2018 JOINT CALL

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WATER JOINT PROGRAMMING INITIATIVE

WATER CHALLENGES FOR A CHANGING WORLD

2018 JOINT CALL
Closing the Water Cycle Gap

Mind the Water Cycle Gap: *In*novating *W*ater Management *O*ptimisation *P*ractice

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1. EXCELLENCE

1.1 Introduction

Optimisation is what you do if you run out of on innovative ideas. Current practice in integrated water management predominantly use **multi-objective** optimisation approaches with aggregated objectives. This biases results towards the status quo and against innovative solutions, can foster stakeholder resistance when they do not recognize their values and objectives in the optimization formulation, while also raising ethical concerns related to the inclusion of undesirable and/or hidden trade-offs[1]. In contrast, **many-objectives** optimisation approaches can consider many non-aggregated objectives, which has the potential to enrich the solution space with alternative courses of action that better reflect the diverging perspectives of stakeholders, and align better with ethical concerns. From the viewpoint of ethics, disaggregated assessment criteria are preferred as these may avoid undesirable and hidden trade-offs. Apart from some pioneering studies in economics[1] and reliability engineering[2], no methods currently exist that specifically aim to avoid such undesirable trade-offs. Here, many-objective approaches to optimisation and decision-making offer a promising way-forward.

Water resources management increasingly relies on integrated models to analyse the socio-economic benefits of the scarce resource. These models typically connect sectoral water uses, such as hydropower, irrigation, and ecology, to water resources, like rivers, surface water reservoirs, and groundwater reserves, in order to estimate performance indicators such as monetized costs and benefit, ecological value, recreational quality, and environmental quality. These integrated models offer great potential in enabling more sustainable management of water resources. Currently these advances in modelling are however in many cases not exploited because their outputs are evaluated using multi-objective optimization on pre-maturely aggregated objective functions that cancel out the potential advantages of these integrated models in unpredictable ways[3].

In the context of Integrated Water Resources Management (IWRM), many-objective approaches offer greater opportunities for handling the many non-aggregated objectives that arise from sectoral integration. In the face of climate change and growing water scarcity[4] the expansion of the solution space and the identification of innovative strategies for water management issues that many-objective approaches have on offer[5] is of great relevance. For dissemination and implementation, it is important that these innovations do not only offer methodological improvements for water managers, but specifically address the innovative characteristics of solutions, the improved alignment with the interests of various stakeholders, as well as producing solutions that are ethically more just. The promise of many-objectives approaches regarding alternative courses of action is especially relevant under conditions of climate change and socio-economic developments, and a growing emphasis on sustainability and inclusiveness in addition to efficiency and effectiveness[6].

The virtues of many-objective approaches have barely reached current practice in water management in Europe and beyond. To realize their promise, this research operationalizes many-objective approaches for water management and contrasts them to existing practices. This project develops, operationalises, and incorporates many-objective optimization in existing regional water management models in close collaboration with local stakeholders and water managers. We apply both existing multi-objective methods, and, collaboratively with local stakeholders, develop many-objective approaches and compare and contrast the strategies that emerge from both as a concrete contribution to practice. Our contribution to science focusses on the validity of the many-objective hypotheses on enriching the solution space, inclusiveness of stakeholder perspectives, and fairness. Finally, for our project partners in the case study areas, we deliver operational models and software for implementation in daily management and decision-making practice. Our case studies cover water management practices under divers climatic, hydrological, soil and socio-economic condition encountered in current and climate change affected Europe and beyond, and serve to disseminate innovated practices.

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[1] Caspar G Chorus et al., "Taboo Trade-Off Aversion: A Discrete Choice Model and Empirical Analysis," *Journal of choice modelling* 27 (2018).

[2] Armin Tabandeh, Paolo Gardoni, and Colleen Murphy, "A Reliability-Based Capability Approach," *Risk Analysis* 38, no. 2 (2018); ibid.

[3] Kenneth J Arrow, "A Difficulty in the Concept of Social Welfare," *The Journal of Political Economy* (1950).

[4] Charles J Vörösmarty et al., "Global Water Resources: Vulnerability from Climate Change and Population Growth," *science* 289, no. 5477 (2000).

[5] Joseph R Kasprzyk, Patrick M Reed, and David M Hadka, "Battling Arrow's Paradox to Discover Robust Water Management Alternatives," *Journal of Water Resources Planning and Management* 142, no. 2 (2015).

[6] Jan H Kwakkel, Warren E Walker, and Marjolijn Haasnoot, "Coping with the Wickedness of Public Policy Problems: Approaches for Decision Making under Deep Uncertainty," (American Society of Civil Engineers, 2016).

The research proposed addresses theme 1, Enabling Sustainable Management of Water Resources and theme 2 Strengthening Socio-economic Approaches to Water Management of the JPI 2018 Closing the Water Cycle Gap – Sustainable Management of Water Resources call.

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

In translating knowledge and system level understanding into practical consequences for water policy or operational management, water policy makers and water manager make use of optimisation to identify the most beneficial policy or operational action. Commonly, these optimisation approaches aggregate the relevant performance metrics into one or two composite objective functions that allows for optimisation using readily available optimisation algorithms[7,8].

The reliance on composite objectives is problematic for several reasons. First, it has been argued that optimisation with composite objective functions can produce overly conservative solutions, overlooking more innovative Pareto optimal solutions[9]. In the context of water management, this theoretical point was confirmed by Kasprzyk et al.[10], who found that aggregation of objectives in a cost reliability formulation indeed severely limits the diversity of the solutions found. Second, water resources management involves a variety of stakeholders. These stakeholders often have diverging ideas about which criteria should be considered and the relative importance of these criteria. The development and introduction of IWRM rapidly increases the number of stakeholders and criteria to assess[11,12]. However, the reliance on composite objectives fails to adequately reflect this, resulting in potential resistance by stakeholders. Third, there is an increasing call for more disaggregated assessment criteria in complex multi-actor decision problems on ethical grounds[13], specifically in the context of managing natural hazards[14]. Many-objective approaches offer an alternative to the reliance on composite objectives, potentially offering a more comprehensive evaluation in support of decision-making.

The possibility of handling many-objective optimization problems, where the number of objective functions is three or more[15], is crucial for exploring multidimensional trade-offs. This enables overcoming decision biases produced by narrow or restrictive definitions of optimality[16], such as **cognitive myopia**, where narrow or restrictive definitions of optimality strongly limit the discovery of decision relevant alternatives that could change stakeholder preferences[17], and **cognitive hysteresis**, where traditional strategies for addressing a problem restrict the generation of new hypotheses for innovative decisions or additional objectives[18]. Recent advances in many-objective optimization and computing make it technically possible to solve these many-objective optimization problems.[19]

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[7] Euan Barlow and Tiku T Tanyimboh, "Multiobjective Memetic Algorithm Applied to the Optimisation of Water Distribution Systems," *Water resources management* 28, no. 8 (2014).

[8] William W-G Yeh, "Reservoir Management and Operations Models: A State-of-the-Art Review," *Water resources research* 21, no. 12 (1985).

[9] Maarten Franssen, "Arrow's Theorem, Multi-Criteria Decision Problems and Multi-Attribute Preferences in Engineering Design," *Research in engineering design* 16, no. 1-2 (2005).

[10] Kasprzyk, Reed, and Hadka, "Battling Arrow's Paradox to Discover Robust Water Management Alternatives."

[11] Asit K Biswas, "Integrated Water Resources Management: Is It Working?," *International Journal of Water Resources Development* 24, no. 1 (2008).

[12] Muhammad Mizanur Rahaman and Olli Varis, "Integrated Water Resources Management: Evolution, Prospects and Future Challenges," *Sustainability: science, practice and policy* 1, no. 1 (2005).

[13] Amartya Sen, *The Idea of Justice* (cambridge machechutes: The Belknap Press of Harvard University Press, 2019)., Neelke Doorn, "Resilience Indicators: Opportunities for Including Distributive Justice Concerns in Disaster Management," *Journal of Risk Research* 20, no. 6 (2017).

[14] "The Blind Spot in Risk Ethics: Managing Natural Hazards," *Risk Analysis* 35, no. 3 (2015). ibid.

[15] Peter J Fleming, Robin C Purshouse, and Robert J Lygoe, "Many-Objective Optimization: An Engineering Design Perspective" (paper presented at the International conference on evolutionary multi-criterion optimization, 2005).

[16] E Downey Brill et al., "Mga: A Decision Support System for Complex, Incompletely Defined Problems," *IEEE Transactions on Systems, Man, and Cybernetics* 20, no. 4 (1990).

[17] Robin M Hogarth, "Beyond Discrete Biases: Functional and Dysfunctional Aspects of Judgmental Heuristics," *Psychological Bulletin* 90, no. 2 (1981).

[18] Charles F Gettys and Stanley D Fisher, "Hypothesis Plausibility and Hypothesis Generation," *Organizational behavior and human performance* 24, no. 1 (1979).

[19] Holger R Maier et al., "Evolutionary Algorithms and Other Metaheuristics in Water Resources: Current Status, Research Challenges and Future Directions," *Environmental Modelling & Software* 62 (2014).

1.3 Objectives and overview of the proposal

The overarching aim of this project is to investigate the contribution of many-objective optimization approaches to IWRM. For this, we use three water management cases in a comparative evaluation of many-objective approaches in diverse hydrological and cultural setting. In Italy our focus is on the **Lake Como Basin** located in the Italian Southern Alps, serving irrigated agriculture and competing demands from navigation, fishery, energy production environmental and flood protection. In the **Seine River,** France, we focus on the coordinated regulation of the Seine river discharge to reduce both floods and droughts. In Tunisia we address the anthropogenic impact on the management of water resources in the **Meguellil Basin**. Cases are selected for their diversity in water resources -ground water, surface water-, water uses -irrigation, recreation, power generation, recreation, fisheries-, and water management issues -drought, floods, over-exploitation-, and their diversity in environmental, institutional and cultural settings. The diversity of our case studies contributes to the dissemination of the results to a diverse set of countries, and adds a comparative component to the research that deepens and generalizes our understanding and findings. The specific objectives of the research are:

1. To complement the integrated water resources management models in our case study areas with a many-objective formulation and solving this using the Borg Many-Objective Evolutionary Algorithm[20,21].
2. To identify more innovative solutions for our case studies resulting from the many-objective optimization.
3. To disseminate these findings to operational water managers and policy makers in our case study areas and countries and beyond.
4. To assess the degree to which pre-mature aggregation of performance metrics in one or more composite objective functions negatively effects the identification of solutions that are innovative, more aligned with the interests and preferences of the various stakeholders, and ethically more defendable.

The research is structured in a methodological work package (WP1), three case study work packages (WP2- 4), and a stakeholder involvement, integration and dissemination work package, WP5. Figure 1 gives an overview of the proposal and summarises the project structure.

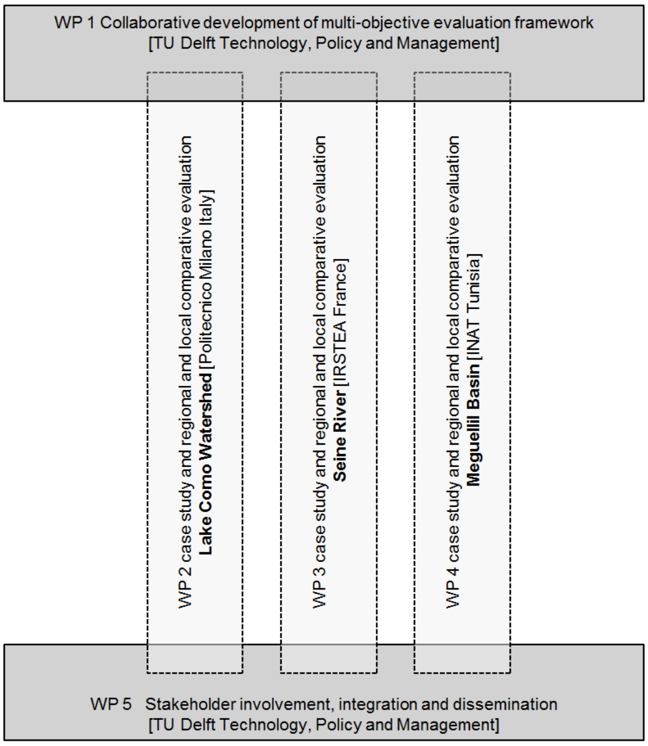

Figure 1 Overview of the proposal and project structure

[20] David Hadka and Patrick Reed, "Borg: An Auto-Adaptive Many-Objective Evolutionary Computing Framework," *Evolutionary computation* 21, no. 2 (2013).
[21] "Large-Scale Parallelization of the Borg Multiobjective Evolutionary Algorithm to Enhance the Management of Complex Environmental Systems," *Environmental Modelling & Software* 69 (2015).

1.4 Research methodology and approach

As summarized in Figure 1 the research project includes 5 work packages. WP1 implements the methodological research and substantive coordination and integration of WP2 through WP4. WP1 proceeds along the following methodological steps:

WP1 Step 1: Development of an ethically informed many-objective framework for IWRM
WP1 Step 2: Development of cross-case comparative framework
WP1 Step 3: Cross case comparison

WP2 trough 4 apply the methodological framework developed under the guidance of WP1 in interaction with regional stakeholders in case studies and deliver the empirical data for the research, while also constituting the vehicle to achieve real-world societal impact. WP2 through WP4, all apply the same basic series of steps. These steps are aligned with the methodological steps of WP1, but are geared towards regional water management practices and partner and stakeholder interaction and involvement:

WP2-4 step 1: Scoping and stakeholder identification
WP2-4 step 2: Model operationalization
WP2-4 step 3: Integration of many-objective approach
WP2-4 step 4: Preliminary results
WP2-4 step 5: Regional feed-back workshop
WP2-4 step 6: Final results
WP2-4 step 7: Dissemination and implementation workshop event

WP5 takes care of the alignment of methodological and case study research, designs workshops, and assures the structured incorporation of feedback from case study stakeholders and partners into the research flow. Below, we elaborate these steps in more detail for each of the work packages and introduce the respective case studies.

WP1 Elaboration and comparative evaluation of a many-objective framework (TU Delft, The Netherlands)

This work package entails a collaborative effort in developing a many-objective evaluation framework and a comparative evaluation of the application of this framework in diverse (future) climatological, hydrological, and socio-economic environments. We take stock of the strengths and weaknesses of many-objective approaches and of the substantive innovations in water allocation practice achieved through its application in diverse environments. This work package is coordinated and guided by the faculty of Technology, Policy and Management of Delft University of Technology. This faculty is a global leader in decision-making under uncertainty with a strong focus on adaptation science and its application to climate change and water management, as well as being home to a globally recognized group on water ethics, risk ethics, and ethics of technology.

Step 1. Development of an ethically informed many-objective framework for water resources management

In this first step, we will develop a broad generic framework of key objectives that are relevant in water resources management, based amongst others on current conceptions on human rights that specify access rights to food, water and a liveable and health ecological environment. As part of development of the framework, particular attention will be given to a recently suggested approach for dealing with taboo trade-offs, which involves specifying minimum performance thresholds beyond which one incurs regret[22].

Step 2. Specification and operationalization of criteria for comparison of methods

In order to compare the outcomes of many-objective optimisation with standard optimisation, we will apply the methods in three cases and compare the outcomes in the respective cases on at least the following three tentative criteria: 1) richness of solution space (*i.e.*, avoiding decision myopia and cognitive hysteresis); 2) stakeholder acceptance of the outcomes; and 3) intra- and intergenerational justice considerations. Based on literature, we will further specify and operationalise these criteria so that they allow for at least ordinal but preferably quantifiable comparison of the two methods in each of the three cases. We will organise a stakeholder workshop to assess the completeness and operationalisation of these three criteria.

[22] Chorus et al., "Taboo Trade-Off Aversion: A Discrete Choice Model and Empirical Analysis."

Step 3. Cross-case and method comparison

Once the three cases have been done, we will evaluate the application of the two methods against the criteria developed in step 2. In each of the cases, the application of the criteria and the interpretation of the results will be done through qualitative data analysis and in a workshop with the relevant stakeholders. Comparison *between* the cases will provide insight in the question where and under what conditions the difference between many-objective optimisation and standard optimisation is most prominent.

WP2 Multi- versus many-objective optimisation - Lake Como Watershed, Italy (Politecnico di Milano, Italy)

Case description

Lake Como is the third largest lake in Italy with a total volume of 23.4 km^3, of which 254 Mm^3 is regulated through a dam on the outflowing Adda River. The natural hydro-meteorological regime is characterized by a peak during the snow-melt season, in late spring, and another, more variable peak, produced by autumn rains[23]. The river serves a dense network of downstream irrigation canals. The river also contains eight run-of-river hydroelectric power plants, managed by the Adda Consortium with the three-fold purpose of power generation, water allocation to the downstream users, and flood protection along the lake's shoreline, particularly in Como city[24].

The lake is fed by a 4,552 km^2 Alpine watershed characterized by a highly varied terrain elevation, which provides a huge hydropower potential exploited through 16 artificial reservoirs operated by different power companies. The alpine reservoirs have a significant influence on downstream streamflow and their release policies are often conflicting with the lake water allocation goals: in summer, when agricultural irrigation demand is at its maximum, the upstream reservoirs limit their release to profit from higher electricity prices in winter. In addition, the operation of Lake Como itself is challenged by clear trade-offs amongst irrigation supply, flood protection, and the diverse interests of water-related sectors, such as navigation, tourism, commercial fisheries, and the environment. A changing climate is already exacerbating tensions between the various sectors[25,26].

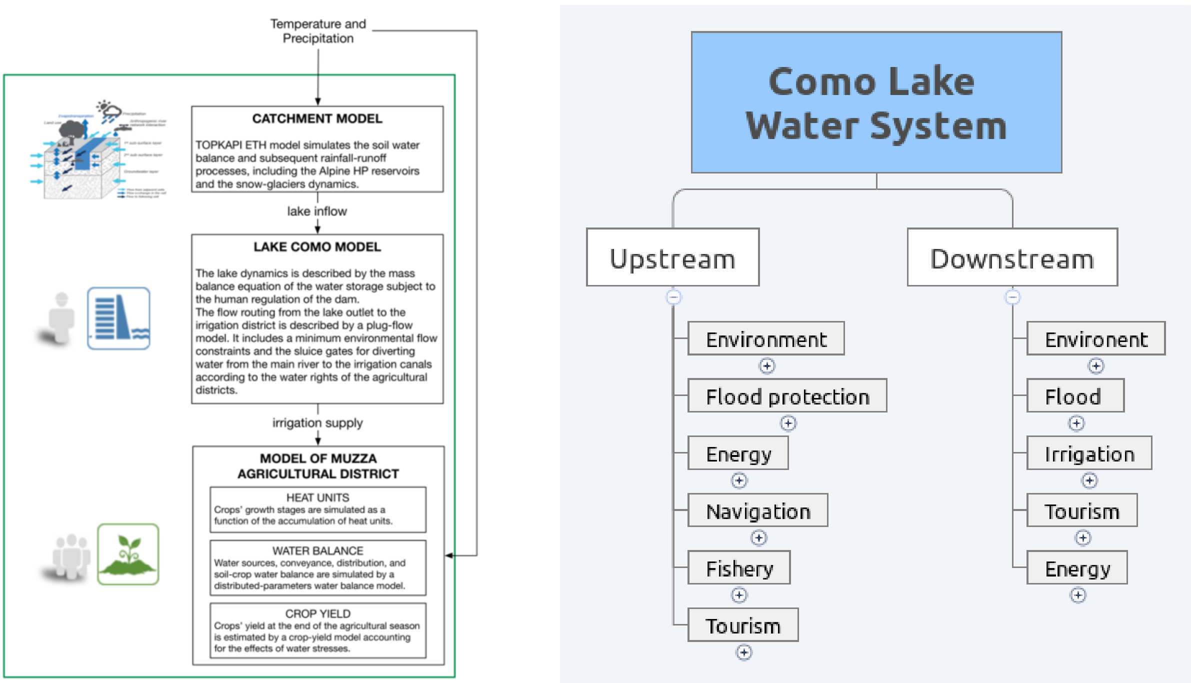

Figure 2. The Lake Como water system sectors and integrated model

[23] Denaro, S., Anghileri, D., Giuliani, M., Castelletti, A., 2017, Informing the operations of water reservoirs over multiple temporal scales by direct use of hydro-meteorological data, *Advances in Water Resources*, 1013.

[24] Galelli, S. and Soncini-Sessa, R., 2010, Combining metamodelling and stochastic dynamic programming for the design of reservoir release policies, *Environmental Modelling & Software* 25(2).

[25] Forzieri, G., L. Feyen, R. Rojas, M. Floerke, F. Wimmer, and A. Bianchi (2014), Ensemble projections of future streamflow droughts in Europe, Hydrol. Earth Syst. Sci., 18(1), 85–108.

[26] Anghileri, D., A. Castelletti, F. Pianosi, R. Soncini-Sessa, and E. Weber (2013), Optimizing watershed management by coordinated operation of storing facilities, J. Water Resour. Plann. Manage., 139(5), 492–500.

Model and data availability
From previous and ongoing projects, Politecnico di Milano has developed a suite of models for the Lake Como Watershed, including a fully-distributed (regular grid of 250 m), physically-based TOPKAPI-ETH model of the lake catchment, a dynamic model of the lake and its operation, a spatially distributed model of the irrigation district (regular grid of 250 m), an ensemble of climate change scenarios Figure 2). We will work with the regional authority, irrigation districts, and Regional Environmental Protection Agency, which have been involved in previous projects.

Stakeholders and interests
The interests of the stakeholders are represented by specific indicators, which were constructed adopting a bottom-up approach over years of interactions and stakeholders' meetings organized as part of several research activities we developed on the Lake Como system (*e.g.*, the TwoLe project funded by Fondazione Cariplo with the goal of testing the Participatory and Integrated Planning procedure for the design of River Basin Plans requested by the Water Framework Directive (2000/60/EC)). The result of these interactions was the formulation, testing, and validation of a hierarchy of indicators and modeling the multi-sectoral interests involved in the system. The regional authority, irrigation districts, and Regional Environmental Protection Agency are the most relevant stakeholders.

Contribution of a many objective formulation
The water management of Lake Como is a focal point of innovations and research on operational water management. In Lake Como, the traditional optimization methods[27,28,29] that severely limited the number of objectives to be considered in the design of the optimal system's operation as well as their mathematical formulation (i.e., only time-separable objectives), are already replaced by a regulation on tradeoff solutions that "heuristically" balance the competing interests of different sectors (mainly flood protection and irrigation supply). This case study will therefore focus on the next innovative step for Lake Como and focus on water management strategies under uncertain future conditions, resulting from climate change and changes in socio-economic preferences. This focus contributes methodological depth to the Italian funded SOWATCH Project.

WP3 Multi- versus many-objective optimization - The Seine River, France (Irstea, Artelia France)

Case description
This case study considers the Seine River basin covering and area of about 43,824 km2 upstream of Paris (Figure 3). The Seine River has its source in the Plateau des Langres in North-East France. The flow regime is characterized by low flows in summer and high flows in winter[30]. The average discharge at the outlet point, i.e. at Austerlitz station, is about 300 m3/s. Because of the gentle slope of Seine Valley, the river has numerous meanders and a slow runoff. Four reservoirs, constructed between the 1950s and the 1990s, regulate the discharge on the Seine River, with the main objectives of reducing both floods and droughts.

Model and data availability
The integrated model for the Seine basin is a semi-distributed model, composed of 2 sub-models:
- **Semi-distributed hydrological model -** The basin is divided into 25 sub-basins corresponding to the 25 available gauging stations. Each sub-basin is modelled using the GR4J model. All the contributions are routed along the channel network to the outlet using a lag and route propagation approach[31].
- **Reservoir operations model -** The reservoir operation model reproduces the behaviour of the reservoir managers to provide the daily decisions of inflows and outflows from each reservoir. The Reservoir operations model utilizes a real-time optimization strategy based on model predictive control (MPC)[32].

[27] Stefano Galelli et al., "Building a Metamodel of an Irrigation District Distributed-Parameter Model," *Agricultural water management* 97, no. 2 (2010).
[28] Daniela Anghileri et al., "Optimizing Watershed Management by Coordinated Operation of Storing Facilities," *Journal of Water Resources Planning and Management* 139, no. 5 (2012).
[29] Matteo Giuliani et al., "Large Storage Operations under Climate Change: Expanding Uncertainties and Evolving Tradeoffs," *Environmental Research Letters* 11, no. 3 (2016).
[30] Ducharne, A., Baubion, C., Beaudoin, N., Benoît, M., Billen, G., Brisson, N., ... & Mary, B. (2007). Long term prospective of the Seine River system: Confronting climatic and direct anthropogenic changes. *Science of the Total Environment*, *375*(1-3), 292-311.
[31] See e.g. Bentura, P. L., & Michel, C. (1997). Flood routing in a wide channel with a quadratic lag-and-route method. *Hydrological Sciences Journal*, *42*(2), 169-189.
[32] van Overloop, P.-J. (2006). *Model predictive control on open water systems*. IOS Press, Delft, The Netherlands.

Stakeholders and interests

The Seine Basin is an extremely important economic region for France and Europe: 20 million people live in the Paris metropolitan area, and the GDP is about €600 billion, corresponding to 19% of the population of France and to 31% of the national GDP[33]. The presence of cities and industries is the cause of vulnerability to droughts and floods. Regarding droughts, the Seine River provides drinking water to the Paris metropolitan area and is a major agricultural and touristic region[34]. Extreme drought can affect the functioning of the Nogent-sur-Seine power plant because of a lack of cooling water. Regarding floods, a repetition of a flood similar to the historically high flooding in Paris in 1910 could affect up to 5 million people today and cause up to €30 billion worth of damage[35]. A preliminary stakeholder analysis identified Seine Grands Lacs, Syndicat des Eaux d'Ile-de-France, Veolia Eau Ile de France, Syndicat interdépartemental pour l'assainissement de l'agglomération parisienne, Ville de Paris, Électricité de France, Voies navigables de France and the Countiesvas as some of the most relevant stakeholder.

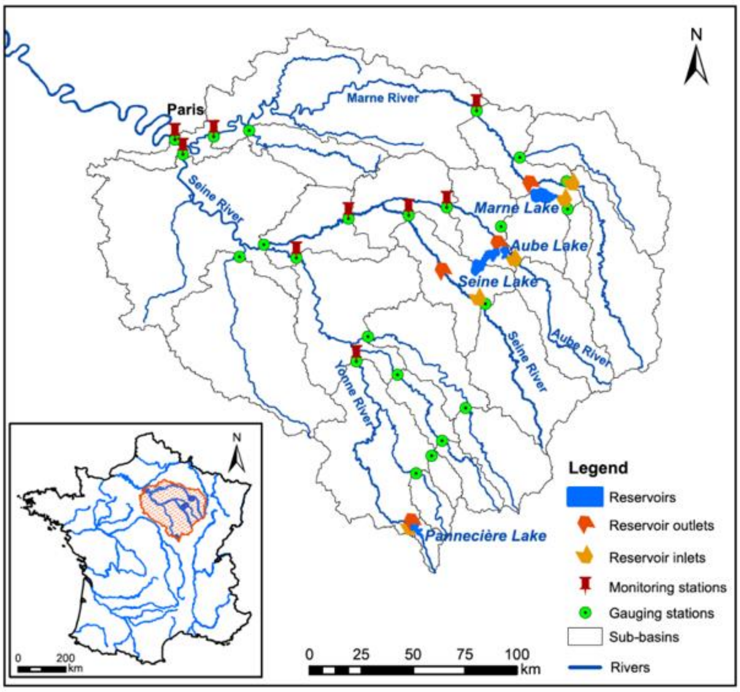

Figure 3 Main river network, reservoirs and gauging and monitoring stations of the Seine River [36]

Contribution of a many objective formulation

Four reservoirs regulate the discharge on the Seine River, with the main objectives of reducing both floods and droughts. Currently, each reservoir is operated independently from the others, following a Rule-Curve that sets the target reservoir volume for each day of the year. Improving management strategies to include is high on the agenda for the River Seine management. Recent research using MPC and Tree-Based MPC shows how a model-based, anticipatory and centralized control method can improve the level of flood protection[37, 38]. These applications, however, aggregate the many-objective problem in a single objective function that suffers from three limitations:

[33] Agnès Ducharne, "Importance of Stream Temperature to Climate Change Impact on Water Quality," *Hydrology and Earth System Sciences Discussions* 4, no. 4 (2007).

[34] David Dorchies et al., "Climate Change Impacts on Multi-Objective Reservoir Management: Case Study on the Seine River Basin, France," *International Journal of River Basin Management* 12, no. 3 (2014).

[35] Charles Baubion, "Losing Memory–the Risk of a Major Flood in the Paris Region: Improving Prevention Policies," *Water policy* 17, no. S1 (2015).

[36] Ficchì, A., Raso, L., Dorchies, D., Pianosi, F., Malaterre, P.O., Van Overloop, P.J. and Jay-Allemand, M., (2015). Optimal operation of the multireservoir system in the seine river basin using deterministic and ensemble forecasts. Journal of Water Resources Planning and Management, 142(1), p.05015005.

[37] Andrea Ficchì, Charles Perrin, and Vazken Andréassian, "Impact of Temporal Resolution of Inputs on Hydrological Model Performance: An Analysis Based on 2400 Flood Events," *Journal of Hydrology* 538 (2016).

[38] L. Raso, M Chiavico, and D Dorchies, "Optimal and Centralized Reservoir Management for Drought and Flood Protection on the Upper

- the selection of the weights values is difficult
- weights are often non-comparable among each other
- assigning higher priority to a station or a process (either flood or drought) is an arbitrary choice.

A many-objective formulation of the Seine River promises to solve these issues and could contribute to the implementation of a more optimal management of the River Seine by generating more innovative strategies and reducing stakeholder resistance by including a wider range of objectives.

WP4 Multi- versus many-objective optimisation - The Meguellil Basin (INED, Tunisia)

Case description

The Merguellil watershed (1183 km^2) situated in the Kairouan region, central Tunisia, is suffering from water scarcity and high variability of precipitation. The aquifer system of the Kairouan plain is the main water resource for agriculture, domestic, tourism, industry and coastal supply, and is only to a small extend supplemented by surface water of the El Houareb dam. The continuous increase and intensification of irrigated area has led to an overexploited of groundwater resources with 150% of its total capacity and a decline of the water level of up to 1 m per year. The study area is made of two distinct parts: a hilly region upstream of the El Haouareb dam (1200 km^2), and the flat Kairouan plain (3000 km^2). The water resources show a typical Mediterranean regime, with a strong heterogeneity in time and space of rainfall and ephemeral runoff. Mean annual rainfall increases from 250 mm in the plain up to 500 mm in the highest part of the basin[39]. Groundwater from the Kairouan plain aquifer (up to 800 m of Plio-Quaternary sediments) represent a massive and mostly reliable water storage.

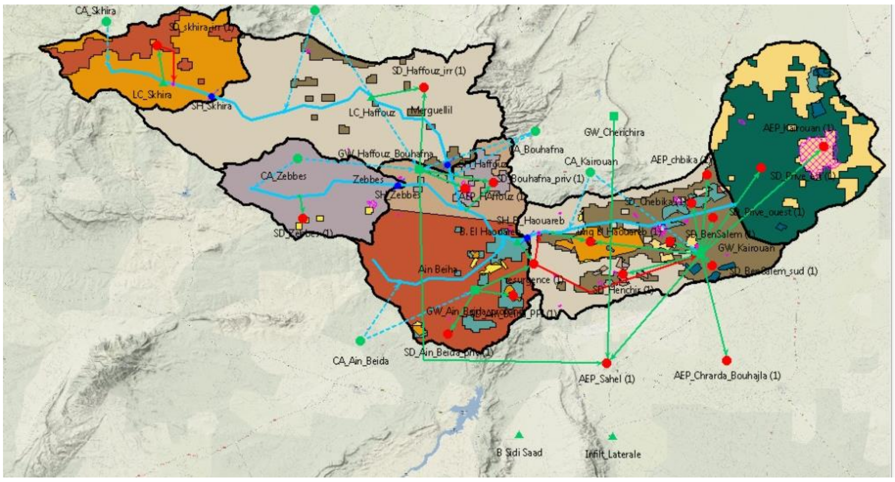

Figure 4 The Merguellil watershed

Model and Data availability

Most models that were developed up to now dealt only or mainly with physical components[40,41]. Our recent work[42,43] showed that major water issues in the Kairouan region are linked with a variable combination of technical, social and environmental constraints. Whatever the scale of analysis, the observation, understanding and modelling of such a complex socio-hydrosystem have to integrate the multiple human and physical dimensions. In fact,

Seine-Aube River Using Stochastic Dual Dynamic Programming," *accepted to Journal of Water Resources Planning and Management* (2018).

[39] Ogilvie A., Le Goulven P., Leduc C., Calvez R., Mulligan M., 2016. Réponse hydrologique d'un bassin semi-aride aux événements pluviométriques et aménagements de versant (bassin du Merguellil, Tunisie centrale). Hydrological Sciences Journal 61(2): 441-453

[40] E.g., Sušnik J., Vamvakeridou-Lyroudia L.S., Savić D.A., Kapelan Z., 2012. Integrated System Dynamics modelling for water scarcity assessment: Case study of the Kairouan region. Sci. The Total Environ. 440, 290-306

[41] I Oueslati et al., "Weap Model as a Tool for Integrated Water Resources Management in Merguellil Watershed (Central Tunisia)," in *Sustainable Watershed Management* (CRC Press, 2014).

[42] Leduc C., Massuel S., Riaux J., Calvez R., Ogilvie A., Benaïssa N., Lachaal F., Jenhaoui Z., 2017. Changement global et ressources en eau souterraines dans la région de Kairouan (Tunisie centrale) : évolutions rapides et à long terme. In Calvache M.L., Duque C., Pulido-Velazquez D. (eds). Impacts of global change on western Mediterranean aquifers. Univ. Granada, 263-269

[43] Massuel S., Riaux J., 2017. Groundwater overexploitation: why is the red flag waved? Case study on the Kairouan plain aquifer (central Tunisia). Hydrogeol J. 25(6): 1607-1620

behaviours of individual farmers, representatives of irrigators groups, institutional managers and politicians do not meet the theoretical optima defined separately by economics, agronomy or hydraulics. The aggregation of qualitative and quantitative information is a big challenge for future work, as well as the transcending of disciplinary and institutional borders. We will build on the System Dynamics Model[40] developed and apply the interactively developed many-objective evaluation framework to identify innovative water management strategies for Merguellil watershed. The model will simulate water resources deriving from numerous catchment sources and demand from four sectors (domestic, industrial, agricultural, external pumping), and will contains multiple feedback loops and sub-models.

Stakeholders and interests
Kairouan has a level of social and economic welfare far below the national mean. It is considered as the region with the highest potential for agricultural development in Tunisia for which access to water is fundamental. Catastrophic floods are now controlled by three dams over the three main rivers (*i.e.*, Zeroud, Merguellil, Nebhana). Many small dams have been built in the hilly upstream region. However, compared to the sporadic surface runoff, groundwater is by far the most important source of drinking water and irrigation water. Irrigated areas are either private (with a large variety of arrangements about land and water, rights, rents, crops) or in public schemes (with a large range of working efficiency, failures). The number of illicit wells (i.e. drilled without the required preliminary licence) has exploded since the Tunisian Revolution, and by now exceeds 10,000. The real amount of water pumped for agriculture is considerably underestimated by authorities. In addition, authorities have lost a large part of their influence and credibility among farmers. Crops and agricultural practices are rapidly changing, following multiple patterns corresponding to various levels of social and environmental pressures, capacities of resilience, and adaptation[44]. A stakeholder identification exercise identified the Regional Agricultural development Office and Grouping of Agricultural development in Kairouan, and the National Institute of cereals as important stakeholders.

INAT and IRD have worked in the Merguellil basin for the last two decades. They have addressed a large set of research questions with different disciplinary approaches, at various spatial and temporal scales. They have implemented physical and social surveys with local authorities and with the trust of most farmers. Field courses with students and dialogue workshops[1] are some of the various forms of interaction with the local stakeholders.

Contribution of a many objective formulation
Throughout the last projects (WASSERMED FP7 and AMETHYST) INAT worked on actual and future water balance of the Merguellil watershed. Next, this knowledge needs to be applied to find and implement solutions. The research in this project is designed to support this important next step. The identification of more innovative water management policies intertwined with a structured and inclusive stakeholder process could well kick start a stakeholder process to complement the limited coordinating ability of the local authorities.

WP5 Stakeholder involvement, integration and dissemination (TU Delft, The Netherlands)
This work package designs and implements the international workshops and designs, attends and reports on the regional workshops in the case study area. It guides the case study researchers in scoping and stakeholder identification and prepares implementation guidelines for the regional workshops. These are especially relevant in assuring the methodological consistency of the three case studies in view of the final comparative conclusions (research objective 4)

1.5 Originality and innovative aspects of the research (ambition)

The research is original and innovative in its **application of recent scientific work** in the field of many-objective optimization to real world cases in diverse hydrological and cultural settings in the field of IWRM. It is also innovative in its **research design** that connects existing optimization applications in water management to an alternative many-objective approach. In addition, it is innovative because the research design effectively supports the aim of our research to **disseminate our results** by identifying alternative optimal solutions that can convince policy makers and operational water managers of the merits of many-objective approaches and at the same time supply them with an **operational implementation**. **Scientifically** the research design offers a comparative approach of existing single and multi-objectives optimization applications versus a many-objective approach. This comparative perspective offers the potential to **evaluate the merits** of **many-objective approaches** versus **single**

[44] *e.g.* Collard A.L., Riaux J., Massuel S., Raïssi M., Burte J., 2015. « Et si on faisait comme ceux de la plaine ? » Aspirations et limites d'une petite agriculture dynamique en Tunisie centrale. Cah Agric. 24(6): 335–341

and multi-objective approaches in diverse hydrological and cultural settings. From a global societal perspective, in the age of climate change and rapid socio-economic development in the global South, water management approaches that enrich the solution space with alternative courses of action that better reflect the diverging perspectives of stakeholders, align better with ethical concerns and carry the promise of inclusiveness, are indispensable for closing the water cycle gap.

Water management offers an effective test-bed for innovative optimization approaches. First, because optimization has a long and strong tradition in water management, especially in control of reservoirs and irrigation systems[45]. Secondly, water management issues are typically many-objective. Third, IWRM poses specific methodological challenges and many-objective optimization approaches are well set to takes these on[46,47].

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

Transfer of knowledge to our scientific and knowledge partners and our societal partners in the 3 case studies is an integral and indispensable part of the project design. The project connects specialists in ethics, operation research, and policy analysis to specialists in water management and hydrological and hydraulic simulation. These specialists have to integrate their methods, models, and tools into an operational many-objective water management model. To secure well organized and structured collaboration and effective transfer of knowledge, we have included a separate work package, WP5, that designs, organises and implements the workshops required to achieve knowledge exchange and realization of project objectives.

Besides academic partners, the case studies include regional stakeholders like irrigations districts, regional authorities and environmental protection agencies and water resources knowledge institutes like Irstea (France) and INAT (Tunisia), and business like Artelia (France). The irrigation districts and regional authorities are end-users of our innovations and are in direct contact with water users and stake-holders and are able to involve them in the research. This facilitates the development and dissemination of best practices to the water management in our case study areas and beyond. WP5 also ensures effective collaboration in the case study areas and effective feedback from the case studies to the research flow.

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

Our consortium partners are selected for their strong records in their respective field. The experience of **prof. dr. ir. Neelke Doorn**, professor of ethics of water engineering at the Department of Values, Technology and Innovation of the Faculty Technology, Policy and Analysis (TPM) at Delft University of Technology is indispensable for the overall guidance of the research. Especially her multi-disciplinary background in civil engineering (BSc MSc), philosophy (BA MA PhD) and law (LLB LLM) will enable the project to reach its multi-disciplinary goals and scientific ambitions. She received a VENI from the Dutch Science Foundation (NWO) is involved in several international and NWO funded research projects, including the H2020 projects BRIGAID and SmartResilience. **Dr. ir. Jan Kwakkel** of the Department of Multi Actor Systems of the Faculty Technology, Policy and Analysis (TPM) at Delft University of Technology will focus on the methodological innovation and guard the implementation of models and simulations. He has a strong methodological focus on operation research, modelling and simulation, and software development and is currently involved as a PI in a number of water management oriented research projects in the NWO-UDW, NWO-Top Sector Water, and NWO-VENI research programs.

The PI's of the 3 case study work packages are all involved in international water management research programs and at the same time foster a strong involvement within their case study regions.

- **Matteo Giuliani, PhD**, is an Assistant professor in the Department of Electronics, Information, and Bioengineering of Politecnico di Milano. He specializes on water resources optimization and control and machine learning. He has been a research investigator in EU-H2020 DAFNE and IMPREX programs and the EU-FP7-ICT SmartH2O project and the IMRR Integrated and Sustainable Water Management of Red-Thai Binh River System (Vietnam), sponsored by the Italian Ministry of Foreign Affairs

[45] DR Brouwer et al., "Improved Reservoir Management through Optimal Control and Continuous Model Updating" (paper presented at the SPE Annual Technical Conference and Exhibition, 2004).
[46] Rahaman and Varis, "Integrated Water Resources Management: Evolution, Prospects and Future Challenges."
[47] Biswas, "Integrated Water Resources Management: Is It Working?."

- **Dorchies David, ir,** of IRSTEA specialises in modelling hydraulics systems. He is one of the developers of the SIC² (Simulation and Integration of Control for Canals) software and coordinated the EU-ClimaWare projects on the management of the dams of the Seine River.
- **Ines Oueslati, PhD**, at INAT, participates extensively in internationally funded water management research projects. She participated in the AMETHYST-ANR project, applied the WEAP model in the frame work of the FP7 WasserMed project and contributed to the FP6 Aquastress research project.

2. IMPACT

2.1 Impact of the proposal

The research proposed addresses **theme 1, Enabling Sustainable Management of Water Resources** and **theme 2 Strengthening Socio-economic Approaches to Water Management** of the JPI 2018 Closing the Water Cycle Gap – Sustainable Management of Water Resources call. It promotes adaptive water management through its focus on the methodologically consistent inclusion of a wider set of decision criteria, considering all water cycle compartments and water/ecosystem services, and the development of innovative management options (Sub-theme 1.1 - Promoting adaptive water management for global change). The many-objective optimisation framework the project aims to develop, apply, and implement, supports the integration of economic and social analyses into decision-making (Sub-theme 2.1 - Integrating economic and social analyses into decision-making processes).

The impact of the research targets United Nations Sustainable Development **Goals 6 "Clean water and sanitation"** and **SDG 13 "Take urgent action to combat climate change and its impacts"**. In SDG 6 the research particularly focuses on the implementation of integrated water resources management at all levels, expansion of international cooperation and capacity-building in water-related activities in developing countries. For Sustainable Development Goal 13 this research maintains a focus on methodologies that support the integration of climate change measures into regional water policies, strategies and planning. Contribution towards the SDG 6 and 13 is mainly achieved through our case studies witch local partners and end-users.

2.2 Expected outputs

The most relevant and tangible output of the research project will be operational many-objective implementations of the existing water management models in our case study areas. This clear objective and deliverable requires effective cooperation between knowledge partners and stakeholders in the case study areas, which will ensure dissemination of our scientific and practical results. In addition the research project will deliver a range of scientific publications, project report, guidelines and documents that support project implementation and dissemination of results to stakeholders (see Gantt chart in section 3.2 for details and timing of deliverables)

2.3 Exploitation and communication activities (measures to maximise impact)

The IN-WOP research project is designed to integrate scientific progress with stakeholder involvement and dissemination of the results. For example, regional stakeholder workshop to develop the many-objective framework contribute both to methodological progress and dissemination of its results (deliverable 1.2, 1.6, 1.8, 2.2, 2.6, 2.8, 3.2, 3.6, 3.8, 4.2, 4.6, 4.8, 5.1, 5.6 in Table 2 Gantt chart and Table 3 Deliverables). Furthermore, exploitation and communication of the results is fostered by working with existing models used and supplied by our stakeholders. After extending these models with a many-objective component, the models will be handed over to our stakeholders for operational use. This occasion is marked with a workshop event (deliverable 1.8, 2.8, 3.8, 4.8 in Table 2 Gantt chart and Table 3 Deliverables). Handing over the innovated models to our water management partners in addition guarantees their accessibility and protection. Communication to the wider stakeholder community is realized through the regional framework development workshops and publications in national professional literature. Scientific publications will be open access.

2.4 Market knowledge and economic advantages/return of investment

Market knowledge and economic advantages from this research will be achieved through two pathways:
- **Business development:** based on our results, water management knowledge organizations and consultants like our partner ARTELIA, and similar organizations and consultants in our partner countries and beyond can develop and marked new product for the international water management market. Here our direct partner ARTELIA has a strategic advantage by directly participating in the research.

- **Sectoral economic benefits:** water management organizations implementing and using our results will contribute to closure of the water cycle gap. This will inevitably result in increased economy performances in the agricultural, hydro-power, water supply and tourism sectors and results in minimizing damages from flooding that will benefit businesses, citizens and the general functioning of the economy alike.

3. IMPLEMENTATION

3.1 Overall coherence and effectiveness of the work plan

The project is designed in 5 closely interlocking work packages. WP1 implements and guides the methodological and ethical research and knowledge concerning many-objective optimization and its impact on the efficiency, effective, innovativeness and fairness of strategies. WP1 is based at the sections of Policy Analysis, and Values, Technology and Innovation of the faculty of Technology Policy and Management at Delft University of Technology. The faculty of TPM has a strong methodological profile with applications in the field of technology especially water management. The work packages 2 trough 4 cover the water management parts of the research. These work packages are implemented by universities and knowledge institutions in Tunisia, Italy, and France. Al these institutions have a strong record in modelling and optimization for water management, and have strong connections to stakeholders in the case study areas. WP5 takes responsibility for coordinating the research with a strong focus on integration and stake holder involvement.

Table 1 Summary of the work packages

WP Number	WP Title	Duration (months)	Starting Month	End Month	WP Description
WP1	Elaboration and evaluation many-objective framework	36	1	36	Interactive development of the many-objective optimization framework. Generic and for all case studies. Cross-case comparison (32 months)
WP2	Multi- versus many-objective optimisation Lake Como case	36	1	36	Implementation of Many-objective Framework in case study area
WP3	Multi- versus many-objective optimisation Seine River case	36	1	36	Implementation of Many-objective Framework in case study area
WP4	Multi- versus many-objective optimisation Meguellil case	36	1	36	Implementation of Many-objective Framework in case study area
WP5	Coordination	36	1	36	Coordination of stakeholder involvement, knowledge dissemination and knowledge integration

Guiding he work plan is a parallel and synchronic implementation of the 3 case studies with intensive formal and informal interaction between the scientific and knowledge partners. This setup requires interaction and learning between the methodological (WP1) and case study work packages (WP2-4) and to realize synergy between the 3 case studies. The work plan including deliverables, milestones, program monitoring, mobility scheme and risk management is presented in the Gantt chart of Table 2 and the related tables 3-7.

Deliverables include reports, guidelines, workshop reports, and running models that mark relevant milestones. These deliverables mark the completion of a research phase, report results and make them available for the next phase of the research. This is especially relevant for coordinating research progress and direction of the case studies and guide them to results that facilitate the comparative approach of WP1. Besides substantive coordination and guidelines, we have included a separate work package, WP5, that implements the interaction between researchers and stakeholders and realize the feedback between case study specific workshops, scientific and knowledge workshops. Risk management is focusses on the progress in model implementation and the participation of stakeholders.

Table 2 Gantt chart

Month/ Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
WP1 Framework	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1
WP2 Lake Como	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2
WP3 Seine River	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3
WP4 Meguellil Basin	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4
WP5 Coordination			WP5				WP5							WP5				
Deliverable		d1.1 d2.1 d3.1 d4.1	d5.1			d1.2 d2.2 d3.2 d4.2	d5.2						d1.3 d2.3 d3.3 d4.3	D5.2				
Milestone			M1				M2							M3				
Progress Monitoring			P1										P2					
Mobility Schemes			m1				m2											
Risk Management			R1						R2	R2	R2	R2					R2	R2
Others																		

Month/ Description	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WP1 Framework	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1	WP1
WP2 Lake Como	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2	WP2
WP3 Seine River	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3	WP3
WP4 Meguellil Basin	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4	WP4
WP5 Coordination				WP5						WP5				WP5			WP5	
Deliverable			d1.4 d2.4 d3.4 d4.4	d5.3				d1.5 d2.5 d3.5 d4.5	d1.6 d2.6 d3.6 d4.6	d5.4			d1.7 d2.7 d3.7 d4.7	d.55		d1.8 d2.8 d3.8 d4.8	d5.6	d1.8 d2.8 d3.8 d4.8
Milestone				M4						M5								
Progress Monitoring				P3														
Mobility Schemes				m3						m4				m5			m6	
Risk Management	R2	R2				R2	R2			R1			R1					
Others																		

Table 3 Deliverables

Number	Description	Method	Type of product
1.1	Evaluation framework review and ethical perspective	literature research	Scientific publication (1)
2.1, 3.1,4.1	Case study base line document and stakeholder identification	Literature research, snowballing questionnaire	report
5.1	Multi objective framework development workshop	workshop	Implementation guideline
1.2, 2.2, 3.2, 4.2	Scoping and framework stakeholder workshop	workshop	Scientific publication framework development
5.2	Quality management and evaluation of Scoping and framework stakeholder workshops	Attendance of all 3 workshops	Evaluation report
1.3, 2.3, 3.3, 4.3	Water management model operationalization and testing	Water management model development	Running water management models
1.2	Integration and final design of optimization framework	Analysis	Guideline for implementation
1.4, 2.4, 3.4, 4.4	Models and optimization implementations up and running	Model development	Running optimization models
5.3	Models and optimization fine tuning and quality control workshop	Workshop	Operational water management and optimization models

Number	Description	Method	Type of product
1.6, 2.6, 3.6, 4.6	Preliminary results stakeholder feedback workshop	workshop	Feedback report
5.4	Attendance of all 3 workshops	Attendance and reporting of 3 workshops	Workshop reports
1.7, 276, 3.7, 4.7	Final multi and many-objective results	Simulation and analysis	Scientific publication for each case study (publication 2, 3 and 4))
5.5	Final scientific comparative workshop	Workshop and paper writing	Comparative scientific paper
1.8, 2.8, 3.8, 4.8	Software and final results deliverance event	Workshop event	Workshop report
5.6	Attendance of all 3 workshops events	Attendance and reporting of 3 workshops	Workshop reports
1.9, 2.9, 3.9, 4.9	Final comparative paper	Writing	Scientific publication (5)

Table 4 Milestones

M1 Ready for implementation of Multi objective framework development workshop case study
M2 Scoping and framework stakeholder workshop implemented for all case studies
M3 Ready for implementation of Many-objective Optimisation framework
M4 Many-objective optimization framework implemented
M5 Preliminary results

Table 5 Progress Monitoring

P1 Monitor invitation and attendance of stakeholders
P2 Models up and running
P3 Integrated models up and running

Table 6 Mobility Schemes

m1 All scientific and knowledge partners travel to Milano, Netherlands
m2 WP5 coordinator and PI travel to all case study workshops. local travel
m3 All scientific and knowledge partners travel to Paris, Netherlands
m4 WP5 coordinator and PI travel to all case study workshops, local travel
m5 All scientific and knowledge partners travel to Tunisia, Netherlands
m6 WP5 coordinator and PI travel to all case study workshops

Table 7 Risk Management

R1 Monitor invitation and attendance of stakeholders to avoid under-participation
R2 Signal model, data and/or ITC bottleneck

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

Prof.dr.ir. Neelke Doorn of the faculty of Technology, Policy and Management (TPM) of TU Delft is responsible for overall project guidance, control of the scientific work, and implementation of the cooperative arrangements. Supervision and coordination of day-to-day project implementation and methodological and substantive progress is the responsibility of the overall project coordinator dr.ir. Jan Kwakkel also of TPM TU Delft. He will be supported by a coordinator with a background in actor analysis and process design for the implementation of WP5.

The PI of the case studies, Matteo Giuliani, PhD, of Politecnico di Milano, Ir. David Dorchies of IRSTEA, and Ines Oueslati, PhD, of INAT, will take responsibility for the water management modelling and project implementation in their respective areas. They will receive support from WP5 for the implementation of the workshops and stakeholder involvement.

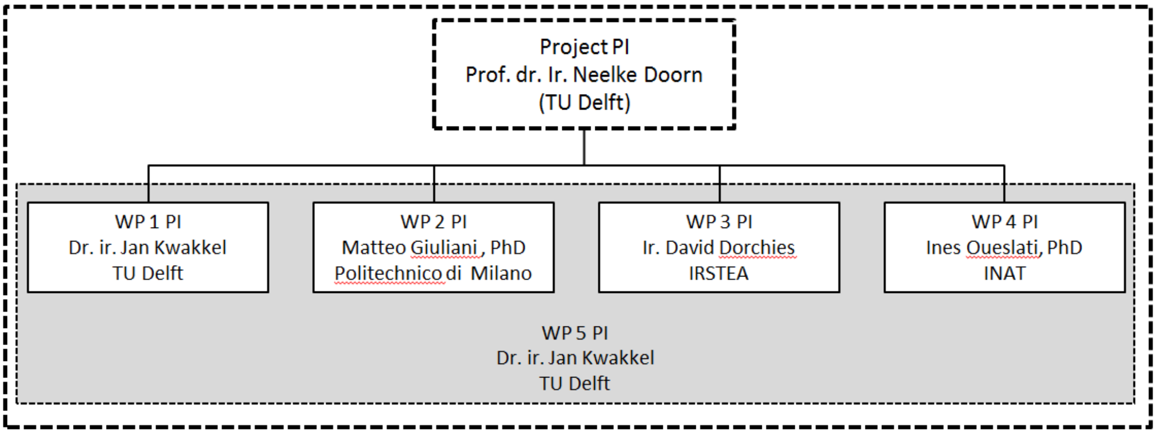

Figure 5 Management structure

3.3 Risk management

The most relevant risks identified for the project are under participation of stakeholders and model and software implementation issues (R1 and R2 in Table 2 GANTT chart and Table 7). To manage the stakeholder risk, we have included a separate work package, WP5, that focusses on the provision of well designed, planned and communicated work shop processes. Risks in modelling and software are mitigated by including the skills and experience of dr. ir. Jan Kwakkel, PI of WP1 and WP5 in the consortium.

3.4 Potential and commitment of the consortium to realize the project

Our consortium partners are selected for their strong records in their respective field. The PI's of the case study packages continue and innovate their work in their specific case study areas. This will both benefit the quality of the project output and the commitment if the consortium partners to the research project. In addition all partners have cooperated before in various EU and nationally funded research projects.

4. DESCRIPTION OF THE PARTICIPATING RESEARCHERS

Partner Number, according to Part A	Research Team Members (for personnel include name, position and affiliation)	General Description
Partner 1 TU Delft-TPM Jan Kwakkel	Prof.dr.mr.ir. N. Doorn, prof. Ethics of Water Engineering, TU Delft TPM.	moral questions in water governance >54 peer-reviewed publications; H-index: 10 (Scopus), 13 (Scholar)
	Dr. Ir. L.R. Raso, doctoral research fellow, TU Delft TPM	Optimal Control of Water Systems >11 peer-reviewed publications; H-index: 6 (Scopus), 8 (Scholar)
	Dr.ir. J.S. Timmermans, Researcher, TU Delft TPM	Actor strategy models >9 peer-reviewed publications; H-index: 5 (Scopus), 8 (Scholar)
Partner 2 Politecnico di Milano Matteo Giuliani	Prof. A. Castelletti, Associate Professor, Politecnico di Milano	Water resources planning, optimal control theory >130 peer-reviewed publications; H-index: 26 (Scopus), 30 (Scholar)
	Dr. J. Zatarain-Salazar, Post-doctoral research fellow, Politecnico di Milano	Integrated water resources management > 2 peer-reviewed publications; H-index: 2 (Scopus), 2 (Scholar)
Partner 3 Irstea David Dorchies	Dr C. Leduc, director of research, IRD France-Tunisia	Water resources management, Merguellil basin > 37 peer-reviewed publications; H-index: 16 (Scopus)
	Dr. A. Ogilvie, researcher IRD Montpellier	Remote sensing, water resource modelling simulation >13 peer-reviewed publications; H-index: 5 (Scopus), 5 (Scholar)
	Dr J.C. Bader, senior researcher, IRD Montpellier	Modelling of hydrology and reservoir management >24 peer-reviewed publications; H-index: 6 (Scopus)
	Dr. P.O. Malaterre, senior researcher, IRSTEA Montpellier	Automatic control and data assimilation. > 45 peer-reviewed publications; H-index: 13 (Scopus), 21 (Scholar)
Partner 4 INAT Ines Queslati	Zohra Lili Chabaâne, INAT	Remote sensing, Hydro climatology > 12 peer-reviewed publications; H-index: 5 (Scopus)
	Mohamed Mechergui, INAT	Hydrogeology > 5 peer-reviewed publications; H-index: 2 (Scopus), 21 (Scholar)
	Nadhira Benaissa, INAT	Soil sciences, Agricultural efficiency > 45 peer-reviewed publications; H-index: 13 (Scopus), 21 (Scholar)

5. CAPACITY OF THE CONSORTIUM ORGANISATIONS

Partner Number (Organization Name)		General Description
Partner 1 TU Delft TPM	Role and main responsibilities in the project	Coordination of the project, methodological implementation
	Key research facilities, infrastructure, equipment	- Game lab - Computer facilities
	Relevant publications and/or research/innovation products	- Exploratory modelling workbench - Actor and strategy models - Random regret minimization model Doorn, Neelke. "The Blind Spot in Risk Ethics: Managing Natural Hazards." Risk Analysis 35, no. 3 (2015): 354-60.
Partner 2 Politecnico Milano	Role and main responsibilities in the project	Implementation and stake holder interaction for the Lake Como case study
	Key research facilities, infrastructure, equipment	- Polifactory multidisciplinary research lab - Hydroinformatics Lab (HIL) Como campus - Climate-Lab monitoring key climatic and environmental variables
	Relevant publications and/or research/innovation products	- Catchment model TOPKAPI-ETH hydrological model of Lake Como catchment - Lake Como model lake dynamics - Agricultural districts model dynamic processes internal to the irrigation districts Giuliani, Matteo et. al. "Large Storage Operations under Climate Change: Expanding Uncertainties and Evolving Tradeoffs." Environmental Research Letters 11, no. 3 (2016): 035009.
Partner 3 Irstea	Role and main responsibilities in the project	Implementation and stake holder interaction for the River Seine case study
	Key research facilities, infrastructure, equipment	- Agencies at Paris, Montpellier and Grenoble. - Computer cluster at Montpellier
	Relevant publications and/or research/innovation products	- River Seine reservoir model Dorchies, David, et. al. "Climate Change Impacts on Multi-Objective Reservoir Management: Case Study on the Seine River Basin, France." International Journal of River Basin Management 12, no. 3 (2014): 265-83.
Partner 4 INAT	Role and main responsibilities in the project	Implementation and stake holder interaction for the Wadi Merguellil case study
	Key research facilities, infrastructure, equipment	five laboratories on priority themes
	Relevant publications and/or research/innovation products	- Model of the Merguellil watershed Oueslati, I., et al. "WEAP model as a tool for integrated water resources management in Merguellil watershed." Sustainable Watershed Management. CRC Press, 2014. 111-112.