Evaluation presentation and development of a web based irrigation management tool

I.L. Tsirogiannis[1], E. Fillis[2], L. Scamarcio[3], A. Parente[4], N. Malamos[5], P. Barouchas[5], A. Christofides[6] and S. Vanino[7]

[1]Technological Education Institute of Epirus, Dept. of Agricultural Technology, Kostakii, 47100, Arta, Greece; [2]Decentralised Administration of Epirus and W. Macedonia, Dept. of Agricultural Development, 20 V. Epirou St., 45445, Ioannina, Greece; [3]Region of Apoulia, Civil Dept. for Rural Development, 45/47 Lungomare N. Sauro St., 70121, Bari, Italy; [4]CNR – Institute of Science for Food Products, 122/O Amendola St., 70126, Bari, Italy; [5]Technological Education Institute of Western Greece, Dept. of Agricultural Technology, Theodoropoulou Terma, Amaliada, 27200, Ilia, Greece; [6]National Technical University of Athens, Dept. of Water Resources and Environmental Engineering, 5 Iroon Polytechniou St., Zografou, 15780, Athens, Greece; [7]National Institute for Agricultural Economy, 41 Nomentana St., 00161, Rome, Italy.

Abstract

In Greece about 70% of the consumed water supply is used for irrigation, and thus optimal irrigation management is an increasingly important crop production objective. At the plain of Arta at Epirus (Greece), the irrigation systems (both central and private) suffer from fundamental problems regarding their design, installation and management. With the given infrastructure, rational water management could promptly and directly increase irrigation efficiency. Based on this hypothesis, a pilot web service was developed and has operated for 6 years. In the present paper, the meteorological network, the web service and the calculation procedures used in the system, along with the front end capabilities, are presented. The main features of the service are the publication of information regarding daily reference and crop specific evapotranspiration. The calculations are based on actual meteorological data and an estimator, based on water balance calculations, for the time and duration to the next irrigation event. The pilot version of the system has already disseminated recommendations to more than 8,000 agro-meteorologists, agronomists, irrigation engineers and farmers. Feedback from the end-users is positive, and relevant water consumption and crop yield data are presented. These results were used to enhance and expand the system at Arta and to upgrade a related web service that is operating in Puglia (Italy).

Keywords: irrigation practice, water needs, web based irrigation scheduling

INTRODUCTION

The EU Water Framework Directive (WFD) 2000/60/EC (EU, 2000) dictates that action has to be taken to protect water mainly in qualitative but also in quantitative terms. In this direction, various measures are proposed to be adopted by member states, among which are the promotion of water-efficient technologies and water-saving irrigation techniques. The UN Environment Program (UNEP, 2005) concluded that a challenge of water-related issues for Mediterranean countries is to apply integrated water demand management models in agriculture and in this context to develop added value tools for optimization of irrigation efficiency. AQUASTAT (2014) states that, in Greece, about 70% of the available water resources are used for irrigation purposes and 82% in Epirus (SWW, 2013). In this framework, irrigation stakeholders are facing a rising challenge to lower water and energy consumption. With the given infrastructure, irrigation system efficiency at end user level would promptly increase if more efficient irrigation techniques (e.g., micro-irrigation) were expanded along with auditing procedures, frequent maintenance and rational water management practices. In the framework of management, the control of irrigation systems involves the determination of frequency, timing and duration of irrigation events.

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Every approach for setting up an irrigation schedule is based on the estimation of the crop or landscape water needs; commonly done by means of an energy and/or mass balance method (Allen et al., 1998; Donatelli et al., 2006). The use of installed or web based software applications for estimation of plant's water needs and setting up irrigation schedules is nowadays a common practice for irrigation managers, farmers and in some cases for garden owners. Some good examples are Ref-ET (Walter et al., 2001), CropWat (FAO, 2014) and CIMIS (CDWR, 2014). In Greece, relevant products concerned in most cases installed software (Chartzoulakis et al., 2007). Evaluation of these tools showed impressive results with reported reduction of water consumption for irrigation by 20% for olives (Chartzoulakis et al., 2007) and of 45% for landscape irrigation (Davis et al., 2009; Nouri et al., 2013). In every case, these tools should be adjusted for local conditions and this presupposes knowledge of the special characteristics of the crops for each region and of the local irrigation practice.

The web tool that is presented in this paper is operational at pilot level since 2008. About 8,000 irrigation recommendations have been generated during this period and selected farms, which take advantage of the tool, are continuously monitored and provide data that are used for the system's evaluation. The characteristics of the tool and the results of its evaluation are presented along with the design outlines for its successor, which is under development.

MATERIALS AND METHODS

Area, crops and irrigation practice

The Region of Epirus (ROE) is located in northwest Greece, where agricultural land corresponds to 14% of the total area. The plain of Arta (45,329 ha, the biggest of ROE), is located at the south of Epirus and it is part of the Aracthos and Louros hydrological basins (SSW, 2013). The elevation of the plain is between 0 and 100 m and the terrain is almost flat as 72% of the area has a slope up to 8%. A recent analysis of about 200 soil samples (0-30 cm) distributed over the plain showed that the pre-dominant soil texture is medium to heavy (TEIEP, 2010). The water table rises up to less than 1 m below the surface during winter in many parts of the plain, but it remains deeper than 1.5 m during summer. The climate of the area is of Mediterranean, which is characterised by hot summers and rainy, moderate winters. Data from the HNMS (2014) shows a 30 years average annual precipitation of 1084 mm, while the monthly average temperature ranges from 4.7°C in January to 32°C in August. The main crops of the plain of Arta and their irrigated and non-irrigated acreages are presented in Figure 1 (DAERSA, 2012). A survey regarding end-users' irrigation systems at the plain of Arta (Tsirogiannis and Triantos, 2009) revealed fundamental problems regarding design, installation and management. That study was focused on three of the main crops of Arta, i.e., orange and olive orchards and kiwi. The survey was conducted using both onsite interviews and comparisons between actually applied water with estimated water needs. The results revealed that surface irrigation was used in 40% of the cases. Sprinkler irrigation was also used in 40% of cases and drip irrigation comprised 20% of the cases. The vast majority of the systems were not designed and installed by professionals and their management was based on empirical irrigation schedules. Water meters, pressure gauges, tensiometers and other control devices were rarely installed. The comparison between applied water and estimated water needs, according to FAO paper 56 methodology (Allen et al., 1998), revealed great differences between them. For citrus and kiwi, excess water was generally applied while too little was applied to olives.

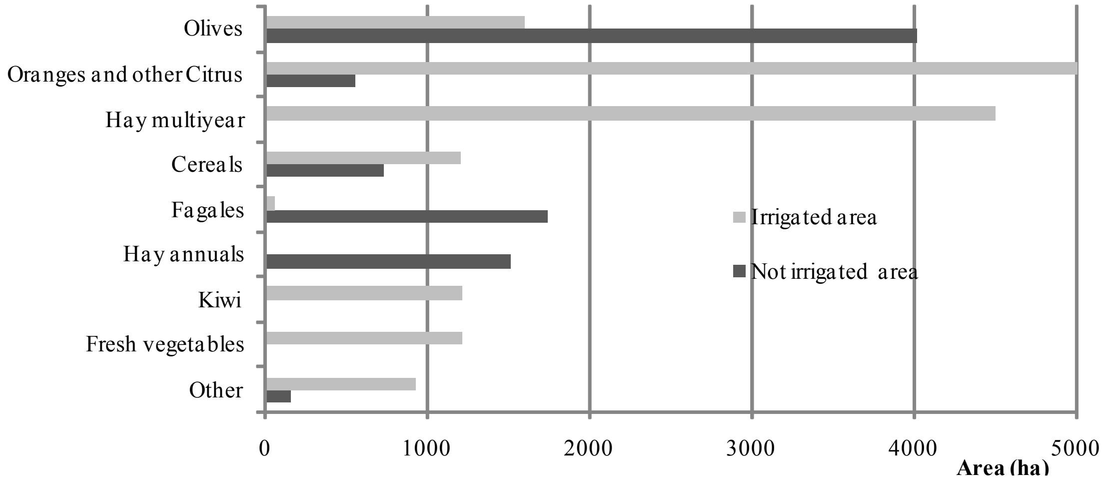

Figure 1. Crops of the plain of Arta (DAERSA, 2012).

System characteristics

The above presented context was the motivation to develop a user friendly web-based information system that would assist local agronomists and act as advisors to farmers and landscape managers to promote good irrigation management practices and document relevant decisions. The website is hosted at: http://probiosis.teiep.gr. It is available in Greek language and provides: a) daily evapotranspiration data (ET_o and ET_c of selected crops), b) an archive of evapotranspiration data, c) a tool for estimation the time and the duration of the next irrigation event and d) documentation regarding use of the tool and the information that the users provide to adjust it to their specific cases.

The web site is based on a straightforward concept. Meteorological stations monitor climatic information, which is retrieved at the end of each day. For the estimation of crop water needs in the plain of Arta, two meteorological stations where used (model Vantage Pro2 Wireless, Fan-aspirated, DAVIS), one at Vlaherna (39°10'21.74"N; 21°05'01.87"E) and one at Kompoti (39°10'21.74"N; 20°59'57.92"E). Both stations are equipped with air temperature and relative humidity sensors, a pyranometer, a rain gauge and an anemometer. Reference evapotranspiration and potential crop evapotranspiration (ET_c) for the selected crops in the area are calculated at the end of each day using the Penman-Monteith approach (Allen et al., 1998) and crop coefficient (K_c). The use of proper K_c values that reflect the characteristics of local cultivars, growing period and local agricultural practice is of great significance for accuracy in estimating ET_c (Allen et al., 1998; Holzapfel et al., 2000; Palomo et al., 2002; Orgaz et al., 2006). The ET information (reference as well as potential for citrus, kiwi, olives and turfgrass) is posted at the front page of the website and stored in the relevant database. The irrigation consultant or the end user can retrieve this information to determine irrigation schedules. The web site also includes an estimation tool to estimate the time and the duration of the next irrigation application. The user provides basic information regarding the site of the field, the soil type, the crop, the available flow and the irrigation system type as well as information regarding the time and duration of the last irrigation. Then a script that is based on water balance equations – as described in FAO p56 (Allen et al., 1998; Jhorar et al., 2009) uses the stored historical ET information along with measured ET and rainfall to forecast for the next three days – is calculated using the Bolam model (Lagouvardos et al., 2003) – to provide recommendations regarding the time and duration of the next irrigation event. Both the daily water balance table and the recommendation are available on the screen and can be printed as a report. A guide regarding the use of the tools and the estimation of the various factors that are used for the next irrigation recommendation is available along with other documents and links to general concepts and special techniques of irrigation scheduling. The dynamic web tool was designed following the object oriented approach and developed using PHP scripting language (Zend

Technologies, 2009).

A series of classes were developed for collecting meteorological data and field measurements from external sources. During operation, classes collecting external data are invoked periodically using two Cron Jobs, and the web server data are collected using CURL operations. Collected data are stored in the database. Another set of classes was developed 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. Temporary and permanent data are stored in a MySQL database (Sun Microsystems, 2008).

Characteristics of the users that participated in the evaluation

For evaluation purposes, ten users were monitored for a period of three years (2011-2013). They agreed to use the recommendations generated by the system to irrigate selected fields and keep records regarding water consumption. Simple survey forms and common 2-inch mechanical water meters were used for that. The peculiarity of local farms that commonly consist of a number of individual fields was an advantage for this case because it is common for a farmer to own 2-3 fields of the same crop in the same area of the plain. All of the selected fields had similar characteristics: they were flat and horizontal, their soil was of medium texture, the water table was lower than 1.5 m during irrigation period, the crops were in early maturity age and irrigation water was delivered using micro-sprinklers.

RESULTS AND DISCUSSION

The above presented system has provided more than 8,000 irrigation recommendations. The area (ha) of the sample that was irrigated using the recommendations generated by the system and that which was irrigated conventionally (based on the experience of the farmer) for olives, oranges and kiwis are presented in Figure 2. Figure 3 presents the average water consumption from irrigation and the corresponding average yield for the two management approaches. Using the recommendations that were generated by the system resulted in a +10% increase in water usage for olive production, but the change in management gave a +15% shift in yield quantity. For citrus and kiwi, there was a decrease of -3 and -7%, in water consumption when recommendations from the system were used. Yield was increased by +2 and +11%, respectively, for the two crops.

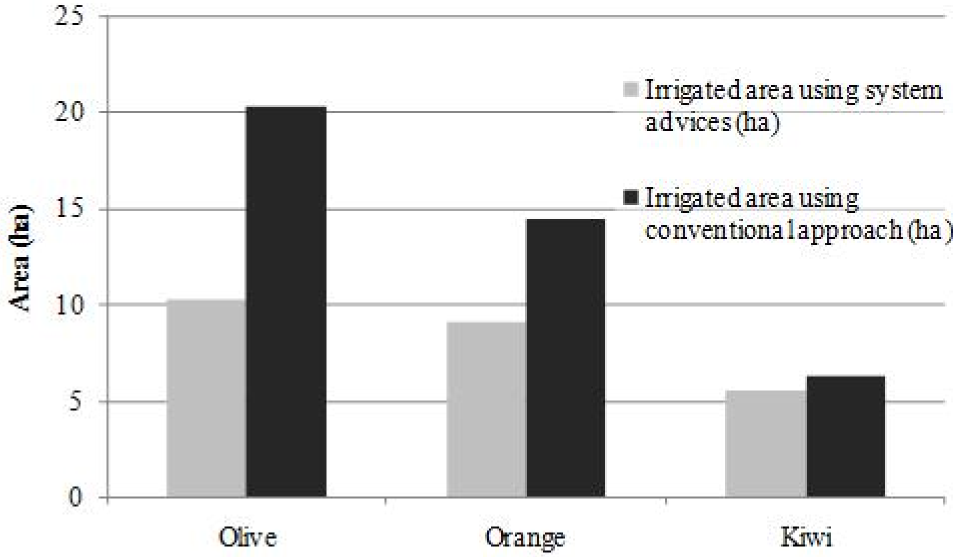

Figure 2. Area of sample crops for system evaluation.

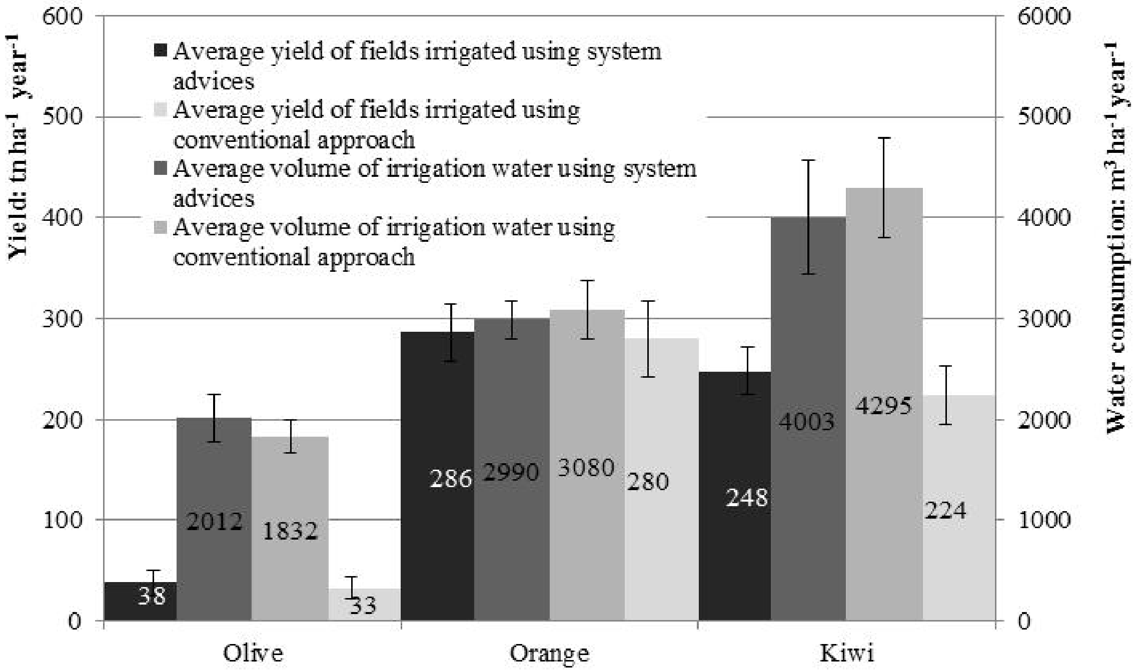

Figure 3. Comparison of irrigation water consumption and relevant yield for the 3-year evaluation period. Error bars represent ± 1.0 standard deviation.

Feedback regarding the use of such systems was optimistic. Better irrigation water management, in most cases, decreased the water and energy consumption while increasing the yield. The lower water consumption was environmentally beneficial because there were fewer effluents, which in many cases contain residuals of fertilisers, chemicals and other contaminants. It also contributes to management of water tables.

From 2013, a new system will enhance and expand the existing pilot system at Arta and a similar system that operates in the Region of Apulia in Italy (http://www.agrometeopuglia.it/opencms/opencms/Agrometeo/Irrigazione/consiglioIrriguo). This system, which is funded by ETCP GR-IT 2007-2013, will be available from the middle of 2015 at: http://arta.irrigation-management.eu/.

A meteorological station network will continuously monitor data to estimate plant water requirements and to set up irrigation schedules. The system will be compatible with various types of meteorological stations to allow other organizations or individuals to be linked and provide data. 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. Also, quality checking procedures will be implemented and unexpected values or gaps will be flagged and filled using suitable spatial interpolation methodologies. Data collection will be performed by the open source software package ENHYDRIS (Kozanis et al., 2012), which allows the storage and retrieval of raw data, processed time series, model parameters, curves and meta-information such as measurement stations overseers, instruments, events, etc.

The system calculates current water needs on an hourly basis. The daily water budget is found by aggregating the hourly time series at the end of each day. For special cases like soilless production or substrate based landscaping systems, the system is capable to provide values of selected parameters (e.g., solar radiation and rainfall) in a finer timescale (e.g., 10 min). Forecasts regarding weather parameters will be available. Spatial interpolation of the collected data (measurements and forecasts) in an appropriate grid size will provide evapotranspiration (Allen et al., 1998) and other water budget parameters throughout the study area. In this way, irrigation scheduling at field level will be feasible by incorporating site specific data and meteorological stations that monitor only some parameters (i.e., solar radiation, cloudiness or temperature) can contribute to the system. Data manipulation and visualization will be performed by an open source software package which will include the GRASS, GEOSERVER and OPENLAYERS open source software modules, in order to be able to provide – via web GIS – the information in map and table format.

The system will be implemented in an interoperable and flexible way so that data are easily accessed by users or by stand-alone smart irrigation controllers connected to the internet and other similar applications. In every case, the final information will help to develop site specific irrigation schedules that are evaluated by irrigation specialists before they are applied.

CONCLUSIONS

The evaluation of irrigation practice for three of the main crops of Arta revealed significant problems which lead to low water use efficiency. In order to succeed in prompt improvement of irrigation management in the area, a web service was developed where crop water requirements are calculated and formation of irrigation schedules can be carried out using inputs regarding climate, crop, soil and irrigation system. After 6 years of operation and dissemination of advice to more than 8,000 users, the overall opinion about the system is positive. Evaluation of the system showed that it can really contribute to irrigation management improvement and crop yield shift. A number of comments that were collected all these years envisaged the design of its successor. The new system will incorporate a more dense meteorological stations' network, spatial integration operations which will involve topography and hydrological data and GIS capabilities and improvement of the user interface and self-training documentation.

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Estimation of monthly FAO Penman-Monteith evapotranspiration in GIS environment, through a geometry independent algorithm

N. Malamos[*a], P.E. Barouchas[a], I.L. Tsirogiannis[b], A. Liopa-Tsakalidi[a] and Th. Koromilas[c]

[a]*Technological Educational Institute of Western Greece, Department of Agricultural Technology, Theodoropoulou Terma, Amaliada, 27200, Greece*
[b]*Technological Educational Institute of Epirus, Department of Agricultural Technology, Kostakioi, Arta, 47100, Greece*
[c]*Technological Educational Institute of Western Greece, Department of Mechanical & Water Resources Engineering, Nea Ktiria, Messolonghi, 30200, Greece*

Abstract

The purpose of this study was to implement the monthly FAO Penman-Monteith evapotranspiration estimation method in a GIS environment, given the importance of spatial estimation of the evapotranspiration in the rational management of water resources and also the lack of easily applicable methodology in GIS environment. In this context, a Python programming language script was developed for implementing monthly FAO Penman-Monteith evapotranspiration equation, in ESRI's ArcMap environment. This approach has the advantage of being independent of the type of geospatial data and can be applied in point, line and polygon data while at the same time being flexible and time saving without loss of accuracy. The methodology was applied using meteorological data of the 2011 irrigation period (March to September), acquired from the meteorological station located at the campus of Technological Educational Institute of Western Greece at Messolonghi (38° 21' 58'' N; 21° 28' 41'' E), with the results being very satisfactory.

Peer-review under responsibility of Data Research and Consulting

Keywords: Evapotranspiration; water resources; FAO Penman-Monteith; GIS; Python

1. Introduction

Evapotranspiration is a key hydrometeorological process and its estimation is important in many fields of hydrological and agricultural sciences. Accurate estimation of evapotranspiration has gained scientific interest due to high importance in hydrological modelling, irrigation planning and water resources management. According to

* Corresponding author. Tel.: +30-261-500-7675. *E-mail address*: nmalamos@teimes.gr

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Farquhar and Roderick (2007), changes in evaporative demand affect fresh water supplies and have impact on agriculture, the biggest consumer of fresh water. Estimating water requirements for irrigation purposes goes back to 1890 in the USA (Jensen and Haise, 1963).

This study presents an implementation of the monthly FAO Penman-Monteith evapotranspiration estimation method by using the Python scripting language, inside the ESRI's ArcMap environment. This approach has the advantage of being independent of the type of geospatial data and can be applied in point, line and polygon data while at the same time being flexible and time saving without loss of accuracy.

The methodology was applied using meteorological data of the 2011 irrigation period (March to September), acquired from the meteorological station located at the campus of Technological Educational Institute of Western Greece at Messolonghi.

2. Penman-Monteith evapotranspiration model

The Penman-Monteith formulation (Monteith, 1981) was proposed by FAO as the standard method for computing Potential or Reference Evapotranspiration (ET_0) (Allen et al., 1989) and has had numerous successful applications in hydrology and agrometeorology in various hydroclimatic regimes.

By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The FAO model (Allen et al., 1998) of the Penman-Monteith equation to estimate potential evaporation or evapotranspiration is expressed as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{\mathrm{T}+273} u_2 (e_s - e_a)}{\Delta + \gamma \;\; 1 + 0.34u_2} \quad (1)$$

where ET_0 is potential evapotranspiration (mm/d), R_n is net radiation at the at the crop surface, G is the soil heat flux density, T is the mean air temperature at 2 m height, u_2 is the wind speed at 2 m height, Δ is the slope of the saturation vapor pressure curve, γ is the psychometric coefficient while e_s and e_a are the saturation and actual vapour pressures.

2.1. Required data

Apart from the site location, the FAO Penman-Monteith equation requires air temperature, humidity, radiation and wind speed data for daily, weekly, ten-day or monthly calculations.

3. Python scripting language

Python is a multi-paradigm programming language: object-oriented programming and structured programming are fully supported, and there are a number of language features which support functional programming and aspect-oriented programming. Python uses dynamic typing and a combination of reference counting and a cycle-detecting garbage collector for memory management. An important feature of Python is dynamic name resolution (late binding), which binds method and variable names during program execution. All Python releases are Open Source and historically, most, but not all, Python releases have also been GPL-compatible (Wikipedia, 2014).

4. Python procedures for calculating ET_0

According to Allen et al. 1998, the variables and expressions presented in Table 1 are required for the ET_0 calculation.

Table 1 Required variables and expressions for FAO ET_0 calculation according to Allen et al. 1998

Variable/Function
Mean saturation vapour pressure (e_s)
Slope of saturation vapour pressure curve (Δ)
Actual vapour pressure (e_a) derived from relative humidity data
Vapour pressure deficit ($e_s - e_a$)
Extraterrestrial radiation (R_a)
Solar or shortwave radiation (R_s)
Relative shortwave radiation (R_s / R_{so})
Albedo (α) and net solar radiation (R_{ns})
Net longwave radiation (R_{nl})
Net radiation (R_n)
Soil heat flux (G)

The above mentioned variables and functions were formulated in a Python script inside the ESRI's ArcMap environment. The goal was to implement the Field Calculator feature, inside the shapefile attribute table. This approach has the advantage of being independent of the type of geospatial data and can be applied in point, line and polygon data while at the same time being flexible and time saving without loss of accuracy.

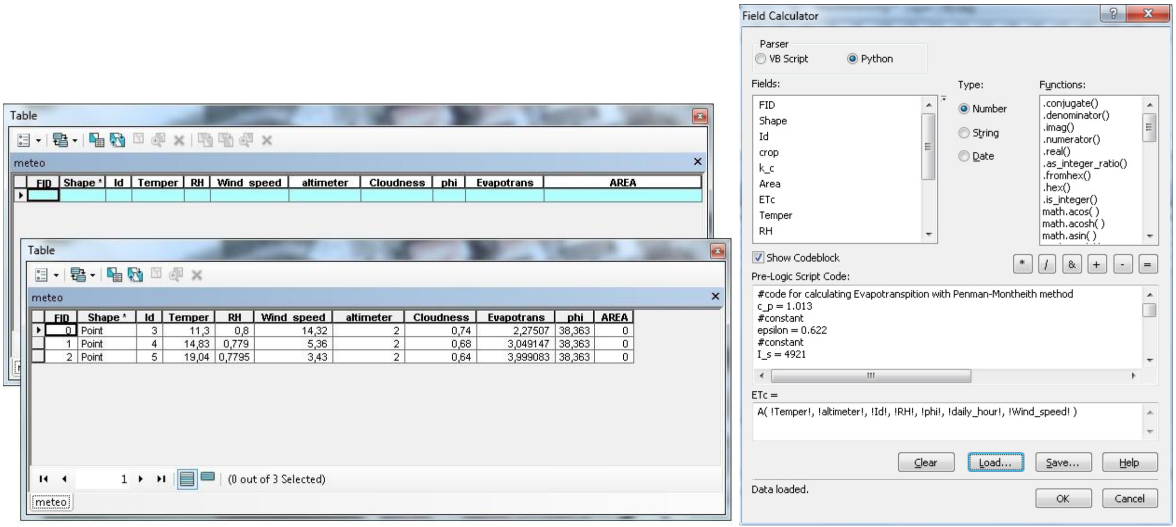


Figure 1 The shapefile attribute table and the Field Calculator tool inside the ArcMap environment

The required monthly data in order to be able to execute the script are (Fig. 1):

- The corresponding latitude φ, (radians) and altitude (m)
- The temperature T, (^{o}C)
- The relative humidity RH
- The wind speed (m/s)
- The actual duration of sunshine n, (h)

All the necessary calculations for the ET_0 estimation are accomplished within the script, which is presented in the Appendix.

4.1. Study area description

The study area is located at the region of Western Greece near the city of Messolonghi (Fig. 2) at the Technological Educational Institute of Western Greece campus and it is most likely dedicated to agriculture since it was reclaimed from the sea during the decade of 1960-1969. Main cultivations constitute from arable crops and some olive and citrus trees.

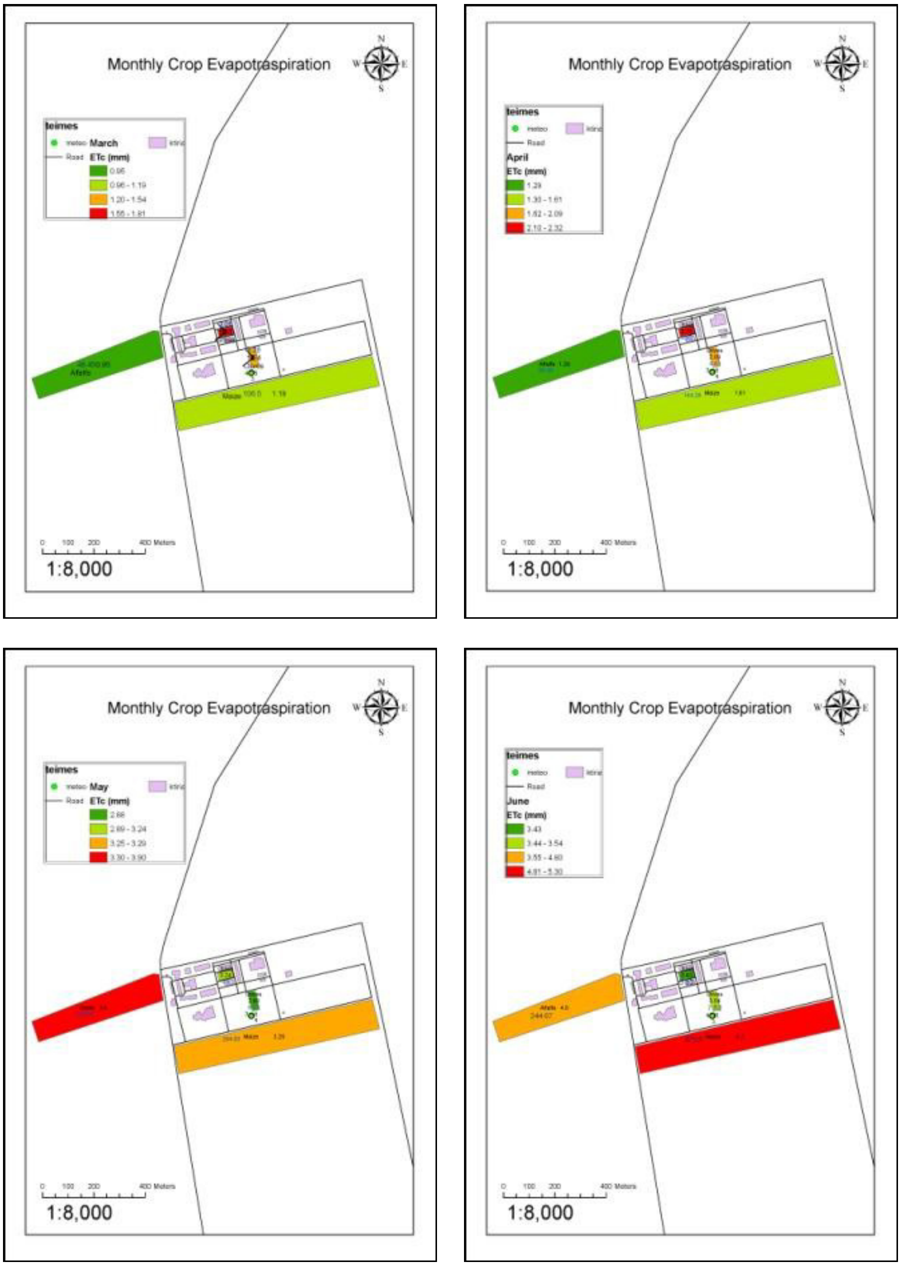
Figure 2 Study area of Technological Educational Institute of Western Greece at Messolonghi

5. Results

The methodology was applied using meteorological data of the 2011 irrigation period (March to September), acquired from the meteorological station located at the campus of Technological Educational Institute of Western Greece at Messolonghi (38^o 21’ 58’’ N; 21^o 28’ 41’’ E). As a consequence, the crop evapotranspiration is easily calculated. For exploration purposes we calculated crop evapotranspiration for fields adjacent to the Messolonghi campus cultivated with maize, alfalfa and olive trees for the corresponding irrigation period. The results are presented in Fig. 3 and in Table 2.

Table 2 Results of the evapotranspiration calculation procedure, for the irrigation period 2011 (March to September)

	March				April			
crop	Grass	Maize	Alfalfa	Olives	Grass	Maize	Alfalfa	Olives
Kc	0.62	0.65	0.9	0.7	0.72	0.5	0.4	0.65
Area (m^2)	1696.51	89665.42	50993.26	2127.07	1696.51	89665.42	50993.26	2127.07
Etc (mm/day)	1.81	1.19	0.95	1.54	2.32	1.61	1.29	2.09
Et0 (mm/day)	2.38	2.38	2.38	2.38	3.22	3.22	3.22	3.22
Water needs (m^3)	3.06	106.5	48.45	3.28	3.93	144.28	65.64	4.45
	May				June			
	Grass	Maize	Alfalfa	Olives	Grass	Maize	Alfalfa	Olives
Kc	0.79	0.8	0.95	0.7	0.68	1.05	0.95	0.7
Area (m^2)	1696.51	89665.42	50993.26	2127.07	1696.51	89665.42	50993.26	2127.07
Etc (mm/day)	3.24	3.29	3.9	2.88	3.43	5.3	4.8	3.54
Eto (mm/day)	4.11	4.11	4.11	4.11	5.05	5.05	5.05	5.05
Water needs (m^3)	5.5	294.63	198.97	6.12	5.83	475.5	244.67	7.52
	July				August			
	Grass	Maize	Alfalfa	Olives	Grass	Maize	Alfalfa	Olives
Kc	0.71	1.05	0.95	0.7	0.71	0.8	1.05	0.7
Area (m^2)	1696.51	89665.42	50993.26	2127.07	1696.51	89665.42	50993.26	2127.07
Etc (mm/day)	3.41	5.05	4.57	3.37	3.54	3.99	5.23	3.49
Et0 (mm/day)	4.81	4.81	4.81	4.81	4.98	4.98	4.98	4.98
Water needs (m^3)	5.79	452.68	232.92	7.16	6	357.32	266.72	7.42
	September							
	Grass	Maize	Alfalfa	Olives				
Kc	0.62	0.65	0.9	0.7				
Area (m^2)	1696.51	89665.42	50993.26	2127.07				
Etc (mm/day)	2.48	2.6	3.61	2.8				
Et0 (mm/day)	4.01	4.01	4.01	4.01				
Water needs (m^3)	4.21	233.49	183.86	5.96				


Monthly Crop Evapotraspiration
N
W
E
S
teimes
meteo
Road
March
ETc (mm)
0.95
0.96 - 1.19
1.20 - 1.54
1.55 - 1.81
1:8,000
Monthly Crop Evapotraspiration
teimes
meteo
Road
April
ETc (mm)
1.29
1.30 - 1.61
1.62 - 2.09
2.10 - 2.32
1:8,000
Monthly Crop Evapotraspiration
teimes
meteo
Road
May
ETc (mm)
2.88
2.89 - 3.24
3.25 - 3.29
3.30 - 3.90
1:8,000
Monthly Crop Evapotraspiration
teimes
meteo
Road
June
ETc (mm)
3.43
3.44 - 3.54
3.55 - 4.80
4.81 - 5.30
1:8,000

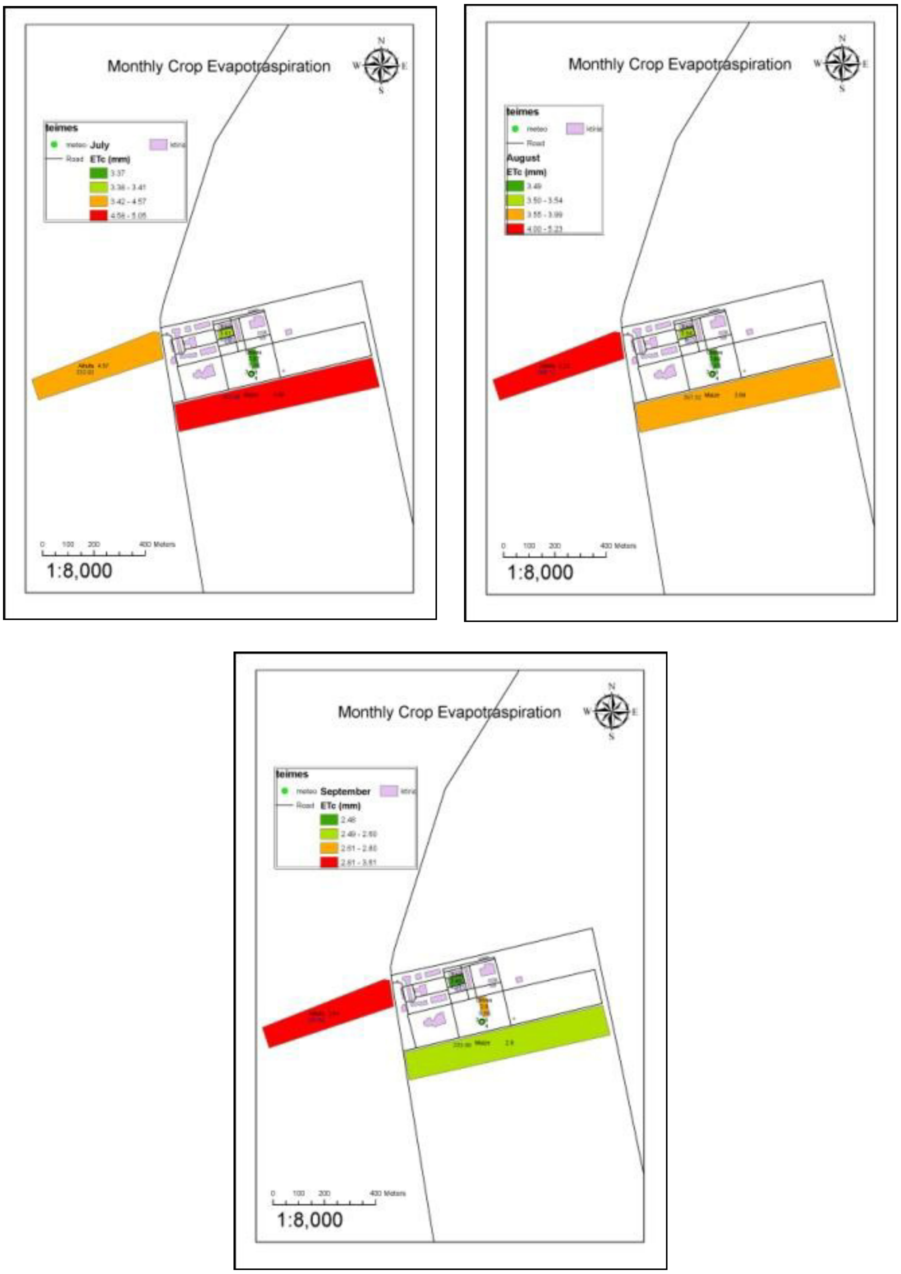


Figure 3 Application maps for the irrigation period 2011 (March to September)

6. Conclusions

The above presented methodology of calculating monthly FAO Penman-Monteith evapotranspiration, which was developed in the ESRI's ArcMap environment, through Python language has the advantage of being independent of the type of geospatial data and is applicable to point, line and polygon geospatial data, resulting in flexibility and economy of time without loss of accuracy. Its application was successful and took place using meteorological data of the 2011 irrigation period (March to September), acquired from the meteorological station located at the campus of Technological Educational Institute of Western Greece at Messolonghi.

Appendix A.

A.1. Code for calculating monthly Evapotranspition with Penman-Montheith method

```
c_p = 1.013
#constant
epsilon = 0.622
#constant
I_s = 4921
#Solar constant, kJ/m^2/h
a_s =0.355
b_s=0.68
#
Albedo = 0.25
#Albedo constant
a_e=0.56
b_e=0.08
#
a_l=0.2
#
sigma=0.0000049
#Stefan-Boltzmann constant, kJ/(m^2 K^4 d)
coef=0.33
#
c2=90
c3=273
#
def A(T, alt, m, RH, phi, n, Wind_speed):
#Specific heat (kJ/kg) for a given temperature (oC)
  templamda = 2501 - 2.361 * T
#Standard pressure (hPa) for a given elevation (m)
  temppressure = 1013 * (1 - 0.00002256 * alt)** 5.256
#Air density (kg/m^3) at a given air pressure (hPa) and temperature (oC)
  tempdensity = 0.3486 * temppressure /(273 + T)
#Psychrometric constant (hPa/oC) for a given pressure (hPa) and Specific heat (kJ/kg)
  tempgamma = (c_p /epsilon)* temppressure / templamda
#Saturation vapor pressure (hPa) for a given temperature (oC)
  tempe_s = 6.11*math.exp(17.27* T /(237.3+ T ) )
#Slope of the saturation vapor pressure curve (hPa/oC) for a given temperature (oC)
  tempdelta = 4098* tempe_s /(237.3+ T )**2
 #Astronomical quantities
  if m==1:
   j = 17
  elif m==2:
   j = 46
  elif m==3:
```

```
     j = 75
    elif m==4:
     j = 105
    elif m==5:
     j =135
    elif m==6:
     j = 162
    elif m==7:
     j = 198
    elif m==8:
     j = 228
    elif m==9:
     j = 258
    elif m==10:
     j = 289
    elif m==11:
     j = 319
    elif m==12:
     j = 345

    #vapor pressure (hPa)
    tempe = tempe_s * RH
  #Solar declination (rad) for a given day
    tempdeclination = -0.4093* math.cos(2* math.pi * j / 365+0.16 )
  #Eccentricity for a given day
    tempeccentricity = 1+0.034* math.cos(2*math.pi* j / 365-0.05 )
  #Sunset angle (rad) for a given day and lattitude
    tempphi_rad = phi *math.pi/180
    tempphi =- math.tan(tempphi_rad)* math.tan(tempdeclination)
  #For lattitude > 66.5 (or < - 66.5)
    tempo_s=tempphi
    if math.fabs(tempo_s) > 1.161:
      o_s=0
    else:
      o_s = float(math.acos(tempo_s))
  #edit 6-12-2013
    tempN=(24/math.pi)*o_s
    cl=n/tempN
  #Extraterrestial shortwave radiation (kJ/m^2/d) for a given day and lattitude
    S0temp= (24/math.pi) * I_s * tempeccentricity
    tempS_0=S0temp*(o_s * math.sin(tempphi_rad) * math.sin(tempdeclination)+ math.cos(tempphi_rad) *
math.cos(tempdeclination) *math.sin(o_s))
    tempf_s = a_s+b_s*(1-cl)
  #Shortwave radiation (kJ/m^2/d) for given albedo, fraction of sunshine duration
    tempS_n = (1-Albedo)*tempf_s*tempS_0
  #Lo
    tempe_n= a_e-b_e*math.sqrt(tempe)
    tempf_l=a_l+(1 - a_l)*(1-cl)
  #Longwave radiation (kJ/m^2/d) for given temperature (oC), fraction of sunshine duration
    tempL_n=tempe_n*tempf_l*sigma*(T+273)**4
  #Mass transfer term for various cases of evaporation calculations
```

```
  tempgamma_rc=(1+coef*Wind_speed)*tempgamma
#Mass transfer term (kg/(hPa m^2 d)) of reference crop for given wind speed (m/s)
  tempF_rc=(c2/(T+c3))*Wind_speed
#Penman-Montieth method
#A=Δ/(Δ+γ')
  tempA=tempdelta/(tempdelta+tempgamma_rc)
#B= γ/(Δ+γ')
  tempB=tempgamma/(tempdelta+tempgamma_rc)
  tempD=tempe_s-tempe
  tempRn=tempS_n-tempL_n
  temp_Epm=tempA*tempRn/templamda+tempB*tempF_rc*tempD
  A=temp_Epm
  return A
```

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Main Features and Application of a Web-based Irrigation Management Tool for the Plain of Arta

Nikolaos Malamos[1], Ioannis L. Tsirogiannis[2], Antonis Christofides[3], Stavros Anastasiadis[4], Silvia Vanino[5]

[1]Technological Educational Institute of Western Greece, Dept. of Agricultural Technology, 27200 Amaliada, Greece, e-mail: nmalamos@teimes.gr
[2]Technological Educational Institute of Epirus, Dept. of Agricultural Technology, 47100 Kostakii, Arta, Greece, e-mail: itsirog@teiep.gr
[3]National Technical University of Athens, Dept. of Water Resources and Environmental Engineering, Iroon Politechniou 5, 15780 Zografou, Athens, Greece, e-mail: anthony@itia.ntua.gr
[4]Chios, Greece, e-mail: anastasiadis.st00@gmail.com
[5]Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, 41 Nomentana St., 00161, Rome, Italy, e-mail: vanino@inea.it

Abstract. Agriculture plays a key role in the management of water use. Especially in Greece, irrigation is an essential element of agricultural production and agricultural water use has a substantial share in total water use. The presented study illustrates the key features of the IRMA_SYSTEM, a regional, user-friendly computer/mobile-based, open and free modular software for estimating site specific crop water requirements and irrigation scheduling at multiple scales, from farm to water basin level. The estimation of irrigation water requirements and irrigation scheduling is based on a modification of the FAO 56 approach. The system takes into account historical and forecast agrometeorological data, along with crop and soil-water data to accomplish its tasks. Also, it is fully customizable, allowing the users to add site and crop specific information taking advantage of additional data. Feedback and evaluation procedures are already applied and expected to contribute to the improvement of the system.

Keywords: irrigation scheduling, open source software, agrometeorological information

1 Introduction

According to the EU Water Framework Directive WFD, 2000/60/EC (EU, 2000 (Greek law (GL) 3199; Govern. Gazette (GG) A'280 9-12-2003) and Presidential Decree (PD) 51;GG A′54 8-3-2007)), action is needed to protect waters primary in qualitative but also in 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

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to develop added value tools to optimize efficiency in irrigation. 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). Also CMMC (2013) predicts a reduction up to 60% in water availability for irrigation in extended Mediterranean areas of EU countries. These facts make optimum irrigation water management a top priority goal. Beyond these, the European Landscape Convention (which was adopted by the Greek state in 2010, GL 3827;GG A'30 25-2-2010) promotes protection, management and planning of natural, rural, urban and peri-urban areas including land, inland water and marine areas and must be also taken into account as an integral part of the environmental and agricultural legislative framework. Among the various measures which member states are proposed to adopt and develop are added value tools to optimize efficiency in irrigation.

The purpose of the present study is to illustrate the key features of such a tool, the IRMA_SYSTEM (http://arta.irrigation-management.eu/), which is a regional, user-friendly computer/mobile-based, open and free modular software for estimating site specific crop water requirements and irrigation scheduling at multiple scales, from farm to water basin level, with high spatial resolution. The system takes into account historical (from the system's stations) and forecast agrometeorological data, along with crop and soil-water data to accomplish the above mentioned tasks. Also, it is fully customizable, allowing the users to add site specific information in order to customize the output of the system, taking advantage of additional information.

Similar systems are: the California Irrigation Management Information System (CIMIS, http://wwwcimis.water.ca.gov/), the Hydrotech-DSS (Todorovic et al. 2013) and the ServiziAgronomici e Fitosanitari, Consiglio Irriquo (http://www.agrometeopuglia.it) (AssocodiPuglia, 2008).

2 Materials and Methods

2.1 Study Area

The Region of Epirus (hydrological area GR05; Fig. 1) is located at the North-West part of Greece, it has a total area of 9.203km^2 (agricultural land corresponds to the 14% of it) and a population of 353.820 p. The plain of Arta (45.329 ha, the biggest of the region), is located at the south edge of Epirus, it is part of the Aracthos and Louros hydrological basins (GR14 and GR46; WFD, 2013) and intersects with Amvrakikos Wetlands National Park.

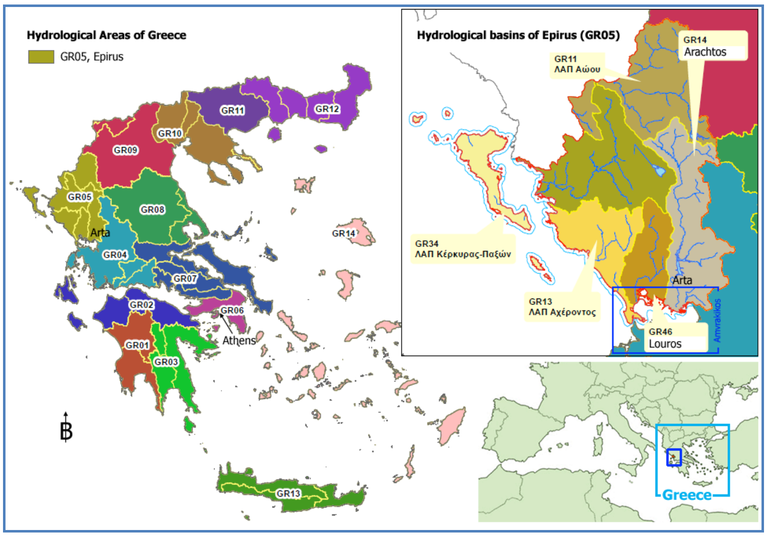

Fig. 1. Hydrological basins of Greece, along with the hydrological basins of Epirus. (WFD, 2013)

2.2 Estimation of daily and hourly potential evapotranspiration, with the Penman - Monteith equation

The Penman - Monteith (PM) equation for the estimation of reference evapotranspiration was developed to describe potential evapotranspiration (PET) 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, Eq. 1). 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 Eq. 1 from the observed climatic variables.

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

where PET is the grass reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2m height (^{o}C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s–e_a is saturation vapor pressure deficit (kPa), Δ is slope of the vapor 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 PET 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. With the use of the IRMA_SYSTEM, automated weather stations, weather data are available for hourly periods. Therefore, the PM equation was applied on an hourly basis (Allen et al., 1998).

2.3 Estimation of irrigation needs

The irrigation needs are 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 (*start date*, *end date*).

The basis for the calculation is the following ormula (Allen et al., 1998):

$$D_{r,i} = D_{r,i-1} - (P_i - RO_i) - IR_{n,i} - CR_i + ET_{c,i} + DP_i \quad (2)$$

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, P_i is the precipitation, RO_i is the runoff, $IR_{n,i}$ is the net irrigation depth, CR_i is the capillary rise, $ET_{c,i}$ is the crop evapotranspiration, DP_i is the water loss through deep percolation.

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

$$\Theta_s <= D_{r,i} <= ASM \quad (3)$$

where Θ_s is the soil moisture at saturation and ASM is the total available soil water, which is the difference between Field Capacity (FC) and Permanent Wilting Point (PWP) as they are presented in Fig. 2. This approach is slightly different that the one proposed by Allen et al., 1998, since they propose that $D_{r,i}$ is always positive.

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

$$RO_i = P_i + \Theta_{i-1} - \Theta_s \text{ when } (P_i + \Theta_{i-1} - \Theta_s) > 0 \quad (4)$$

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

The equation therefore becomes:

$$D_{r,i} = D_{r,i-1} - P_i - IR_{n,i} + ET_{c,i} + RO_i \quad (5)$$

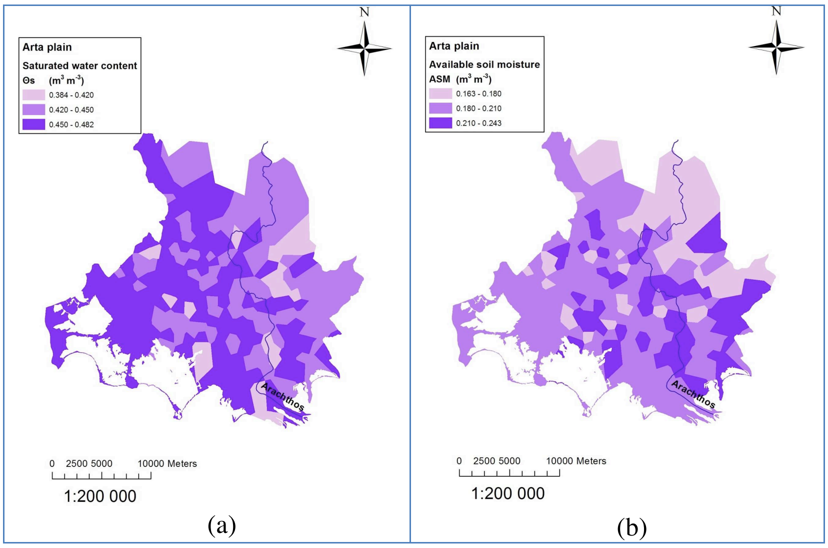

Fig. 2. Saturated water content (*Θs*) map (a) and Available soil moisture (ASM) map (b) of IRMA_SYSTEM area at Arta plain.

$ET_{c,i}$ is calculated using crop coefficient approach by multiplying evapotranspiration by 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 i=1 and $D_{r,1}=0$.

The point i=1 is specified by *start_date*, which is a datetime object. The *initial_soil_moisture* will usually equal FC (this, according to the essential simplifying assumption, means that the crop was irrigated on *start_date*). However, if the crop has not been irrigated recently, *initial_soil_moisture* will be set to another value (such as a soil moisture measurement made at *start_date*).

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

$$\Theta_i = FC - D_{r,i} / \text{Root depth} \tag{6}$$

So, since the *initial_soil_moisture* is given, $D_{r,1}$ is also known.

The method returns the root zone depletion for *end_date* in millimeters (mm). Precipitation and ET_c must have non-null records for all days from the day following *start_date* to *end_date*.

2.4 System Implementation

The system is 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. The general organisation of the system is presented in Fig. 3, while the flowchart of the system modules is presented in Fig. 4.

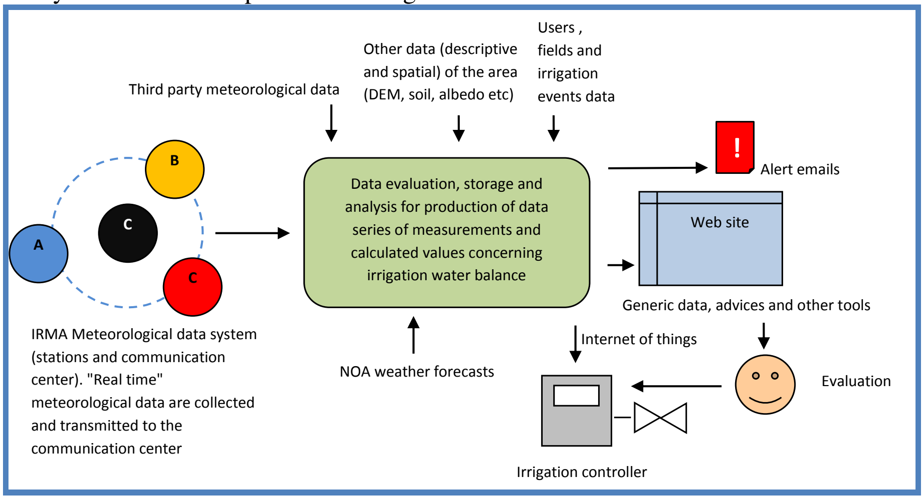

Fig. 3. IRMA_SYSTEM organisation plan

The IRMA_SYSTEM is a user-friendly computer/mobile-based, open and free modular software, with its source available at: https://github.com/openmeteo/aira, under the terms of the GNU General Public License as published by the Free Software Foundation, written in Python and Django, along with NumPy (http://www.numpy.org/) and GDAL - Geospatial Data Abstraction Library (http://www.gdal.org/) modules.

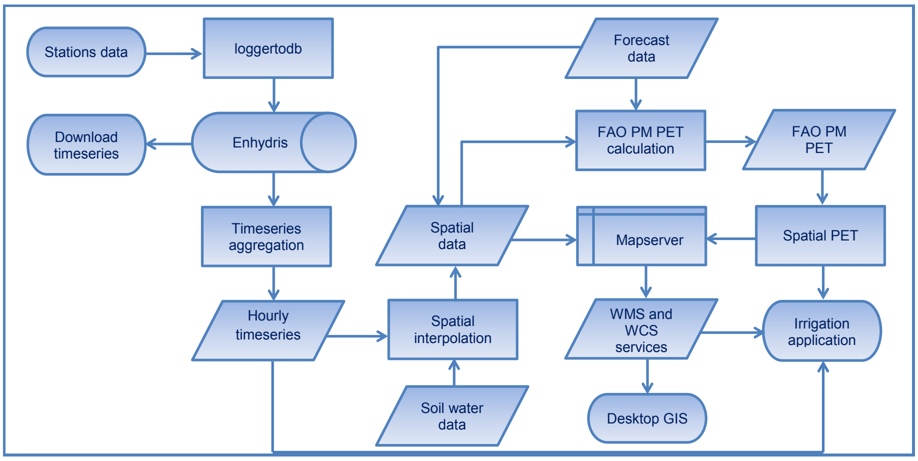

Fig. 4 Flowchart of IRMA system modules

The Enhydris database (http://system.irrigation-management.eu, https://enhydris.readthedocs.org) web interface, with the available meteorological stations is presented in Fig. 5. It includes a map that provides information about the location of each station, together with the identification numbers, water basin, water division, owner and type of the meteorological stations.

Agrometeorological data timeseries and crop water requirements estimations are provided to users and 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.

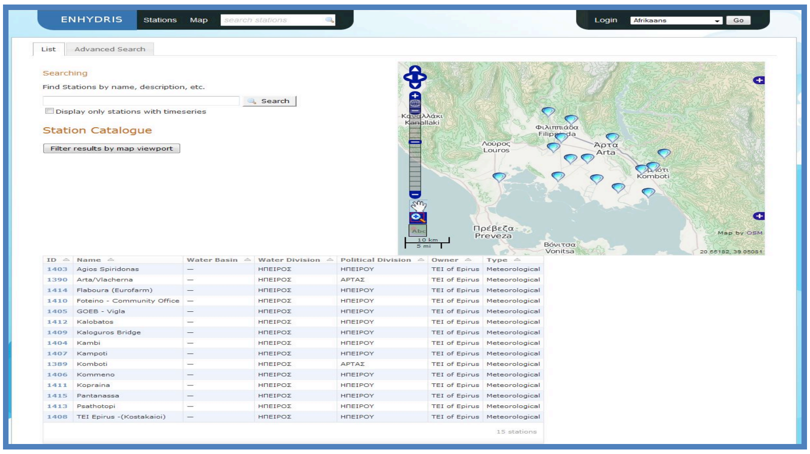

Fig. 5. The Enhydris database web interface

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.

Figure 6 presents the home page of the system. The main feature is 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 are produced by implementing the Inverse Distance Weighting (Burrough and McDonnell, 1998) method for spatial interpolation, found in the GDAL library.

The system provides this information of the study area, through the WMS service provided by the Mapserver that was set for the purposes of the present project (http://mapserver.org/). The historical data are kept from 1/1/2015 onwards, while several maps produced by satellite images are also available.

Registered users can add their fields into the system (Fig. 7) 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. 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 is available at the bottom of the page.

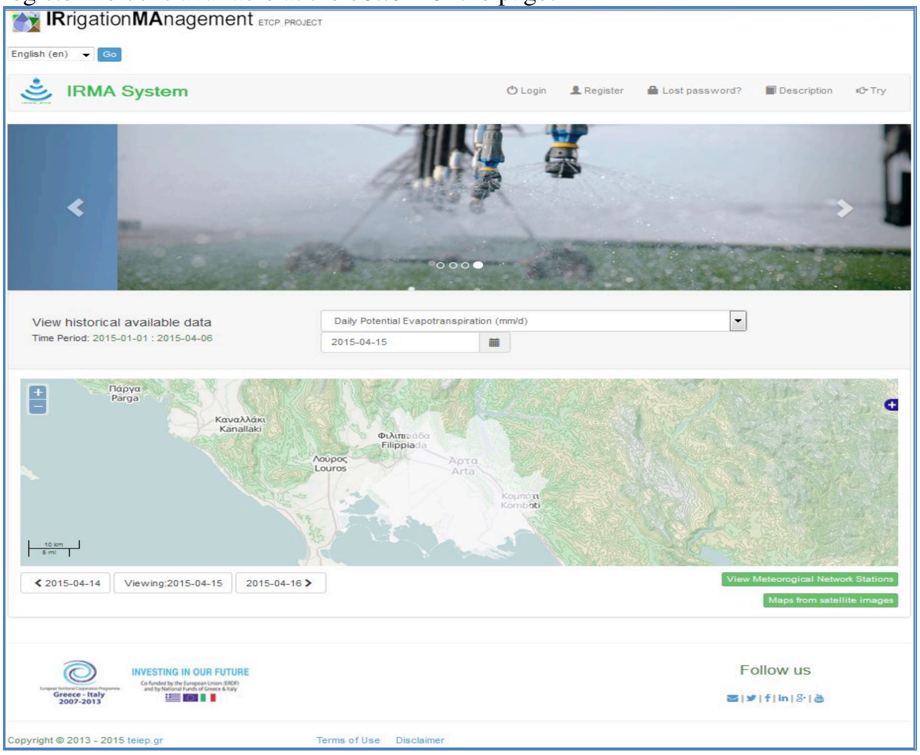

Fig. 6. IRMA_SYSTEM front page

If appropriate information is available to the registered users, they are able to modify the properties of each field, based on this information, as shown in Fig. 7. This information consists 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, are available to the user in order to provide guidance.

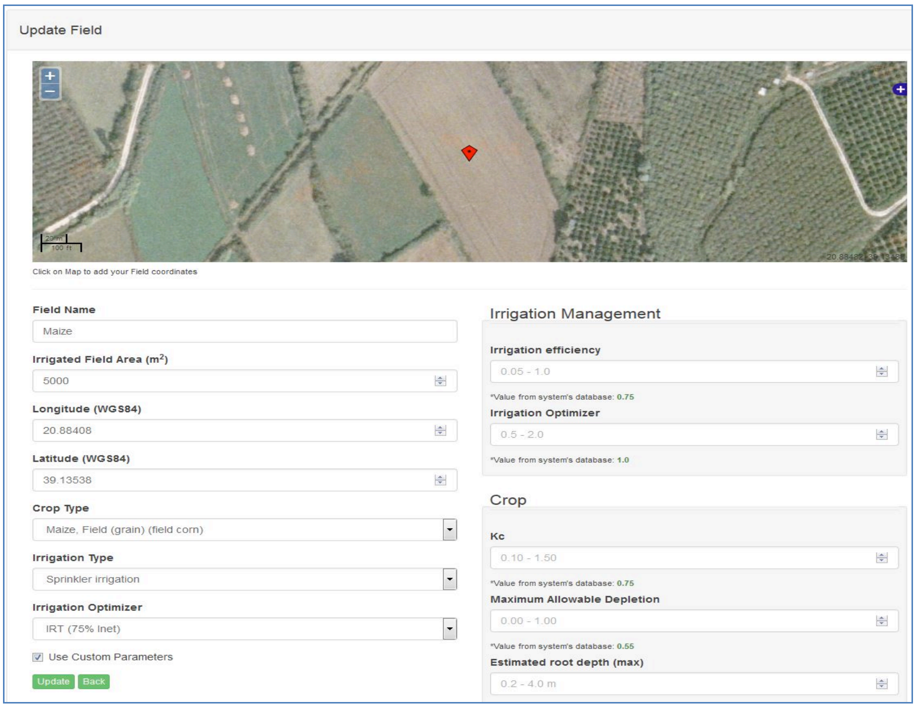

Fig. 7. The Update Field module of the IRMA_SYSTEM

Since the initial soil moisture is included in the initial conditions of the soil water balance module of the IRMA_SYSTEM, register users should add the irrigations that they have applied for each field, in order to get the appropriate irrigation advices. If the user does not provide information about the applied irrigation water volume, the system assumes that the applied water was enough in order for the soil to reach field capacity. Figure 8 depicts the irrigation events list module of the IRMA_SYSTEM.

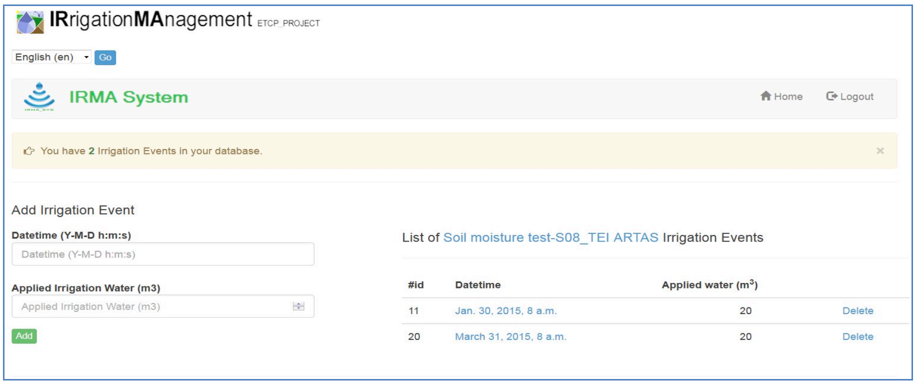

Fig. 8. The Irrigation Events list module of the IRMA_SYSTEM

Since the registered users provide the above information, the system produces detailed irrigation advice estimates, in hourly basis, based on both historical and forecast data as presented in Figures 9, 10.

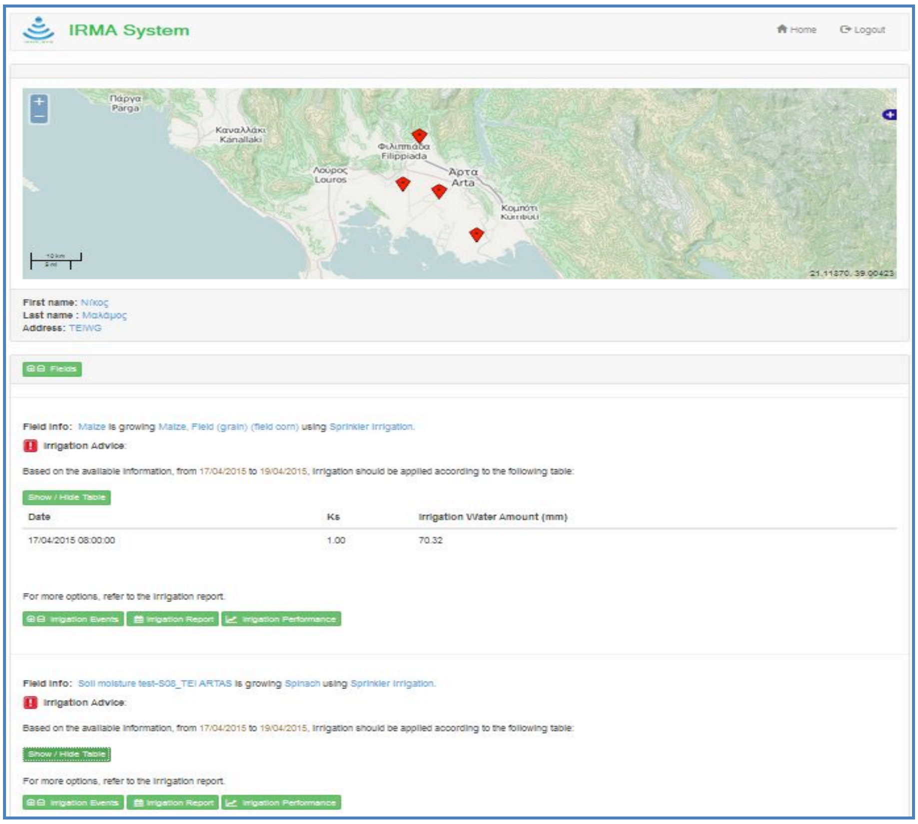

Fig. 9. Irrigation advice module of the IRMA_SYSTEM

2.5 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. 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 tool's web site.

Field evaluation will be held for both agriculture and landscaping case studies, against soil moisture readings from installed sensors at the agrometeorological stations and irrigation water amount recordings.

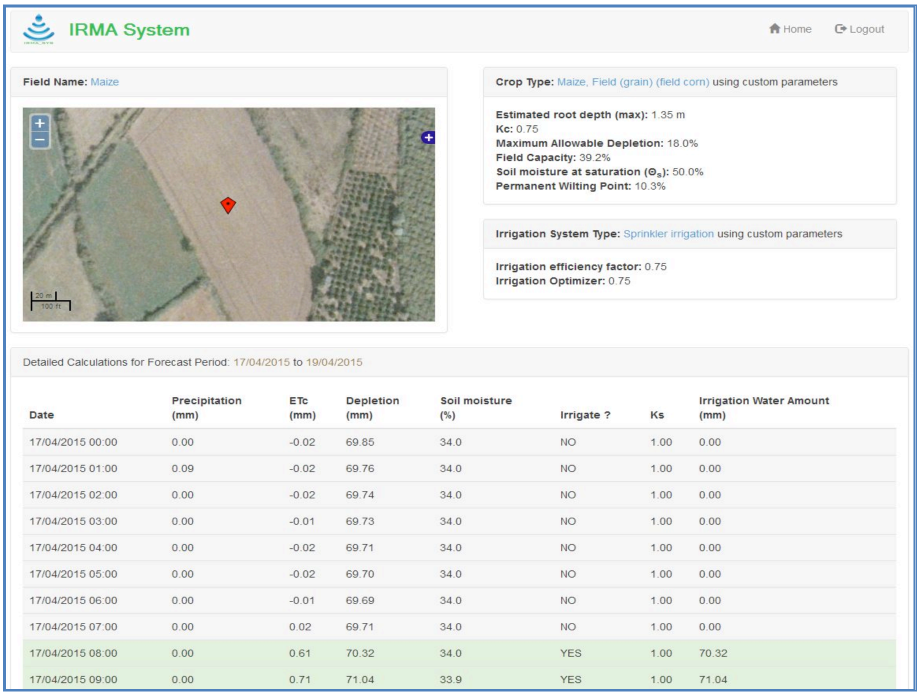

Fig. 10. Detailed irrigation report module of the IRMA_SYSTEM.

3 Conclusions

The IRMA_SYSTEM is an added value regional management and planning tool designed to contribute along with the other tools of IRMA project (http://www.irrigation-management.eu/) to the improvement of efficiency in irrigation techniques and irrigation scheduling from farm to water basin level, with high spatial resolution.

It is a user-friendly computer/mobile-based, open and free modular software that provides crop water requirements estimations and irrigation advices to users and visitors, based on agrometeorological data timeseries and a modified FAO 56 approach.

The system is fully customizable, allowing the users to add site and crop specific information in order to customize the output of the system, taking advantage of additional information.

It is easily expandable, since the individual modules are independent of the number of stations and accepts all kinds of forecast data.

The feedback and experimental evaluation procedures will contribute to the further improvement and versatility of the system, aiming at increased experience gain at regional level with different type of farms, crops and soil water information.

Acknowledgments. This work has been co-financed by EU / ERDF (75%) and national funds of Greece and Italy (25%) in the framework of the European Territorial Cooperation Programme (ETCP) GREECE-ITALY 2007-2013 (www.greece-italy.eu): IRMA project (www.irrigation-management.eu), subsidy contract no: I3.11.06.

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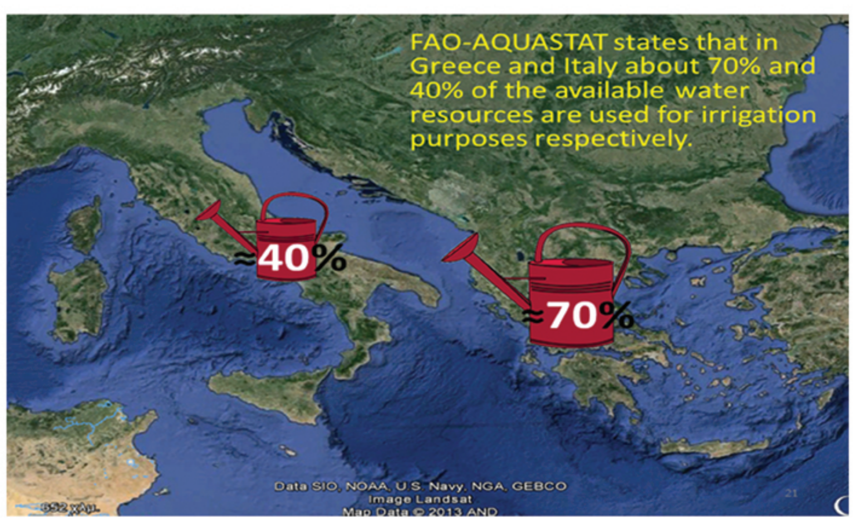
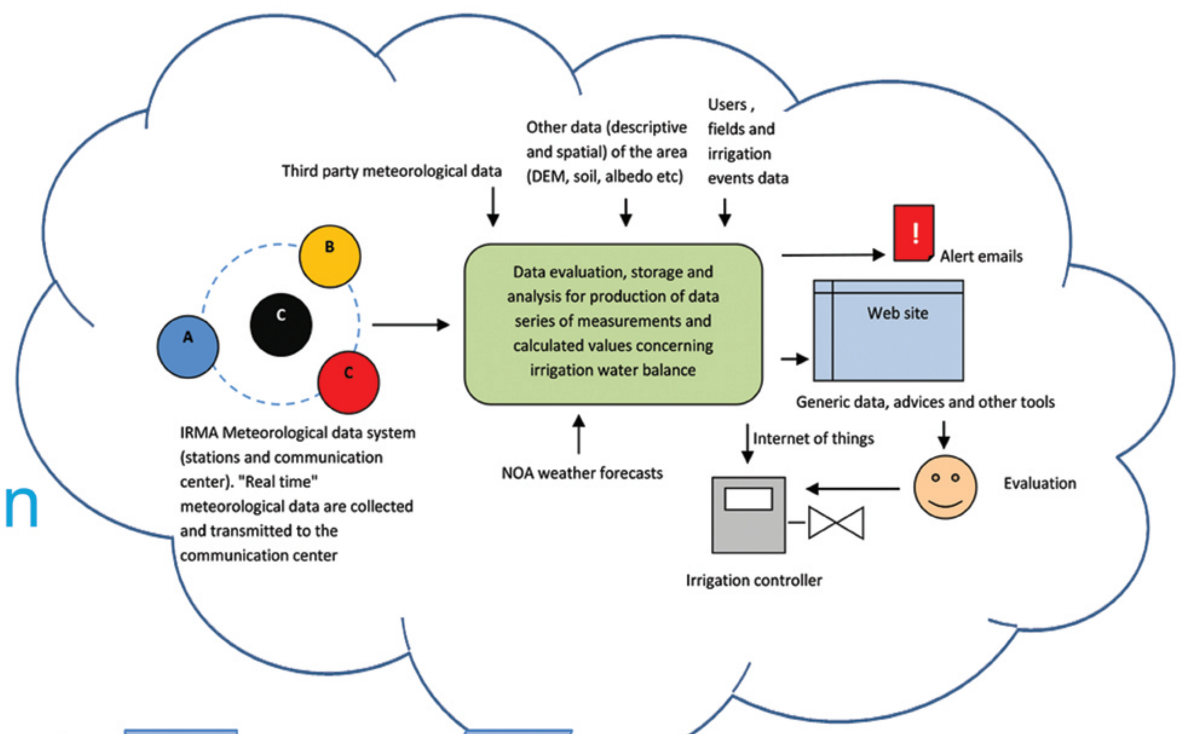
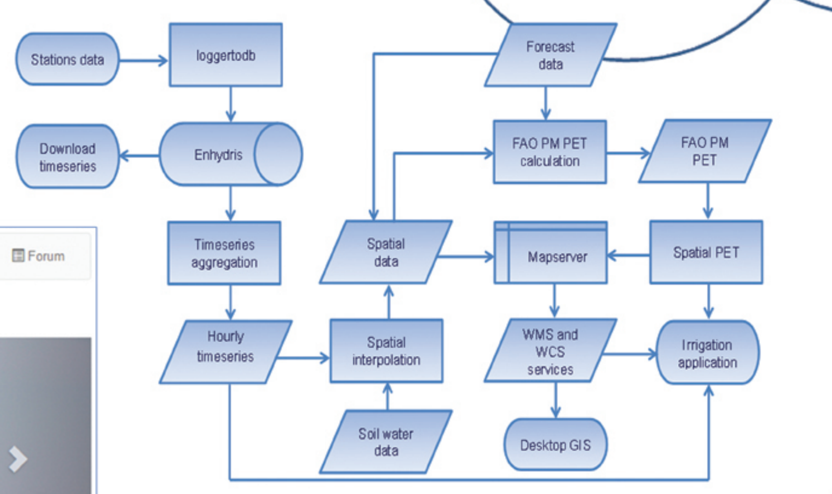
IRMA_SYS



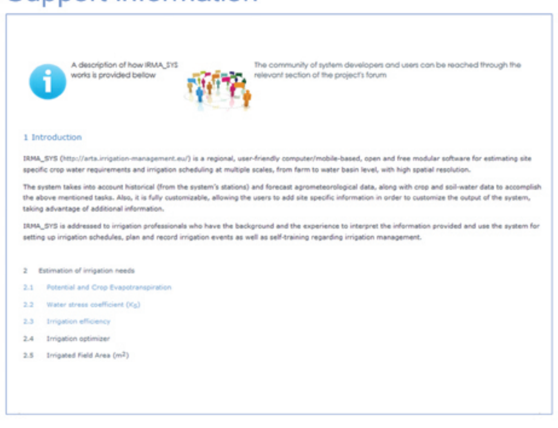
Inspiration based on actual needs and excisting solutions

Concept and design

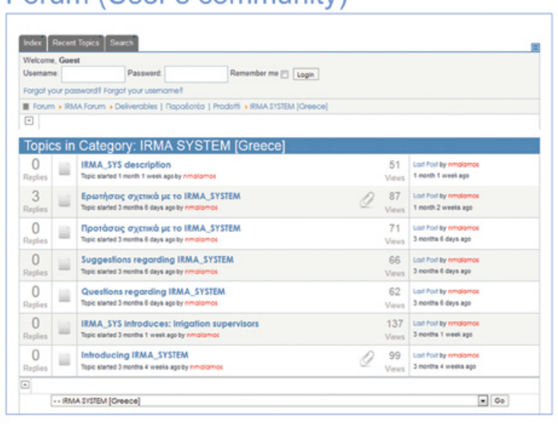




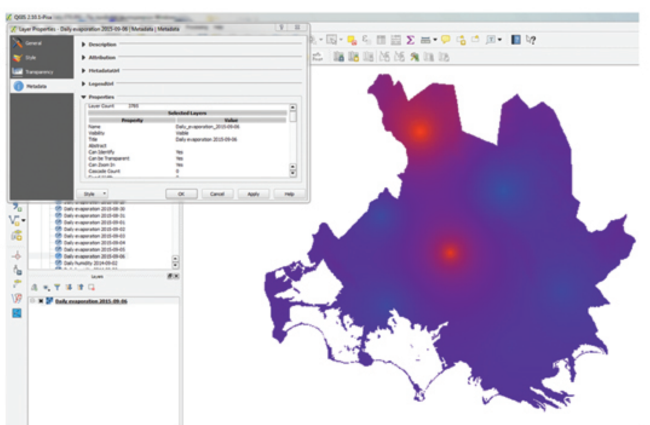
Support information

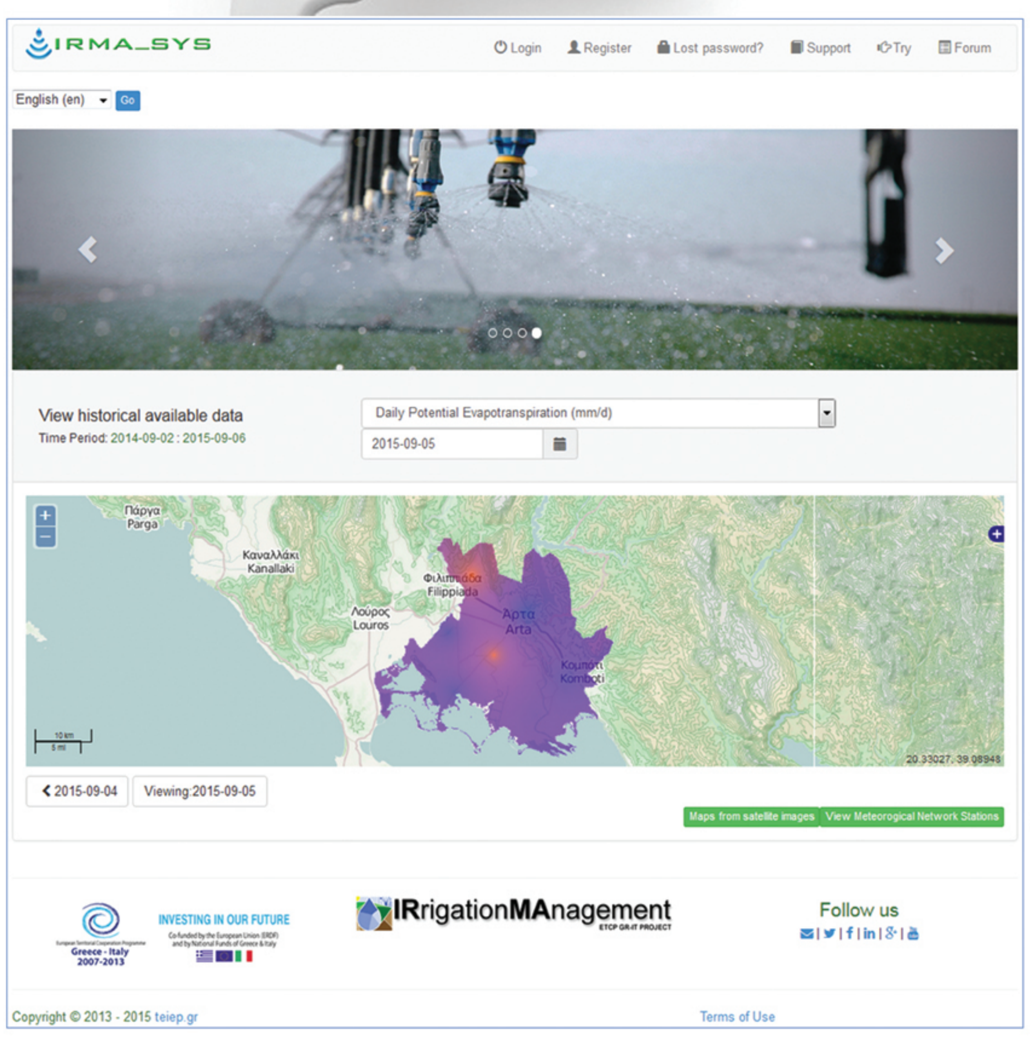


Forum (User's community)



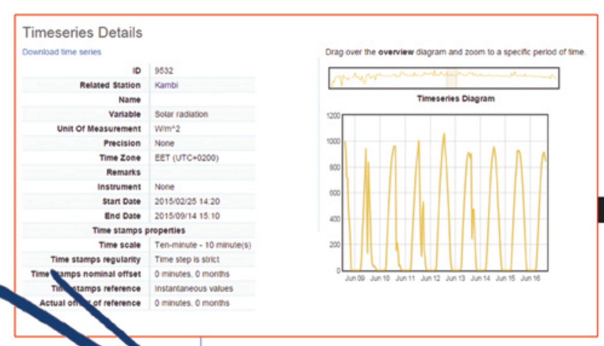
Try mode
Allows anyone interested to try the functionality of the tool



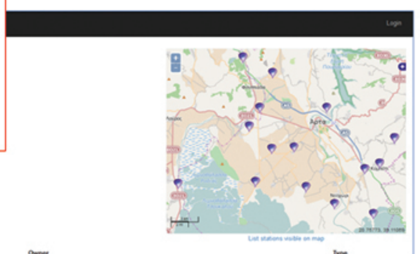


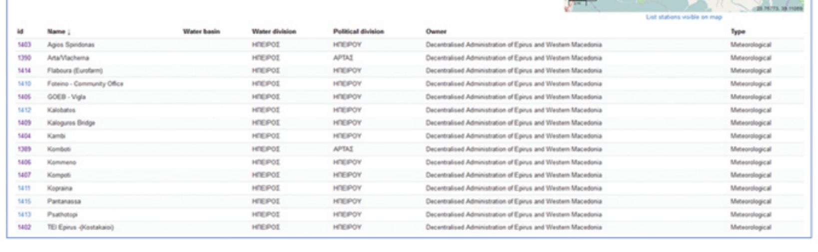
WCS-WMS services
http://arta.irrigation-management.eu/mapserver-historical

Meteo data time series

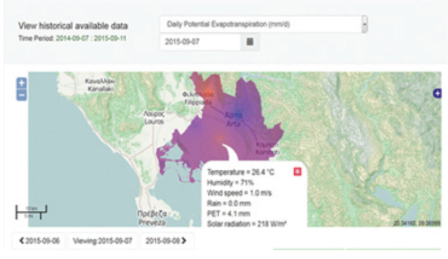


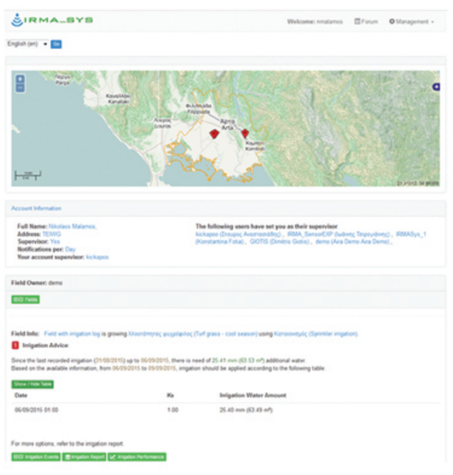
Powered by: NTUA's Enhydris and openmeteo.org



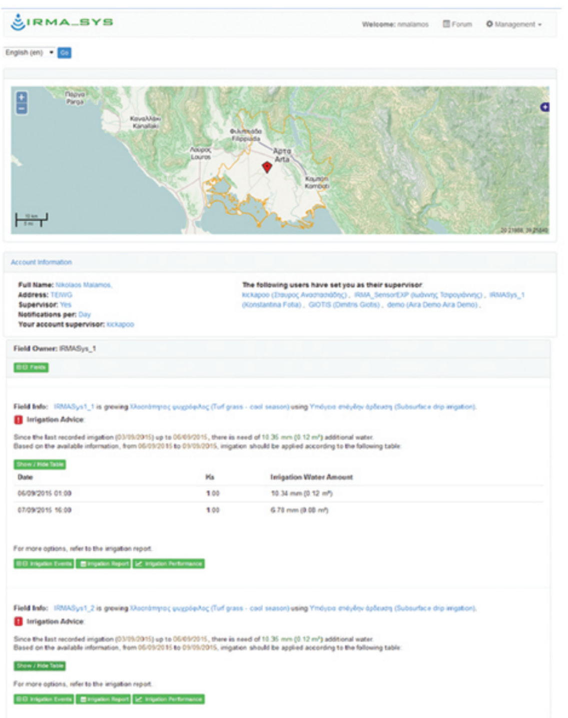


Interactive maps of variables

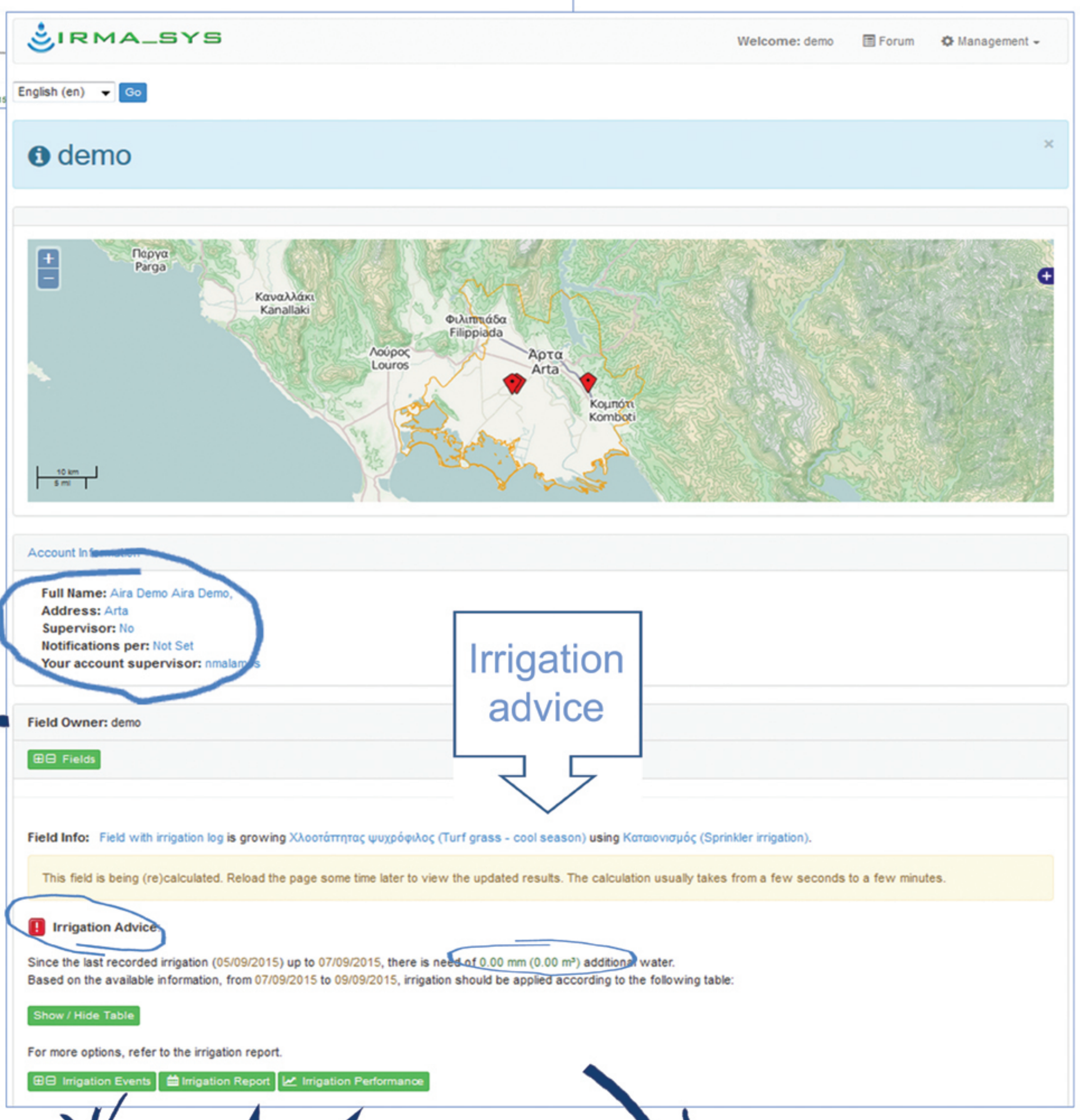


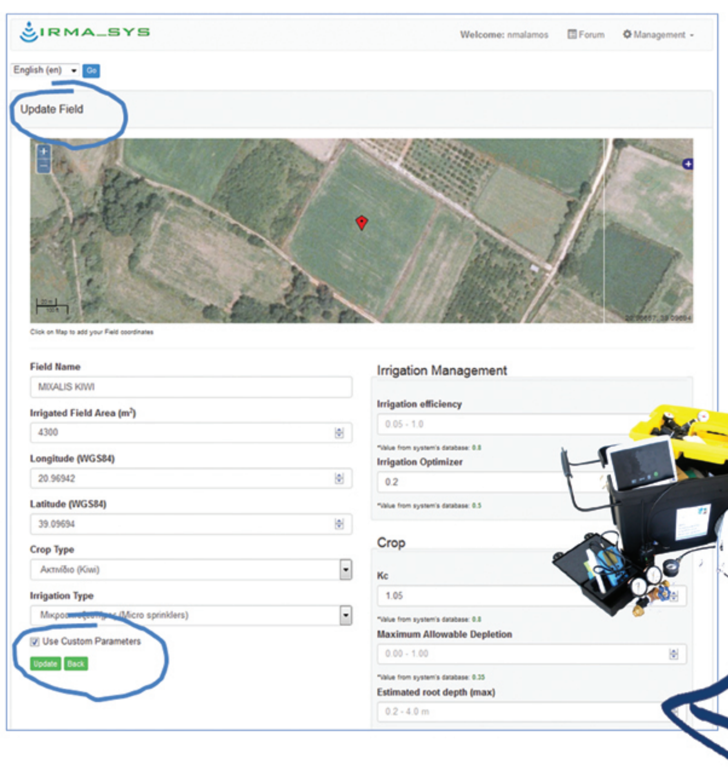


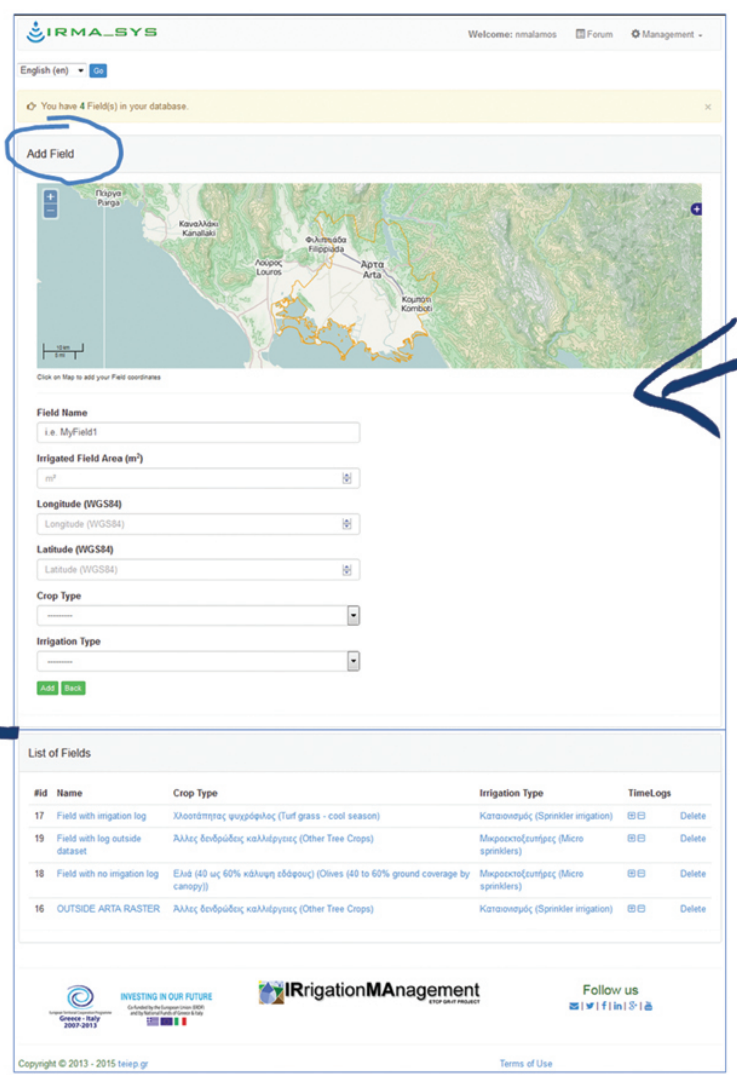
Irrigation advices for all fields on one page



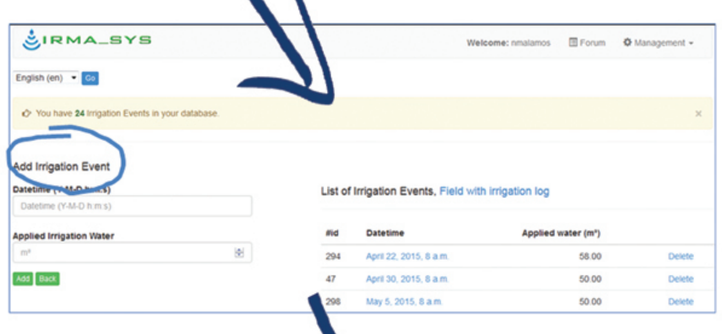
Irrigation advice

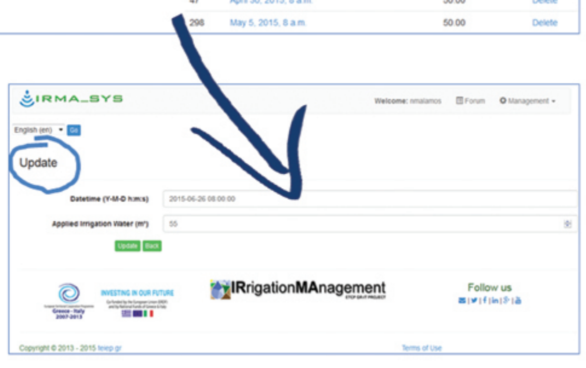






Registration of applied irrigation events (date, time, volume)

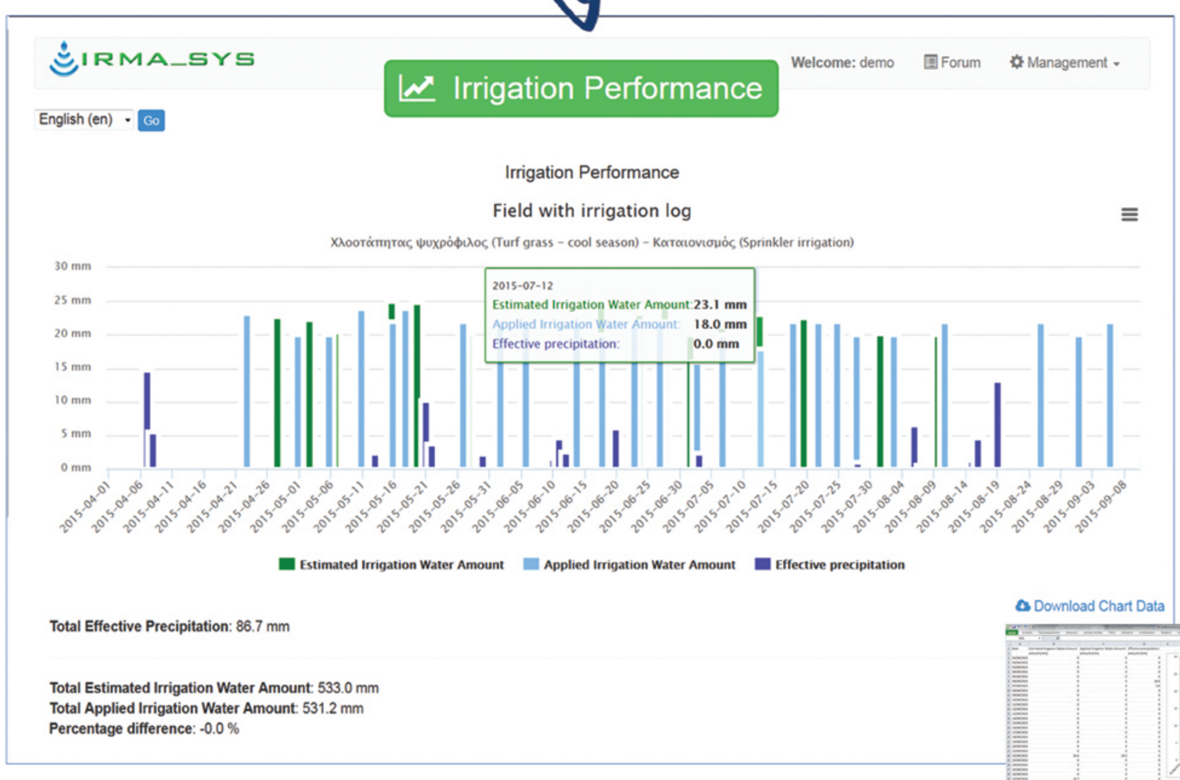


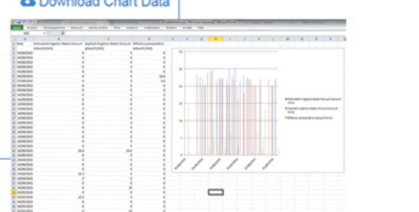


Hourly irrigation forecast

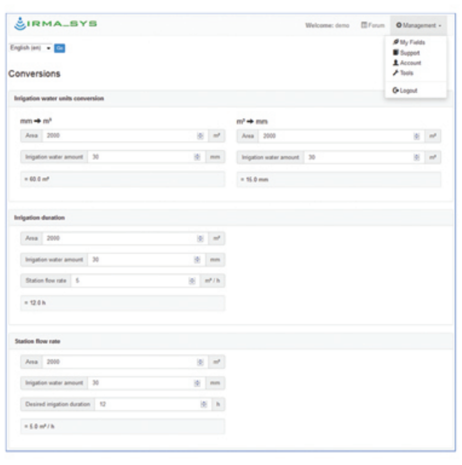
Irrigate from this point

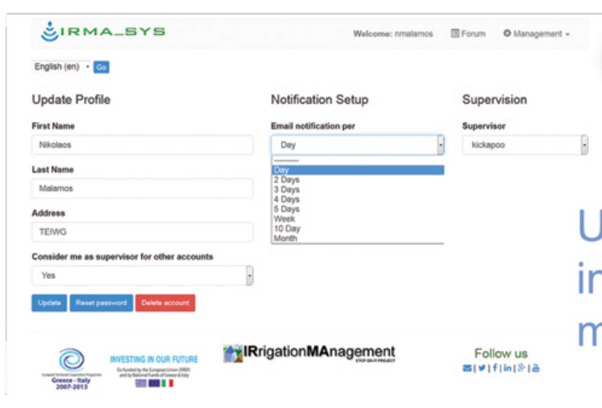
Comparison of estimated and applied irrigation throughout the irrigation period





Conversions





User info management

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