Brussels, 24 March 2020

COST 023/20

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "WATer isotopeS in the critical zONe: from groundwater recharge to plant transpiration" (WATSON) CA19120**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action WATer isotopeS in the critical zONe: from groundwater recharge to plant transpiration approved by the Committee of Senior Officials through written procedure on 24 March 2020.

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MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA19120
WATER ISOTOPES IN THE CRITICAL ZONE: FROM GROUNDWATER RECHARGE TO PLANT TRANSPIRATION (WATSON)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. “Rules for Participation in and Implementation of COST Activities” (COST 132/14 REV2);
b. “COST Action Proposal Submission, Evaluation, Selection and Approval” (COST 133/14 REV);
c. “COST Action Management, Monitoring and Final Assessment” (COST 134/14 REV2);
d. “COST International Cooperation and Specific Organisations Participation” (COST 135/14 REV).

The main aim and objective of the Action is to address three major scientific challenges related to water flux partitioning in the critical zone based on the use of water isotopes:
Challenge 1 - Groundwater recharge.
Challenge 2 - Vegetation water uptake and transpiration.
Challenge 3 - Residence and travel time.. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 76 million in 2019.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

OVERVIEW

Summary

Understanding water exchange within the critical zone, i.e.the dynamic skin of the Earth that extends from vegetation canopy to groundwater, is vital for addressing key environmental problems linked to the sustainable management of water resources. The main aim of WATSON is to collect, integrate, and synthesize current interdisciplinary scientific knowledge on the partitioning and mixing of water in the critical zone taking advantage of the unique tracing capability of water isotopes. These efforts will allow going beyond the current fragmented knowledge providing a novel conceptual framework on the interactions between groundwater recharge, soil water storage, and vegetation transpiration useful for water resources management across a variety of climatic settings. The Action activities are based on a network of early career and senior scientists from different complementary disciplines who are experts in the use of water isotopes, and stakeholders from governmental agencies and private companies from 19 COST countries and one Near Neighbour Country. Meetings and training events will involve scientists and water managers, facilitating communication between academia and stakeholders, promoting the transfer of the latest scientific findings, and helping to identify research gaps and management priorities. The ultimate goal of the network is to build capacity in the use of robust isotope approaches for water resource management. The deliverables include practical tools, such as maps of groundwater recharge and water sources used by vegetation in different European regions that will enable the translation of scientific cutting-edge knowledge into tangible recommendations to support European agencies responsible for water management in agro-forest systems.

Areas of Expertise Relevant for the Action	**Keywords**
● Earth and related Environmental sciences: Hydrology, water resources ● Environmental engineering: Water management and technology ● Agriculture, Forestry, and Fisheries: Sustainable forest management ● Biological sciences: Ecology	● Water isotopes ● Groundwater recharge ● Water residence and travel time ● Vegetation water use ● Water resources management

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

- To create European open-access databases of water isotope-based studies in the critical zone.
- To define protocols, standardized sampling procedures, and analysis techniques for isotope data.
- To compare and assess state-of-the-art, isotope-based methods and models to estimate groundwater recharge, water sources for vegetation transpiration, and catchment-scale travel and transit time, as well as analyse and summarize current technological approaches to collect and measure water isotope data.
- To foster communication and collaboration between researchers and water management agencies from different geographic regions responsible for water resource management, water use, land-use planning, forestry and agriculture.

Capacity Building

- To establish a large international network of researchers who are experts in the use of water isotopes in different scientific disciplines; to develop connections between ongoing European studies and to promote long-lasting collaboration for future research projects and applications for funding.
- To foster interdisciplinary knowledge exchange and bridge isolated fields of critical zone science into an integrated framework that is necessary to obtain more extensive understanding on functional interrelations between groundwater, soil water, and vegetation, and to achieve societal breakthroughs on sustainable

management of water resources.
● To develop a joint research agenda around the use of isotopes in critical zone studies. This includes promoting the exchange of ideas, capabilities, and experiences on the latest developments in isotope sampling and measurement techniques to study water transfer in the critical zone.
● To provide high-quality interdisciplinary training opportunities for PhD students, Early Career Investigators (ECIs), and practitioners on isotope-based methods and techniques for water resources research and management.
● To ensure geographic, age, and gender balance, and support activities for young researchers.

TECHNICAL ANNEX

1 S&T EXCELLENCE

1.1 SOUNDNESS OF THE CHALLENGE

1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

The **critical zone** is the thin dynamic skin of the Earth, extending from the top of the vegetation canopy through the soil, down to the bottom of the groundwater. It is the place where "rock meets life", and where humans and most of the animals live, and it is therefore ''critical'' to our survival [1, 2]. The critical zone is the domain where water cycle dynamics connect the subsurface to vegetation, atmosphere and climate, controlling water quantity and quality [1]. **Understanding water storage and transfer within the critical zone is therefore vital for addressing key environmental and social problems linked to ecosystem services in natural and human-impacted environments**: maintaining soil productivity in intensively managed systems, ensuring forest vitality, and improving landscape resilience to natural hazards [2]. Such an understanding is pivotal to develop sustainable management and use strategies that can ensure a reliable and consistent supply of clean surface water and groundwater, including providing water for human consumption, industry and agriculture, which are all themes of growing concern in Europe [3, 4]. The ongoing modifications in climate and land cover are altering the structure of the critical zone and affect the partitioning of water in the hydrological cycle [2]. Knowledge of when and where groundwater resides in the subsurface [1], and the conditions under which plants access diverse water sources [5] is necessary for comprehending vegetation and groundwater dependent ecosystems resilience to environmental changes, and remains a key challenge in critical zone studies. Improving understanding and prediction of the effects of changing environmental conditions on water availability in agricultural and forested landscapes, climate, hydrological, and land surface models urgently require detailed information on water partitioning in the critical zone. This includes how much precipitation and/or irrigation water is stored in soils, recharges the groundwater, or is transpired by vegetation, and the temporal dynamics of these processes across different climates. However, the spatial and temporal scales of water moving through and mixing in the critical zone can be highly variable [6] **limiting the comprehension of the feedbacks between groundwater, soil water and vegetation** [7]. Quantifying water fluxes and knowing time scales of transport is essential to understand transfer and retention of water and solutes in soil, which in turn control biogeochemical cycling and contamination persistence, offering crucial information to assess the vulnerability of water resources [8].

Given the complexity of interrelated processes in the critical zone and the factors that affect them, efforts aimed at investigating water exchanges require a **new interdisciplinary approach** that integrates the specific knowledge of complementary disciplines, such as hydrology, hydrogeology, soil physics, forest and landscape ecology, agroecology, biogeochemistry and plant physiology. This holistic approach is necessary to contribute to a deeper understanding of the water cycle components and their spatio-temporal dynamics [9]. Water isotopes (stable isotopes: ^{2}H, ^{18}O; radioactive isotope: ^{3}H) are established investigation tools in the aforementioned disciplines. Being part of the water molecule, isotopes are naturally-present fingerprints of the water, allowing for effective tracing of water as it moves in the hydrological cycle. Water isotopes have been used as powerful hydrological, hydrogeological and ecophysiological tracers for more than five decades [10, 11, 12]. However, the rapid development of new analytical and sampling methods [e.g., 13, 14, 15] has led to unprecedentedly high-resolution monitoring opportunities, including in-situ measurement of the isotopic composition of precipitation, irrigation water, stream water, groundwater, soil pore water, xylem water, and water vapour in order to estimate evaporation, transpiration and soil water fluxes. These **recent developments in measurement techniques have opened up new avenues for the use of water isotopes across different scientific fields** to quantify important physical processes and variables, such as vegetation water uptake from different sources, groundwater recharge rates, residence time (the age of a water parcel at a certain location within the system) and travel time (the elapsed time from the input of water to a system to the exit of that water) of water in the subsurface [16].

The study of the interactions of abiotic and biotic processes involved in water transfer in the critical zone is an emerging frontier in earth and life sciences [2]. A number of recent hydrogeological, hydrological and ecohydrological investigations have provided complementary ''windows'' into subsurface water storage and movement [1]. Recent advances, partly based on the use of water isotopes, revealed huge heterogeneity in groundwater recharge rates and groundwater residence time [10], as well as highly dynamic catchment-scale travel time distributions [17]. Plant physiological and ecohydrological observations, often supported by isotopic tracers, confirmed these findings and suggested that subsurface water stores and vegetation water uptake are highly variable in space and time, and that vegetation is "opportunistic" in accessing subsurface water [1]. The latest results based on the use of water isotopes in studies around the globe show a ubiquitous subsurface water compartmentalization [18], and a large prevalence of groundwater use by vegetation [19]. Despite these latest advancements, most of the knowledge about how water moves through the critical zones is still fragmented because it relies on site- and time-specific isotope studies that are often not directly comparable due to the use of different sampling and analysis methods. Therefore, **coherent and reliable quantifications on the amount, movement, residence and travel times of subsurface water, as well as on water sources available for vegetation, remain open challenges.**

1.1.2 DESCRIPTION OF THE CHALLENGE (MAIN AIM)

WATSON (WATer isotopeS in the critical zONe: from groundwater recharge to plant transpiration) will address three major scientific challenges related to water flux partitioning in the critical zone based on the use of water isotopes. The Action will address these challenges through the activities of three interconnected Working Groups (WGs), with an extra WG dedicated to dissemination:

Challenge 1 - Groundwater recharge: What are the spatio-temporal patterns of groundwater recharge and mixing of groundwater and soil water across different climatic and physiographic regions? What factors affect the mixing and storage of different water sources in different climates, soils, or land uses? How do vegetation characteristics (e.g., species assemblage and spatial distribution) influence infiltration, percolation, and storage of water in the subsurface?

Challenge 2 - Vegetation water uptake and transpiration: How are precipitation and irrigation water partitioned into evaporation, vegetation interception, transpiration, soil water, and groundwater storage? What controls the spatio-temporal variations in vegetation water uptake from different soil depths and different water sources across a variety of climatic and physiographic regions? Which modelling approaches can be used to upscale plant water uptake patterns from the plant/stand scale to the catchment/landscape scale?

Challenge 3 - Residence and travel time: How do catchment-scale residence times and travel times vary across different climates and landscapes? How does plant water uptake affect catchment travel times? What modelling methods are best suited to derive consistent estimates of residence and travel times and how consistent are these estimates?

Addressing these challenges calls for the collaboration of different, complementary disciplines that apply water isotopes as investigation tools. **Studying the critical zone is inherently an interdisciplinary science effort**, requiring the perspectives and methods of hydrologists, hydrogeologists, ecologists, soil scientists, biogeochemists, and plant physiologists [2, 20]. However, despite the recent advances in critical zone science and the establishment of critical zone observatories, an international platform for interaction and discussion among researchers that is also open to stakeholders is missing, resulting in a **lack of communication between overlapping scientific disciplines, and between academics and water managers and practitioners**. Particularly, for the main stakeholders, accessing current scientific information on water partitioning in the critical zone and on transit time across landscapes is essential in order to implement adaption to changing climatic conditions, to optimize land use changes, and to assess groundwater supply and vulnerability. Efforts toward broader scientific exchanges in critical zone science and more effective communication between academia and practitioners require **collection, integration, and synthesis of current interdisciplinary scientific knowledge on the partitioning and mixing of water in the Earth's critical zone,** specifically seen through the lens of water isotopes. The Action will take advantage of the COST networking tools to bring together researchers and stakeholders from complementary disciplines across Europe. Meetings and training events will foster sharing of data, ideas, and experiences, and will facilitate collaboration between experienced and young academics and water resource managers. The **ultimate goals are to build capacity in the use of robust and consistent water isotope approaches and to translate scientific cutting-edge knowledge into tangible outputs and recommendations** that can support national and international European agencies responsible for water resources management in agricultural and forest ecosystems.

WATSON is a highly timely initiative because it builds on the increasing attention given by the scientific community to, and the public awareness of, the importance of **sustainable management of water resources**. In the last few years there has been a noticeable increase in research activities on critical zone processes that led to the establishment of critical zone observatories around the globe. At the same time, there have been significant technological improvements in measuring the isotopic composition of different ecohydrological compartments at affordable costs and at high spatial and temporal resolution which was not possible before. This has led to the development of different methodologies and sampling procedures for isotope applications in water studies that still need to be standardized in order to increase their efficiency and comparability. Therefore, meetings between the different groups that develop the new analysis methods, and training events to standardize protocols and to teach researchers and water managers about these methods are necessary to advance the uptake of these new methods in water resources research. The larger availability of isotope data has also resulted in a significant expansion in the number of modelling studies to estimate the water residence and travel times at the catchment scale. **It is now the right time to compare these studies and to bring them together under the umbrella of a common conceptual framework of water movement within different ecohydrological compartments.** Given the relevance of these emerging research fields and the increased consideration for these themes, it is timely to bring together experts with different scientific and management backgrounds from different countries. This will facilitate the exchange of ideas, establishment of common analytical protocols and training guidelines, and synthesis of knowledge on water partitioning in the critical zone to support water management needs in Europe.

The match between the WATSON objectives and international and EU initiatives aiming at fostering sustainable management of water resources further highlights the timeliness of the Action. The EU water policies (e.g., Water Framework Directive, 2000/60/EC, Groundwater Directive, 2006/118/EC, and the Floods Directive, 2007/60/EC) support research in themes such as the changing sources of water supply under climate and land use change. Moreover, the EU 2020 Biodiversity Strategy recommends the development of green infrastructures and the adoption of nature-based solutions to restore the health of ecosystems and ensure that natural areas remain connected together. Within the Horizon 2020 programme framework, the EU supports projects that aim to strengthen the collaboration among researchers and managers to analyse the interrelationships between vegetation growth and water use, and to find the most cost-effective measures for sustainable management of water, agriculture, and forest resources. For instance, the EU promotes the Joint Programming Initiative (JPI) “Water Challenges for a Changing World” centring priority themes on water use for agriculture and forestry, and stresses the need for ecohydrological understanding of the functional relations between vegetation, groundwater dependent ecosystems, and water in agro-forest ecosystems. These themes correspond well to the main challenges addressed in this Action. Moreover, the goals of WATSON meet the recommendation of the EU Strategy on adaptation to climate change and the Chair’s vision of the Intergovernmental Panel on Climate Change [21] on the practical measures and operations needed to mitigate climate change effects. Furthermore, the US National Research Council recommended the integrated study of the critical zone as one of the most compelling research areas in earth and biological sciences in the 21st century [22].

1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

By addressing the three specific challenges outlined above, the Action will develop a **novel interdisciplinary conceptual and methodological framework** based on the use of isotopes as tracers for better understanding the exchange of water between groundwater, soil, vegetation, and the lower atmosphere in different climatic settings. This will allow for significant scientific advancements, currently limited by the non-standardized sampling and analysis techniques resulting in only fragmented knowledge about critical-zone processes. Thus, WATSON will synthesize all current information on the latest advancements in the field of water isotope measurement and sampling, **propose and publish currently missing standardized sampling and analysis protocols, as well as training materials**. Recent technological advancements have increased the availability and the performance of isotope measurement instruments, but Europe-wide inter-laboratory comparisons have revealed large discrepancies between laboratory procedures [19]. These discrepancies must be understood to assess how the applied methods influence results interpretation. The standardization of sampling and analysis protocols will also help future studies and ensure comparability of results. Furthermore, the highly-fragmented ecohydrological isotope datasets for different parts of Europe inhibit pan-European comparisons and an interdisciplinary and integrated research approach. The Action will therefore **compile a new, comprehensive database** from existing site-specific datasets for different crops and forest types in Europe. The database will be developed and updated in the course of the Action and will be open to the public. This will overcome the time-consuming issue of searching, quality-checking, and arranging isotope data from different sources, which often limits the available datasets for studies that aim to compare results or determine patterns across continental scales.

In addition, WATSON will use **isotope-aided modelling** to provide original isotope-based information on groundwater recharge rates, water residence and travel times, and plant water sources in several regions across Europe, with a special focus on those regions that are highly vulnerable to future changes in water availability. Both simple conceptual models and complex physically-based models will be used. While the former are parsimonious and allow for parameter optimization and uncertainty estimation (e.g., using Monte Carlo approaches), the latter take advantage of high-resolution isotope datasets and allow disentangling the spatially variable flow processes. WATSON activities will allow for comparison of the results of the different models to obtain useful information about their structural limitations. These isotope-aided modelling activities will help researchers and, in turn, practitioners and managers, to better quantify subsurface water fluxes, residence and travel times and their dependence on climate, landscape and vegetation, and thus to more effectively address the major issue of freshwater availability and management. This will allow **going beyond the current fragmented knowledge** on water movement in the soil-vegetation-atmosphere continuum. Finally, the Action networking tools will promote communication and collaborative interactions among academic and non-academic experts from different but complementary disciplines that apply isotope-based experimental and modelling techniques. Particularly, the substantial presence of stakeholders in water use and management sector (government agencies, private water companies, agricultural companies, an isotope laboratory) will improve the current weak communication among different disciplines, among researchers from different geographic regions, and between scientists and water managers. Moreover, the specific COST networking tools such as workshops, Training Schools and Short-Term Scientific Missions (STSMs) will allow managers and practitioners **to acquire skills and expertise on the application of stable isotopes in critical zone science,** which is currently typically limited to research agencies. Because of these activities, the number of stakeholders already included in the network of proposers is expected to increase during the Action life. The innovative approach of WATSON resides in merging, synthesizing and making the current locally sparse isotope data and information on water movement in the critical zone across Europe available to researchers, managers, and the general public. The networking tools and the integration activities of the Action will pave the way for the development of new theories and integrated models for a more accurate and holistic conceptualization of water partitioning and mixing in the critical zone, and, ultimately, to ensure science-based decisions in water management.

1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

The overarching objective of WATSON is to gather and synthesize new interdisciplinary, water isotope-based understanding on the **partitioning and mixing of water in the Earth's critical zone**, water residence and travel times, and the water sources used by vegetation across different climatic and physiographic regions in Europe in order to support science-based management of water and agro-forest resources. The specific and measurable coordination objectives of the Action are:

1. **To create European open-access databases** of water isotope-based studies in the critical zone. Three main open-access databases and related maps, derived from isotopic data and implemented by open-source geographical information systems, will be created: a) a database and a map on isotope-based estimates of groundwater recharge rates across different regions in Europe, b) a database and estimates on water sources used by vegetation in different climatic regions in Europe, and c) a database on catchment-scale residence and travel times in different European regions. The extent of the databases and the coverage of the maps will depend on the density of available isotope data and will be complemented with isotope-aided modelling applications in regions with scarce data. Free access to these products will be made possible through the Action website.

2. **To define protocols, standardized sampling procedures, and analysis techniques** for isotope data, providing training guidelines for future isotope applications in critical zone science. These will allow creation of comparable isotope datasets in Europe that are essential for future analyses and comparisons and support robust understanding of critical zone processes.

3. **To compare and assess state-of-the-art, isotope-based methods and models** to estimate groundwater recharge, water sources for vegetation transpiration, and catchment-scale travel and transit time, as well as analyse and summarize current technological approaches to collect and measure water isotope data.

4. **To foster communication and collaboration** between researchers and water management agencies from different geographic regions responsible for water resource management, water use, land-use planning, forestry and agriculture. To facilitate interaction between scientists and other stakeholders, such as private laboratories involved in environmental analysis, in order to ensure transferability of the new analysis methods from the academic world to practise, and to translate current scientific knowledge on water transfer in the critical zone into tangible recommendations to effectively address water management needs.

1.2.2.2 Capacity-building Objectives

WATSON is based on a network of **European researchers and stakeholders from different and complementary backgrounds.** All researchers of the Action have significant experience in the use of water isotopes as a tool to trace water in the critical zone. The stakeholders are water users for commercial purposes, as well as experienced land and water managers from river basin authorities, water authorities, agriculture agencies, and national parks, who all share a practical vision on local water resources management. Each participant, through the Action networking tools, will bring their specific views and expertise and contribute to the development of skills and abilities of the network as a whole. These events will see a **significant participation of non-academic experts** working on the management of water resources in agro-forest ecosystems in Europe, facilitating communication useful to produce science-based recommendations. The specific capacity building objectives of the Action are:

1. **To establish a large international network of researchers** who are experts in the use of water isotopes in different scientific disciplines; to develop connections between ongoing European studies and to promote long-lasting collaboration for future research projects and applications for funding.

2. **To foster interdisciplinary knowledge exchange and bridge isolated fields of critical zone science** into an integrated framework that is necessary to obtain more extensive understanding on functional interrelations between groundwater, soil water, and vegetation, and to achieve societal breakthroughs on sustainable management of water resources.

3. **To develop a joint research agenda** around the rapidly evolving use of isotopes in critical zone studies. This includes promoting the exchange of ideas, capabilities, and experiences on the latest developments in isotope sampling and measurement techniques to study water transfer in the critical zone in order to promote comparability of results and datasets and to identify current needs and future research directions.

4. **To provide high-quality interdisciplinary training** opportunities for PhD students, Early Career Investigators (ECIs) and practitioners on isotope-based methods and techniques for water resources research and management, e.g., computing water residence and travel times, assessing mixing processes, and quantifying the proportion of rainfall and irrigation water in groundwater, soil water and water taken up by vegetation. These educational opportunities will allow sharpening the analysis skills of researchers, ultimately fostering career development, and introducing practitioners to isotope-based analysis methods. This will, in turn, favour an increased understanding of water exchange processes in agro-forest landscapes in Europe, and develop a network of leading researchers in critical zone science.

5. **To ensure geographic, age, and gender balance**, and support activities for young researchers. The network at the proposal submission stage includes 53% of COST Inclusiveness Target Countries (ITCs) and one Near Neighbour Country (NNC). The Action will pay specific attention to the organization of meetings and training events in ITCs, to ensure that the scientific and operational dissemination outputs will reach a broad audience across Europe. The current composition of participants to the entire network includes almost 40% of ECIs, and 49% of the network members are females. Particular efforts will be made to encourage young researchers from other countries and institutions to join the network in the future. Young researchers will be actively involved in all Action stages. When assigning key management roles in the Action Plan geographic, age and gender balance will be a priority.

2 NETWORKING EXCELLENCE

2.1 ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1 ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

WATSON is a unique European platform for stimulating scientific and management-oriented discussion on water transfer and mixing and its interaction with vegetation. The Action will be complementary to several existing research efforts related to water resources management in agricultural and forest environments, thus integrating and extending current European research programs. The activities of this Action will complement current research programmes organized within the Water JPI framework that plan to elaborate new principles of transnational research related to water challenges, such as IC4WATER ("Tackling Water Challenges in the International Context"), "Water Works 2016-2020", and "Water Works 2018-2022". WATSON will particularly complement ongoing projects within the Horizon 2020 framework following interdisciplinary approaches and focusing on sustainable water management practices and policies, such as WATERPROTECT ("Innovative tools enabling drinking water protection in rural and urban environments"), NextGen ("Towards a next generation of water systems and services for the circular economy"), WaterSpy ("High sensitivity, portable photonic device for pervasive water quality analysis"), FAirWAY ("Farm systems that produce good water quality for drinking water supplies"), and INTCATCH ("Development and application of novel, integrated tools for monitoring and managing catchments"). The Action has clear links with other current Horizon 2020 projects aiming at incentivising practical measures for sustainable management of soil and groundwater to support intensification of agricultural and forestry practices and ecosystem biodiversity, such as LANDMARK ("Land management: assessment, research, knowledge base"). The Action objectives also fit well with those of the GeoERA Groundwater initiative that aims to provide data, information, and decision-support tools for the long-term protection, sustainable management, and improvement of groundwater resources across Europe. WATSON objectives also match goals 2, 6 (promoting sustainable agriculture and management of water), 13 (combatting climate change), and 15 (sustainable use of terrestrial ecosystems and forests) of the **EU 2030 Agenda for Sustainable Development**. Furthermore, the Action research activities will benefit from the interaction, mostly in terms of technical approaches and comparison of results, with current international projects coordinated by the International Atomic Energy Agency (IAEA) on the use of isotopes to study groundwater resources and hydrological processes. Current examples are "Isotope-enabled models for improved estimates of water balance in catchments", "Isotope techniques for the evaluation of water sources in irrigation systems", "Isotope techniques for the evaluation of water sources for domestic supply in urban areas" and "Use of isotope hydrology to characterize groundwater systems in the vicinity of nuclear power plants". Finally, WATSON will also benefit from possible exchanges with the final part of other COST Actions that focus on related themes, such as PESFOR-W ("Payments for ecosystem services - Forest for water"), SMIRES ("Science and management of intermittent rivers and ephemeral streams"), CONVERGES ("Knowledge conversion for enhancing management of European riparian ecosystems and services") and TOPWATER ("Taste and odor in early diagnosis of source and drinking water problems").

2.2 ADDED VALUE OF NETWORKING IN IMPACT

2.2.1 SECURING THE CRITICAL MASS AND EXPERTISE

Isotope-based studies on water partitioning and mixing processes in the critical zone are expanding rapidly but remain fragmented. Such fragmentation of scientific knowledge, between academics having different but complementary research backgrounds, and between academics and stakeholders, hampers a detailed and holistic understanding of the dynamics of water flow between subsurface water, vegetation, and the lower atmosphere, and limits **translation of scientific findings into operational tools to support water resources management**. The WATSON Action will create a large international and interdisciplinary collaborative network that will provide a meeting and discussion platform for researchers, managers, and practitioners to communicate, exchange experiences, and share data and results. The already large original network of proposers will expand during the Action's life as new members, both from academia and stakeholders from other countries, will be encouraged to join. This will ensure that the Action will reach the critical mass needed to obtain a broad overview on water-related scientific and practical issues all over Europe and hence to successfully achieve the Action objectives. The composition of the network reflects the wide range of competences and the interdisciplinary nature of critical zone science on which the Action challenge builds. The network already encompasses researches, including the young ones, who are qualified in field monitoring, analysis of experimental data, laboratory work, hydrological, hydrogeological and ecophysiological modelling, as well as stakeholders who are experts in adopting the most suitable strategies to use water resources in agro-forest environments (including the main social aspects related to water consumption). Such an interaction of specific skills, knowledge, and abilities, coupled to the additional ones derived by new members joining the Action, will ensure the broad interdisciplinary and topic-specific in depth expertise that is required to address the Action's challenges in a robust and fruitful way.

WATSON will also provide a way to establish standardized sampling and analysis protocols and training materials, and to integrate different datasets. Short-Term Scientific Missions (STSMs) on different specific topics will be organized, allowing participants, especially early career researchers and practitioners, to visit member institutions within the network. This will ensure training on specific isotope analysis protocols and techniques, and will allow development of complementary research and management strategies. Researchers and stakeholders will be involved in topical and interdisciplinary networking events, such as workshops, seminars, meetings and Training Schools, that will promote cooperation and will help to identify **research gaps and management priorities**. These efforts will allow synthesis and extension of current novel scientific knowledge across different disciplines to obtain a holistic conceptual framework that can describe water flow in the critical zone. At the same time, the development of international collaborations will lead to new opportunities for comparative and interdisciplinary studies and to create partnerships for future funding opportunities. In addition, the inclusion of decision makers and water managers in the network will contribute to raising awareness of management priorities at the local, national, and international level in Europe, and will stimulate the production of operational tools and science-based recommendations and guidelines to effectively address water resources management in different environmental contexts. The Action will particularly encourage the stakeholders to participate in the Training Schools and STSMs to broaden their understanding of isotope analysis techniques and data, and to host STSMs so that young researchers can evaluate how methods are applied to real-world issues outside academia.

2.2.2 INVOLVEMENT OF STAKEHOLDERS

The most relevant stakeholders for the Action are public institutes or governmental bodies at the local, regional, national, and international level working on land management and planning, such as water agencies, river basin authorities, reclamation and irrigation districts, government agencies for agriculture and forest management and protection, national parks, municipalities and regional councils, and local decision-makers. Furthermore, stakeholders relevant to the Action are private companies using water for commercial purposes (such as water supply, water extraction and bottling for human consumption, beverage and liquor production) as well as laboratories for isotope measurements and chemical analysis. The network of proposers already encompasses ten (27%) stakeholders from eight different European countries, including governmental bodies, three large companies and two small and medium-sized enterprises (SME). Specifically, the network of the proposers includes a large governmental river basin authority, a governmental institution dealing with agriculture and agrometeorological activities, a national water management agency, a national environmental agency, a national park, two international private companies producing drinking water and other beverages, and a private company active in environmental consulting that runs state-of-the-art laboratories for isotope measurement. These institutes have already agreed to host STSMs for early career scientists training, to allow their technicians to attend relevant meetings, to contribute to STSMs and Training Schools organized within the Action, and to propose round tables and seminars on specific topics, such as exploitation of groundwater supply for irrigation and drinking purposes, sources of water used by plants in agro-forest systems, relation between water travel times and water pollution, and the latest techniques in isotope measurements. During the first year of the Action, other stakeholders will be invited to join the existing network through local contacts of the participants in each member country. The plan for involving the main stakeholders in active participation to the Action is based on two main lines: 1) the identification of practical issues related to vegetation water use, soil, and groundwater reported by agencies working directly on water resources management, and 2) the delivery of science-based knowledge (and its corresponding uncertainty) related to groundwater recharge, water residence and travel times, and water sources for vegetation in different climatic contexts. These two lines are implemented in the Work Plan through the production of reports, guidelines, and maps that will be translated by the participants in different languages, sent out to specific stakeholders, and posted on the Action website. At the same time, the Action will support the organization of training and educational events, such as round-table meetings, workshops, Training Schools, and topical seminars. Particular attention will be paid to invite non-academics to Technical Training Schools in order to make them aware of the potential of isotope-based applications to address specific issues or knowledge gaps more effectively. In general, networking events will see the combined participation of experienced and young researchers, students from all countries of the network as well as non-academic stakeholders to ensure a close interaction and a mutual collaboration. A Stakeholder Involvement Committee will be created, formed by selected representatives of the network participants. The Stakeholder Involvement Committee will have regular contact with the Action Management Committee (MC), and will be responsible for ensuring information flow and constant communication and connection with all stakeholders involved in the Action.

2.2.3 MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

WATSON will be based on the integration of experts with different professional and scientific backgrounds, and solid and internationally-recognized competence (also in the case of Early Career Investigators-ECIs) on water exchange in the Earth's critical zone and water isotopes investigations, covering complementary disciplines. At the time of the proposal submission, the network is formed by 37 participants, almost half of whom identify as female, 38% are ECIs and 27% are stakeholders. The current network includes participants from 20 different countries spanning oceanic, temperate, continental, Mediterranean, cold and arid climates. This geographical spread will ensure data collection and process understanding and conceptualization over a wide range of physiographic, climatic, and land-use characteristics. The network comprises ten Inclusiveness Target Countries (ITCs), representing 53% of the total number of COST Member States. The network also includes one Near Neighbour Country (NNC), Morocco. The participant from this NCC is a well-established scientist with an expertise on water isotopes to estimate sources and recharge of groundwater and surface water. The presence of this NNC is strategic to the network because it will allow for the inclusion of isotopic data from different water sources both in hot and dry regions close to the Saharan desert and in subtropical mountain zones (Atlas range), and thus complement the climates found in the other network countries. The benefits for the Moroccan institute to join a large European network include strengthening international collaborations, access to European research facilities, and the ability to join the Action training events.

3 IMPACT

3.1 IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1 SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

The overall expected impact of WATSON Action is a detailed comprehension of water mixing and partitioning processes in the Earth's critical zone across different European climates based on water isotope data, resulting in guidance tools for more effective management of water resources. The Action will have a direct relevance at the national and European level by providing maps, recommendations, and best practices for integrating scientific knowledge on the main factors controlling groundwater recharge, water residence and travel times, and the proportion of precipitation and irrigation water used by different vegetation types, which is needed for sustainable planning of water utilization. The integration of interdisciplinary scientific findings from the researchers, and operational knowledge from the stakeholders will induce shared methodological developments and facilitate appropriate integrated conceptualization of water exchange in the Earth's critical zone, promoting innovation and ensuring the successful achievement of the Action objectives. The in-depth review of current water isotope-based understanding of interrelations of water fluxes among different storages in the critical zone will provide an interdisciplinary conceptual and methodological framework that is currently lacking. Exhaustive research synthesis will serve as a basis to develop solid benchmarks, shared terminology, and standardized analytical approaches that will reduce the risk of misinterpretation of results and, in turn, inadequate management interventions. The creation of shared databases and the related application of numerical models will allow for the production of maps of groundwater recharge rates and estimates of water sources for vegetation use in selected European regions spanning different climatic characteristics. These products will help to **identify sensitive areas vulnerable to groundwater exploitation and areas of high resilience** due to the capability of vegetation to access different water sources. These products will have **practical consequences in land and water resources management** and will allow for the **definition of intervention priorities** at the national and international level. WATSON outputs are expected to result in major breakthroughs, such as the definition of regulations to mitigate or prevent groundwater depletion and favour groundwater recharge in sensitive public or private areas; policy decisions on conservation of natural areas subject to groundwater depletion; support to the development of sustainable plans for land use interventions (e.g., tree logging) and irrigation based on predicted changes of water storage and availability; and selection of plant species that are more resilient to drought conditions in agricultural and forest systems. These potential breakthroughs will, in turn, provide societal benefits not only for the involved stakeholders but also for local citizens of the member states. Particular attention will be paid to create a strong connection within the network, assuring smooth information exchange among the participants from different countries, and to avoid potential language or cultural communication problems. This will increase the efficiency of the training activities and will support an effective transfer of scientific-based outcomes to the most relevant stakeholders. The wide range of dissemination tools (section 3.2.2.) will help to ensure effective communication inside and outside the network.

Short-term scientific impacts include: 1) definition of standardized field collection and analysis methods for isotope data; 2) harmonization and sharing of extensive isotopic databases across different climates and physiographic regions in Europe; 3) conceptualization of new interdisciplinary scientific paradigms on water mixing and partitioning in different ecohydrological compartments; 4) improved understanding of resilience to environmental changes of agro-forest landscapes; 5) progress in the identification of knowledge gaps and multidisciplinary research priorities.

Short-term socioeconomic impacts include: 1) improvement of communication and interactions between researchers and stakeholders; 2) increased societal (land and water managers, agricultural and forest managers, local decision-makers) understanding of groundwater exploitation and water sources used by vegetation; 3) more efficient use of research tools and facilities, available datasets and study sites among European countries; 4) increased understanding of scientific community of the research needs for sustainable water management.

Long-term scientific impacts encompass: 1) improved scientific integration and visibility of European research. The Action networking activities will pave the way for long-term interdisciplinary collaborations in Europe and future joint research proposals; 2) advancement in establishing synergies between researchers from different countries and with complementary expertise to identify and face new scientific challenges with important societal implications; 3) education of a new generation of hydrologists, hydrogeologists, ecohydrologists and plant physiologists with robust interdisciplinary backgrounds and strong inclination to collaborative research.

Long-term socioeconomic impacts encompass: 1) implementation of sustainable and more effective strategies for water resources management in areas vulnerable to exploitation of groundwater and water available to plants; 2) improved agriculture and forestry management that take advantage of ecohydrological resilience of ecosystems to environmental stresses, particularly droughts; 3) increase in awareness among society and decision-makers of the importance of an integrated, science-driven management of agro-forest ecosystems to ensure and maximize crop productivity, forest biodiversity, ecosystem services and water availability.

3.2 MEASURES TO MAXIMISE IMPACT

3.2.1 KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

The Action will rely on a large international network of experts, on a constant interaction between scientists and stakeholders, and on high-quality training events to promote scientific and operational knowledge creation and transferability, as well as career development of the participants. The WATSON network and activities will allow the scientific community to bridge complementary disciplines, to develop accepted analysis procedures and protocols, and to achieve breakthroughs in understanding the transfer of water in the critical zone that requires an often advocated but seldom achieved interdisciplinary approach. This integration will lead to synthesis, new paradigms, and concepts that will be made available to the scientific community, the managers, and the general public through the dissemination activities, and that will advance the current knowledge on water partitioning and mixing in the critical zone. WATSON will pay particular attention to the **interaction between academic researchers and public agencies** responsible for water resources management in agricultural and forest ecosystems. Several different stakeholders are already included in the network and new ones at the local, national, and international level will be actively approached and involved in meetings and specific training events organized by the Action. Significant efforts will be made to promote the transfer of the latest scientific findings to the stakeholders, ensuring a continuous and well balanced exchange of experiences and inputs between researchers and land and water managers, **promoting a bilateral communication**, and to favour the identification of water management priorities. These actions will result in the production of new tangible outputs, including recommendations and innovative best practice schemes to support managers and practitioners in making science-based decisions.

The Action will organize **high-level scientific training and education events** for PhD students, Early Career Investigators (ECIs), as well as practitioners and managers on topics related to water partitioning techniques, mixing models, residence and travel time estimation, through the efficient use of COST networking tools, such as Working Group (WG) meetings, workshops, conferences, seminars, Training Schools and Short-Term Scientific Missions (STSMs). In addition, a specific session on critical zone science and the interdisciplinary topics of the WATSON Action will be proposed at the annual general assembly of the European Geosciences Union (EGU), by far the largest scientific conference in Europe on Earth sciences, and an excellent platform for networking and communicating the Action outcomes. All these opportunities will allow young researchers to access cutting-edge analytical methods and knowledge in a rapidly expanding research field, and to obtain a **new set of scientific and analysis skills that will enrich their research potential and support the development of their career**. The international mobility, the participation to stimulating and interdisciplinary international working environments, and the exposure to new inputs provided by well-known specialists, combined with specific training on state-of-the-art tools and modelling techniques, will allow young researchers to further develop their research potential and to make their professional profile highly competitive. Broadening research perspectives, enlarging scientific knowledge, and widening the network of contacts and collaborations will allow the young researchers to further expand the boundaries of their career in the professional market, offering the potential for future employment opportunities not only in academia but also in the operational world (management of water resources, environmental agencies, private firms). At the same time, the training opportunities organized by WATSON will enable stakeholders to learn new investigation approaches related to the use of water isotopes in agro-forest environments, which are yet typically limited to academic studies. In addition, the stakeholders will have the opportunity to acquire new specific science-based knowledge that can be applied to practical management issues in various contexts, to extend their professional skills and capability, and to obtain international visibility at the European level. All these outcomes will significantly **increase the professional profile of young researchers and stakeholders** and promote their career development.

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

The dissemination plan aims at increasing the international visibility of the Action and at maximizing its impact at different levels, ensuring an efficient transfer of the Action outputs to both the international scientific community and European stakeholders. Given the comprehensive sets of objectives, the Action will adopt different strategies for dissemination.

1. Working Groups (WGs) 1-3 will publish scientific papers in high-profile international open-access journals, and individual participants of the WGs will present synthesis results at national and international conferences (e.g., European Geosciences Union (EGU), ERB (Euro-Mediterranean Network of Experimental and Representative Basins), HydroEco).

2. Short-Term Scientific Missions (STSMs) will be organized for young scientists and stakeholders to visit research facilities in other institutions, land and water management agencies and private companies in Europe, to identify research gaps, management needs, and practical operational issues.

3. Training Schools and seminars led by highly qualified experts, topical meetings and thematic workshops (including workshop minutes) involving both researchers and stakeholders will be organized by each of the first three WGs to share competences and skills, and to foster bilateral knowledge exchange. The final workshops coordinated by each of the first three WGs will communicate the results from the entire Action. A final Action conference (including conference proceedings) will be organized at the end of the fourth year to summarize the activities and the findings of the Action.

4. Specific, tangible outputs will be produced and freely distributed through the Action website. These include a comprehensive database on isotope-based studies in the critical zone in Europe, the integrated isotope-derived databases on groundwater recharge, water used by vegetation, and residence and travel times for regions in Europe for which sufficient data are available, the related maps of groundwater recharge rates and estimates of water used by vegetation, protocols for sampling and isotope analyses, technical and educational reports and diagrams on experimental data and modelling application on water residence and travel times, recommendations and best practises for collecting and using isotopic data for water resources management. To facilitate accessibility, executive summaries of the key documents, especially those mainly dedicated to stakeholders, will be provided in multiple languages.

5. Press-releases will be written midway and at the end of the Action to promote the work of the network in national newspapers and online news sources in the involved countries, and one or two articles will be sent to magazines that focus on environmental and water issues or popular science in order to reach a broader audience. Where possible, meetings with local policy makers and branches of government agencies will be organized to maximize the impact.

6. The Action website will be created at the beginning of the Action life and will be continuously updated. The website will host general information on the Action composition and objectives, will inform about the schedule of educational and training events, and will be used as a platform to distribute the tangible outputs of the Action activities (databases, protocols, open-access scientific papers, workshop minutes and conference proceedings, technical reports and diagrams, maps, and guidelines).

7. Social network accounts (e.g., Twitter, YouTube) will be created to quickly publish news and updates on the Action activities. Short movies on the Action meetings and events will be made in order to attract researchers and the general public to the accounts.

4 IMPLEMENTATION

4.1 COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1 DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

WATSON is organized in four Working Groups (WGs) that are closely linked to each other to address the Action objectives. Three WGs are based on the scientific questions and correspond to the Action challenges. The fourth WG is dedicated to networking activities and dissemination of the findings of the three other WGs to ensure the efficient organization of meetings and training events, a good visibility of the Action outcomes, and an effective transfer of knowledge. The WG composition is defined by the Action Management Committee (MC), which will be in charge of planning and coordinating all Action activities, evaluating the achievement of the Action objectives, and monitoring the appropriate use of COST funds. The MC will elect the Action Chair and the Vice Chair, and will also select the WG Leaders and Vice Leaders. The Action Chair, Vice Chair, WG Leaders, and the Short-Term Scientific Mission (STSM) Coordinator will form the Core Group (CG), in charge of risk control, monitoring the progress of the different WGs based on analysis and discussion of the reports provided by the WGs. The WG Leaders and Vice Leaders will be responsible for the organization and management of WG-specific events such as meetings, workshops, conferences, Training Schools and Short-Term Scientific Missions (STSMs) in different European countries, and for the organization of tasks, milestones and deliverables of the individual WGs. They will ensure that educational and training events will reach the largest number of WG participants (including making the teaching and training material easily available) in order to promote knowledge exchange and to share of experiences. The WG Leaders and Vice Leaders will also be responsible for active connection and effective communication within and between WGs. They can organize additional meetings if required by the Action's objectives, particularly to interact with local stakeholders. The objectives, task and milestones of the four WGs are as follows:

WG 1: Spatio-temporal patterns of groundwater recharge and soil water mixing processes

Objectives:
1. Identifying isotope-based experimental datasets on groundwater recharge and the quantification of subsurface water mixing.
2. Characterising and elucidating dominant controls on spatial and temporal patterns of groundwater recharge and water mixing based on rainfall, irrigation, soil water, and groundwater isotope data for different regions in Europe.

Tasks:
1. Literature review on groundwater recharge and subsurface water mixing.
2. Development of a database of isotope studies on groundwater and soil water.
3. Collection and integration of available water isotope-based methods to estimate groundwater recharge.
4. Collection and integration of existing datasets on groundwater recharge in Europe.
5. Data analysis and synthesis of findings from long-term experimental monitoring sites in different climate regions in Europe.

Milestones:
1. STSMs to define datasets, data collection criteria and protocols.
2. Creation of the database of isotope-based studies on groundwater and subsurface water mixing in Europe.
3. Workshop on groundwater exploitation in Europe (including a field trip).
4. Training School on groundwater recharge and mixing processes.

5. Workshop for final presentation of the WG results.

WG 2: Spatio-temporal patterns of water sources used by vegetation

Objectives: 1. Providing experimental evidence on spatial and seasonal patterns in vegetation water sources, spanning a variety of climates in Europe with different vegetation cover and soil types.
2. Identifying the main conditions leading vegetation to switch between different water sources, and assessing the temporal dynamics of water transfer within the soil-vegetation compartment.
3. Identifying datasets and modelling methods to upscale the spatio-temporal patterns of water used by vegetation from the plant/stand scale to the catchment/landscape scale, and to explore if catchments are appropriate landscape units for upscaling vegetation water sources.

Tasks: 1. Literature review on vegetation water sources and upscaling methods.
2. Development of a database on plant-soil isotope studies in Europe.
3. Definition of standard sampling procedures and analysis techniques for isotope data from various ecohydrological compartments.
4. Collection and integration of different existing isotope-based datasets on water sources for vegetation.
5. Data analysis and synthesis of findings on the spatial and temporal variability of water isotopic composition in ecohydrological compartments at experimental sites across different climates in Europe.

Milestones: 1. WG meeting and STSMs to define sampling criteria and protocols for isotope data collection and integration.
2. Workshop on physiological, climatic and local controls on vegetation water uptake and transpiration (including a field trip).
3. Training School on spatio-temporal patterns of water sources taken up by plants.
4. Creation of the database on plant-soil isotope studies in Europe.
4. Workshop for final presentation of the WG results.

WG 3: Catchment-scale water residence time and travel times

Objectives: 1. Synthesis of current isotope-aided modelling frameworks to estimate water residence time and travel time at the catchment scale.
2. Comparison of isotope-aided modelling frameworks to derive consistent estimates of residence and travel times for different locations in Europe.

Tasks: 1. Literature review of existing isotope-aided modelling methods for residence time and travel time computation.
2. Creation of a database on catchment-scale residence and travel times in Europe.
3. Application and comparison of the reviewed models (in close cooperation with WG1) to assess their structural differences.

Milestones: 1. Meetings and STSMs to define gaps, potentials and limitations in water isotope-based models to estimate catchment-scale residence time and travel time.
2. Creation of the database on isotope-based residence and travel time studies.
3. Workshop on catchment hydrological processes, residence time and travel time.
4. Training School on modelling approaches to determine residence and travel times at the catchment scale.
5. Workshop for final presentation of the WG results.

WG 4: Networking and dissemination

Objectives: 1. Communication and dissemination of the findings of WGs 1-3.
2. Involvement and communication with the main stakeholders to ensure their active participation in the Action activities, and to deliver the provided tools and recommendations.
3. Ensuring visibility of the Action at the European and international level.

Tasks: 1. Creating dissemination and communication plans.
2. Defining a Stakeholder Involvement Committee.
3. Identifying and integrating new network partners from academia and stakeholders.
4. Building, populating, maintaining and advertising the Action website and the social media networks (e.g, Twitter, YouTube).
5. Preparing press releases, writing articles for environmental magazines or popular science magazines, organizing the promotion materials and the final conference.

Milestones: 1. Dissemination and communication framework.

2. Creation of the Stakeholder Involvement Committee.
3. Launch of the website and social network accounts.
4. Preparation of the executive summaries of recommendations and best practises in multiple European languages.
5. Final Action conference.

4.1.2 DESCRIPTION OF DELIVERABLES AND TIMEFRAME

The tasks and milestones of the four WGs will serve as tools and steps to achieve the specific objectives of each WG and to produce the expected deliverables, which are organized as follows:

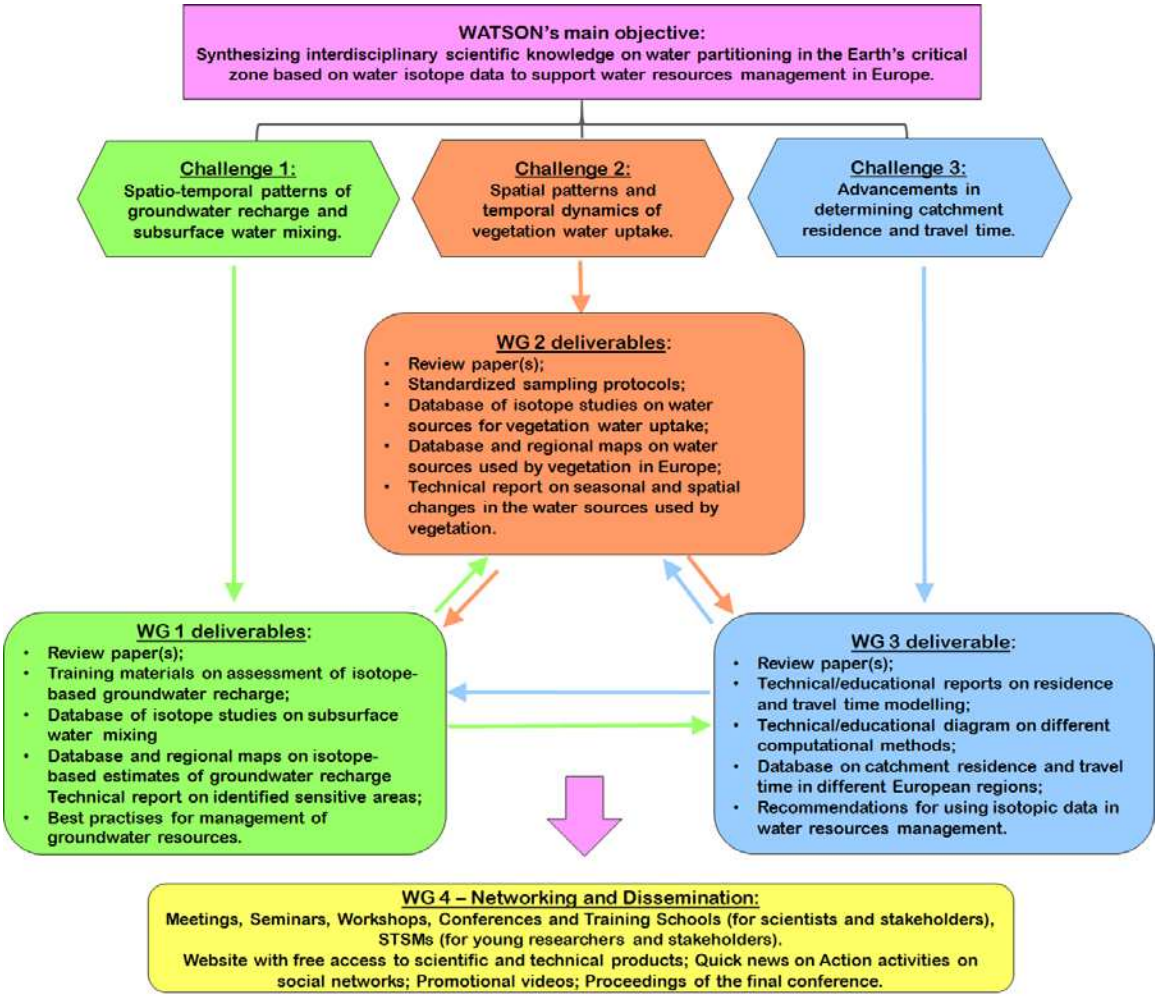
WG 1: Spatio-temporal patterns of groundwater recharge and soil water mixing processes
Deliverables: 1. Review paper(s) on groundwater recharge and subsurface mixing processes.
2. Training materials on isotope-based assessment of groundwater recharge.
3. Databases of isotope studies on groundwater and subsurface water mixing.
4. Databases of isotope-based groundwater recharge rates that will be integrated with modelling applications to derive regional maps of groundwater recharge rates across different climates in Europe.
5. Technical report on identified sensitive areas (i.e., potentially vulnerable to groundwater exploitation affecting vegetation growth and management).
6. Workshops minutes.
7. Recommendations and best practises for management of groundwater resources.

WG 2: Spatio-temporal patterns of water sources used by vegetation
Deliverables: 1. Review paper(s) on isotope-based studies on water sources for vegetation.
2. Protocols describing standardized sampling procedures and analysis techniques of water isotope data.
3. Databases of isotope-based studies on water sources for vegetation transpiration.
4. Databases of isotope-based water sources for plant transpiration that will be integrated with modelling applications to derive large-scale estimates of water sources used by vegetation across different plant species and climates in Europe.
5. Workshops minutes.
6. Technical report on seasonal and spatial differences in water sources used by vegetation, resulting in an ecohydrological conceptual framework, including the identification of areas of high resilience due to the capability of vegetation to access different water sources.

WG 3: Catchment-scale water residence and travel times
Deliverables: 1. Review paper(s) on different isotope-aided models to compute residence and travel times.
2. Technical and educational reports on water residence time and travel time modelling.
3. Technical and educational diagrams on model comparison.
4. Database on catchment-scale water residence and travel times across Europe.
5. Workshops minutes.
6. Recommendations and best practises for using isotope-aided models in water resources management.

WG 4: Networking and dissemination
Deliverables: 1. Website with free access to scientific and technical products (protocols, databases, maps, open-access papers, technical and educational reports and diagrams, training materials, recommendations and best practises).
2. Visibility on social networks.
3. Promotional videos.
4. Executive summaries of key documents translated into several European languages.
5. Proceedings of the final Action conference.

Deliverables of WGs 1, 2 and 3 will be mainly produced during the second half of the Action life, reflecting the activities, tasks and milestone of each WG. Specific deliverables of WG4, dedicated to networking activities and results dissemination, will be initiated at the beginning of the Action life (such as information through website and social media) and will continue for the entire duration of the Action (see Gantt chart in section 4.1.4). The functional relations between the challenges addressed in WATSON and the expected deliverables for each WG are reported in the PERT chart below.



4.1.3 RISK ANALYSIS AND CONTINGENCY PLANS

Risks for the WATSON Action activities are limited due to the structure and the well balanced composition of the network, the experience of researchers to work in close collaboration with stakeholders and in scientific teams, and to coordinate (or be involved in) national and international projects, the enthusiasm of the several Early Career Investigators (ECIs) in carrying out collaborative research and educational and career-stimulating actions, and the benefits envisaged for the various stakeholders. However, potential risks exist, and risk control will be carried out continuously during the entire Action life by the Action Core Group (CG), the Working Group (WG) Leaders and Vice Leaders, and the Short-Term Scientific Missions (STSMs) Coordinator who will regularly report to the Action Management Committee (MC). Potential risks and conceived contingency countermeasures are:

- Poor management and coordination, and work overload. This risk is minimized by the experience of the participants in managing and coordinating research groups, especially those acting in key roles of the Action, in leading and coordinating international organizations, and careful sharing of duties within the different Action committees. The MC and the CG will continuously monitor the progress of the action to ensure that the Action objectives will be reached.

- Difficulty in achieving a critical mass of participants and stakeholders. This will be minimized by the already large number of participants and by the numerous European contacts that the network members have established during their individual careers. Furthermore, particular efforts will be made during the initial phase of the Action to ensure the expansion of the original network and to organize specific meetings and training events to attract participants from local, national, and international agencies.

- Lack of adequate isotope datasets to create regional maps. The participants of the 20 countries currently involved in the network will share the isotope data from different hydrological compartments in the critical zone that they have collected over the years. Moreover, the databases will be extended through data collected by individual partners in their field sites during internal ongoing long-term projects and data integrated through modelling applications performed by the several modellers belonging to the

Action network. Moreover, specific technical meetings will be devoted to develop strategies for identifying general patterns of groundwater recharge and plant water uptake across different zones in case the obtained datasets are insufficient to create regional maps.

- Insufficient and/or difficult transfer of scientific findings to stakeholders. This will be minimized by the active participation of stakeholders in meetings and training events, by bidirectional communication between scientists and managers, by defining a common language and shared terminology that is comprehensible to both scientific and non-scientific parts in the first meetings, and by the dissemination strategies such as the translation of the tangible Action outputs into different European languages.

- Risk of not accomplishing appreciable scientific and societal impact across Europe. This will be mitigated by organizing high-quality interdisciplinary meetings, training events, and education opportunities, involving a combination of experienced and well-known researchers from different disciplines, early career researchers, as well as relevant stakeholders, who will ensure the delivery of excellent scientific results and effective management outputs.

4.1.4 GANTT DIAGRAM

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