) for the Region of Apoulia, Italy will be upgraded (Fig. 2). Both systems will be designed and developed in a flexible way that will allow adaptation (after setting the relevant parameters) to other regions of both countries. The Technological Educational Institute of Epirus (partner LP-TEIEP of IRMA project) will develop from scratch a new web based irrigation advice system (IRMA_SYS Arta). A network of fully equipped weather stations properly distributed in order to cover microclimate at hydrological basin scale will be installed in the plain of Arta by the Decentralised Administration of Epirus and Western Macedonia (partner P6-ROEDM of IRMA project).

Notes

General framework regarding irrigation in Greece

Two ministries are basically in charge for irrigation and relevant water issues in Greece:

- The Ministry of Environment Energy & Climate Change through its Special Secretariat for Water (WFD, http://wfd.ypeka.gr/). It is in charge for the implementation of Water Framework Directive (WFD) 2000/60 (EU, 2000) in Greece and the relevant management plans which also regard the cost of irrigation water. In 2013, WFD has completed and published the WFD management plant for the hydrological region of Epirus (WFD, 2013). In each administrative area of the country, a Directorate of Water Recourses operates in the framework of the relevant Decentralised Administration Entity. This links WFD with each area of the country.

- The Ministry of Agricultural Development and Food (MINAGRIC) which includes the Directorates of Land Reclamation and Hydrology (Directive for Land Reclamations Projects Design and Soil Resources Efficient Use and Directive of Geology and Hydrology, http://www.minagric.gr/index.php/el/for-farmer-2/eggeiesbeltioseis). Their main duties have to do with drillings equipment and operation, public central irrigation networks design and supervision, irrigation water needs calculation etc. In each region of the country, relevant offices operate in the framework of the local administration. These offices are linked to MINAGRIC.

Two basic types of irrigation setups exist in Greece, the public participatory irrigation projects which cover about 40% (572,000 ha) and the private projects 60% (858,000 ha) of the irrigated area. The water sources for irrigation differ radically between public and private networks. The public networks, mainly use surface water, while the private ones use underground water. The water used in public participatory irrigation networks originates from rivers and springs (42%), artificial lakes (25%), drilled wells and wells (24%), natural lakes (5%), drainage ditches (4%). The water used in private irrigation systems mainly originates from drilled wells / drillings (82%) and rivers / springs (13%). Recent observations and research showed that the construction of storage dams (artificial water reservoirs) is increasing. During the last years a state initiative (JMD 110424 (GG B/1190 11-4-2012 and Decision 145026 GG B/31 14-1-2014) scopes to the register, evaluate and legalize all the water supply points (including private drillings), but the cost of the procedure and the mistrust of farmers make incommode the effort. Another interesting issue is the use of recycled water for irrigation purposes (for both landscape and agricultural systems) which has recently allowed in Greece (GG B/354 2011).

Field water in the case of public networks is applied by means of surface irrigation, sprinkler irrigation and drip irrigation in proportions of 37%, 53% and 10% respectively, with a distinct falling tendency of surface irrigation. Water in the private networks is applied by means of surface irrigation, sprinkler irrigation and drip irrigation at rates of 7%, 49% and 44% respectively. During the last 15 years the application of new technology irrigation systems has been financed through Farm Development Plans (in the framework of European Co-funded programmes) and numerous farmers took advantage of this occasion.

Anyone that want to get permission to participate in a public irrigation system or to construct and exploit a water source point (drilling etc.), must submit an irrigation plan, developed by a certified professional. Regarding estimation of plants water needs, the 1989 (GG 428 2-6-1989) decision of the Agricultural Development and Food for the use of Blaney-Cridle method has substituted in 1992 by a decision (120.344 11-2-1992) which recommended the use of Penman method. In both cases any approach that could provide better results was allowed to be used under the condition that the expected improvement would be documented. The 1989 decision (GG 428 2-6-1989) also incorporated values regarding irrigation system efficiency. Regarding landscaping setups, information for plants water needs (not methodology, just value limits) are provided in the relevant Greek Technical Standards (General Secretariat for Public Works (GSPW) and Greek Standards Organisation (ELOT)), namely: 10-06-02-01/Irrigation of plants and 10-06-02-02/Irrigation of lawn, ground cover plants and slope cover plants. These two documents have power only on public projects.

In reality the vast majority of farmers, irrigation managers etc., does not consider any irrigation plan and waters using practical information and experience. The use of controllers, sensors etc. is very limited. The water and energy consumptions are increased in the public projects where consumptions of 10.000 m^3 ha^{-1} are usual with water losses more than 50%. In the case of private projects the cost of irrigation water is significant and it is totally chargeable to the farmers. In this way both the losses and consumptions are reduced by 10-20% and 5.000 m^3 ha^{-1} respectively.

Management of public irrigation networks

Referring to the management of irrigation systems, the authorities that are responsible for water management of the public irrigation projects are the Local Organization of Land Reclamation (LOLR). When special attendance of first level land reclamation works is needed, groups of LOLRs are linked to General Organizations of Land Reclamation (GOLR) which supervise the upper level works. Both organisations are "private entities" which are in charge for the good operation of public systems. Their operation is supervised by MINAGRIC (http://www.minagric.gr/index.php/el/for-farmer-2/eggeiesbeltioseis/axiopoisileitoyrgia). There are 10 GOLRs and 382 LOLRs in Greece. These organisations operate under the supervision and scientific support of the relevant Regional Authorities.

Various software packages for central irrigation systems management exist (Irricad[2], Niriis[3]) but in most cases, no electronic registration of both descriptive and spatial data exists and management is done manually using experience.

Some public entities that manage landscape setups (regional or municipal authorities etc.), take advantage of central management systems. The Municipality of Kallithea (Athens) is a good example.

Management of public and private end user irrigation systems

For the management of public landscape setups, the two standards that were previously mentioned contain also some information (not methodology) regarding irrigation scheduling. A recent relevant law is the one for golf fields (Dec. 21527, FEK 2905/B 29-10-2014).

[2] http://www.irricad.com/

[3] Developed by the Irrigation & Drainage Lab of the Agricultural University of Athens

All the farmers that apply for EU subsidies, sign every year a relevant application (it is called single application (OPSEAE) and it is provided from and submitted to the Greek Payment Authority (OPEKEPE) of Common Agricultural Policy (C.A.P.)) in which they state that they follow good agricultural practices[4]. The same happens when a proposal for an investment regarding crop cultivation is submitted for EU and/or National funding. Good agricultural practices (FEK B/477B 6-4-2000 (Dec. 85167/820), KYA 85167/820 20-03-2000 and KYA 100949 2478 09-10-2000.) include the efficient and sustainable use of water for irrigation. Recent observations and research showed that the nitrate problem in ground water remains at low levels.

Integrated management cultivation systems require sustainable resources (water is included) management. The groups of farmers that apply integrated management provide special information regarding irrigation of the cultivation they are specialized to and each farmer should register all irrigation events and other relevant information using the provided template. All relevant software packages (e-farmer[5], i-grow[6], i-farma[7], Farm manager[8], etc.) include tabs for irrigation registration.

Decisions, standards and laws regarding efficient and sustainable use of water for irrigation purposes are expected to be published more frequently in the years to come as billing of irrigation water will become a reality (Fig. 3, Fig. 4). A very recent example is the Decision 19527 (GG B/2713 10-10-2014) for the support of sugar beet cultivation. It requires documentation regarding the registration of the total volume of water that was applied during each year, the irrigation doses and the dates of irrigation events in order for the farmer to receive the benefits.

Pricing of water

Regarding pricing of water, in the public reclamation works the operational costs (administrative-operational-maintenance) are estimated; then, the distribution of proportional expenses is based on an area-basis of the irrigated land. This way of distributing expenses has the following disadvantages. The estimation of the cost for each organization (LOLR) is different and it is based more on the operational expenses (energy for pumping, etc.) and less on the salaries of administrative staff. For the most of the cases, the relevant cost for maintenance and depreciation of the works is not included.

Experience has shown that the pricing of water based on the size of parcel is in a way obligatory and sufficient for surface networks but it is particularly problematic in irrigation networks under pressure. It does not create motives for saving water and energy. A usual characteristic of Greek irrigation networks is that the energy cost is higher than the personnel cost. This fact is opposite to the rational management according to the international standards. Regarding the economic parameters, it can be pointed out that by converting a dry land to an irrigated one the family income is increased by more than 70%. For social parameters, it can be said that the conversion increases the employment at a rate of 20%. The environmental impacts from the developments of irrigation networks there are

[4] The exact Greek title is: Κώδικας Ορθής Γεωργικής Πρακτικής, which does not entirely match with the title used by EU.
[5] http://www.foodstandard.gr/oi-efarmoges-mas/e-farmer/
[6] http://igrow.gr/agro/index.html
[7] https://ifarma.agrostis.gr/
[8] http://web2.teiser.gr/web-programming/FarmManager/welcome.html

positive (as creation of artificial wetlands) and negative (as draining of wetlands, salinization of coastal aquifers, increasing of agricultural inputs) effects.

Fig. 3 Irrigation water meter using prepaid card and monitoring software

Fig. 4 Aqua Card system for irrigation water billing (Italy, CIHEAM IAM Bari)

The use of drinkable water from the civil water supply system for irrigation happens. Almost all municipalities in Greece, charge water using volume levels. In some cases where gardens border public irrigation networks there is a special price for the network water that is used.

Focusing in the Greek part of IRMA project area

In the Regions of Epirus and Western Greece the general image is relevant to that of the country. Epirus is characterised by high rainfall but the plains typically do not have a lot of rain during summer and irrigation is needed. Most farmers protest against the luck or the bad condition of central public irrigation networks. In Western Greece there are more problems regarding water deficiency. A major irrigation connected project at the Regional Unit of Aetoloakarnania (Region of Western Greece) is the split of the route of Acheloos river in order to cover irrigation needs of the great plain of Thessaly which is at the East side of country. The project is unfinished for more than 15 years due to environmental issues.

Notes

Description of the IRMA_SYS Arta area (plain of Arta)

The Region of Epirus is located at the North-West part of Greece, it has a total area of 9.203km^2 and a population of 353,820 p. Agricultural land corresponds to the 14% of its total area. The plain of Arta (45,329 ha, the biggest of the region, Fig. 5), is located at the south of Epirus, it is part of the Aracthos and Louros hydrological basins (Fig. 6, GR14 and GR46 according to WFD, 2013) and borders with Amvrakikos Wetlands National Park. The general water management plan for the Region of Epirus (EU Water Framework Directive (WFD) 60/2000/EC (EU, 2000)) was published in 2013 (WFD, 2013).

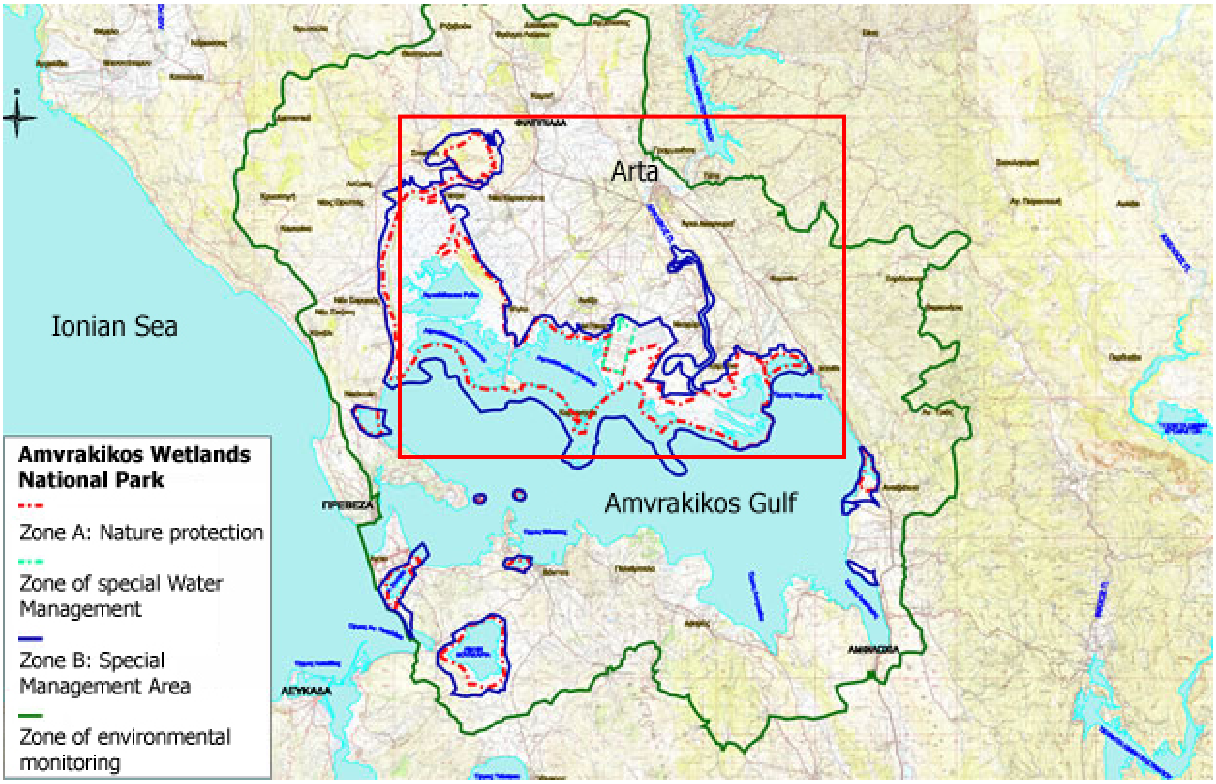


Fig. 5 The plain of Arta (red rectangle), the IRMA_SYS Arta area (base map: AWMD, 2014)

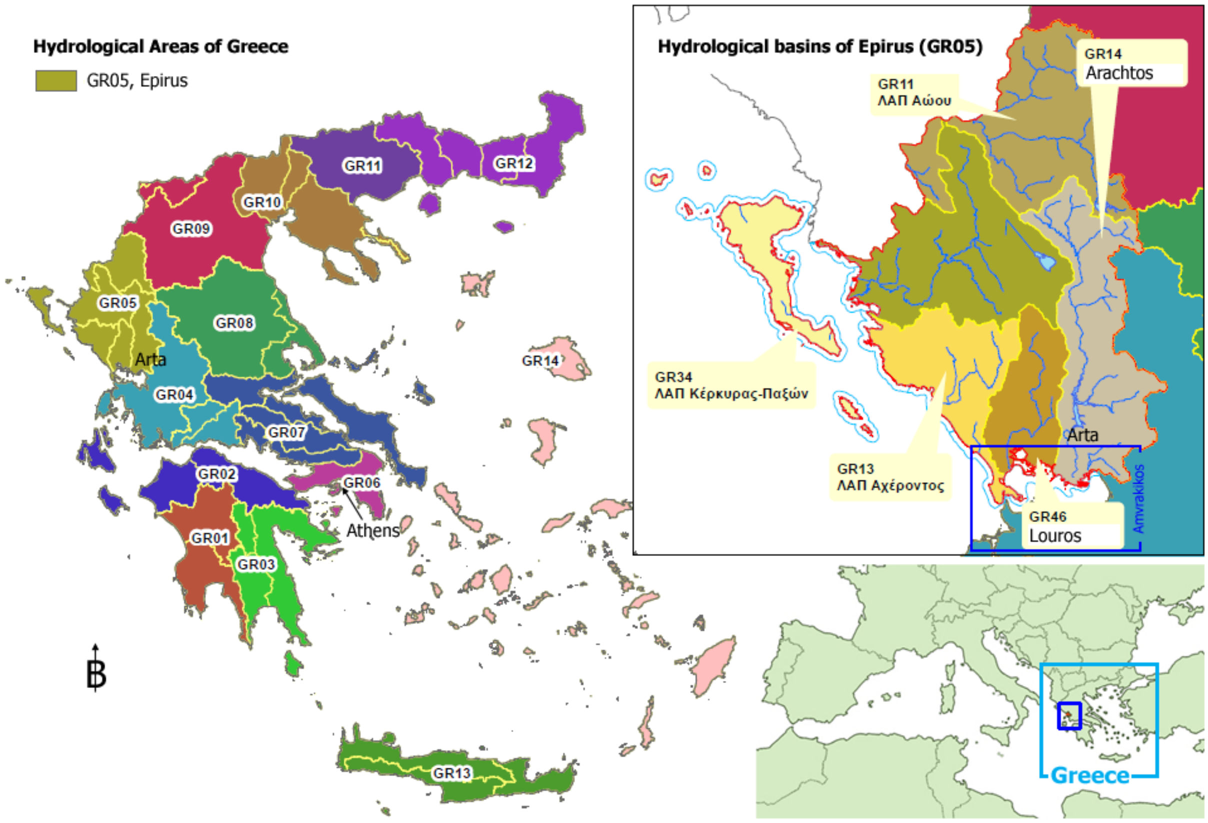


Fig. 6 Hydrological basins of Greece (WFD, 2013). Arta plain is part of the Aracthos (GR14) and Louros (GR46) basins

The Amvrakikos Wetlands National Park which includes a big part of the plain of Arta, is considered one of Europe's most important protected natural areas. The gulf is protected by Ramsar Convention (Ramsar, 2014), the park is part of the NATURA 2000 network (EEA, 2014; EKBY, 2014) and it is managed by Amvrakikos Wetlands Management Body (AWMD, 2014). This fact makes the need for more efficient irrigation water management in the area more significant, in order to protect ground water as well as surface waters from pollution related to agricultural cultivations.

Climate

The climate of Arta's plain is of Mediterranean type, with hot summers and rainy moderate winters (Gouvas and Sakellariou, 2011). According to Tselepidakis and Theoharatos (1989), all of Western Greece is categorized in the mesomediterranean climate with a lower mean yearly number of dry days. Data from the local state meteorological station (HNMS, 2014; Longitude 21°0'0" / Latitude 39°10'0" / Alt 10.5m; recording period: 1976-1997) have been used to develop an ombrothermic diagram (Gaussen (1952), Fig. 7).

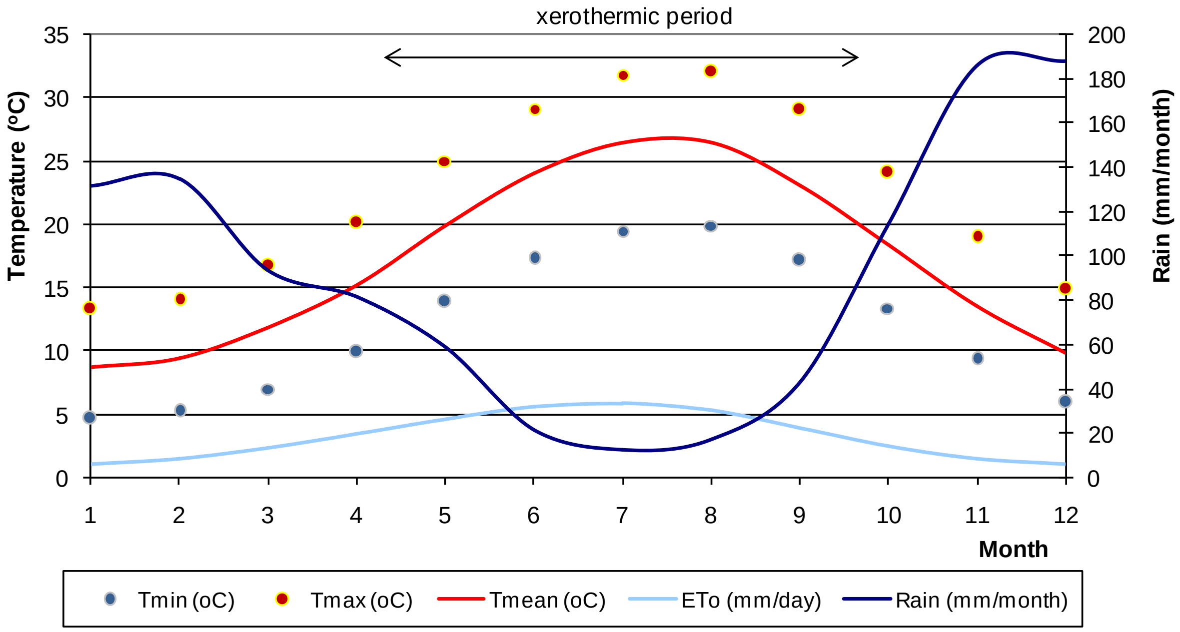


Fig. 7 Bangouls- Gaussen's ombrothermic diagram (T in °C, R in mm month^{-1} / xerothermic period, data from HNMS Arta MS)

Main cultivations

The main cultivations of the plain of Arta are presented in Table 1 (Karras et al., 2006) while in Fig. 8 and

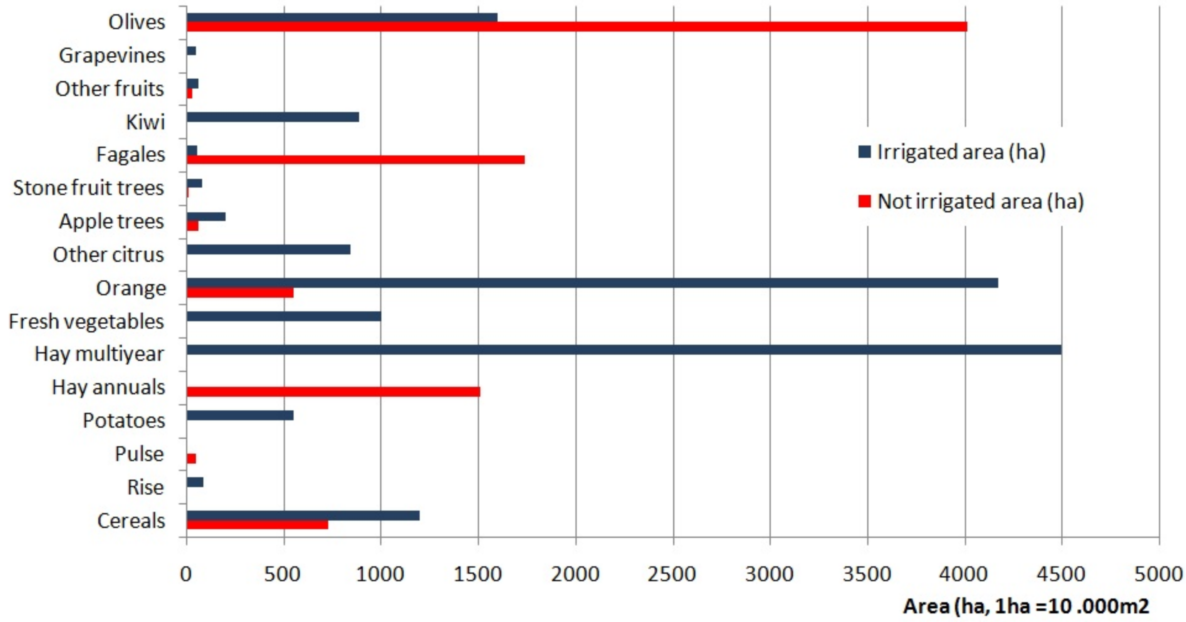


Fig. 8 Cultivations of the plain of Arta (Directorate of Agriculture of the Regional Sector of Arta, 2012)

Table 2, the irrigated and not irrigated acreage for the various cultivations of the part of the plain that belongs to the Regional Sector of Arta are showed (Directorate of Agricultural Economy and Veterinary of the Regional Sector of Arta, 2012).

Table 1 Main irrigated crops area at Arta plain (Karras et. al., 2006)

Crop	**Citrus**	**Olives**	**Maize**	**Alfa-alfa**	**Kiwi**	**Cotton**	**Other**	**Total**
Area (kha)	6.49	4.36	2.98	4.58	0.44	0.38	0.77	**20**

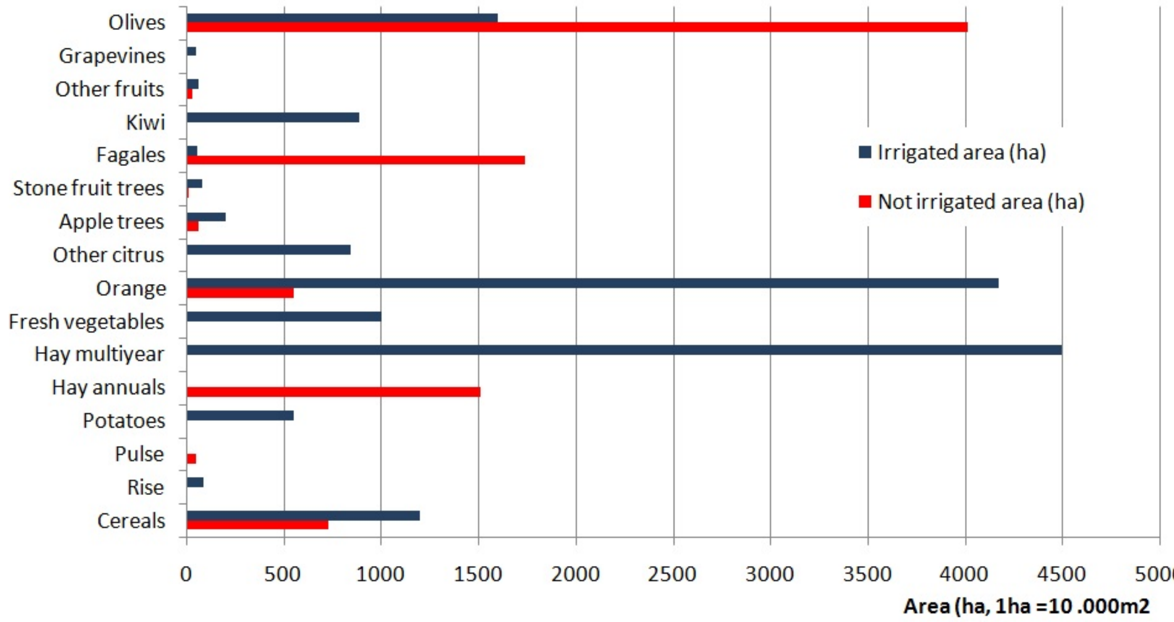


Fig. 8 Cultivations of the plain of Arta (Directorate of Agriculture of the Regional Sector of Arta, 2012)

Table 2 Main cultivations of the plain of Arta (Directorate of Agriculture of the Regional Sector of Arta, 2012)

Cultivation	Not irrigated area (ha)	Irrigated area (ha)
Cereals	733	1,200
Rise	0	90
Pulse	48.5	0
Potatoes	0	555
Hay annuals	1,510	0
Hay multiyear	0	4500
Fresh vegetables	0	1,006.35
Orange	550	4,173
Other citrus	0	842.3
Apple trees	64	206
Stone fruit trees	13	81.7
Fagales	1,741	60.2
Kiwi	0	890

Cultivation	Not irrigated area (ha)	Irrigated area (ha)
Other fruits	31	65.5
Grapevines	0	50
Olives	4,017	1,600
Total	**8,707.5**	**15,320.05**

The Integrated information system concerning single application (OPSEAE) of the Greek Payment Authority (OPEKEPE) of Common Agricultural Policy (C.A.P.) provides yearly updated spatial and descriptive information regarding cultivations in Greece.

Topography

Fig. 9 presents the Digital Elevation Model (DEM) of the Arta region, adopted from SRTM Data Version 4.1 (Jarvis et al., 2008), with square grid size of 84 m.

In the context of a study by Malamos and Tsirogiannis (2012), a terrain slope classification of the plain was implemented. This contained three distinctive classes (Table 3 and Fig. 9).

Table 3 Agricultural land evaluation according to the slope criterion and relevant area

Class	Slope range	Area (ha)
1	from 0% to 8%	32,220
2	from 8% to 25%	8,599
3	greater than 25%	4,510

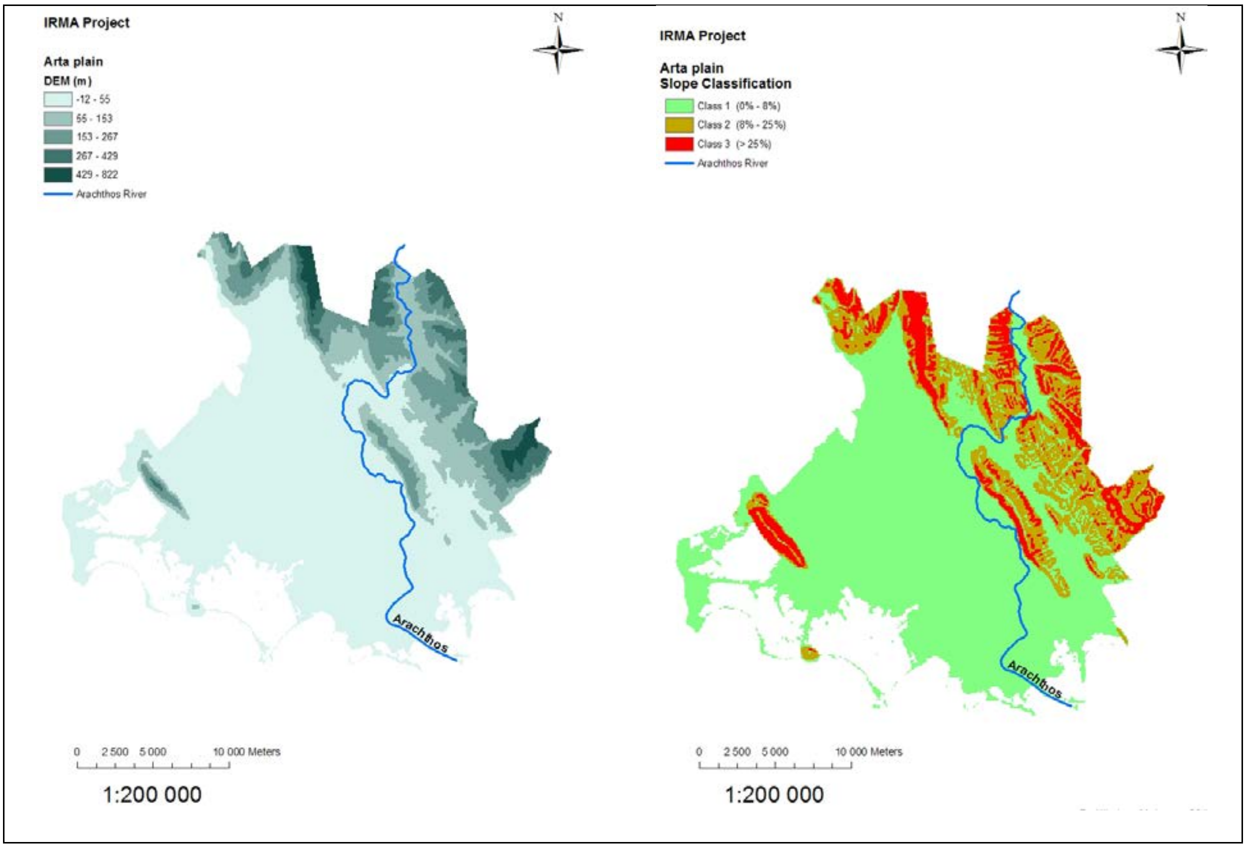


Fig. 9 Digital Elevation Model (DEM) and slope classification of the Arta plain

Soil mapping

The Greek Ministry of Agricultural Development and Food during the design stage of Arta land reclamation works (1965) had performed a number of soils samples analyses (0-30, 30-60cm, Fig. 10 a, b). In the context of the New Land project (TEIEP, 2010), about 200 soil samples (0-30cm, Fig. 10 c) of all around the plain were analyzed. The sampling sites positions were obtained with the use of Satellite Positioning System (GPS, accuracy of ±5 meters), using WASS and the European System EGNOS.

It is apparent that the majority of the samples are medium to heavy textured. Fig. 10, Fig. 11 and Table 4, present the soil texture map of the IRMA_SYS Arta area, based on soil texture analyses of the samples of the New Land project.

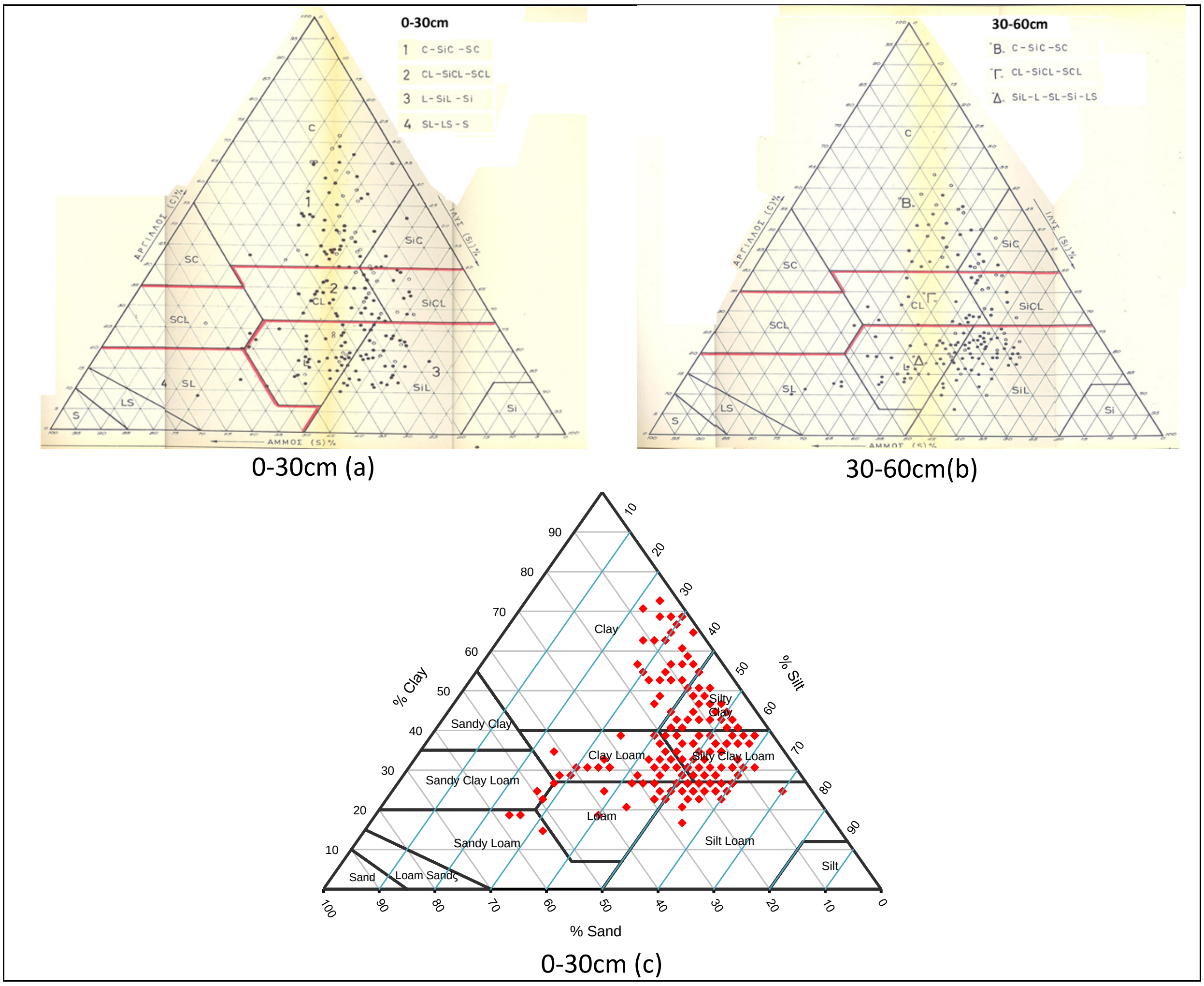


Fig. 10 **Soil type (according to USDA soil texture classification) of samples all around the Arta plain. Soil analyses data from Ministry of Agricultural Development and Food for 0-30 cm (a) and 30-60 cm (b) and from New Land project for 0-30 cm (c)**

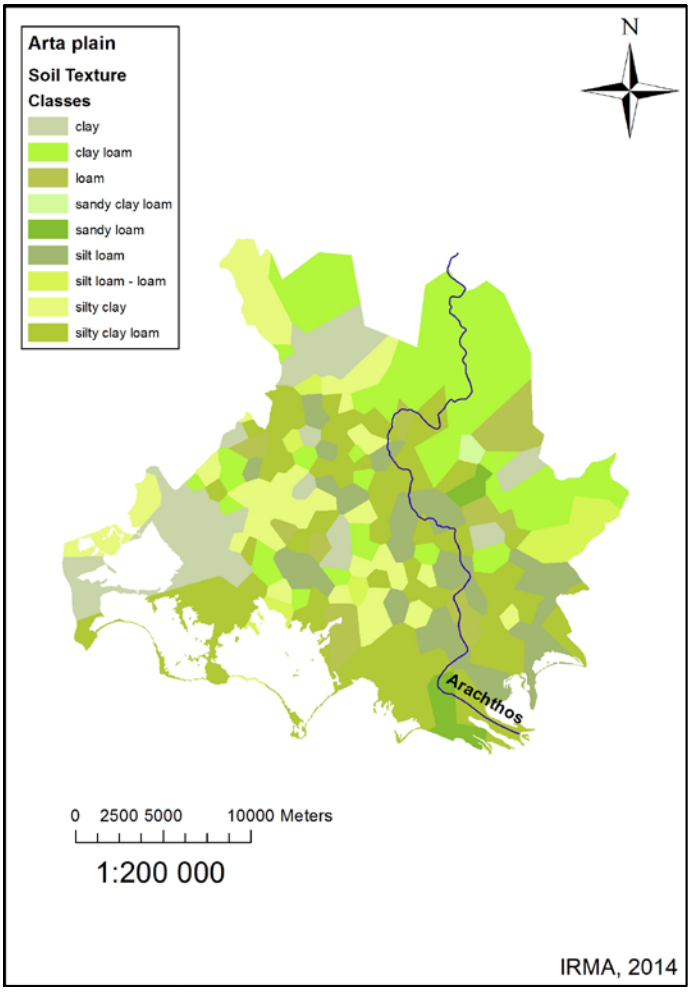


Fig. 11 Soil texture map of Arta plain

Table 4 Soil texture distribution

Soil Texture	Number of samples	(%)
Silty Clay Loam	57	28.8
Silty Clay	33	16.7
Clay	30	15.2
Silt Loam	30	15.2
Clay Loam	27	13.6
Loam	12	6.1
Silty Loam	5	2.5
Sandy Loam	3	1.5
Sandy Clay Loam	1	0.5
Total	**198**	**100**

Land cover information

CORINE (Coordination of information on the environment) is a European Commission program intended to provide consistent localized geographical information on the land cover of the member states of the European Union (Bossard et al., 2000; EEA, 2007). CORINE is the only broadly available geospatial database concerning the land cover of the Arta plain. The integrated information system concerning single application (OPSEAE) of the Greek Payment Authority (OPEKEPE, http://www.opekepe.gr/english/index.asp) of Common Agricultural Policy (C.A.P.) provides yearly updated spatial and descriptive information regarding cultivations in Greece. The relevant data are available after approval by OPEKEPE regarding their use.

From the CORINE dataset (Fig. 12), we removed all but the agricultural land uses and combined the above mentioned criteria (topography and soil) in order to get an estimation of the most valuable agricultural land of the plain of Arta. The results are presented in Table 5 and in Fig. 13. It is apparent that the implementation of the three criteria, resulted in the reducing at a magnitude of more than 50% the initial area, since from a total of 45,329 hectares, we concluded to a total of 20,409.01 hectares of high value agricultural land.

Table 5 Coverage of agricultural areas, according to the specified criteria

Number	**CORINE id**	**CORINE General Description**	**CORINE Detailed Description**	**Area (ha)**	**Slope**
1	231	Pastures	Pastures	66.23	Class 1
2	212	Arable land	Permanently irrigated land	1,338.19	Class 1
3	222	Permanent crops	Fruit trees and berry plantations	3,692.47	Class 1
4	223	Permanent crops	Olive groves	832.77	Class 1
5	242	Heterogeneous agricultural areas	Complex cultivation patterns	1,2618.45	Class 1
6	243	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	723.24	Class 1
7	211	Arable land	Non-irrigated arable land	743.39	Class 1
8	213	Arable land	Rice fields	394.27	Class 1
Total				**20,409.01**	

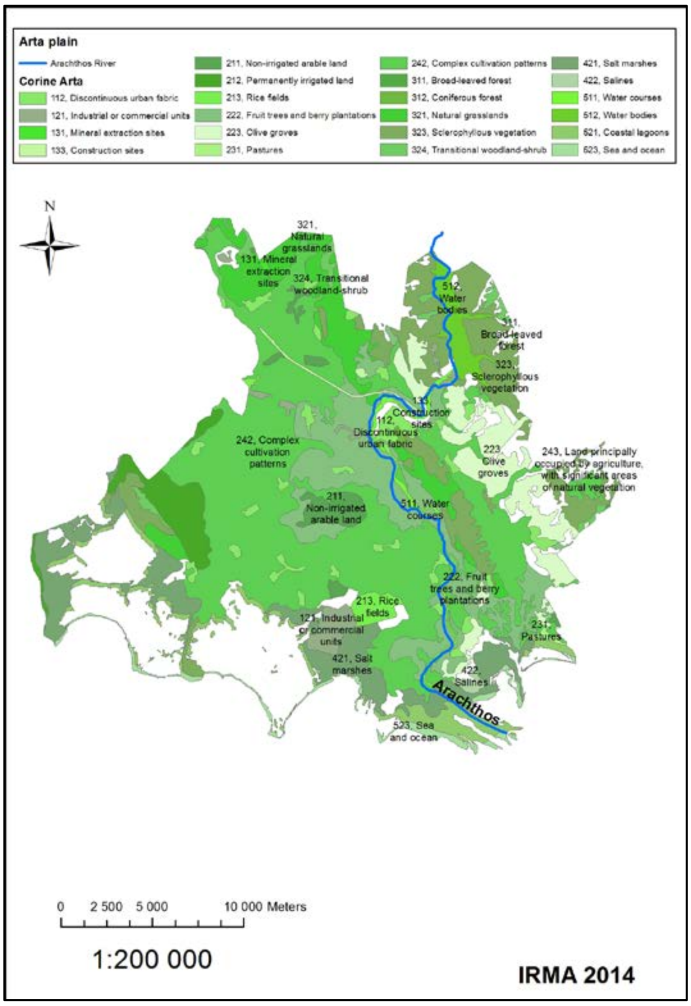


Fig. 12 CORINE coverage of Arta plain

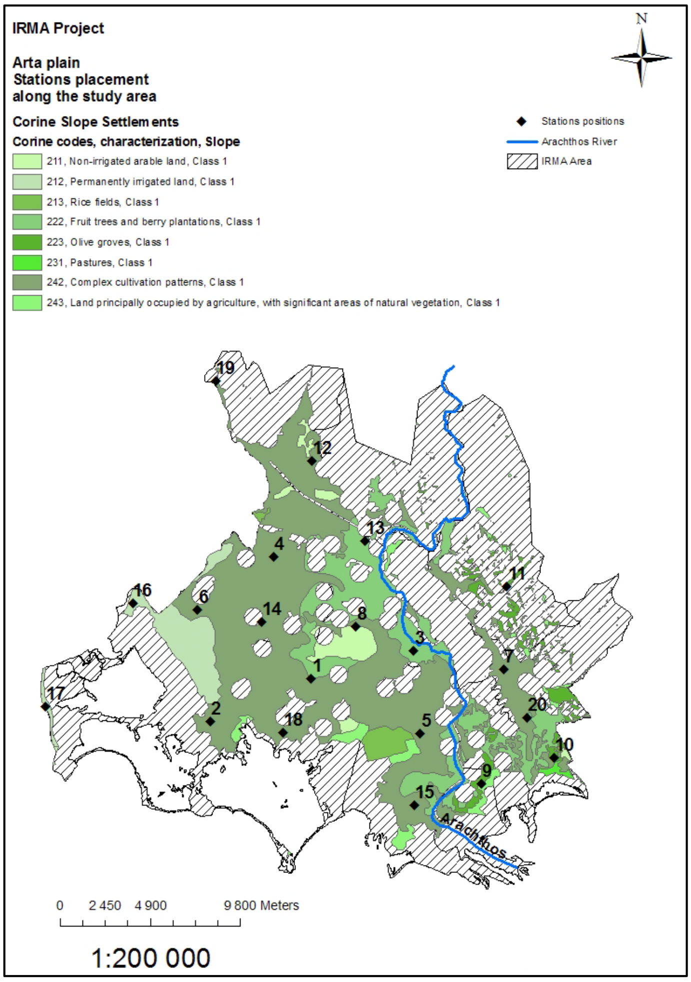


Fig. 13 Combination of IRMA area, CORINE, slope and settlements exclusion criteria on the Arta plain

Albedo

As FAO paper 56 (Allen et al., 1998) states, a considerable amount of solar radiation reaching the earth's surface is reflected. The fraction, α, of the solar radiation reflected by the surface is known as the albedo. The albedo is highly variable for different surfaces and for the angle of incidence or slope of the ground surface. It may be as large as 0.95 for freshly fallen snow and as small as 0.05 for a wet bare soil. A green vegetation cover has an albedo of about 0.20-0.25. For the green grass reference crop, α is assumed to have a value of 0.23.

The albedo (α) can be calculated in different ways (from empirical to physical based approaches). The standard approach is based on empirical broadband coefficients, which are applied to the spectral radiance measured by each channel of the satellite sensor (D'Urso & Belmonte, 2006). Hereby three main problems arise: the directional integration of the spectral radiance detected by the sensor, the spectral integration for obtaining the planetary albedo (albedo of the top of atmosphere (TOA) and the correction of atmospheric effects to achieve the surface albedo (for more details see D'Urso & Belmonte, 2006). So, in IRMA project, the calculation of α has been simplified in the following way:

$\alpha = \Sigma_{\lambda} w_{\lambda} \cdot \rho_{\lambda}$, $\lambda = 1, 2, \ldots, n$ (1)

where ρ_{λ} presents spectral reflectance (corrected for atmospheric effects) in the corresponding band (D'Urso & Belmonte, 2006; Menenti et al., 1989).

Coefficients w have been calculated for Landsat 8 OLI, as shown in Table 6.

Table 6 Weighting coefficients for the calculation of albedo (α) by using Eq. (1) and surface reflectance derived from Landsat 8 OLI.

Sensor & band	E°_{l} [mW/cm^2 mm]	w_l
Landsat 8 OLI 1	186.311	0.2163
Landsat 8 OLI 2	202.916	0.2356
Landsat 8 OLI 3	188.115	0.2184
Landsat 8 OLI 4	156.339	0.1815
Landsat 8 OLI 5	95.144	0.1105
Landsat 8 OLI 6	24.395	0.0283
Landsat 8 OLI 7	8.200	0.0095

Another way is to derive the ground albedo, the ground reflectance integrated over the wavelength region 0.3 – 2.5 µm. as value adding product from ATCOR (Add-On Module to Intergraph's IMAGINE).

The values of albedo derived from ATCOR are free from atmospheric effects and closer to those shown in Table 7.

Table 7 Sample albedos

Surface	Features	Typical albedo
soil	dark and damp	0.05
	clear and dry	0.4
sand		0.15-0.45
lawn		0.16-0.26
agricultural crops		0.18-0.25
forest	decidua	0.15-0.20
	conifers	0.05-0.15
water	Low zenith angle	0.03-0.1
	high Zenith angle	0.10-1.0
snow	old	0.4
	fresh	0.95
Cloud	dense	0.3-0.5
	thin	0.30-0.50

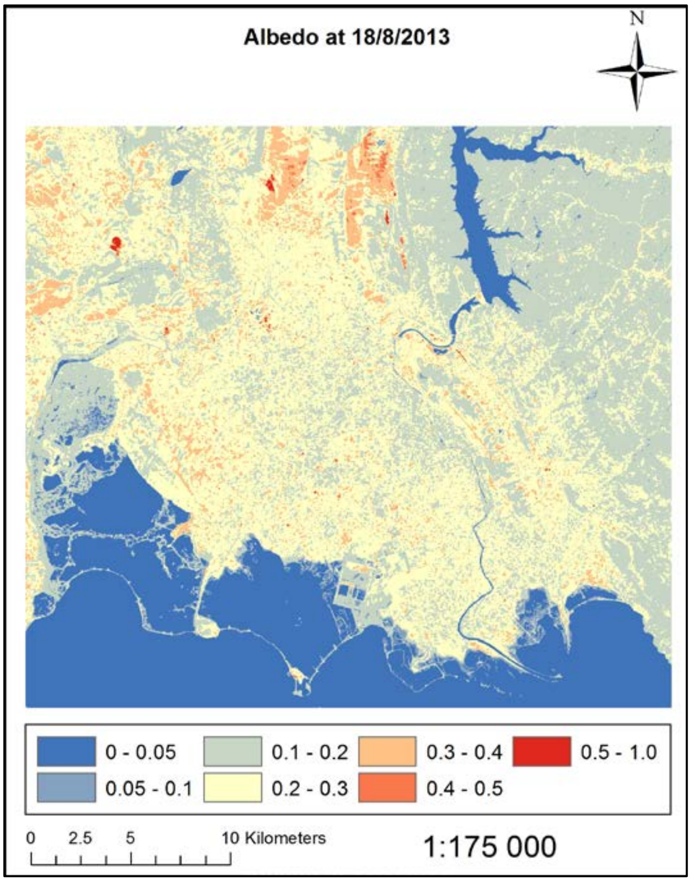


Fig. 14 Albedo map of the study area, acquired by satellite imaging, at 18/8/2013

Notes

Irrigation scheme and agricultural practices in the plain of Arta

Both Ministries that involved in irrigation water management (Environment Energy & Climate Change and Agricultural Development and Foods, operate relevant offices in Epirus, with branches at the Regional Sector of Arta. The plain of Arta is included in the area of responsibility of the Decentralised Administration of Epirus and West Macedonia and of the Directorate of Agricultural Economy and Veterinary of Arta which is a branch of the Region of Epirus.

In the plain of Arta, a participatory irrigation project (Arta), which is still under construction, operates for more than 40 years at the west part of the plain, while at the east part (Peta-Kompoti) the works are at initial stage (Fig. 15). The authority responsible for water management of this public irrigation project is the General Organization of Land Reclamation (GOLR) of Arta which supervises a number of Local Organizations of Land Reclamation (LOLR). This GOLR operates the Arta scheme, while the Peta - Kompoti scheme does not operates.

Fig. 15 The irrigation scheme of the plain of Arta (white lines; Arta (west part); black lines; Peta-Kompoti (east part)), the 3 rivers (blue lines; from left to right: Louros, Aracthos and Vovos and the 3 main drainage canals of the plain (yellow lines; from left to right: Salaoras (DC1), Fidocastrou (DC2) and Neochoriou (DC3))

No electronic registration of both descriptive and spatial data exists and the management is done manually based on the experience of the personnel.

Irrigation in the area is performed by means of surface irrigation, sprinkler irrigation and drip systems in proportions of about 40%, 40% and 20% respectively (Tsirogiannis and Triantos, 2009), with a continuous diminution of surface irrigation. The vast majority of farmers irrigate based on experience and inherited practical advices. As water is plentiful and cheap, most farmers over irrigate using water by the old open canal scheme that covers part of the plain and from numerous drillings most of which are illegal. Except of deep percolation, the main pathways of agricultural run-off and drainage are three rivers (Louros, Aracthos and Vovos) and three main draining canals (Salaoras, Fidokastrou and Neochoriou).

The groups of farmers that apply integrated management provide special information regarding cultivation techniques (including irrigation) for the cultivation they are specialized to. For the plain of Arta, even it includes citrus, kiwi-trees and olive trees in its integrated management system, provides an irrigation advices sheet only for the last one (ASAF, 2012a). During application of the integrated management system, each farmer should register -among others- all the irrigation events and relevant information using the provided by ASAF's template (Fig. 16).

ΑΡΔΕΥΣΗ

Κωδικοί Αγροτεμαχίων	Τρόπος ποτίσματος	Προέλευση νερού	Ποσότητα νερού	Συχνότητα ποτίσματος

ΕΞΑΙΡΕΤΙΚΑ ΚΑΙΡΙΚΑ ΦΑΙΝΟΜΕΝΑ

Αγροτεμάχια	Ημερομηνία	Παγετός Ένταση ζημίας	Χαλάζι Ένταση ζημίας	Ανεμοθύελλα Ένταση ζημίας	Καύσωνας Ένταση ζημίας
	__/__/__				
	__/__/__				

Fig. 16 Extract from the farmers field diary (page 3 of 4; ASAF, 2012b)

According to Tsirogiannis et al. (2012), for the main irrigated cultivations (which represent only the 51% of the total irrigated agricultural land) of the plain of Arta, a total of about 50 Mm^3 of water is expected to be used per year for irrigation using the current managerial practices. Thus, the potential for savings is very high.

Environmental issues

Agricultural activity at the river basins of Louros and Aracthos is the major threat for the ecosystem of the park (WFD, 2014). Pollutants (fertilizers, pesticides etc.) find their way to Amvrakikos, while overirrigation is causing salinisation of the water table (which is very shallow), but the problem is still not significant (Karras et al., 2006; Karras et al., 2007). During the last decade, the market problems regarding the orange cultivations, results limited interest for harvesting the fruits which are left to fall on the soil and decay. The relevant effluents are a new threat for both ground and underground water. Floods, which are common in the area, are also responsible for the transportation of fertilizers and other contaminants to the sea.

Fig. 17 Typical aspects of crop production effects on landscape in the area

Notes

Existing irrigation advice systems overview

FAO's Cropwat (http://www.fao.org/nr/water/infores_databases_cropwat.html) which calculates ETo and ET and produces irrigation schedules according to FAO paper 56 (Fig. 18; Allen et al., 1998)[9] will be used as a basis, regarding calculations, for the system that will be developed.

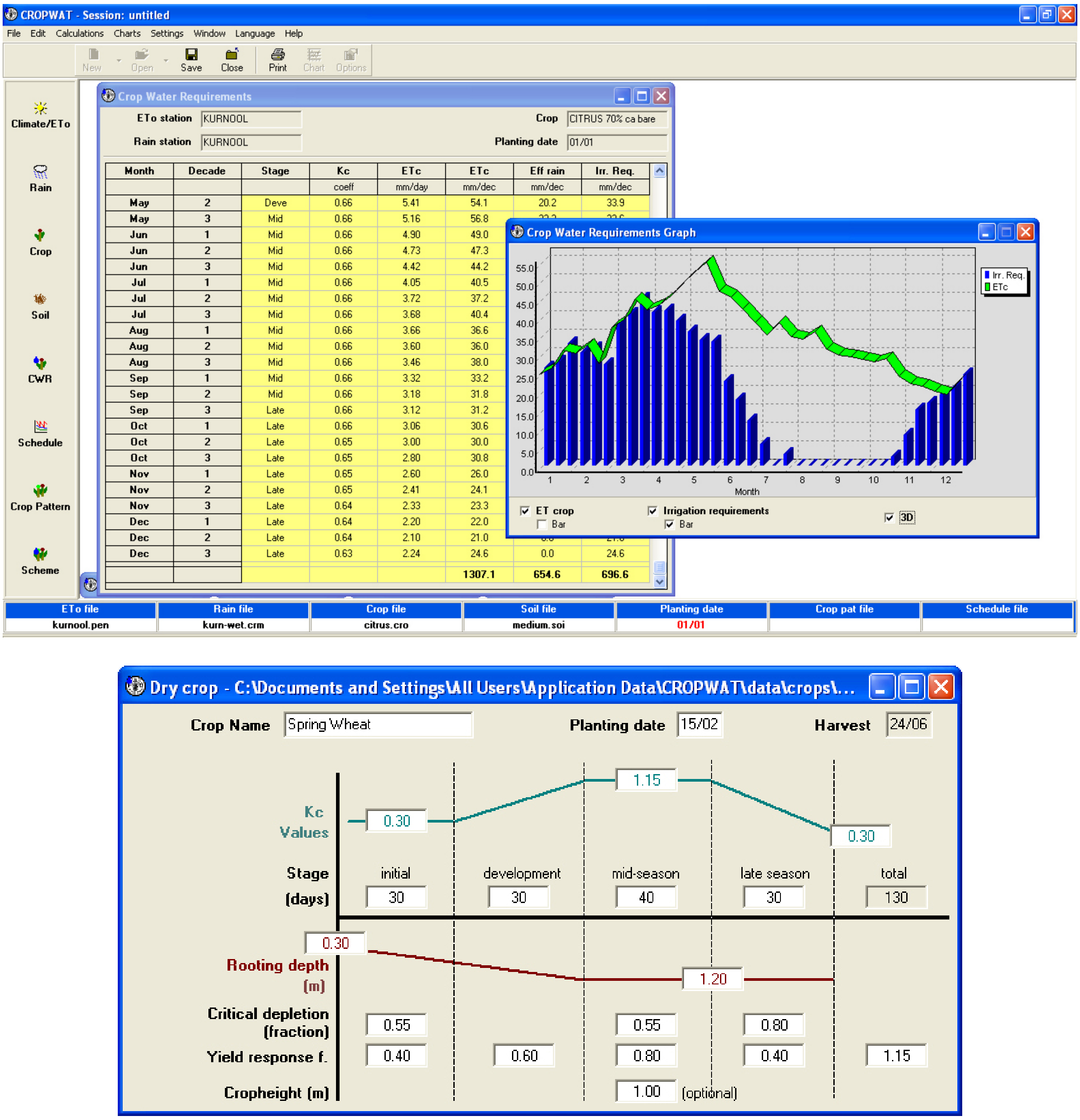


Fig. 18 Cropwat screenshots regarding climatic factors and plant periods - Kc

[9] FAO also provides an ETo calculator (http://www.fao.org/nr/water/eto.html)

The selected generic prototype for the development of the web based information system is the California Irrigation Management Information System (CIMIS, http://wwwcimis.water.ca.gov/, Fig. 19). CIMIS is an initiative of the Office of Water Use Efficiency (OWUE), California Department of Water Resources (CDWR) that manages a network of over 120 automated weather stations in the state of California. The system was initially developed in 1982 by the California Department of Water Resource and the University of California at Davis to assist California's irrigators to manage their water resources efficiently and save water, energy, and money. Most of the provided services require user registration.

Fig. 19 CIMIS website (http://www.cimis.water.ca.gov/)

In IRMA project area, the Region of Puglia runs Assocodipuglia (http://www.agrometeopuglia.it), which has developed a web tool for irrigation management tool (ServiziAgronomici e Fitosanitari, Consiglio Irriquo, http://www.agrometeopuglia.it/opencms/opencms/Agrometeo/Irrigazione/consiglioIrriguo, Fig. 20). This model provides irrigation advice regarding the suitable time of the intervention and the irrigation amounts of water to be given to the crop. The proposed irrigation schedules vary depending on the phenological stages of the crop, the hydrological characteristics of the soil, the climatic conditions (meteorological parameters are available from the Agrometeo stations) and the irrigation method. The model is based on the calculation of the daily evapotranspiration water loss as estimated using the FAO-Penman-Monteith method (Allen et. al., 1998). The service requires user registration (AssocodiPuglia, 2008).

Fig. 20 AssocoDiPuglia's irrigation scheduling tool website (http://www.agrometeopuglia.it/opencms/opencms/Agrometeo/Irrigazione/consiglioIrriguo), typical meteorological station (left, middle) and computer room (right).

The Technological Educational Institute (TEI) of Epirus, in the framework of Interreg III GR-IT ProBioSis project has developed a low budget pilot web tool for irrigation scheduling (http://probiosis.teiep.gr, Fig. 21) which uses point data from one meteorological station (ProBioSis, 2008).

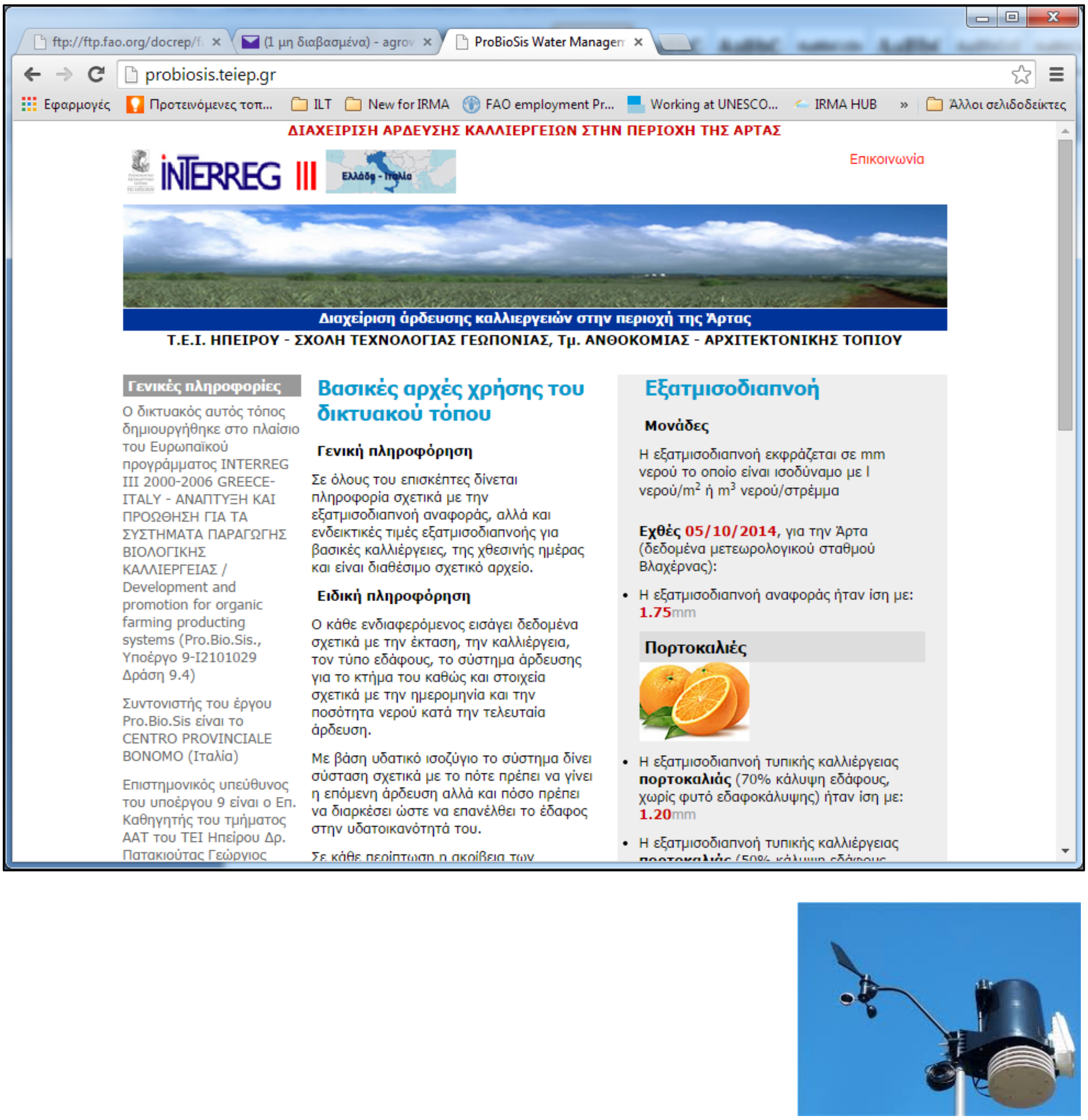


Fig. 21 ProBioSis web page and meteorological station (http://probiosis.teiep.gr/)

Hydrotech-DSS (Todorovic et al., 2013b, Riezzo et al., 2013), an application developed by CIHEAM IAM Bari, is a decision support system that incorporates continuous sensor-based monitoring in the soil-plant-atmosphere system, as well as the remote and automated control of irrigation supply networks. HT-DSS integrates real-time and remote monitoring in the water supply network and control of actuators to support farm operational management.

IRRISAT (http://www.irrisat.it/) is a project that has as objective the development and application of a support system for irrigation, both on a corporate consortium, based on the use of satellite imagery. The observation from space of agricultural land is used for monitoring the development of the crop, with a detail of 20 × 20 m. It is thus possible to evaluate the maximum quantity of water to be used for irrigation (irrigation advice) within hours of satellite acquisition (http://italia.irrieye.com/irrisat/2013/template.php).

A number of software programs and calculators, as well as smart sensors-controllers, have been developed during the past decade in order to assist irrigation managers and farmers to schedule irrigation and monitor relevant variables (ET, soil moisture, rain etc). The following are selected examples that will be also taken into account for the development of IRMA system:

- FAO's Aquacrop (http://www.fao.org/nr/water/aquacrop.html), which investigates the relationship between irrigation and yield following the model presented in FAO paper 66 (2012)
- UCDavis', Biomet toolbox (http://biomet.ucdavis.edu/irrigation-scheduling.html)
- Smart farms (Fig. 22; http://www.smart-farms.net/)
- OlirriWare (http://www.nagref-cha.gr/)
- ENORASIS Service Platform and Components (android application, https://play.google.com/store/apps/details?id=com.imaxdi.enorasisclient&hl=en; Fig. 23 and Fig. 24)
- Irritrol ClimateLogic Smart sensor / controller (http://www.irritrol.com/sensors_climatelogic.aspx)
- ARGOS Electronics / TEIEP Solar Radiation Irrigation Management Tool
- TORO Precision Soil Sensor (http://www.toro.com/en-us/professional-contractor/irrigation/sensors/Pages/Model.aspx?pid=Precision-Soil-Sensor)
- Koubachi Wi-Fi Plant Sensor (Fig. 25; http://www.koubachi.com/products/outdoor/)
- DIDAS (Drip Irrigation Design and Scheduling) (Fig. 26, http://app.agri.gov.il/didas/)
- IRRIGA System (http://www.irrigasystem.com/)
- BluLeaf (http://www.hydrotech-project.it/nuovosito/new-blueleaf/it/)

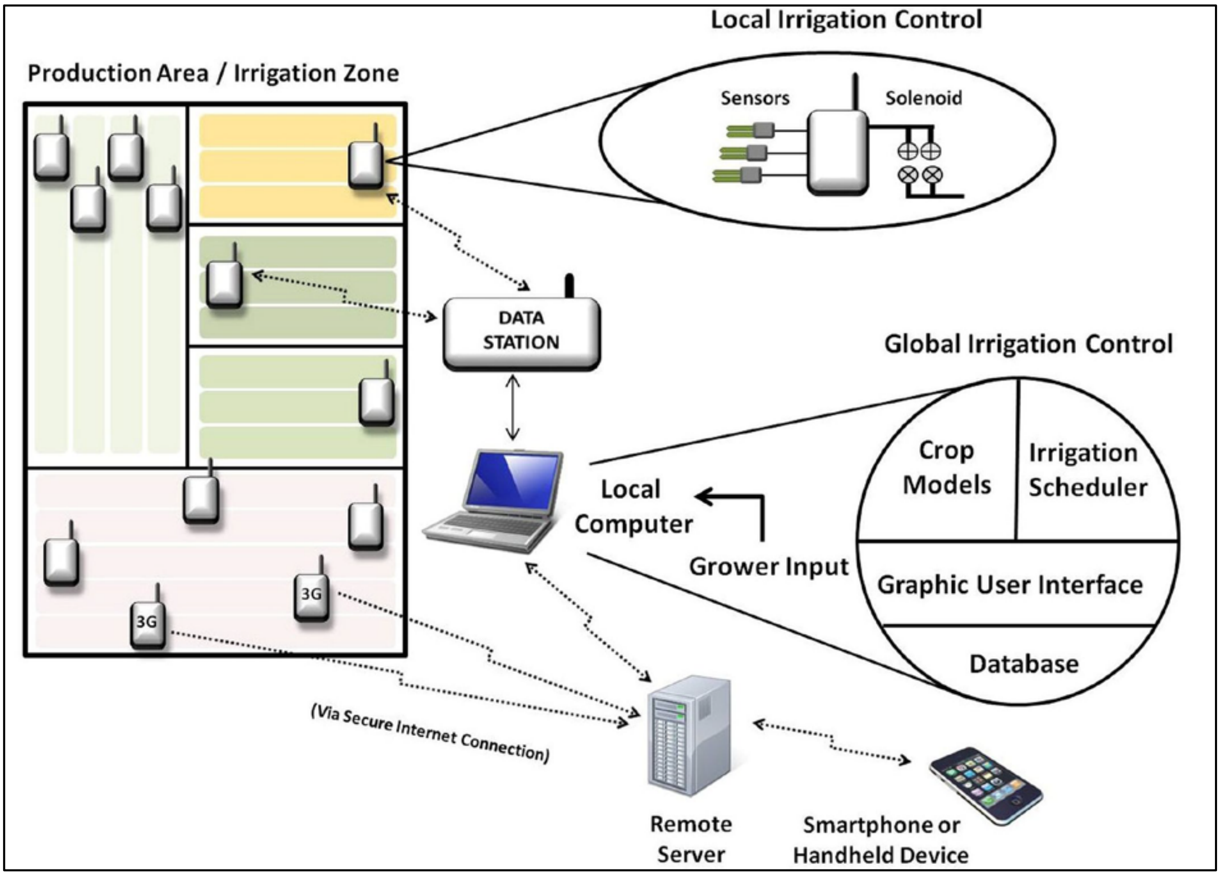


Fig. 22 Smart - Farm system concept

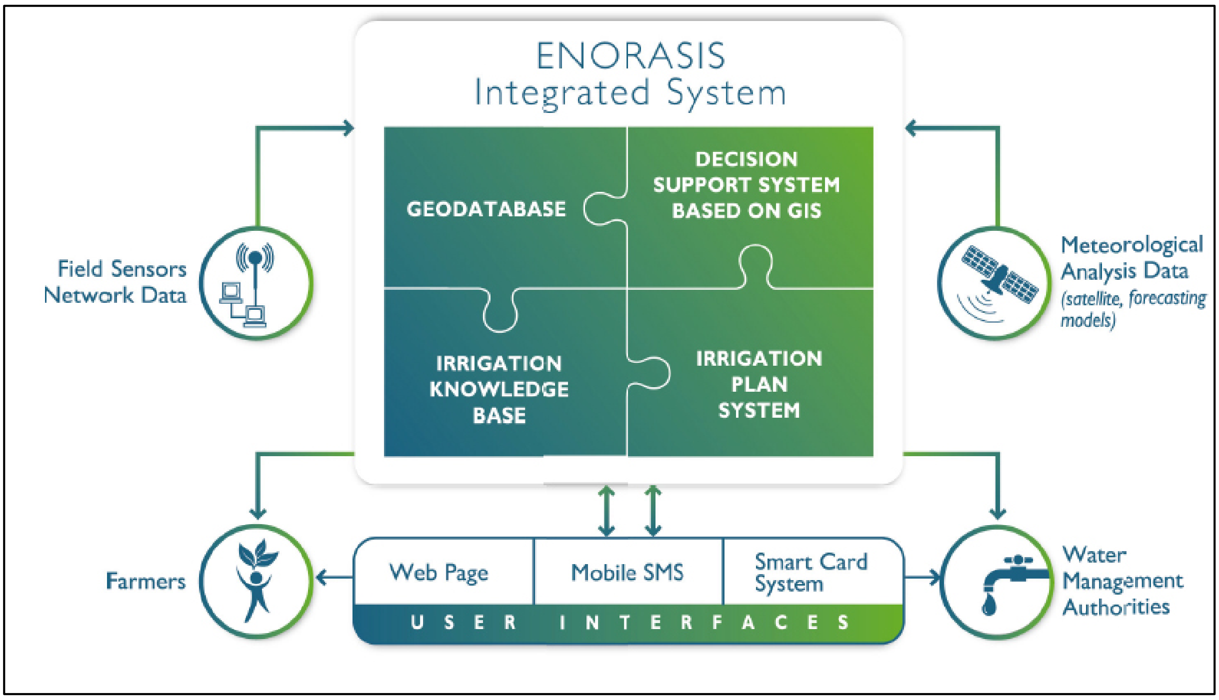


Fig. 23 Enorasis model plan

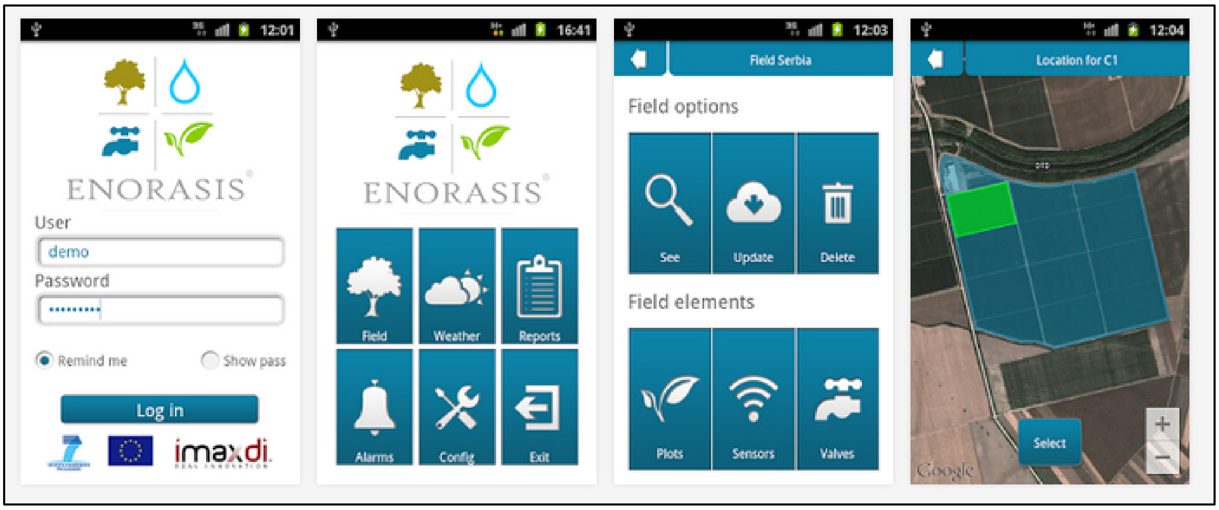


Fig. 24 Screenshots from Enorasis application for irrigation management

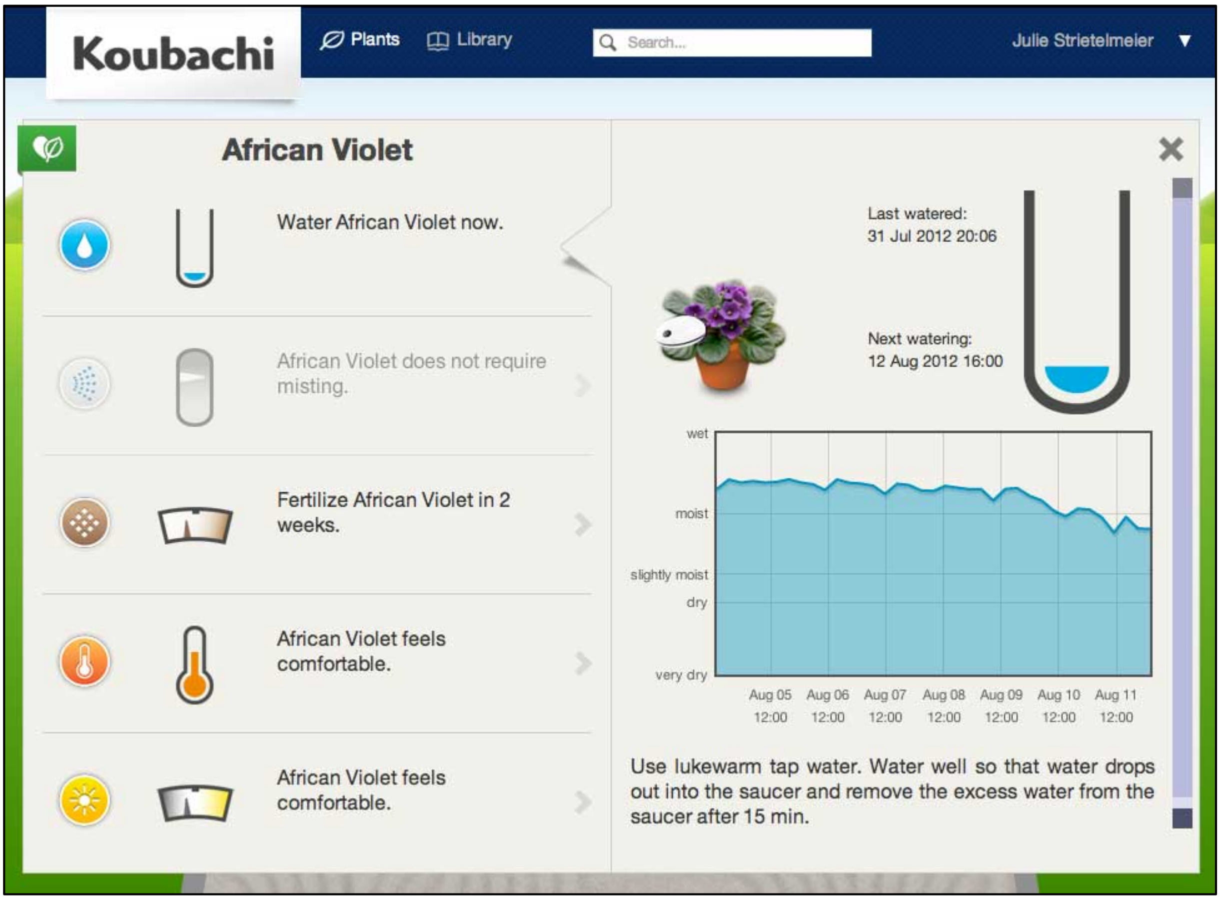


Fig. 25 Koubachi Wi-Fi Plant Sensor, software interface

Fig. 26 DIDAS software interface - main screen

During the implementation of IRLA, other R&D projects that scope to develop irrigation advice systems and include partners from Greece and/or Italy are: FIGARO (Precision Irrigation platform; http://www.figaro-irrigation.net/about/en/) and opIRIS (Irrigation Scheduling Expert System; http://www.opiris.eu/index.php/home/; Fig. 27).

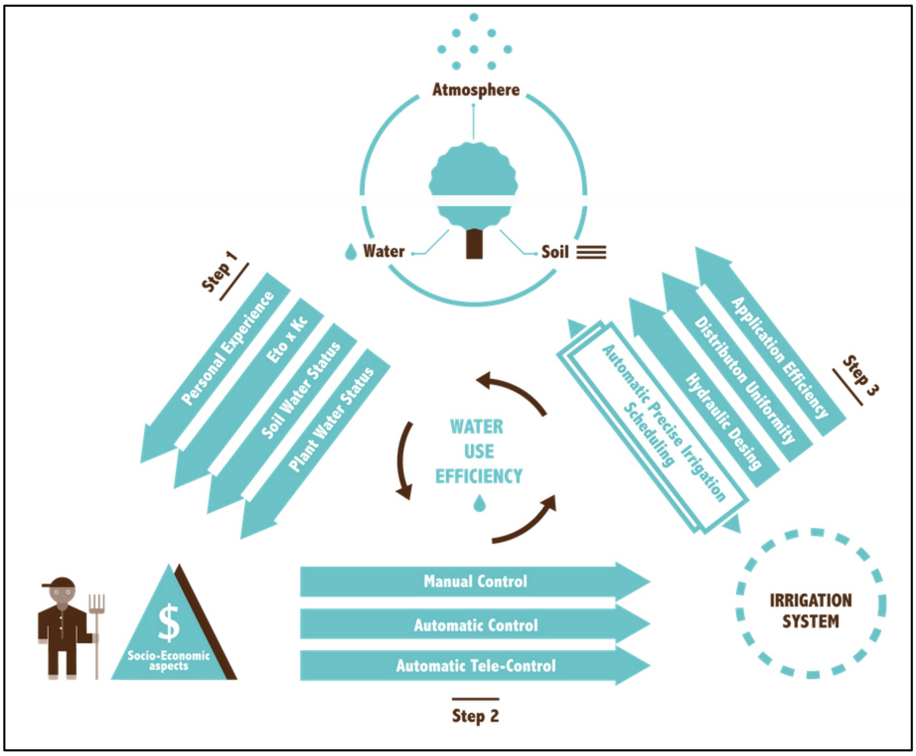


Fig. 27 opIRIS concept plan

The experience gained from the operation of these tools -and mainly the local ones- is expected to be capitalized in the development of the IRMA system.

Brief description of the existing pilot system for Arta plain (ProBioSis)

This low budget pilot system was developed in 2008 in the framework of the INTERREG III 2000-2006 GREECE-ITALY project Pro.Bio.Sis. (Development and promotion for organic farming production systems). The main features of this web tool for irrigation management, are: i) the publication of information regarding daily evapotranspiration –based on actual meteorological data- and ii) an estimator –based on water balance calculations- for the time and duration of the next irrigation event.

The site is hosted at http://probiosis.teiep.gr, is available in Greek language and provides:

- information regarding the evapotranspiration (ET_o and ET_c of selected cultivations) of the previous day,
- archive with historical meteorological and evapotranspiration data,
- estimator for the time and the duration of the next irrigation event and
- help regarding the use of the tool and the estimation of the information that the user should provide.

The web tool is based on a straightforward concept. Meteorological stations gather climatic data which –after a very simple quality control- is send to the server at the end of each day (00:00 Greek time). A script is used to calculate reference and cultivation specific evapotranspiration of the past day, which is then available at the site. All data and information is stored at a database which is accessible from everyone. Land field specific and last irrigation information along with information from the database is also used by a second script in order to set a water balance and provide advice regarding the next irrigation event. Weather forecast information is also used in this procedure in order to avoid irrigation proposal when rain is expected.

The dynamic web tool was designed following the object oriented approach and developed using PHP scripting language (Zend Technologies, 2008). Temporary and permanent data are stored in a MySQL database. A series of classes were developed for fetching meteorological data and field measurements from external sources. Classes fetching external data are invoked periodically using two Cron Jobs and on the web server data are fetched using CURL operations. Fetched data are stored in the database. Another set of classes were developed in order to perform the required calculations, display historical data and provide advice regarding the time and duration of next irrigation. Configuration parameters are stored in special files.

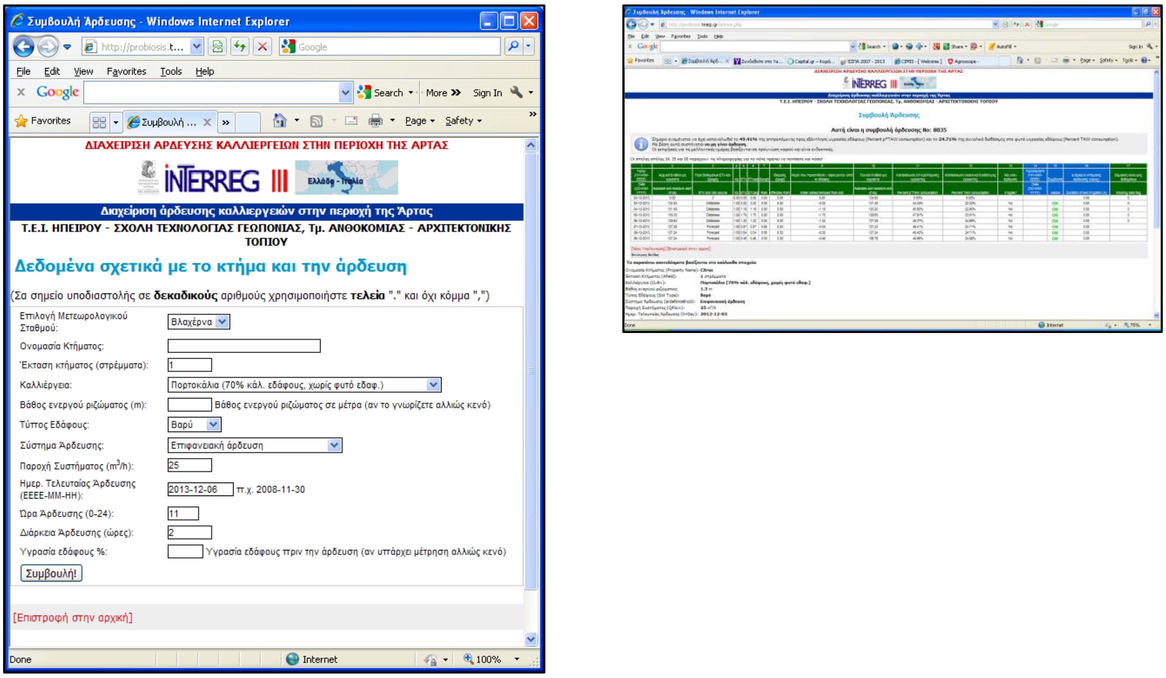


Fig. 28 Irrigation advices (ProBioSis)

Two meteorological stations were initially used (model Vantage Pro2 Wireless, Fan-aspirated, DAVIS), which are based at Vlaherna/Arta (39° 10′ 21.74′′N, 21° 05′ 01.87′′E). and at Kompoti (39° 10′ 21.74′′B, 20° 59′ 57,92′′A). Both stations are equipped with air temperature and relative humidity sensors, pyranometer, rain and wind speed meter. Data are logged using special software (WeatherLink, DAVIS). The software allows the user clear "bad data" (highs and lows, alarm thresholds, calibration numbers, etc.). Dashes are used in the database to mark "bad data" points. From this only the station of Vlaherna/Arta is used by the system now (2014).

Reference and cultivation potential evapotranspiration for the selected cultivations of the region is calculated at the end of each day using the Penman-Monteith (PM) approach (Allen et al., 1998). The use of proper Kc factors which reflect the characteristics of local varieties, cultivation period and local agricultural practice is of great significance for the precision of the each cultivation's potential evapotranspiration. For this purpose, an extensive literature review was performed (Balatsouras, 1992; Blanchet, 1987; Dimoulas, 1988; Grattan et al., 2006; Holzapfel et al., 2000; Judd et al., 1989; Michelakis et al., 1996; Moriana et al., 2007; Orgaz et al., 2006; Palomo et al., 2002; Paloukis and Dinopoulos, 1989; Pontikis, 1990; Testi et al., 2006; Xiloyannis et al., 1990).

When there is a lack of sufficient data to calculate the reference evapotranspiration using the PM equation, the Hargreaves formula is proposed for use (Allen et al. 1998). The ET information (reference and potential for citrus, kiwi, olives and grass) is then posted at the home page of the site and stored at the database. The end user or her/his counselor can use this information to form irrigation schedules but the system is primary addressed to agriculturalists, which were trained in its use.

The web tool also includes an estimator for the time and the duration of the next irrigation. The user provides basic information regarding the site of the field, the soil type, the cultivation, the available flow and the irrigation system type as well as information regarding the time and duration of the last irrigation. Then a script which is based on water balance equations -as described in FAO paper56 (Allen et al., 1998; Jhorar et al., 2009)- and uses the stored historical ET information along with ET and rain forecasts for the next 3 days –provided by the National Observatory of Athens which uses the Bolam model (Lagouvardos, 2003) to make the calculations- provides advice regarding the time and duration of next irrigation. The advice with the relevant water balance can be printed as a report.

In order to support the use of the site and the formation of irrigation schedules relevant information is provided. A guide regarding the use of the tools and the estimation of the various factors which are used in the next irrigation estimator is available along with documents and links regarding the general concepts and special techniques of irrigation scheduling.

In order to support the use of the site and the formation of irrigation schedules relevant explicatory information is provided. At the website of the tool, a guide regarding the use of the tools and the estimation of the various factors which are used in the next irrigation estimator is available along with documents and links regarding the general concepts and special techniques of irrigation scheduling.

Also training sessions were planned for local agriculturalists in order to present them the tools as they could play a key role to its use in irrigation practice. The web tool was made available from May 2008 and up to 2013 more than 8000 advices have been provided.

Notes

Existing meteorological stations and networks in and around the plain of Arta

Hellenic National Meteorological Service (HNMS)

The Hellenic National Meteorological Service (member of WMO, http://www.hnms.gr/) was founded in 1931 and its mission was to cover all the meteorological and climatological needs of our country. Today, according to the law in force, the HNMS is a National Service under the subordination of Ministry of Defense and the auspices of the Hellenic Air Force General Staff.

In the plain of Arta HNMS runs one agrometeorological station which does not provide online data). The station (WMO number 654, Arta Filothei, 37° 36'N 22° 447E; alt. 10,5) operates from 1976, and measurements (air temperature, min and max air temperature, air pressure, relative humidity, wind velocity, cloudness, rain, day duration, solar radiation, evaporation and soil temperature) are taken at 06, 09, 12 and 18. A second station (WMO No 656, Arta city, 39° 10'N 22° 59'E) operated from 196 up to 1995.

Ministry of Agricultural Development and Food (MINAGRIC)

The Ministry of Agricultural Development and Food, with the 805/11-3-2011 document (reply to the Greek Parliament question no 10451/4-2-2011), stated that there 80 meteorological stations around the country (managed by the Regional Centers of Plant Protection and Quality Control, one of which is in Epirus), 40 meteorological stations installed at the various biotopes of the country, 240 stations which are managed by the Land Reclamation directorate and are installed in 13 of the 14 hydrological sectors of the country. The Ministry (Directorate of Geology and Hydrology) participates in the National Bank of Hydrological and Meteorological Information (http://ndbhmi.chi.civil.ntua.gr/el/index.html). Additionally, a number of entities that are supervised by the Ministry run meteorological stations all around the country.

National Observatory of Athens (NOA)

The National Observatory of Athens runs meteo.gr and among others (http://www.meteo.gr/meteoplus/gmap.cfm) maintains in the plain of Arta two meteorological stations, which will be included in the system (at least during the prototype development phase), a third station will provide boundary data (Fig. 29):

1. Inside the plain of Arta:
    a. Kompoti station (21.08397 E, 39.10218 N, http://penteli.meteo.gr/stations/kompoti/)
    b. Vlacherna-Arta station (20.99920 E, 39.17250 N, http://penteli.meteo.gr/stations/arta/)
2. Around the plain of Arta (boundary station):
    a. Preveza (http://penteli.meteo.gr/stations/preveza/)

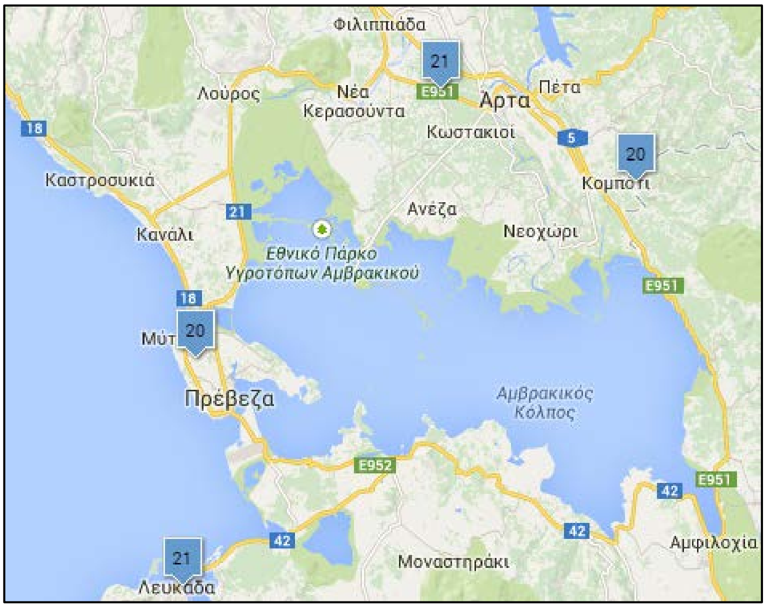


Fig. 29 Locations of NOA / meteo.gr meteorological stations in the area

Other networks

The Technological Educational Institute of Epirus except of the initial fully-equipped agrometeorological station which operated from 1993-1998 and the meteorological stations of the hydroponic glasshouse D. Savvas which operates from 2003, from time to time operates meteorological stations in the framework of specific projects. In the framework of New Land project, 5 HOBO stations were installed in various locations of Epirus and this period two meteorological stations (Ano Kostilata: 21.16091 E, 39.45922 N and Kato Kostilata: 21.17988 E, 39.44852 N) are operating in the framework of New Knowledge project: Pilot development of innovative geographical information system for the sustainable management of the mountainous - sub alpine meadows of Theodoriana / Arta.

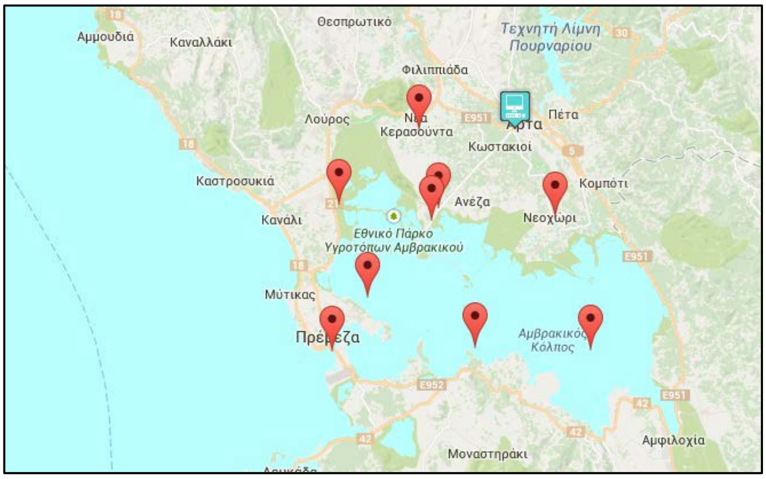


Fig. 30 Locations of Amvrakikos Wetlands National Park meteorological stations in the area

Meteoalarms (http://www.meteoalarms.gr/) is a local network of the Region of Epirus that has been developed 10 years ago. Most of its stations are not functioning well or at all due to poor maintenance.

Amvrakikos Wetlands National Park, operates a system with meteorological station distributed all around the park but mainly in the sea (http://www.xmeox.gr/monitoring/).

Other organisations like the National Roads (http://www.neaodos.gr/, http://www.egnatia.eu/) companies, the Public Power Corporation S.A. (http://www.dei.gr/) as well as a number of individuals run meteorological stations in the area.

Integration of meteorological data

HYDROSCOPE is a Greek nation-wide research programme with several participating organizations aiming at the development of a national distributed data-base system for meteorological, hydrological and hydrogeological information. Hydroscope (http://www.hydroscope.gr/), begun in 1992 and it was completed in 2010.

The project (1996-2001) of the National Data Bank of Hydrological & Meteorological Information (http://ndbhmi.chi.civil.ntua.gr/el/index.html), which was assigned to N.T.U.A. by the Ministry of Environment, Planning & Public Works, is an initiative which scopes to provide the required infrastructure for the implementation of the E.U. Water Framework Directive for the protection, rational management and exploitation of the water resources in the national level.

Available official or broadly approved weather forecast providers

World Meteorological Organisation forecasts

The World Meteorological Organisation provides forecasts and/or climatological information from the Hellenic National Meteorological Service (http://worldweather.wmo.int/en/home.html) only for only Athens and Thessaloniki.

HNMS forecasts

The Hellenic National Meteorological Service (member of WMO, http://www.hnms.gr/) is the official meteorological and climatic information and weather forecasts organisation in Greece.

NOA forecasts

National Observatory of Athens provides forecasts for Greece by three models: BOLAM, MM5 and WRF. Detailed forecasts are issued for 40 major Greek cities. Forecasts are presented as maps, time-plots, word text and outlook tables at the system's web site (http://www.meteo.gr). IRMA_SYS Arta will incorporate three hour forecasts.

RiskMed forecasts

RiskMed (http://www.riskmed.net/) is an output of an EU co-financed project (ARCHIMED) which provides high spatial accuracy weather forecasts for an area that contains the area of IRMA_SYS Arta (Fig. 31). The system uses data from an independent meteorological stations network and updates its forecasts every 12 hours. The data are analyzed at the University of Ioannina.

Fig. 31 The RiskMed area

Other forecast providers

A number of private companies (national and international) provide forecasts for the area of IRMA_SYS Arta.

OpenWeatherMap service provides open weather data for more than 200000 cities and any geo location that is available on http://openweathermap.org and through API. For the IRMA area data are available from: http://openweathermap.org/city/264559.

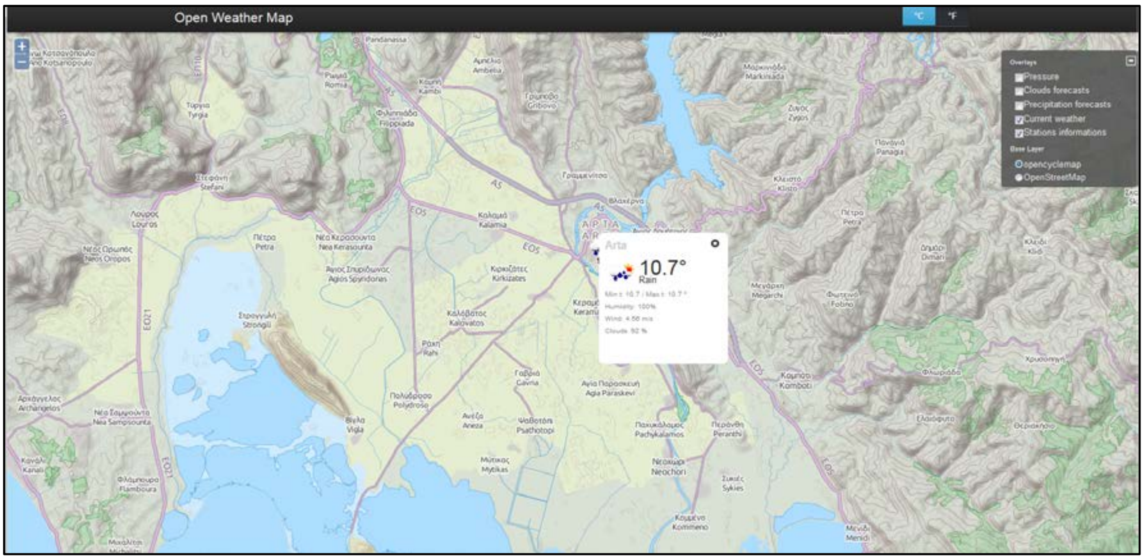


Fig. 32 OpenWeatherMap service for the IRMA area

Theoretical background regarding estimation of crops water needs and irrigation scheduling

Every approach for setting up an irrigation schedule is based on the estimation of the cultivation's or the landscape's water needs. This is commonly performed by mass and/or energy balance methods which include in which, key factors are the evapotranspiration of crops, terrain and soil characteristics and irrigation water parameters.

According to FAO paper 45 (Walker, 1989) important soil characteristics in irrigated agriculture include the water-holding or storage capacity of the soil; the permeability of the soil to the flow of water and air; the physical features of the soil like the organic matter content, depth, texture and structure; and the soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements.

Soil water properties

Available soil water

The total available water (TAW), for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure from 0.1 to 0.33 bar (a soil moisture level called field capacity, FC) and 15 bars (called the permanent wilting point, PWP). The TAW will vary from 250 mm m^{-1} for silty loams to as low as 60 mm m^{-1} for sandy soils (Fig. 33; Bouma, 1972).

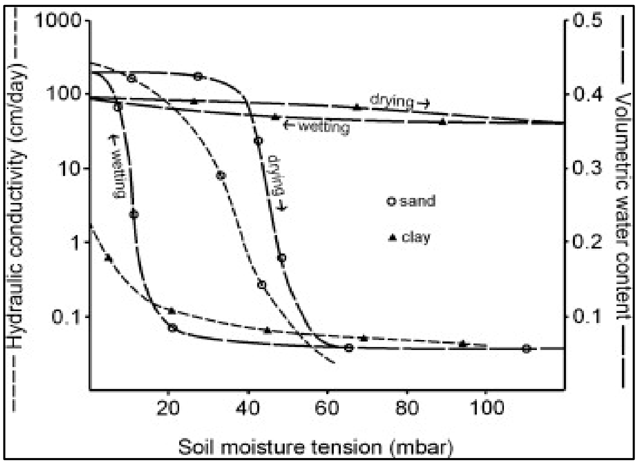


Fig. 33 Relationship between volumetric water content, soil moisture tension and hydraulic conductivity in sand and clay soils (Bouma, 1972)

The readily available water content (RAW) in the root zone can be calculated using the following equation, as a fraction of the total available soil moisture (TAW) as:

$$RAW = TAW \times MAD \text{ with } TAW = FC - PWP \quad (1)$$

where, RAW (% m^3 m^{-3}) is the amount of water that a crop can extract from its root zone, FC (% m^3 m^{-3}) is the volumetric water content at Field Capacity, PWP (% m^3 m^{-3}) is the volumetric water content at the Permanent Wilting Point and MAD (%) the Maximum Allowable Depletion of the available moisture before the next irrigation (a generic value for MAD is 50%).

Since the only available soil data were those of the New Land Project soil texture analyses, we implemented the soil hydraulic parameters for the analytical functions of van Genuchten (1980) for twelve textural classes of the USDA textural triangle as obtained data set by combining soil data from two databases used by Schaap et al. (2001) and Minasny et al. (2004) as they are presented in Twarakavi et al. (2009), Table 8. Through this procedure we obtained the corresponding values of field capacity (FC) and permanent wilting point (PWP) for the Arta plain soils distribution.

Table 8 Soil hydraulic parameters for the analytical functions of van Genuchten (1980) for twelve textural classes of the USDA textural triangle as obtained from Twarakavi et al. (2009).

Textural class	Θr	Θs	α	n	Ks
	(m^3 m^{-3})	(m^3 m^{-3})	(cm^{-1})	-	(cm d^{-1})
Sand	0.05	0.372	0.035	3.214	579.4
Loamy Sand	0.05	0.383	0.031	1.694	89.5
Sandy Loam	0.057	0.379	0.024	1.517	29.2
Loam	0.088	0.428	0.015	1.489	12.4
Silt	0.071	0.432	0.003	2.203	30.7
Silty Loam	0.14	0.425	0.008	1.710	6.5
Sandy Clay Loam	0.06	0.381	0.020	1.274	14.6
Clay Loam	0.081	0.45	0.018	1.297	11.3
Silty Clay Loam	0.086	0.481	0.008	1.469	11.7
Sandy Clay	0.098	0.384	0.045	1.167	20.8
Silty Clay	0.103	0.5	0.018	1.276	9.6
Clay	0.098	0.471	0.016	1.197	12.7

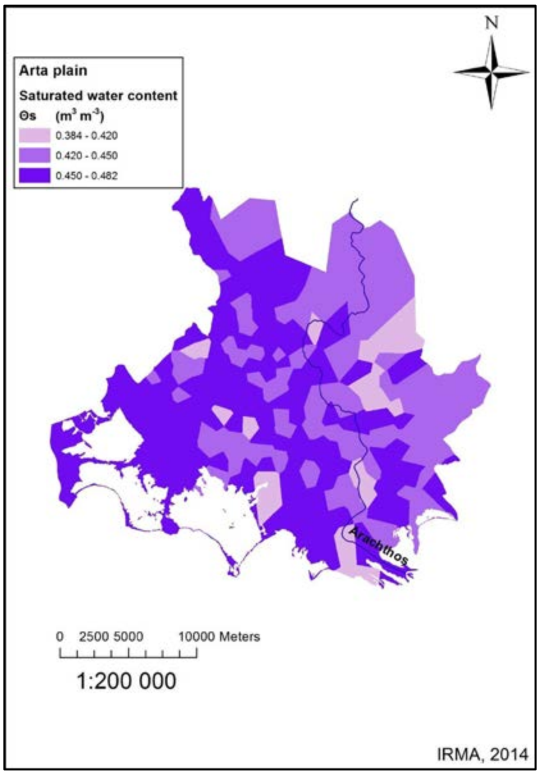
where Θs is the water content at saturation, Θr is the residual water content (equal to PWP), Ks is the saturated hydraulic conductivity and a, n are model parameters described in van Genuchten (1980)

Table 9 Arta plain Field Capacity (FC) and Permanent Wilting Point (PWP) distribution

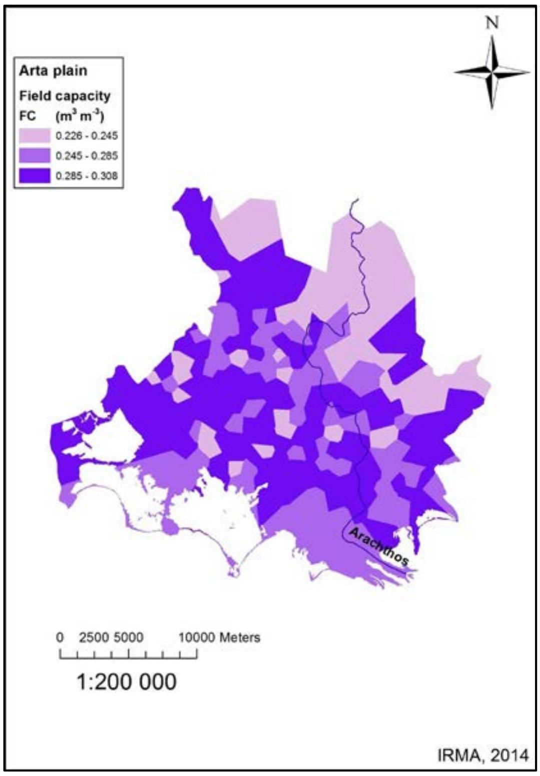
Soil Texture	**Number of samples**	**(%)**	**FC (% m^3 m^{-3})**	**PWP (% m^3 m^{-3})**	**ASM (% m^3 m^{-3})**
Silty Clay Loam	57	28.8	32.8	8.6	0.242
Silty Clay	33	16.7	39.2	10.3	0.289
Clay	30	15.2	40.3	9.8	0.305
Silt Loam	30	15.2	28.7	14	0.147
Clay Loam	27	13.6	33.9	8.1	0.258
Loam	12	6.1	28.5	8.8	0.197
Silt Loam - Loam	5	2.5	28.7	14	0.147
Sandy Loam	3	1.5	21.9	5.7	0.162
Sandy Clay Loam	1	0.5	29	6	0.23
Total	**198**	**100**			

Table 9 denotes that the majority of soils across the IRMA_SYS Arta area vary from 14.7% (or 0.147 $m^3\ m^{-3}$) to 30.5% or (0.305 $m^3\ m^{-3}$).

Fig. 34 presents the saturated water content (Θs) and the field capacity (FC) maps of IRMA_SYS Arta area, respectively, while Fig. 35 presents the available soil moisture (ASM) distribution map, as estimated by the above presented methodology.



(a)



(b)

Fig. 34 Saturated water content (Θs) map (a) and Field capacity (FC) map (b) of IRMA_SYS Arta area

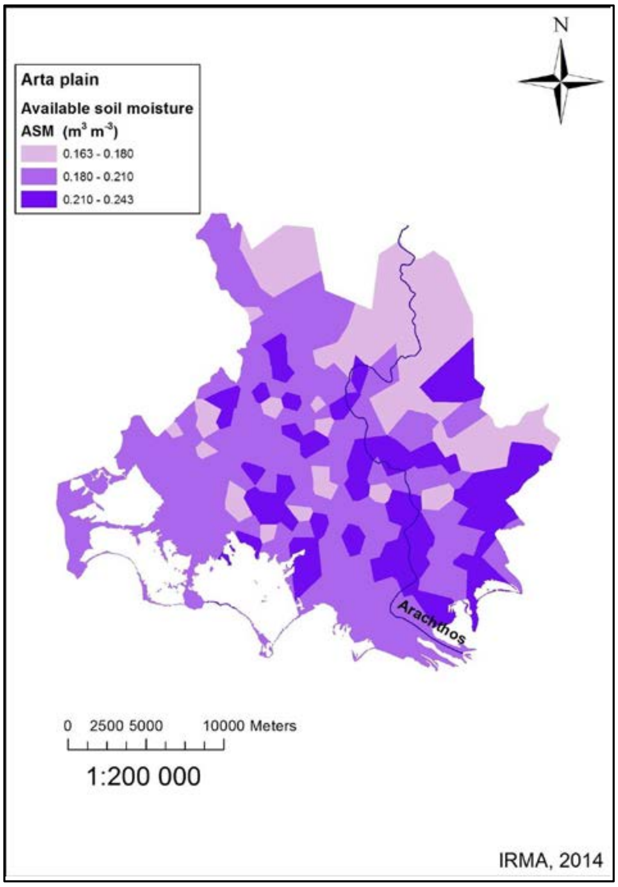


Fig. 35 Total available soil water (TAW) map of the IRMA_SYS Arta area

Information regarding soil moisture will essentially contribute to the irrigation balance calculation (this is an issue for the lower parts of the plain of Arta where the water table frequently rises up to 1 meter depth.

Net irrigation needs

The net irrigation requirement (IRN) is derived from the general water balance equation:

$$IRn = ETc - (ER + GW + RAW) + LR \quad (2)$$

where IRn is the Net Irrigation Requirement (mm), ETc is the Crop Evapotranspiration (mm), ER is the Effective Rainfall (mm), GW is the Ground Water contribution from water table (mm), RAW is the Readily Available Water at the beginning of each period (mm) and LR is the Leaching Requirement (mm).

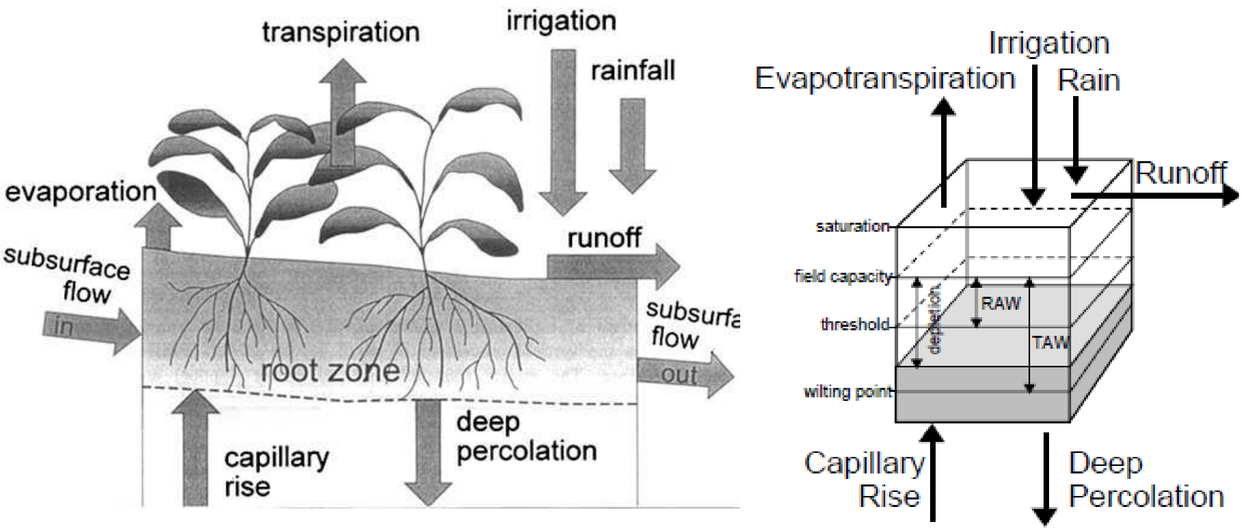


Fig. 36 Soil water balance of the root zone (Allen et al., 1998)

The gross irrigation requirements (IRg) account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements (IRn), as:

$$IRg = IRn / IE \quad (3)$$

where IE is the overall irrigation system efficiency.

System efficiency

Different efficiencies are attributed to different irrigation systems. The overall project efficiency values shown in Table 10 can be used for various irrigation systems.

Table 10 Generic values regarding application efficiency for different types of irrigation systems (Allen et al., 1998)

Irrigation system	Overall efficiency
Surface	45%
Sprinkler	75%
Localized	90%

Also, the 1989 Greek ministerial decision (GG 428 2-6-1989) suggested values regarding irrigation system efficiency according to the following table:

Table 11 Generic values regarding application efficiency for different types of irrigation systems (GG 428 2-6-1989)

Irrigation system	Overall efficiency
Surface	75%
Sprinkler	85%
Localized	90%

Crop water needs

Several methods are used for the estimation of crops' evapotranspiration (Table 12; Stanghellini 1987; Allen et al. 1998; Donatelli et al. 2006; Ilahi, 2009).

Table 12 Selected procedures for estimation of crops' evapotranspiration (Ilahi, 2009)

ET models	Classification	
FAO Penman	Combination method based on energy balance	Physical model
FAO Penman-Monteith	Combination method based on energy balance	Physical model
Stanghellini	Combination method based on energy balance	Physical model
Fynn	Combination method based on energy balance	Physical model
Penman-Monteith Screen-house	Simplified model from Penman-Monteith	Physical model
Energy Balance equation	Energy balance	Physical model
FAO Radiation	Radiation based	Empirical model
Priestley Taylor	Radiation based	Empirical model
Hargreaves-Samani	Radiation - temperature based	Empirical model
Simplified model	Simplified model from Penman-Monteith	Empirical model

The IRMA_SYS Arta will apply the Penman-Monteith (PM) method or in the case of limited data availability the Hargreaves-Shamani (HS) method (Allen et al. 1998, Hargreaves and Samani, 1982, Droogers and Allen 2002, Farmer et al. 2011, Todorovic et al., 2013a).

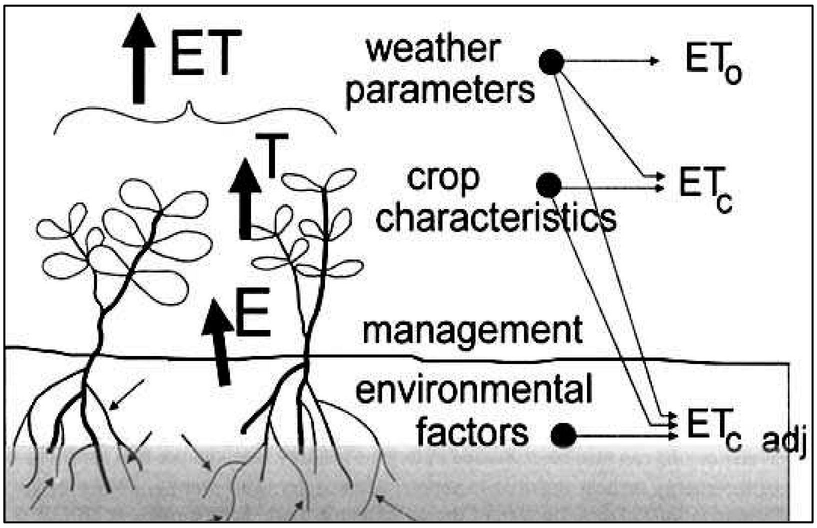


Fig. 37 Evapotranspiration calculation concept (Allen et al., 1998)

Estimation of daily and hourly *ET_0*, the Penman - Monteith (PM) equation

The PM equation for the estimation of reference evapotranspiration was developed to describe ET of a reference grass crop, which is defined as the rate of evapotranspiration from a hypothetical crop with an assumed fixed height (12 cm), surface resistance (70 sm^{-1}) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of a disease free green grass cover of uniform height, actively growing, completely shading the ground, and with adequate water and nutrient supply (Allen et al., 1998, Fig. 37). To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water. Standard methods are proposed by Allen et al. (1998) to compute the parameters of Eqs. 4 and 5 from the observed climatic variables.

The proposed formula of ET_0 calculation on daily basis (Allen et al., 1998)

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)} \tag{4}$$

where ET_0 is the grass reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the grass surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s–e_a is saturation vapour pressure deficit (kPa), Δ is slope of the vapour pressure curve (kPa °C^{-1}), and γ is psychometric constant (kPa °C^{-1}). This equation uses standard meteorological records of solar radiation (net, short wave, or sunshine duration) or sunshine duration, minimum and maximum air temperature, air humidity (preferably minimum and maximum relative humidity) or wet and dry bulb temperature, and wind speed.

In areas where substantial changes in wind speed, dew point or cloudiness occur during the day, calculation of the ET_0 equation using hourly time steps is generally better than using 24-hour calculation time steps. Such weather changes can cause 24-hour means to misrepresent evaporative power of the environment during parts of the day and may introduce error into the calculations. However, under most conditions, application of the FAO Penman-Monteith equation with 24-hour data produces accurate results. With the advent of electronic, automated weather stations, weather data are increasingly reported for hourly or shorter periods. Therefore, in situations where calculations are computerized, the FAO Penman-Monteith equation can be applied on an hourly basis with good results.

When applying the FAO Penman-Monteith equation on an hourly or shorter time scale, the equation and some of the procedures for calculating meteorological data should be adjusted for the smaller time step. The FAO Penman-Monteith equation for hourly time steps is:

$$\begin{gathered} ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{37}{T_{hr}+273} u_2 (e_o(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)} \\ e_a = e_o(T_{hr}) \frac{RH_{hr}}{100} \end{gathered} \tag{5}$$

where ET_0 is the grass reference evapotranspiration (mm hour^{-1}), R_n is the net radiation at the grass surface (MJ m^{-2} hour^{-1}), G is soil heat flux density (MJ m^{-2} hour^{-1}), T_{hr} is the average hourly air temperature at 2 m height (°C), u_2 is the average hourly wind speed at 2 m height (m s^{-1}), e^o is saturation vapour pressure at air temperature T_{hr} (kPa), e_a is the average hourly actual vapour pressure (kPa), Δ is slope of the vapour pressure curve at air temperature T_{hr} (kPa °C^{-1}), RH is the average hourly relative humidity (%) and γ is the psychometric constant (kPa °C^{-1}).

Alternative estimation of daily ET_0, the Hargreaves - Samani (HS) equation

When radiation and sunshine duration measurements are not available, the system will uses the Hargreaves - Samani (HS) equation (Hargreaves and Samani, 1982; Droogers and Allen, 2002; Farmer et al. 2011; Todorovic et al., 2013). The HS method requires only minimum (T_{min}) and maximum (T_{max}) air temperature and extraterrestrial radiation (Ra) for the estimation of ET_0 (mm day^{-1}) by the following equation:

$$ET_0 = 0{,}0023(T_{mean} + 17{,}8)(T_{max} - T_{min})^{0{,}5} R_a \quad (6$$

or $ET_0 = 0.0023\, Ra/\lambda\, (T_{max} - T_{min})^{0.5} (T + 17.8)$ in mm.

The coefficient 0.0023 is an empirical coefficient including both the conversion from American to the International metric units system, R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}) and k is the latent heat of vaporization (MJ kg^{-1}) for the mean air temperature T (°C) given as:

$\lambda = 2{:}501 - 0.002361 \times T$

Generally, it is assumed k = 2.45 MJ kg^{-1}.

Water stress coefficient (K_S)

The effects of soil water stress on crop ET are described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient, Ks (Allen et al., 1998) that describes the effect of water stress on crop transpiration. Where the single crop coefficient is used, the effect of water stress is incorporated into K_c as:

$$ET_{c\ adj} = K_S \times K_c \times ET_0 \quad (7)$$

where

$$Ks = (TAW - D_r)/(TAW - RAW) \quad (8)$$

For soil water limiting conditions, Ks < 1, while in the absence of soil water stress Ks = 1.

Evapotranspiration from a cropped surface

The effects of characteristics that distinguish the cropped surface from the reference surface are integrated into the crop coefficient. By multiplying ET_0 by the crop coefficient (K_c), ET_c is determined:

$$ET_c = K_c \times ET_0 \quad (9)$$

Crop characteristics, Kc

Several approaches are used to calculate Kc, such as the single or dual crop coefficient (Allen et al., 1998). The factors that affect the crop coefficient are:

- Crop type
- Climate
- Soil evaporation

- Crop growth stage

The generalized crop coefficient curve for the single crop coefficient approach is shown in Fig. 38.

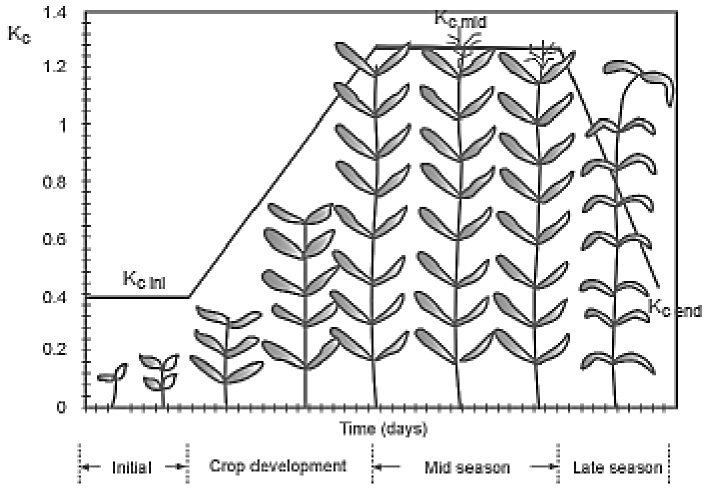


Fig. 38 Generalized crop coefficient curve for the single crop coefficient approach (FAO, 1998)

Landscape characteristics: K_L

(KL) has been substituted for the crop coefficient (Kc): ET = KL x ETo (Allen et al., 1998, Costello et. al., 2000). The landscape coefficient is calculated as:

$$K_L = k_s \times k_d \times k_{mc} \quad (10)$$

where the factor k_s reflects the effect of species, the factor k_d reflects the effect of plants density and the factor k_{mc} reflects the effect of microclimate on evapotranspiration respectively and their value ranges as follows:

- k_s: very low≤ 0.1; low= 0.1 – 0.3; moderate= 0.4 – 0.6 and high= 0.7 – 0.9
- k_d: low=0.5 – 0.9; moderate= 1,0 and high=1.1 – 1.3
- k_{mc}: low=0.5-0.9, moderate=1.0 and high= 1.1 – 1.4

Effective rainfall (ER)

If the rainfall is sufficient to cover the water needs of the crops, irrigation is not required. If there is no rainfall, all the water that the crops need has to be supplied by irrigation. If there is some rainfall, but not enough to cover the water needs of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water needs of the crop. This is often called supplemental irrigation: the irrigation water supplements or add to the rain water.

Not all rain water which falls on the soil surface can indeed be used by the plants. Part of the rain water percolates below the root zone of the plants and part of the rain water flows away over the soil surface as run-off. This deep percolation water and run-off water cannot be used by the plants. In other words, part of the rainfall is not effective. The remaining part is stored in the root zone and can be used by the plants. This remaining part is the so-called effective rainfall. The factors which influence which part is effective and which part is not effective include the climate, the soil texture, the soil structure and the depth of the root zone.

If the rainfall is high, a relatively large part of the water is lost through deep percolation and run-off.

Deep percolation: If the soil is still wet when the next rain occurs, the soil will simply not be able to store more water, and the rain water will thus percolate below the root zone and eventually reach the groundwater. Heavy rainfall may cause the groundwater table to rise temporarily.

Run-off: Especially in sloping areas, heavy rainfall will result in a large percentage of the rainwater being lost by surface run-off.

Another factor which needs to be taken into account when estimating the effective rainfall is the variation of the rainfall over the years. Especially in low rainfall climates, the little rain that falls is often unreliable; one year may be relatively dry and another year may be relatively wet.

In many countries, formulae have been developed locally to determine the effective precipitation. Such formulae take into account factors like rainfall reliability, topography, prevailing soil type etc.

If such data are not available, Table 13 could be used to obtain a rough estimate of the effective rainfall.

Table 13 Rainfall (R) and Effective Rainfall in mm/month (Brouwer et al., 1985)

R (mm/month)	ER (mm/month)	R (mm/month)	ER (mm/month)
0	0	130	79
10	0	140	87
20	2	150	95
30	8	160	103
40	14	170	111
50	20	180	119
60	26	190	127
70	32	200	135
80	39	210	143
90	47	220	151
100	55	230	159
110	63	240	167
120	71	250	175

In FAO's Cropwat, in the case of unavailable data, Effective Rainfall is acquired as the 80% percent of the total rainfall, which is useful in the case of smaller time scales than monthly.

The increase in soil moisture, plus evapotranspiration loss from the time the rain starts until the soil moisture sensors that are placed at the meteorological stations stop reporting increasing values, is the amount of effective rainfall. After heavy rainfall evapotranspiration can be assumed to be at the potential rate during the short period from cessation of rainfall until the sampling time (FAO, 1978). Thus:

$$ER = \Theta_2 - \Theta_1 + ET_0 \quad (11)$$

where ER is the effective rainfall, ET_0 is the evapotranspiration value, Θ_1, Θ_2 are the soil water content values in the root zone before and after rain.

The determination is simple and accurate but it is dependable on soil and crop variations. Since the soil moisture sensors distribution describes the soil variation across the study area, the method is applicable and takes into account the soil and the crop characteristics.

Leaching requirements (LR)

The salinity in the root zone is directly related to the water quality, irrigation methods and practices, soil conditions and rainfall. A high salt content in the root zone is normally controlled by leaching. An excess amount of water is applied during the irrigation, where necessary, for the purposes of leaching.

This excess amount of water for leaching purposes is called the Leaching Requirement (LR) (Allen et al., 1998). To estimate the LR, both the irrigation water salinity (ECw) and the crop tolerance to salinity, which is normally expressed as electrical conductivity of the soil saturation extract (ECe), have to be known. The ECw can be obtained from laboratory analysis, while the ECe should be estimated from the crop tolerance data provided by literature.

When estimating the LR, it is important to consider the leaching efficiency (Le). Le varies with the soil type, internal drainage properties of the soil and the field. The value of Le varies from 30% for heavy clay soils to 100% for sandy soils.

For sandy loam to clay loam soils with good drainage and where rainfall is low, the leaching requirement, for localized irrigation and high frequency (near daily) sprinkler irrigation can be obtained through:

$$LR(\text{fraction}) = \frac{EC_w}{2\,Max\,EC_e} \times \frac{1}{L_e} \quad (12)$$

where LR (fraction) is the fraction of the water to be applied that passes through the entire root zone depth and percolates below, EC_w is the Electrical conductivity of irrigation water (dS/m), EC_e is the Electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (dS/m), Max EC_e is the Maximum tolerable electrical conductivity of the soil saturation extract for a given crop (dS/m) and Le is the Leaching efficiency (in decimals).

Finally, the Leaching Requirement is given by the following expression:

$$LR = \frac{ET_c}{1-LR_{(fraction)}} - ET_c \quad (13)$$

where LR is the Leaching requirement for the period under consideration (mm), ETcis the Crop evapotranspiration or crop water demand for the period under consideration (mm), LR(fraction) is the Leaching requirement fraction.

Irrigation scheduling

In order to prepare an irrigation schedule, the following parameters will be required:

- Cropping program
- Daily water requirements of the different crops (ETc)
- Root zone depth
- Total available soil water (TAW)
- Allowable soil moisture depletion level (MAD)
- On-site rainfall data

The cropping program provides the different crops, their rotation and the time of planting and harvesting, the ET_c of each crop can be derived as previously discussed, the root zone depth of each crop at the different stages of growth can be derived preferably from local information or, in their absence, from literature, the TAW is usually determined through laboratory analysis during the soil surveys. The level of MAD depends on the crop and its stage of growth as well as on the soil type and irrigation system.

Irrigation frequency and duration have to be calculated for each crop of the existing cropping pattern and an robust irrigation schedule has to be put together in order to irrigate all crops at the time and for the duration they require the water.

The rainfall can be taken into consideration at the time the irrigation schedule is applied. By acquiring the rainfall data from the local meteorological stations and by recording the amount of rainfall on a daily basis, this amount can be weighed against part of, or one or more irrigation applications. Therefore, the irrigation cycle is interrupted and a number of days are skipped, depending on the amount of rainfall, the daily water requirements and the moisture to be replenished in the root zone depth of the soil.

Irrigation frequency

Irrigation frequency is defined as the frequency of applying water to a particular crop at a certain stage of growth and is expressed in days. The maximum irrigation frequency (MF), in days, is estimated as:

$$MF = RAW / ET_c \tag{14}$$

where RAW (mm) is the readily available soil water and ET_c is the crop evapotranspiration (mm/day).

However, the number of days between two successive irrigation events depends also on:

- The irrigation strategy and practices that each farmer follows
- Water availability, especially in collective irrigation systems
- The size of the irrigation equipment
- Other farm and crop tasks that need to be carried out at the same time

System characteristics overview

The general concept of IRMA_SYS Arta

The Technological Educational Institute of Epirus (partner LP-TEIEP of IRMA project) will develop from scratch a new web based irrigation advice system. The system will be a product of cooperation between experts in the fields of meteorological data acquisition, agricultural cultivation and landscapes water needs, irrigation management, irrigation controllers manufacturing and software developers.

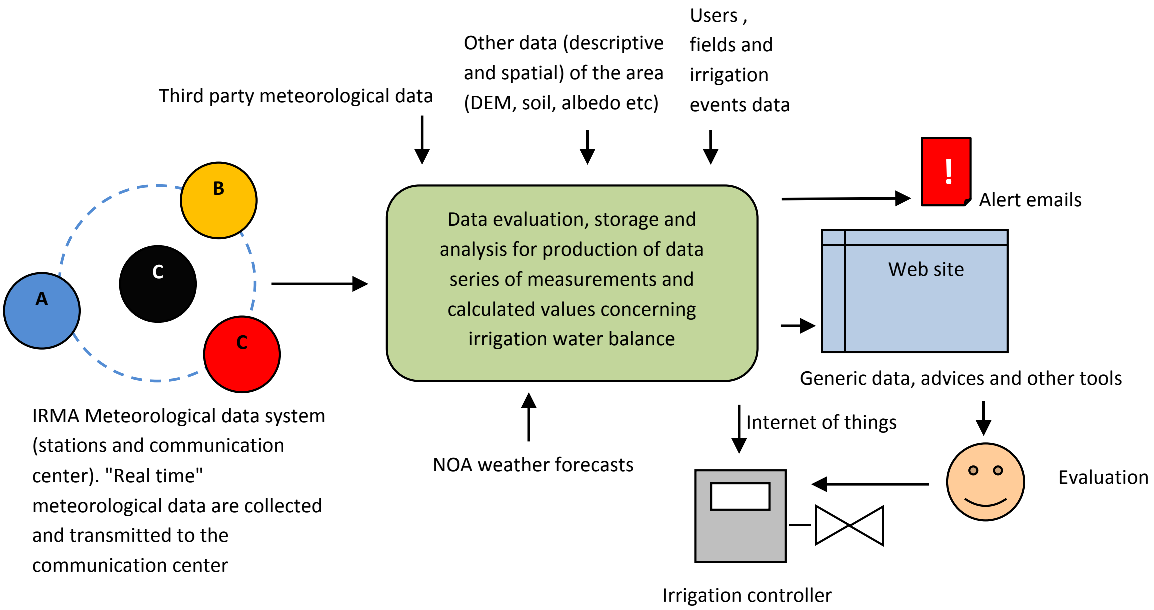


Fig. 39 IRMA system schematics

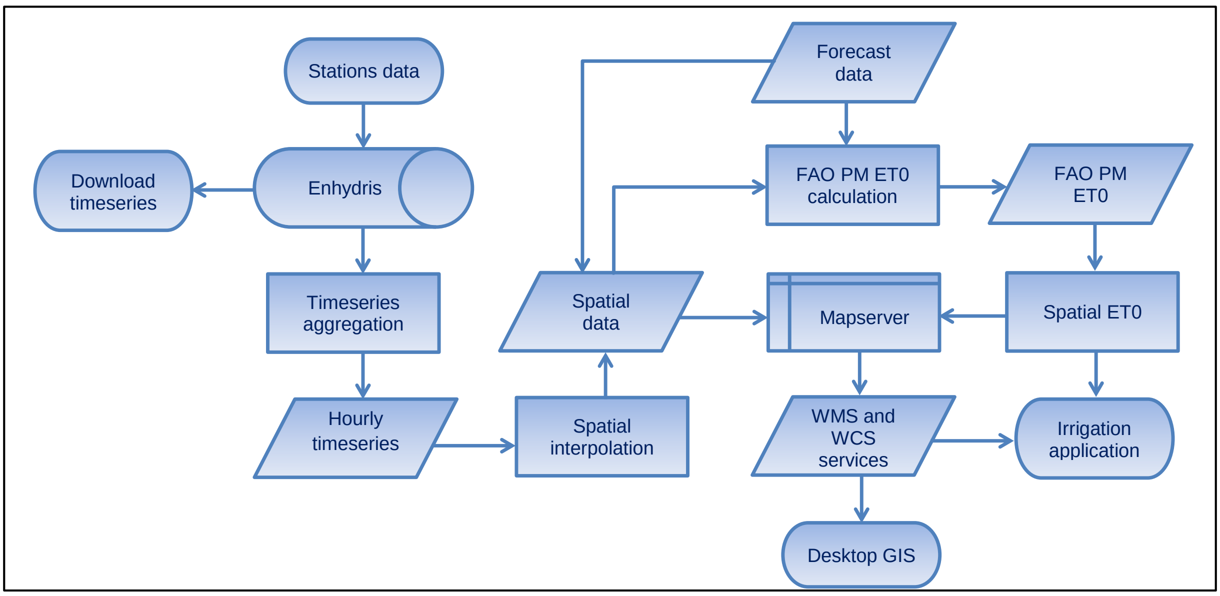


Fig. 40 Flowchart of IRMA_SYS main calculation modules prior to the irrigation application

The system outputs will be available through a relevant website. All data, generated information and tools will be available to system users for free. Agrometeorological data series and crop water requirements estimations will be provided to all visitors, while irrigation advices and a series of other utilities will be available only to registered users. Users that want more precise results will have to install meteorological and/or soil moisture sensors and dataloggers at their fields.

Agriculturalists, green infrastructure managers, farmers and gardeners will be able to use the system for setting up irrigation schedules, plan and record irrigation events as well as self-training regarding irrigation management. Finally, irrigation controllers could also take advantage of the system in order to automatically adjust irrigation events based on an internet of things basis.

System logo

The system logo (Fig. 41) originates from the WiFi logo in blue, with the top circle been substituted by a water droplet. At the bottom, the title is written in green using a font and a style which refers to computer systems.

Fig. 41 The proposed system's logo

System language

The system will be available in both English (working language of the project) and Greek (language of the study area in Greece).

Appropriately designed tables will allow the easy translation of the whole system to other languages (i.e. Italian etc.).

The meteorological stations network

A meteorological station's network of fully equipped weather stations will continuously monitor critical factors that are used for the determination of plants water requirements and the setting-up of irrigation schedules. The network will be consisted by 20 meteorological stations (nodes). 3 (A, B and C) types of stations which will have different configurations will be used. This has been selected in order to evaluate the linkage of a variety of stations to the system in order to be able to receive data from various types of sources. The decision to develop a system which will be compatible to various types of meteorological stations lies in the concept to be open to any public or private entity that wants to be linked to it by providing data. Authorization will be needed before connection of a new station to the network. Information regarding the technical requirements and the connection procedure will be available at the system web site).

The network's nodes will be properly distributed at the plain of Arta in order to cover microclimate at hydrological basin scale. The central data collection point will be installed at TEIEP Kostakii Campus, at the centre of Arta plain (Fig. 42). The backbone of the system will be consisted by 6 wireless (UHF) stations equipped by high quality and accuracy sensors (Fig. 43). 9 type B and 5 type C stations will complete the network. All the stations will be compatible with FAO's (Allen et. al., 1998) and WMO's (WMO, 2010) specifications for agro meteorological stations. The stations will be equipped by the following sensors:

- Type A (core of the system): Tair, RHair, Solar radiation, Wind speed and direction, Rain, Soil moisture in 3 depths. Also on of them will have a day length sensor.
- Type B: Tair, RHair, Wind speed and direction, Rain
- Type C: Tair and RHair

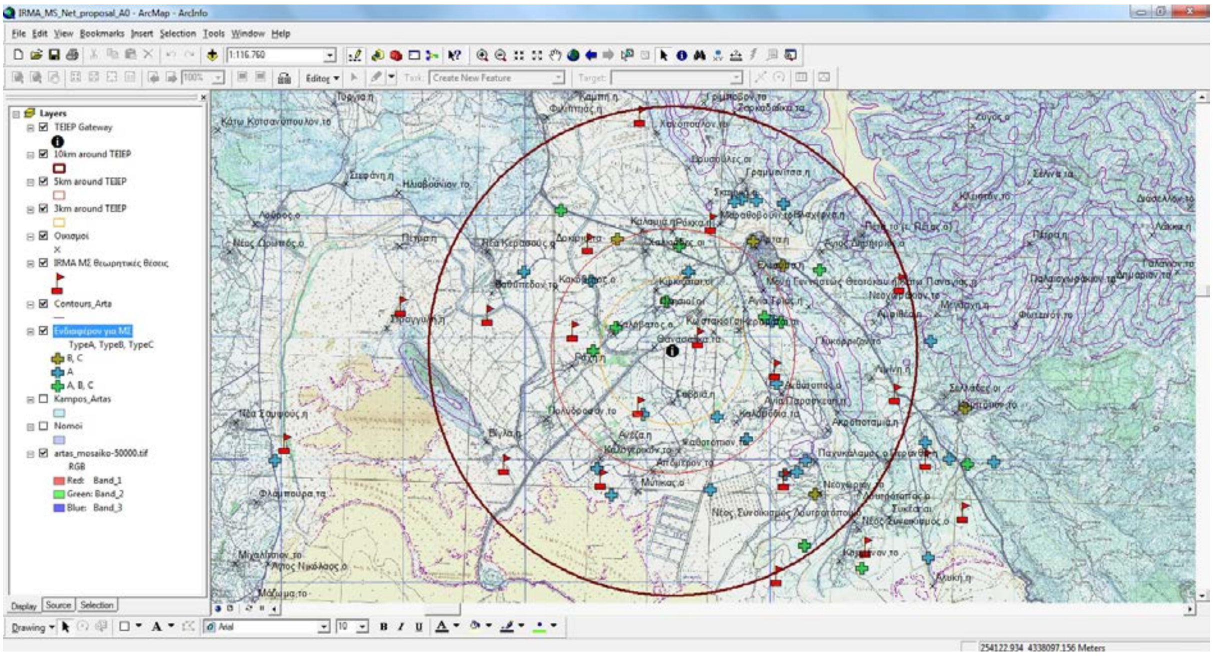


Fig. 42 Initial placement proposal (2012) and registered interest for hosting meteorological stations (2014)

The use of a dense network of stations will provide better accuracy regarding the microclimatic effects. Data from meteorological stations surrounding the study area (plain of Arta) will be used as boundary values (these stations are part of National Observatory of Athens -NOA/meteo.gr system).

An initial theoretical layout of the stations has been developed in the preparation phase of IRMA project (Malamos and Tsirogiannis, 2012). The final placement and sitting will be based on this plan but refinements (i.e. because of equipment safety reasons) are expected to occur (Fig. 42).

The Decentralised Administration of Epirus and Western Macedonia (partner P6-ROEDM of IRMA project) is responsible for the purchase and placement of the meteorological stations. TEIEP (LP) will also participate in the sitting process.

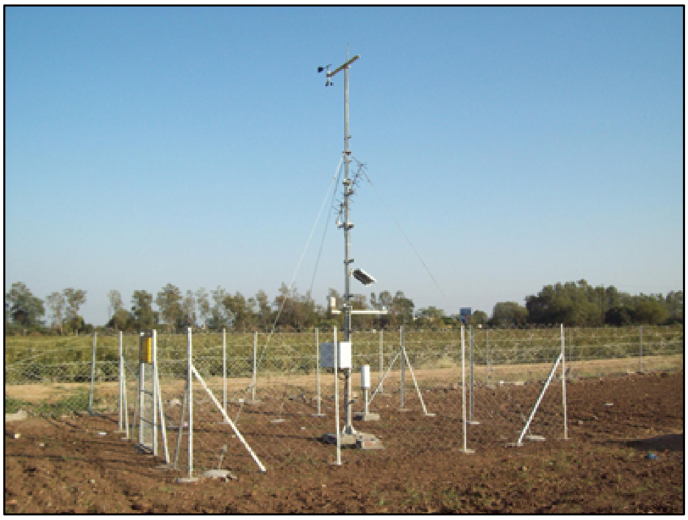


Fig. 43 A typical open field agrometeorological station

All the data from the meteorological stations will be available at openmeteo (http://openmeteo.org/) under Database Contents License v.1.0 for individual measurements and Open Database License v.1.0 for the data series as they are published at Open Data Commons (http://opendatacommons.org/).

Static information (spatial and descriptive data)

As presented in Fig. 40, meteorological data information will be uploaded in the ENHYDRIS database, where aggregation to hourly and daily time scales will take place. The map presentation of the different variables, in daily time scale, that are involved in the irrigation requirements methodology presented above, such as: Rainfall, Potential Evapotranspiration, Humidity, Temperature, Wind speed and Solar Radiation, with high spatial resolution of 70×70 m grid.

The maps will be produced by implementing the Inverse Distance Weighting method for spatial interpolation, found in the GDAL library - Geospatial Data Abstraction Library (http://www.gdal.org/).

The system will provide this information of the study area, through the WMS/WCS services of the Mapserver (http://mapserver.org/).

All databases will be accessible by the system administrator, using the backend CMS.

Registered users should be able to add their fields into the system using a map, in order to pinpoint the geographic location of each field, with the help of the Hellenic Cadaster orthophoto imagery basemap (http://gis.ktimanet.gr/wms/ktbasemap) that allows zoom in scales up to 1 m or OPEN Cycle Map (http://www.opencyclemap.org/). The user should provide information regarding the field's area, crop, irrigation type and strategy. Also, a list of the user's already register fields should be available at the bottom of the page.

Soil information

In the context of the New Land project (TEIEP, 2010), about 200 soil samples (0-30cm, Fig. 10 c) of all around the plain were analyzed. The sampling sites positions were obtained with the use of Satellite

Positioning System (GPS, accuracy of ±5 meters), using WASS and the European System EGNOS. Information regarding the field capacity, the permanent witling point and the soil moisture at saturation throughout the study area were estimated by GIS techniques from point measurements of soil texture.

Crops library

Crop information included in FAO 56 (FAO, 1998) will be incorporated in IRMA_SYS. Such information is:

- Crop coefficient, K_c
- Maximum Allowable Depletion (MAD)
- Estimated root depth

The user will have the right to alter the default /generic values for each cultivation.

Albedo

Since water stress and the degree of ground cover have an effect on the albedo, in the context of IRMA the acquired satellite images provide the opportunity to estimate the spatial and temporal variation of albedo thus making possible more accurate estimation of the reference evapotranspiration.

The albedo (α) can be calculated in different ways (from empirical to physical based approaches). The standard approach is based on empirical broadband coefficients, which are applied to the spectral radiance measured by each channel of the satellite sensor (D'Urso & Belmonte, 2006). Hereby three main problems arise: the directional integration of the spectral radiance detected by the sensor, the spectral integration for obtaining the planetary albedo (albedo of the top of atmosphere (TOA) and the correction of atmospheric effects to achieve the surface albedo (for more details see D'Urso & Belmonte, 2006). So, in IRMA project, the calculation of α has been simplified in the following way:

$$\alpha=\Sigma_{\lambda} w_{\lambda}\cdot\rho_{\lambda},\ \lambda=1, 2, \ldots, n \qquad (2)$$

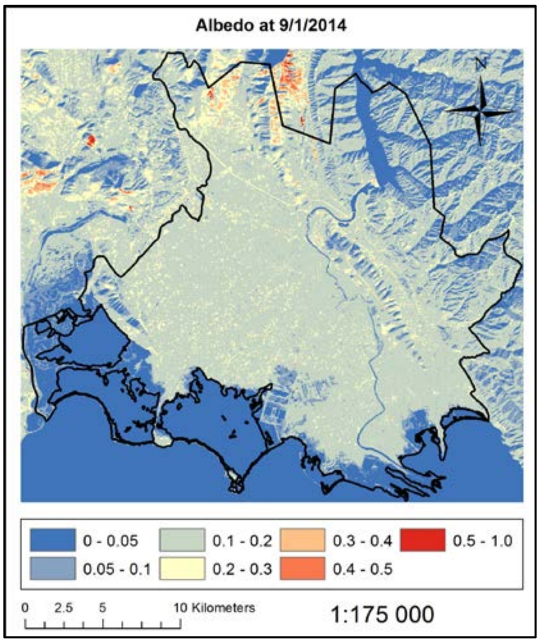
where ρ_{λ} presents spectral reflectance (corrected for atmospheric effects) in the corresponding band (D'Urso & Belmonte, 2006; Menenti et al., 1989).

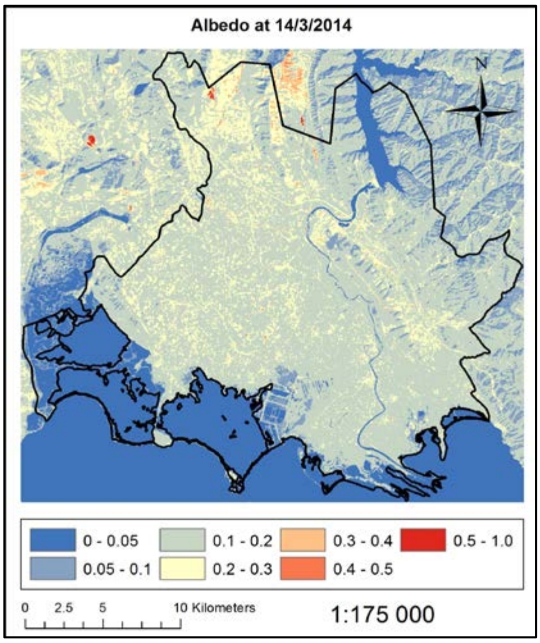
Another way is to derive the ground albedo, the ground reflectance integrated over the wavelength region 0.3 – 2.5 μm. as value adding product from ATCOR (Add-On Module to Intergraph's IMAGINE). The values of albedo derived from ATCOR are free from atmospheric effects and closer to those shown in Table 14.

In Fig. 44 the albedo maps of the study area at different dates are presented, allowing the system to implement a time and space varying albedo in the calculation of potential evapotranspiration. Concerning the time variation, there is a clear season variation (from winter to summer), depending on the prevailing conditions while the spatial variation depends on the dominant cultivations and the terrain morphology. The map dates were selected according to the availability of high quality satellite images of the study area, in terms of cloud coverage.

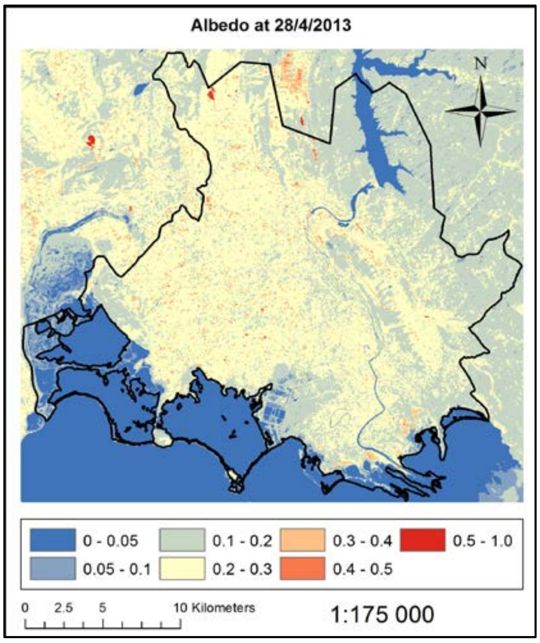
Table 14 Sample albedos

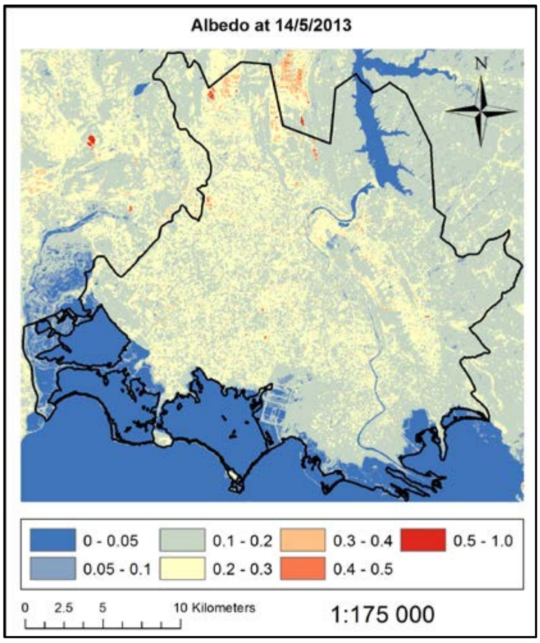
Surface	Features	Typical albedo
soil	dark and damp	0.05
	clear and dry	0.4
sand		0.15-0.45
lawn		0.16-0.26
agricultural crops		0.18-0.25
forest	decidua	0.15-0.20
	conifers	0.05-0.15
water	Low zenith angle	0.03-0.1
	high Zenith angle	0.10-1.0
snow	old	0.4
	fresh	0.95
Cloud	dense	0.3-0.5
	thin	0.30-0.50





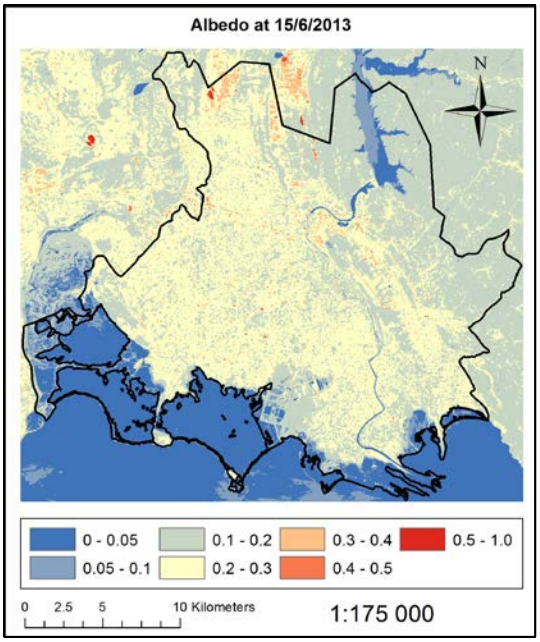
(1) (2)





(3) (4)

Fig. 44 Albedo maps (1-10) used for the estimation of evaporation in the study area



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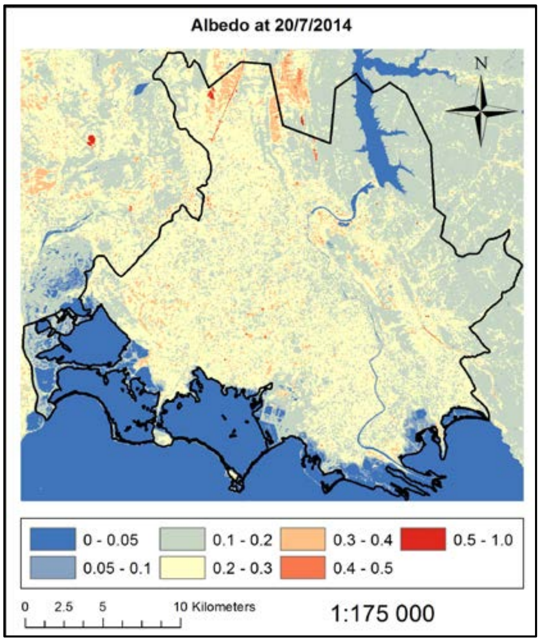

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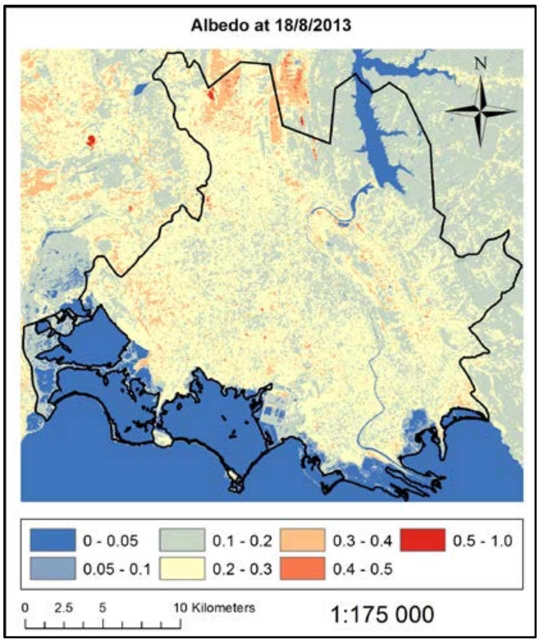

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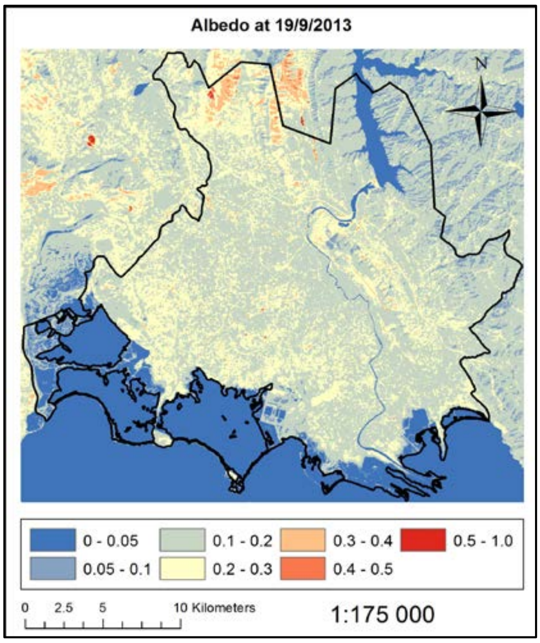
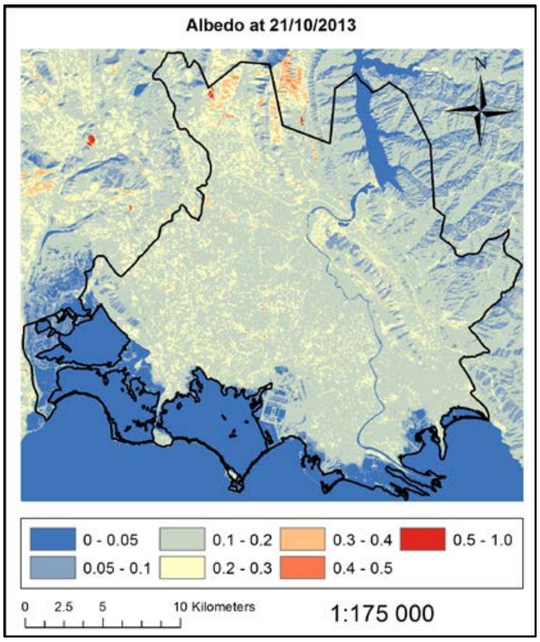
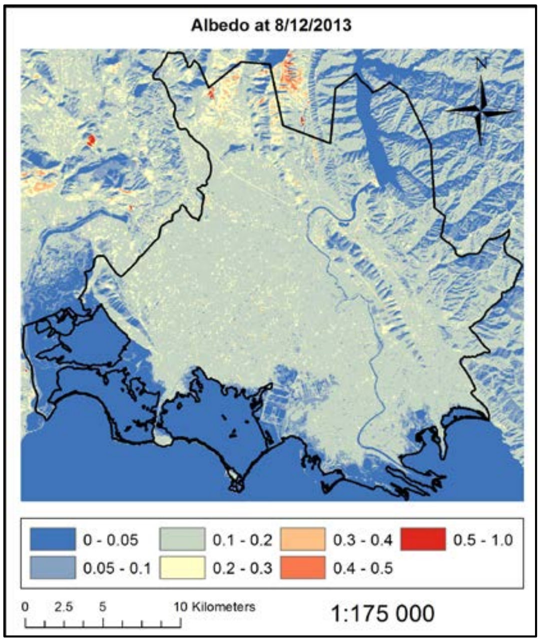


(8)

Fig. 44 Albedo maps (1-10) used for the estimation of evaporation in the study area (continued)



(9)



(10)

Fig. 44 Albedo maps (1-10) used for the estimation of evaporation in the study area (continued)

Weather forecast information

Description of BOLAM model setup

In the frame of the project the most recent version of BOLAM model, which is based on previous versions of the model described by Buzzi et al. (1994; 1997; 1998) and Buzzi and Foschini (2000). The main features of the model are summarized below:

- hydrostatic primitive equations;
- dependent variables: surface pressure, u, v, potential temperature, specific humidity, and five microphysical variables;
- Arakawa C grid (rotated lat.-lon. coordinates); σ vertical coordinate;
- forward-backward (FB) 3-D Eulerian advection scheme (Malguzzi and Tartaglione, 1999) and semi-Lagrangian advection of hydrometeors;
- split-explicit time scheme (FB for gravity modes);
- 4th order horizontal diffusion and 2nd order divergence diffusion;
- Davies-Källberg-Lehmann (Lehmann, 1992) relaxation scheme for lateral boundary conditions.

Physical parameterizations include:

- dry adiabatic adjustment;
- radiation: infrared and solar, interacting with clouds (Ritter and Geleyn, 1992);
- vertical diffusion (surface layer and planetary boundary layer parameterization) depending on Richardson number (Louis, 1979; Louis et al., 1982);
- surface thermal and water balance (3 soil layers);
- explicit microphysical scheme with two water and three ice species;
- convective parameterization scheme proposed by Kain and Fritsch (1990, 1993), with implementation (see Buzzi and Foschini, 2000) of the modifications suggested by Spencer and Stensrud (1998), as it concerns the delay of downdrafts in newly developed convection.

Specifically, model forecasts regard to precipitation; the microphysical scheme was coded mainly on the basis of the transformation process models described in Schultz (1995). This is a simple and computationally efficient approach to represent cloud processes in an operational model. The scheme includes five hydrometeor categories: cloud ice, cloud water, rain, snow, and graupel. In his paper, Schultz compares the results of his scheme against both the results of a well-documented research microphysics algorithm and observations. He found that both schemes provided similar and generally skilful precipitation forecasts, with the advantage that his scheme is about 7-10 times faster than the research oriented algorithm.

The sub-grid scale precipitation is treated in BOLAM following the Kain-Fritsch convective parameterization scheme (Kain and Fritsch, 1993). The Kain-Fritsch scheme is based on the Fritsch-Chappell scheme with improvements on the detrainment effect and the cloud model. It has been developed for mesoscale models with a grid size of a few tens of kilometers. In this scheme convection is triggered by lifting a lower-level slab layer with an impetus heating as a function of grid-scale vertical motion at the lifting condensation level. The Kain-Fritsch scheme, has shown considerable success in simulating the development and evolution of convection under a variety of convective and synoptic environments (Kuo et al., 1996; Wang and Seaman, 1997; Ferretti et al., 2000). Additionally, the Kain-Fritsch scheme has shown the most consistent behavior among a number of convective parameterization schemes implemented in MM5 model for the simulation of cold period precipitation cases over Greece (Kotroni and Lagouvardos, 2001).

BOLAM has the capability to perform one-way nested simulations, using two nested grid domains:

- the coarse grid consists of 135x110 points with a 0.21 deg horizontal grid interval (~23 km) centered at 41°N latitude and 15°E longitude, covering the area of the Eastern Mediterranean (Fig. 45a). This configuration was valid for the second year of operational use, while during the first year the coarse grid covered about half of this domain (90x84 grid points).
- - the fine grid consists of 160x148 points with 0.06 deg horizontal grid increment (~6 km) (~6.5 km), centered at 38°N latitude and 24°E longitude (approximately the position of Athens). The fine grid covers the Greek peninsula with its maritime areas expanding from the Ionian Sea in the west up to the Turkish coasts in the east (Fig. 45b).

For the project needs, the study area is enclosed with a red rectangle in Fig. 45b. Data for this area are provided in the project's database with a time interval of 3 hours.

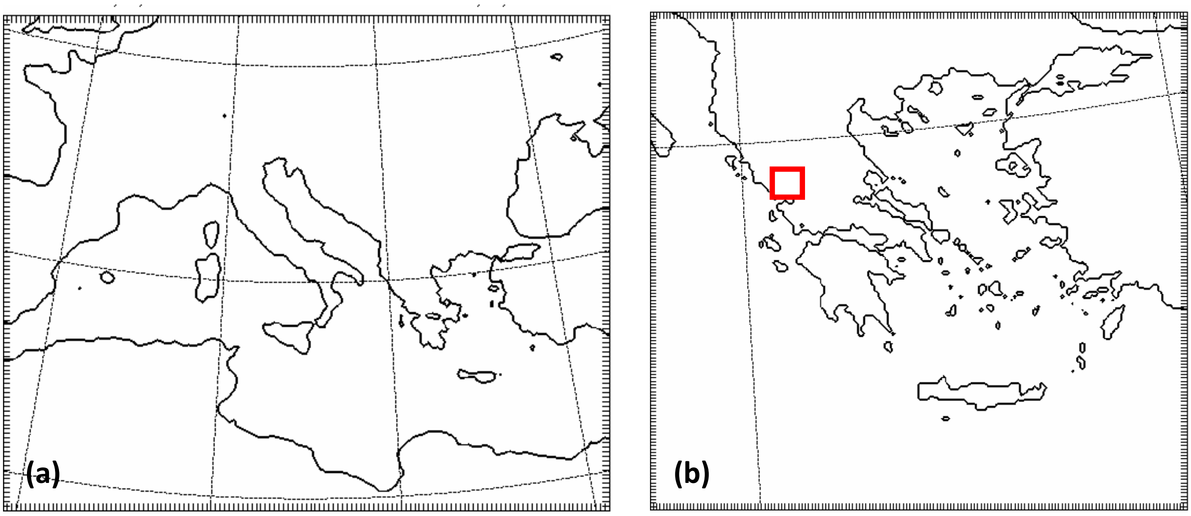


Fig. 45 Horizontal extension of (a) the coarse grid and (b) the fine grid of BOLAM model. The red square denotes the study area

In the vertical, 30 levels are used in the coarse grid and 36 levels in the fine grid, while model top has been set at about 10 hPa on both nests. The vertical resolution is higher in the boundary layer and, to a lesser extent, at the average tropopause level.

The Medium-Range Forecast (GFS, provided by the National Centers for Environmental Predictions-NCEP, USA) gridded analysis fields and 6 h interval forecasts, at 0.5 degree lat/lon horizontal grid increment, are used to initialize the model and to nudge the boundaries of the coarse grid during the simulation period. The orography fields are derived from a 30 arcsec resolution terrain data file provided by USGS.

Model verification

In order to evaluate the model skill in providing accurate precipitation forecasts during the studied period, a verification procedure has been undertaken for the studied area, against rain observations at Arta station. For the verification, the closest to Arta station model grid point was selected. From the observed and forecast values a contingency table is built as shown in the following:

Table 15 Example of 2x2 contingency table

2x2 Contingency Table		**Event Observed**	
		Yes	No
Event Forecast	Yes	*A*	*B*
	No	*C*	*D*

where A is the number of events for which the model-forecast precipitation and the observed precipitation equaled or exceed a threshold (hits), B is the number of events for which only the model-forecast precipitation equaled or exceed a threshold (false alarm), C is the number of the events for which only the observed precipitation equaled or exceed a threshold (misses) and D is the number of the events for which neither the model-forecast precipitation nor the observed precipitation equaled or exceed a threshold (correct negatives). The following measures are calculated:

Bias, $\mathrm{B} = \frac{A+B}{A+C}$ (15)

Probability Of Detection, $POD = \frac{A}{A+C}$ (16)

False Alarm Ratio, $FAR = \frac{B}{A+B}$ (17)

Critical Success Index, $CSI = \frac{A}{A+B+C}$ (18)

In the framework of this study, the aforementioned statistical scores are calculated for 24-h observed rain exceeding 1 mm. The verification is made for the period from 1 September 2014 up to 30 April 2015 (8 months).

The bias measures the ratio of the frequency of forecast events to the frequency of observed events and indicates whether the model has a tendency to under predict (B<1) or over predict (B>1) events. Table 16 shows the bias score. The bias is very close to 1 (1.06) indicating no overestimation or underestimation of rain events.

As far as the ability of the model to correctly forecast the observed precipitation events is concerned, probability of detection (POD) has been calculated and it is also shown in Table 16. POD shows a value of 0.77 for 24-h accumulated rain exceeding 1 mm. Concerning the false alarm ratio (FAR) shown in the same table, it is 0.27, indicating that the model has low tendency to provide false alarms. Finally, the critical success index (CSI) is examined, a score that measures the fraction of observed and/or forecast events that were correctly predicted. CSI can be thought of as the accuracy when correct negatives have been removed from consideration and is sensitive to hits, penalizes both misses and false alarms and the unity is the perfect score, while 0 is the lowest possible value. The CSI score shown in Table 16 is very close to 0.6.

Table 16 Results for the calculated statistical scores for 24-h accumulated rainfall exceeding 1 mm.

	24-h rain exceeding 1 mm
Bias	1.06
POD	0.77
FAR	0.27
CSI	0.60

Finally, Fig. 46 shows the time evolution of 24-h rainfall (osberved values in blue line and forecast values in red line), permitting to follow the day-by-day evolution of forecast values against observations, for the totality of the 242 days of the 8-month verification period.

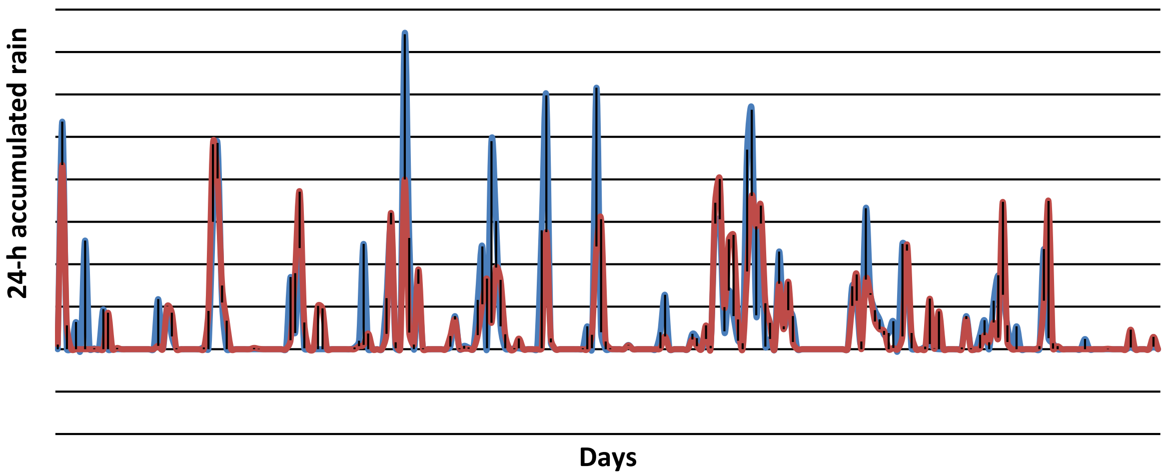


Fig. 46 Time evolution of 24-h rainfall (osberved values in blue line and forecast values in red line) for the totality of the 242 days of the 8-month verification period.

Spatial regression

For the needs of this WP, an exchange of ideas was performed on the methods of spatial regression of station data, such as kriging, or inverse distance weighting factor. NOA, for these purposes uses, for several years, the Cressmann method, through the application of the graphical package GRADS.

Arta’s plain meteorological station network

The National Observatory of Athens in collaboration with the TEI of Arta, will study the plain of Arta and the site positions will cover the study area. The site selection will take place according to main criteria for obtaining accurate meteorological data. Firstly, the sites should be relatively exposed and away from obstructions such as buildings and trees, over earth surface or short grass. The temperature and humidity sensors as well as the rain gauge will be mounted at 2 meters and the anemometer at 3 meters above ground. Furthermore, the solar as well as ultraviolet sensors will be mounted approximately at 2 meters above ground away from shadows.

The second criterion is to make the 10-min meteorological observations available, in a real-time environment to a wide variety of internet users and primarily the data transmission using communications systems to relay data back to the center server of National Observatory of Athens. For this reason, private or public sectors will host meteorological stations ensuring the stable internet connections as well as they are relatively secured.

The wireless Davis Vantage PRO2 automatic meteorological stations will be used. Davis Company provides low cost category meteorological station that can supply accurate and reliable data (Burt, 2009). A meteorological station consists of: a three-cup anemometer and wind vane, temperature and humidity sensors placed into a fan aspirated shield, rain gauge, solar and ultraviolet sensors. Moreover, the pressure sensor is integral to the station display unit.

Additional meteorological stations

The National Observatory of Athens (NOA) automatic meteorological stations network consists of 300 meteorological stations covering the major part of Greece. At the study area two meteorological stations of NOA network have been already sited at Vlacherna (Arta) and Kompoti region since 2006, and 2008, respectively (Table 17). Moreover, solar radiation data for both stations is available providing similar meteorological data with the rest stations over the plain of Arta. For the project needs, the data from these stations will be used in order to cover larger area over the plain. The locations of the eleven meteorological stations are presented in Fig. 47.

Table 17 Position and geographical information of NOA stations at the plain of Arta

Station	Latitude (degrees)	Longitude (degrees)	Elevation (m)
Vlacherna (Arta)	39.1725	20.999167	50
Kompoti	39.166667	21.133333	75

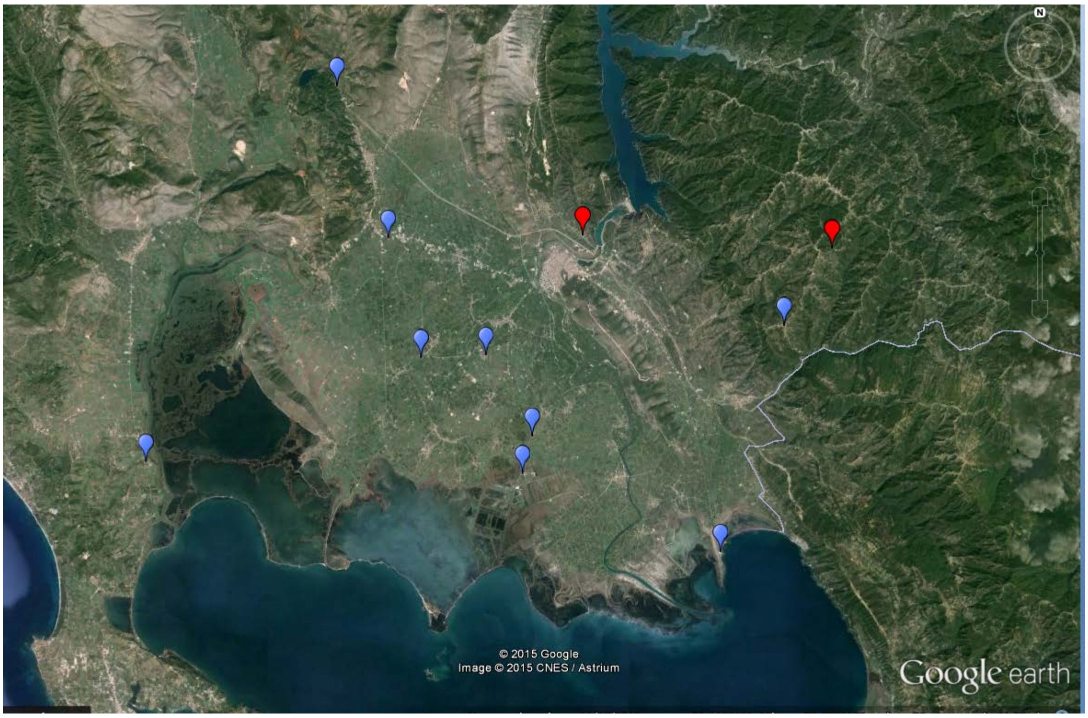


Fig. 47 Location of the eleven meteorological stations at the plain of Arta. Blue balloons represent the location of the meteorological stations which are placed in the frame of IRMA project, and red balloons the NOA stations.

Adaptation of data provided by the automatic stations

The National Observatory of Athens (NOA) will provide data from its stations to IRMA at 10-min intervals. All the necessary procedures are set up in order the data to be ingested automatically to the IRMA interface.

Forecast data

The National Observatory of Athens (NOA) will provide daily forecast data for 3 days for the area around Arta. Fig. 48 presents the 9x7 grid (63 points in total) for which all basic meteorological parameters (including rain forecast) are provided at 3-h steps. The corresponding file will be given in the following URL:
http://www.meteo.gr/customs/IRMA.txt

The forecasts are provided by Grid 2 of BOLAM model, described in detail in Section 1 of this document. The procedure is fully automated and the file is ingested automatically to the IRMA interface.

The provision of data will continue for 5 years, according to the signed contract.

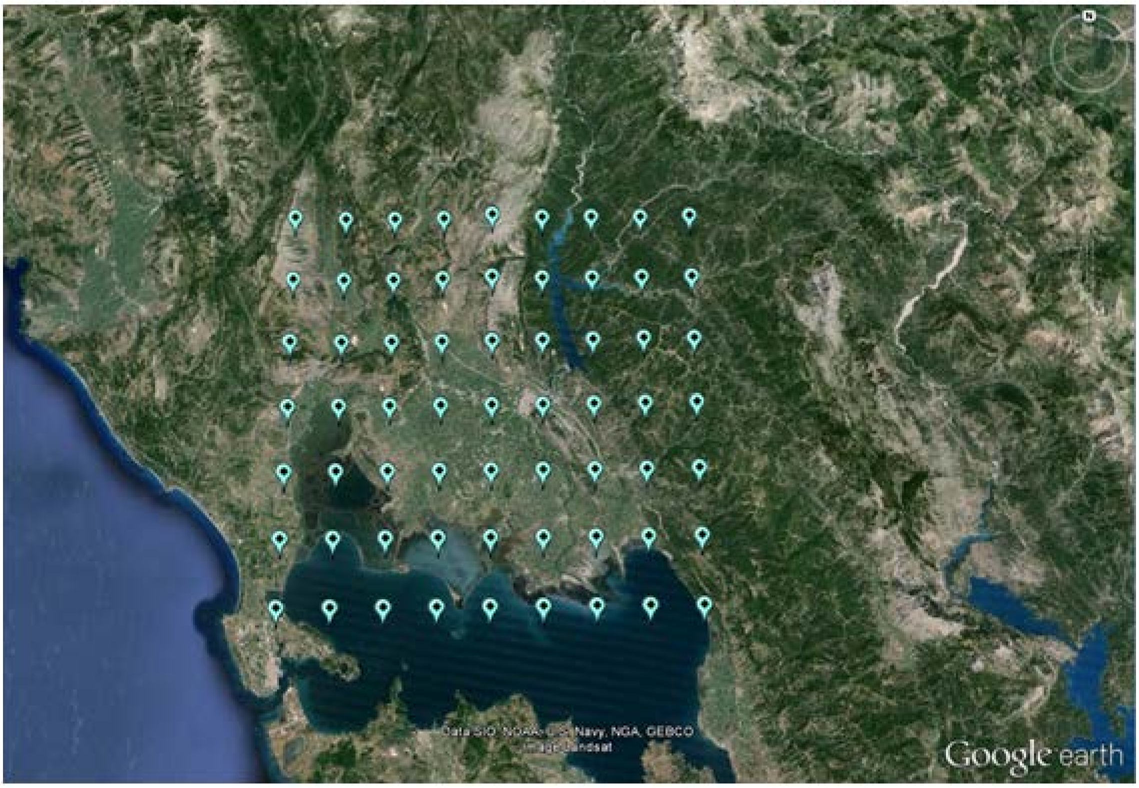


Fig. 48 Forecast 9x7 grid provided daily by BOLAM model.

Estimation of irrigation needs

The irrigation needs will be estimated based on an approach that is called root zone soil water depletion, which is a simplified soil water balance based on an initial soil moisture condition and runs for a specified time period.

The basis for the calculations is the following formula (Allen et al., 1998):

$$D_{r,i} = D_{r,i-1} - (P_i - RO_i) - IR_{n,i} - CR_i + ET_{c,i} + DP_i \quad (19)$$

where i is the current time period (i.e. the current day, or hour), $D_{r,i}$ is the root zone depletion at the end of the previous time period (mm), P_i is the precipitation (mm), RO_i is the runoff (mm), $IR_{n,i}$ is the net irrigation depth (mm), CR_i is the capillary rise (mm), $ET_{c,i}$ is the crop evapotranspiration (mm) and DP_i is the water loss through deep percolation (mm).

The following limits were imposed on $D_{r,i}$:

$$\Theta_s <= D_{r,i} <= TAW \quad (20)$$

where Θ_s is the soil moisture at saturation (mm) and TAW is the total available soil water (mm), which is the difference between Field Capacity (FC) and Permanent Wilting Point (PWP)), i.e.:

$$TAW = FC - PWP \quad (21)$$

This approach is different than the one proposed by Allen et al., 1998 since according to them $D_{r,i}$ is always positive.

RO_i equals the amount of water that exceeds soil moisture at saturation after heavy rain, i.e.:

$$RO_i = P_i + \Theta_{i-1} - \Theta_s \text{ when } (P_i + \Theta_{i-1} - \Theta_s) > 0 \quad (22)$$

where Θ_{i-1} is the soil moisture at the previous time step. CR_i and DP_i are considered equal, since in the case of the Arta plain there is a shallow water table and equilibrium between them is considered.

So equation 19 becomes:

$$D_{r,i} = D_{r,i-1} - P_i - IR_{n,i} + ET_{c,i} + RO_i \quad (23)$$

$ET_{c,i}$ is calculated using crop coefficient approach by multiplying reference evapotranspiration with the appropriate crop coefficient Kc (Allen et al., 1998).

Each time the user irrigates, the initial depletion derives from the provided irrigation water volume. An essential simplifying assumption of this method is that each time we irrigate without providing the irrigation water volume, we assume that enough water was applied in order for the soil moisture to reach FC, i.e. zero depletion. Therefore, in this case we have $D_{r,1}$=0, for i=1.

Soil moisture (Θ_i) and depletion are related with this formula:

$$\Theta_i = \Theta_0 - D_{r,i} + IR_{n,i} \quad (24)$$

where Θ_0 is the initial soil moisture. Since the initial soil moisture is provided, $D_{r,1}$ is also known.

$D_{r,i}$ given, irrigation is triggered when the following condition is met:

$$D_{r,i} \geq RAW,\ RAW = MAD \times TAW \quad (25)$$

where RAW is the readily available soil water calculated from TAW:

$$RAW = MAD \times TAW \quad (26)$$

depending on the maximum allowed depletion (MAD).

In this case, the net irrigation depth ($IR_{n,i}$) is set equal to the corresponding root zone depletion from the previous time step, therefore:

$$IR_{n,i} = D_{r,i-1} \quad (27)$$

So for the next time step the root zone depletion is calculated as:

$$D_{r,i} = P_i + ET_{c,i} + RO_i \quad (28)$$

The system will take into account historical (from the system's stations), forecasts of the necessary agrometeorological data along with soil water information, in order to estimate the above mentioned soil water balance variables throughout the study area.

Irrigation optimizer

Irrigation frequency is an essential parameter for irrigation systems design and is defined as the frequency of applying water to a particular crop at a certain stage of growth and is expressed in days. The maximum irrigation frequency (MF), in days, is estimated as:

$$MF = RAW / ET_c \quad (29)$$

where RAW (mm) is the readily available soil water and ET_c is the crop evapotranspiration (mm/day).

However, the number of days between two successive irrigation events depends also on:

a. The irrigation strategy and practices that each farmer follows
b. Water availability, especially in collective irrigation systems
c. The size of the irrigation equipment
d. Other farm and crop tasks that need to be carried out at the same time

Based on the above, the actual irrigation frequency is always less or equal than the maximum irrigation frequency and is hereby defined as the practical irrigation frequency (PF).

In this context, we introduce a factor named: "Irrigation Optimizer - IRT" defined as the ratio of practical to maximum irrigation frequency:

$$IRT = PF / MF, \text{ with } 0.1 \leq IRT \leq 1 \quad (30)$$

So, Eq. 27 now becomes:

$$IR_{n,i} = IRT \times D_{r,i-1} \quad (31)$$

IRT's default value is set to 0.5, indicating that the next irrigation event should take place at the 50% of the maximum irrigation frequency and with the half of the calculated $IR_{n,i}$.
By implementing IRT, the user will be able to experiment with several alternative solutions in order to conclude to the best irrigation strategy, depending on the given conditions.

As a rule of thumb, small values of IRT result in frequent irrigations with smaller water amounts, while IRT values close to 1 result in infrequent irrigations with larger water amounts, close to RAW.

Initial conditions

Since the initial soil moisture is included in the initial conditions of the soil water balance module, registered users should add the irrigations that they have applied for each field. IRMA_SYS will provide detailed irrigation advices estimates, in hourly basis, based on both historical and forecast data from the last irrigation event and forth.

IRMA_SYS will take into account three different sets of initial conditions, depending on provided information for the last irrigation event. For time steps greater than zero, i.e. $i > 0$, root zone depletion and soil moisture are calculated from Eqs. 23 and 24, respectively.

The user does not provide any information considering irrigation

If the registered user does not provide any information considering irrigation, the IRMA_SYS will use the following initial condition, where $D_{r,0}$ is the root zone depletion one day before the last available historical data:

$$D_{r,0} = FC - \Theta_0 \quad (32)$$

with

$$\Theta_0 = FC - IRT \times RAW \text{ from the 1}^{st} \text{ of April until the 30}^{th} \text{ of September} \quad (33)$$

or

$$\Theta_0 = FC \text{ from the 1}^{st} \text{ of October until the 31}^{th} \text{ of March} \quad (34)$$

where Θ_0 is the initial volumetric soil water content (mm).

The user does provides only the last irrigation date

If the registered user provides only the last irrigation date and time, but he does not provide information about the applied irrigation water volume, the system will assume that at the specified time, the applied water was enough for the soil to reach field capacity, i.e.:

$$D_{r,0} = 0 \quad (35)$$

In this case, the calculated water amount needed for the soil to reach field capacity will be presented in the "Irrigation Report" page in m^3.

The user provides the last irrigation date and the applied irrigation water

Since the registered user will provide the last irrigation date and time together with the corresponding applied irrigation water in m^3, the system will calculate $IR_{n,1}$ (mm) based on the irrigation system efficiency and the field area. Then the initial root zone depletion, at the specified time, is calculated as:

$$D_{r,0} = FC - \Theta_0 \quad (36)$$

with

$$\Theta_0 = FC - IRT \times RAW \text{ from the 1}^{st} \text{ of April until the 30}^{th} \text{ of September} \quad (37)$$

or

$$\Theta_0 = FC \text{ from the 1}^{st} \text{ of October until the 31}^{th} \text{ of March} \quad (38)$$

where Θ_0 is the initial volumetric soil water content (mm).

Potential and Crop Evapotranspiration

Potential Evapotranspiration (ET_0 or PET) is estimated by implementing the FAO model (Allen et al., 1998) of the Penman-Monteith equation, in daily and hourly time steps.

The system will take into account daily aggregated historical data (from the system's stations) and three hour forecasts, which are disaggregated to hourly values, of the necessary agrometeorological data to estimate potential evapotranspiration at the stations locations and then, through spatial interpolation, produces the corresponding ET_0 maps of the study area.

The effects of characteristics that distinguish the cropped surface from the reference surface are integrated into the crop coefficient. By multiplying ET_0 by the crop coefficient (K_c), ET_c is determined:

$$ET_c = K_c \times ET_0 \tag{39}$$

IRMA_SYS will incorporate crop coefficients for various crops adopted from literature but if appropriate information is available to the registered users, they are able to modify the K_c values, based on this information.

Water stress coefficient (K_S)

The effects of soil water stress on crop ET are described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient, Ks (Allen et al., 1998) that describes the effect of water stress on crop transpiration. Where the single crop coefficient is used, the effect of water stress is incorporated into K_c as:

$$ET_{c\ adj} = K_S \times K_c \times ET_0 \tag{40}$$

where

$$Ks = (TAW - D_r)/(TAW - RAW) \tag{41}$$

For soil water limiting conditions, $Ks < 1$, while in the absence of soil water stress $Ks = 1$.

Irrigation efficiency

To express which percentage of irrigation water is used efficiently and which percentage is lost, the term: "irrigation efficiency" is used.

The water amount applied by the irrigation system and not being made available to be taken up by plant roots is wasted and reduces irrigation efficiency. The major causes for reduced irrigation efficiency are drainage of excess irrigation water to soil layers deeper than the depth of active roots and evaporation losses.

Registered users will be able to provide custom information about irrigation efficiency to the system.

The following table presents the efficiencies of the different irrigation systems incorporated in the IRMA_SYS.

Table 18 Irrigation systems incorporated in the IRMA_SYS and their efficiencies

Irrigation system	Irrigation efficiency
Surface irrigation	60%
Sprinkler irrigation	75%
Micro sprinklers	80%
Drip irrigation	90%
Subsurface drip irrigation	95%

Irrigated Field Area (m^2)

In IRMA_SYS when a user will record an irrigation event with the corresponding volume of water in m^3, the system will calculate the mm of irrigation water by dividing the volume (m^3) with the irrigated area (m^2).

In this context, the IRMA_SYS term: "Irrigated Field Area (m^2)" will represent the actual wetted area that the irrigation water is distributed.

So when the irrigation system distributes water locally, not covering the total field area, which is the case for microirrigation or drip systems, it is of great importance that the users register in IRMA_SYS the actual wetted area and not the total field area.

Depending on the irrigation system layout, the wetted area may vary from 5% to 100% of the total field area.

Irrigated Field Area is always a fraction of total field area, and it can be estimated by multiplying the field area with factors like:

1. Percentage of wetted area - P_w (%)
2. Microirrigation ET reduction factor (r), that refers to the percentage of soil surface that is shaded by plants during midday/0.85, having 1 as maximum value

Following the guidelines of FAO for localized and sprinkler systems design:

1. Irrigation Manual - Localized irrigation systems: planning, design, operation and maintenance, Volume IV
2. Irrigation Manual - Sprinkler irrigation systems: planning, design, operation and maintenance, Volume 3

the user will be able to estimate the actual wetted area.

IRMA_SYS web site

IRMA_SYS will be located at: http://arta.irrigation-management.eu/.

The main feature of the landing page will be the map presentation of the different variables, in daily time scale, that are involved in the irrigation requirements methodology presented above, such as: Rainfall, Potential Evapotranspiration, Humidity, Temperature, Wind speed and Solar Radiation, with high spatial resolution of 70×70 m grid.

The parameters maps will be produced by implementing the Inverse Distance Weighting method for spatial interpolation or Kriging or another similar spatial interpolation methodology, found in the GDAL library. The system will provide this information of the study area, through the WMS/WCS services provided by the Mapserver (http://mapserver.org/) that is going to be set for the purposes of the project. In the case of full data availability the method of estimating ET_0 will be the FAO - Penman-Monteith approach.

The maps will be showing data for a point when clicking on a point, or showing ET and irrigation data for a field, when the user draws his own field, or the field is available to the system database. (using the WMS features of Mapserver (http://mapserver.org/) or other open source GIS server).

The application may also offer functionality for notifications through email alerts to users, concerning, e.g., the need to change the irrigation plan.

Also, access to the meteorological stations network data and albedo maps acquired from satellite images of the study area, will be available through buttons in the main IRMA_SYS page.

The following modules will be available to the users:

Registration

Registration will require from potential users to provide a username, an e-mail and a password. If someone wishes not to register, a "Try" feature will provide full access to the application features without the ability to store any changes to the already provided information.

User home

Registered users will be able to see their account information along with the irrigation advises based on the available historical and forecast data. Also, they will be able to access the "Irrigation Events" page in order to manage the irrigation dates and irrigation water volume, the "Irrigation Report" pages for detailed information about the soil water balance and the "Irrigation Performance" graph to visualize and access information about the estimated water amount and the applied irrigation water.

Add field/Edit field

Registered users will be able to add their fields into the system using a map, in order to pinpoint the geographic location of each field, with the help of the Hellenic Cadaster orthophoto imagery base map (http://gis.ktimanet.gr/wms/ktbasemap) that allows zoom in scales up to 1 m. The user should provide information regarding the field's area, crop and irrigation type. Also, a list of the user's already register fields is available at the bottom of the page.

If appropriate information is available to the registered users, they will be able to modify the properties of every registered field, based on this information. This information will consist of parameters grouped in three major categories:

- Irrigation Management
- Crop Parameters
- Soil Parameters

Irrigation Management includes information regarding irrigation efficiency and strategy. Crop includes information regarding the crop coefficient (Kc), the maximum allowed depletion factor (MAD), the estimated maximum and minimum root depth. Soil includes information regarding the FC, PWP and Θ_s.

Appropriate ranges and the system's default values, according to literature, will be available to the users in order to provide guidance.

Irrigation Events

Registered users will be able to add irrigation events and see a list of the already applied irrigations.

In the case of unknown irrigation water volume, the system will assume that enough water was applied in order for the soil moisture to reach FC, i.e. zero depletion. The corresponding irrigation water quantity (m^3) will appear at the "Irrigation Report" for user guidance and future reference.

Irrigation Report

The "Irrigation Report" page will present a summary of the information applied by the user, regarding the crop, the field, the irrigation system and the last irrigation, along with a tabulated presentation of the essential soil water balance variables, on an hourly time step, for the available forecast period, i.e. 72 hours.

If the user modifies the default properties of the field, in "Custom Parameters" section of the "Edit field" page, then the message: "using custom parameters" will appear in the appropriate section.

Irrigation Performance

The "Irrigation Performance" graph will provide users means to visualize and access information about the estimated water amount, the applied irrigation water and the effective precipitation during the irrigation period that for Greece spans from 1st of April to 30th of September. Also, the data will be available for downloading as "comma separated values - csv" file for further processing.

Also, the quantities of Total Effective Precipitation (mm) together with the Total Estimated Irrigation Water Amount (mm) and the Total Applied Water Amount (mm) along with their Percentage difference (%) will be available to the users, based on the registered irrigation events and the IRMA_SYS estimates, for the above specified period.

User management

Account

Registered users will be able to change their personal information, set the notifications interval and choose their supervisor from the list of available supervisors.

Also, they will be able to register themselves as potential supervisors. For further information about supervisors please refer to section: Irrigation supervisors.

Tools

The "Tools" page will contain a set of useful tools for unit conversions, as:

- From mm to m^3 of irrigation water and vice versa, since the corresponding field area is provided
- Irrigation duration in hours (h) according to mm of irrigation water and station flow rate (m^3/h)
- Station flow rate (m^3/h) according to mm of irrigation water and desired irrigation duration in hours (h)

Irrigation report alert

The system will run a soil water budget routine at the beginning of each day and will send an email to the users that have agreed for this, which will contain an estimation regarding the need of irrigation for the current and the 3 upcoming days. For the latest the last available weather forecast will be used.

Irrigation supervisors

A supervisor will be assigned to another system user, by the user himself, in order to utilize the IRMA_SYS in his account.

Every user will be able to declare himself as a supervisor, in his/hers "Account" menu, but in our perspective a supervisor is considered to be either:

1. An irrigation guru, which is a scientist in the field of Irrigation and Drainage
2. A certified professional that can supervise a number of irrigators as generic consultant or in the framework of an applied quality cultivation system (i.e. organic farming, integrated management etc.)

or

3. A user with great experience regarding irrigation and drainage issues

Through a list, available in his/hers *Account* menu, the user will be able to choose one from the already declared supervisors and provide access to his fields to him.

A supervisor will have no access to any other information apart from the registered fields in the IRMA_SYS.

The user, at his will, will be able to remove or to change the supervisor from his/hers *Account* menu also.

In this context, potential supervisors and certified professionals should be encouraged to post their work contact details, along with their IRMA_SYS usernames, in order for the users to easily contact them at the appropriate section of the Irrigation Management Forum that will be located at: http://www.irrigation-management.eu/forumx/irrigation-system-gr.

Spatial interpolation application

All the data that the meteorological stations will pass through a spatial interpolation process in order to develop relevant data for any point of the area. A new web application will be developed, that will be able to retrieve and process the available data from Enhydris in order to produce the necessary raster maps, of the involved parameters.

Raster maps for each parameter involved in the soil water balance will be produced. Spatial variation of reference evapotranspiration (ET_0) will be estimated from calculations between raster maps of the involved parameters, instead of applying a methodology to spatially interpolate calculated ET_0 values at stations locations. This is essential for the system calibration, since live lysimeter data are unavailable, thus ET_0 cannot be measured and obviously cannot be calibrated. On the other hand, each of the parameters involved in the estimation procedure of ET_0 is measured at stations locations and thus capable for calibration.

The grid size of the raster maps will be70×70meters, as already defined in the preliminary study of Malamos and Tsiroyiannis (2012).

Since the time scale of the variables will be hourly for the current day the system will store twenty four raster maps of all parameters, used for the detailed calculation of the soil water balance components and at the end of the day (i.e. at 24:00) will produce the daily raster maps by aggregation.

The irrigation advice forecast maps will be produced using the three hour weather forecasts provided by the NOA or other appropriate service.

Infilling of missing data

In the special case that the current data required for irrigation calculation are not available due to sensors or communication failures, the previous day forecast values will be used.

In the case of timeseries infilling, techniques like Regression Analysis and Broken Line Smoothing (Koutsoyiannis 2000, Malamos and koutsoyiannis 2014) will be implemented in order to acquire the best results.

IRMA_SYS Forum

The IRMA_SYS Forum will be located at: http://www.irrigation-management.eu/forumx/irrigation-system-gr, will act as an online discussion site where system users will be able to hold conversations regarding topics of interest. Users should be encouraged to participate with questions, suggestions and comments about the IRMA_SYS and to share experience and feedback.

Self-training

IRMA_SYS will be addressed to irrigation professionals who have the background and the experience to interpret the information provided and use the system for setting up irrigation schedules, plan and record irrigation events as well as self-training regarding irrigation management.

However, IRMA_SYS will provide information in the form of diagrams, where the actual irrigation events and the relevant estimated irrigation events as calculated from the water balance, will be plotted for the irrigation period. In this way a self-training lace since the system users will be able to compare the theoretical results to their irrigation practices.

Tailored services

Irrigators that want more accuracy -mainly regarding soil moisture and cloudiness- will have to install relevant sensors at their field and provide data to the system. The positioning of the sensors will be studied by the system operation team which will be based on data regarding terrain morphology, soil analysis, cultivation etc.

Internet of things - Irrigation data

The system will provide spatial information of parameters like Rainfall, Potential Evapotranspiration, Humidity, Temperature, Wind speed and Solar Radiation, which in the future will be easily accessed by stand-alone smart irrigation controllers connected to the internet and other similar applications (internet of things).

Compatibility with certified cultivation systems

The system will be compatible (meaning that it will offer relevant documentation and registration functions) with applied certified cultivation systems such as integrated agriculture.

Evaluation and feedback

A feedback procedure will be available for users that want to contribute to the improvement and evolution of the system by evaluating it .

Documentation and Training

A series of training seminars for agriculturalists, which are expected to be the main type of users (in order to analyze the provided information before make relevant suggestions to farmers and green spaces managers) will follow the development. Also special seminars for end users, in order to have a basic understanding of the system operation will be made. Relevant training and help material will be available at the IRMA_SYS web site.

System software architecture

The IRMA_SYS will be user-friendly computer/mobile-based, open and free modular software, with its source available at repositories such as github, under the terms of the GNU General Public License as published by the Free Software Foundation.

It will be written in Python and Django, along with NumPy (http://www.numpy.org/) and GDAL - Geospatial Data Abstraction Library (http://www.gdal.org/) modules.

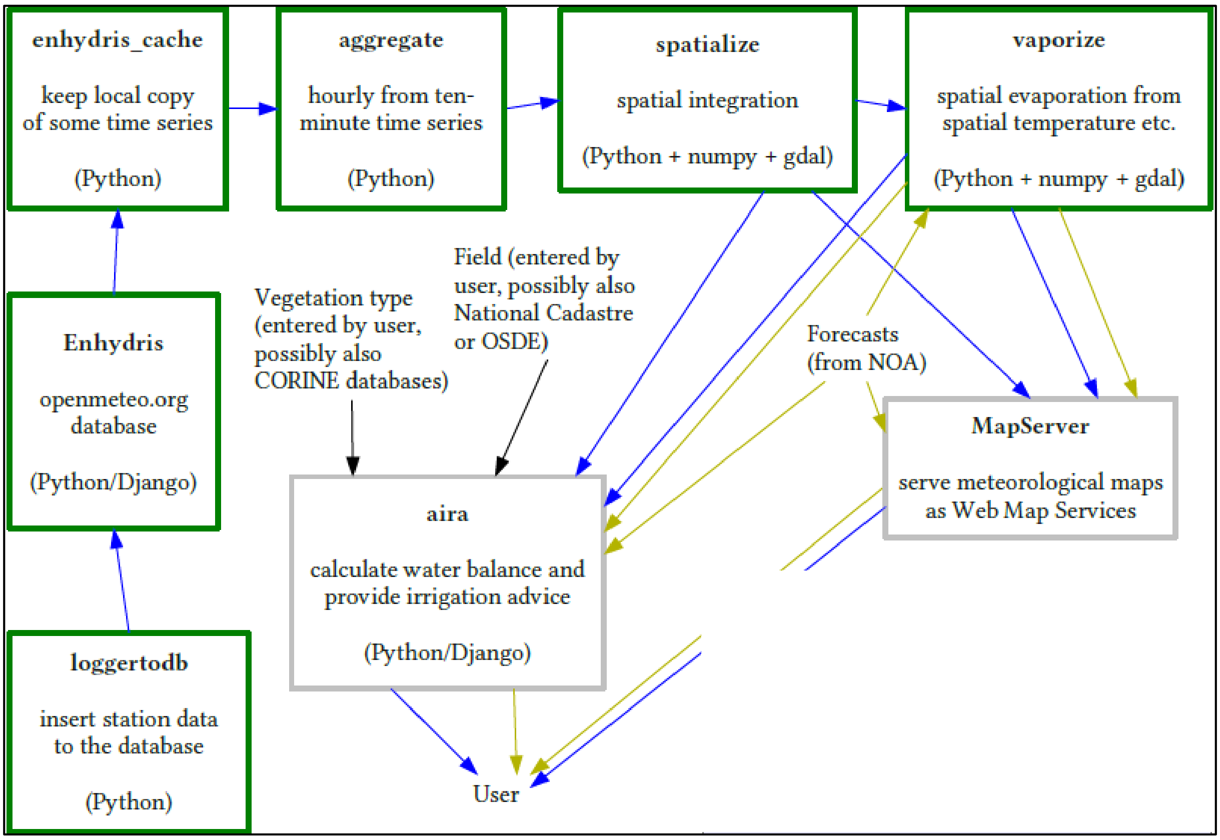


Fig. 49 System architecture

Fig. 50 github – social coding platform

The development of the open source script will be available to anyone interested through github, at: https://github.com/openmeteo/aira/.

Notes

System evaluation

The IRMA_SYS will be evaluated through experiments that will take place in experimental fields located at the TEI of Epirus Campus at Kostakioi Arta. An evaluation team will be assembled in order to perform these experiments

System sustainability

IRMA includes deliverables which because of their light character have the potential to be directly implemented in broader areas.

The “efficient irrigation” network (WP3) is expected to continue its operation for life. The network site and information system (WP5) will be formed in a way that minimum intervention will be needed for their operation. The meteorological stations will need a regular yearly inspection.

LP is committed to host the network and the information systems and maintain the relevant hardware while PP6 will have the responsibility for the stations’ maintenance (maximum full cover warranty will be asked by the supplier).

The number of advices already provided by Assoco di Puglia and the pilot application of PROBIOSIS during the last 3 years guarantee the potential for the sustainability of the service. The deliverables of WP4 and 6 have the form of reports, guides and scientific papers. These outputs are expected to be used creatively by the project’s target groups.

Notes

Further research

Further research concerning the following scientific field is going to contribute to further validation and development of the system:

- Evaluation of system use by end users in quantitative and quality terms.
- Definition of the optimum number / positioning of meteorological stations in order to provide information of acceptable level.
- Comparison and implementation of several hi-end spatial interpolation methods (e.g. Kriging etc.) for the parameters involved.
- Experimental evaluation of the site in real world situations for both agriculture and landscaping (case study on the results of the website introduction, its reception by farmers and landscape managers and its impacts in the field).

Notes

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Annex I. Characteristics of selected cultivations (growth, stages, duration, crop coefficients, root depths and maximum allowable depletion inputs)

Regarding cultivation periods, Kc or KL and rooting depth, the system will support the generic relevant concept of FAO p56 (Allen et., 1998). In this framework for every crop the data presented in Table 19 will be provided by the user or inserted by the system crop library.

Table 19 Inputs regarding crop coefficients and root depths according to the 1989 decision (GG 428 2-6-1989)

Crop Name	Crop Name_el	Min	Max	Depletion Fraction (MAD)	kc	GG F16/6631/1989 category
Cucumber - Machine Harvest	Αγγουράκι - Μηχανικής συγκομιδής	0.7	1.2	0.5	0.7	4
Cucumber - Fresh Market	Αγγούρι	0.7	1.2	0.5	0.7	4
Artichokes	Αγκινάρα	0.6	0.9	0.45	0.65	3
Kiwi	Ακτινίδιο	0.7	1.3	0.35	0.8	6
Other Leafy Vegetables	Άλλα φυλλώδη λαχανικά	0.15	0.15	0.4	0.7	4
Other Large Crop Plants	Άλλα φυτά μεγάλης καλλιέργειας	0.3	0.3	0.55	0.75	5
Other Tree Crops	Άλλες δενδρώδεις καλλιέργειες	0.3	0.3	0.52	0.65	3
Almonds	Αμυγδαλιά	1	2	0.4	0.65	3
Cotton	Βαμβάκι	1	1.7	0.65	0.65	3
Apricots, Peaches, Cherries, Stone Fruit	Βερικοκιά, Ροδακινιά, Κερασιά, Λοιπά πυρηνόκαρπα	1	2	0.5	0.65	3
Oats	Βρώμη	1	1.5	0.55	0.75	5
Sweet Potato	Γλυκοπατάτα	1	1.5	0.65	0.7	4
Turnip (and Rutabaga)	Γογγύλι	0.5	1	0.5	0.7	4
Rapeseed, Canola	Ελαιοκράμβη	1	1.5	0.6	0.65	3
Olives (40 to 60% ground coverage by canopy)	Ελιά (40 ως 60% κάλυψη εδάφους)	1.2	1.7	0.65	0.55	1
Citrus - 20% Canopy	Εσπεριδοειδή - 20% κάλυψη εδάφους	0.8	1.1	0.5	0.55	1

Crop Name	Crop Name_el	Min	Max	Depletion Fraction (MAD)	kc	GG F16/6631/1989 category
Citrus - 50% Canopy	Εσπεριδοειδή - 50% κάλυψη εδάφους	1.1	1.5	0.5	0.55	1
Citrus - 70% Canopy	Εσπεριδοειδή - 70% κάλυψη εδάφους	1.2	1.5	0.5	0.55	1
Sugar Cane	Ζαχαροκάλαμο	1.2	2	0.65	0.8	6
Sugar Beet	Ζαχαρότευτλο	0.7	1.2	0.55	0.7	4
Sunflower	Ηλιοτρόπιο	0.8	1.5	0.45	0.7	4
Maize, Sweet (sweet corn)	Καλαμπόκι γλυκό	0.8	1.2	0.5	0.75	5
Safflower	Κάρδαμο	1	2	0.6	0.65	3
Carrots	Καρότο	0.5	1	0.35	0.7	4
Watermelon	Καρπούζι	0.8	1.5	0.4	0.7	4
Walnut Orchard	Καρυδιά	1.7	2.4	0.5	0.65	3
Pumpkin, Winter Squash	Κολοκύθα	1	1.5	0.35	0.7	4
Squash, Zucchini	Κολοκυθάκι	0.6	1	0.5	0.7	4
Fababean (broad bean) - Dry/Seed	Κουκί ξερό	0.5	0.7	0.45	0.65	3
Fababean (broad bean) - Fresh	Κουκί χλωρό	0.5	0.7	0.45	0.65	3
Cauliflower	Κουνουπίδι	0.4	0.7	0.45	0.7	4
Onions-seed	Κρεμμύδι - κοκκάρι	0.3	0.6	0.3	0.7	4
Onions- dry	Κρεμμύδι - ξερός βολβός	0.3	0.6	0.35	0.7	4
Onions-green	Κρεμμύδι χλωρό	0.3	0.6	0.2	0.7	4
Barley	Κριθάρι	1	1.5	0.55	0.75	5
Cabbage	Λάχανο	0.5	0.8	0.45	0.7	4
Brussel Sprouts	Λάχανο Βρυξελλών	0.4	0.6	0.45	0.7	4
Flax	Λινάρι	1	1.5	0.5	0.65	3
Rye Grass hay	Λόλιο - για σανό	0.6	1	0.6	0.55	1
Lettuce	Μαρούλι	0.3	0.5	0.3	0.7	4
Egg Plant	Μελιτζάνα	0.7	1.2	0.45	0.7	4
Mint	Μέντα	0.4	0.8	0.4	0.65	3
Alfalfa - for hay	Μηδική - για σανό	1	2	0.55	0.55	1
Apples, Pears	Μηλιά, Αχλαδιά	1	2	0.5	0.65	3
Berries (bushes)	Μούρο (θάμνος)	0.6	1.2	0.5	0.55	1

Crop Name	Crop Name_el	Min	Max	Depletion Fraction (MAD)	kc	GG F16/6631/1989 category
Peas - Fresh	Μπιζέλι - νωπό	0.6	1	0.35	0.65	3
Peas - Dry/Seed	Μπιζέλι - ξερό/σπόρος	0.6	1	0.4	0.65	3
Broccoli	Μπρόκολο	0.4	0.6	0.45	0.7	4
Potato	Πατάτα	0.4	0.6	0.35	0.7	4
Sweet Melons	Πεπόνι	0.8	1.5	0.4	0.7	4
Sweet Peppers (bell)	Πιπεριά φλάσκα	0.5	1	0.3	0.7	4
Radishes	Ραπανάκι	0.3	0.5	0.3	0.7	4
Chick pea	Ρεβίθι	0.6	1	0.5	0.65	3
Green Gram and Cowpeas	Ροβίτσα και Αμπελοφάσουλο	0.6	1	0.45	0.65	3
Rice	Ρύζι	0.5	1	0.2	1.2	8
Celery	Σέλινο	0.3	0.5	0.2	0.7	4
Sesame	Σήσαμο	1	1.5	0.6	0.65	3
Spring Wheat	Σιτάρι εαρινό	1	1.5	0.55	0.75	5
Winter Wheat	Σιτάρι χειμερινό	1	1.8	0.55	0.75	5
Garlic	Σκόρδο	0.3	0.5	0.3	0.7	4
Soybeans	Σόγια	0.6	1.3	0.5	0.65	3
Sorghum - grain	Σόργο	1	2	0.55	0.75	5
Spinach	Σπανάκι	0.3	0.5	0.45	0.7	4
Asparagus	Σπαράγγι	1.2	1.8	0.45	0.65	3
Grapes - Table or Raisin	Σταφύλι - Επιτραπέζιες ποικιλίες ή Σταφίδα	1	2	0.35	0.55	1
Grapes - Wine	Σταφύλια - Οινοποίηση	1	2	0.45	0.55	1
Tomato	Τομάτα	0.7	1.5	0.4	0.7	4
Clover hay, Berseem	Τριφύλλι - για σανό	0.6	0.9	0.5	0.55	1
Lentil	Φακή	0.6	0.8	0.5	0.65	3
Beans, green	Φασόλι - χλωρό	0.5	0.7	0.45	0.65	3
Strawberries	Φράουλα	0.2	0.3	0.2	0.65	3
Pistachios	Φυστικιά	1	1.5	0.4	0.65	3

Crop Name	Crop Name_el	Min	Max	Depletion Fraction (MAD)	kc	GG F16/6631/1989 category
Turf grass - warm session	Χλοοτάπητας θερμόφιλλος	0.5	1	0.5	0.85	6
Turf grass - cool season	Χλοοτάπητας ψυχρόφιλος	0.5	1	0.4	0.95	6

Annex II. Analytical info for the main cultivations of the study area

Olive

Olive trees have been sparsely planted for centuries, without irrigation, on marginal lands in Mediterranean climate conditions because of their high resistance to drought, lime and salinity. In Spain, Italy and Greece only 28%, 20% and 26% of olive cultivation area is irrigated (EU, 2012).

Typical densities of traditional groves are between 50 and 100 tree ha^{-1}. Fruit yields are low, ranging from less than 1 up to 5 t h^{-1} of olives. Intensive orchards have a density of between 200 and 550 tree ha^{-1}, which leads to higher productivity per unit land area than traditional systems, particularly during the first 10 years of production. In the last 15 years very high density, hedgerow type, olive orchards (from 1.000 to 2.000 tree ha^{-1}) have been developed to further reduce harvesting costs using over-the tree harvesting machines. Average yields can be quite high (5-15 t ha^{-1}) in the first years of production (third to seventh year after planting) and may average 10-14 t ha^{-1} over a 10-year period, but there are questions about the sustainability of high yields in the long term, and about the adaptation of many cultivars to this production system.

Olive trees withstand long periods of drought and can survive in very sparse plantings even in climates with only 150-200 mm annual rainfall. However, economic production requires much higher annual precipitation or irrigation. In areas of annual rainfall higher than 600 mm, production can be maintained under rainfed conditions in soils with good water-holding capacity. However, irrigation plays an important role in the drier areas, and/or for soils with limited water storage. Elsewhere, irrigation plays an important role to stabilizing yields in the years of low rainfall (Moriana et al., 2007). Irrigation is becoming common in the intensive orchards as it allows early onset of production (from the second to forth year after planting), high yields (averages up to 10-15 t ha^{-1}) under optimal conditions and less variability because of alternate bearing.

Table 20 summarizes the crop coefficient (Kc) values proposed by various authors that have been developed in different environments. The range of Kc values is quite wide, varying from less than 0.5 to about 0.75, average values varying from 0.55 to 0.65, depending on the season (Fereres et al., 2011). Crop coefficients should be further increased (up to about 0.8 to 1.0 in winter and early spring, depending on the type of the cover crop and its density) if the orchard floor has a permanent grass cover (Steduto et al., 2012)

Table 20 Summary of recommended olive Kc values (Fereres et al., 2011)

Climate* / Season	Semi-arid	Arid
Spring	0.65-0.75	0.45-0.55
Summer	0.50-0.55	0.50-0.55
Fall	0.60-0.70	0.55-0.65
Winter	0.65-0.75	0.40-0.55

* Mediterranean-type climates; the one labelled semi-arid has seasonal rainfall values around 500 mm or more, mostly between autumn and spring, while the arid climate would have less than 400 mm rainfall and is more continental, with relatively cold winters. The higher Kc values of the range should be used for high rainfall situations. Kc values to be used with ETo calculated following FAO Paper No. 56 (Allen et al., 1998)

In Apoulia, Epirus and Western Greece, the areas of IRMA project, irrigation of olives usually starts in late spring and may extend well into the fall season. In any case water is preferably applied to olives by microirrigation. According to Steduto et al. (2012) in poorly-drained soils it is desirable to reduce the frequency of irrigation to 1-2 times a week as the use of longer intervals with microirrigation is often inefficient because there may be significant losses to deep percolation. When water agencies supply water at longer intervals (2-4 weeks), it is desirable to build on-farm storage facilities to irrigate as frequently as needed.

The Greek Ministry of Agriculture (GMA, 1989), provides seasonal Kc values for olive orchards for the various hydrological areas of Greece.

Olive fruit yield decreases as ETc decreases below its maximum. However, it has been found that the decline in production is hardly detectable with small reductions in ETc (Steduto et al., 2012). As ETc is further reduced, however, yields decline more. Thus, the response curve of yield (fruit or oil) to ETc is almost linear at low levels of consumptive water use, but levels off when water consumption is high. As a result, the overall response curves are parabolic and can be described by second order equations. The shape of the curve implies that the water productivity (WP) increases as ET decreases and, therefore, one can find an economic optimum, in terms of ET and therefore of irrigation amount, if the price of oil and the irrigation water costs are taken into consideration.

Michelakis (1990) found that for three of the most wide spread olive varieties in Greece (Kalamon, Koroneiki and Amfissis), fruit yield per tree were significanly higher in irrigated treatments (drip irrigation was used) than in non irrigated one but they did not differ significantly among the irrigated treatments.

The yield response of table olives to a reduction in applied water from a case study (Goldhamer et al., 1994) is shown in Fig. 51. According to the relevant discussion provided in Steduto et al. (2012), a reduction in provided water of 21% did not affect fruit yield or revenue (revenue data are not presented here). A further reduction down to 62%, decreased relative fruit yield by 10%, and relative revenue by 25%. The more drastic reduction in revenue was associated with a lower price due to the reduction in fruit size.

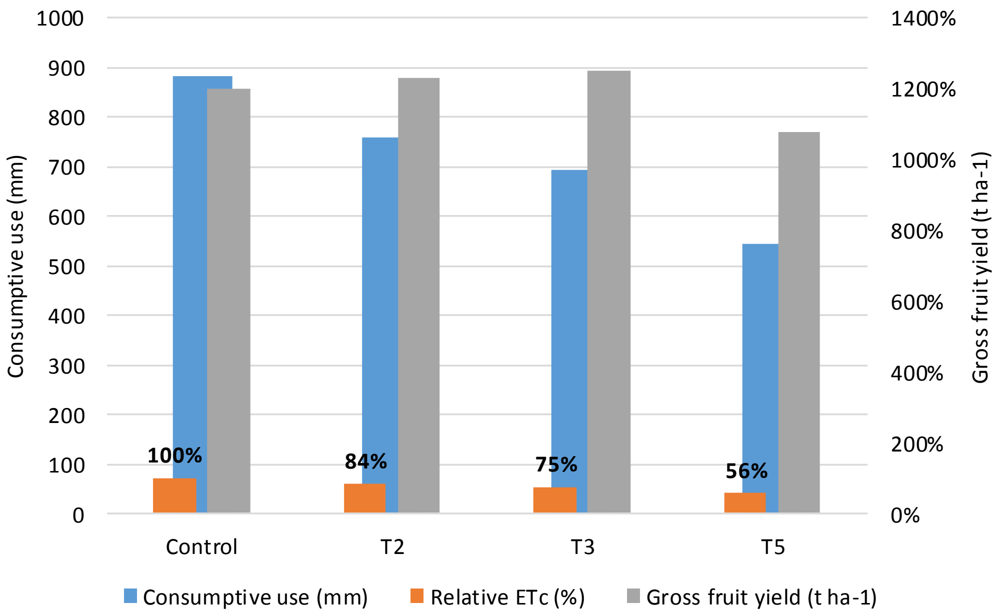

Fig. 51 Relative yield and gross revenue of table olives under deficit irrigation (Goldhamer et al., 1994).

In another case study (Moriana et al., 2007) the fruit yield of a traditional irrigated olive groove in Spain showed the normal biannual pattern. Fruit production in 2003, the ''on'' year, varied from 4 to 5.5 t ha^{-1}. In the 2004 ''off year'' season, a reduction in fruit yield of around 50% of the ''on'' year value was seen, with the amounts collected varying between 2 and 2.5 t ha^{-1}.

In coastal, central Italy (about 600 mm annual precipitation), Gucci et al. (2007) found that less than 100 mm of irrigation water are sufficient to obtain yields that are over 80% of those of fully irrigated orchards.

In every case, quantitative response should be investigated also in response to qualitative one and the expectations regarding earnings.

Kiwifruit

The main training systems adopted for the kiwifruit are the T-bar and the Pergola (the latest is the only one applied in the IRMA project area, **Error! Reference source not found.**), with plantation densities ranging from 400-600 (Pergola) up to 720 plant ha^{-1} (T-bar). Values of LAI are around 2.5-3 in orchards trained to T-bar (~400 vine/ha), and up to 4-5 in orchards trained to the pergola system (~700 vine/ha).

Kiwifruit is quite sensitive to water stress throughout the whole growing season. According to Steduto et al. (2012), on a midsummer day, a Mediterranean kiwifruit orchard consumes ~ 6-7 mm of water and seasonally, around 300-350 L of water per kg of fruit are supplied (for a yield of 35 t ha^{-1}). Because of its high water demand and the sensitivity to dry environments, kiwifruit grown in areas of high evaporative demand must be irrigated by micro-sprinklers in order to maximize the soil surface area that is wetted. Volumetric soil water content should remain close to field capacity at all times (never reaching values below 30 percent of the root zone water storage capacity), hence the need for frequent irrigation applications (Miller et al., 1998).

Xylogiannis et al. (2012) pointed out that except in soils of low water-holding capacity, localised irrigation methods (drip irrigation or sub-irrigation) are best for all fruit tree species grown in the Mediterranean area. However, in the case of kiwifruit because of its physiology and its root system characteristics irrigation methods that wet the whole soil surface should be considered instead. Additionally, the adoption of localised irrigation methods require water availability almost every day (June-September, Northern Hemisphere) and often current networks irrigation agencies (responsible for water management at regional scale) cannot adequately meet the water supply demands. Deficit irrigation is not considerable feasible in this species, and full water supply to meet the crop water requirements must be ensured for sustainable kiwifruit production (Steduto et al., 2012).

FAO Paper 56 (Allen et al., 1998) provides the following information regarding the calculation of kiwi (crop height about 3m; maximum root depth: 0.7-1.3 m) water needs:

- Single (time-averaged) crop coefficients, Kc (Kc_{ini}, Kc_{mid} and Kc_{end}), for non-stressed, well-managed crops in subhumid climates (RHmin about 45%, u2 about 2 m s^{-1}) for use with the FAO Penman-Monteith ETo: 0.40, 1.05 and 1.05 respectively

- Depletion factor 0.35 (for ET about 5 mm/day)

The latest implies high irrigation frequency in order to keep the upper soil wet. FAO Paper 56 (Allen et al., 1998) refers that for frequent wettings such as with high frequency sprinkle irrigation, the provided values of Kc_{ini} may increase substantially and may approach 1.0 to 1.2. Steduto et al. (2012) provide a synopsis (Table 21) of recommended crop coefficients for kiwifruit.

The Greek Ministry of Agriculture (GMA, 1989), provides seasonal Kc values for kiwifruit for the various hydrological areas of Greece.

Table 21 Crop coefficients for a mature microjet irrigated kiwifruit (Hayward) orchard grown in the Northern Hemisphere (N 40° 23' E 16° 45') (seasonal irrigation volume = 10 012 m3/ha). Note that the whole soil surface area was wetted and the soil was not tilled.

Month	Apr	May	June	July	Aug	Sept	Oct
Kc	0.5	0.7	0.9	1.1	1.1	0.8	0.8

A number of references exists regarding the amount of water that is provided by irrigation to kiwifruit cultivations in Greece:

- Irrigation water used (mm/year) in kiwi irrigated with different systems (Chartzoulakis et al., 1991): drip: 340; micro-sprinkler: 477; overhead sprinkler: 782.

- According to Kalavrouziotis et al. (2011) the net irrigation requirements (mm / irrigation period) for kiwifruit at Agrinion (Aitoloakarnania, Western Greece) is about 600mm.

- Tsirogiannis et al. (2012) calculated using FAO's CropWat software, that the net water needs of kiwifruit cultivation for the plain of Arta, are expected to be about 600mm/year (without taking account of the efficiency of the irrigation system).

- Tsirogiannis et al. (2014) have monitored (using water meters) a 425 and 478 mm y^{-1} water use in kiwifruit cultivation in Arta (total yearly rainfall >1000mm, http://www.hnms.gr/hnms/english/climatology/climatology_region_diagrams_html?dr_city=Arta) using an ET advising system and conventional approach respectively. A recent audit test (this work is in progress and we are referring to only one field) register about 650mm/year in a kiwifruit cultivation in Arta. Have in mind that the fuel cost is considerable in Greece and it is a restricting factor regarding irrigation duration.

- According to ProBioSis (2008) in organic cultivation of kiwifruit, about 400-500mm are used in rainy areas while this number can be shifted up to 1,000 mm for semi-arid areas.

In Italy, Villani et al. (2011) registered between 1996-2008 yearly irrigation ranged from 250 to 450 mm in the Faenza area (Emilia-Romagna). Steduto et al. (2012) refer a study of Montanaro et al. (in preparation) in which irrigation of a Hayward kiwifruit orchard (southern Italy 40°08' N; 16°38' E, soil was not tilled, vines were irrigated by microjet wetting the whole soil surface) has been scheduled when soil water content was below the lower threshold of the readily available water (RAW). The seasonal irrigation volume was 10,012 m^3 ha^{-1} (ETo from April to September: 993.7 mm).

Citrus

Citrus fruit is a category that includes oranges, small citrus fruit, such as mandarins, tangerines, tangelos, clementines, satsumas, lemons, limes and grapefruit. Because citrus is an evergreen crop sensitive to low temperatures, subtropical regions produce the bulk of the world's citrus.

There is a large volume of research on the responses of different citrus physiological processes to water stress. Responses vary with the timing of stress during the season and thus the study of water stress effects has been studied separately for spring, summers, fall and winter (Steduto et al., 2012).

Since citrus is an evergreen plant, many water use studies report a single crop coefficient (Kc) value. These include 0.62 for Valencia in Sunraysia (Grieve, 1989), 0.44 for clementines in Mazagon, Spain (Villalobos et al., 2009), and 0.52 for lemons in Ventura, California (Grismer, 2000). Others have divided the season into winter and summer and suggested that the Kc was 0.70 and 0.65, respectively. They suggested increasing these values by 0.1 or 0.2 for humid and semi humid regions (Allen et al., 1998).

Many studies indicate that, compared to the summer, the citrus Kc is slightly higher in the winter and early spring and appreciably higher in the autumn. Also the Kc in the mild Mediterranean and coastal climates is expected to be higher than those of more arid, inland valleys. In addition, in Mediterranean environments, high Kc values in winter reflect high soil evaporation rates from frequent rainfall during that part of the season. Not all studies found that the Kc was minimum in the summer. One study for cv. Valencia (Hoffman et al., 1982) and another for navels (Chartzoulakis et al., 1999) reported just the opposite. Table 22 presents indicative Kc values for citrus crops (Allen et al., 1998).

The Greek Ministry of Agriculture (GMA, 1989), provides seasonal Kc values for citrus crops for the various hydrological areas of Greece.

Table 22 Single (time-averaged) crop coefficients, Kc, for non-stressed, well-managed crops in subhumid climates (RH_{min}<45%, u_2<2 m s^{-1}) for use with the FAO Penman-Monteith ETo (Allen et al., 1998)

Citrus, with active ground cover or weeds	Kc_{ini}	Kc_{mid}	Kc_{end}
70% canopy	0.75	0.70	0.75
50% canopy	0.80	0.80	0.80
20% canopy	0.85	0.85	0.85

No findings were available in the international literature regarding applied water and relevant yield for citrus crops in Italy and Greece. At the other hand, as it is also proved from Steduto et al. (2012), this kind of information is plenty for Spain.

Castel et al. (1987), studied for the period 1981 to 1984, 8 mature sweet orange orchards (cv. Salustiana and Washington Navel on sour orange) irrigated by strip-border at Valencia, Spain.

Table 23 Applied water (irrigation and rainfall) and water use efficiency for orange orchards in Valencia, Spain (Castel et al., 1987). Average values for the period 1981-1984 (4 years)

Plot	Irrigation (mm)	Rain (mm)	Water applied / Yield (m^3 Mg^{-1})
1	705	330	218.75
2**	773	330	410.67
3*	640	383	223.67
4**	646	330	210.00

* no data for 1981, ** no data for 1984

García Tejero et al. (2011), studied sweet oranges cvs. Salustiana and Navelina orchards at Guadalquivir river basin, within the provinces of Seville and Cordoba, Spain. The trees were 12 years old, using a grid of 6×4m on calcareous sandy-clay loam soil. The soil surface between trees was totally shaded with a controlled grass cover and irrigation water was provided using a drip system. SDI, sustained deficit irrigation; RDI, regulated deficit irrigation; LFDI, low-frequency deficit irrigation; C-100, fully irrigated treatment according to the total crop water demand (100% ETC) were applied. The evaluation of the agricultural WUE was based in the ratio between the crop yield (economic yield), and the total water applied (WUEagr(kg m^{-3}) = Yield (economic) / irrigation + rain). The 3 years averages of irrigation (mm), irrigation + rain (mm) and yield (kg $tree^{-1}$) for cv. Salustiana and cv. Navelina are presented in Table 24.

Ballester et al. (2011) studied the response of a 'Clementina de Nules' orchard (*Citrus clementina*, Hortex Tanorchard (6x4m tree spacing, clay to clay loam soil texture, drip irrigation) at Liria, Valencia, Spain. For the period 2007 to 2009 the average ET_0 was 1,070 mm, the rainfall 450 mm and the applied irrigation was 364 (control), 309 (RDI[10]-1) and 298 mm (RDI-2). The average for the period 2007–2009 yield (t ha^{-1}) and water use efficiency (kg mm^{-1}) for the various irrigation treatments was

[10] Regulated Deficit Irrigation

found to be 42.0 t ha^{-1} and 0.12 kg mm^{-1} for the control, 40.8 t ha^{-1} and 0.13 kg mm^{-1} for the RDI-1 and 36.1 t ha^{-1} and 0.12 kg mm^{-1} for the RDI-2.

Ballester et al. (2013) studied the response of a 7 years old Navel Lane Late citrus orchard (6x4m tree spacing, clay to clay loam soil texture, drip irrigation) at Chulilla, Valencia, Spain. For the period 2007 to 2010 the average ET_0 was 1,221 mm, the rainfall 506 mm and the applied irrigation was 407 (control), 332 (RDI[11]-1) and 316 mm (RDI-2). The average for the period 2007–2010 yield (t ha^{-1}) and water use efficiency (kg m^{-3}) for the various irrigation treatments was found to be 40.0 t ha^{-1} and 4.4 kg m^{-3} for the control, 36.1 t ha^{-1} and 4.4 kg m^{-3} for the RDI-1 and 33.9 t ha^{-1} and 4.2 kg m^{-3} for the RDI-2. The conclusion was that moderate water restrictions during summer can be applied in commercial orchards in case of water scarcity, allowing water savings up to 19% without significant reductions in yield or in the economic return.

Table 24 3 years average applied water volume and fruit yield for two orange cultivars at Cordoba, Spain (Gracia Tejero et al., 2011)

Treatments*	Irrigation (mm)	Irrigation + rain (mm)	Yield (kg $tree^{-1}$)
cv. Salustiana			
SDI-1	363	449	105.7
SDI-2	454	540	109.9
SDI-3	522	608	105.7
C-100	681	767	116.8
cv. Navelina			
SDI-1	200.3	507.9	136.5
SDI-2	213.3	520.3	137.9
SDI-3	180.7	487.7	134.2
SDI-4	216.3	547.3	155.7
C-100	317.0	624.0	161.5
cv. Salustiana			
SDI	157.3	472.7	92.9
LFDI	185.3	500.7	115.5
C-100	288.0	603.3	128.7

* SDI, sustained deficit irrigation; RDI, regulated deficit irrigation; LFDI, low-frequency deficit irrigation; C-100, fully irrigated treatment according to the total crop water demand (100% ETC)

[11] Regulated Deficit Irrigation

Annex III. On the scaling and spatial interpolation method of the IRMA project

Introduction

The questions needed to be answered in the context of the IRMA project, is:

1. What meteorological and soil variables,
2. What degree of certainty and
3. What spatial and temporal resolution

These are needed to establish a reliable irrigation plan with a scientifically sound basis for water management and irrigation best practices.

Generally speaking in atmosphere studies, meteorology can be divided into distinct areas of emphasis depending on the temporal scope and spatial scope of interest. At one extreme of this scale is climatology. In the timescales of hours to days, meteorology separates into micro-, meso-, and synoptic scale meteorology. Respectively, the geospatial size of each of these three scales relates directly with the appropriate timescale. In the IRMA project we refer to meso-scale meteorology, taking into account the fact that meso-scale timescales last from less than a day to the lifetime of a meteorological event.

Essential variables

Irrigation planning can have different focal points, such as the rate of certain fluxes of the hydrological cycle (e.g. evapotranspiration, groundwater recharge, deep percolation, precipitation, surface runoff), the description of water resources state (e.g. water stored in the soil, groundwater level), or their combination. Depending on the actual focus, different meteorological and soil conditions have to be provided and are of varying relevance. For example, for an assessment concerning irrigation timing the provision of precipitation and soil water content availability information is essential. If greenhouse irrigation is discussed, radiation information also needs to be provided.

Since energy and water balance models are the basis of irrigation needs estimation, time series of temperature, precipitation, solar radiation, humidity, wind speed and soil water content are the most important variables for analyses that account for plant transpiration and soil evaporation.

Scale issues

Depending on the process under consideration, different typical space and time scales are relevant for an appropriate description of that process. Questions relating to climate change impacts on water resources management need to be analyzed at the “management scale”, which is usually a mid - size or large river catchment or a spatial unit for water allocation and distribution. Such spatial domains usually embrace areas of several 1,000km² to several 10,000km², in exceptional cases even in the order of 100,000km². Besides water management, this scale also addresses most vulnerability issues of the sectors dependent on water resources, such as agriculture, energy production or municipal water supply.

The time scale of decades to century is the most relevant for water management and adaptation, that's why climate projections should provide information for a similar time span. However, for some "quick" hydrological processes it is of equal importance to provide the data in the appropriate temporal resolution.

Since IRMA project deals with irrigation management, the appropriate time step is smaller than days – i.e. hours or even less – because this process is primarily controlled by the rainfall intensity and water infiltration through soil surface, which vary in such relatively short time increments.

Variability

Besides the relevance of different processes and scale issues, the appropriate representation of the variability of meteorological variables in time and space is the third essential. This means that an adequate consideration of the variability in time and space is required. Some processes may show a rather high variability in space and time (such as rainfall), while others (such as soil infiltration rate and groundwater table dynamics) might be more homogeneous, and this has to be reflected by the climate change projections.

Spatial interpolation methods

Since most data for variables involved in the IRMA project are collected from point sources, the spatial array of these data may enable a more precise estimation of the value of properties at unsampled sites than simple averaging between sampled points. The value of a property between data points can be interpolated by fitting a suitable model to account for the expected variation.

A key issue is the choice of interpolation approach for a given set of input data. This is especially true for areas such as mountainous regions, where data collection is sparse and measurements for given variables may differ significantly even at relatively reduced spatial scales.

Methods that produce smooth surfaces include various approaches that may combine regression analyses and distance-based weighted averages. A key difference among these approaches is the criteria used to weight values in relation to distance. Criteria may include simple distance relations (e.g., inverse distance methods), minimization of variance (e.g., kriging and co-kriging), minimization of curvature, and enforcement of smoothness criteria (splining). On the basis of how weights are chosen, methods are "deterministic" or "stochastic." Stochastic methods use statistical criteria to determine weight factors.

Much of the recent literature concerning spatial interpolation of meteorological fields has focused on the generation of surfaces of long-term average or climatological precipitation. Particular attention has been given to the development of sophisticated statistical methods which, given certain assumptions, generate explicit optimality criteria and guarantees of unbiased predictions. Some examples are optimal interpolation (Gandin, 1965), kriging and its variants (e.g. Phillips et al., 1992), and smoothing splines (Hutchinson and Bischof, 1983). Simpler methods which lack such optimality criteria and guarantees of unbiasedness have been applied extensively for the determination of mean areal precipitation. The method of nearest neighbors (Thiessen, 1911) is an early example, and others include multiple nearest neighbors, inverse-distance weighting schemes, and arithmetic means. Several studies have compared various of these sophisticated and simple methods in the context of the area1 distribution of rainfall (Creutin and Obled, 1982; Tabios and Salas, 1985; Phillips et al., 1992). Other studies have focused on one method but offered comparisons with others (Chua and Bras, 1982; Hevesi et al., 1992). The comparison studies generate a somewhat surprising result: although the statistical methods are for the most part more accurate than the simple methods, they are not overwhelmingly so. For example, from Tabios and Salas (1985) (Table 10), there is no significant difference between inverse-distance methods and a suite of statistical methods based on coefficients of determination for estimates of mean annual precipitation from five sites in homogeneous terrain, whereas the nearest-neighbor method was significantly inferior, but only by approximately 10%.

Such results led us to incorporate an inverse-distance weighting scheme as a quick interpolator capable to address the characteristics of the study area.

Inverse Distance Weighted Averaging method

The IDWA method is a straightforward and noncomputationally intensive method. It has been regarded as one of the standard spatial interpolation procedures in geographic information science (Burrough and McDonnell, 1998; Longley et al., 2001) and has been implemented in many GIS software packages as a default method to generate a surface when attribute values are available only at sampled locations. Formally, the IDWA method is used to estimate the unknown value $\hat{y}(S_0)$ in location, S_0 given the observed y values at sampled locations S_i in the following manner:

$$\hat{y}(S_0) = \sum_{i=1}^{n} \lambda_i y(S_i) \tag{1}$$

Essentially, the estimated value in S_0 is a linear combination of the weights (λ_i) and observed y values in S_i where λ_i is defined as:

$$\mathrm{\lambda_i = d_{0i}^{-a} / \sum_{i=1}^{n} d_{0i}^{-a}} \tag{2}$$

with:

$$\mathrm{\sum_{i=1}^{n} \lambda_i = 1} \tag{3}$$

In Eq. (2), the numerator is the inverse of distance (d_{0i}) between S_0 and S_i with a power α, and the denominator is the sum of all inverse-distance weights for all locations i so that the sum of all λ_i's for an unsampled point will be unity (Eq. (3)). The α parameter is specified as a geometric form for the weight while other specifications are possible. This specification implies that if α is larger than 1, the so-called distance-decay effect will be more than proportional to an increase in distance, and vice versa. For the case of IRMA_SYS the parameter α should be set to α = 2, as proposed from literature.

Notes

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