Part C

WATER JOINT PROGRAMMING INITIATIVE

WATER CHALLENGES FOR A CHANGING WORLD

2018 JOINT CALL
Closing the Water Cycle Gap

An integrative information aqueduct to close the gaps between global satellite observation of water cycle and local sustainable management of water resources （iAqueduct）

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0. PROJECT SUMMARY

An integrative information aqueduct (iAqueduct) is proposed to close the gaps between global satellite observation of water cycle and local needs of information for sustainable management of water resources. In the past decades, various satellite missions have been developed to monitor the global water cycle, in particular the variables related to precipitation, evapotranspiration and soil moisture, often at (tens of) kilometre scales of spatial resolution. Whilst these data are highly effective to characterise water cycle variation on regional to global scale, they are not suitable for sustainable management of water resource, which always needs more detailed information on local (e.g. in terms of information provided by an in-situ sensor, e.g. a TDR for soil moisture or a piezometer for groundwater level) and field scale. To effectively exploit existing knowledge at different scales we thus need to answer the following questions: How to downscale the global water cycle products to local scale? How to convert the coarse resolution data into fine scale water information at the management scale for water, vegetation and soil processes? And how to use such fine-scale water information to improve the management of soil and water resources? The envisioned iAqueduct aims to accomplish these goals combining EC/ESA Copernicus satellite data (with intermediate resolution) with high resolution Unmanned Aerial System (UAS) and in-situ observations to develop scaling functions for soil properties and soil moisture and evapotranspiration at meter scales. iAqueduct will integrate the various components from the global water cycle observation to local soil and water states in an open-source water information system and test and demonstrate their utility on pan-European scale at a set of carefully selected research sites for sustainable management of water resources. iAqueduct complements the actions developed under the European Strategy Forum for Research Infrastructures (ESFRI) by coordinating a set of European research groups and sites allowing the scaling up to pan-European level under the aegis of the COST action Harmonization of UAS techniques for agricultural and natural ecosystems monitoring (HARMONIOUS) in which 70 institutions from 32 countries participate.

1. EXCELLENCE

1.1 Introduction

Water resources observation, experimental work and modelling are required to better understand hydrological processes. This better understanding is crucial to analyse and forecast the effectiveness of water management options in particular in adaptation to climate changes. Water resources observation can be obtained from different sources. While in-situ observations provide the most reliable data for the relevant observation scale (e.g. at cm scale for TDR-type soil moisture sensors), such observations are in general inadequate to address water management problems, which require detailed space-time information from local to field scale. At larger spatial scales, various satellite missions monitor the global water cycle, especially for the variables related to **precipitation, evapotranspiration and soil moisture**, but often at (tens of) kilometre scales. Whilst these data are highly effective to characterise water cycle variation on regional to global scale, they are not suitable for management of water resource which requires more detailed information at field and catchment scales. Indeed, water resource management needs to consider a wide range of spatial scales and address a variety of problems, e.g. monitoring and managing droughts and water availability for different uses (root zone soil moisture, stream discharge as well as groundwater levels). Models provide an alternative to observations by bridging different scales and different processes, but the fidelity of model output strongly depends on the physical processes considered which in turn requires detailed information on the state of the soil and vegetation system and relevant forcings at the scale of interest. Therefore, there is a pressing need to harmonize the available information on the soil/vegetation system to reach a feasible approach for actual water management. Furthermore, such detailed information needs to be communicated to the stakeholders (in particular citizens) so as to influence them towards desirable behaviour in water management. A recent example is the 2018 summer drought, which posed challenges for water availability in vast regions in Europe, including some ill prepared to cope with water scarcity. Climate change presents additional challenges regarding the preparedness and adaptation to future extremes, because e.g. similar or worse future events to that in 2018 may be expected more frequently.

In order to address these needs, new strategies and methods must be developed to further exploit actual global satellite water cycle observation (at coarse scale) and the EC/ESA Copernicus satellite data (with medium resolution), enabling the end-user-oriented description of agricultural and natural ecosystems. Such systems, especially in Europe and the Mediterranean basin, are characterized by high spatial heterogeneity in physical characteristics and as a consequence in soil moisture and evapotranspiration signatures. Such heterogeneity can be measured only via in-situ observations or by UAS at high resolution. This last technology may open a new potential strategy in the study of soil moisture and vegetation states given its ability to provide observations with a level of details comparable with filed observations but over much larger areas than the latter can achieve economically. Therefore, the use of combined measurements may help the identification of scaling functions for soil properties, soil moisture and evapotranspiration at meter scales.

1.2 State-of-the-art and relation to the work programme

Precipitation: Numerous evaluations of available satellite precipitation products have been conducted (Maggioni et al., 2016, J. Hydromet.) for different climates and CMORPH, CHIRPS, and TRMM (and by extension GPM, Gebregiorgis et al., 2018, JGR-Atmos.) showed consistently high performance (Kimani et al. 2017, RS). Nevertheless there remains the necessity for downscaling global products to local estimates to account for the spatiotemporal characteristics of error as well as its relation to rain rate (e.g. AghaKouchak et al., 2012, GRL).

Evaporation and transpiration: In the past years, several satellite evapotranspiration products have been generated, among which, the MOD-16 ET (Mu et al., 2007, RSE) at 1km and daily interval, PM-ET (Zhang et al., 2010, WRR) at 8km and monthly interval, GLEAM (Mirallies et al., 2011, HESS) at 0.25 degree and daily interval, ALEXI-ET (e.g. Anderson et al., 2010, HESS) at various spatial and temporal scales, and SEBS-ET (Su, 2002; Chen et al., 2014) at 5km monthly and 1km daily scale. Evaluations of these and other global evapotranspiration products (e.g. Mueller et al., 2011, GRL; Vinukollu et al., 2011, HP; Wang and Dickinson, 2012, RevGeophys.) concluded that all have different uncertainties for local scale studies (e.g. Bhattarai et al., 2018, HESS).

Soil moisture: Satellite observation of soil moisture has significantly advanced in the last decade as demonstrated by two dedicated missions (the Soil Moisture Ocean Salinity - SMOS (Kerr et al., 2012, TGRS), and the Soil Moisture Active and Passive – SMAP (Colliander et al., 2018, RSE)), providing soil moisture products at nearly daily temporal resolution and coarse spatial resolution (e.g. 36 km for SMAP).

The spatial scale of the above mentioned products is too coarse for a large variety of applications. Therefore, there is a growing need to develop downscaling procedure in order to reach a reference scale comparable with the emerging hyper-resolution modelling trend (Bierkens et al., 2015, HP). The spatial and temporal variability of soil moisture process has been investigated by several authors that provided a clear path for the description of its dynamics (Isham et al., 2005, Proc. Royal Scoc.; Manfreda et al., 2007, AWR). In this context, Qu et al. (2015, GRL) developed a method to predict sub-grid variability of soil moisture based on basic soil data.

To estimate soil moisture at higher resolution, active microwave Synthetic Aperture Radars (SARs) have been employed (such as Sentinel-1), capable of providing 1 km daily soil moisture products (Montzka et al., 2018, RS). Other methods focus on the use of optical and thermal images to downscale coarse products to 1km (e.g. Mishra et al., 2018, JAG) often in combination with modeling approach (e.g. Malbéteau et al., 2018, J. Hydromet.). Optical remote sensing method to assess the surface soil moisture content from airborne hyperspectral sensor also exist (Haubrock et al., 2008, JARS; Ben Dor et al., 2004, IJRS).

Soil moisture monitoring is also limited because satellite sensors only provide surface measurements (< 5 cm). Therefore, methods able to infer root-zone soil water content (SWC) from surface measurements are highly desirable (Ochsner et al., 2013, SSSAJ; Reichle, et al., 2017, J.Hydromet.). To do so, Wagner et al. (1999, RSE) suggested the use of an exponential filter and recently a new simplified formal mathematical description was proposed (named SMAR, Manfreda et al. 2014, HESS). The SMAR model has been coupled with Ensemble Kalman Filter (EnKF) to reduce bias (Baldwin et al. 2017, JH) and predict root-zone SWC over broad extents.

Relation to the work programme: iAqueduct addresses Theme 3 - Supporting tools for sustainable integrative management of water resources, as well as Sub-theme 2.3 - Connecting science to society in order to develop approaches to influence stakeholders (in particular citizens) towards desirable behaviour (Water JPI 2018 Joint call, Closing the Water Cycle Gap – Sustainable Management of Water Resources).

1.3 Objectives and overview of the proposal

The main objectives of this research project can be summarized as follows.

Science and technical objectives

- **Fill the existing knowledge gap in space-time variability of earth observations such as soil physical characteristics, soil water content and evapotranspiration fluxes**. iAqueduct will identify a sequence of tools able to exploit to their maximum value of the remote sensed observations making it useful for practical applications;
- **Establish networks and information sharing among existing research facilities/field labs, analytical methods, monitoring tools and programmes** by complementing available field sites with data products from satellite observations bias-corrected with in-situ observation, harmonized protocols for retrievals of soil properties, and scaling between soil moisture and evapotranspiration for pan-European applications;

- **Complement the actions developed under ESFRI** to provide fine scale mapping of hydrological variables by coordinating a set of European research groups and sites using space technologies, UAS and in-situ observations;
- **Access to databases and platforms, exploring the use of big data solutions and establishing reliable hydrological standards** by developing generic toolboxes that include models, soil parameters, forcing and field scale observation and gridded water states and fluxes, suitable for research and actual management practices.
- **Coordinate on global scale, the large body of knowledge, methodology and data related to hydrology and the water cycle to explore the potential of being beneficial for a wide range of the world's regions** by coordination with the satellite missions GPM for precipitation, SMOS and SMAP for soil moisture, and Copernicus data and services as well as to international programmes such as GEWEX and GEO. Such coordination will be greatly enhanced, by offering the additional sites for calibration and validation of global satellite water cycle products.

Socio-economic objectives

- Support progress based on previous finding, and **facilitate the establishment of water management policies addressing rapid climatic changes** by involving researchers, water management authorities, companies and farmers strongly supporting progress based on previous findings in each site/catchment and by dealing with local needs, and helping establish water management policies addressing rapid climatic changes;
- Support the translation of the tools and procedures developed and tested in the project into a **marketable web-based application, service and/or product for the smart management of water resources**, establishing science-policy-business-society interfaces to allow for continuous dialogues and interactions across different scales and levels, influencing stakeholders (in particular citizens) towards desirable behaviour;
- **Align water-related research and sharing of data and results to avoid duplication of research** by coordinating research and sharing data among the different selected groups and sites for pan-European purpose.

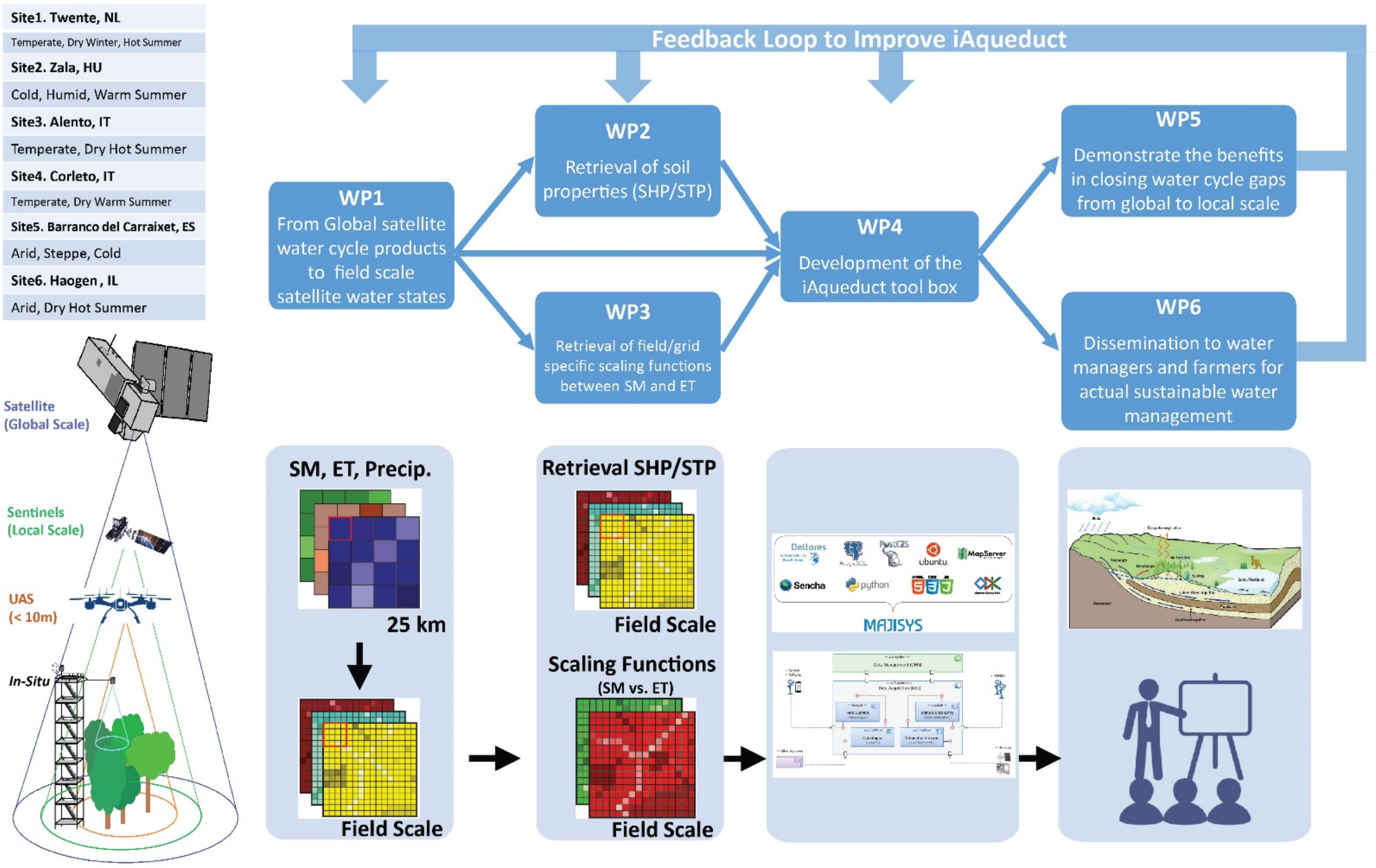

Fig. 1. iAqueduct – Work Breakdown Structure

1.4 Research methodology and approach

An overview of the methodology and approach is presented in the iAqueduct Work Breakdown Structure (WBS) as shown in Figure 1. It includes 6 closely connected work packages (WP) jointly conducted by 7 consortium partners. WP 1 deals with the scaling from global satellite water cycle products to field scale water states which includes both the surface and profile information on water states. Because it has been demonstrated that the soil hydraulic and thermal properties (SHP/STP) play critical role in determining soil water and heat flow and such information is rarely available at detailed scales, WP2 is designed to bridge spectral information that can be obtained at high resolution by satellites and UAS and the needed soil properties that are traditionally obtained at limited locations by in-situ sample collections. Using the information obtained from the two previous WPs, WP3 attempts to retrieve field and grid specific scaling functions between soil moisture and evapotranspiration which is expected to advance hydrological modelling by demonstrating the benefits in closing water cycle gaps from global to local scale in WP5. WP 4 is designed to encapsulate the tools developed in the previous WPs and make them as open source codes so as to easily disseminate the generated knowledge and tools for actual sustainable water management (WP6).

The seven partners are the University of Twente (Uni. Twente) in the Netherlands, Universitat Politecnica de Valencia (UPV) in Spain, University of Tel Aviv (TAU) in Israel, University of Basilicata (Uni. Basilicata) in Italy, University of Naples Federico II (Uni. Naples) in Italy, Swedish University of Agricultural Sciences (SLU) in Sweden, and the Centre for Agricultural Research of the Hungarian Academy of Sciences (CAR-HAS) in Hungary. Each of the partners is a recognized expertise center for the assigned task (see description of partner expertise). Six field sites (five across Europe and one in Israel) will be intensively studied: the Twente site in the Netherlands which serves as a core international site for SMOS/SMAP cal/val activities, the Zala catchment in Hungary which has served as a study site for analysing the performance of the European pedotransfer functions in deriving soil hydraulic maps, the Haogen field in Israel which is well-documented as a playground area for soil investigation in Israel, the Alento River Hydrological Observatory in Italy that serves as a field site for intensive soil moisture and hydrological observation and modelling, the Corleto area in Italy that has been used for detailed UAS research and the Barranco del Carraixet area in Spain that has been used to study dry land water management and interaction with stakeholders. The details of each WP are described as follows.

WP1. From global satellite water cycle products to field scale water states *(Uni. Basilicata, Uni. Twente, UPV)*
This WP will focus on the monitoring and downscaling of soil moisture data based on remotely sensed data. It is divided into two main trajectories: one aimed at the spatial description of soil moisture and the second focusing on the prediction of soil moisture in the root-zone. The WP will be developed in close connection with the activities of WP2.

Task 1.1 Spatial downscaling procedures and data products
Task 1.1 will develop and test a number of procedures to downscale remotely sensed water cycle products to scales suitable for water management purposes:

1) Bayesian statistical bias correction of satellite data based on in-situ observation - calibration and validation at selected field sites with in-situ observation will form an integral part of this task (at kilometer scale but corrected for spatio-temporal error, e.g. due to topography, soil texture and climate, cf. those by Kimani et al., 2018 RS, for precipitation; Chen et al., 2014 ACP, for evapotranspiration and Zeng et al., 2016 RS, for soil moisture);
2) Development of downscaling methods by the use of Copernicus Sentinel data (from kilometer to hectometer scale). This task concerns evapotranspiration and soil moisture (by assuming the precipitation is homogeneous at kilometer scale). Downscaling will be achieved by combined use of optical, thermal and radar data from Sentinel-1,2,3;
3) Generation of high resolution water cycle products of soil moisture, vegetation patterns and vegetation stress ((sub)meter spatial scale and daily interval). High resolution maps will be provided with UAS equipped with thermal cameras, multispectral and hyperspectral cameras. Such data will support the development of downscaling procedures linking satellite to point measurements for calibration and validation in the selected field sites;
4) Characterization of the spatio-temporal distribution of soil moisture and evapotranspiration processes will be conducted after validations of the high resolution imagery from UAS with outcomes of field measurements and outputs from other models. The proper description on the controlling factors for the spatial variability of soil moisture is crucial to further advance the potential of downscaling methodologies;
5) Downscaling of the remote sensing data up to the field scale (from hectometer to plot scale) using a Bayesian approach exploiting the predicted variance and spatial correlation of soil moisture process along with the ancillary data derived from UAS and WP2 activities on the physical characteristics of soil and vegetation. In particular, WP2 will support the development of new strategies aimed at the mapping of soil hydraulic and physical characteristics that will enhance the capabilities of soil moisture downscaling procedures (see e.g. Nasta et al., 2018, JH; Montzka et al., 2018, RS).

Task 1.2 Derive profile soil water content from surface soil moisture information

While downscaling coarse scale remotely sensed water cycle products to fine spatial scales is achieved in Task 1.1, the remote sensing products typically refer to surface information that needs to be transferred to the depth, at least to the root-zone and be linked up in a consistent physical framework that will be accomplished in this task.

1) Prediction of root-zone SWC with the SMAR-EnKF (Manfreda et al., 2014 HESS; Baldwin et al., 2017 JH). Such an approach derives SWC based on the relative fluctuations of surface soil moisture retrieved from satellite or UAS. Given the physically based nature of the model, it will benefit from the information collected on the hydraulic characteristics of the soil (see WP2). The use of such methodology will provide a strategy to derive useful information on dynamics of vegetation (e.g. evapotranspiration);
2) The STEMMUS numerical soil-water-atmosphere model (Zeng and Su, 2013 ITC; Yu et al., 2016 HESS; Yu et al., 2018 JGR) will be applied to analyze the sensitivities of the predicted root-zone SWC at sites with detailed observation of soil and water properties (soil hydraulic and thermal parameters) and states (profiles of soil moisture and soil temperature and surface radiation, sensible, and latent heat flux, precipitation and other meteorological forcing).

This task will provide high resolution spatio-temporal pattern of root-zone SWC that can be linked to the patterns of soil (see WP2) and evapotranspiration (see WP3) in the different catchments.

WP2. Retrieval of soil properties (SHP/STP) *(CAR-HAS, TAU, Uni. Naples)*

WP2 will retrieve soil hydraulic and thermal parameters (SHP/STP) from spectral signatures and knowledge of near-surface soil moisture dynamics. This WP will initially employ commonly used pedotransfer functions (PTFs) for regional applications and then locally calibrate them using readily measurable surface soil spectral features. The world Soil Spectral Library (SSL, Rossel et al. 2016, ERS), European Spectral Soil Library (LUCAS, Toth et al., 2013, EMA) and some local SSL (e.g. the GEO-CRADLE Mediterranean Balkan SSL) will be used to generate global to local spectral based models to assess soil properties. A harmonized protocol will be developed from the selected sites.

Task 2.1 Collection of field scale data

This task aims to collect and complete relevant data for selected sites (e.g. as those for the Alento River Hydrological Observatory (ARHO, Romano et al., 2018 VZJ) for Tasks 2.2, 2.3 and 2.4). Information on soil physical and hydraulic properties, terrain and environmental attributes (topographical, geological, pedological, and land-use/land-cover information together with hydro-meteorological datasets and soil physical and hydraulic properties), and topsoil spectral data will be collected. Whereas needed, similar activities will be carried out also at other sites (e.g. at the Twente site such field data are collected routinely as the site is used as a SMAP cal/val site (Colliander et al., 2017 RSE)).

Task 2.2 Soil spectroscopy and hyperspectral remote sensing

This task aims at harmonizing standards and protocols for hyperspectral remote sensing in the laboratory, field, air and space domains for soil mapping (Ben Dor, 2012 CPR Press). Existing world SSL with local ones will be utilized for developing spectral based models for soil hydrophobicity, soil hydraulic properties, soil texture, carbonate and organic matter content (Ben Dor et al., 2009 RSE). Attempts will be made to extend the knowledge in hyperspectral remote sensing to the thermal region.

Task 2.3 Basic pedotransfer functions

Application and evaluation of already established PTFs (Toth et al., 2015, EJSS) will be carried out at selected field sites using the 3D Soil Hydraulic Database of Europe at 250 m resolution (Toth et al., 2017, HP) as a baseline dataset. This task will explore if and to what extent the prediction capability of these basic PTFs can be suitably improved through in-situ remote measurements, via both UAS and satellite, of spatial patterns of land cover for mapping soil hydraulic and thermal properties (Zhao et al., 2018 ESSD).

Task 2.4 Advanced pedotransfer functions

Hyperspectral data will be used to derive spectrotrasfer functions (STF) and spectral pedotransfer functions (SPTFs) (Babaeian et al., 2016, RSE) using soil and environmental data as well. Such function will be used for the description and mapping of topsoil hydraulic properties with high level of details. Further to the site specific STFs the relationship between SSLs and hydraulic properties will be analysed on European datasets (LUCAS, EU-HYDI, Weynants et al., 2013 EUR-STR). Hyper- and multi-spectral sensors on ground and UAS will be employed for in-situ prediction of soil organic carbon (SOC), soil sealing and soil particle size distribution by vis–NIR spectroscopy. Soil hydraulic properties will be mapped for the study sites with SPTFs, STFs based on the available data, similarly to Task 2.3. Validation will be performed using measured values obtained in Task 2.1. Such task will support the downscaling procedures described in WP1 - Task 1.1.

WP3. Retrieval of field/grid specific scaling functions between soil moisture and evapotranspiration *(SLU, Uni. Naples, Uni. Twente, UPV)*

This WP concerns the retrieval of field/grid specific scaling functions (task 3.1) and their generalisation (task 3.2).

Task 3.1 Field/grid specific scaling functions between soil moisture and evapotranspiration:

This task will provide soil moisture datasets measured in two sub-catchments of ARHO at two different scales: at local scale (by the wireless sensor network) and at field scale (by the cosmic-ray neutron probe). With the availability of hierarchical information of soil moisture (from satellite, UAS, cosmic-ray probe, and capacitance probe) both upscaling and downscaling relationships will be developed to link soil moisture and evapotranspiration (as obtained from Task 1.1). Tests will be done at other sites that will be used to validate the proposed procedure (see next Task 3.2).

Task 3.2 Generalizing scaling functions between soil moisture and evapotranspiration

The STEMMUS numerical soil-water-atmosphere model (Zeng and Su, 2013, ITC; Yu et al., 2016, HESS) will be used as a numerical toolbox to examine the field/grid derived scaling functions between soil moisture and evapotranspiration (Task 3.1) in order to link the states of soil moisture to evapotranspiration products on regional scale, while pertaining to the physical consistency. The derived scaling relationship will be compared and used as benchmark for simplified parametrizations in other operational hydrological models (see WP4, WP5).

WP4: Development of the generic (iAqueduct tool box) *(Uni. Naples, and all model groups)*

WP4 intercompares different models, soil and vegetation parametrizations and parameters (Task 4.1) and integrates the results into the iAqueduct toolbox (Task 4.2).

Task 4.1 Intercomparison of models, soil and vegetation parametrizations and soil parameters

Analysis of water flow processes will be made, with the different models used in the different sites, e.g. in the soil-vegetation-atmosphere (SVA) system making use of the detailed field observations available in ARHO and integration of the data into a process-based ecohydrological model, considering also validation and output uncertainties. To facilitate the integration of models into the iAqueduct toolbox (Task 4.2), particular attention will be devoted to identify models that provide robust realistic results, while at the same time having low parameter requirements and easy transferability across sites. To this aim, a minimalist soil-vegetation-atmosphere model will be developed and its applicability across sites assessed, employing the data collated within this project. The model will be based on the coupling of the soil moisture dynamics and plant activities (chiefly transpiration and carbon fixation; Manzoni et al, 2013). For crops, yield will be determined from the total accumulated crop biomass employing the harvest index, with biomass growth rate depending on the growing conditions (Vico and Porporato, 2013 WRR; Manzoni et al., 2013 AWR). For more computationally-intensive models, machine leaning algorithms will be experimented to speed up the usually computational intensive process-based computations.

Task 4.2 iAqueduct toolbox

The results of analysis in previous WPs will be integrated into a library as the iAqueduct toolbox which consists of water flow processes in relations to the models, soil and vegetation parametrizations and soil parameters as well as forcing fields. The existing open–source software system MajiSys water information system at University of Twente will serve as the integration platform. Such a toolbox will then be used for robust application (incl. machine learning algorithms) to other sites and also for use by stakeholders (See WP5 and WP6).

WP5: Demonstrate the benefits in closing water cycle gaps from global to local scale (case studies) (*UPV and all groups operating sites*)

The aim of this WP is closing water cycle gaps by improving hydrological model implementations using spatial information. The calibration of a hydrological model has traditionally only relied on the temporal variation of the discharge at the catchment outlet. But discharge provides only limited insight on the spatial behavior of the catchment (Conradt *et al.*, 2013 HESS). The development of distributed hydrological models and the availability of spatio-temporal data (WP1-3) appear as key alternative to overcome those limitations and can facilitate a spatial-pattern-oriented model calibration (Ruiz-Pérez et al., 2017 HESS). This WP will advance how to effectively handle spatio-temporal data when included in model calibration and how to evaluate the accuracy of the simulated spatial patterns. Numerical experiments will be conducted for calibration of a parsimonious distributed ecohydrological daily model in ungauged basins using exclusively spatio-temporal information obtained from WP1 and other remotely sensed information, so as to bridge the scales from plant to plot, subcatchment, and catchment/basin respectively with the representative size of 1-10 m^2 to 50-500 m^2, 1-10 km^2, and >100 km^2, as derived by means of TDR observations, to cosmic ray/drone observations, drone/satellite, and satellite observations, respectively. Findings will be implemented in the iAqueduct toolbox and easily tested at other sites.

WP6. Disseminate generated knowledge and tools for actual sustainable water management (*Univ. Twente, and all groups operating sites*)
The aim of WP6 is to disseminate and communicate the generated knowledge and tools to water managers, companies and farmers for actual sustainable water management. In order to be effective, stakeholders will be engaged in the entire project for the effective transfer of the project achievements and will be consulted for the actual needs for real life water management. We will use the 2018 summer European drought as a concrete retrospective application to demonstrate the advantage of using detailed water cycle information for water management. The aim here is connecting science to society in order to experiment approaches to influence stakeholders (in particular citizens) towards desirable behaviour. Besides the traditional activities of dissemination such as the project website and newsletters, a series of three workshops will be planned at each year of the project, working in close collaboration with the COST Action HARMONIOUS in order to disseminate our results over a larger audience that includes researchers, stakeholders and private companies. Stakeholders will be expected to take active role in the project, and specific actions will be focused on depending on the local circumstances. For the selected specific sites, detailed actions will take place as follows.

- University of Twente will involve the water authority Vechtstromen (for which lasting collaboration exists, https://www.vechtstromen.nl/). The developed scaling functions and soil and water datasets will be used by the company Cosine to develop machine learning algorithms. University of Twente and Deltares are in further development of the MajiSys water information system (developed in a joint project), which will serve as the information backbone of the iAqueduct project and the new development will be readily taken up by Deltares for application in the national Delta plan for water management under climate change;
- University of Naples will collaborate with the "Velia" Consortium Authority of Land Reclamation (which manages the dams and the irrigation district) and the "Cilento and Diano Valley" National Park (the largest park in Italy);
- The Confederacion Hidrografica del Jucar (CHJ) as the Spanish Water Authority for part of the Mediterranean basins of Spain will use the case study by the Universitat Politecnica de Valencia to help solve the climatic, environmental and socio-economic problems in the practice of water management. The Spanish company with European experience in UAS, Geosystem, will uptake the project results in developing services;
- Scenarios will be worked out for each of the selected sites using a technique developed in the EC CORE-CLIMAX project (Su et al., 2018 BAMS) whereby the distribution of forcings will be derived from the 2018 summer European drought period and by replacing the distribution with that of another site, mimicking potential future climate changes and impact to water resources. For example, the observed climate in the Twente region during the drought of 2018 summer will be replaced by that of the Spanish or Italian site and the spatio-temporal water situation in the Twente region be simulated. In collaboration with the water authority Vechtstromen, potential management scenarios will be developed and citizens will be invited to propose additional measures (e.g. water saving measures) as a preparation for such a scenario, thus connecting science to the society more effectively and influencing citizens towards desirable behaviour. For example, a first response to the water crisis experienced toward the end of eighties and beginning of nineties in the Alento catchment in Italy was the construction of the earthen dam at Piano della Rocca, which has been operating since 1994. Would the citizens in the Twente region welcome a similar measure? What else would be needed in order to cope with future drought events? These and other questions by the water authorities and citizens alike could then be worked out in the chosen scenarios.

1.5 Originality and innovative aspects of the research (ambition)

The main original and innovative aspects of this project are as follows.

- Advancing the space-time characterization of soil moisture and evapotranspiration processes through the coupled use of field, UAS and satellite observations. In particular, the combined use of high resolution soil characteristics and satellite data will increase our capabilities to describe soil moisture and evapotranspiration processes with high level of details (WP1);
- Retrieval of soil properties that are needed for modelling soil and water dynamics – soil hydraulic properties (SHP, water flow in soil and between land and atmosphere) and soil thermal properties (STP, heat flow between land and atmosphere). We advance the current state-of-the-art by using pedotransfer functions based on generalised soil maps to local field specific SHP/STP properties for modelling of soil and water processes for pan-European scale sustainable management of water resources at field scale precision, using soil spectral information from the global and local soil spectral libraries (WP2);
- Retrieval of scaling relationships between soil moisture and evapotranspiration. This is expected to revolutionise the current hydrological modelling concepts in which the actual evapotranspiration is parameterised on the

availability of soil moisture using untested (linear) assumption. Field specific scaling functions will be generated on the basis of downscaled satellite observation of soil moisture and evapotranspiration (WP3);

- Development of the generic iAqueduct open source toolbox – integrating models, soil parameters, forcing and field scale observation and gridded water states and fluxes to support the translation of science knowledge into water productivity information for the smart management of water resources (WP4);
- Demonstrating the benefits in closing water cycle gaps from global to local scale by deploying a set of well monitored field sites and advancing how to effectively handle spatio-temporal data (from in-situ, UAS and satellites) to bridge the scales from plant to plot, subcatchment, and catchment/basin (WP5).
- Disseminating and communicating generated knowledge and tools to water managers, companies and farmers for actual sustainable water management of their responsible domains. The 2018 summer European drought will be used as a case study, to facilitate the engagement of the society. The goal is to develop potentially more effective approaches connecting science to the society thus influencing citizens towards desirable behavior in water management (WP6).

1.6 Clarity and quality of transfer of knowledge for the development of the consortium partners in light of the proposal objectives

The seven involved partners in iAqueduct are the core members of working group 3 of the COST Action "Harmonization of UAS techniques for agricultural and natural ecosystems monitoring". As such the partners will continue to benefit from previous expertise in projects (see description of expertise below) related to the research objectives. The design of the 6 WPs jointly executed by 7 partners at 5 research sites ensures that iAqueduct will be operated as a whole to achieve the stated research objectives. The northern partners (Uni. Twente and SLU) will gain insightful knowledge from the southern partners (UPV, *Uni. Basilicata and Uni. Naples*) via field experiments in Italy and Spain, while contributing state-of-the-art knowledge in satellite observation of water cycle, modeling of soil heat and water processes (*Uni. Twente*) and ecological processes, in particular in scaling between soil moisture and evapotranspiration (*SLU*). TAU will contribute to the consortium with its renowned expertise in hyperspectral remote sensing and CAR-HAS does so with her expertise in research in pedotransfer functions. Both will gain new knowledge in linking different processes from coarse satellite observation to fine field scale water states and all partners will benefit strongly from the close collaboration with stakeholders at 5 different sites. An additional important aspect of the iAueduct project is to learn the lessons in different climate in coping with extremes.

1.7 Quality of the consortium partners and collaborative arrangements. Capacity of the consortium to reinforce a position of leadership in the proposed research field

The iAqueduct consortium is designed as a collaborative whole in order to effectively exploit existing knowledge at the local to global scale by answering the questions: How to downscale the global water cycle products to local scale? How to convert the coarse resolution data into fine scale water information at the management scale for water, vegetation and soil processes? And how to use such fine-scale water information to improve the management of soil and water resources? By combining EC/ESA Copernicus satellite data (with intermediate resolution) with high resolution Unmanned Aerial System (UAS) and in-situ observations to develop scaling functions for soil properties and soil moisture and evapotranspiration at meter scales, the iAqueduct consortium is ensured to position itself in a leadership role in this emerging research field. The seven partners *Uni. Twente*, *UPV*, TAU, *Uni. Basilicata*, *Uni. Naples*, *SLU* and *CAR-HAS* each brings specific expertise contributing to iAqueduct objectives and are briefly described below, while more detailed description of the principal investigators and project members are given in sec. 5-6.

Uni. Twente undertakes education, research and advisory services in Earth observation and spatial information collection, analysis and management. We provide tools and methods for the exploitation and conservation of resources and environment, particularly in developing countries. The Department of Water Resources (WRS) is a multidisciplinary scientific department specializing in scientific research and education in Earth Observation and Geo-information Sciences for the understanding, monitoring, predicting and sustainable use and management of water resources under the context of climate change. ITC-WRS has maintained ITC GEO Land-Atmosphere Interaction Observation Networks at Eurasia continental scale, as well as East Africa Monsoon Observation Network, which has contributed to international and national projects. In particular, ITC-WRS has coordinated EU FP7 CORE-CLIMAX (COordinating Earth observation data validation for RE-analysis for CLIMAte ServiceS) and the ESA WACMOS project in generating Earth Observation based water cycle products as well as the NWO/GO project on modelling freeze-thaw processes with active and passive microwave observations. The most relevant ongoing projects are the core SMAP mission calibration and validation by NASA (2011+) in the Twente area and the Tibetan Plateau; the retrieval of soil thermal and hydraulic properties by means of passive microwave remote sensing and the modeling of coupled soil heat and water and groundwater flows. Uni. Twente will coordinate iAqueduct and be leading WP6, as well as participate in other tasks.

UPV is the best technological university in Spain, according to Times Higher Education Ranking. The UPV Research Institute of Water and Environmental Engineering (IIAMA) organizes the technical and scientific research in the field of water and environment. IIAMA coordinates the Spanish network of Water Research Institutes (RIAMA) and is a member of the Spanish Technology Platform (PTEA) and the European WssTP and participates in 3 Action Groups of the EIP-Water. The UPV partner has many years of experience working in collaboration with both private companies and public organizations around the globe and has participated in many European programs as INTERREG, 4th, 5th, 6th and 7th FP, ERANET, LIFE, Climate-Kic and H2020. Among them, some are closely related to the topics addressed in this proposal, for instance the ongoing LIFE project coordinated by IIAMA "Coupling water, fire and climate resilience with biomass production in Forestry to adapt watersheds to climate change" (LIFE17 CCA/ES/000063). Staff's previous experience is expected to offer the other partners a new perspective on the importance of an advanced hydrological modelling approach. In addition, the Spanish case study will provide deep knowledge on the exploitation of remote sensing information at different scales.

TAU has more than 25 years experience in soil spectroscopy and hyperspectral remote sensing. They are known as the pioneer in soil proxy spectral based analysis. National projects from ministry of agriculture (Israel soil spectral library, developing spectral assembly for soil in situ measurements) ministry of Science and Technology (establishing hyperspectral capacity for environmental monitoring in Israel) or bilateral project with US (BARD, assessing soil hydrophobicity using spectral means), Czech– IL foundation (Soil contamination as monitored by spectral means) and FP7 project (EO-MINERS) and H2020 project (GEO- CRADEL). High prestige national foundation of the ISF (Israel Science Foundation, 3 times) and bilateral international foundation GIF (German Israel Foundation) and BARD (Bi-national Agriculture Research and Development, Israel USA) were also achieved at TAU. More than 180 peer review papers, chapters and proceeding papers with 4 patents have been the outcrop of the TAU group. TAU will contribute to the consortium all of its knowhow on soil spectroscopy and remote sensing that gathered over the past 25 years. TAU will be active in Task 2 and observer in all other tasks.

Uni. Basilicata has a significant experience on hydrological and hydraulic research. It has been leading several research activities on the use of UAS for environmental monitoring and hydrological modelling. It has been involved in relevant projects such as: the cooperation project entitled "Monitoring the soil water content in semi-arid environments" - CRUI 2017; the COST Action "Harmonization of UAS techniques for agricultural and natural ecosystems monitoring"; COSMO-SkyMed AO Project: "Use of COSMO-SkyMed SAR data for landcover classification and surface parameters retrieval over agricultural sites"; MEDDMAN project "Integrated water resources management, development and confrontation of common and transnational methodologies for combating drought"; Project "Space-time Variability of Soil Moisture of the Cooperative Institute for Climate Science (Princeton University and NOAA)".

Uni. Naples was established in 1224 and is the oldest, public non-religious university in the world. It has a long-lasting and well-established experience and expertise in hydraulic engineering and agricultural hydraulics. With more specific reference to this proposal, laboratory and field research facilities are available to support the identified tasks. The Soil Hydrology Laboratory is a renowned laboratory all over the world, equipped with a wide range of instruments and facilities for teaching and research in soil physics and vadose zone hydrology. Computer facilities are available for both computing requirements and controlling over experimental equipment. Software for image-processing and GIS is available. Facilities are also available for monitoring variables under field conditions. Main research topics currently under way are: determination of soil physical and hydraulic properties; identification of sensitive areas to drought and soil degradation; analysis of space-time water dynamics in the soil-vegetation-atmosphere system; mapping soil erosion risk. The research group led by N. Romano contributed to the European database of soil properties, with the related development of pedotransfer functions, manages the "Alento" Critical Zone Observatory and will use its range of experience and expertise in the monitoring of variables and modeling of processes to provide information that will improve the understanding of how to interpret measurements and processes so that their information content can be transferred to the larger domain of practical application. As for the latter point, this will benefit from the very good collaborations under way with the "Velia" Consortium Authority of Land Reclamation that manage the dams and the irrigation district in the Alento Basin.

SLU is the only Swedish university focusing on basic and applied research on agriculture, forestry and veterinary. It aims at creating knowledge that contributes to achieving the goals for sustainable development in Sweden and globally. A continuous interaction with industry and society is a key aspect at SLU. Within SLU, the Department of Crop Production Ecology addresses issues related to crop- and forest-environment interactions, with a strong focus on the underpinning functional mechanisms and their modelling and a long-standing tradition of stakeholder engagement and participatory research. As such, the SLU team provides to the project the plant ecophysiological dimension needed to quantify the effects of fluctuations in water availability on vegetation. On-going projects related to the proposal: 2017-2020: “Ensuring food security from field to globe - Climate-related risk and vulnerability to climate change in agricultural systems”. Swedish Research Council (Vetenskapsrådet), 2016-04910; 2016-2020: “TC4F - Trees and crops for the future”. Swedish government co-operative project between established strong research environments at the Swedish University of Agriculture (SLU), Umeå University and Skogforsk.

CAR-HAS is the largest agricultural research complex in Hungary and carries out basic and applied research and development in the field of agricultural sciences, participates in the dissemination of professional and scientific knowledge, and works in cooperation with organisations involved in agriculture, the food industry, rural development, environment protection and sustainable development, at both national and international levels. CAR-HAS focuses among others also on research on the consequences of climate change for processes involved in the soil, water, material and energy cycles on relationship between soil hydraulic properties and environmental factors. The Centre cooperates with other research institutes in Hungary, and maintains contacts both with scientific institutions in other countries and with international scientific societies or bodies such as Global Soil Partnership (GSP), Sino-European Panel on Land and Soil (SEPLS), International Soil Modelling Consortium (ISMC), International Union of Soil Sciences (IUSS), European Soil Partnership (ESP). Ongoing projects related to the proposal: 2017-2019: “Development of new methodology for 3D soil hydraulic property mapping and testing its application on the catchment of Lake Balaton”. National Research, KH124765; 2017-2019: “Elaboration of spatial predictions together with modelling of their uncertainty for specific functions and processes of soils applying spatial statistical and machine learning methods”. National Research, KH126725.

iAqueduct will integrate the various components from the global water cycle observation to local soil and water states in an open-source water information system and test and demonstrate their utility on pan-European scale at a set of carefully selected research sites for sustainable management of water resources.

2. IMPACT - Expected Outcomes and Impact of the Research

2.1 Impact of the proposal

iAqueduct will contribute to each of the expected impacts mentioned in the Call Announcement as summarized below.
Sub-theme addressed: iAqueduct addresses Theme 3 - Supporting tools for sustainable integrative management of water resources, as well as Sub-theme 2.3 - Connecting science to society in order to develop approaches to influence stakeholders (in particular citizens) towards desirable behaviour (Water JPI 2018 Joint call, Closing the Water Cycle Gap – Sustainable Management of Water Resources);
UN SDG targets: iAqueduct contributes to the implementation of key UN Sustainable Development Goals (SDGs): SDG 6, SDG 13 and SDG 1, by developing an integrative information aqueduct to close the gaps between global satellite observation of water cycle and local sustainable management of water resources and applying the project results in real time water management practices (e.g. the stress test in the Dutch Delta plan). iAqueduct toolbox will be transferred to the water authorities for water management and companies for developing business for irrigation management (in Spain, Italy and the Netherlands). The involvement of the partners in international fora ensures the contribution of the developed knowledge, data and toolbox to the relevant UN bodies (e.g. UN World Water Assessment Programme);
Beyond the State-of-the-Art: iAqueduct will enable test and develop beyond the state-of-the-art approaches to derive local field scale water states information (precipitation, evapotranspiration and profile soil moisture) using satellite, UAS and in-situ observations, as well as modeling and big data analytics tools for water management under climate change;
Case studies: Several case studies are proposed at local level and coordination ensured by engaging water authorities and companies (in Spain, Italy and the Netherlands); these case studies cover a variety of climates, thus ensuring the generality of the methods developed;
Connect to stakeholders: water authorities and companies (in Spain, Italy and the Netherlands) are involved in the proposal and project execution;
Gender dimension: In all WPs we will ensure gender balance by engaging female and male researchers in the relevant WPs (2 WPs are led by female partners, each partner will strive to engage one female investigator);
International participation in water R&I in different environments: From north to east and south Europe, five different but well monitored field sites with various climatic regimes, hydrological and soil conditions are selected and partners with complementary expertise are involved, the inclusion of Tel Aviv University further enhances the international participation.

2.2. Expected outputs

The main expected outputs are:
(i) iAqueduct outputs will include a database of measurements (satellite/UAS-data/soil moisture/PTF etc.) for the 5 experimental sites as well as the corresponding open source publications at ISI journals (we anticipate ca. 15

publications 2 years after the completion of the project). The generated codes and software will be integrated in the MajiSys open source system for distribution and wider use. Training of junior researchers at PhD and postdoc level, joint experiments and publications in the 6 WPs as well as internships at each other partner's by (to be recruited) junior researchers will strongly benefit the exchange of knowledge by mobility. Three workshops (incl. analyses and suggestions for measures for the drought events in 2018) will be organized with stakeholders;
(ii) iAqueduct will enhance innovation capacity with substantial impacts not mentioned in the Announcement. The scaling up to pan-European level of iAqueduct results will take place under the aegis of the COST action Harmonization of UAS techniques for agricultural and natural ecosystems monitoring (HARMONIOUS) which undoubtedly would enhance pan-European innovation capacity;
(iii) iAqueduct will support an end-to-end system, which ingests scientific data and translates into tailored water productivity information for end-users/stakeholders across scales and levels for their decision makings.

2.3. Exploitation and communication activities (measures to maximise impact)

Exploitation: WP6 is specifically designed to address the exploitation issue. Dissemination and communication will take place for the use of generated knowledge and tools by water managers, companies and farmers for actual sustainable water management (training for iAqueduct toolbox will be organized for stakeholders in different countries; case analyses for the drought events in 2018).

Added-value of the partnership to Water RDI: iAqueduct complements the actions developed under ESFRI by coordinating a set of European research groups and sites for studying soil and water processes using space technologies, UAS and in-situ observations and the scaling up to pan-European level under the aegis of the COST Action Harmonization of UAS techniques for agricultural and natural ecosystems monitoring (HARMONIOUS) which is highly effective given the fact that there are 70 participating institutions from 32 countries in HARMONIOUS. This has a strong added-value of the partnership to Water RDI and can serve as a prototype ESFRI for water which does not exist in Europe so far.

iAqueduct will be further linked to international programmes such as GEWEX and GEO. The project coordinator Prof. Bob Su is appointed as GEWEX SSG member and establishes/maintains ITC GEO Land-Atmosphere Interaction Observation Networks at Eurasia continental scale. Such coordination will be greatly enhanced, by offering the additional sites for calibration and validation of global satellite water cycle products.

2.4. Market knowledge and economic advantages/return of investment

As explained in WP6, Uni. Twente will collaborate with the company Cosine to exploit the developed scaling functions and soil and water datasets to develop machine learning algorithms (to enhance the scientific aspects of an newly approved ESA project to use Sentinel data and commercial CubeSat data to generate products for agricultural management). Uni. Twente and Deltares (a public research institution in the Netherlands) are in further development of the MajiSys water information system (developed in a previous joint project) and the new development generated in iAqueduct will be taken up by Deltares for application in the national Delta plan for water management under climate change. Uni. Naples will collaborate with the "Velia" Consortium Authority of Land Reclamation for actual management of dams and the irrigation district and the "Cilento and Diano Valley" for the management of the National Park in Italy. UPV will engage the Confederacion Hidrografica del Jucar (CHJ) as the Spanish Water Authority for part of the Mediterranean basins of Spain to use the case study to help solving the climatic, environmental and socio-economic problem in the practice of water management. The Spanish company with European experience in UAS, Geosystem, will uptake the project results in developing services.

Furthermore, the iAqueduct can easily be translated into a marketable web-based application, service and/or product for the smart management of water resources, establishing science-policy-business-society interfaces to allow for continuous dialogues and interactions across different scales and levels, influencing stakeholders (in particular citizens) towards desirable behaviour other than simple financial incentives.

3. IMPLEMENTATION

3.1 Overall coherence and effectiveness of the work plan

As discussed in Sec. 1, the scientific content of the iAqueduct project will be implemented in 6 closely connected WPs jointly conducted by 7 partners (Fig. 1). The WPs are designed in an optimal way to achieve the desired impact (see Sec. 2.1) by means of the outputs (described in Sec. 2,2). The intended exploitation and communication activities (Sec 2.3) and the potential market for the to-be generated new knowledge and innovative technological solutions and services for practical water management (Sec. 2.4) further strengthen the project effectiveness. WP1 develops scaling methods from global satellite water cycle products to field scale surface and profile information of water states. WP2 bridges spectral information from high resolution satellites and UAS observations to field scale soil information in terms of soil hydraulic and thermal properties (SHP/STP) that determine soil water and heat flow. Subsequently, WP 3 retrieves field and grid specific scaling functions between soil moisture and evapotranspiration. WP 4 encapsulates the developed tools in previous WPs into open source code for wide distribution and easy use and in WP5 are demonstrated the advantage and benefits in closing water cycle gaps from global to local scale. This is further used for actual sustainable water management in WP6 by developing scenarios with the 2018 drought events as concrete cases. Each WP is led by a partner with a solid track record in the respective scientific content and is assisted by other partners to ensure its successful implementation. The use of the six field sites operated by the partners minimizes logistic risks that often occur in complex field investigations. In addition to the six scientific WPs, a management WP0 will be led by Uni. Twente to coordinate among the WPs and among partners. Table 1 summaries the WPs, Tab. 2 provides details of the deliverables and milestones and Tab. 3 gives the connections in time with a simple Gantt chart, while the logic relations among the WPs are given in Fig. 1.

Table 1. List of iAqueduct WPs

WP Number	WP Title	Duration (months)	Starting Month	End Month	WP Description
WP0	Coordination and management	1.5 (36 days)	1	36	Project coordination and management
WP1	From global satellite water cycle products to field scale water states	24	1	24	Developing scaling methods from global satellite water cycle products to field scale surface and profile information of water states.
WP2	Retrieval of soil properties (SHP/STP)	24	4	27	Retrieval of soil properties from RS means (optical and thermal, multi and hyperspectral), developing of spectral based models for several soil attributes to execute field implementation of the WP products.
WP3	Retrieval of field/grid specific scaling functions between soil moisture and evapotranspiration	24	7	30	Developing field and grid specific scaling functions between soil moisture and evapotranspiration.
WP4	Development of the generic (iAqueduct tool box)	24	10	33	Developing open source iAqueduct toolbox (integration of content of WP1-3 and modeling).
WP5	Demonstrate the benefits in closing water cycle gaps from global to local scale (case studies)	24	10	33	Demonstration cases for benefits in closing water cycle gaps from global to local scale.
WP6	Disseminate generated knowledge and tools for actual sustainable water management	12	7 (19 (31	-12 -24) -36)	Scenarios for actual sustainable water management with stakeholders (with the drought events in 2018 as concrete cases).

3.2 Appropriateness of the management structure and procedures, including quality management

To achieve the project objectives, timely and close interactions among the six WPs, and with the consortium partners are essential. The management structure is designed to suit such requests.

Project Board: The Project Board consists of representatives of all participating organisations. iAqueduct General Assembly (Project kick-off, 1st, 2nd and final assembly concurrent with the three workshops) is the highest decision making organ regarding strategic issues. A majority based voting system will be used for decision making. The chair of the PB is Prof. Z. Bob Su, who also serves as Project coordinator, each participant will appoint one representative as PB member (by default the PIs as listed are PB members unless otherwise communicated upon project commencement). Guidance and directions from the national funding agencies will be observed by the respective PIs and communicated to the Project coordinator via WP0 and implemented as timely actions.

Uni. Twente proposes to install Dr. Yijian Zeng as project manager for technical matters and ir. Bert Boer, senior project officer, for administrative/legal /financial aspects of iAqueduct to assist the Coordinator Prof. Bob Su in managing the project execution. The Project coordinator is supported by a project secretariat for all management issues (WP0).

AB: We intend to install an Advisory Board consisting of senior members closely involved in the scientific content of the project as well as those from the major stakeholder organisations. This however should be subject to advices of the funding organisations. The AB members are expected to provide the iAqueduct consortium with external emerging initiatives and opportunities, in addition to the existing networking by the consortium members. AB members are expected to participate in three meetings, at the three workshops, Month 12, 24 and 36.

WP leads: the implementation of the work tasks are organised in 6 WPs, each with a WP lead. Each WP is led by a WP lead who is responsible for the implementation of the WP tasks as detailed in Sections 1.4.

Reporting takes place from task contributors (to be appointed by each WP participating partner) to the corresponding WP lead, then to WP0 via project secretariat. Links between WPs and crosscutting meetings are ensured by the participation of consortium partners in multiple WPs, by the web meetings (every three months) and the annual project meetings. The flow of information between WPs is also guaranteed in the same manner.

Management meetings will be held quarterly by teleconference (or in person when collocated with project workshops/progress meetings) to ensure the project will be run according to plan and will achieve its objectives. PIs will attend these meetings. The quarterly meetings are formal reporting moments with the minutes recorded and archived on the project reporting website for inspections. Written quarterly progress reports will be submitted by all WP leads to the project coordinator for assessing the adequacy of progresses. All documents and reports will be made accessible to all partners and the funding agencies. Other reports will be made public also via the project web site.

By jointly submitting the iAqueduct proposal, all project members agree to its content which prescribes the tasks, working practices and approach to running the project. Additional guidance by the respective national funding agencies will be followed by the concerned PIs. All project management work carried out by Uni. Twente is consistent with best practices as done in recent NWO funded projects. The thematic contributions to the Tasks and WPs are decided based on the high quality and expertise of the individual participants which are detailed in section 4 as well as shown by the enclosed CVs of the PIs.

Table 2. List of iAqueduct deliverables and milestones

WP Number	WP Title	Description of deliverables (D) and milestones (M)
WP0	Coordination and management	D: Quarterly progress (D0.x_1 - x_4) and three annual (D0_x.0) project reports M: kick-off meeting, and three workshops (M0_0, M0_x) *(x: refers to year 1-3, timing of milestones are indicated in Tab. 3)*
WP1	From global satellite water cycle products to field scale water states	D1.1. Satellite/UAS-data; D1.2. Scaling methods from global satellite water cycle products to field scale surface and profile information of water states.
WP2	Retrieval of soil properties (SHP/STP)	D2.1. Soil spectral libraries of distinct soil groups in both laboratory and field and their relationship (month 10); D2.2. Maps of soil hydraulic properties for the 5 experimental sites based on traditional and vis-NIR spectral analysis (month 24).
WP3	Retrieval of field/grid specific scaling functions between soil moisture and evapotranspiration	D3.1. Field and grid specific scaling functions between soil moisture and evapotranspiration (month 24); D3.2. STEMMUS simulation results across the selected experimental sites.
WP4	Development of the generic (iAqueduct toolbox)	D4.1. Intercomparison of models, soil and vegetation parametrizations and soil parameters; D4.2. iAqueduct toolbox.
WP5	Demonstrate the benefits in closing water cycle gaps from global	D5.1. Spatial-pattern-oriented model calibration;

	to local scale (case studies)	D5.2. Multiscale parsimonious distributed ecohydrological model to bridge the scales from plant to plot, subcatchment, and catchment/basin respectively;
WP6	Disseminate generated knowledge and tools for actual sustainable water management	D6.1. Scenarios for actual sustainable water management with stakeholders (with the drought events in 2018 as concrete cases). D6.2. Connecting science to society - approaches to influence stakeholders (in particular citizens) towards desirable behaviour: - D6.2-1a. Options for optimal water management in Twente (Uni. Twente interacts with the water authority Vechtstromen); D6.2-1b. Machine learning algorithms (Uni. Twente with the company Cosine); D6.2-1c. Suggestion for application of the iAqueduct toolbox in the national Delta plan for water management under climate change (Uni. Twente with the Deltares); - D6.2-2. Demonstration in the "Cilento and Diano Valley" National Park (Uni. Naples will collaborate with the "Velia" Consortium Authority of Land Reclamation); - D6.2-3a. Case study to help solve the climatic, environmental and socio-economic problem in the practice of water management (UPV with the Confederacion Hidrografica del Jucar (CHJ)); - D6.2-3b. Initiative for up-taking project results in developing services (UPV with Geosystem).

**Each scientific WPs will enable the scientific publications (Dx.x* in Tab. 3). Expected ISI publications are listed as below for relevant WPs: (1) possible topics for WP1 are: Characteristics of high resolution spatio-temporal patterns of soil moisture fields; Scaling from global satellite products to sub-meter UAS scale water cycle products; Water states from surface RS information to profile); (2) WP2: Soil Spectral Library with a protocol on how to implement the SSL to field condition; Spectral based models to assess hydraulic soil properties on a spatial domain; (3) WP3: Field/grid scaling functions for soil moisture and evapotranspiration; Generalised scaling functions for soil moisture and evapotranspiration; (4) WP4: High resolution ecohydrological modelling; iAqueduct toolbox; and WP5:Model calibration based on high resolution spatial data; Multiscale parsimonious ecohydrological modelling.*

Table 3. iAqueduct timeline – WPs, events, etc.

Month/ Description	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
WP0	X	X	X	X	X	X	X	X	X	X	X	X
WP1	X	X	X	X	X	X	X	X				
WP2		X	X	X	X	X	X	X	X			
WP3			X	X	X	X	X	X	X	X		
WP4				X	X	X	X	X	X	X	X	
WP5				X	X	X	X	X	X	X	X	
WP6			X	X			X	X			X	X
Deliverable (*)	**D0.1_1**	**D0.1_2**	**D0.1_3**	**D0.1_4** **D1.1** **D2.1** **D6.1**	**D0.2_1**	**D0.2_2** **D3.1** **D4.1** **D5.1**	**D0.2_3**	**D0.2_4** **D1.2** **D2.2** **D4.2** **D5.2** **D6.2**	**D0.3_1**	**D0.3_2**	**D0.3_3**	**D0.3_4** **D1.3** **D2.3*** **D3.2,** **D3.3*** **D4.3*** **D5.3*** **D6.2-1** **D6.2-2** **D6.2-3**
Milestone	**M0_0**			**M0_1**				**M0_2**				**M0_3**

(See Table 2 for description of deliverables and milestones; D6.2-1a,b,c; D6.2-3a,b)*

3.3 Risk management

iAqueduct anticipates no potentially major barriers/obstacles, and any framework conditions at this point in time as all the developed knowledge, data and toolbox will be open source and open access. We notice though national regulations may prohibit operating UAVs in certain areas. It is also beyond the scope of project to assess the financial follow-up steps in developing the envisioned value chain by the companies.

- Group cohesiveness (Impact: high. Probability: low) – Cohesion within the research units (RUs) is very high mainly because of already performed joint experimental activities. Links between partners of this consortium are also high since some of them have already participated in common funded research projects and are involved in the COST Action HARMONIOUS.
- Internal structure and deliverables/milestones problems (Impact: medium. Probability: medium) – There might be a potential risk that the internal structure of the project proposal (especially in terms of WPs) might prove not to be effectively able to support the completion of the defined objectives. On the one side, the proposed structure and links among the WPs is definitely solid, but on the other hand we also plan from the kick-off meeting that the partners agree on the organizational structure, especially with a view to efficiency in joint works and transfer of data and experiences.
- **Damage to deployed instruments and equipment** (Impact: medium. Probability: low). Each RU of this consortium has experience with this problem, which is typical of any monitoring activity, but regular data download, regular visits to the experimental sites, and instrumental maintenance are considered. The probability of occurrence of this problem is marked as "low" because of our previous knowledge of the local situations.
- Data retrieving and scenario analysis (Impact: high. Probability: low) – One of the strengths of the present proposal is that it refers to experimental activities that do not start from scratch, but rather they will be conducted in exemplary sites where certain databases have been already created and are still kept fully operational. However, we cannot overlook the fact that there can be a potential risk of insufficient data availability, especially with reference to information relevant to the spectral analysis. An initial in-depth report on the available data for each site and the additional information required to feed the subsequent tasks will definitely lower to minimum, or avoid altogether this barrier.
- Stakeholders and end-users involvement (Impact: medium. Probability: medium) – A key element of the iAqueduct proposal is the consultation with stakeholders, public authorities, and end-users that will have the opportunity to express their views on matters that can affect them more or less directly.
Other specific risks related to each anticipated WP may be identified on a technical level but we deem them as low impact as the existing expertise and proven track records of the partners guarantee the execution of the majority of WPs content.

3.4 Potential and commitment of the consortium to realise the project

The detailed expertise of the partners has been explained in 1.7 (Quality of the consortium partners and collaborative arrangements) that shows the consortium can successfully realise the project. All partners are well experienced with conducting and carrying out multi scientific projects under national and international collaboration. By jointly submitting this project proposal, the partners commit themselves to the content and agree to jointly realise the project according to its design.

Uni. Twente is a world leader in Earth observation of water cycle, in particular in microwave remote sensing which enjoys a field-weighted citation impact of 3.31 (Scopus 2012-2017, way above the world average of 1.0). It operates the Twente cal/val site for SMAP mission and collaborates with various national (and international) partners for application of Earth observation to water management. Uni. Twente will act as coordinator of the iAqueduct project and leads WP6 and contributes to several WPs.

UPV is well-known for its expertise in distributed ecohydrological modelling. It provides the Barranco del Carraixet area and the contact with local stakeholders in Spain, will lead WP5 and participates in several WPs.

TAU has a well-known reputation in soil spectroscopy and soil remote sensing from many aspects including standard and protocol and chemometrics. To that end with the partners of this project, especially those of WP2, the tasks related to soil spectral observation of soil are provisioned. It also provides the Haogen area in Israel for experiment in hyperspectral observation of soil properties.

Uni. Basilicata leads research activities on the use of UAS for environmental monitoring and hydrological modelling and is coordinator of the COST Action "Harmonization of UAS techniques for agricultural and natural ecosystems monitoring". It provides iAqueduct with the Corleto area in Italy, with its UAS expertise and coordination with the COST project for scaling up to pan-European level. It leads WP1 and participates in several other WPs.

Uni. Naples provides the Alento River Hydrological Observatory in Italy that serves as a field site for intensive soil moisture and hydrological observation and modelling as well as its well-known expertise and laboratory facilities for soil water and hydrological research. It leads WP4 and participates in several other WPs.

SLU provides to iAqueduct the plant ecophysiological expertise needed to quantify the effects of fluctuations in water availability on vegetation. It leads WP3 and participates in several other WPs.

CAR-HAS has expertise in deriving pedotransfer functions and mapping soil hydraulic properties at field, regional and continental scale. It leads WP2 and contributes to other WPs by providing the Zala research area in Hungary.

4. DESCRIPTION OF THE PARTICIPATING RESEARCHERS

<table>
<tr><th>Partner Number, according to Part A</th><th>Research Team Members (for personnel include name, position and affiliation)</th><th>General Description</th></tr>
<tr><td rowspan="3">University of Twente (PI: Bob Su)</td><td>Yijian Zeng, assistant professor, Department of Water Resources, Faculty ITC, University of Twente</td><td>Dr. Zeng is developer of the STEMMUS model (Simultaneous Transfer of Energy, Mass and Momentum in Unsaturated Soil) and pioneered the analysis on how soil airflow affected surface evaporation and demonstrated the importance of including airflow mechanism in land surface process studies (Zeng et al. 2011b, WRR; Zeng and Su, 2011b, JGR), which is recognized by a WMO young scientist award. He also coordinates the Tibetan Plateau SMST Observatory that serves as an SMOS and SMAP cal/val sites.</td></tr>
<tr><td>Bert Boer, Project Officer, Department of Water Resources and Department of Natural Resources</td><td>ir. Bert Boer is Project Manager and acted as interim Head ITC project bureau; project cycle management, project acquisition: acquisition for bilateral funding (DGIS), EU financed projects, NWO, ESA, EDF.</td></tr>
<tr><td>Postdoc (to be recruited)</td><td>Who will be responsible for the execution of Uni. Twente technical tasks</td></tr>
<tr><td rowspan="2">Universitat Politecnica de Valencia, UPV (PI: Francisco Valles)</td><td>Félix Francés, Full Professor at UPV and leader of the Research Group of Hydrological and Environmental Modelling at IIAMA-UPV</td><td>Prof. Dr. Francés is Vice-president of the Spanish Water Technological Platform and Associate Editor of Journal of Hydrology. He has participated and managed more than one hundred research projects and engineering studies in different fields of Hydrologic Engineering, publishing 67 research papers and 33 books and book chapters, and coauthoring more than two hundred congress communications. In 2011, Dr. Francés obtained the Engineering Innovation Award from the Spanish National Civil Engineering Association.</td></tr>
<tr><td>PhD (to be recruited)</td><td>Who will be responsible for the execution of UPV technical tasks</td></tr>
<tr><td rowspan="2">Tel Aviv University (PI: Eyal Ben-Dor)</td><td>Nicolas Franco, a PhD student</td><td>Responsible to carry out the field work for WP2.1 and 2.2 as part of his PhD thesis</td></tr>
<tr><td>Tania Podolsky, a PhD student</td><td>Responsible for the data mining stage of the SSLs and RS set of data</td></tr>
<tr><td rowspan="2">University of Basilicata (PI: Salvatore Manfreda)</td><td>Pietro Vuono, PhD student</td><td>UAS data processing</td></tr>
<tr><td>Caterina Samela, Post-doc</td><td>Soil moisture data processing and modelling applications</td></tr>
<tr><td rowspan="2">University of Naples Federico II Falento (PI: Nunzio Romano)</td><td>Paolo Nasta</td><td>Who will be responsible for the monitoring programme in the Alento catchment</td></tr>
<tr><td>PhD (to be recruited)</td><td>Who will be responsible for the execution of UPV technical tasks</td></tr>
<tr><td>Swedish University of Agricultural Sciences (PI: Giulia Vico)</td><td>Postdoc (to be selected)</td><td>Model development and testing</td></tr>
</table>

Centre for Agricultural Research of the Hungarian Academy of Sciences (PI: Brigitta Tóth)	*	Work described will be carried out in collaboration with other partners (in particular Uni. Twente).

(not funded)*

5. CAPACITY OF THE CONSORTIUM ORGANISATIONS

Partner #		General Description
Partner 1 **(University of Twente)**	**1***	Coordinate the project; Lead WP6
	2	The Twente SMST cal/val SMOS/SMAP site; geoscience lab equipped with state-of-the-art spectrometers from visible to thermal range; Drone lab.
	3	MajiSys water information system; STEMMUS model (Matlab). - Zhao, H., et al. (2018) Analysis of soil hydraulic and thermal properties for land surface modeling over the Tibetan Plateau, ESSD 10 (2), 1031. - Su, Z. et al (2013) Evaluation of ECMWF's soil moisture analyses using observations on the Tibetan Plateau, JGR 118 (11), 5304-5318. - Zeng, Z., et al. (2011) Numerical analysis of air-water-heat flow in unsaturated soil: Is it necessary to consider airflow in land surface models? JGR (1984–2012) 116 (D20)
Partner 2 **(Universitat Politecnica de Valencia, UPV)**	**1**	Lead WP5 and participant in WP1, WP3, WP4 and WP6
	2	The Research Institute of Water and Environmental Engineering (IIAMA) has 4 heavy laboratories and several experimental sites at different scales: from plot to catchment. It has 10 research groups and close to 100 highly qualified staff members, approximately 40 of them with a PhD degree in different fields of engineering, biology and chemistry.
	3	Eco-hydrological distributed model TETIS - Ruiz-Pérez, G., et al. (2017). Calibration of a parsimonious distributed ecohydrological daily model in ungauged basins using exclusively the spatio-temporal variation of NDVI. *Hydrol. Earth Syst. Sci*., 21 (12), 6235–6251. - Ruiz-Pérez, G., et al. (2016). Can a simple parsimonious model implemented with satellite data be used for modelling the vegetation dynamics and water cycle in water-controlled environments? *Ecological Modelling*, 324, 45–53.
Partner 3 **(University of Tel Aviv TAU)**	**1**	TAU with CAR-HAS and Uni. Naples will be responsible for most of the WP2 activity and deliverables. TAU will provide the knowhow to obtain soil spectral information (standard and protocol, laboratory and field) and the infrastructure available to do so along with utilizing TAU's homemade analytical tool to carry out the data mining stages
	2	Drones (5kg and 2 kg), Thermal calibrated FLIR, MicaSense camera, ASD field spectrometer , SoilPRO assembly for fast field measurements, HyperCAM hyperspectral LWIR sensor, PARACUDA II ® Software
	3	- Ogen, Y., et al. (2017). 3D spectral analysis in the VNIR–SWIR spectral region as a tool for soil classification. *Geoderma*, *302*, 100-110. - Ben- Dor, E., et al. 2015. Reflectance measurements of soils in the laboratory: Standards and protocols. *Geoderma*, *245*, 112-124. - Ben-Dor, E., et al. (2017). A simple apparatus to measure soil spectral information in the field under stable conditions. *Geoderma*, *306*, 73-80. - Carmon, N., & E. Ben-Dor, (2017). An advanced analytical approach for spectral-based modelling of soil properties. *IEEE Geosci. Int. J. Emerg. Technol. Adv. Eng*, *7*, 90-97.
Partner 4 **(University of Basilicata)**	**1**	Uni. Basilicata will support UAS hydrological monitoring at high resolution and soil moisture modelling and downscaling. It is also actually managing the experimental river basin Fiumarella of Corleto.
	2	Multicopters DJI – Phantom 3 and 4; Single wing drone Skywalker equipped with different sensors; Thermal Camera FLIR Tau 2; Multispectral ADC Snap Camera – Tetracam
	3	- Manfreda, S., et al., 2018, On the Use of Unmanned Aerial Systems for Environmental Monitoring. RS 10(4), 641. - Baldwin, D., Manfreda, S., et al., (2017), Predicting root zone soil moisture with soil properties and satellite near-surface moisture data at locations across the United States, JH, 546, 393–404. - Manfreda, S., et al., (2014), A physically based approach for the estimation of root-zone soil moisture from surface measurements, HESS, 18, 1199-1212. - Manfreda, S., et al., (2007), Spatial Patterns of Soil Moisture from Distributed Modeling, AWR, 30(10), 2145-2150.

Partner 5 **(University of Naples Federico II)**	**1**	*Uni. Naples* provides a range of expertise in the monitoring of soil and vegetation and modeling of soil hydrological processes. It also provides the very good collaborations with the "Velia" Consortium Authority of Land Reclamation that manage the dams and the irrigation district in the Alento Basin.
	2	world renowned Soil Hydrology Laboratory, the Alento catchment and monitoring instrumentation
	3	- Romano, N., et al., (2018), Monitoring Hydrological Processes for Land and Water Resources Management in a Mediterranean Ecosystem: The Alento River Catchment Observatory, Vadose Zone Journal 17 (1). - Nasta, P., (2018), Downscaling near-surface soil moisture from field to plot scale: A comparative analysis under different environmental conditions, Journal of Hydrology 557, 97-108 - Romano, N., P Nasta, (2016), How effective is bimodal soil hydraulic characterization? Functional evaluations for predictions of soil water balance, European Journal of Soil Science 67 (4), 523-535. - Romano, N., (2014), Soil moisture at local scale: Measurements and simulations, Journal of Hydrology 516, 6-20.
Partner 6 **(Swedish University of Agricultural Sciences)**	**1**	SLU will support ecohydrological model development and testing in WP3 and WP4
	2	The Department of Production Ecology addresses issues related to crop- and forest-environment interactions, with a strong focus on the underpinning functional mechanisms and their modelling and a long-standing tradition of stakeholder engagement and participatory research
	3	- Manfreda, S., et al. (2018), On the Use of Unmanned Aerial Systems for Environmental Monitoring. Remote Sensing, 10(4), 641. - Vico G, Brunsell NA, 2018, Tradeoffs between water requirements and yield stability in annual vs. perennial crops, AWR, 112, 189-202. - Manzoni S., et al. (2014), Optimal plant water-use strategies under stochastic rainfall, WRR, 50, 5379–5394 - Manzoni S., et al. (2013), Biological constraints on water transport in the soil-plant-atmosphere system, AWR, *51*, 1, 292-304
Partner 7 **(Centre for Agricultural Research of the Hungarian Academy of Sciences)**	**1**	CAR-HAS with TAU and Uni. Naples will carry out tasks of WP2. CAR-HAS will support deriving pedotransfer functions and mapping soil hydraulic properties.
	2	Server for data mining calculations.
	3	- Tóth, B., et al. (2017). 3D Soil Hydraulic Database of Europe at 250 m resolution. Hydrological Processes. 31:2662–2666. - Makó, A., et al. (2017). Pedotransfer functions for converting laser diffraction particle-size data to conventional values. European Journal of Soil Science. 68: 769–782. - Tóth, B., et al. (2015). New generation of hydraulic pedotransfer functions for Europe. European Journal of Soil Science. 66: 226–238. - EU-SoilHydroGrids: Tóth, B., Weynants, M., Pásztor, L., Hengl, T. 2017. 3D Soil Hydraulic Database of Europe at 250 m resolution (EU-SoilHydroGrids ver 1.0). http://mta-taki.hu/en/eu_soilhydrogrids_3d - https://esdac.jrc.ec.europa.eu/content/3d-soil-hydraulic-database-europe-1-km-and-250-m-resolution - euptf R package: Weynants, M., Tóth, B. 2014. *The euptf package.* The European Soil Portal.: 5 https://esdac.jrc.ec.europa.eu/public_path/shared_folder/themes/euptf.zip

(1: Role and main responsibilities in the project. 2: Key research facilities, infrastructure, equipment. 3: Relevant publications and/or research/innovation products)*