PROJECT FINAL REPORT

Grant Agreement number: 619120

Project acronym: MARSOL

Project title: Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought

Figures included in the final project report

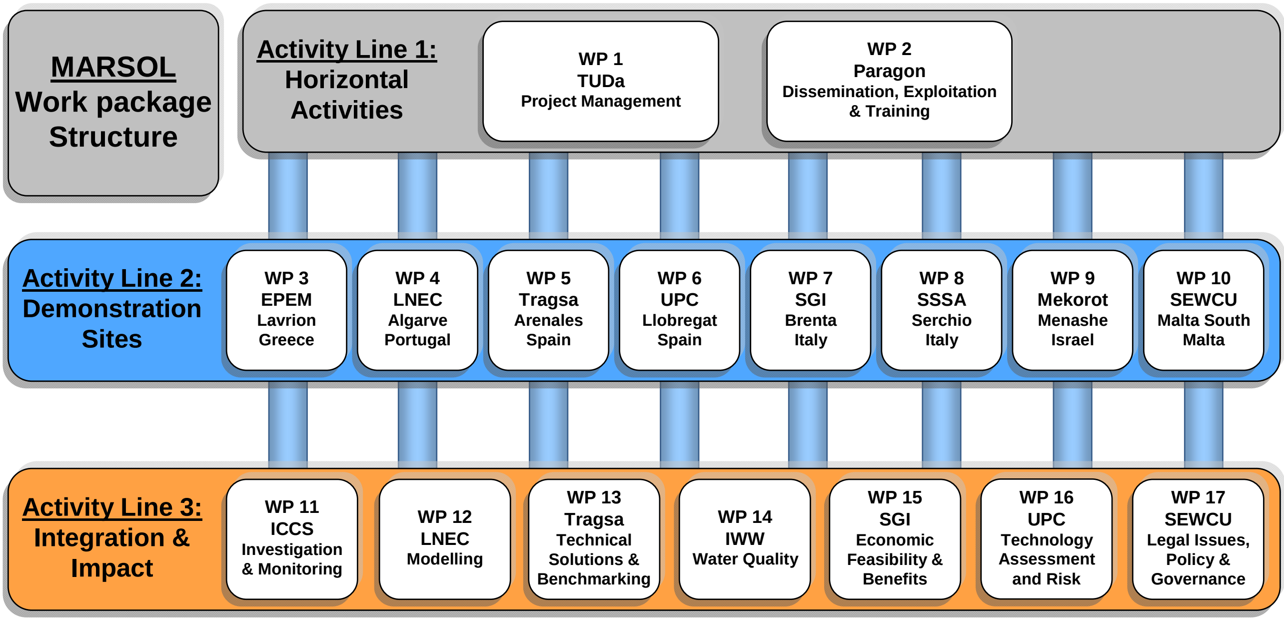

Fig. 1: Overall structure of the MARSOL project. Three activity lines organize the work packages that are arranged around the demonstration sites, the backbone of the project.

Fig. 2: Direct push activities for the characterization of the subsurface in the Lavrio catchment (left) and for the selection of the optimal location for the infiltration basin at the Lavrio Technological and Cultural Park (right).

Fig. 3: Training activities for students from TU Darmstadt, Germany (left) at the Lavrion Technological and Cultural Park, and for students from National Technical University Athens, Greece (right) in the Lavrion catchment.

Fig. 4: Prepared river bed at the Rio Seco to allow efficient infiltration of water (left), and response of groundwater levels below the river bed during a strong rain event in January 2016 (right).

Fig. 5: Old large-scale diameter well before (left) and after rehabilitation (right).

Fig. 6: Typical infiltration pond during a wetting phase (left) and typical channel for the diversion of water for MAR infiltration (right) in the Arenales region.

Fig. 7: 'Triplet' in the Santiuste basin to study water quality improvements for treated wastewater. Inflow of treated wastewater into the canal system (left), section with dense plant growth as a ‘green biofilter’ (middle), and constructed wetland (right).

Fig. 8: Construction of the infiltration pond at the Llobregat river in Barcelona (left), and set-up and composition of the reactive layer (right).

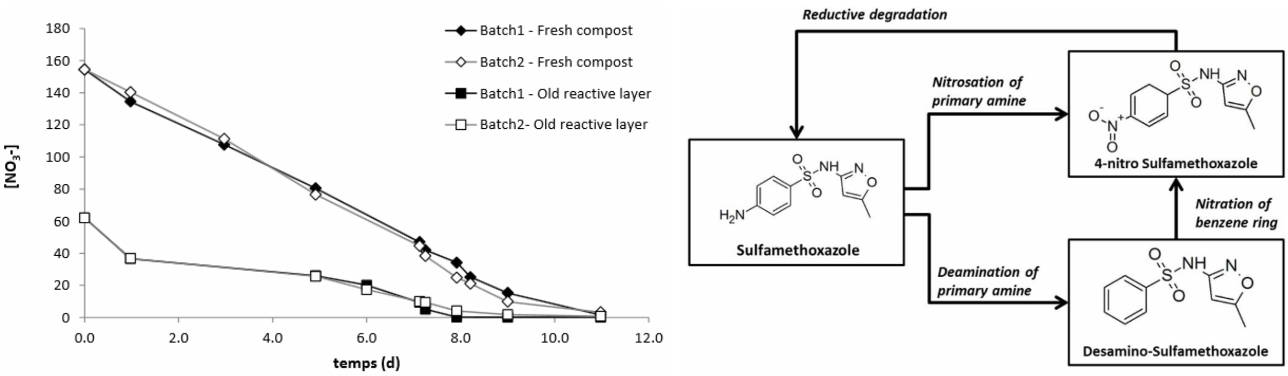

Fig. 9: Degradation of nitrate in laboratory experiments with fresh and aged compost (left), and degradation pathways for sulfamethoxazole under nitrate reducing conditions (right).

Fig. 10: The Schiavon Forested Infiltration Area (FIA, left), and the Loria retention basin (right).

Fig. 11: Installation of waveguides for the TDR system using direct push equipment (left), and connection of the waveguides to the TDR system that were housed in a box on-site for permanent data recording (right).

Fig. 12: Sant'Alessio well field at the Serchio River in Lucca, Tuscany (left), and Geoprobe activities for subsurface characterization of the aquifer (right).

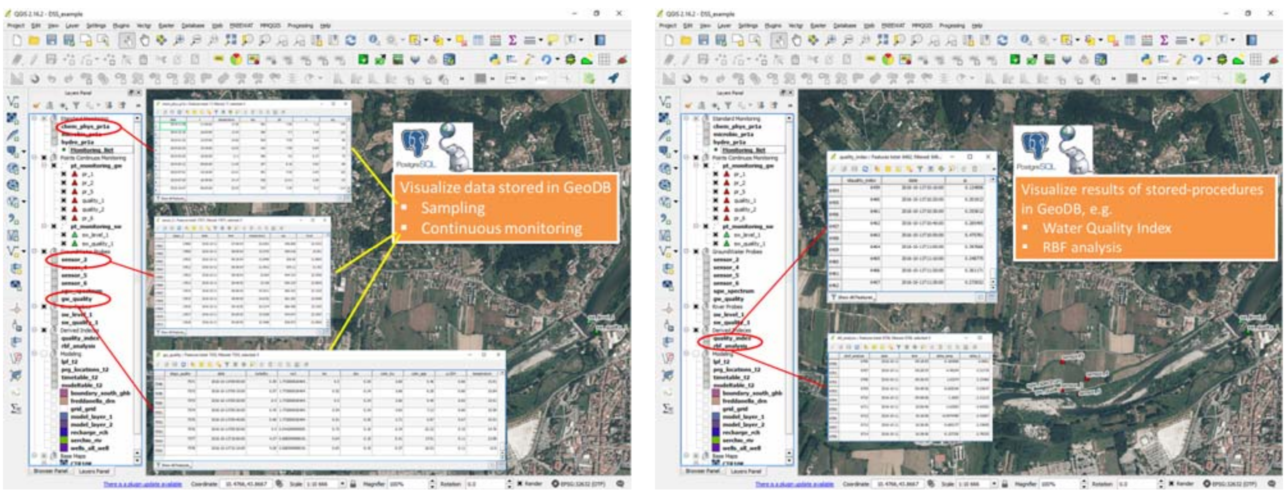

Fig. 13: Screenshots of the user interface of the developed Decision Support System (DSS). Control and visualization of measured parameters by connection with the GeoDB, where monitoring data are saved (left); and statistical analysis of time series, by applying the DataExplorer plugin (right).

Fig. 14: Location of the infiltration ponds of the Menashe field site with the infiltration pond for desalinated water (left), and filling of the pond with desalinated seawater for infiltration (right).

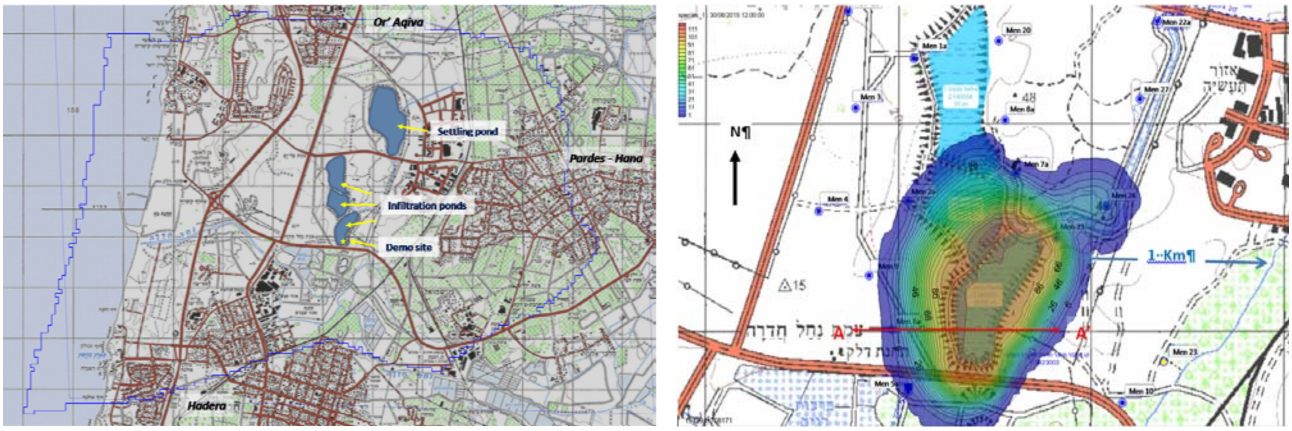

Fig. 15: Conservative regional groundwater flow model (left), and modelled percentage of desalinated water in groundwater at the demonstration site for the end of June 2016, considering 2.6 MCM and 1.3 MCM of desalinated water infiltrated at the pond during January 2015 and January 2016, respectively (right).

Fig. 16: Location of the Malta South wastewater treatment plant and implemented infiltration wells for the polished effluent (green) and up-gradient monitoring wells (yellow) for control of groundwater levels (left). Detail of the distribution network and infiltration gallery (right).

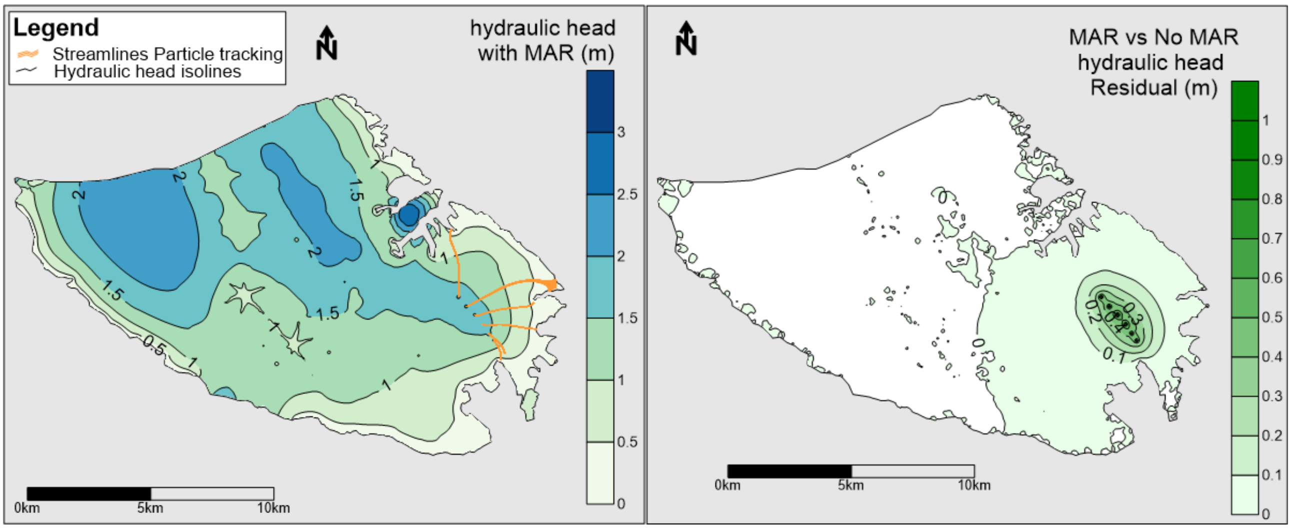

Fig. 17: Calculated hydraulic head isolines for the year of 2026 (10 years of MAR) and particle tracking showing the direction of flow of the injected water in the injection wells (left). Hydraulic head isolines residual between MAR scenario and business as usual (no MAR) for the year 2026 after 10 years of MAR (right).

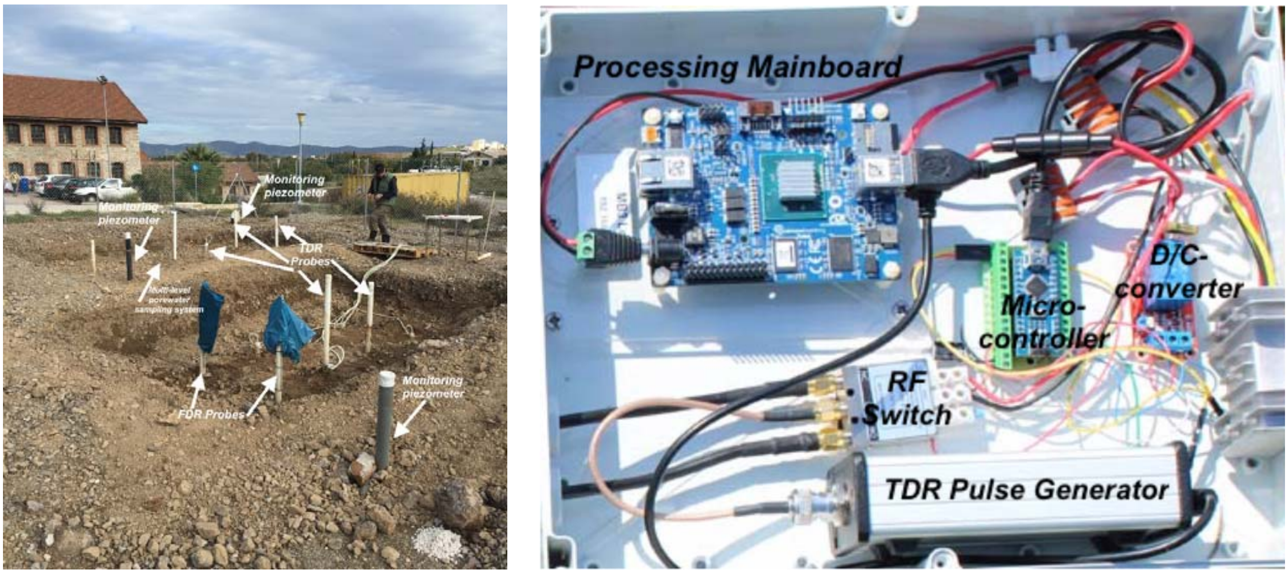

Fig. 18: Test site at Lavrion for development of monitoring equipment (left), and compact and low-cost time-domain-reflectometry system (TDR) for monitoring of soil moisture content, developed in Lavrion.

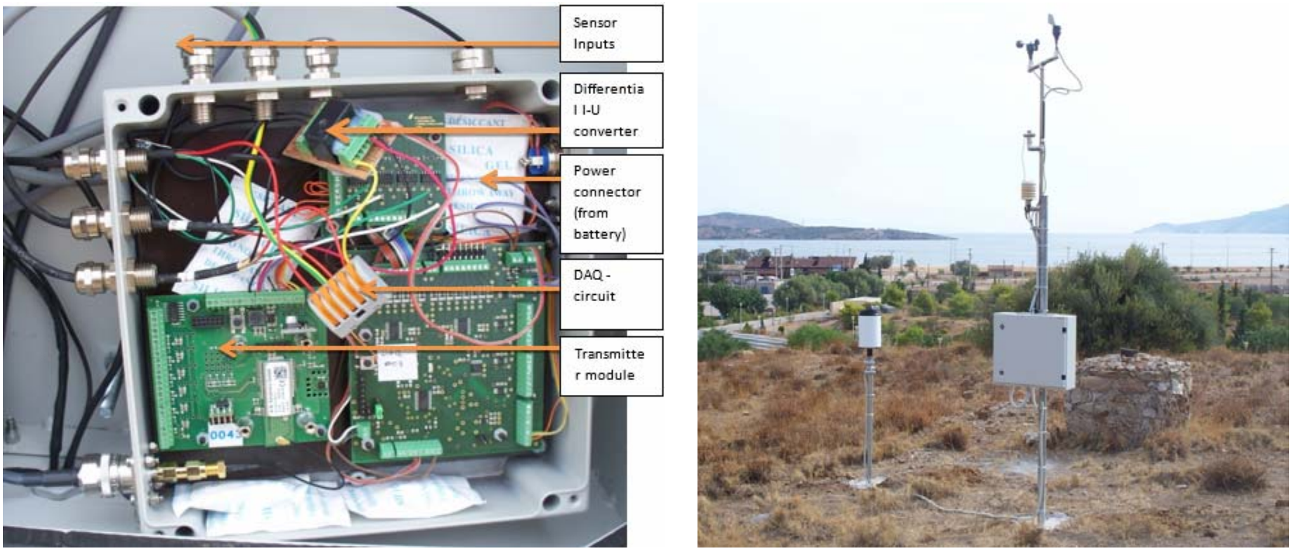

Fig. 19: Setup of the sensor network note (left), and implementation of a weather station with rain sensor and other meteorological sensors into wireless sensor network (right).

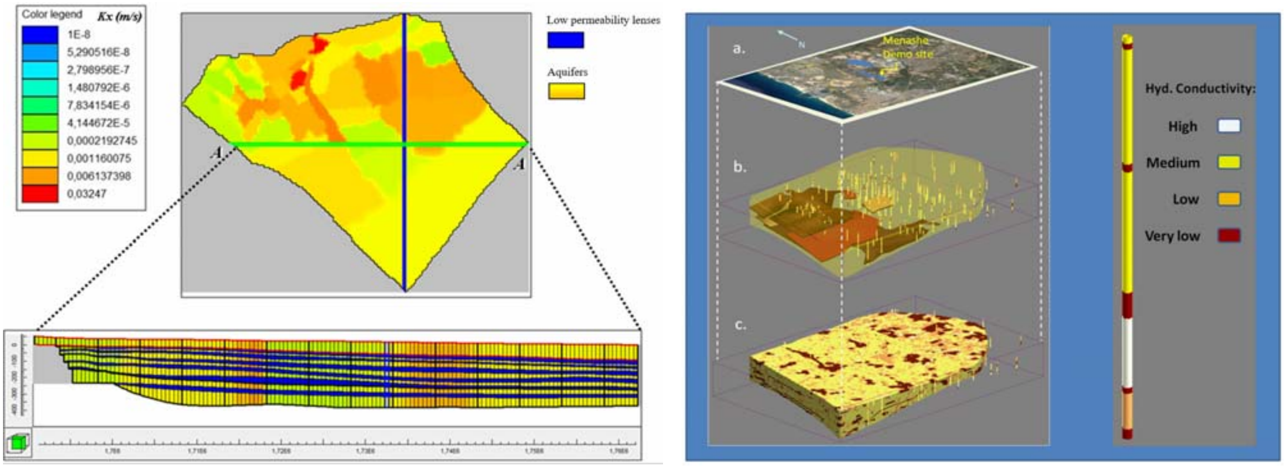

Fig. 20: Geo-structural model of the Venetian Central Basin with a single (undifferentiated) unconfined aquifer in the northern part of the domain and with seven (one unconfined and six confined) aquifers separated by six low-conductivity lenses of varying thickness in the southern part of the basin (left). Conceptual model structure of the Menashe region (right): the modelled area (a), the major marine clay lenses (b), and the combined deterministic and stochastic material array representing the aquifer (c).

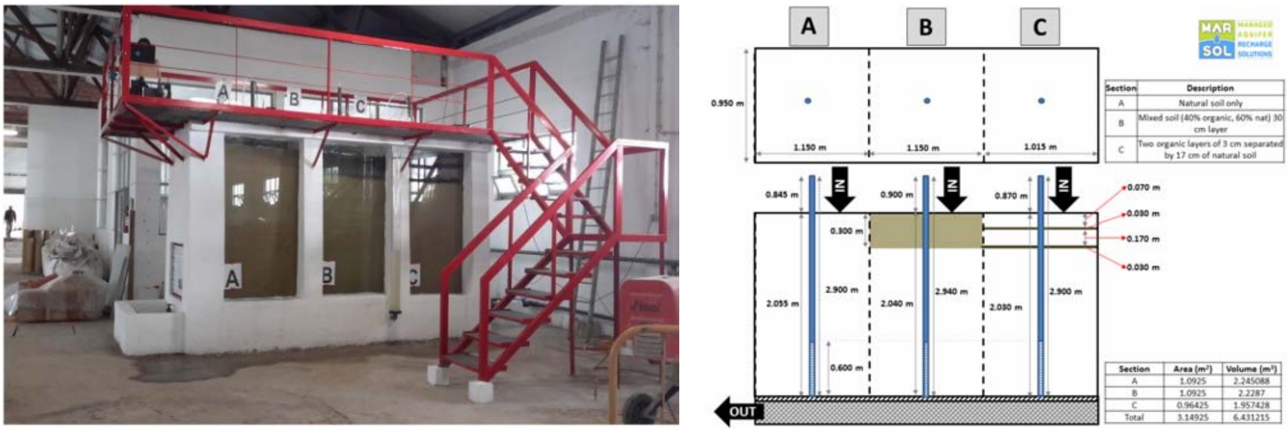

Fig. 21: Sandbox model to study infiltration under well-defined conditions to get high quality data (left), and schematics of the model with dimensions (right).

#	SYSTEM	MAR DEVICE	LOGO	FIGURE	PHOTO	LEGEND	1: Lavrion, Greece	2: Algarve and Alentejo, Portugal	3: Los Arenales, Spain	4: Llobregat River, Spain	5: River Brenta, Italy	6: Serchio River, Italy	7: Menashe, Israel	8: South Malta, Malta
1	DISPERSSION	INFILTRATION PONDS/ WETLANDS				Artificial wetland to recharge in Sanchón, Coca, Arenales aquifer		✓	✓	✓				
2	DISPERSSION	CHANNELS AND INFILTRATION DITCHES				Artificial recharge channel of the Basin of Santiuste, Segovia, Spain, operative since 2002.			✓					
3	DISPERSSION	RIDGES/ SOIL AND AQUIFER TREATMENT TECHNIQUES	SAT			Furrows at the bottom of a infiltration pond in Santiuste basin (Arenales)	✓	✓	✓	✓	✓			
4	DISPERSSION	INFILTRATION FIELDS (FLOOD AND CONTROLLED SPREADING)				Infiltration field in Carracillo, Arenales aquifer	✓		✓		✓			
5	DISPERSSION	ACCIDENTAL RECHARGE BY IRRIGATION RETURN				Artificial recharge by irrigation return. Extremadura, Spain. Photo: Tragsa		✓			✓			
6	DISPERSSION	BOFEDALES WETLANDS				Bofedales (Colombia)								
7	CHANNELS	RESERVOIR DAMS AND DAMS				Artificial recharge dam in Arenales. Segovia, Spain.			✓					
8	CHANNELS	PERMEABLE DAMS				Permeable dam in Huesca, Spain. Photo: Tragsatec.								
9	CHANNELS	LEVEES				Levees in Santa Ana river, Orange County, California, USA. Photo: A. Hutchinson.								
10	CHANNELS	RIVERBED SCARIFICATION				Scarification at Besós riverbed, Barcelona, Spain. Photo: J. Armenter.								

Fig. 22: Extract from the technical solution schemes that can be applied in MAR systems worldwide and that are partly applied at MARSOL demonstration sites. A total of 25 different designs were identified.

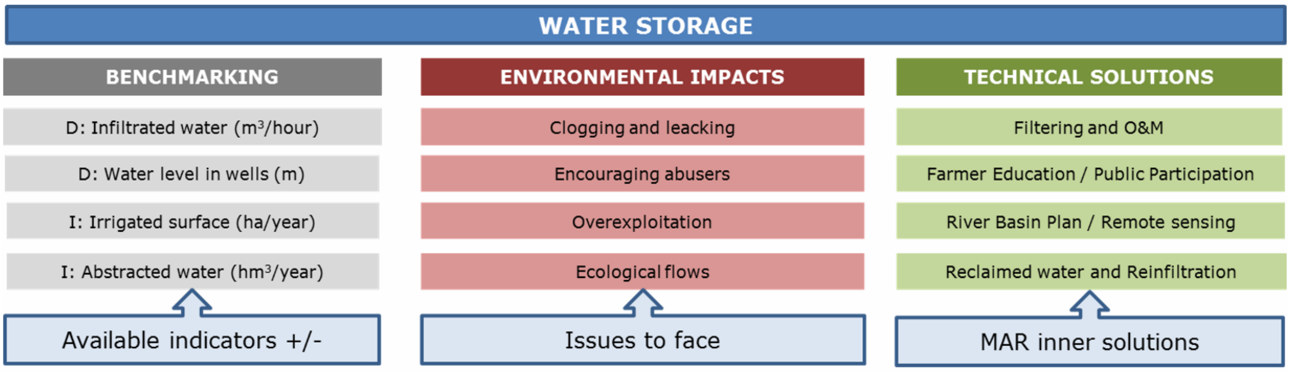

Fig. 23: Benchmarking factors of a MAR installation and associated environmental impacts and technical solutions that have to be considered.

	Treated waste water (municipal) [µg/L] Min	Max	Comparison Max	Surface water [µg/L] Min	Max
Pharmaceuticals					
Carbamazepine	0.0020	67.7150	>	0.0001	11.5612
Ciprofloxacin	0.0030	5.6920	<	0.0010	13.5670
Clarithromycin	0.0040	1.7270	<	0.0008	2.3300
Clofibric acid	0.0020	1.8000	<	0.0002	7.9100
Diclofenac	0.0017	97.0000	>	0.0002	18.7400
Erythromycin	0.0009	3.8470	>	0.0007	0.3625

Fig. 24: Pharmaceutical concentrations found in treated waste water and surface water in Europe based on a literature search.

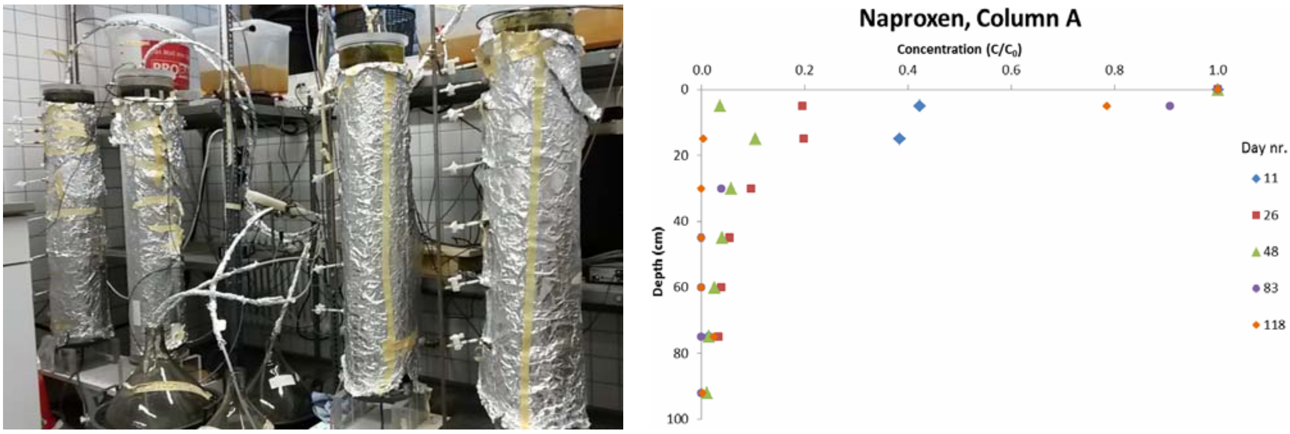

Fig. 25: Column experiments to analyse the fate of pharmaceuticals during the passage through soil. Experiments were performed with continuous infiltration and with drying-wetting phases (left). Exemplary results of the column experiments (right), showing the profiles of naproxen concentrations in the water phase after 11 to 118 days of percolation. Decrease of naproxen concentrations is due to a combination of sorption and degradation processes.

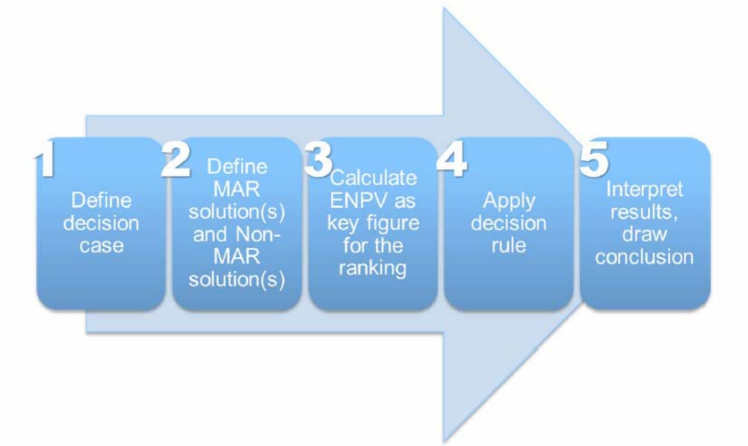

Fig. 26: MAR economic evaluation framework.

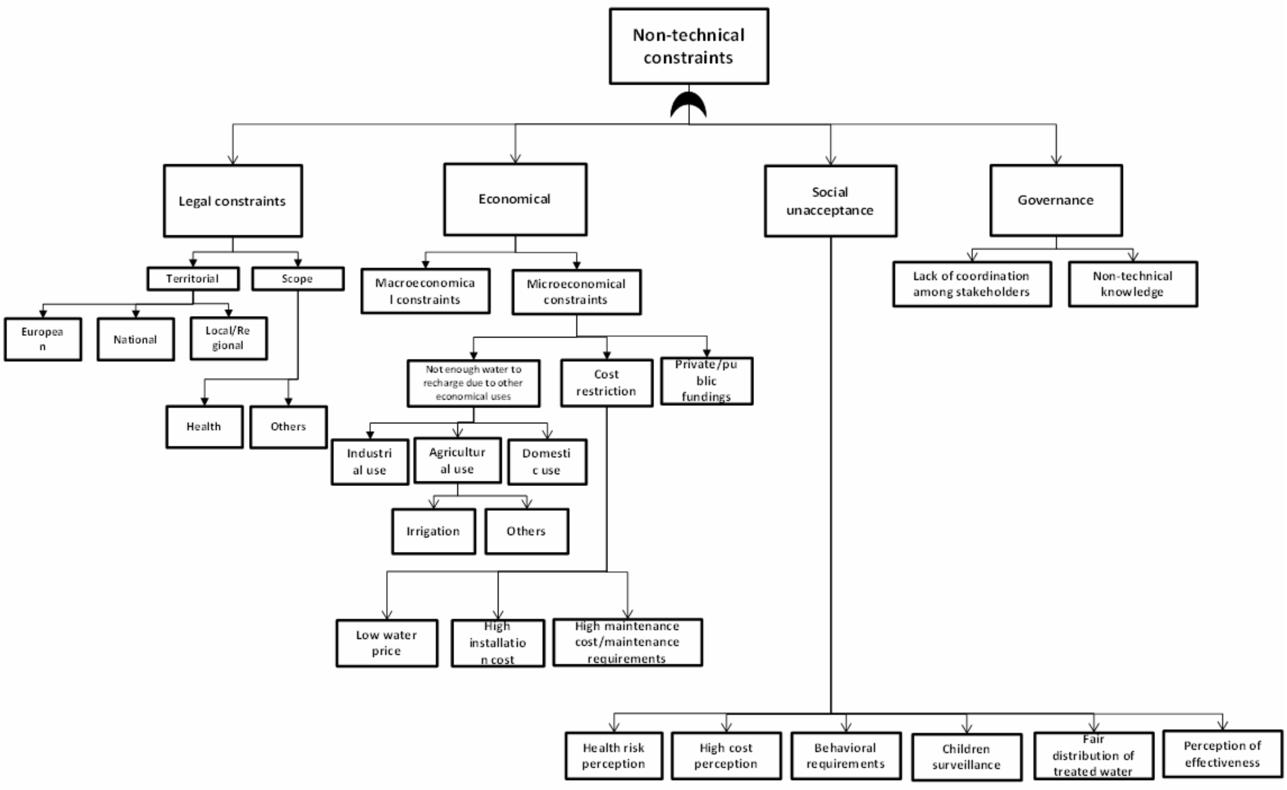

Fig. 27: Fault tree for non-technical constraints - a full overview of all non-technical points to be considered as potential hazards for failure of a MAR facility.

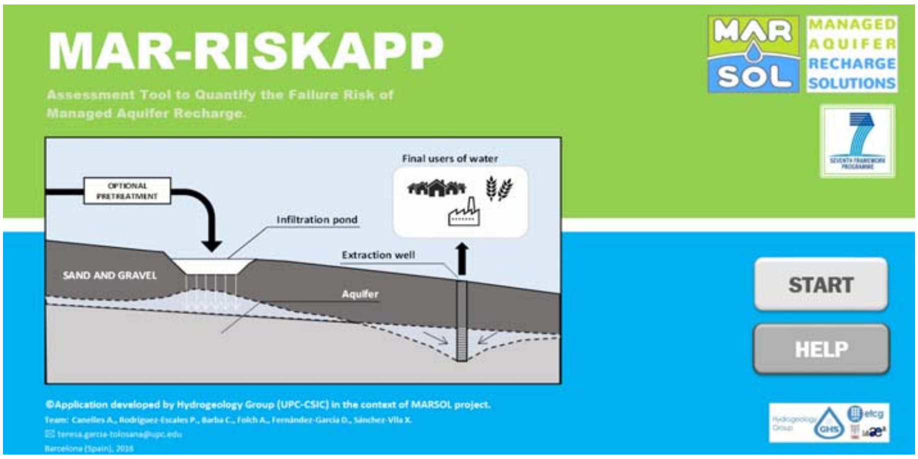

Fig. 28: Screenshot of the risk assessment tool with an easy-to-use interface, customizable to various sites.

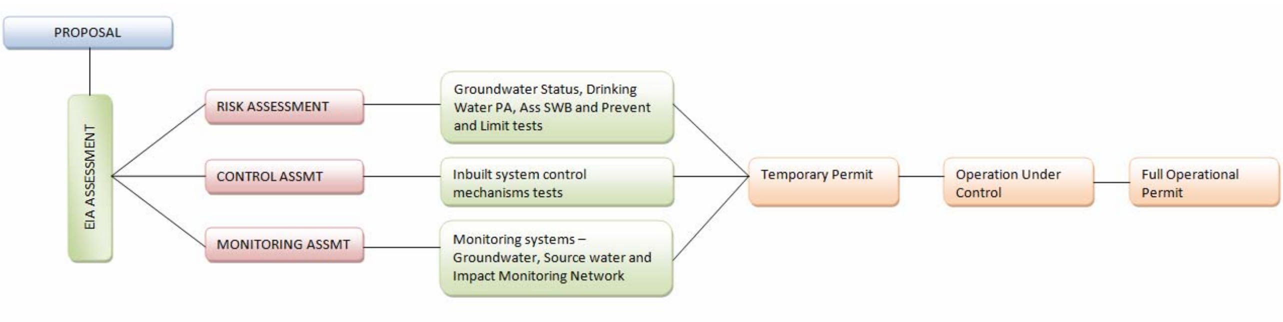

Fig. 29: Proposed regulatory scheme for the implementation of a MAR scheme.

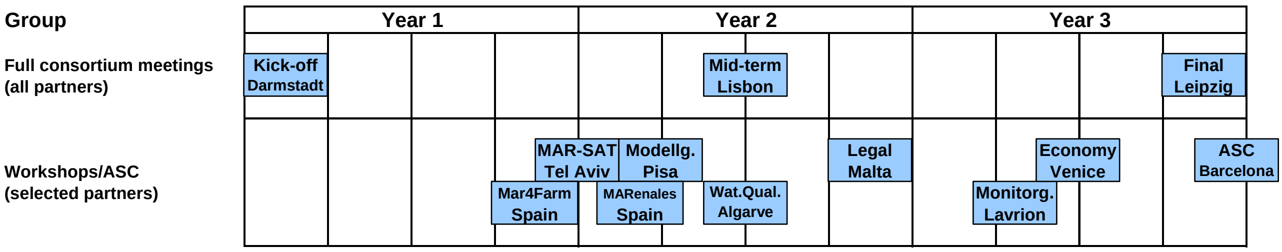

Fig. 30: Overview of realized meetings and workshop schedule.