MAGDA
INNOVATIVE SENSING FOR FARMING

METEOROLOGICAL ASSIMILATION FROM GALILEO AND DRONES FOR AGRICULTURE

**Grant Agreement: 101082189**

# D6.2 Demonstrator operational irrigation advisory service

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# 1 Introduction

## 1.1 Project background

### 1.1.1 MAGDA concept

The agricultural sector is the largest human-induced water user in most countries. According to the Food and Agricultural Organization (FAO), approximately 70% of the world's water supply is extracted and used for agricultural purposes. As the global population continues to expand, the demand for water for the cultivation of food is rapidly increasing. Additionally, in many areas, climate change is expected to lead to a higher frequency and magnitude of extreme events such as droughts and floods. The agricultural sector, in this context, has the potential to assume a key role in water conservation efforts by striving for a more efficient water use by achieving "more crop per drop", through innovative irrigation practices.

Against this background, Irrigation Advisory Services (IAS) are agricultural extension services and powerful management instruments to achieve the best efficiency in irrigation water use. These systems are often conceptually oriented to simulate or predict crop water demand, providing a set of options. The introduction of IAS could advance irrigation practices and water efficiency in the near future, while providing an economic advantage for farmers: the adoption of new irrigation management systems can both increase farmers' income and reduce energy costs.

The MAGDA project aims at providing an integrated – but modular – system to provide both severe weather forecasts and irrigation advisories enhanced by means of various satellite-borne, drone-borne and ground-based weather-observing technologies. The weather forecasts will be produced by weather models ingesting a wide array of atmospheric observations and will be used as an input for the irrigation advisory, next to being used for generating warnings for extreme weather events. The warnings and irrigation advisories will ultimately be channelled through a Farm Management System to ensure the capability to effectively reach farmers and agricultural operators.


**Figure 1. MAGDA concept visualization**

### 1.1.2 MAGDA targets

The target of the MAGDA project is to build a system based on hardware, software and data sources components to monitor and process environmental quantities, to deliver to farmers information and suggestion to improve the management of their farms.
In order to monitor the progress of system implementation, a set of key performance indicators will be defined according to the specific of each target. The main targets are:

- Successful deployment of hardware systems (EGNSS receivers, meteodrones and in-situ sensors).
- Successful setting of pre-processing tools (GNSS data, in-situ data and Copernicus data).
- Successful setting and implementation of the weather and hydrological models.

### 1.1.3 MAGDA tools structure

MAGDA system will be based on a suite of tools for pre-processing GNSS data, in-situ data and Copernicus data, for weather and hydrological modelling as well as tools for farm management (Table 1). A detailed description of MAGDA tools is provided in D3.1, section 4.1.9.

**Table 1. MAGDA tools description**

| Developer | Tools | Description |
|---|---|---|
| GRED | Atmospheric water vapor / soil moisture monitoring service | low-cost GNSS stations and BREVA cloud-based GNSS processing software |
| MM | Drone observation service | perform atmospheric measurements along the vertical direction |
| CAP2020 | In-situ sensors | perform ground-bases observation of key meteorological variables |
| CIMA | WRF | provide weather forecast for early warning of extreme events |
| FW | SPHY-Irrigation | provide irrigation advisory based on a hydrological water balance model |
| CAP2020 | FMS | provide an operational tool (adaptive dashboard and APIs) for farm management system |

In the framework of MAGDA project all these tools will be integrated into a system (Figure 2) in order to provide operationally improved weather forecasts by assimilating the new spatial technologies and irrigation advisory direct to farmers and agriculture operators.

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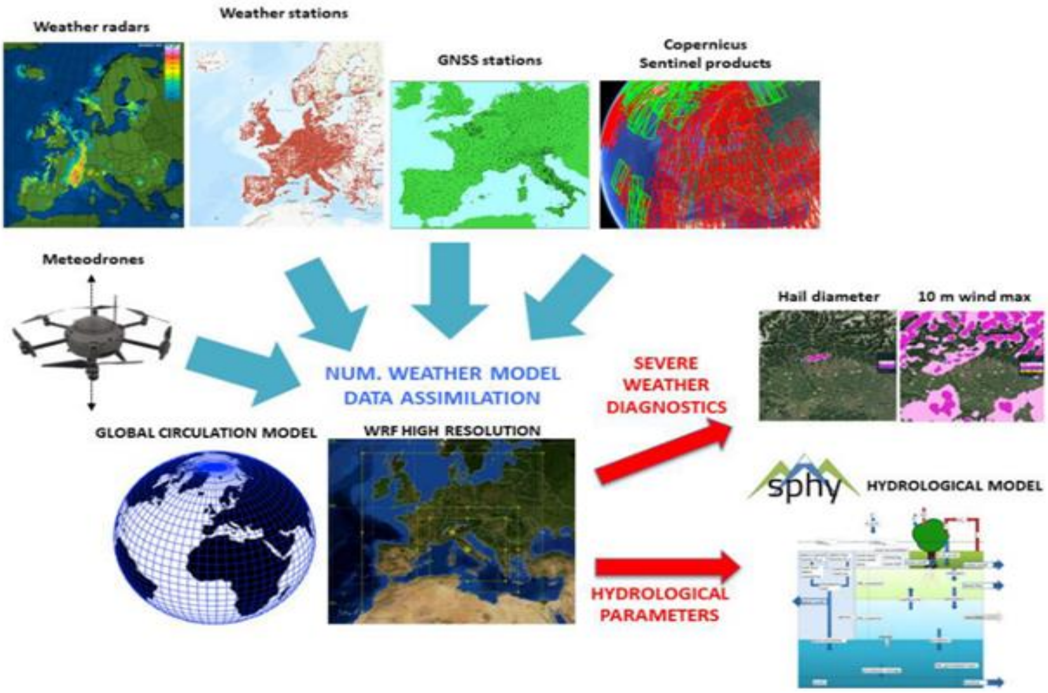


Figure 2. MAGDA forecast concept

## 1.2 Pilot areas and demo sites

The pilot areas for the MAGDA project are multiple farms located in multiple countries. The pilot areas are situated in Beaune (FR), Piedmont (IT), Braila (RO). The SPHY Model will be run for all three pilot areas. Furthermore, every pilot area has multiple demo sites. These demo sites mostly consist of farms, which will be monitored for the eventual irrigation advisory service. Most demo sites have GNSS and/or a weather station installed on the premises of the farm.


Figure 3. Locations of the three pilot areas across Europe.

### 1.2.1 Burgundy, France

The pilot area in Burgundy (France) covers Beaune, a well-known vineyard area. Sensors will be deployed on vineyard fields owned by la Maison Louis Jadot.
The possible interest in the outcome of the project for Maison Jadot include:

- better anticipation of extreme events such as frost & hail impact.
- more usable decision-making data. They rely on an existing Farm Management System, but the data is not very usable, and neither very reliable.
- Even if they cannot irrigate, they are very interested in knowing better the water status of the vineyard. There are some levers to activate, especially soil management.
- Better understanding of their (micro) climate and its evolution due to climate change.

Figure 4 shows the pilot area in Beaune, France, including the five MAGDA demo sites.

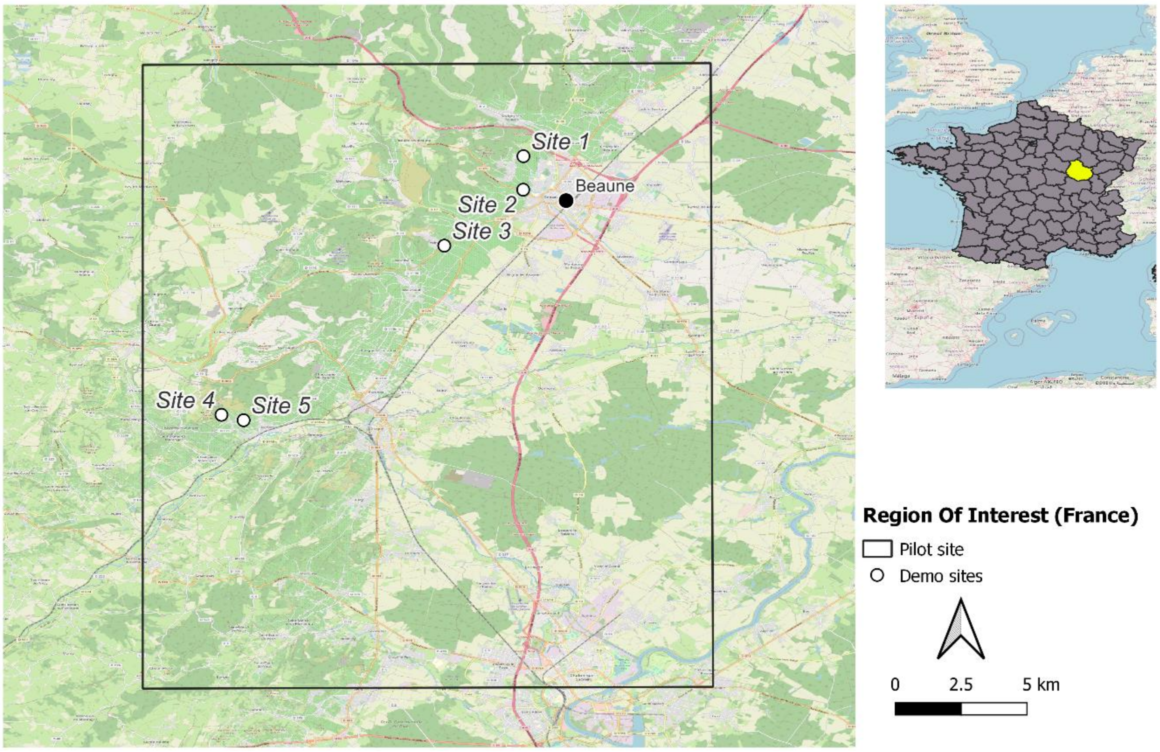


**Figure 4. Pilot area in Beaune, France, including the five MAGDA demo sites.**

### 1.2.2 Piedmont, Italy

The Italian case studies will focus on the site proposed by the Italian Confederation of Farmers – Cuneo section (ICF-C). Situated in Piedmont region (north-west Italy), the area between Cuneo and Saluzzo is recognized as a major hub for fruit production in both Italy and Europe. The bigger plantations have a greater inclination towards experimenting cutting-edge technologies, and they have already formed a partnership with the CIA to pursue this goal. Their attention is currently centred on anticipating late frost, heatwaves, and rainfall events. Since weather forecasts already provide accurate predictions of frost and heatwaves, the focus in the MAGDA project will be on the rainfall events forecast improvement, not only the most intense one (i.e., causing floods), but also on normal rainfall days. In fact, rainfall can have a significant impact on fruit crops and their susceptibility to pests and diseases (Yadav et al., 2023). Providing more accurate rainfall forecast can help in developing effective management strategies and ensuring the health and productivity of fruit orchards.

- Site 1 grows apples and peaches. Irrigation is localized, with soil moisture sensors (tensiometers) already in place to define when and where to irrigate. Soil moisture sensors are already in place (tensiometers).
- Site 2 grows apples, cherries, almonds, hazelnuts. No localized irrigation at the time of the site inspection. No sensors already in place.
- Site 3 grows apples, peaches, plums. Irrigation is localized, regulated by soil moisture sensors. “Watermark” soil moisture sensors are already in place.

Figure 5 shows the pilot area in Piedmont, Italy, including the three MAGDA demo sites.

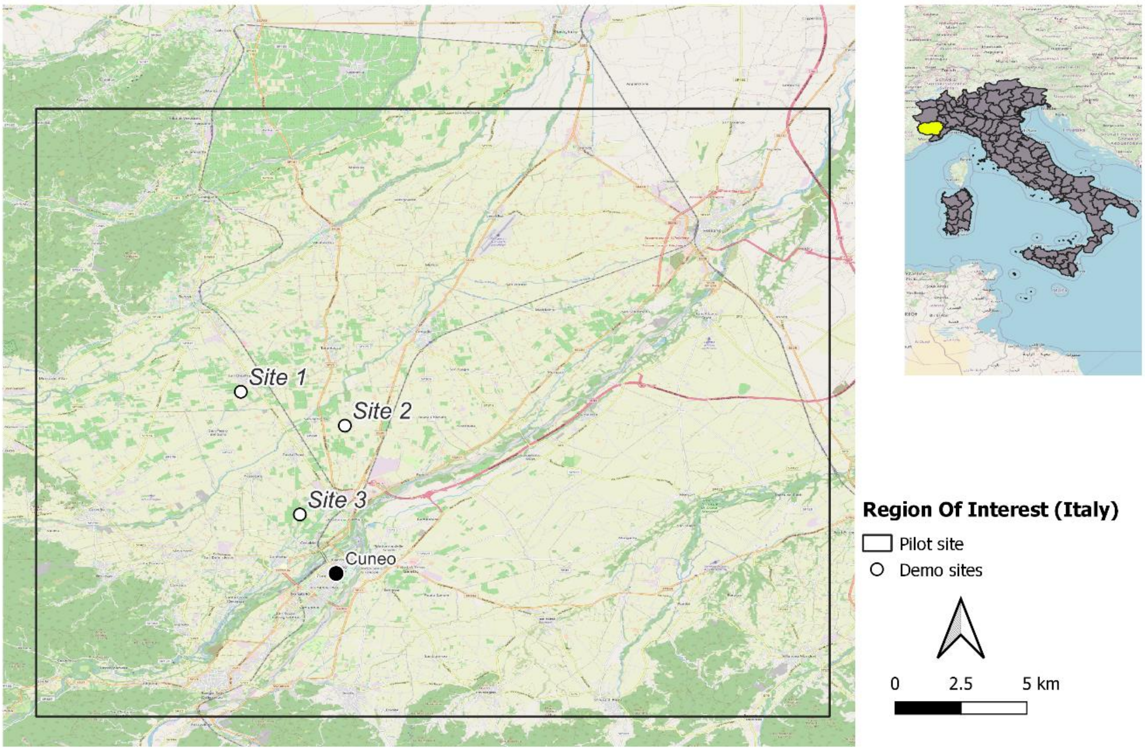


**Figure 5. Pilot area in Piedmont, Italy, including the three MAGDA demo sites.**

### 1.2.3 Braila, Romania

In Romania, the demonstration sites are in the South-East of the country, in the Brăila County that includes fields owned by Agriculture Research and Development Station Brăila, with long expertise in irrigation and drainage activities. These fields are in the Brăila Plain and in the Danube River Floodplain (Embanked Great Island of Danube River, Brăila).

The capillary rise induced by water table variation is an important water input for crop water needs between April and June when the Danube water levels record high values. For the rest of the crop season, the irrigation is required in order to avoid crop losses and to ensure high crop productivity. Brăila county is the most important agriculture area in Romania due to the high fertility of the soils and to the presence of the Danube lower sector that ensures water resources for irrigation. The

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demonstrator in Romania will be focused on the summer crops (April-September) such as corn, sunflower and soybean.

There are no sensors in place and the irrigation system consists of a channel network for water conveyance, electric pumping stations stations, and a network of buried pipes of various orders for water distribution. Irrigation water is delivered at specific outlets where farmers connect their overhead distribution equipment for applying sprinkler irrigation (centre pivots, front advanced lateral irrigation systems, travellers, etc.) in the field.

Figure 6 shows the pilot area in Braila, Romania, including the two MAGDA demo sites.

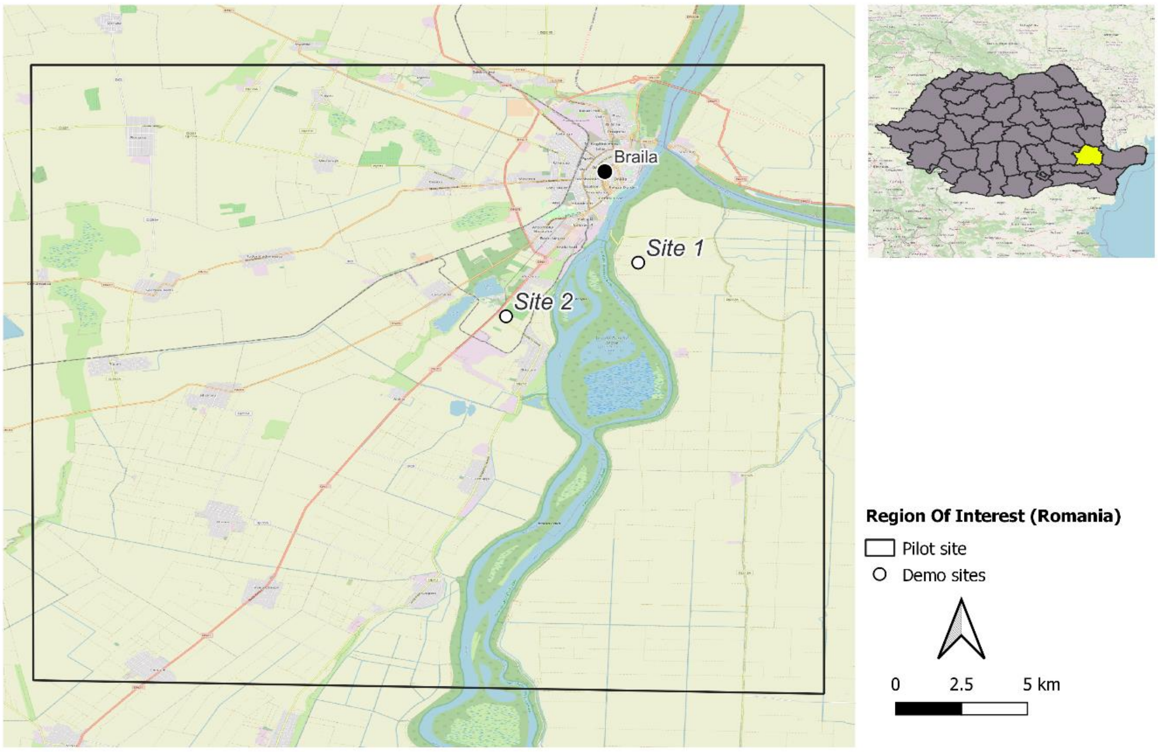


**Figure 6. Pilot area in Braila, Romania, including the two MAGDA demo sites.**

# 2 Methodology

## 2.1 Operational Irrigation Advisory Service

### 2.1.1 Overview

The modelling architecture of the MAGDA irrigation advisory service is shown in Figure 7. This new approach is justified due to the need for simulating accurately the daily soil moisture dynamics at the point -plot- scale. This fact can be reached only by improving the calibration of some key hydraulic parameters through the usage of weather and soil moisture measurements collected at the field. The crop model behind the irrigation service combines features from the FAO56 model and novel components from the SPHY model.

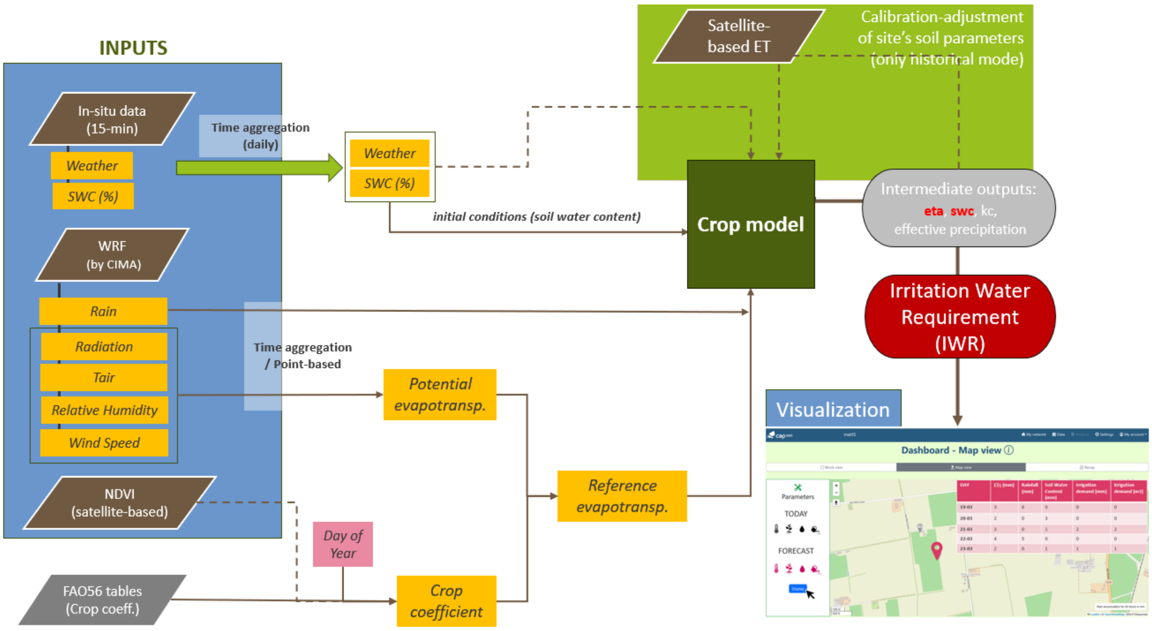


**Figure 7. Flowchart of the irrigation advisory service blueprint.**

### 2.1.2 Crop-hydrological model

The MAGDA irrigation model rests on the FAO56 model and includes novel features from the SPHY tool already implemented at the regional scale in previous exercise (see Deliverable 6.1.). The model quantifies the irrigation needs of a crop through the simulation of the soil moisture dynamics at the daily and plot scales. Irrigation Water Requirement (IWR) (Equation 1) is defined as the supplemental water needed to meet crop water demand that is not fulfilled by rainfall and existing soil moisture.

$$IWR = ET_c - (P_{eff} + ET_{sm})$$

**Equation 1**

where $ET_c$ is the crop evapotranspiration under non-stress conditions, and Etc_act is the actual crop evapotranspiration. $P_{eff}$ is the effective precipitation, and $ET_{sm}$ is the fraction of the soil moisture at the root-zone that is used by crops for evapotranspiration (also known as the Root Zone Water Supply). The component $P_{eff}$ + $ET_{sm}$ to the total of water available from rainfall and soil moisture to meet the water needs of a crop. Under stress conditions for which Peff + ET does not match $ET_c$, the Peff + $ET_{sm}$ component may be similar to the crop evapotranspiration computed by using satellite-based evapotranpisration methods.

Non-stress crop evapotranspiration ($ET_c$)

ETc under non-stress conditions refers to the rate of evapotranspiration when a crop is growing in optimal conditions. It represents the maximum of water that a crop can used without abiotic stressors or limitations.

$$ET_c = ET_0 \cdot k_c$$

**Equation 2**

Where, $ET_0$ is the reference evapotranspiration and $k_c$ is the crop coefficient under non-stress conditions.

By default, the MAGDA irrigation service allows to computes $ET_0$ through the Penman-Monteith-FAO equation (Allen et al., 1998). When not sufficient weather data is available, the Hargreaves-Samani equation (Hargreaves & Samani, 1985) can be alternatively be used (Box 1). In general, $ET_0$ values from PM-FAO equation are higher than the ones from HS due to the inclusion of the advective component of the evapotranspiration (Figure 8). However, and particularly in arid and semiarid regions, the HS method usually performs quite well and can be a good alternative approach when air humidity and wind values are not readily available.

Actual Crop Evapotranspiration ($ET_{c\_act}$)

Actual crop evapotranspiration can be computed in the MAGDA irrigation advisory by assuming an NDVI-Kc based approach, as:

$$ET_{c\_act} = ET_0 * k_{c_{act}}$$

**Equation 3**

$$k_{c\_act} = k_{c\_min} + \left(k_{c\_max} - k_{c\_min}\right) * \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})}$$

**Equation 4**

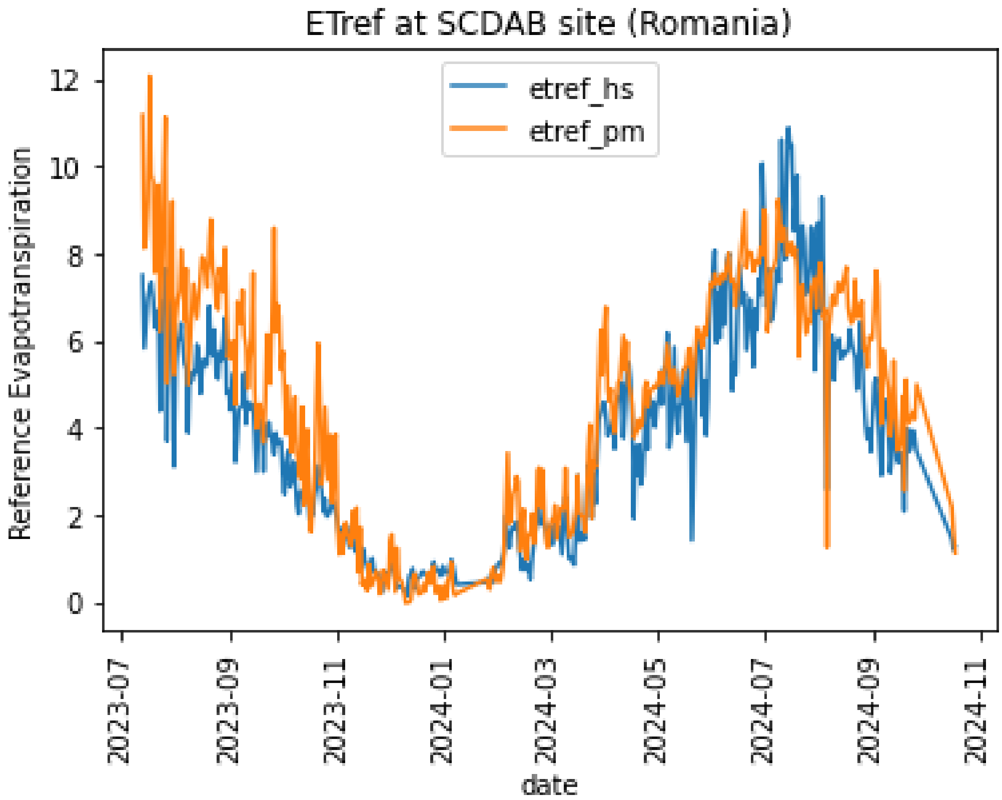


**Figure 8. Reference evapotranspiration computed with Penman-Monteith-FAO (etref_pm) and Hargreaves-Samani (etref_hs) equations.**

**Box 1. Methods for the computation of Reference Evapotranspiration in the MAGDA irrigation advisory service.**

*Hargraves-Samani formula*

$$ET_0 = 0.0023 * R_a * (T_{\max} - T_{\min})^{0.5} * (T_{mean} + 17.8)$$

where:
ET0 = Potential evapotranspiration
Ra = Mean extra-terrestrial radiation in mm/day which is a function of latitude
Tmax = Maximum daily air temperature
Tmin = Minimum daily air temperature
Tmean = Average daily air temperature

*Penman-Monteith-FAO formula*

$$\lambda ET_0 = \frac{\Delta(R_n - G) + \rho_a c_p \frac{e_s - e_a}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

where:
$R_n$ = net radiation
G = soil heart flux
$e_s - e_a$ = vapour pressure deficit of the air
$\rho_a$ = main air density at constant pressure
$C_p$ = specific heat of the air
Δ = slope of the saturation vapour pressure temperature relationship
γ = psychrometric constant
$r_s$ = surface resistance
$r_a$ = aerodynamic resistance

The crop coefficient under non-stress -optimal- conditions are those tabulated by FAO according to the 4-stage growth model suggested by FAO Irrigation and Drainage Paper No. 24 (Doorenbos and Pruitt, 1977). The MAGDA irrigation advisory service accounts the growth stage of the crop based on the crop planting date, and orientative values of lengths of growth stages. These values can be tailored to local conditions if expertise knowledge or field observations are available.

Effective precipitation ($P_{eff}$)

According to FAO, effective precipitation ($P_{eff}$) is defined as the fraction of rainfall that becomes available to meet the evapotranspiration crop's water needs. Effective precipitation takes into account interception, and drainage - surface runoff plus deep percolation - losses (Allen et al., 1998). The MAGDA irrigation service delivers daily values of effective precipitation to farmers as part of the service. The computation of crop evapotranspiration depend on the simulation selected: when the aim is to calibrate the model by using historical data, values of actual (satellite-based) crop evapotranspiration retrieved with Equation 3 and Equation 4 are computed, while values of crop evapotranspiration under non-stress conditions are used during the irrigation-forecast advisory mode (Equation 5).

$$P_{eff} = \begin{cases} min(ET_{c\_act}, ERZP), for\ calibration - historical\ analysis\ purposes \\ min(ET_c, ERZP), for\ forecasting\ purposes \end{cases}$$

**Equation 5**

where, ERZP is the effective root-zone precipitation [mm], i.e. the depth of the root zone that can be fulfilled with water from the net precipitation. ERZP is computed as:

$$ERZP = min(P_{net,} AWC - SW)$$

**Equation 6**

where $P_{net}$ is the portion of the rainfall (*Prcp*) that reaches the surface once subtracted the interception losses by vegetation (*Int*) [mm] (Equation 7), and SW and AWC are the actual soil water content stored in the root zone and the available water capacity (range between soil water content at field capacity and the permanent wilting point), respectively, both in depth units. AWC values can be derived from the analysis of field measurements of soil water content during the driest and wettest periods of soil moisture, or from pedrotransfer equations that uses soil texture and organic matter content data.

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$$P_{net} = Prcp - Int$$

**Equation 7**

In MAGDA, interception (*Int*) is computed by adopting a constant-threshold parameter which represents the rainfall threshold below which soil moisture in the root zone remains unchanged. The value of this threshold

Drainage losses due to surface runoff or deep percolation from the root zone is computed,

$$Dra = min\left(0, P_{net} - SW_{fc}\right)$$

**Equation 8**

Root Zone Water Supply ($ET_{sm}$)

$ET_{sm}$ represents the contribution of the water stored in the root zone that is used for evapotranspiration, besides the effective precipitation. It only accounts when effective precipitation is not enough to meet the crop's water needs. It can be simply computed as

$$ET_{sm} = \min(ET - P_{eff}, SW)$$

**Equation 9**

where *ET* is the $ET_c$ or $ET_{c\_act}$ depending on the simulation mode selected, and SW is the available soil water content in the root zone. In the MAGDA irrigation service, the SW can be retrieved/ingested from soil moisture measurements in the root zone or derived from the simulation of the daily evolution of the main inflows and outflow accounted at each timestep. SW is generated by computing the daily water balance of the root zone layer, as

$$SW_t = SW_{t-1} + P_{net} - \left(P_{eff} + ET_{sm} + Dra\right)$$

**Equation 10**

### 2.1.3 Recalibration of pilot area and demo sites

The site-specific calibration of the crop-hydrological model is a critical step to estimate accurately the soil moisture dynamics in the root zone, and by hence to forecast the irrigation water requirements of crops along the dry-spells or inter-rainfall periods. A key parameter to calibrate the MAGDA irrigation model refers to the root zone depth. This parameter controls the total water storage content in the soil-root zone or the soil domain that is subjected to evapotranspiration losses.

To calibrate root depth at the plot scale, soil moisture evolution is taken from moderate-long drying spells of >15 days. Model is forced setting a range of root depth values, and correlation and rmse metrics between observed and simulated soil water content for each selected dry-spell is extracted. Root depth is finally set up for the value with the highest and lowest average values for correlation and rmse, respectively. For the particular case of the SCADB pilot site, the calibrated value for root depth was set up at 150 mm (Figure 9, Figure 10).

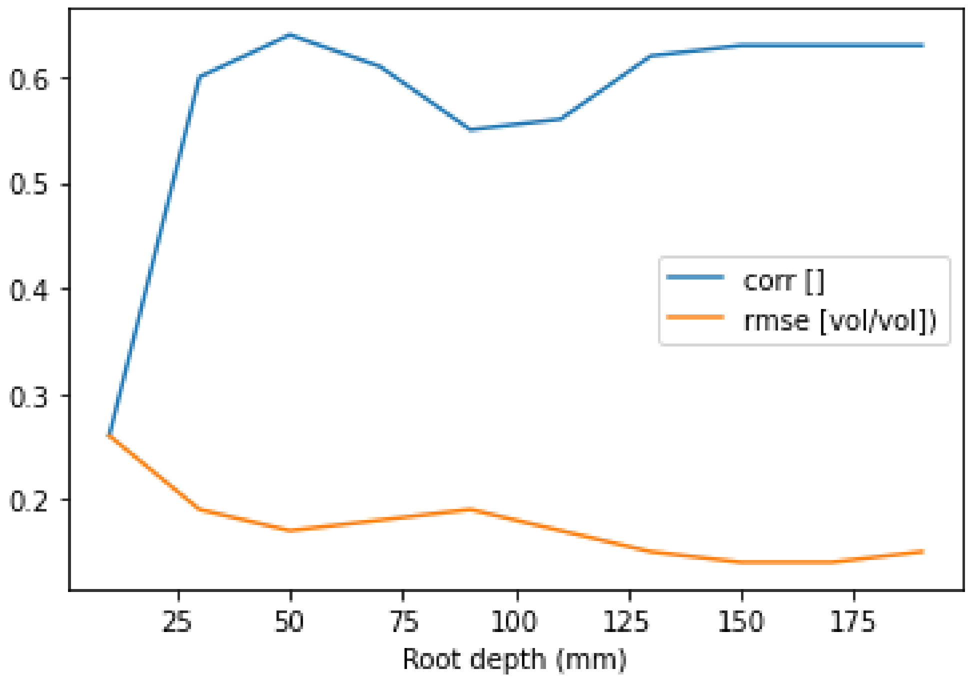


**Figure 9. Statistical metrics between observed and simulated soil water content in the SCADB pilot site (Romania) for a range of root depths**

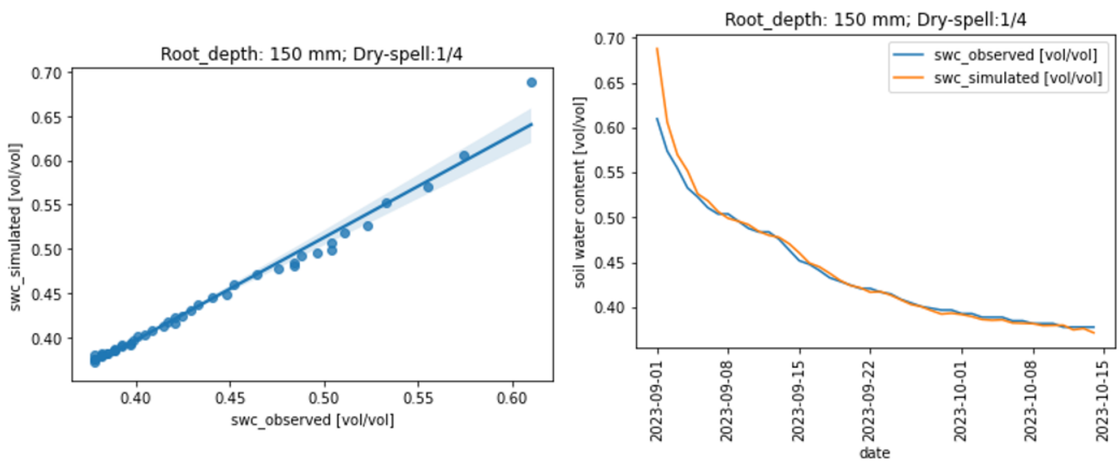


**Figure 10. Scatter- and line-plots between observed and simulated soil water content for a dry-spell (01/09/2023 – 15/10/2023) in the SCADB pilot site (Romania) using the calibrated root-zone depth of 150 mm.**

## 2.2 Demonstrator phase

How water from rain pulse is effectively stored in soil-root zone is critical to deliver accurate irrigation advice in the next days and during the inter-rainfall periods. Consequently, the ability to to early forecast rainfall inputs may improve the quantification of irrigation needs. It is assumed that a potential for water saving remains if more accurate weather forecasts can be ingested in the irrigation advisory services.

This phase aims to demonstrate the applicability of the MAGDA's irrigation advisory service. The exercise will consist on the ingestion of: a) meteorological and soil moisture data collected from sensors located in the pilot sites, and b) 5-days weather forecasts generated by the MAGDA team with and without assimilation of GNSS, radar and weather information collected by MAGDA's meteodrones. The add-value of assimilation of ground and MAGDA data will be evaluated in terms of differences in the irrigation advisory outputs generated with the irrigation model.

The demonstrator exercise firstly consisted of the selection of few meteorological events of interest during the summer-early autumn at the Romanian pilot sites. The selected events represent adverse weather conditions which include moderate and intense rainfall events. Once those events have been identified, 5-day forecasts are ingested into the model. More detailed information on the procedure can be found in the following subsections.

### 2.2.1 Selection of pilot sites and experimental dates

The selection of pilot sites and experimental dates for the demonstrator phase are critical to evaluate the effectiveness and usefulness of the MAGDA data for the irrigation service.

A detailed analysis of different rainfall events was conducted over demo sites in Italy and Romania to find the best time windows for testing the system. The final selection of the dates also considered the availability of MAGDA data resulting from meteodrone flights. The dates selected are listed in Table 2. The dates selected are listed in Table 2. France will be not part of the experiments due to the lack of irrigated crops in the MAGDA pilot sites.

**Table 2. Demo sites and dates of the demonstrator**

| Site | Experimental periods of interests | Total rainfall in each forecasting period (mm) | Total rainfall evaluated (mm) |
|---|---|---|---|
| SCDAB & ISMB (Romania) | 29 June – 3 July 2024 | 13 | 109 |
| | 22 July – 26 July 2024 | 23 | |
| | 4 Aug – 8 Aug 2024 | 16 | |
| | 6 Sep – 10 Sep | 57 | |
| Tetto-Bernardo (Italy) | 20 -24 Jun 2024 | 48 | 48 |

### 2.2.2 Ingestion of 5-day MAGDA-forecasts

The demonstrator exercise will consist on three steps:

- Selection of periods of interest (briefly explained in the previous subsection)
- Preparation of 5-days forecasts. Two types of weather forecasts are being prepared: 1) benchmark forecasts, i.e. the ones with no assimilation of MAGDA data collected from in situ sensors, GNSS, and meteodrones, and 2) MAGDA forecasts, for which data from different are (the sources of data assimilated may change based on their availability). It is assumed that the use of MAGDA's forecasts with assimilation (option 2) may provide higher potential for water savings in comparison with the benchmark option.
- Forcing the crop-hydrological model with data from both type of forecasts, and comparison of outputs scenarios in terms of accumulated values of "Irrigation Water Requirement" and "Effective Precipitation" during the forecasting period. Differences between benchmark and forecasts-with-assimilation will be translated in terms of water savings.

# 3 Results

## 3.1 Modelling results

Results will be reported in D6.3 once weather forecasts are properly generated by the MAGDA team.

## 3.2 Data sharing and transfer

The MAGDA irrigation advisory service is fully connected to the MAGDA's data server which uses a Secure-FTP. Outputs from the irrigation service will be also uploaded to the MAGAD's server follow a similar structure that shown in Figure 11.

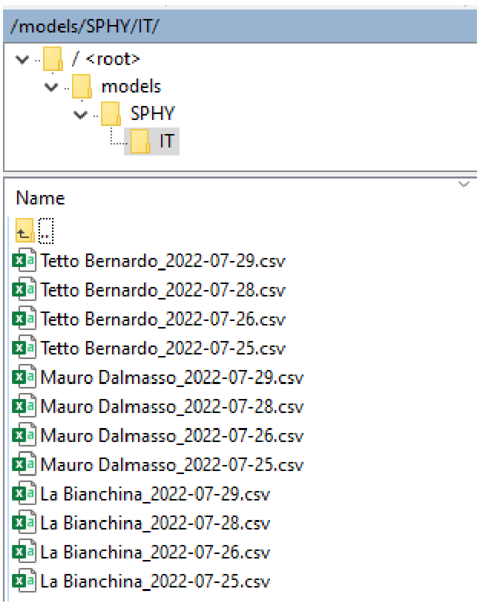


**Figure 11. FTP connection structure.**

## 3.3 Dissemination through the Farm Management System

The data from the S-FTP server is used by consortium partner cap2020 to visualize in the Farm Management System (Figure 12). This integration displays key outputs from the 5-day forecast models, specifically for the MAGDA demonstration sites within the pilot areas. To access the portal, visit: http://www.captrap.io/metIS/client/connexion.php (user registration and credential are required to log in).

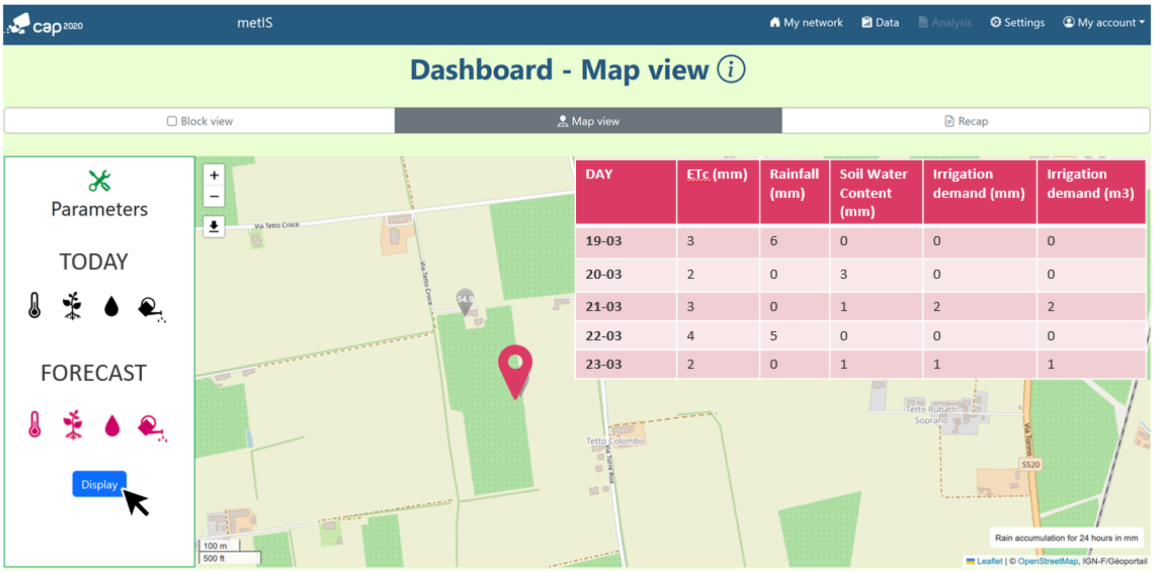


Figure 12. Mockup of Irrigation advisory service integrated into the dashboard.

# 4 Next steps

This document reports on the methodological approach adopted for the MAGDA's irrigation advisory service, and introduce some of the key components and design features taken required for setting up the demonstrator. Next steps, which will be reported in D6.3, include the comprehensive analysis of the results from the demonstration exercise, and the main conclusion and remarks to be adopted for the practical implementation and upscaling of the service to other regions.

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