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Project deliverables

Deliverable #D3.3

Set of Regional Draft Agreements tailored to the project case studies

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AGREEMAR

Adaptive agreements on benefits sharing for managed aquifer recharge in the Mediterranean region

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Set of Regional Draft Agreements tailored to the project case studies

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Executive summary

Deliverable D3.3 covers the technical assessments, stakeholder engagement, regulatory framework analysis, and the elaboration of guidelines for managed aquifer recharge (MAR) agreements implementation tailored to each case study of the AGREEMAR project in Spain, Portugal, Tunisia, and Cyprus. These components are considered as essential for the MAR agreements and provide instructions on how to implement them. They will be further refined and discussed at a local scale to generate local MAR agreements in the framework of Work Package 5 (WP5).

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Abstract

This report is the output of the work done to develop specific MAR agreements for the AGREEMAR project case studies in Spain, Portugal, Tunisia, and Cyprus. It covers technical assessment, stakeholder engagement, regulatory framework, and elaboration of guidelines for implementation of MAR agreements. It identifies what can be considered as essential components of the MAR agreements for each case study and provides instructions on how to implement them. These components will be included and discussed at a local scale to generate local MAR agreements in the framework of WP5. In the Spanish case, the emphasis was placed on exploiting induced MAR techniques to reduce groundwater pumping and prevent seawater intrusion. The Portuguese case study identified potential MAR sites and assessed their technical viability, emphasizing the importance of stakeholder involvement. The Tunisian case study tackled the challenges of water scarcity and overexploitation of aquifers, exploring the feasibility of using treated wastewater for MAR. The Cypriot case study assessed the technical feasibility and regulatory support required for successful MAR implementation. The results show that a participatory and organized approach with the involvement of stakeholders is needed for MAR agreements to be accepted. Technical assessments provided critical information on the feasibility and optimization of sites, while the analysis of the regulatory framework ensured compliance with national and regional policy.

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1. Introduction

The AGREEMAR project presents an integrated, participatory and coordinated methodology for assessing and managing aquifer recharge solutions for climate change adaptation. Aligned with the principles of integrated water resources management in the Mediterranean basin, AGREEMAR seeks to address the problems and challenges facing aquifer recharge. It aims to provide an improved governance structure, adapted to existing regional policy and decision-making structures.

Agreements can be potential instruments for boosting the implementation of managed aquifer recharge (MAR) projects and supporting water governance. They may contribute to the establishment of structured relationships between the various stakeholders and define their roles and responsibilities. It is important that stakeholders get involved in the process of shaping the agreements, to reflect different interests and priorities. In this way, stakeholders can be effectively coordinated, and sustainable water management practices can be promoted. A regional agreement is a written agreement to identify the roles and responsibilities of stakeholders and to provide a systematic basis for MAR implementation at a regional level. It spells out the common understandings on aquifer recharge and it clarifies what type of elements need to be considered and what kind of support can be provided to facilitate MAR implementation. Provisions for regional agreements serve to ensure that the relevant regional stakeholders approve the MAR initiative while provisions for local agreements serve to ensure that implementation is successful and sustainable. One of the crucial non-technical capacities for the development of these agreements is the need for the availability and willingness of all stakeholders to reach an agreement.

Based on all the project's activities and interactions with regional and local stakeholders, as will be illustrated later in the case study descriptions in this deliverable, it becomes clear that it is unrealistic to expect the AGREEMAR project to produce agreements that will be signed by regional or local stakeholders during the project period. Stakeholders have shown their interest in the project and its results, but in the context of AGREEMAR, they are not in a possible position to sign agreements, as this will depend on several other factors, such as the national, regional and/or local legislation of each case study. It is therefore convenient to consider that this project will produce proportional guidelines for agreements and that these are general guidelines that can be valid at general, regional and local levels, facilitating the implementation of agreements.

This report describes what can be considered essential components of MAR agreements for each case study, and provides guidance on their implementation. These components will be incorporated at a specific scale and level of detail for each case study.

2. The Spanish case study located in the Júcar River Basin District

In Spain, there is a water planning and management system that seeks the reliable supply of water in sufficient quantity and quality to efficiently develop society and its economy while offering high levels of security by minimizing the risk of system failure. Water governance system in Spain serves as an example of adaptability to the environment through a governance system based on planning, public participation, technological development, and innovation. In the context of climate change, the country establishes guidelines and measures to consider in water planning and management through the Law 7/2021 of May 20, which outlines strategic orientations on water and climate change (MITERD, 2022). The "Libro Verde de la Gobernanza del Agua" (Green book on Water Governance in Spain) also stands as a significant precedent for improvement in collaboration with institutional actors and stakeholders (Gobierno de España, 2020).

As a member of the European Union, Spain adheres to the Water Framework Directive, thereby strengthening its sustainable management of water resources and pursuing the good status of water bodies and basins. Furthermore, water is regarded as a public good, highlighting its crucial importance for the well-being of Spanish society.

In Spain, the planning and management of water resources is coordinated by river basin agencies. They are inclusive entities bringing together representatives from all relevant actors, including national and local authorities and stakeholders. The organizational chart of the river basin agency in Spain illustrates this complex but collaborative structure, where water planning, monitoring and regulation are conducted transparently and participatively.

To promote integrated and local management, allowing for adaptation to the specific characteristics of each region, the role of each river basin agency includes preparing, monitoring, and revising the basin hydrological plan, as well as administering and controlling the water public domain, uses of general interest, or affecting more than one autonomous community, and the construction and operation of facilities carried out with the agency's own funds and those entrusted to it by the state.

What we refer to as regional agreements in the AGREEMAR project represent the elements included in the river basin management plans. These regional agreements cover all provisions or necessary aspects of effective water management, including artificial recharge initiatives. They serve as a comprehensive framework for coordinating actions at the regional level, ensuring a consistent and coordinated approach to water resource planning and management. From these regional agreements, specific agreements are developed, often referred to as local agreements, focusing on more detailed and operational aspects of water management. These specific agreements define the roles and responsibilities of stakeholders at the local level, particularly regarding operation and financing.

The approach for crafting these agreements for MAR aligns with the principles outlined in Deliverable D3.2 (Ghannem et al., 2024), emphasizing a comprehensive governance framework for MAR. It considers four dimensions: technical, social, economic, and regulatory, to ensure that agreements align with the key elements influencing MAR success.

Initially, a preliminary assessment is carried out, including an in-depth analysis of MAR conditions in the region, such as hydrogeological characteristics, environmental considerations, assessment of water demands, etc. Subsequently, potential MAR sites are identified along with their suitability in terms of the MAR methods employed. Once it has been confirmed that a site is suitable for MAR implementation, a technical assessment follows, using various numerical models to optimize MAR deployment and assess potential impacts on water resources. At the same time, stakeholders and their relationships will be identified to foster their involvement in the MAR process, ensuring inclusive and transparent decision-making processes. Finally, regulatory compliance is addressed to ensure compliance with national and European regulations governing MAR, water management and environmental protection. The outcome of these milestones will be a regional agreement defining the conditions and responsibilities for MAR implementation and governance.

2.1 Preliminary assessment

The Júcar River Basin District, managed by the Júcar River Basin Agency, is geographically located in the central-eastern part of the Iberian Peninsula. The total area of the delineated territory is 42,735 km^2. From a physiographic perspective, it consists of an interior mountainous area with higher altitude points and a coastal area, comprised of plains commonly known as "Planas" among which are the Oropesa-Torreblanca, Castellón-Sagunto, Valencia-La Ribera, and Favara-Gandía-Denia plains. The territorial distribution of the Júcar River Basin Agency (CHJ) extends across five regions: the Valencian Community, the Castilla-La Mancha Community, Aragon, Catalonia and Murcia.

The Júcar Water District is located in a region of fractured Mesozoic coverage during the Alpine orogenesis and covered with Neogene materials. The different existing lithologies condition the hydrodynamic behavior and hydrological responses of the flows generated by precipitation. Figure 1 presents the different existing lithologies grouped according to the lithological type based on their nature and hydrodynamic behavior.

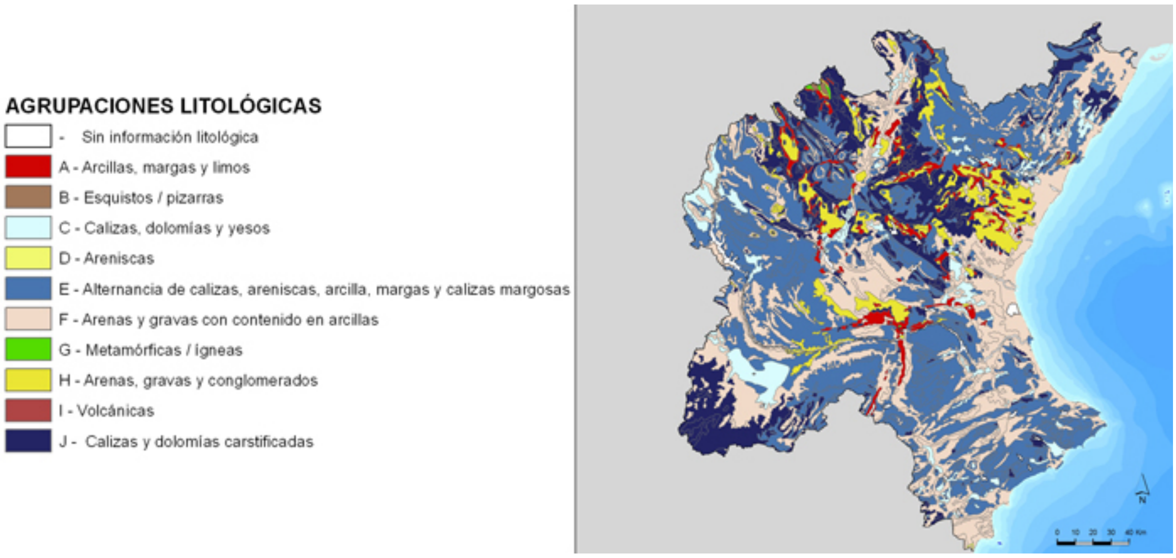


Figure 1 Lithological clusters within the Júcar River Basin (CHJ,2011).

The climate in the Júcar Water District is a typical Mediterranean climate with hot summers and mild winters. Maximum temperatures are recorded in July and August, coinciding with the dry season. Annual average temperatures range between 14 ºC and 16.5 ºC. Total annual precipitation is approximately 500 mm, as an average of values from the recorded series in the existing network of rain gauges with data since 1940, ranging from maximum annual values of 780 mm in the wettest years to just over 300 mm in the driest years. Over the past decade, the series average has slightly decreased to reach 487 mm (CHJ, 2022b).

The contribution of groundwater is fundamental to the management of inland resources in the territory of the Júcar River Basin Agency. Given the predominance of highly permeable geological formations on the surface, the infiltration of surface water from precipitation into underground layers is very important, so that aquifers act as natural water reserves, promoting the joint management of surface and groundwater resources, depending on availability and environmental aspects at any given time (CHJ, 2022a).

The sector that contributes the most to gross value added of the Júcar River Basin is the service sector, particularly tourism activity. Industry is the second most important sector, followed almost equally by the agriculture and energy sectors. However, agriculture is the economic activity that occupies nearly half of the territorial extent of the Júcar River Basin Agency, which has an irrigated area representative of the current situation of about 390,000 ha. This area is mainly concentrated in the Plana de Castellón, Valencia and the lower Turia Basin, the Mancha Oriental, the Ribera, and the lower Júcar Basin, as well as the irrigated lands of the Vinalopó and Monnegre valleys. In this irrigated area, structured into 98 agricultural demand units, the total consumption demand of the Júcar River Basin is 3,112.79 hm^3/year, the main demand being agricultural, with 2,482 hm^3/year, which represents almost 80% of total demand (CHJ, 2022b).

Preliminary indications on the MAR feasibility in Spain were already available before the AGREEMAR project. During the national conference held in Madrid in 2022 on aquifer recharge management in Spain, representatives of aquifer recharge in Spain, as well as actors from different river basin areas, convened to discuss the current state of artificial aquifer recharge. At the regional level, the Júcar River Basin Agency and the UPV identified key issues within its territory, including seawater intrusion, declining groundwater levels, intensive groundwater exploitation for irrigation, low water supply reliability during droughts, and shifts in the river-aquifer relationship.

An analysis of the entire Júcar Water District through previous studies demonstrating the feasibility of MAR, along with the presence of existing infrastructure and social potential for its application, led to the identification of two key areas for the development of MAR agreements. These areas include the Belcaire River by Vall d'Uixó, located in the Mijares river basin, and the Algar Reservoir area, located in the Palancia River Basin. This choice is based on technical and social considerations, as these two areas already have adequate structures for MAR implementation (two MAR techniques: infiltration wells and surface infiltration dam, as well as a variety of stakeholders interested in it. Furthermore, these two areas have addressed key questions regarding the necessity and feasibility of MAR, including water availability, demand for irrigation and other uses, as well as the potential presence of issues such as seawater intrusion or declining groundwater levels. Feasibility mapping, which was developed later during the project, confirmed the suitability for MAR in these two study areas.

In the Spanish context of water resources management, it is crucial to assess the potential effects of each technique, strategy, or decision on both the environment and the rest of water uses of the basin. The implementation of MAR can have repercussions on various aspects, such as drinking water supply, agriculture, industry, and the health of aquatic ecosystems. Therefore, a thorough analysis is necessary to understand how MAR can interact with these uses and influence water availability and quality in the river basin. MAR, particularly in Mediterranean countries like Spain, involves the management of both surface and groundwater resources, involving both direct and indirect methods. In the case of Spain, it is advantageous to rely on conjunctive use of water to maximize efficiency and resilience in water management practices. Hence, the justification for using Decision Support Systems (e.g., AQUATOOL), which serve as tools to evaluate the potential impacts of MAR on water uses and environmental issues in the river basins. AQUATOOL was developed by the Technical University of Valencia (UPV) (Andreu et al., 1996) and includes tools to specifically address the conjunctive management of surface and groundwater resources. It serves as an essential starting point for the preliminary analysis of MAR effects. This helps anticipate potential interactions between MAR and other water uses in the river basins, providing a framework for integrated planning and informed decision-making. As a result, it establishes common ground for negotiating agreements with relevant stakeholders, as it helps them better understand the benefits and challenges associated with MAR and how they will benefit from it. This allows facilitating the implementation of MAR agreements while ensuring the sustainability of other sectors using water resources.

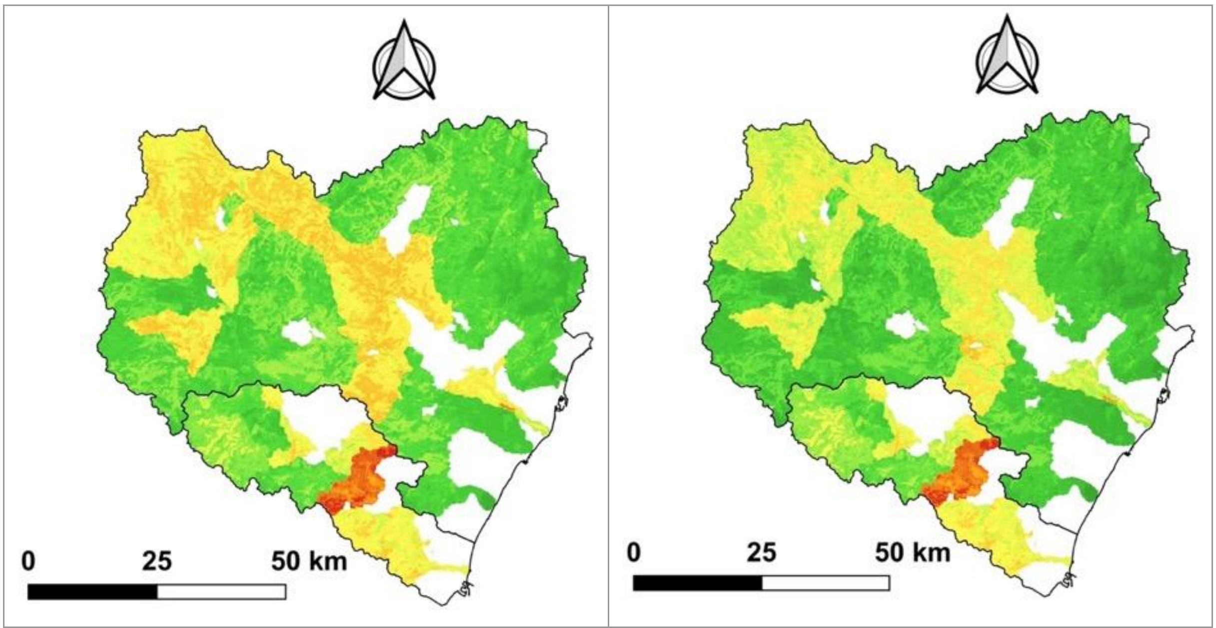
2.2 Identification of potential MAR sites

As outlined in Deliverable D2.3 (Chekirbane et al., 2023), two feasibility maps for MAR within the Júcar Water District have been established. These maps were developed following workshops and consultations to assess stakeholders' needs and provisions concerning the fundamental objectives of MAR. The main objective of MAR in both Spanish regions revolves around reducing aquifer overexploitation, which leads to water table drawdown and seawater intrusion. This includes groundwater level restoration, addressing overdraft replacement, and mitigating saltwater intrusion. To achieve these goals, the utilization of infiltration wells, ponds, and reservoirs, and appropriate management of conventional water sources has been considered.

The approach to establishing these maps is participatory and divided into two phases. The first phase involves criteria selection and weighting coefficients based on experts, incorporating the technical aspect of the approach by considering input from MAR experts. For example, assembling the non-physical categories based on MAR objectives, evaluating the relevance of non-physical categories based on integrated water resources management (IWRM) principles and selected non-physical categories, and determining weighting coefficients for all physical categories. The second phase represents a stakeholder-based selection processes, ensuring direct stakeholder involvement in map elaboration. This was facilitated through various meetings and discussions with stakeholders from the chosen sites, Belcaire pond and Algar reservoir, contributing to surveys regarding physical criteria preselection and their weighting (Panagiotou et al., 2022; Martins et al., 2022).

Stakeholders contributing to this task mainly include the Júcar River Basin Authority (CHJ) and other institutions directly or indirectly related to the selected sites: Territorial Unit of the Spanish Geological and Mining Institute (IGME), National Enterprise for General Interest Water Developments (Acuamed), General Community of Irrigators of Vall d'Uixó, Community of irrigators of the Acequia Mayor of Sagunto, Moncofar Irrigation Cooperative, etc. Together with the AGREEMAR team in Spain, criteria for studying site feasibility were selected. The approach for the Spanish case studies is detailed in Deliverable D2.3 (Chekirbane et al., 2023). Three MAR suitability maps were produced, covering intrinsic suitability, water availability, and water demand, validated by stakeholders. The final step was creating feasibility maps, which are available in Deliverable D2.3 (Chekirbane et al., 2023) and are shown in Figure 2.

These feasibility maps highlight similarities for both MAR objectives for the Spanish case studies. Objective 1 focuses on restoring groundwater level and overdraft replacement, while Objective 2 focuses on establishing barriers to prevent saltwater intrusion. The Belcaire pond area scores highly in terms of feasibility, indicating strong potential for the implementation of MAR. In contrast, the Algar reservoir region presents a moderate feasibility, suggesting challenges that need to be overcome for MAR activities to be successful. Nevertheless, the overall assessment confirms the feasibility of MAR initiatives in both regions.



S1	S2

- Constraint areas (0)
- Very low feasibility (0 – 0.2)
- Low feasibility (0.2 – 0.4)
- Moderate feasibility (0.4 – 0.6)
- High feasibility (0.6 – 0.8)
- Very high feasibility (0.8 – 1)

Figure 2 MAR feasibility maps of the demo regions in Spain (Chekirbane et al., 2023).

2.3 Technical assessments based on numerical modelling

The technical evaluation of the selected MAR sites serves primarily to analyze their effects on the other water uses of the basin and on the evolution of the aquifers. In order to cover these two objectives at the Spanish case studies, water resources management models were developed with the AQUATOOL DSS. These models allow for the evaluation of various scenarios presenting different MAR approaches or different strategies of conjunctive use of surface water, groundwater and non-conventional water resources. The use of AQUATOOL models in Spain is helpful to support and get national and regional stakeholders' approval for the development of MAR projects.

The models developed for the Belcaire pond and Algar reservoir areas provide a basis for assessing the impact of MAR on different water uses within the river basin (Figure 3 and Figure 4). Aquifer dynamics, surface and groundwater interactions, and environmental factors are considered throughout the different scenarios simulated. The management strategies simulated and evaluated as part of the AGREEMAR project are subject to prior review through public consultation discussion in the framework of the Management Plan of the Júcar Water District for the period 2022-2027 and stakeholder engagement processes.

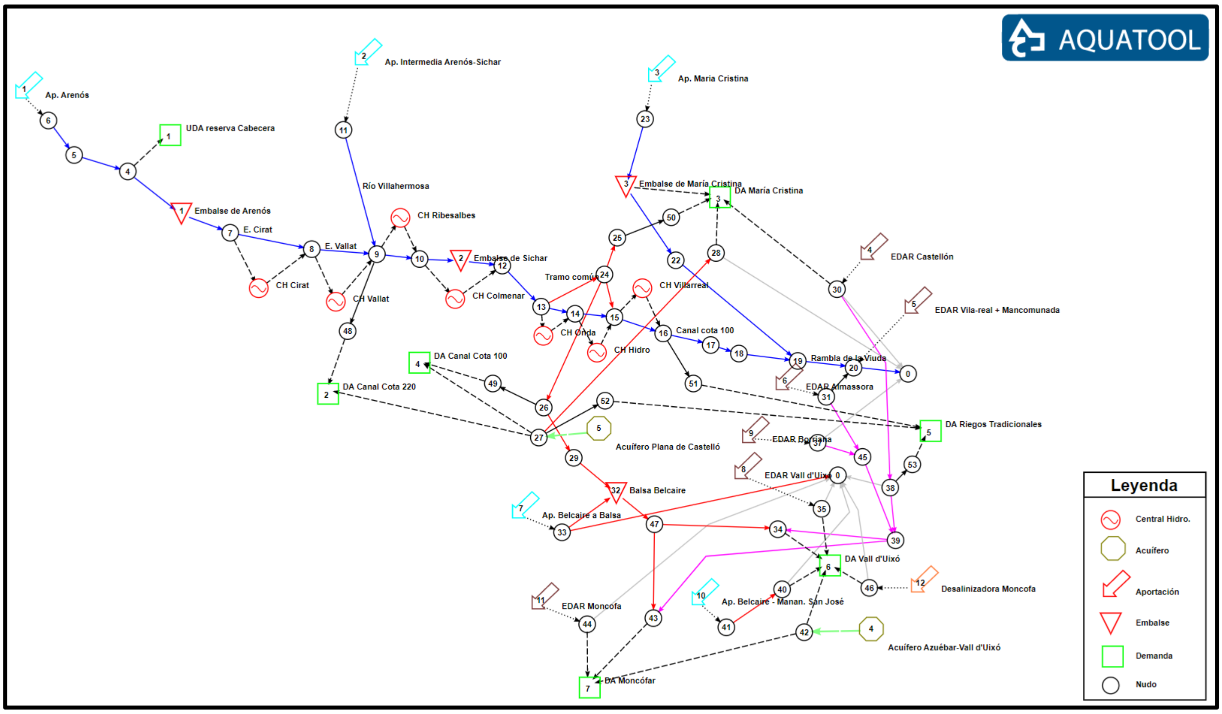


Figure 3 Topology of the AQUATOOL model of the Mijares river basin.

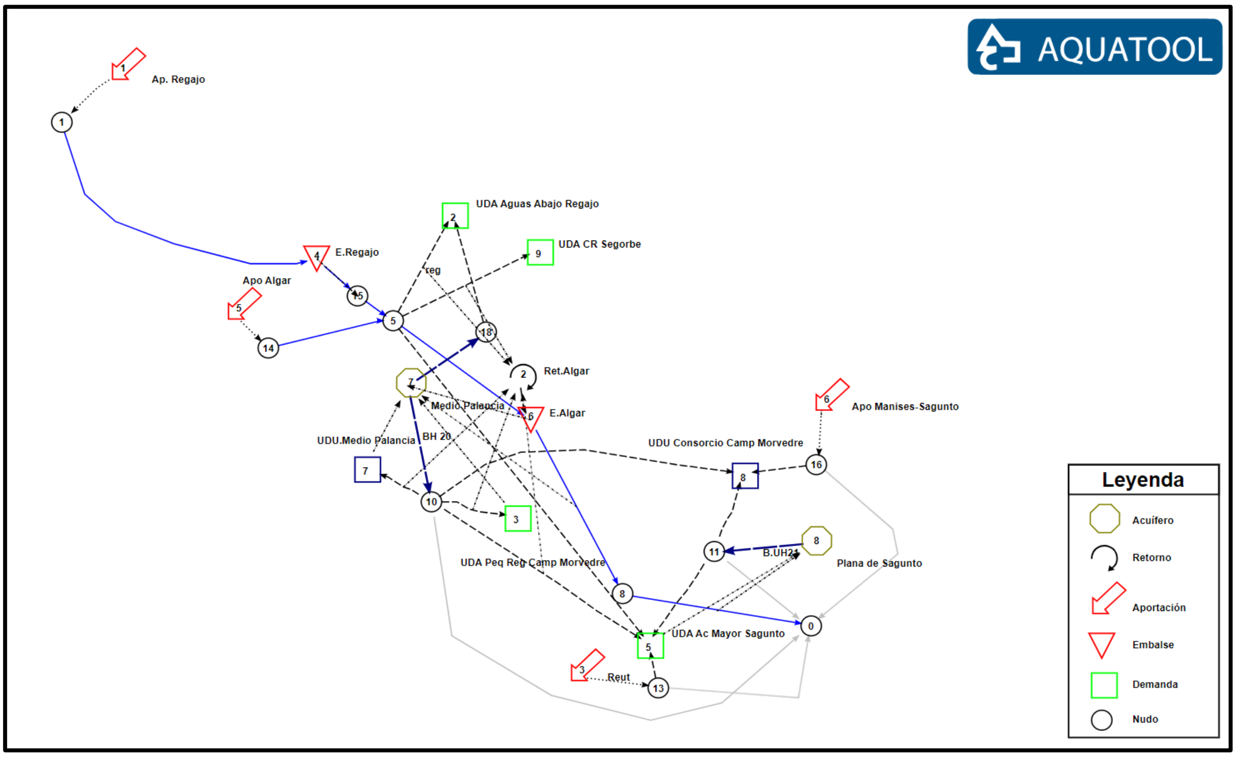


Figure 4 Topology of the AQUATOOL model of the Palancia river basin.

The analysis carried out in the Belcaire pond and Algar reservoir regions involved the simulation of several management scenarios to assess the effectiveness of different measures for improving aquifer sustainability and meeting water demand. For the de Belcaire region in the Mijares river basin, four management scenarios were analyzed, including the effects of the wastewater treatment plant (WWTP), contributions from desalination plants, Belcaire pond regulation and supply from María Cristina reservoir. Each scenario was designed in consultation with stakeholders to ensure a comprehensive evaluation and consideration of diverse viewpoints. Similarly, in the Palancia river basin, which covers the Algar reservoir area, three scenarios were assessed, including the impact of spring inflows, the effects of the WWTPs and inflows from desalination plants.

The evaluation of the different scenarios reveals their effectiveness in reducing aquifer pumping and improving water demand reliability. By incorporating unconventional water resources through induced MAR, the simulations demonstrate significant potential for improving the quantitative and qualitative status of aquifers, thereby enhancing sustainability and resilience of aquifers to future droughts.

MAR techniques not only contribute to the recovery of aquifers, but also reduce the energy costs associated with groundwater extraction, while improving water supply to meet demand. The assessment highlights the importance of the joint use of surface water, groundwater and non-conventional water resources, to optimize the planning and management of water resources.

For the Spanish case study, the results suggest that induced MAR techniques can play a vital role in preparing aquifers for future challenges, ensuring sustainable water management practices in Spain and other similar Mediterranean regions. Through predictive modelling tools and stakeholder engagement, informed decisions can be made to effectively address water resource challenges, contributing to long-term water security and resilience.

More details on model results about the effects of MAR on the evolution of aquifers and its impacts on other water uses in the Spanish case studies are provided in Deliverable D4.1 of the AGREEMAR project. These results are based on the joint implementation and application of the water allocation models and the aquifer models of the AQUATOOL DSS, which have been performed in the framework of WP3 (adaptive governance framework) and WP4 (validation through numerical modelling).

2.4 Identification of stakeholders and their relationships

As mentioned in Deliverable D3.2 (Ghannem et al., 2024), identifying stakeholders and their relationships requires recognition of the cultural and social complexities of the region. The purpose is to understand the stakeholders identified as relevant for MAR in terms of their interests, needs, and influence on MAR implementation. In Spain, activities are focused on the Júcar Water District. A stakeholder map was created, dividing them into three groups: general, regional, and local actors. Each stakeholder is grouped into societal sectors based on the nature of stakeholders: policy/decision-makers, practitioners/civil, or science.

Specific stakeholders identified include: The Spanish General Directorate for Water (Ministry for the Ecological Transition and the Demographic Challenge), the Júcar River Basin Agency (CHJ), the Water General Directorate of Valencia Region, Alicante Provincial Council, ACUAMED, EPSAR, IGME, Institute of Water and Environmental Engineering of the Universitat Politècnica de València, Institute of Water and Environmental Sciences of the University of Alicante, Department of Agrochemistry and Environment of the University Miguel Hernández Elche, Remote Sensing & GIS Group of the Regional Development Institute of Universidad de Castilla-La Mancha, Centre for Hydrographic Studies of CEDEX, Irrigation Associations (e.g., JCR Mancha Oriental, Acequia Real del Júcar, Canal Júcar-Turia, Real Acequia de Moncada, Tribunal de las Aguas), FENACORE, Spain AEAS, Water boards of the cities and towns, and national, regional and local NGOs (e.g., WWF, Fundación Nueva Cultura del Agua, Xúquer Viu, Acció Ecologista-AGRÓ). For each stakeholder, their roles and competencies in MAR, needs related to MAR outcomes, the stakeholder group, scale, and thematic mapping of stakeholders were identified (more details can be found in Deliverable D1.1a (Conrad et al., 2022a).

After identifying and ranking the relevant stakeholders, consultations were conducted based on specific engagement objectives to identify entities interested or affected by MAR in the region. Institutional and political consultations are conducted to define who is responsible for decisions that may affect MAR and who might be affected by MAR or interested in it. As mentioned in Deliverable D1.1 (Conrad et al., 2022b), stakeholder analysis criteria include a general classification, level of influence, interest, and engagement strategy.

Therefore, stakeholders are classified into 4 categories based on their influence and interest, including stakeholders to involve, collaborate with, inform, and consult. Engagement formats for each stakeholder category were described in Deliverable D1.1 (Conrad et al., 2022b). In Spain, the Ministry for the Ecological Transition and the Demographic Challenge is responsible for water management at the national level, under the General Directorate of Water (DGA) of the State Secretariat for the Environment. The DGA approves the

River Basin Management Plan (RBMP) prepared by regional water basin authorities. At the local level, municipalities are responsible for water supply and wastewater treatment, water pricing, and urban planning activities related to water.

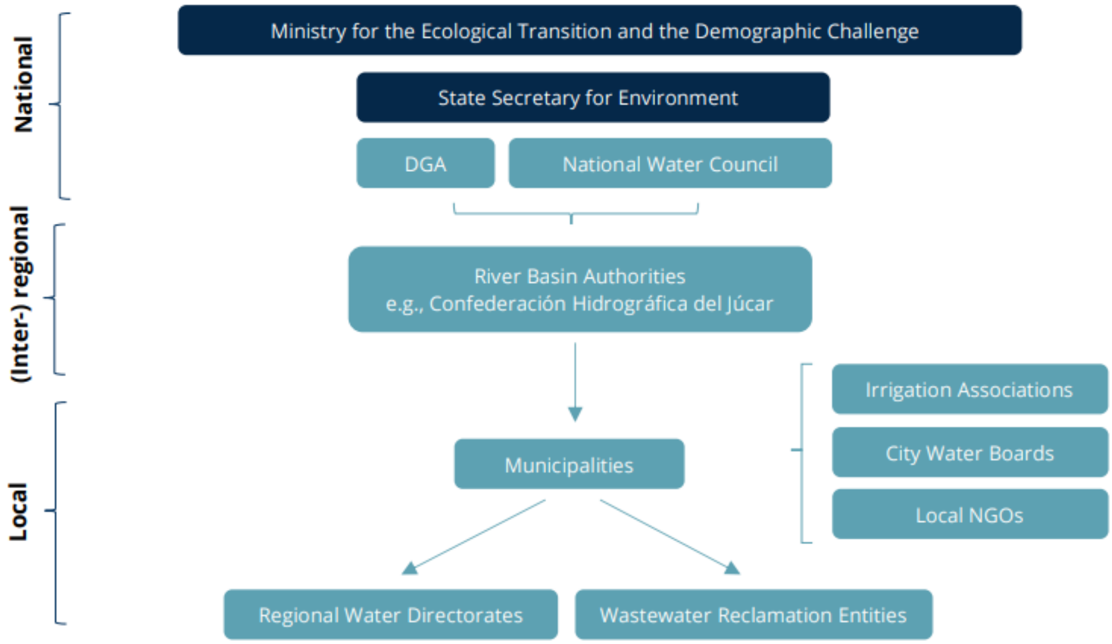


Figure 5 Decision-making structure for water management in Spain (Conrad et al., 2022b).

Among the previously mentioned stakeholders, the most relevant are identified for the region and classified based on their level of influence and the themes of MAR project feasibility (Figure 6).

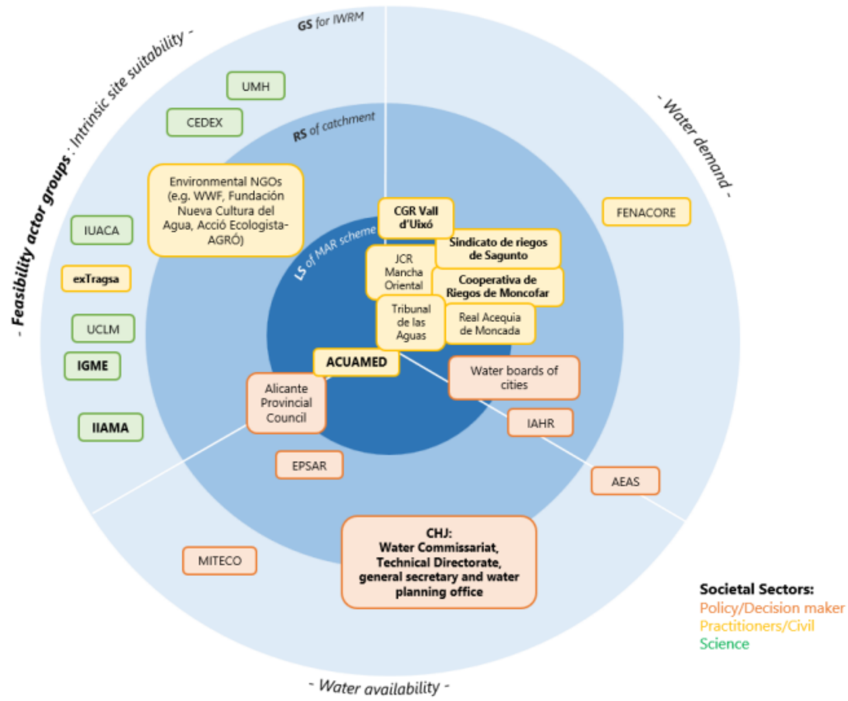


Figure 6 Stakeholder map for the Júcar Water District, Spain (Conrad et al., 2022b).

The engagement strategy is based primarily on regular and transparent sharing of project progress and various activities until agreements are obtained. Workshops, interviews, policy briefs, and recommendations have also been used, as well as steering committees.

The Spanish approach was to initially organize a joint meeting with all stakeholders to view and analyze the different perspectives regarding MAR. This meeting took place in November 2022 and brought together the key stakeholders identified earlier to discuss the possibilities and limitations of MAR and the conjunctive use of surface water, groundwater, and non-conventional water resources. Additional bilateral meetings were held to delve deeper into their perspectives and to foresee and analyze the interests of each stakeholder and to determine the best way to engage them in MAR. Gathering stakeholders in one place, and providing them with a space to discuss, helped raise awareness of the importance of addressing the governance aspect of MAR in Spain. MAR depends on several aspects, and therefore, it is crucial to understand that each stakeholder must make compromises while considering their interests and the interests of others. It was essential to ensure a trusted space where each stakeholder felt equally valued regarding their needs and their willingness to engage. This approach with Spanish stakeholders significantly facilitated communication and maintained their willingness to be involved.

2.5 Standards and regulations

In Spain, water resources management is regulated by various laws and regulations, such as the Water Framework Directive, the Spanish Water Law, and the Regulation on the Management of Public Waters.

2.5.1 European Water Framework Directive

The European Water Framework Directive was established to unify water management actions within the European Union. The challenge of this directive is to protect water qualitatively and quantitatively, ensuring its sustainability, as water resources within the European Community face increasing pressure due to the continuous rise in demand for good quality water in sufficient quantity for all uses (European Union, 2000).

This European directive aims to establish a framework for the protection and management of surface and groundwater, promoting an integrated approach to water management at the watershed scale. The transposition of Directive 2000/60/EC in Spain was carried out through Law 62/2003, of December 30, on fiscal, administrative, and social measures, which transposes Directive 2000/60/EC into Spanish law, establishing a community framework of action in the field of water policy. This law encompasses several measures related to different aspects of water resources management, such as the evaluation and management of flood risks, protection of groundwater against pollution and deterioration, improvement of the quality of continental waters for fish life, quality of water intended for human consumption, conservation of natural habitats and wildlife, and urban wastewater treatment, among others (European Union, 2000).

Regarding the protection of groundwater against pollution and deterioration, the European Water Framework Directive considers groundwater as a precious natural resource that must be protected against chemical pollution and deterioration. This is particularly important for ecosystems dependent on groundwater and for the use of groundwater for human consumption. Groundwater is the most sensitive and important water resource in the European Union, particularly the main source of public water supply. It is necessary to protect groundwater in water bodies used for drinking water abstraction or intended for such use in the future, to prevent the deterioration of the quality of these water bodies and reduce the level of purification treatment required for drinking water production. The directive establishes specific measures to prevent and control groundwater pollution, including criteria to assess the chemical status of groundwater, criteria for identifying and reversing significant and sustainable trends towards deterioration, and criteria aimed at preventing or limiting contaminant inputs into groundwater and avoiding deterioration of the state of all groundwater bodies (European Union, 2006).

2.5.2 Spanish Water Law

The Water Law in Spain serves as a fundamental legal framework for the proper management of water resources in the country. This legislation establishes regulations, rights, and principles aimed at ensuring sustainable and equitable use of water, as well as the protection of aquatic ecosystems. It has a broad scope, covering both surface water and groundwater. It sets out guiding principles for water resources management, such as integrated planning and management, protection of aquatic ecosystems, citizen participation, and priority use for drinking water supply. Additionally, the Water Law regulates water uses, water rights, and usage concessions, as well as permits for discharges and works in the hydraulic public domain. It also addresses coordination among different public administrations and establishes mechanisms for monitoring and sanctions to ensure compliance with the legislation.

Specifically addressing groundwater management, this legislation focuses on the protection of aquifers, prevention of overexploitation, and regulation of groundwater uses. It mandates the assessment and monitoring of groundwater resources, implementing protective measures such as delineating aquifer protection zones and regulating activities that may affect their quality or quantity. It also encourages artificial recharge of aquifers and promotes the participation of users and local communities in sustainable groundwater management. The Spanish water law states that:

- In the public domain of aquifers or geological formations through which groundwater flows, the owners of the land may carry out any work on their property as long as it is not for extracting or using water, does not disrupt the water flow, and does not degrade its quality.
- To address situations where groundwater bodies are at risk of not achieving good quantitative or chemical status, the council of the River Basin Agency may declare such risk without the need to consult the Water Council, triggering the implementation of measures such as creating user communities, approving action programs for restoring the good status of water, and adopting extraction limitations and groundwater quality protection measures. These programs include organizing the extraction regime, replacing individual withdrawals with collective withdrawals, providing for external resources, delineating protection perimeters, and considering conditions to temporarily overcome established limitations. Additionally, there is provision for gradually reducing limitations and increasing the available volume if the status of the aquifer improves, while always ensuring compliance with environmental objectives.
- The River Basin Agency has the authority to request the creation of communities responsible for jointly managing the use of surface and groundwater when it is more beneficial for integrated water resources management in a particular area. Additionally, for water supply to multiple localities, concessions will be subject to local authorities forming Communities of Municipalities, Consortiums, or similar entities, or all populations receiving water through a single concessionaire.
- Protection of groundwater against saline water intrusion, whether from continental or maritime sources, will be achieved, among other actions, by limiting exploitation of affected aquifers and, if necessary, spatially redistributing existing withdrawals. Basic criteria for this purpose will be included in Basin Management Plans, and it will be the responsibility of the Basin Authority to adopt appropriate measures.

2.5.3 Public Water Domain Regulations

The "Boletín Oficial del Estado" (BOE) is the official journal of the Spanish government and serves as the platform for publishing laws, provisions, decrees, resolutions, regulations, and other administrative acts of national importance. In August 2023, amendments were made to the regulation of the public hydraulic domain in Spain. The second section addressed the topic of artificial recharge for the first time in the Spanish regulation, and covered the main points (BOE, 2023):

- Aquifer artificial recharge actions are not considered discharges.
- Authorization to artificially recharge aquifers is dependent on the absence of groundwater contamination, overloading effects, or the generation of additional pressure by incompatible extraction.
- Excess water of suitable quality from various sources can be used for artificial recharge, including surface water bodies, adjacent groundwater bodies, springs, basins, sewage treatment plants, or desalination sources.
- Applications for artificial recharge can be initiated by competent authorities or proposed by user communities, developers, or individuals, with consideration of subsequent water use.
- Preliminary studies and pilot tests may be authorized by the basin authority to establish the viability and characteristics of the recharge system.
- Application requirements include justification for recharge, viability reports, detailed recharge system descriptions, water volume to be recharged, and confirmation of recharge land availability.
- Public consultation precedes resolution issuance, feedback from municipalities and stakeholders is considered, authorization conditions needed to be outlined, including work timelines, monitoring,

emergency procedures, reporting obligations, and compliance with established requirements in hydraulic public domains.

2.6 Guidelines for Regional Agreement tailored to the Spanish case study

The agreements tailored to the Spanish case study in the Júcar Water District should include several key elements aligned with the regulatory framework governing aquifer and basin management activities in Spain. These elements must be delineated and correlated with the aspects that support the agreements (technical, social, economic and regulatory), ensuring comprehensive coverage of their scope (regional or local). These agreements should provide a comprehensive description of:

- Explicit statement of MAR activities. This includes that at national, regional and local levels and within the legal aspects considered in the agreement in Spain, artificial recharge actions are not considered discharges.
- Information about the requirement for authorization, which can only be granted if the initiative does not cause groundwater contamination or negative effects due to overexploitation and if it does not generate additional pressure through incompatible extraction from the aquifer. This represents one of the technical aspects in the agreement that should be addressed at regional and local levels. For this purpose, it should reflect the findings of the technical assessment based on numerical modelling, and using related indicators (environmental indicators, water demand reliability indicators, feasibility maps indicators, etc.).
- Different MAR techniques to be considered whether it is direct or induced MAR. Direct MAR is defined as the intentional aquifer recharge by directly introducing surface water into groundwater systems through the use of infiltration basins, injection wells, etc., while induced MAR refers to the use of alternative water resources to meet water demand and thus reducing reliance on aquifer pumping which alleviate pressure on aquifers and facilitate their natural restoration processes. In this context, induced MAR initiatives have proven their efficiency in the Spanish case studies; as demonstrated in scenarios in Belcaire pond area involving the use of water from Belcaire pond, WWTP, or desalination plants. These scenarios have shown significant reductions in aquifer overexploitation and improvements in water demand reliability indicators, illustrating the potential of induced MAR as a tool for conjunctive use of surface, groundwater and non-conventional water resources in Spain. Similar initiatives evaluated in the Algar reservoir area, including springs, WWTPs, and desalination plants, offer long-term potential to mitigate aquifer pumping and enhance agricultural water supply reliability.
- Information about authorized sources for artificial recharge, covering legal and technical aspects, such as the quality of surplus water and its extraction from surface water bodies, nearby resources and non-conventional water resources. In this respect, the use of a water management model is key to identifying excess water volumes in the river basin and assessing the potential impact of MAR on other water uses in the basin.
- Overview of the various stakeholders involved and their levels of engagement, benefits and obligations. At regional and local levels, MAR applications may be initiated by a competent hydraulic administration or proposals from user communities, developers, or individuals. It is essential to detail the roles of each stakeholder category, such as those involved in initiating, collaborating, informing, or consulting on MAR projects. Feasibility mapping plays a crucial role in identifying suitable MAR sites and stakeholders, confirming project feasibility and initiating stakeholder engagement.
- Information about the need of preliminary studies on recharge or infiltration through pilot tests or trials, along with other hydraulic or hydrogeological works. This must be addressed at local level and covers both legal and technical aspects. In Spain, the river basin agencies have the power to approve these studies, which aim to furnish the submitter with essential data to determine the feasibility and eventual specifications of the recharge system. Therefore, it is imperative to incorporate provisions to accommodate such requirements if deemed necessary, ensuring that any necessary resources, permissions, and timelines are clearly outlined and agreed upon by all parties involved.
- Legal requirements for applying artificial recharge covering both legal and technical dimensions at regional and local levels, including justification for recharge, destination of stored water,

hydrogeological reports describing aquifer characteristics, viability and compatibility reports, confirmation of water availability, and verification of environmental impact. It also requires a detailed description of the recharge system, including works, installations, and infrastructure, along with a recharge and extraction program considering hydrological planning and drought scenarios. The volume of water to be recharged should also be specified and the availability of suitable recharging land or surfaces must be confirmed.

- Information about the public consultation to guarantee the Transparency and public participation at two levels: regional (published in the Official National Bulletin) and local (published by the City Halls). This covers the social aspect of the agreement promoting transparency, accountability and inclusion in decision-making.
- Information about how long it will take to process the MAR request. It is important to realize that the period of approval must be reasonable. This also covers the social aspect of the agreement at a local level.
- Artificial recharge authorizations that cover the legal aspect of the agreement at a local level, outlining the conditions under which they must be conducted. These conditions encompass the start and end dates of works and installations, including commissioning procedures. Additionally, measures to prevent negative impacts on the hydraulic public domain during system installation must be detailed. Requirements for monitoring and maintaining the recharge system, such as measuring piezometric levels and possibly conducting groundwater quality control, should be outlined. It should also specify actions and measures to be implemented by the authorization holder in case of emergency situations. Criteria for modification and revocation of the authorization, as well as any other conditions deemed appropriate by the basin authority based on the characteristics and objectives of the recharge system, must also be included.
- Reporting on the operation of the system in a specific time frame to cover the technical aspect at a local level. These reports provide insights into the performance, efficiency and effects of artificial recharge on the hydrogeological system. Performance metrics, such as the total volume of water utilized for MAR annually, are documented to assess operational effectiveness, and efficiency indicators, including the ratio between the recharged water volume and the recovered water volume, offer insights into resource utilization and system optimization. Additionally, the effects of artificial recharge on the hydrogeological system, such as changes in groundwater levels, water demand or water quality, are evaluated to inform ongoing management strategies and ensure sustainable aquifer management.
- Specification of the cost of implementing MAR, and its distribution among stakeholders. This covers the economic aspect of the agreement at a local level. The financial obligations required to implement MAR must be described, including the costs associated with infrastructure development, maintenance and operation.

2.7 Conclusions of the Spanish case study in the Júcar Water District

Situated in the Mediterranean region, the Júcar Water District faces significant challenges regarding water resource management. Given this context, implementing MAR can be helpful, with a focus on both direct and indirect methods. However, the most effective approach appears to be the induced method. This method prioritizes the utilization of non-conventional water sources such as treated wastewater or desalinated water or surface water to fulfill water demand, thereby reducing reliance on aquifer pumping. By doing so, stress on vulnerable aquifers exposed to overexploitation and seawater intrusion can be alleviated. It is imperative to prioritize sustainable water management practices that strike a balance between the needs of agricultural water users and the protection and preservation of groundwater resources.

The agreements tailored to the Júcar Water District should outline the specific objectives and scope of the MAR project, including the targeted aquifers and recharge methods to be employed. It should take into consideration the Spanish legislation for artificial recharge and define the roles and responsibilities of each stakeholder involved. Furthermore, the agreement should outline the monitoring and evaluation mechanisms to assess the effectiveness of the MAR project in recharging aquifers and improving its quality. Finally, provisions for public participation, stakeholder engagement and conflict resolution should be included to ensure transparency, accountability and inclusivity throughout the implementation process.

Several meetings have been held with the Júcar River Basin Agency to discuss the Belcaire and Algar case studies in Spain. Even though both projects were endorsed and approved at regional scale by previous Júcar Management Plans, during these discussions, it was emphasized that Belcaire was considered a priority case study, while Algar is more complicated and would require a longer-term approach to be considered because, at the moment, it is challenging to identify stakeholders willing to be included in modifying the current situation, which limits the opportunities for action. The different stakeholders have not shown willingness to cooperate in the implementation of MAR, especially concerning the financial aspects at the Algar reservoir. However, in the Belcaire region, where clear needs for agreements have been identified, stakeholders such as the community of irrigators of Vall d'Uixó, and the Moncófar irrigation cooperative are more inclined to engage in water management initiatives. This willingness of stakeholders to reach agreements is essential for the successful implementation of the AGREEMAR project's objectives in the Spanish case study as in any other case. The results of the feasibility mapping also have revealed greater MAR feasibility of the Belcaire Pond area compared to the Algar area, as indicated in Deliverable D2.3 (Chekirbane et al., 2023). This supports the selection of the Belcaire Pond area as a potential area for generating local agreements.

The clear needs for agreements in Moncófar and Vall d'Uixó areas, facing issues such seawater intrusion, aquifer overexploitation and low reliability of water supply during droughts, motivate stakeholders to act. In contrast, the complexity of the infrastructure and the lack of stakeholder willingness in the case of Algar reservoir make the situation more delicate. Thus, the choice of Belcaire pond area as the main site for local agreements within the AGREEMAR project is based on solid grounds, including the recognition of the willingness and capacity of stakeholders to engage in MAR initiatives. Therefore, the agreement to be reached for Belcaire will not focus exclusively on direct MAR, but also on the joint use and management of surface water, groundwater and non-conventional water resources, aiming to indirectly implement MAR by minimizing groundwater pumping and thus engaging in a nature-based solution for aquifer recovery (induced MAR). As a result, the quantity of water reserved for (direct) MAR will be lower, but still aligns with the objectives of the AGREEMAR project, aiming to promote conjunctive use of groundwater and surface water, improve water quality and increase availability or recover water for irrigation.

3. The Portuguese case study in the Guidana and Sado e Mira districts

3.1 Preliminary assessment

3.1.1 Regional case study

The southern region of mainland Portugal considered in AGREEMAR comprises two river basin districts – Guadiana (PTRH6) and Sado e Mira (PTRH7) with approximately 11 600 km^2 and 10 000 km^2, respectively, included in Alentejo and partially in the Algarve Administrative regions.

Geologically, the whole region consists of several types of contrasting lithologies, being in its majority comprised of metamorphic rocks – mostly schists and graywackes – covered in some areas by sedimentary deposits with several hundreds of meters in thickness. Some of these deposits support relevant sedimentary multi-layer aquifer systems (Figure 7) such as the *Margem Esquerda Tejo-Sado* aquifer, the biggest groundwater body in Portugal, partially covering the Sado and Tagus river basins.

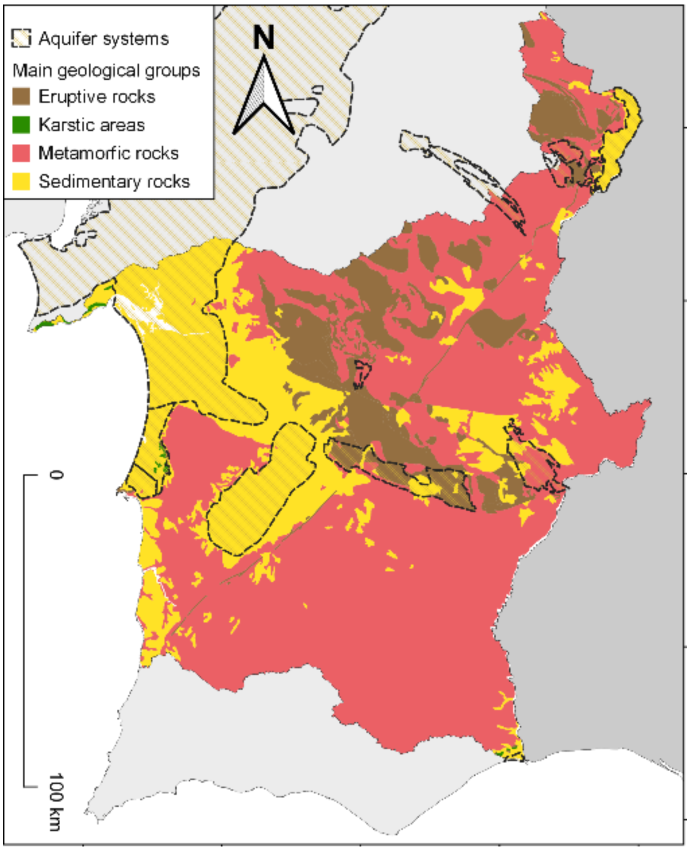


Figure 7 Main lithological groups and aquifer systems occurrences within the study area (adapted from the 1:500 000 geological map and SNIAMB, 2024).

3.1.2 Sado and Mira (PTRH6)

Sado and Mira, as the name perceives, includes Sado and Mira river basins and the coastal river basins, including their respective groundwater and adjacent coastal waters. It comprises 23 municipalities, divided into the Península de Setúbal, Alentejo Central, Alentejo Litoral and Baixo Alentejo subregions. Sado is the basin with the largest area entirely in Portugal mainland, bounded to the north by the Tagus basin, to the east by the Guadiana basin, to the south by the Mira basin, and to the west by the Atlantic Ocean coastline, draining directly to the sea. The Mira basin is bounded to the north by the Sado river basin, to the east by the Guadiana basin, to the south by the Ribeiras do Algarve basin, and to the west by a coastal strip, which drains directly to the sea. This river basin district is comprised of 226 riverine water bodies and 9 groundwater bodies.

This hydrographic region has the lowest average temperatures (9.5ºC) recorded in January while the highest are recorded in August (23.4ºC) (period of analysis between 1930 and 2015, IPMA, 2023 in APA 2023b).

Regarding rainfall, APA (2023b) conducted an analysis for the period between 1930 and 2015, concluding that the wettest month is December (average 90 mm) and the dryest is July (3 mm). A generalized reduction in precipitation is observed in the period 1989-2015 compared to the previous period of 1930-1988, with this decrease being 25% in a dry year, 13% in an average year, and 16% in a wet year.

Concerning the pressures, the main volumes captured/consumed were related to energy (non-consumptive volumes), with about 70% of the total, agriculture with 25%, industry with 1.6%, and public supply with 1.4%. In the case of agriculture, the captured volume is 90% originating from surface water and 10% from groundwater. In the urban sector, the percentage is 37% for surface water and 63% for groundwater (Figure 8, APA, 2023). The urban and industrial sectors were the ones that contributed the most to the loads of COD (Chemical Oxygen Demand) and BOD5 (Biochemical Oxygen Demand) rejected. However, agriculture and livestock were the economic activities responsible for most of the total nitrogen load that potentially reached the water bodies. Regarding the urban sector, secondary treatment systems predominated. As for the manufacturing industry, the activity of the cement industry contributed the largest loads to the water environment, with COD being the most representative parameter. Regarding the food and wine industry, the activities of animal slaughter and the preparation of meat products and the preservation of fruits and vegetables, contributed the largest loads to the water environment, with BOD5 and COD being the most representative parameters.

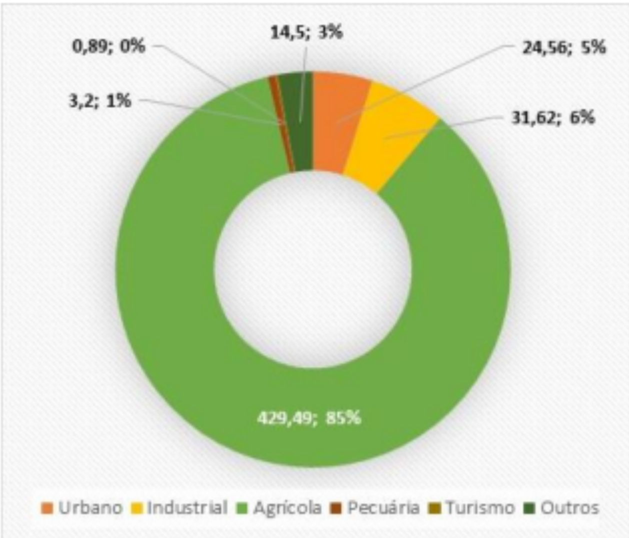


Figure 8 Distribution of water volumes captured for the main consumptive uses for the PTRH6 (hm^3) (APA, 2023).

In the recent river basin management plan (RBMP) cycle, 1 of the 9 groundwater bodies was classified as Poor quantitative status (one more in comparison to the previous RBMP cycle), and 2 showed Poor chemical status (one more in comparison to the previous RBMP cycle).

3.1.3 Guadiana (PTRH7)

PTRH7 represents only 17% of the total area of the Guadiana river basin, the remaining being located in Spain. The Portuguese part of the river basin comprises 31 municipalities and is limited to the north by the Tagus river basin, to the west by the Sado and Mira river basins and to the south by the Ribeiras do Algarve river basins and the coastline. The river basin district is comprised of 261 riverine water bodies and 8 groundwater bodies.

In PTRH7, the lowest average temperatures (9.3ºC) are recorded in January while the highest are recorded in July and August (24.7ºC) (period of analysis between 1930 and 2015, IPMA, 2023 in APA, 2023c)

Regarding rainfall, APA (2023c) conducted an analysis for the period between 1930 and 2015, concluding that the wettest month is December (average 80 mm) and the dryest is July (3 mm). A generalized reduction in precipitation is observed in the period 1989-2015 compared to the previous period of 1930-1988, with this decrease being 22% in a dry year, 11% in an average year, and 15% in a wet year.

Regarding pressures, the main volumes captured/consumed were related to energy (non-consumptive volumes), with about 88% of the total captured, followed by agriculture with 9.1% and public supply with 1.8%. Excluding the non-consumptive volumes associated with the production of hydroelectric power, it was observed that, in terms of consumptive uses, the sector that consumed the most water was agriculture with about 76%, followed by the urban sector with 15% (Figure 9). In the case of agriculture, 79% originated from surface water and 21% from groundwater. In the urban sector, the percentage is 60% for surface water and 40% for groundwater. The urban sector was the one that contributed the most to the loads of COD and BOD5 rejected. However, agriculture and livestock were the economic activities responsible for most of the total nitrogen load that potentially reached the water bodies. Regarding the urban sector, secondary treatment systems predominated. Concerning the manufacturing industry, the associated activities are linked to public wastewater treatment systems, so no discharges to the water environment or to the soil were identified. As for the food and wine industry, the most expressive activity, in terms of loads, was wine production (APA, 2023a).

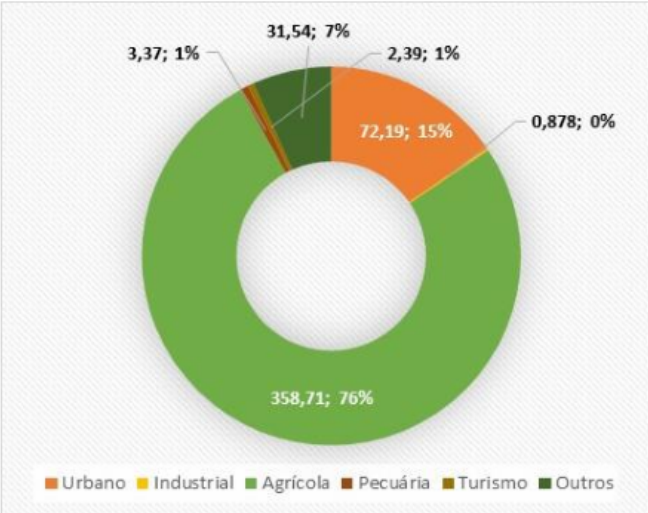


Figure 9 Distribution of water volumes captured for the main consumptive uses for the RH7 (hm3) (APA, 2023a).

In the recent RBMP cycle, 2 of the 8 groundwater bodies classification registered Poor quantitative status (2 more in comparison to the previous RBMP cycle), and 5 showed Poor chemical status (3 more in comparison to the previous RBMP cycle).

3.1.4 Local case study

In the Portuguese context of water scarcity, especially in Alentejo and Algarve regions, the use of alternative water resources (AWR) is becoming a need, namely the direct or indirect use of treated wastewater. Climate change impacts and multiplication of the population in the summer period is exacerbating water stress in agriculture and in urban sectors. The public/social acceptance of conventional and AWR, as solutions helping to protect natural sensitive areas providing benefits for local economic activities, is at the center of the willingness to embrace new answers to the water scarcity problems.

Comporta Wastewater Treatment Plant (WWTP) is the first example of a soil aquifer treatment (SAT)-MAR system running in Portugal since October 1st, 2021. Understanding and gaining trust using Comporta as an example of good practices is of crucial importance. The WWTP is equipped with a technologically advanced treatment system, including primary, biological treatment and additional disinfection to produce water for reuse and treatment of sludge by dehydration. The MAR system is composed of four infiltration ponds, and it is presented as an alternative to the commonly implemented method of direct discharge of treated effluents into surface water bodies, therefore protecting Sado estuarine ecosystem, a sensitive area classified as a Nature Reserve located over the *Margem Esquerda Tejo-Sado* aquifer system (the largest aquifer system of the Iberian Peninsula with 6,875.44 km^2).

Due to the size of the Comporta system, it is not likely that it has a regional impact, but it can serve as a small example that can be replicated in many parts of the Alentejo region, together with other MAR systems in areas where flood risk zones were identified. In the case of Portugal, it is not anymore expected that a single solution is able to solve the existing problems, since most areas prone to accumulate big reserves were already built.

The solution rather relies on conjunctive use of surface and groundwater, also considering MAR, desalination, and other small water storages to maximize efficiency and resilience of water supply.

The use of feasibility mapping (Section 3.2) and numerical modelling (Section 3.3) allows us to understand how MAR can interact and influence water availability and quality in the area, providing a framework (Section 3.4) for integrated planning and informed decision-making. Relevant stakeholders have been involved and the results obtained were shared to help understanding potential areas for MAR, together with the benefits and challenges associated, allowing to facilitate future MAR agreements.

Research and applied research on this subject are being carried out in Portugal in the last 19 years during several EU projects such as the FP5 GABARDINE project (2005-2009, LNEC, https://www.lnec.pt/fotos/editor2/dha/DHA%20PDFs/gabardine_uk.pdf), FP7 MARSOL project (2013-2016, LNEC, TARH, UALG, https://cordis.europa.eu/project/id/619120), H2020 MARSoluT project (2019-2023, LNEC, UALG, https://www.marsolut-itn.eu/), AGREEMAR project (2022-2025, LNEC, https://www.agreemar.inowas.com/), and finally MARCLAIMED HEurope project (2024-2027, LNEC and AgdA, https://www.lnec.pt/hidraulica-ambiente/en/core/water-resources-and-hydraulic-structures-unit/activity-2/). It is our conviction that the results of these projects are contributing for the necessary scientific support for MAR application in Portugal.

3.2 Identification of potential MAR sites

The assessment of MAR feasibility presented in Deliverable D2.3 (Chkirbane et al., 2023) following the criteria structure defined in Panagiotou et al., 2022 with the methodology established in Deliverable D2.2 (Martins et al., 2022) allowed for the production of two maps for the study region of Alentejo and Algarve - Figure 10. The two maps refer to the objectives defined within a participatory approach in which the stakeholders establish the main priorities for the implementation of MAR: from the results of a questionnaire, 62% of the replies point to the "Increase piezometric levels, groundwater and energy storage" (objective defined as P1), followed by 16% that give priority to “Improve groundwater quality" (objective defined as P2).

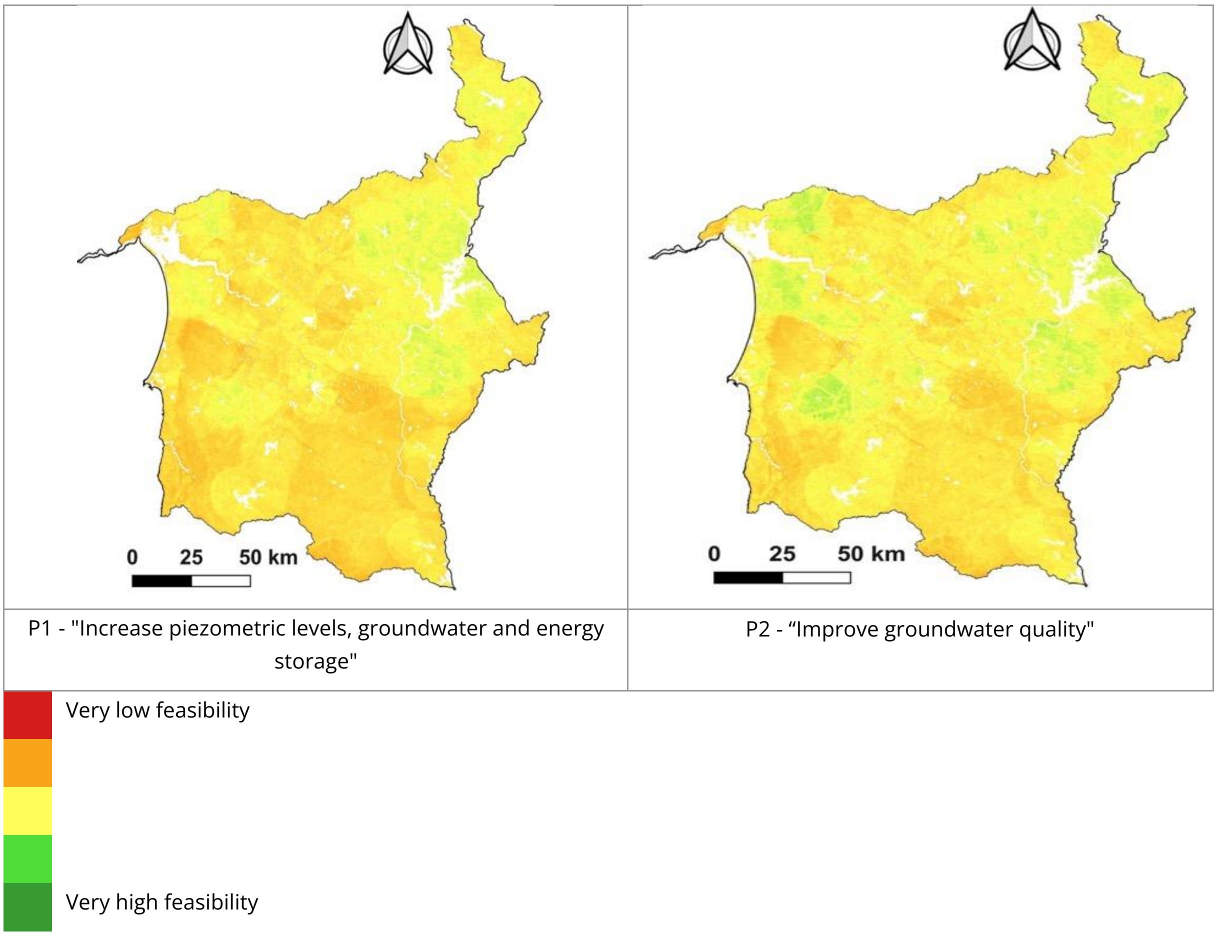


Figure 10 MAR feasibility maps of the Portuguese demo region (adapted from Chrkirbane et al., 2023).

These maps are expected to support the policy makers and water authority in the first step in the decision-making process for MAR implementation. The maps don't aim to replace detailed studies based on numerical models or other more robust tools, but rather increase the dissemination of such methods and include them in the day-to-day integrated water resources management decision-making flowchart.

3.3 Technical assessments based on numerical modelling

As the Portuguese case study is situated toward the extremity of the Comporta water system, it was concluded during the preliminary assessment that MAR in this region has no effects on other water uses in the basin, so only the effect of MAR on the evolution of the aquifer is considered. Therefore, the objective of the numerical groundwater modelling is to validate the feasibility map, study the impact of using MAR at local scale, test specific MAR scenarios, allow a participative collaboration of stakeholders from different societal sectors by negotiation of agreements and finance the MAR system to be used. As Figure 11 details, feasibility index in the location of the Comporta WWTP is 0.607 and the neighboring area, consisting of a 500 m square-shaped buffer around the WWTP, varies between 0.543 and 0.649.

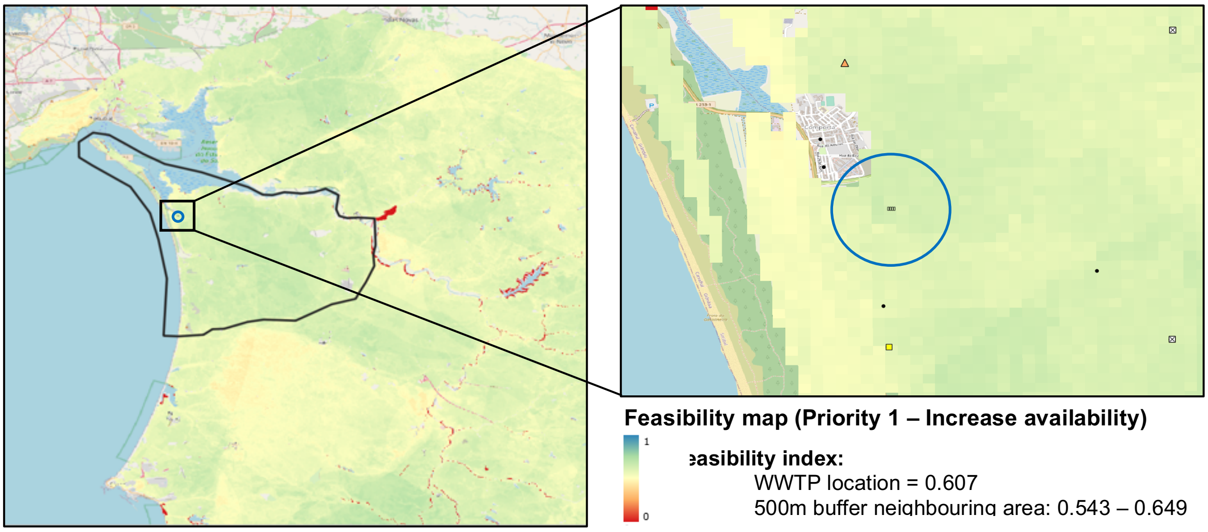


Figure 11 Feasibility map of the Comporta WWTP location, and limit area of the regional scale model.

The use and benefit of setting up numerical models for Comporta site serves primarily the goal to compare the influence of different MAR operational schemes (e.g., volume of infiltrated TWW) on the aquifer and subsequently the water table. No different MAR techniques were tested as SAT-MAR is the scheme in use. For the Portuguese case study, the numerical models were set up (developed) using jointly (1) the online modelling platform INOWAS (Glass et al., 2022, Release: v1.14.1, https://www.inowas.com/), based on MODFLOW-2005 (USGS), and (2) QGIS, a free and open-source geographical information system (https://qgis.org/en/site/), where part of the model information was originally prepared to ease its implementation in the INOWAS platform.

Two models were implemented, Figure 12, a regional (base) model with coarser cell size (240.5m x 240.1m) and a local model with finer cell size (16m x 32m). The local model was necessary to set up, as the impact on the regional model groundwater heads is smoothed due to its large cell size. The regional groundwater flow model acts as base model to feed the boundary conditions of the local scale model. Both models were implemented with 11 layers representing the lithology of the area. The lithology information was based on the interpolation and extrapolation of well log data provided by authorities using a methodology to be described in AGREEMAR Deliverable 4.1. Hydraulic properties of the units were based on bibliography standard values that relate lithology with hydraulic properties (e.g. Freeze and Cherry, 1979). Recharge was based on BALSEQ_MOD results, prepared for Deliverable D2.3 (Chekirbane et al., 2023) and implemented cell dependent. In total 382 pumping wells were included as sink term in case of the regional model and 19 in case of the local model.

Until now, both models were run as steady state. The local scale model is a 3D section of the regional scale model meaning that all the information used for building the regional model is included in the local model. The heads of the regional base model were taken as input constant head boundary condition for the local model. The local model served to study the influence of MAR on the water table with adequate spatial resolution.

Figure 12 Regional groundwater flow model (left) and local groundwater flow model (center and right for the detail of the WWTP) for Comporta field site area.

In total, five runs were performed, one for the situation prior to the installation of the WWTP ("without MAR"), one for the expected steady state situation of infiltrating the up-to-today average amount of treated water ("MAR (1x Vol)"), and three hypothetical future scenarios of infiltrating twice, five times and ten times the actual amount of treated waste water ("MAR (2x Vol)", "MAR (5x Vol)", "MAR (10x Vol)", respectively).

As hypothesized (see section 3.1) the influence on the water table of the Comporta MAR field site with the current volumes of infiltration of TWW is only local (Figure 13). The increase of the maximum head almost triples in case of 10 times increase of the infiltrated volume of TWW.

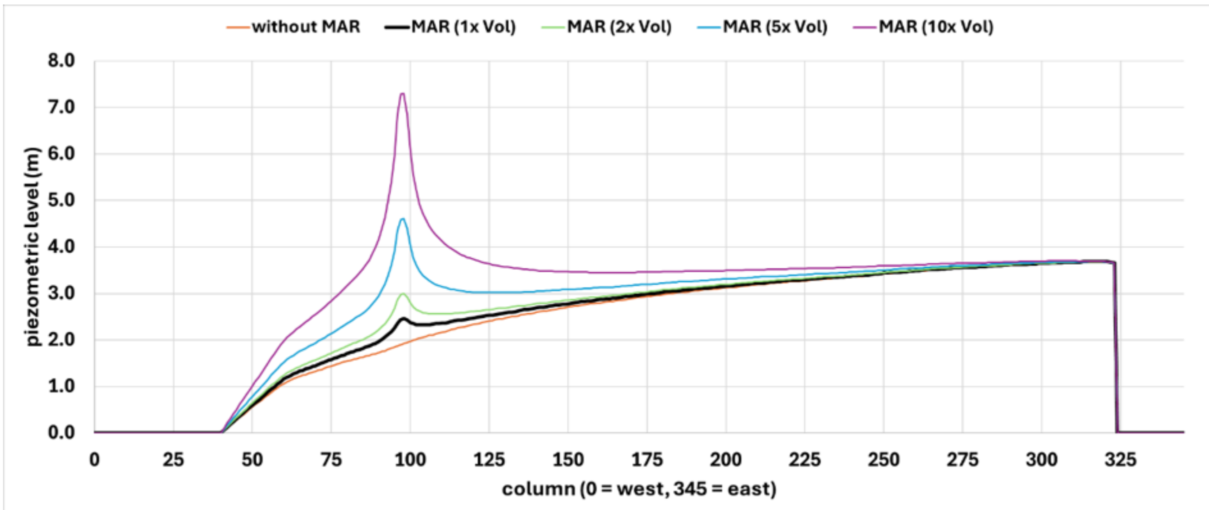


Figure 13 Influence of infiltration volume on the water table for the local groundwater flow model (each cell represents 16 m distance).

These results provide a basis for assessing the impact of MAR in the local area and may be used for planning and further discussion with stakeholders, in a participatory way, including exploring the use of other locations for infiltrating water. More details on model results about the effects of MAR on the evolution of the aquifer in the Portuguese case study are provided in Deliverable D4.1.

3.4 Identification of stakeholders and their relationships

As a complement to the technological framework that has been developed in this project, AGREEMAR has considered the social component where the human adaptation to adversity, or the confrontation of Complex Problems, including water scarcity, occurs in a complementary and non-exclusive way. Two aspects are considered: adaptation through the use of technologies whose principles are aligned with the innovative and sustainable form of the so-called Reflexive Modernity (Beck, 2013) and, through cultural or social adaptation, motivated and also based on the same principles, for which the issue of the environment is at the center of the processes of social change and considered as the basis for full harmony with the technologies inspired by nature (e.g., theories of Human Ecology, Theory of Ecological Modernization, cf. Olivieri, 2009).

The first step of stakeholders' interaction was reported in Deliverable D1.1 (Conrad et al., 2022b), the identification stage, where the main stakeholders related to the implementation of MAR systems were listed, organized by scale (national, regional, and local scale), by their expectations in relation to MAR, and by their influence (Figure 14).

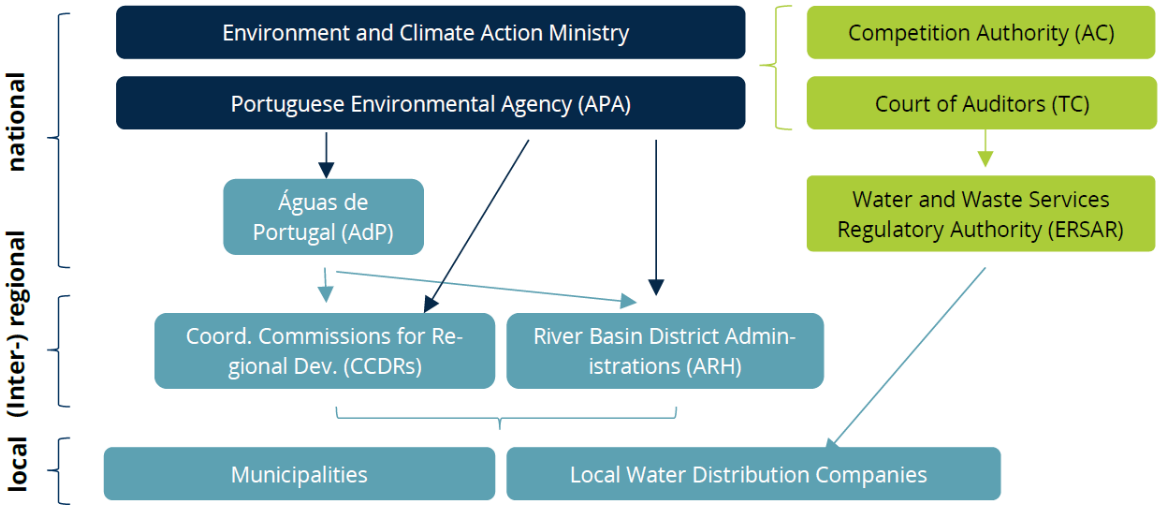


Figure 14 Institutional framework of the water sector in Portugal (adapted from Marques and Simões 2020, in Conrad et al., 2022b).

In Portugal, the activities are focused in the Alentejo region. A stakeholder map was created, grouping them into societal sectors based on the nature of stakeholders, in terms of their role, interests, needs, and influence on MAR implementation: policy/decision-makers, practitioners/civil, or science. Figure 15 maps the relevant stakeholders identified for the demo region, and updated during the initial project visits, categorized by their level of influence or interest in MAR. Stakeholders that are considered the most important to engage with were highlighted in bold.

Engagement with these key stakeholders has been initiated, focusing on understanding their perspectives and addressing their concerns. The process is designed to foster a collaborative environment, encouraging active participation in the MAR implementation. Regular meetings and workshops are conducted to keep them informed and involved. This approach ensured that the project aligns with the stakeholders' interests and needs, thereby increasing the likelihood of its success and acceptance within the Alentejo region. The stakeholder map serves as a dynamic tool and can be further updated and adapted throughout the project progress.

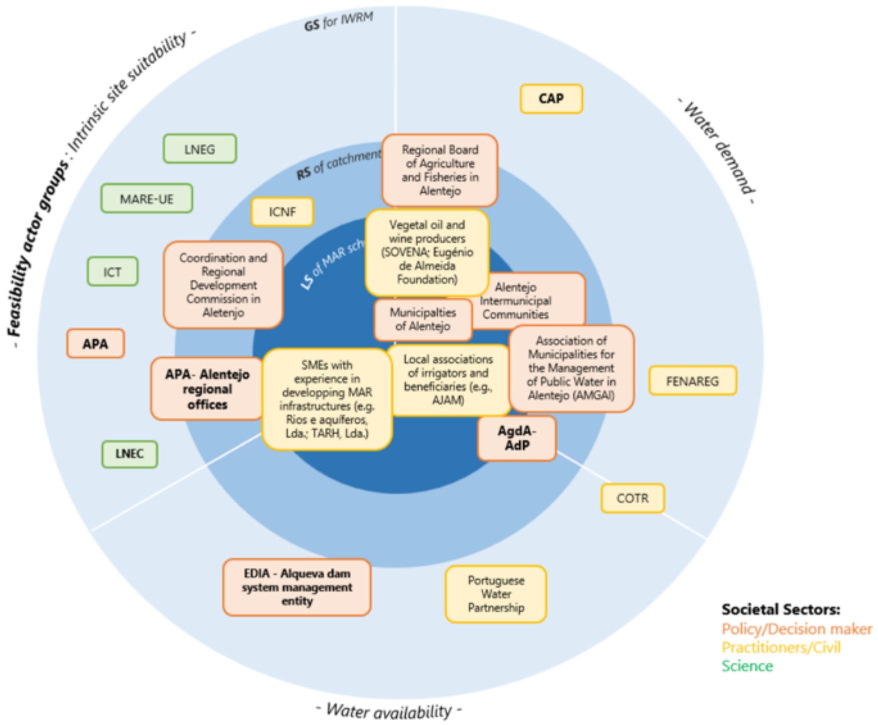


Figure 15 Stakeholder map for Alentejo, Portugal (Conrad et al., 2022b).

For each stakeholder, their roles and competencies in MAR, needs related to MAR outcomes, the stakeholder group, scale, and thematic mapping of stakeholders were identified (more details can be found in Deliverable D1.1a (Conrad et al., 2022a).

After identifying and ranking the relevant stakeholders, consultations were conducted based on specific engagement objectives to identify entities interested, or affected, by MAR in the region. Institutional and political consultations are conducted to define who is responsible for decisions that may affect MAR and who might be affected by MAR or interested in it. As mentioned in Deliverable D1.1 (Conrad et al., 2022b), stakeholder analysis criteria include a general classification, level of influence, interest, and engagement strategy.

More recently, a new approach to engage and involve the stakeholders that have demonstrated more interest in future MAR agreements has taken place in a 3rd workshop, held on April 18th 2024, using the Constellation Analysis (CA) (Schafer et al., 2010).

In this new approach, or the second phase of the social project approach, the main objective was the integration of MAR elements and the construction of the relationship to facilitate the future agreements for MAR implementation. To this end, the CA tool was used as a facilitating instrument for the implementation of MAR methods in Portugal, focusing on the Comporta case study. The use of this methodology allowed to integrate and relate the elements identified in MAR in a dialogical, participatory and cooperative way, in the search for agreed solutions based on Good Governance, defined in Osmont (1998).

The use of that innovative approach to facilitate the reach of MAR agreements is well justified in the words of Schafer et al. (2010):

"Sustainability research is aimed at meeting the challenge of dealing with important societal problems related to the 'metabolic' process between society and nature in a global context. Besides generating knowledge about the characteristics and dynamics of the complex process involved (climate change, loss of biodiversity, increasing poverty and hunger, water scarcity), it should also contribute to normative knowledge about how to evaluate these processes and develop strategies for social change towards sustainability. An interdisciplinary composition of research team is necessary to deal with the complexity of sustainability problems. The normative questions and the need for decisions to be made in situations of uncertainty additionally call for a transdisciplinary research design, involving actors from the life-world as equal partners." The process of integrating knowledge from different disciplines as well as from the life-world is a great challenge which needs to be met through methodological innovation. In this sense, it could be also useful for the interaction with the beneficiaries for the local agreements.

The Annex 1 of this document introduces the Constellation Analysis methodological approach for bridging different knowledge from the specialists, stakeholders and beneficiaries in the agreements implementation (WP5) based on the AGREEMAR case study to demonstrate its application.

For that new social complementary approach, an invitation was sent to a list of stakeholders that could be potentially interested and determinate in the first phase of the social approach. The list of participants confirmed the group of interested stakeholders and their influence in implementing MAR.

3.5 Standards and regulations

In Portugal, water resources management is set by various laws and regulations, namely the Portuguese Water Law (Lei n. º 58/2005), which transposes the main European legislation relating to water – the Water Framework Directive –, and the Groundwater Directive (Decreto-Lei 208/2008), also transposing an EU directive.

The management of water resources – surface and groundwater – has the following three principles: right to access water; its protection, as an environmental asset; and its efficient use, as a scarce resource. Therefore, water legislation exists to protect available water resources in the long term, by controlling their use. The legal framework provides for the licensing of the water resources uses and requires compliance with quality standards for discharges into the water environment, seeking to ensure the gradual reduction of pollution and achieving the good status of surface waters.

There is also legislation that provides for planning the management of water use in the territory, in hydrographic regions, on the coast, in estuaries, and in public water reservoirs. This framework also includes dam safety and flood and drought risk management. The ownership of water resources is also defined in the law, to guarantee that certain areas and water resources are intended for public use.

APA, as the National Water Authority, is responsible for developing and implementing the legal framework. That is, to define policies and management instruments that ensure the application of the legislation principles. This role is shared with other entities – such as ERSAR (Water and Waste Services Regulatory Entity) – which regulates the supply of water for human consumption and the sanitation of urban wastewater.

The management of hydrographic regions is materialized through services deconcentrated in the territory: the Administrations of the Hydrographic Region (APA regional) of the North, Center, Tagus and West, Alentejo and Algarve. Furthermore, the regional administration (water authority) plays a crucial role in ensuring that the policies and regulations are effectively implemented and adhered to within its respective region, thereby enforcing and supervising the sustainable management of water resources.

3.5.1 European Water Framework Directive

See section 2.5.1.

3.5.2 Portuguese Water Law

The Portuguese Water Law (Lei n. º 58/2005) serves as a fundamental legal framework for the proper management of water resources in the country. Its operational form is the National Water Plan, a strategic instrument for the water management, which establishes the major options of the national water policy, as well as the principles and rules guiding that policy, to be applied by RBMP and other water planning instruments.

This legislation establishes regulations, rights, and principles aimed at ensuring sustainable and equitable use of both surface and groundwater, as well as the protection of aquatic ecosystems. Additionally, the Water Law regulates water uses, water rights, and usage concessions, as well as permits for discharges and works in the hydraulic public domain. It also addresses coordination among different public administrations and establishes mechanisms for monitoring and sanctions to ensure compliance with the legislation.

Specifically addressing groundwater management, this legislation focuses on the protection of aquifers, and prevention of overexploitation. The Portuguese water law states the following main measures concerning groundwater:

- Characterization of the existing aquifers in the hydrographic region, including the identification of resources, the delimitation of water bodies, and the determination of reference conditions.
- Identification of pressures and description of the significant impacts of human activity on the state of groundwater, with the assessment, among others, of source and diffuse sources of pollution, existing and planned uses and significant morphological changes, and the balance between water potentialities, availability and demands.
- Protection of wellhead protection areas, maximum infiltration zones, and vulnerable zones.
- Establishing and ensuring the operational status of monitoring networks and the analysis of the results of monitoring programs on the availability and status of groundwater, as well as on protected areas.
- Definition of environmental objectives for bodies of groundwater and protected areas, as well such as identifying the short, medium, and long-term socioeconomic objectives to be considered, particularly regarding water quality and wastewater discharge levels.
- Prohibition of direct discharges of pollutants into groundwater, except in specific situations that do not compromise compliance with environmental objectives, and control of managed aquifer recharge of these waters, including the establishment of a licensing regime.

Therefore, under to the Portuguese Water Law, MAR is considered as a complementary measure for achieving good chemical and quantitative status, provided that it does not result in adverse impacts. The need for proper MAR regulation is already outlined. Nevertheless, it does not yet exist.

3.5.3 Regulatory framework regarding MAR in Portugal

There is no specific regulation for Managed Aquifer Recharge (MAR) in Portugal. Nevertheless, there are two resolutions from the Parliament about MAR: Resolução da Assembleia da República n 86/2022 - Recommends that the Government encourages managed aquifer recharge to reinforce water efficiency, and the Resolução da Assembleia da República n 87/2022 - Recommends the Government to increase the reuse of treated wastewater. The watershed management plans also refer to the use of MAR, but no specific actions have been proposed. In 2024, the XIV Government Program refers as one action to be done “Implement a pilot project for artificial aquifer recharge”.

The MAR systems where natural recharge is enhanced are generally accepted (e.g., infiltration basins typically built to decrease flood impacts) and no restrictions are known. Typically, those projects are not “labeled” as MAR.

For the MAR systems using alternative water sources, such as treated wastewater, as the source of water for recharge, the water quality must comply with the quality standards listed in the Annex I of Directive 91/271/EEC (which regulates the discharge of wastewater, transposed into Decreto-Lei 152/97). The proponent must have a permit from the APA (Portuguese Water Authority) that defines the necessary Environmental Impact Assessment (EIA) studies to be able to acquire a license and the necessary monitoring procedures (before and after MAR).

Based on the Portuguese regulations, the following points are clear:

- MAR where natural recharge is enhanced are currently not being considered MAR, therefore they are not subject to an EIA.
- MAR systems using alternative water sources are still considered discharge according to Decreto-Lei 152/97 (transposition of Annex I of the Directive 91/271/EEC). A license for discharges and the necessary monitoring procedures can be obtained if the hydrogeological studies prove the harmlessness of the recharge project, although the concept of harmlessness lacks a legal definition.

The only official MAR site currently implemented in Portugal is the SAT-MAR at Comporta, representing an investment of 1.9 million euros. In this case, the promoter (Águas Públicas do Alentejo, AgdA) has made the Comporta WWTP Execution Project and submitted a Request for Prior Information (Pedido de Informação Prévia, PIP) to APA, as the licensing entity for discharges in the soil. PIP021704.2019.RH6 regarding the rejection of treated wastewater from the Comporta WWTP, sent on 14/10/2019, received a reply on 23/12/2020, requesting a hydrogeological study and a groundwater monitoring program. AgdA reply to this request was sent to APA on 08/07/2021, which approved the terms of the study in 13/07/2021, requiring to receive the results when ready. Based on the results of the study presented in 20/09/2021, APA emitted a license and in October 2021 the SAT-MAR started to operate. The PIP considers the discharge valid if the requirements of Decreto-Lei 152/97 are accomplished, meaning maximum levels for BOD5, COD, TSS, Ntotal, Ptotal, oils and grease. The groundwater monitoring program approved considers the following parameters: temperature, pH, EC, HCO3-, Cl-, Na+, Ca2+, Mg2+, K+, SO42-, Br, being the maximum concentration levels defined by APA (2021).

Regarding Water Reuse methods, the Portuguese legal framework already integrates a set of legal instruments, namely:

- Decreto-Lei 119/2019, which establishes the legal regime to produce water for reuse, obtained from the treatment of wastewater, as well as its use.
- Ordinance No. 266/2019, of August 26, which approves the information and signage to be used by producers and users of water for reuse (Água para Reutilização – ApR).
- Regulation (EU) 2020/741 of the European Parliament and of the Council, of May 25, 2020, which establishes minimum requirements for water quality and its monitoring and provisions on risk management, for the safe use of water for reuse in the context of integrated water management (directly applicable from June 26, 2023).

The objective of those instruments in Portugal is the following (APA, 2024):

1. Integrate the latest developments on the matter, notably at the European level.
2. Cover non-potable uses (urban, agricultural, forestry, industrial, landscape, among others) including ecosystem support.
3. Evaluate potential producers and potential users.
4. Define a flexible regime but with mechanisms that guarantee safety for health and the environment.

These ApR regulations are being tested in a set of pilot projects in partnership with the main water for reuse producers and the final users. At the moment, MAR technologies are not considered in those instruments, and mainly focus on the use in irrigation, urban (street washing, etc.) and industrial uses (Table 1).

Table 1 Institutional framework of the water sector in Portugal (adapted from Marques and Simões 2020, in Conrad et al., 2022b)

Source of treated wastewater (WW)	Type of systems	Uses / requisites	Risk evaluation
Urban **Domestic** **Industrial** **Others**	**Centralized** (Urban WW) – the only authorized to produce to third parties **Decentralized 1** – Only produces for own uses. Includes cooperation between industries **Decentralized 2** – Use of other types of water sources. Includes cooperation between different agriculture entities	**Non-potable uses** (irrigation, urban, industrial); Supporting ecosystems **Fit-for -purpose** (requires successful risk evaluation and implementation of barriers) **Autonomous production and use licenses** (always needed if the final user is different from the producer)	Complexity/project size/vulnerability of receptors Risk evaluation must include health and environment Health impact report (in all projects) Farming practices impact report (only required in agriculture and forestry related projects)

The lack of specific legislation for MAR operation in Portugal does not help its implementation, due to the apprehension and uncertainty concerning water quality preservation. It is likely that standards, regulations, and guidelines on water quality from other countries are considered, namely the more recent case of Italian legislation (https://www.gazzettaufficiale.it/eli/id/2016/06/13/16G00111/sg) regarding maximum allowable concentrations (MACs) and other legislative frameworks (e.g., https://doi.org/10.7343/as-2020-462)

3.6 Guidelines for Regional Agreement tailored to the Portuguese case study

An agreement is a written document where the roles and the responsibilities of the involved stakeholders are identified, both for the planning and implementation phases. A good agreement should guarantee that the relevant stakeholders are available and have the will to be involved in a MAR initiative, providing a roadmap for a feasible, sustainable, and successful MAR implementation. It also allows understanding and clarifying what kind of support must be provided by each to ensure a good MAR implementation.

The regional agreements for the Alentejo area, Portugal, could be considered for two situations: 1) the replication of Comporta SAT-MAR using other similar WWTP and 2) the use of MAR to infiltrate flood water in areas where floods typically occur. Having 1) in mind, based on all the WWTPs with similar treatment within the geographical area of activity of AgdA (one of the main stakeholders identified in the project) around 300 WWTP were identified, where 42 are intersecting aquifer systems (Figure 16). Many of these 42 WWTP identified are not yet ready for MAR and further investment is required, particularly in polishing the treatment system prior to infiltration, ensuring safety patterns. Concerning 2) flood prone areas defined under Decreto-Lei n.º115/2010 - the transposition to the Portuguese law of the Floods Directive – were identified in one of the aquifer within the study area (*Bacia de Alvalade*), corresponding to one of the high feasibility areas presented in section 3.2.

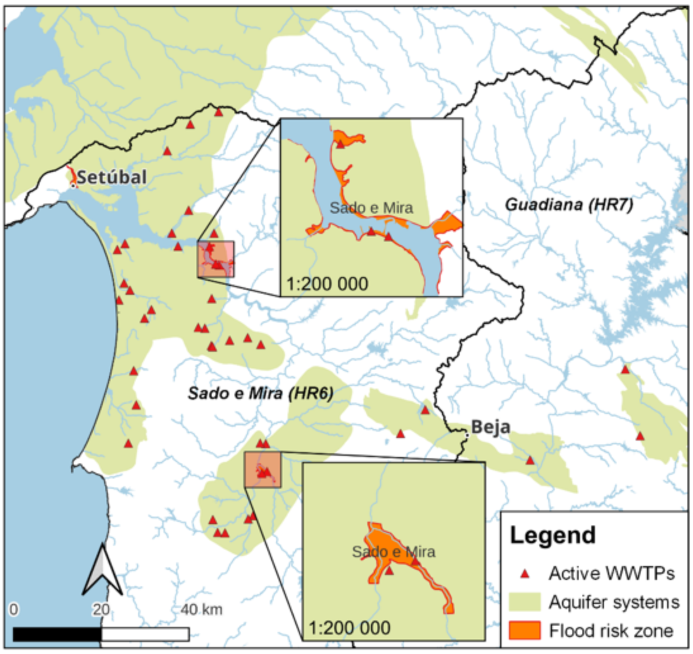


Figure 16 WWTP and flood risk zones located within the main groundwater bodies area in the Alentejo region (map developed from the information available in SNIAMB 2024 (https://sniamb.apambiente.pt/)

This information can be used for future MAR agreements, when complemented with all the necessary aspects to support specific agreements, namely technical, social, and economic. The agreements can be made among the stakeholders, promoters, and beneficiaries, provided that the following information is gathered, including the information required to receive a license for operation:

- Detailed description of the MAR project, including the structural and operational characteristics of the MAR technique to be used (e.g., infiltration basins, trenches, etc.). Include a preliminary cost-benefit analysis (initial investment and operational costs vs economical and/or environmental benefits achieved [e.g., "is there potential benefits to the surrounding ecosystem services?" [Y/N], "If Y, are they water, agriculture, cultural, ecological?", "Is there any relevant economical sector possibly identified? Which one: tourism, industry, agricultural, urban supply?", "Expected initial cost of infrastructure?", "Costs regarding infiltrated and recovered (if applied) [€/m^3]?")

- Compliance with Decreto-Lei 152/97 (Directive 91/271/EEC), i.e., with water quality standards for discharges. Presently in Portugal MAR does not have specific legislation and, in the example known, MAR was considered a discharge and had to comply only with Decreto-Lei 152/97. It is our opinion that recharge water quality for MAR should consider other parameters related to the source of water for recharge. Other countries' legislation should be considered (cf. section 3.5).
- Compliance with Lei n.º 58/2005 (Water Framework Directive) and Decreto-Lei 208/2008 (Groundwater Directive) with a hydrogeological and groundwater monitoring program. The studies can start by using a 1st approach with MAR feasibility maps, and a detailed study of the aquifer characteristics, hydrogeology (permeability, transmissivity, storage), existing water quality, proof of no environmental impact nor groundwater contamination, MAR volume contribution to the aquifer, groundwater monitoring program, environmental indicators, groundwater numerical model, etc.). Pilot tests or any other hydrogeological works can be defined at this stage.
- Specification of the volume of water available to be recharged, considering existing and future scenarios for water demand and availability (e.g., feasibility maps).
- Identification of the potential stakeholders that should be involved and their levels of engagement, benefits, and obligations. The use of feasibility maps (considering water demand, water availability, and area suitability) to identify suitable MAR areas, of the results from the hydrogeological study, of the monitoring data collected, and of future scenarios, if possible, using numerical models, can be the basis to initiate stakeholder engagement and to discuss their involvement and role.
- Information about the public consultation to guarantee transparency, accountability, and inclusion in decision-making.
- Reporting on the results of MAR in the hydrogeological system, e.g., as changes in water quality and groundwater levels.
- Specification of the cost and benefits of implementing and maintaining MAR (including monitoring), and its distribution among stakeholders. This covers the economic aspect of the agreement at a local level. The financial obligations required to implement MAR must be described, including the costs associated with infrastructure development, maintenance, and operation.
- In Portugal, the river basin authorities have the decisional capabilities to approve these studies and to give the operating license permit. All the necessary resources, permissions, and timelines should be clearly defined and agreed upon by all parties involved in the MAR agreements.
- Propose the Constellation Analysis as an optional methodology to the conventional mode of analyzing and structuring decision making in relation to the implementation of MAR. The methodology, further described in Annex 1, integrates and relates the various elements determined in AGREEMAR, working as a structuring tool and as a facilitation instrument for the realization of agreements and governance policies.

3.7 Conclusions of the Portuguese case study

Portugal, like many other Mediterranean countries such as Spain, faces several challenges related to water scarcity due to its climate, geography, and socio-economic activities. To address these challenges and improve the water resources management, the country has deeply invested in surface water storage since 1960, and more recently in different water management strategies that included measures to promote water conservation and efficiency, namely through the investment in more adequate water supply infrastructures. A more financially modest and recent investment is being made in enhancing water reuse and recycling practices, increasing public awareness about the importance of sustainable water management through the integration of non-conventional water sources. Within this context, MAR is not yet receiving the attention it deserves, as most permits for water reuse are given for direct use in irrigation and street cleaning. Even the existing MAR structures, such as infiltration basins to accommodate flood water, are not seen as MAR and in most cases no monitoring exists. So, besides some experimental MAR infrastructures (e.g., rio Seco, Algarve, https://web.archive.org/web/20230321113040/http://marsol.eu/files/marsol_d4-5_mar-south-portugal_final-report.pdf), the only MAR system currently working with a permit is the Comporta case-study site.

Trying to understand the delay in MAR application in Portugal, three AGREEMAR stakeholder meetings were held, and this issue was deeply discussed (e.g., Annex 2). It was clear that the main existing constraints that hold MAR application in the country are: 1) it is not clear which are the more feasible areas for MAR; 2) it is not clear who are the beneficiaries; 3) it is lacking proof that the water quality to be infiltrated will not deteriorate the groundwater quality; and 4) it is missing a legal framework for the implementation of MAR. This reality makes the development of the MAR approach conceived by the AGREEMAR methodology even more important and motivating since it will contribute to reply to the first two questions (cf. sections 3.2 and 3.3), and a sister project, MARCLAIMED, is now contributing to reply to the third question. Nevertheless, and also based on the results from AGREEMAR and other MAR projects presented, the different stakeholders have shown a clear interest and even willingness to apply MAR if clear answers to the previously stated questions are provided. Presently, and considering that there are not yet new specific MAR projects with studies done to be implemented (although several MAR potential projects were identified), the different stakeholders have not yet shown the willingness to sign an agreement for the implementation of MAR. However, this does not mean that they will not do so in the future, based on the results of the necessary studies to implement MAR. Having that in mind, and to contribute for future agreements, the following issues should be considered, based on the discussions conducted with the stakeholders. The main premise is that, in the future, these agreements serve a specific purpose by providing a clear roadmap for implementation well integrated in the national and European legal framework.

Hence, a first step for MAR application is to consider MAR in the European and national strategy for the valorization and use of treated wastewater, namely the closing of the water cycle. It is on this premise, and on the idea of integrated water resources management, that future implementation agreements can be based.

The second step concerns the agreements tailored to the Portuguese case study. They should refer to the:

1) MAR project objective [see AGREEMAR Deliverable D2.1 (Panagiotou et al., 2022) for a complete list of possible implementation objectives];
2) MAR recharge methods to be used [see AGREEMAR Deliverable D2.1 (Panagiotou et al., 2022) for a complete list of possible implementation methods];
3) targeted aquifer(s) and, if applicable, the surface water bodies impacted or benefited (e.g., wetlands, protected areas);
4) priority areas for implementation based on MAR feasibility map and (if possible) pre-feasibility study (e.g., Boolean flowcharts) [see Deliverable D2.3 (Chekirbane et al., 2023)];
5) environmental impact assessment where all the geographic and climatic features are characterized;
6) clear identification of impacts and beneficiaries (e.g., models, dissemination, and participatory methodologies, such as Constellation Analysis, to gather critical mass);
7) quality and operational indicators (e.g., which alert indicators stop MAR operation);
8) possible funding mechanisms to cover initial investment cost (e.g., based on the RBMPs);
9) consider the Portuguese legislation, namely, to comply with existing standards and regulations;
10) established economical value for the infiltrated water which can be established as a possible benefit (co-payment or water tariff discount) to the entity that promotes the safe and environmentally responsible implementation of MAR to partially cover operational costs.

MAR methodologies should be aligned with the principles and values of sustainability, coming out not only from the established national and European environmental goals but also from the forefront of Reflexive Modernity (Beck, 2013), both in the adaptation of technological innovation, with the use of technology inspired by nature, and in the adaptation of social innovation, with the use of participatory methodologies, where stakeholder engagement, public participation and conflict resolution can take place in a transparent and constructive manner. The robustness of the methodological framework, based on theoretical framework and on similar successful examples carried out in other countries and, in the case study of Portugal, allows us to affirm that such a methodology could serve as a guide for the implementation of MAR methods in other locations, observing the necessary adaptations to each environmental and social reality. At the time this document is being published, the results obtained so far suggest that the use of the participatory methodology Constellation Analysis can be a facilitator of the realization of future agreements for successful and sustainable implementation, not only from a technical point of view, but also from a socio-political point of view.

4. The Tunisian case study in the Chiba watershed

4.1 Preliminary assessment

The Chiba watershed covers the southeastern part of Djebel Abdurrahman within the Nabeul governorate. Spanning latitudes 36°41′N to 36°47′N and longitudes 10°45′E to 10°56′E, it encompasses approximately 204 km^2, including both upstream and downstream areas of the Chiba Dam. Characterized by forested upstream regions and mainly farmland downstream, the watershed hosts the Korba Aquifer, a crucial coastal aquifer supporting downstream water needs. Main crops like tomatoes, peppers, and potatoes require substantial water, with annual precipitation averaging around 400 mm/year and October witnessing the highest precipitation at approximately 66 mm/year and July the lowest at 1.78 mm/year (INM , 2021). Facing an annual water deficit of less than 754 mm from February to October, the region's evapotranspiration is estimated at 1440 mm/year (Khemiri et al., 2024). Geological formations within the watershed range from the Eocene to the Quaternary, with predominant soil types including calcimagnesic, alluvial, and colluvial (Ennabli, 1980). The Chiba Dam, constructed in 1963 with a storage capacity of about 5 million m3, serves as a vital water source for downstream irrigation, although prolonged drought has depleted its reservoir, affecting regional irrigation (MARHP, 2006). To address this, several wells have been developed within the watershed. The aquifer system comprises two distinct layers separated by a Pliocene-formed layer, contributing to its hydrogeological properties and water storage and transmission capabilities (Ennabli, 1980).

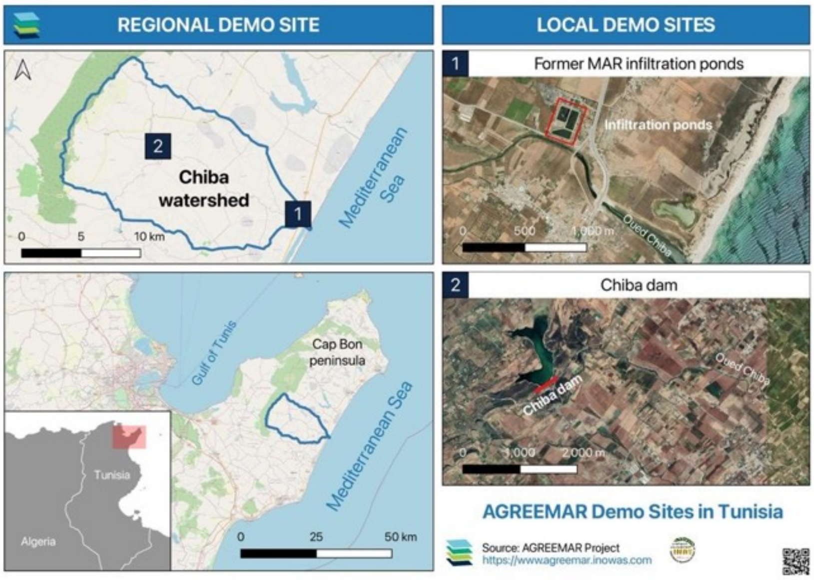


Figure 17 Tunisian case study location (Chekirbane et al., 2023).

In Tunisia, coastal aquifers are subject to various pressures resulting from the overexploitation of groundwater resources, mainly for agriculture. These pressures have exacerbated risks such as pollution, declining groundwater levels, salinization, and seawater intrusion (Chekirbane et al., 2013). Artificial groundwater recharge began in the 1970s as pilot projects and became an effective water management method in the 1990s (DGRE, 1990). This approach has produced promising results in restoring groundwater levels. For example, in the coastal aquifer of Teboulba, a significant increase of 30 m in groundwater levels was observed (Bouri and Ben Dhia, 2010). Similarly, in the Kairouan aquifer in central Tunisia, water levels rose significantly from 0.2 to 5.25 m in five months of artificial recharge, using a total volume of water of 13 Mm^3 from the Sidi Saad dam (Bel Hadj Salem et al., 2012). The recharge also had a positive effect within an 8-km radius of the injection wells, increasing water levels. Some studies have confirmed similar increases in water levels in aquifers such as the El Khairat underflow, with an increase of 2.6 m following recharge initiatives between 2002 and 2005 (Ben Brahim-Neji et al., 2014). However, Tunisia recognizes the need to adapt methods of artificial groundwater recharge, by using treated wastewater as an alternative to conventional water resources. Although the use of treated wastewater for recharge purposes began in the 1980s for irrigation and to combat seawater intrusion, its application remains limited and fragile (DGRE, 2005).

The Chiba watershed is notable for its significant agricultural activity and the excessive extraction of groundwater from the Korba aquifer, leading to declining groundwater levels and salinization over the past three decades. This aquifer, downstream of the Chiba dam, has been subject to exploitation (Nebli, 1980; Ben Hamouda et al., 2011; Chekirbane et al., 2013; Zghibi et al., 2019). To address these issues, water authorities proposed the creation of the Korba–Elmida artificial recharge site, located 1.5 km from the Mediterranean Sea and approximately 300 m north of the Korba wastewater treatment plant, utilizing treated municipal wastewater. The current site employs a Soil Aquifer Treatment (SAT) process with three ponds covering 1500 m^2 each, targeting a recharge rate of 1500 m^3/day. However, challenges such as clogging, insufficient treated wastewater, and small infiltration basins have hindered its effectiveness in mitigating groundwater depletion, unlike the existing piezometric depression (Gaaloul et al., 2012). This highlights a broader sustainability challenge facing MAR initiatives in Tunisia and specifically within the Chiba watershed, where initiatives have often been reactive measures to quantitative and qualitative degradation, rather than pre-emptively assessed through mapping techniques prior to implementation.

4.2 Identification of potential MAR sites

The feasibility map was created through weighted evaluations by stakeholders during the validation workshop of the results of work package 2, which took place at INAT on 13 July 2023. Using pairwise matrices, stakeholders selected the scenario that prioritizes water availability, aligning best with their preferences and priorities for MAR in the Chiba watershed. The assigned weights are as follows: Intrinsic site suitability: 19.6%; Water availability: 49.3%; Water demand: 31.1%. The resulting maps show similar patterns for both dry and wet seasons. Areas where MAR is feasible and highly feasible are primarily situated near the coastal region, characterized by suitable intrinsic site conditions, availability of conventional and non-conventional recharge water resources, and high agricultural and ecosystem demands. The high feasibility areas adjacent to the water supply network underscore the significance of the water availability aspect (with a weight coefficient of approximately 50%). Low feasibility zones are found in the upstream part of the watershed where intrinsic characteristics are unsuitable (e.g., steep slopes exceeding 20°) and recharge water is scarce.

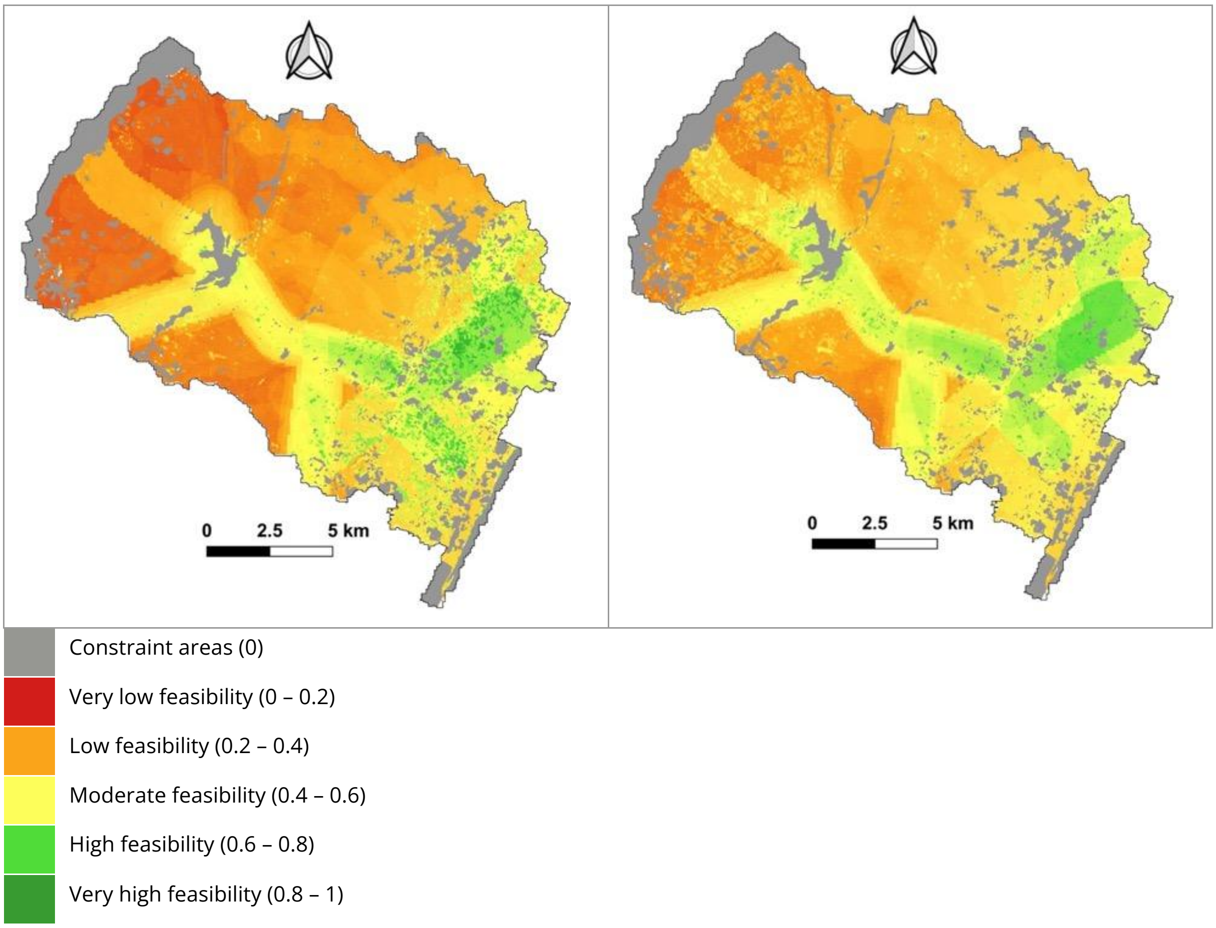


Figure 18 MAR feasibility maps of the demo regions in Tunisia (Chekirbane et al., 2023).

Considering the MAR objectives and typology of the Chiba watershed, the most relevant MAR schemes could involve infiltration basins and Soil Aquifer Treatment (SAT) near the coastal region to mitigate seawater intrusion, utilizing treated wastewater from the Korba Wastewater Treatment Plant. However, in the dam region, water release and check dams could efficiently contribute to long-term groundwater storage. Existing dug wells in public irrigated areas could serve as a MAR scheme based on the concept of injection wells.

4.3 Technical assessments based on numerical modelling

The technical assessment of the selected MAR site aims to validate the feasibility map and analyze the impact of MAR on both the water uses and aquifer dynamics in the basin. For this reason, the AQUATOOL DSS is utilized in the Tunisian case study. This tool helps to address various water use objectives and provide stakeholders with results that help in analyzing the impact of MAR and discussing the possible implementation of MAR agreements.

The model developed for the Chiba River Basin provide a basis for assessing the impact of MAR on different water uses within the river basin (Figure 19). It considers aquifer dynamics, surface-water interactions, groundwater interactions, and environmental factors across the simulated scenarios. Stakeholders' perspectives and regional expertise guided the selection of these scenarios.

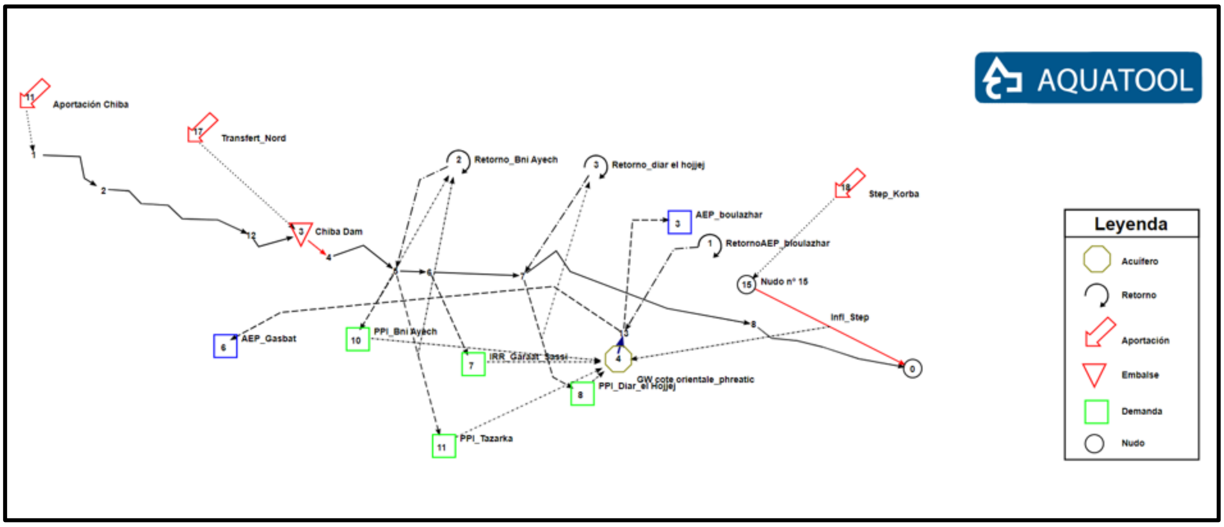


Figure 19 Topology of the AQUATOOL model of the Chiba River Basin.

The assessment carried out in the Chiba River Basin involved the simulation of four scenarios to assess the effectiveness of different measures improving aquifer sustainability and meeting water demand. The four MAR scenarios analyzed include Scenario 1, representing the current state without MAR; Scenario 2, involving MAR via the Korba wastewater treatment plant; Scenario 3, employing MAR directly from the Chiba reservoir; and Scenario 4, which combines MAR from the Chiba reservoir with operational rules for aquifer recharge during periods of water surplus. Each scenario was developed in consultation with stakeholders to explore the potential of MAR in the region.

The assessment of the different scenarios reveals their effectiveness in aquifer replenishment and water demand reliability. The results indicate an improvement in aquifer water volume in the scenarios where MAR was used. MAR using water from WWTP required firstly ensuring water quality for recharge, and resulted in an improvement in net aquifer recharge, as this unconventional water resource provides an additional source of water for infiltration. MAR through water from the Chiba dam presents the most effective scenario in terms of optimizing the net recharge of the aquifer, but giving it priority, as was done in scenario 3, puts direct pressure on the agricultural water demands that rely on water from the dam. On the other hand, MAR using water from the Chiba dam only during periods of excess water improves net recharge and ensures water supply to agricultural water demands.

More details on model results about the effects of MAR on the evolution of aquifer and its impacts on other water uses in the Tunisian case study are provided in Deliverable D4.1. These results are based on the joint implementation and application of the water allocation model and the aquifer models of the AQUATOOL DSS, which have been performed in the framework of WP3 (adaptive governance framework) and WP4 (validation through numerical modelling).

4.4 Identification of stakeholders and their relationships

A mapping of key stakeholders has been developed for the Tunisian case, categorized by local, regional, and national scales, as well as their sectoral roles and interests in the project (Figure 20). Members of the AGREEMAR project have ensured consultation, involvement, and collaboration with stakeholders at each demonstration site. This has been realized through various activities, including an engagement mission and needs assessment conducted from December 12 to 16, 2022, where interactions with major stakeholders such as the DGRE, BPEH, DGGREE, ONAS, Nabeul CRDA, ANPE, DGEQV, UTAP, and CERTE were carried out. Additionally, the first AGREEMAR project steering committee meeting on March 14, 2023, at INAT facilitated discussions on project methodology and preliminary results from feasibility mapping (WP2) and numerical modelling (WP4). Meetings such as the validation meeting for WP2 results on July 14, 2023, and engagements with the DGRE and the Tunisian Association for the Protection of Nature and the Environment (ATNPE) of Korba further enriched collaboration and discussion on project activities and ecological considerations.

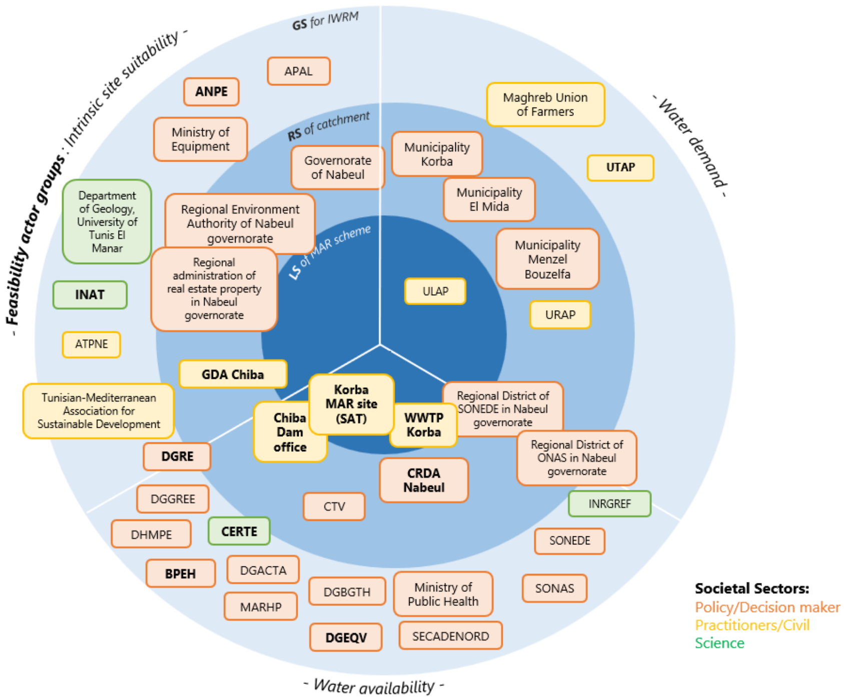


Figure 20 Stakeholder map for Chiba Watershed, Tunisia (Conrad et al., 2022b).

4.5 Standards and regulations

In Tunisia, specific legislation on MAR is limited or absent. It was only once recognized by the water code (1975) in its sixth chapter, Article 87, as a beneficial measure for water resource development (Closas et al., 2018). MAR is administratively belonging to the activities of the General Directorate of Water Resources in the Ministry of Agriculture, Hydraulic Resources and Fisheries (MAHRF). The Sub-directorate of "Artificial recharge" is responsible for planning new MAR schemes, monitoring, and management of the existing MAR projects. On the regional scale, MAR is a sub-activity of the water resources department at every regional commissariat of agricultural development (CRDA). MAR is strictly dependent on the recharge water availability, which is planned by the Bureau of Planification and Hydraulic Equilibrium (BPEH) in the MAHRF and allocated mainly by the National Company of North Water Canal and adductions exploitation (SECADENORD) and the existing dams for conventional water. Unconventional water, especially treated wastewater is provided by WWTPs belonging to the National Sanitation Utility (ONAS). Other administrations are involved in MAR monitoring, especially in the case of TWW reuse: principally the National Agency of Environmental Protection (ANPE) and the directions of hygiene and environment protection (Ministry of Public Health).

4.6 Guidelines for Regional Agreement tailored to the Tunisian case study

Due to the legal binding aspect of agreements, the preference of the Tunisian stakeholders – as it was assessed during the engagement activities - is going to a lower legal binding tool such as Memorandum of Understanding (MoU), charter, etc. Such document will be used because the parties prefer to outline their intentions and establish a mutual understanding without entering into a binding contract.

The provided document should include a comprehensive description of:

- The procedure of acquiring an authorization: the general water authority, represented by the General Directorate of Water Resources in the Ministry of Agriculture, Hydraulic Resources and Fisheries is the responsible authority to deliver such permission. This consent requires a prior study of impact of the MAR project of the groundwater quantity and quality of the target aquifer. Results of numerical models can serve as an asset in this aspect.
- The MAR typology: the conducted MAR feasibility mapping study can address this issue by pointing out the suitable location of the MAR project implementation, simultaneously with the most adequate MAR scheme.
- Information about the recharge water source: although mentioned during the MAR feasibility mapping, the available water for recharge should be discussed. Qualitative assessment can cover not only the ordinary quality parameters such as salinity, nitrate, BDO, CDO, etc., but also the suspended materials and colloids (first cause of clogging) as well as some representative indicators of the contaminants of emerging concern (CECs). The temporal availability of recharge water should also be highlighted together with the possible conflicting usages.
- Overview about the different stakeholders: a clear vision about the engagement, benefits and obligations should be summarized.
- Economical study: once the MAR typology specified, the costs of the project implementation should be determined and shared with the stakeholders. A specific report detailing the infrastructure development as well as its maintenance and operation is required.
- Time frame: information about the duration of the MAR project implementation is necessary.

4.7 Conclusions of the Tunisian case study

The Chiba watershed, like many areas in Tunisia, faces significant challenges with water availability due to limited rainfall, over-extraction of groundwater, and the impacts of climate change. MAR offers a strategic solution by storing both conventional and non-conventional water into the aquifer. This not only helps in replenishing depleted groundwater reserves but also improves water quality by mitigating salinity and combatting seawater intrusion. Furthermore, implementing MAR can support agricultural activities, which are vital for the local economy, by ensuring a more reliable water supply for irrigation.

To achieve these goals, a participatory approach in MAR project is needed for the Chiba watershed. In fact, it can greatly enhance its success by involving local communities and stakeholders in every stage of the project. This involvement ensures the incorporation of local knowledge, fosters a sense of ownership, and builds trust among participants. Moreover, formal agreements among stakeholders can solidify commitments, clarify responsibilities, and establish clear guidelines for cooperation, ensuring that all parties are aligned and accountable, thereby enhancing the project's effectiveness and sustainability. Nevertheless, due to the legally binding aspect of the agreements, other forms can be considered such as MoU or charters as usually suggested by the stakeholders during the engagement and interaction events with them.

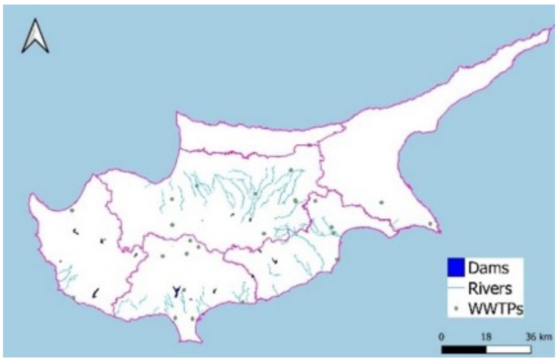
The local agreements (or MoUs) tailored to the Chiba watershed should include clear roles, benefits and obligations of the stakeholders. The chosen MAR typology as well as the necessary implementation steps including authorization and preliminary technical and economic studies together with the time frame of project realization are necessary information that should be highlighted in these agreements.

5. The Cypriot case study

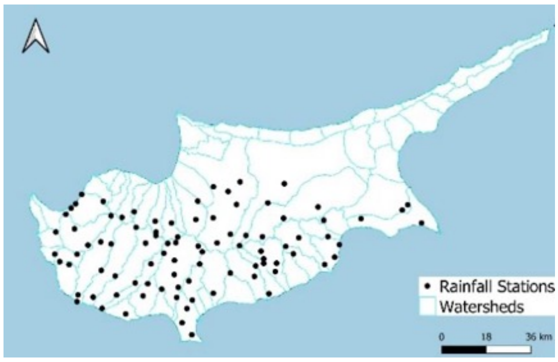
5.1 Preliminary assessment

The island of Cyprus is located in the south-eastern part of the Mediterranean basin, with longitude varying between 35.05 o and 35.68 o and latitude varying from 33.02 o and 34.08 o, covering a projected area of 9251 m^2. Cyprus is partitioned into six administrative districts (Figure 21a), namely: Limassol, Nicosia, Paphos, Larnaca, which are under the effective control of the Republic of Cyprus, whereas Famagusta and Keryneia are located within the occupied part of the Republic. The government is represented at each district via district offices, who coordinate the activities of all Ministries in the district. According to UNESCO (1979), the climate of Cyprus is characterized as semi-arid.

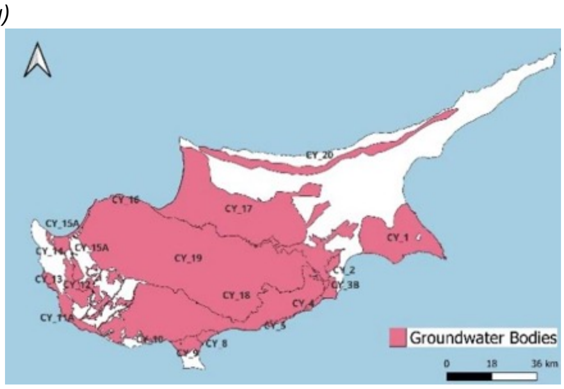
The hydrological network contains 70 major watersheds, whereas 90 rainfall stations are currently installed within the non-occupied part of the Republic of Cyprus (about 64% of the total area) that provide daily precipitation values (Figure 21b). Numerous ephemeral rivers are present in the island, stemming from the Troodos mountainous range where the highest precipitation amounts are observed. Numerous dams (108 in total) are constructed downstream of these rivers to store these amounts, whereas part of the rainwater percolates the vadose zone and recharges the local aquifers. There are sixty-six aquifer systems, mainly phreatic aquifer which originate from either coastal or river alluvial deposits, which are grouped into 20 groundwater bodies (Figure 21c).



(a)



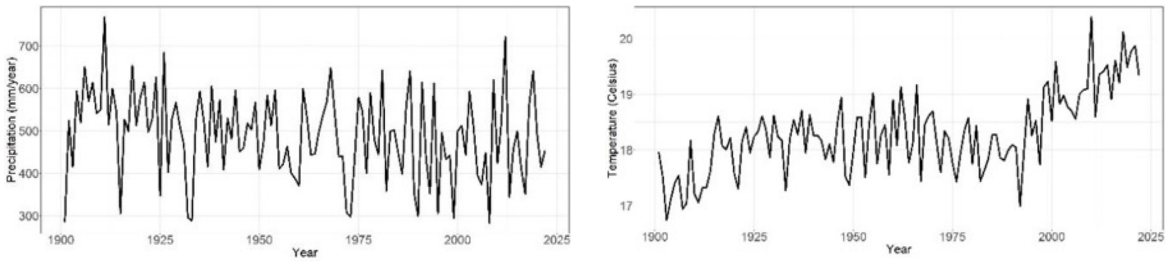
(b)



(c)

Figure 21 Geographical distribution of (a) the ephemeral river network, the major dams and the WWTPs; (b) major watersheds and the ground-based rainfall stations and (c) groundwater bodies, containing sixty-six aquifers.

According to the Climate Change Knowledge portal, the long-term annual mean precipitation values ranged from 282 mm to 768 mm for period 1901-2022 (Figure 22a), whereas the annual mean air temperature ranged from 16.74 to 20.39 oC, having a distinct increasing trend during the last two decades (Figure 22b). Highest precipitation values are observed in the inland, mountainous part of the island, mainly covered by Troodos massif.



(a) *(b)*

Figure 22 Long-term time series (1901-1922) for (a) annual mean precipitation and (b) annual mean temperature.

According to the Department of Geological Survey, Cyprus consists of four major geomorphologic regions:

- The Troodos Mountain range, located in the central-western part of the island, having the highest elevation peak at Mount Olympus, measured at 1951 meters above sea level (m.a.s.l.)
- The mountain range of Pentadaktylos, being relatively small in width, which extends along the northern coasts of the island, having peaks up to 1000 m.a.s.l.
- The plain of Mesaoria which is crossed by two rivers, namely Pediaos and Gialia. This zone extends between the Troodos and Pentadaktylos mountain ranges and exhibits low terrain elevations.
- The coastal plains and valleys along the coasts.

Figure 23 shows the spatial distribution of the hydrogeological formations. The largest formation is observed at the central part of the island, covered by Troodos Ophiolite Complex. It is considered one of the most well-preserved and well-studies ophiolites globally, comprising plutonic, mantle, extrusive and intrusive rock units. A fractured, unconfined aquifer exists in this region, caused by the rapid lift of ultramafic units and subsequent faulting and fracturing of the ophiolite rocks (Christofi et al., 2020). A list of all formations, and their connection with water bodies, is provided in Table 2.

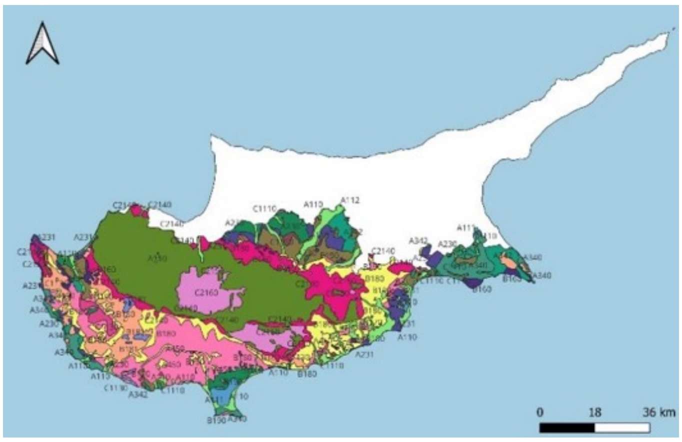


Figure 23 Hydrogeological map of Cyprus (showing only the non-occupied part of the Republic of Cyprus).

Table 2 Description of the hydrogeological formations that exist in the study area.

Formation code	Description
A110	Unconfined water generally at shallow depth in connection with riverbeds, deltaic gravel-sand deposits and including estuarine deposits.
A111	Water in alluvial deposits with impermeable to semi-permeable surface
A112	Clay and silt of undefined thickness containing water-bearing lenses of sand, underlain by generally impervious marl or siltstone, water commonly mineralized
A230	Unconfined water in marine and terrestrial fanglomerate and terrace formations, locally including calcarenite.
A231	Very shallow ground water controlled by the configuration of underlying silt, clay or marl, in some formations as above

Formation code	Description
A340	Unconfined ground water in sandstone, sandy marls and calcarenite (i.e. Nicosia formation), mineralized at depths and along coast by sea water intrusion
A341	Confined ground water in sandstone, sandy marls and calcarenite (i.a. Nicosia formation), mineralized at depths and along coast by sea water intrusion
A342	Shallow unconfined ground water controlled by the configuration of impervious or semi-pervious strata, in same formations as above
A450	Unconfined ground water in sandy parts of Middle Miocene (Pakhna formation)
B160	Unconfined ground water in reef limestone and detrital limestone (Koronia limestone, Terra limestone), saline in coastal areas
B170	Unconfined ground water in gypsum aquifers, saline in deep confined aquifers
B180	Unconfined ground water in aquifers of secondary importance of mainly massive, highly retentive chalk, occasionally mineralized
B181	Unconfined ground water in aquifers of secondary importance consisting of cherty, locally marly chalk, sometimes including strata of massive chalk (Chalks of the Lapithos formation of the Kyrenia Range included), occasionally mineralized
B190	Ground water in highly retentive rocks sych as chalk interbedded with marls (Pakhna formation and Lapatza formation)
C1110	Clay, marl and siltstone (Mainly rocks of the Mesaoria Group locally including marl, silt and clay of the Allyvium)
C1130	Mamonia Complex, including serpentine
C2140	Volcanics with dominantly submarine pillow lavas, occasional pockets of highly saline water
C2150	Heavily fractured intrusive rocks
C2160	Plutonic rocks, springs common

Cyprus possesses the highest water exploitation index among the European member states due to the combined effect of extensive drought periods and excessive water exploitation to satisfy the continuously increasing water demands due to population growth and economic development (Eurostat, 2024).

The agriculture sector consumes the majority of the water resources, accounting for 64% of the island's water resources. The other water consuming sectors are the domestic (28.4%), tourism (4.7%) and industry sector accounting for 2.9% of water demands (WDD Annual report, 2022).

Due to the limited freshwater resources, the water authorities promote the use of non-conventional water resources (desalinization and treated wastewater) as an alternative choice. According to the most recent annual report of the water authorities (Christofi et al., 2020), about 53 Mm^3 desalinated water are used to satisfy the drinking water supply, whereas treated wastewater is currently reused in agriculture and livestock, as well as green areas. As pointed out by the ex-director of WDD (Hadjigeorgiou, 2015), the long-term objective of the national water authorities is to use treated wastewater for covering at least 40 % of the irrigation needs of the agricultural sector, which consumes the majority of the water supply quantities, followed by the domestic and tourism respectively. Regarding the allocation of treated wastewater, the agriculture sector consumes the majority of the produced amounts (>70 %), whereas a significant portion is used for artificial recharge at the two MAR sites (Ezousa and Akrotiri, Figure 24). The remaining portions are either transferred to Polemidia dam or discharged to the sea.

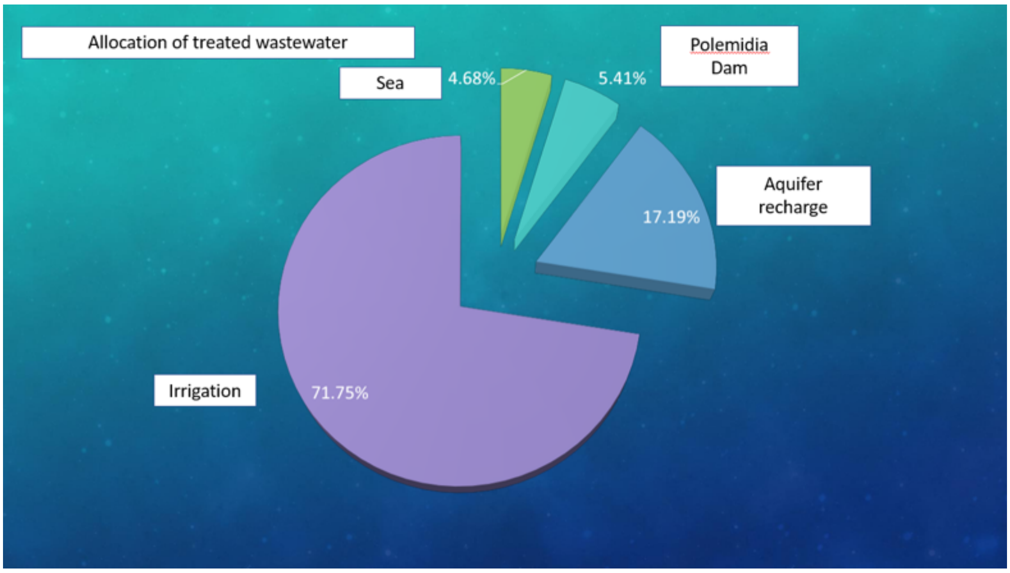
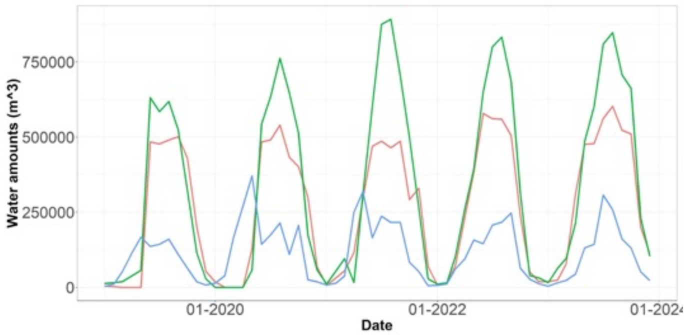


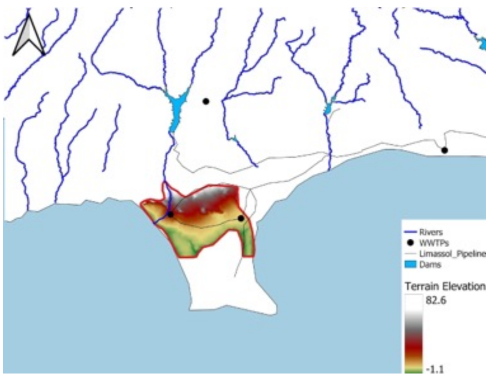
Figure 24 Distribution of the treated wastewater in a national level. Picture taken by Christidou (Water Development Department, 2018)

Local Site: Akrotiri area

Water is allocated from different sources to cover the irrigation needs within the study site, particularly groundwater (from wells located outside the study area), dam water and treated wastewater, and groundwater abstracted from Akrotiri aquifer. Around 12 Mm^3 per year are required to satisfy the crop irrigation needs within the study area. The main economic activities are related to agriculture sector, although recently the domestic sector experiences rapid development in this region.



(a)



(b)

Figure 25 (a) External water sources used to satisfy the irrigation needs in Akrotiri region. Green line denotes the amount of water extracted from irrigation wells (outside the study area), red lines denote the amount of wastewater that is directly allocated for irrigation, and blue lines denote the water amount collected from three nearby dams: Kouris, *Polemidia and Yermasoyia. (b) Basic information regarding Akrotiri site (terrain elevation, dams, rivers and wastewater pipeline network).*

There are currently two MAR schemes operating in the non-occupied part of the island, both using treated wastewater as water source and infiltration ponds as a recharge technique. These systems aim at preventing the seawater intrusion and storing water for later use, mainly in agriculture. The first MAR facility is located close to Limassol urban area (southern part of the island) and recharges the Akrotiri aquifer between 1 and 4 Mm^3 during winter period, whereas the surplus of the treated wastewater is discharged into the sea. The second MAR scheme is installed close to Paphos urban area, located in the southwestern part of Cyprus, and recharges the Ezousa aquifer 1.7-4.7 Mm^3 in an annual basis. This choice is recommended by the water authorities (personal communication) as the only MAR technique suitable for recharging the groundwater systems with treated wastewater due to quality considerations (e.g., additional microbial and chemical purification processes via water-rock interactions).

Figure 26 shows a schematic overview of the MAR scheme, which can be separated into six steps. Particularly, raw wastewater is gathered from the urban area (Step 1) and is discharged to Wastewater Treatment Plant (WWTP). There, the influent is subjected to three consecutive treatment processes (Step 2): primary, secondary and tertiary (Panagiotou, 2023). After pre-treatment, the effluent is distributed through pipeline networks to infiltration ponds (Step 3), from which it percolates until it reaches the saturated zone and is mixed with the ambient groundwater (Step 4). Eventually, groundwater is extracted from multiple wells (Step 5), located nearby the infiltration basins, mixed with dam water and then distributed to the end-users (mainly farmers) through canal (Step 6).

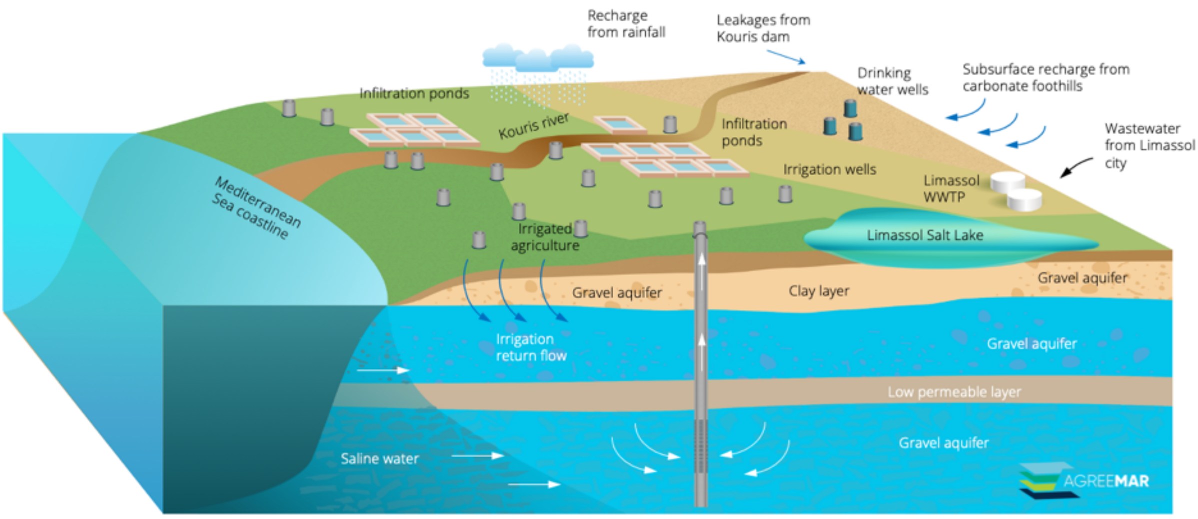
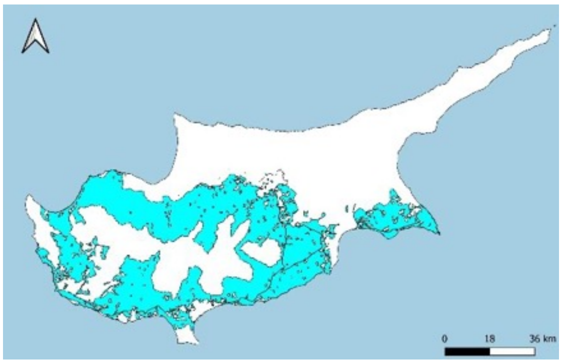


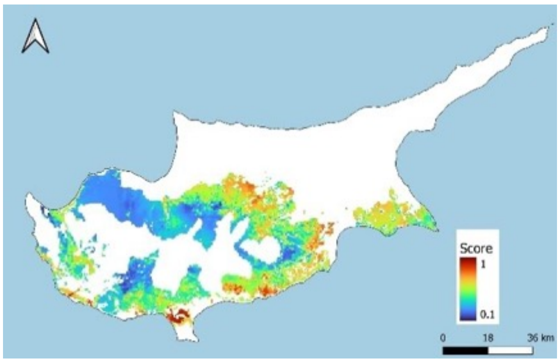
Figure 26 Sketch of the MAR concept in Akrotiri MAR site.

5.2 Identification of potential MAR sites

The only feasibility study for MAR in Cyprus has been conducted recently by Martins et al. (2022). In their study, the authors applied an integrated approach for the identification of eligible locations for MAR via the active involvement of key stakeholders from the water sector at several stages of a multi-criteria decision analysis (MCDA) for ensuring the acceptance of the outcomes. Twelve criteria have been selected to characterize the intrinsic suitability, water availability for MAR, and water demand based on information collected from literature, discussions with MAR experts and technical reports which are conducted to assess the environmental impact of MAR facilities currently operating in Cyprus. Particularly, seven criteria are selected to assess the three thematic layers, particularly intrinsic suitability (i.e., terrain slope, aquifer geochemistry, land-use land-cover, thickness of vadose zone, aquifer hydraulic conductivity, aquifer specific yield and aquifer storage), water availability (i.e., proximity to wastewater distribution networks, actual evapotranspiration, quality standards of the source water and amount of water available for MAR) and water demand (crop irrigation needs). Weights are assigned at each criterion during stakeholders' workshops to compile the thematic maps. Subsequently, the three thematic maps are used to generate the feasibility map (Figure 27). The results suggested that the most feasible regions for MAR are located close to the southern and south-eastern coastline, along with a large-scale region in the central part of Cyprus, close to Nicosia urban area. The inland part of Cyprus is characterized by low feasibility potential, which can be attributed to a number of factors, such as the sparse presence of crop fields and the frequent and intense presence of rainfall events, steep terrain slopes, distant areas from existing infrastructures, limited availability of wastewater for MAR, etc. In addition, the direct involvement of key stakeholders at multiple stages of the decision analysis enhances the transparency and trust among the multiple water-related sectors. Overall, the regions where the two MAR schemes are currently operating (Ezousa and Akrotiri) are found to be highly feasible for MAR, supporting the decision of the water authorities. Furthermore, additional favourable regions have been identified which might be considered by the policy makers in case new MAR schemes are needed.



(a) Constraint map



(b) Feasibility map

Figure 27 Constraint map, used to remove the parts of the study area which are subjected to regulation constraints (geopolitical, protection zones etc.) (a); Feasibility map for the unconstrained part of the study area (b).

The impact of the artificial recharge to the quality status of the groundwater system is monitored by the personnel of WDD since December, 2015 (xenobiotics are also measured since 2017 after request by the community council of Akrotiri). Four sampling campaigns take place during the winter period: 1 before the beginning of artificial recharge (October/November), 2 during the recharge period (January/February) and 1 after the recharge period (May/June). In particular, groundwater samples are collected from 5 nearby boreholes. In addition, surface water samples are collected from Kouris delta recharge pond twice per year, and the outlet of the wastewater pipeline (once per year). The quality standards for the parameters which are analyzed are determined by the WFD. To further align with the European guidelines (2014/80/EE), nitrates and phosphorus has been added in the monitoring list for ions.

Regarding the quantitative status, piezometric levels are measured from nearby wells. Interestingly, it was pointed out (personal communication) that an empirical approach is adopted for restoring the groundwater levels. Specifically, the piezometric measurements are used to plot the variation of the piezometric levels as a function of distance from the coast and compared to a reference plot. In case the piezometric levels are found to be less than the reference value at a specific location, additional recharge takes place at upstream wells.

5.3 Technical assessments based on numerical modelling

The technical assessment in the Cyprus case study involves analyzing the impact of MAR on the evolution of the aquifer and its effects on the other water uses in the basin, providing data on potential aquifer replenishment and its implication for water management.

Similar to the Spanish and Tunisian case studies, the SIMGES module of the AQUATOOL DSS was employed to develop the water allocation model for the Akrotiri region. The model simulates the management of the basin and intricate water resource systems, incorporating surface and groundwater elements for regulation, storage, intake, transport, consumption, utilization, and artificial recharge, among others.

The model developed for the Akrotiri region provides a basis for assessing the impact of MAR on different water uses within the river basin (Figure 28). The management strategies simulated and evaluated as part of the AGREEMAR project are subject to an assessment based on regional needs and stakeholder input regarding MAR feasibility.

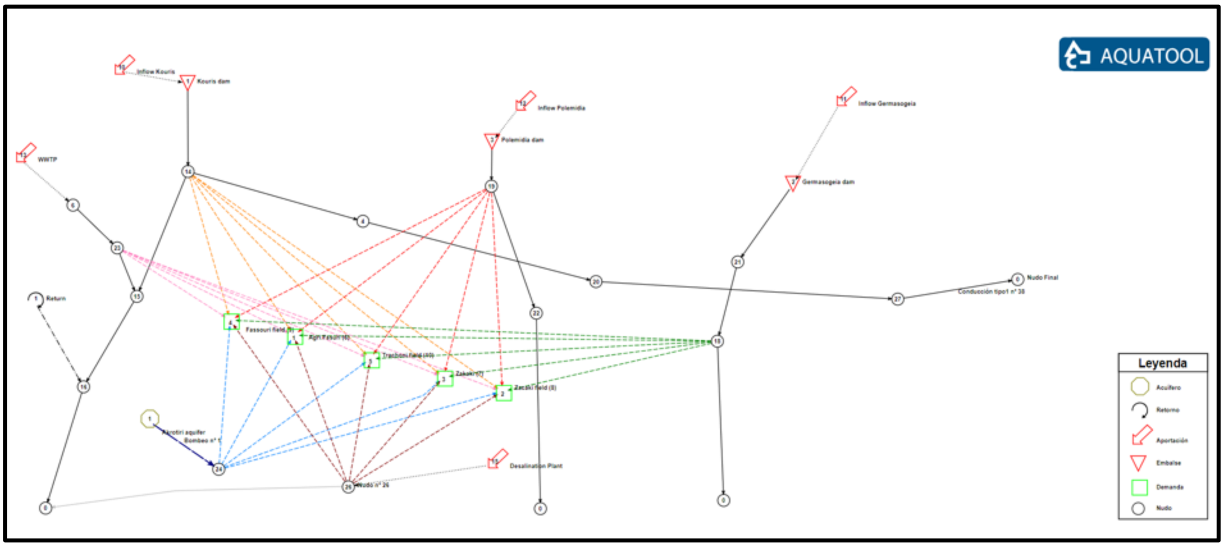


Figure 28 Topology of the AQUATOOL model of the Akrotiri region, Cyprus.

The assessment involved simulating two scenarios to evaluate the effectiveness of measures for improving aquifer sustainability and meeting water demands. Scenario 1 represents the current state without MAR activities and scenario 2 incorporates MAR through infiltration basins. The analysis of these scenarios shows that Scenario 2, which includes MAR activities, results in significant improvements in aquifer recharge. However, it also highlights a potential increase in agricultural water demand deficit, emphasizing the need for a balanced approach in designing effective water resource management strategies, especially in agriculturally dependent regions. Future scenarios, developed in consultation with stakeholders, will explore the possibility of adding new operating rules for MAR implementation and the use of non-conventional water sources, either for recharge or to mitigate agricultural water demand deficits.

More details on model results about the effects of MAR on the evolution of aquifer and its impacts on other water uses in the Cyprus case study are provided in Deliverable D4.1. These results are based on the joint implementation and application of the water allocation model and the aquifer models of the AQUATOOL DSS, which have been performed in the framework of WP3 (adaptive governance framework) and WP4 (validation through numerical modelling).

5.4 Identification of Stakeholders and their relationships

As shown in Figure 29, the water policy makers are under the Ministry Council, particularly the Ministry of Agriculture and Environment and Ministry of Interior. Water Development Department is assigned responsibilities/jurisdictions regarding the water resources management by law (see next subsection), and closely collaborates with the Water Board, responsible for distributing the drinking water to the end users, and the Sewage Board which responsible for collecting the raw wastewater and providing treated wastewater at the exit of the WWTPs. The distribution of the treated wastewater among the different end-users (e.g. farmers, businesses, dams) is conducted by the WDD. Regional offices of WDD exist for facilitating the implementation of the activities within each district, whereas a significant number of municipalities and small communities are responsible for managing their own water resources (mainly groundwater). The Department of Geology Survey serves as a consultant of the WDD with respect to hydrogeological considerations, such as assessment of groundwater status, hydrogeological studies, monitoring network, etc. Further interactions among the different governmental services involves the purchase of water, for example:

- Water board is buying water from WDD for drinking purposes, which is then distributed to the consumers (the consumers are then paying their water bills to the Water Board)
- WDD is paying the Sewage Board for transferring the treated wastewater from the exit of WWTPs to the end-users (the end-users are then paying their water bills to the WDD)

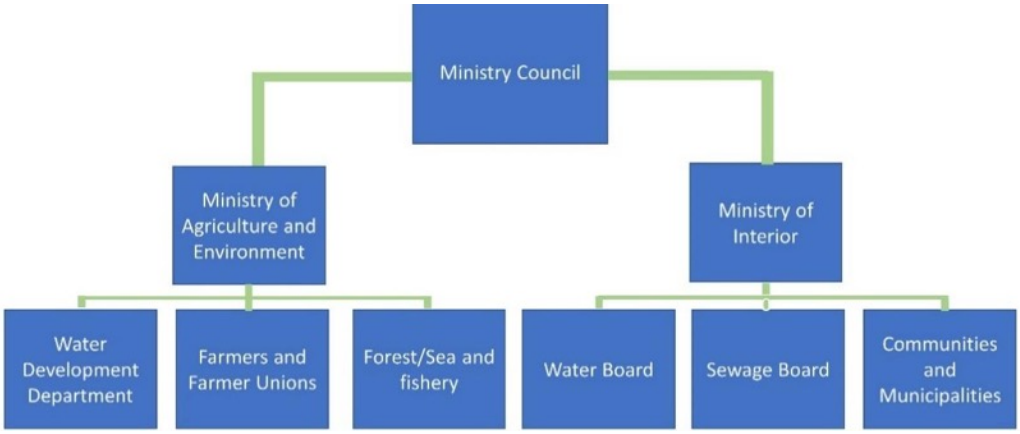


Figure 29 Decision-making structure for water management in Cyprus.

Having that in mind, the following stakeholder map was compiled in Deliverable 1.1 (Conrad et al., 2022b), which focused on the identification of all stakeholders that are relevant, either directly or indirectly, with MAR.

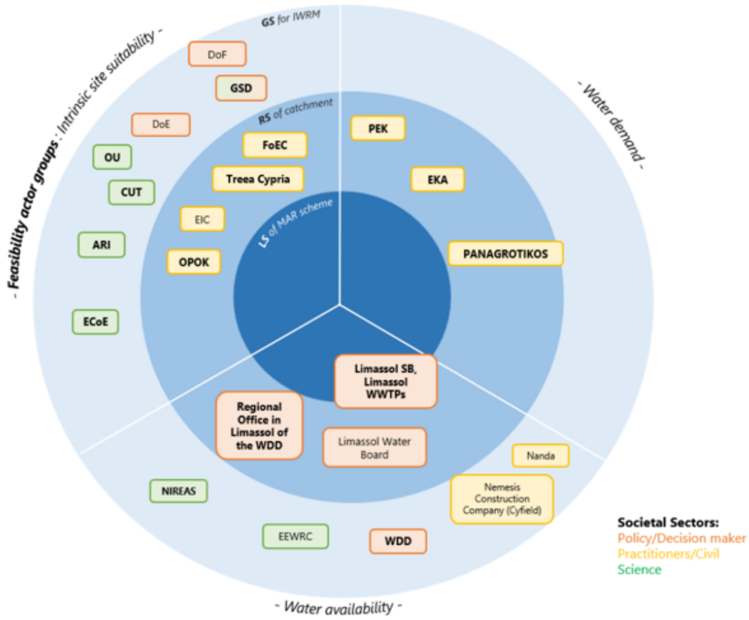


Figure 30 Stakeholder map for the Republic of Cyprus (Conrad et al., 2022b).

Bilateral meetings have been conducted with multiple stakeholders to quantify the level of interest and engagement in the activities of AGREEMAR project.

5.5 Standards and regulations

The management of water resources in Cyprus is regulated mainly from the following laws:

- **Law regarding Unified Water Management (N. 79/2010):** All responsibilities/jurisdictions regarding the water resources management are assigned to the Water Development Department.
- **Law regarding the protection and Management of the Water resources (N. 13/2004):** Harmonization legislation of the European Guideline Framework for Water protection and management of the water bodies and resources within the EU
- **Law regarding the evaluation, management, and treatment of flood hazards (N. 70/2010):** Harmonization with the European guidelines for floods (2007/60/EK)
- **Law regarding the control of Water Pollution/contamination (N. 106/2002):** Harmonization with the European guidelines for urban sewage treatment (91/271/EOK)

Hence, the specific measures and provisions outlined in the laws and regulation are aligned with the recommendations of the European guidelines.

Specifically, the above laws aim at implementing the following water-related European guidelines:

- WFD for Water (2000/60/EK):
  - Compile a River basin Management Plan that contains Drought Management Plan and mitigation measures
  - Revision/update of the Management plan every six years
- European directive for management and assessment of flood risks (2007/60/EK):
  - A Flood Hazard Management plan has been compiled in 2015
  - Revision/update of the Management plan every six years
- European directive for urban waste-water treatment (91 /271/EOK):
  - Installation of central sewage networks and wastewater treatment plant stations in communities and municipalities with human population greater than 2000.
  - Update in 2022 (annual report of WDD)

A monitoring network is currently operating in Cyprus for assessing the chemical and quantitative status of the water systems. Particularly, water samples from all groundwater monitoring stations are collected and analyzed twice per year. The first sampling campaign occurs at the end of the winter/wet period (Spring) and the second one at the end of the summer/dry period (Autumn). Regarding the surface waters, monthly samples are obtained. This network is also related to the implementation of the European directive 91/676/EEC for water protection against nitrate pollution of agricultural origin, also relation to National Law (N 106/2002).

5.6 Guidelines for Regional Agreement tailored to the Cypriot case study

Water Development Department is responsible for implementing MAR systems according to the local, regional and national water needs. This is a challenging task due to the involvement of various expertise, from biologists to engineers, to conduct a detailed environmental and economical assessment regarding the construction and operational stages, prior to the implementation of the MAR site. A management/monitoring plan is proposed for both stages (construction and operation) with respect to anthropogenic, environmental and biological factors.

According to the technical report for implementing Ezousa MAR site, several local aspects have been taken into account. Particularly:

5.6.1 Evaluation of the current status

- National and European providences and legislation provisions: for water-related legislations, enhanced with legislations for solid wastes, air pollutants, environmental sustainability etc.
- Demographic information, economical activities, land use, archaeological monuments and geographical location
- Development plans for infrastructure
- Local climatic conditions, air quality, existing pollution sources
- Seismic and hydrological information
- Biological environment (flora, fauna and ecosystems)
- Water availability for MAR purposes (in this case treated wastewater) is explored in terms of the quantitative and quality standards. For surface spreading methods (i.e., infiltration ponds), threshold values are set for specific parameters (BOD, TSS, total-nitrogen, total phosphorous, coliforms) of the source water. Regarding the groundwater, several parameters are monitored via an existing monitoring program, such as pH, BOD, TDS, ions, heavy metals, total phosphorous and total nitrogen, ammonia, total coliforms, organic and inorganic substances.

5.6.2 Environmental consequences during the construction stage

- Anthropogenic: proximity, aesthetic, noise, safety
- Environmental: Solid waste produced, air quality, liquid and gas wastes
- Biological: ecosystems, flora and fauna

In addition, numerical models are developed to evaluate the performance of different scenarios, enabling the optimal location and number of MAR components that need to be installed (ponds, wells), quantify the economic aspects, assess the hydrogeological response of the local aquifer and the spatio-temporal evolution of the pollutants/contaminants.

Regarding the social aspect, discussions are conducted with representatives of the local communities and events to address their concerns and inform them about the potential hazards and benefits.

Regarding the economic aspects of the MAR project, the following information has been provided after communication with key personnel of the WDD:

- The maintenance and construction fees for MAR are distributed among all citizens of the Republic of Cyprus due to the high cost that would have been assigned to the consumers, and since all citizens are directly or indirectly benefited by this project (e.g., mitigation of seawater intrusion)
- The government is funding the capital costs (infrastructures such as the pipeline networks) and the costs associated with the transfer/treatment of the wastewater that is used for MAR.
- WDD is seeking for new consumers/clients at the vicinity of the existing infrastructures to sell the groundwater abstracted from the vicinity of MAR facilities. It was pointed out that the main motivation behind the construction of MAR facilities stems from the need to improve the quality status of the aquifer systems (mitigate seawater intrusion), and secondary for satisfying the agricultural needs, since the existing pipeline networks enables the allocation of treated wastewater directly to the farmers.

5.7 Conclusions of the Cypriot case study

Cyprus suffers from over-exploitation of the water resources (highest WEI+ among European members). As a result, environmentally sustainable technologies, such as MAR, are used to mitigate the adverse consequences of the water scarcity. Multiple meetings have been conducted with various stakeholders in order to understand their perspectives, their role/responsibilities with respect to MAR, and identify their needs/concerns so that these can be included within the current study.

Some major outsides of these activities are the followings:

- All citizens are paying the costs for MAR construction and operation via taxes.
- Government funds the capital costs for the relevant infrastructures
- GIS-based multi-criteria decision analysis has been conducted that explicitly takes into account the intrinsic suitability, water demand and water availability for MAR. The results showed high feasibility scores for two regions where MAR facilities are already installed, enhancing the validity of the selected MAR locations, and proposed additional regions which are favorable for MAR installation.
- Numerical model for optimal allocation of the existing water sources in Akrotiri area have been conducted with the use of AQUATOOL. The assessment involved simulating two scenarios to evaluate the effectiveness of MAR for improving aquifer sustainability and meeting water demand. In addition, a numerical groundwater flow model of the Akrotiri aquifer is currently developed to better assess the impact of MAR on the groundwater system.

By taking into account all the above, an initial set of guidelines can be compiled that takes into account the actual needs of the Cypriot decision-makers, which is the ultimate goal of AGREEMAR project.

6. Conclusions

The set of regional draft agreements tailored to the different case studies of the AGREEMAR project needs to be done within the framework of the General Governance Framework. These agreements are considered as tools to support the implementation of MAR projects and support water governance simultaneously. MAR agreements need to be designed to engage stakeholders in MAR projects and ensure its long-term implementation.

To identify the main elements that MAR agreements should cover, several aspects addressed in Deliverable D3.2 (Ghannem et al., 2024) of the General Governance Framework were assessed at each case study. A preliminary assessment of the case study is required to identify the specific provisions and potential benefits. Then, potential MAR sites have to be identified using feasibility maps to determine where MAR can be most effective, and to provide a visual support for MAR feasibility in the region which will be used as a communication and involvement tool for stakeholders. Technical assessment based on numerical modelling is essential for valuing MAR project performance and efficiency as it provides insight into the expected behavior of MAR systems in different scenarios, enabling design and operating strategies to be optimized. Moreover, it is crucial for assessing the effect of MAR on the other water uses in the basin and on the environment. In addition, identifying stakeholders and understanding their relationships is essential to the elaboration of MAR agreements and successful implementation of MAR projects, because it ensures that all parties concerned are involved and that their interests and concerns are considered allowing building consensus and cooperation between stakeholders. Standards and regulations at each case study site are essential to be considered also to avoid potential legal obstacles and to ensure that MAR practices align with regional and national water management policies. The economic aspects are very important to support the feasibility, governance and sustainability of the MAR. However, in the AGREEMAR project it is not developed because it is out of the scope of the project. Once these aspects had been analyzed, guidelines for regional agreements adapted to each case study were outlined, considering regional specificities and stakeholder involvement. All the guidelines from the various AGREEMAR case studies can be combined to provide insights into other case studies and what may need to be taken into account for MAR agreements.

The summaries of the guidelines for the agreement structures for the AGREEMAR case studies are indicated in the following table:

Table 3 Summary of agreements structure for different AGREEMAR case studies.

Subjects found as relevant	Spain	Portugal	Tunisia	Cyprus
Identification of objectives	Yes	Yes	Yes	Yes
Relevant stakeholders to include	Water authority, agricultural communities	National authorities, local to regional stakeholders (Water Utilities, Farmers, Tourism sector)	Water authority, local stakeholders,	Water authority, local communities,
Pre-feasibility studies	Pre-feasibility studies must be conducted if not yet	Pre-feasibility studies must be conducted if not yet	Pre-feasibility studies must be conducted if not yet	Pre-feasibility studies must be conducted if not yet
Risk assessment methodologies	Environmental impact studies	Environmental impact must include risk analysis	environmental and economic impact assessments	environmental and economic impact assessments
Quality indicators to be considered	Should include water quality standards	Should be included, defined based on the MAR objective, groundwater quality and source water quality	Should be included, especially for arid regions	Should be included, defined based on the MAR objective
Identification of beneficiaries	Yes	Yes	Yes	Yes
Regulatory framework alignment	Should be aligned with national and EU regulations	Should be aligned with national and EU regulations	Should be aligned with national regulations	Should be aligned with national and EU regulations

Subjects found as relevant	Spain	Portugal	Tunisia	Cyprus
Financial mechanisms for implementation	Government funding and stakeholder contributions	Government funding (national or EU Community mechanisms) and stakeholder contributions	Government funding	Government funding
Use of non-conventional water sources	Included	Included	Included	Included
Stakeholder communication and engagement	Regular meetings, consultations, workshops	Stakeholder workshops, community meetings	Stakeholder workshops, community meetings	Stakeholder workshops, community meetings
Implementation of agreements	Through stakeholder consensus	Through stakeholder consensus and Environmental Agency (water authority) approval	Through stakeholder consensus and government Commitment for funding	Through stakeholder consensus

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Annex 1

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Participatory approach to the construction of agreements for the implementation of MAR methods in Portugal – Comporta's case study

A1. Justification

In the field of Environmental Sociology, the Theory of Ecological Modernization (EMT) states that economic development and environmental quality are interdependent and not necessarily incompatible. For the defenders of EMT, modern science and technology are essential for an ecological reform, which would be promoting the evolutionary transition of society to what EMT called Reflexive Modernity (RM). Characterized by social practices and institutional forms that are constantly monitored and improved by their new informational inputs, RM would transform the current institutional order itself. In the same sense, human adaptation to face today's complex problems, including the problem of water scarcity, occurs through technological, cultural, or social adaptation (Olivieri, 2009).

To this end, a workshop was held, in which the praxis of the Constellation Analysis (CA) was carried out with stakeholders from various scales and institutional scopes, whose focus was the MAR system already implemented in Comporta/PT. The use of the CA methodology in the AGREEMAR project is justified by the understanding that the realization of Agreements and Good Governance, in the management of groundwater resources using MAR, prevents the occurrence of the social phenomenon called "Tragedy of the Commons". For the realization of agreements and Good Governance, the application of an adequate and well-structured social methodology is essential to ensure the success of innovation and the sustainability of projects.

A2. Introduction

This annex presents the experimental use of the CA methodology as an instrument to support the implementation of MAR methods in Portugal, facilitating agreements and governance.

This tool provides a fundamental guide for the establishment of agreements based, not only on the force of the Law, but also - in a complementary and non-exclusive way – on established and sustained willpower, fundamental for creating intentional commitments that maintain the success and sustainability of the MAR methodology application. It is a concept whose main characteristics are its ability to integrate and relate the constituent elements of complex problems, shedding light on possible and desired solutions in a participatory, cooperative, and consensual way.

That said, the main objective of this document is to be a tool capable of integrating the elements involved in the MAR system, namely nature, institutions, governance instruments and technology, to facilitate decision-making. In this sense, CA presents a structured, systemic approach, to facilitate the construction of agreements aligned with the principles of sustainability.

One of the challenges of the AGREEMAR project is to be an integrated, participatory method for sharing the benefits generated. In this sense, a governance that is close to what is defined as Good Governance, and agreements elaborated in a participatory way can enhance the conversion of MAR technology into social and ecological benefits, expanding its impact on the equation of the water issue and, conferring even greater longevity and sustainability to the method due to the intentional social commitment that it enables. It can be easily understood because beyond the force of the law, there is the force of the will, as said in Holz (2015) and because our choices become our life, in the philosophy of Plato.

However, the use of participatory methodologies is also justified by law in Portugal (case-study worked here) rights, freedom and guarantees of public participation of interested parties in the preparation of urban planning instruments and any other physical planning instruments of the territory is guaranteed in point 5 of article 65 of the Constitution[1].

Participatory or collaborative approaches are currently being experimented and conceptualized in the development of "Soft Systems Methodologies" (SSM) (Williams, 2005). CA, for example, can enable a participatory and cooperative involvement of stakeholders with a consultative character, a reflexive co-production for future agreements for the implementation of MAR methods. But of course, those participatory methodologies are not a panacea or a way to solve all the humanity problems but at least it´s a human approach, an approach that can transform because it´s operate under human's laws of function.

This document proposes a theoretical/practical framework for approaching the social component in MAR systems - applied to the case study of Comporta, in Portugal - and may serve as an example for the development of future MAR installations in Portugal, or in other places that are interested in implementing these models, respecting the necessary adaptations to the particularities of each environment and scale.

A3. Constellation Analysis definition

The CA is an interdisciplinary and transdisciplinary methodology that interconnects different perceptions of a given complex problem of innovation, technology, and sustainability.

The CA is built collectively in focus groups and workshops, with the participation of experts, stakeholders, and beneficiaries, resulting in an interconnected structure that allows a quick understanding of the issue, as well as facilitating dialogue and decision making.

In AGREEMAR project, the interdisciplinarity occurs in the interaction between the specialists during the focal group to build the first CA and shortly after, during the analysis of the three groups CA, this time among all AGREEMAR partners (to validate the CA built). The Transdisciplinarity occurs during the interaction with the stakeholders to build and analyse the three group CA and in the future with the involvement of the beneficiaries to add one more layer of analysis to build the constellation for the development stage of MAR Comporta system by AGREEMAR.

The CA uses four types of elements and different relationships among them, as shown in Table.

Table 1. The elements of constellation analysis and relationships, adapted from Schon *et al*., 2007.

Natural	Technical	Institutional	Governance

Interdependent relationship	————————
Subordinate relationship	————————→
Conflictual relationship	——— ↗ ———
Unknown relationship	———?———
Weak interface	------------------------------

Such elements form cohesive groups that are differentiated by the constellation builders. This construction, according to the methodology, is divided into four stages - mapping, description, characterization, and analysis - which are interactive and interconnected, but not necessarily consecutive, and can also be performed several times or in parallel, because, according to the author, empirical description, reconstruction, and interpretation are together.

[1] According to the CRP, 1976, art. 65, paragraph 5, " The participation of interested parties in the elaboration of urban planning instruments and any other instruments of physical planning of the territory is guaranteed".

After element's identification, they are arranged in a graphic representation according to their centrality or distance in relation to the issue and, according to the proximity or distance from other elements (Paula et al., 2014).

In the next step, it should be observed how the elements are related to each other, how they influence each other. Ohlhorst (2009) explains that the elements relate to each other forming an arrangement that constitutes the CA, which "illuminates" the issue dealt with as the relationships between the elements are clarified, agreements and commitments are outlined, "woven" along the same line of "Good Governance".

According to Rodorff et al. (2015), the concept of CA is aimed at all levels of governance, including main actors, influences, and formal and informal instruments, as well as environmental elements.

KEY CONCEPTS:

Facilitator – A member of the team explains the exercise that will be carried out.

Mediator – A member of the team who master's the overall theme of the project.

A4. Methodological approach

Prior to the workshop, a focus group was set up among the experts of AGREEMAR/LNEC to build the CA, the central and peripheral elements for MAR application were chosen – from the elements identified in WP1 and WP2 and, after analyzing their relationships, the first MAR constellation was structured. Then, video conferences, the constellation was analyzed by the partners and suggestions on the first sub-constellation were incorporated.

Between the construction of the first sub-constellation and the next step, which would be the final workshop, a first presentation was made on the CA methodology and its contribution to the AGREEMAR project, for a group of about 30 stakeholders of APA.

The final workshop, held on April 18, at LNEC, had 20 people from various institutions and hierarchical scales, from the public and private spheres. The following steps were carried out:

First, in a large group, the AGREEMAR project was briefly presented, followed by the main outcomes of WP2 and WP4, followed by the social analysis component of the project: WP3. The CA methodology was introduced and the practice that would be carried out after the lunch break was explained. To initiate the involvement of stakeholders, the first exercise on the CA was carried out before the lunch break: a digital answer using *Mentimeter* to the question "Being MAR a successful technology in so many countries, what do you consider to be the main barrier to its implementation in Portugal?". The main objective of this question was to guide the whole process of building the CA and to identify possible conflicts between elements or understand the adverse conditions for implementation. The raw result was visualized shortly after the exercise, making it possible for everyone to see the results. This allowed reflecting and exchanging ideas during lunch break, getting involved to each other's point of view in a semiformal way, therefore creating a first path for understanding intentional agreements and commitments.

In the following exercise, a vote was carried out using *Google Forms* from a given list of elements identified in WP1 and WP2 and chosen in a focus expert group. The objective was to identify the central and peripheral elements for the implementation of MAR. Each participant voted by mobile phone, element-by-element proposed, weighting on a scale of 1 to 5: 1=not at all relevant; 2=not very relevant; 3=don't know/no opinion; 4=relevant; 5=very relevant. There was also an option to suggest any element considered missing. The answers were aggregated on a projection screen.

Exercise three, which intended to identify the degree of importance of each actor for the agreements, was disregarded, as the question generated a dubious understanding among stakeholders. However, there was no prejudice to the process, because during the joint construction of the constellation, in exercise four, the relationships were clear. During the moment of the plenary in exercise five it was perceived whether the stakeholders should be more directly involved in the realization of the agreements and their relations.

In exercise four, three groups were formed with a diversity of hierarchies and institutions previously defined, and a CA co-construction was done. The main objective was to identify elements, entities and their relationships that establish the general features of the agreements that will later be suffrage.

In the fifth exercise, the plenary session, a representative from each group explained their constellation, summarizing the key points. The objective was to understand the added value to be achieved for the commitments or their constraints.

A5. Application of the CA methodology in the workshop and results

7.1.1 Exercise 1 – Individual

Materials: Mentimeter[2], smartphones, power point equipment.

Methodology: A guiding question was formulated to guide the CA practice for the description and analysis of the constellation.

To break the ice: Using the Mentimeter all the answers were visualized together and projected soon after, that was useful to start involving the stakeholders and to keep the data. But later the analysis was done using the Content Method (Figure 1 and Figure 2).

Guiding question: Being MAR a successful technology in so many countries, what do you consider to be the main barrier to its implementation in Portugal?

Figure 1. Photo of the group working during Exercise 1.

Methods of analysis: Direct Observation and Content Analysis[3]

Results: Later the automatic result (from the Mentimeter) was worked using the Content Analysis method to find out what were the main barriers (Table) to implement MAR.

Table 2. Results obtained in Exercise one.

[2] Mentimeter is an eponymous app used to create presentations with real-time feedback (https://www.mentimeter.com/integrations/powerpoint)

[3] Content Analysis - The Content Analysis research technique advocated by Bardin (2011) is structured into three phases: 1) pre-analysis; 2) exploration of the material, categorization, or coding; 3) treatment of results, inferences and interpretation. A validity of research findings is the result of internal coherence and systematic between these phases, whose rigor in the organization of the investigation inhibits ambiguities and constitutes a founding premise.

Categorization of aspects that constrain the implementation of MAR Comporta/PT

Social / Human	Technician	Educational	Legality	Economic	Environmental
1	2	2	3	3	4
Distrust (4x)	Water quality (3x)	Unfamiliarity (2x)	Questões Legais (2x)	Cost	Climate
Fear	Contamination	knowledge	Políticas	Cheaper alternatives	
Fear of the unknow	Pollutants	Lack of knowledge (2x)	Enquadramento legal	Little water to infiltrate	
People	G.W.	Lack of information	Atribuição de responsabilidades	Aquifer recovery	
Selfishness	Pollutants unknow	Information	Controle	Lack of necessity	
Disinterest	Quality problems	Effective communication	Desresponsabilização	Other existing origins	
Apathy	G.W. quality	Awareness		Barely visible result	
Indifference (2x)	Groundwater quality	Prejudice			
Lack of territorial cohesion	Fear of pollution	User acceptance			
Rivalry between sectors	Supply	Stigma of water use			
	Underdeveloped technology				

Figure 2. Photo of the debate during Exercise one.

The result of Table points out some needs and/or gaps that future agreements should meet to promote an intentional and consensual commitment to the implementation of MAR systems.

7.1.2 Exercise 2 – Individual

Materials: Google forms[4], smartphone, PowerPoint equipment

Methodology: Individual voting. Given a table of elements, determined in WP1 and WP2, a value was asked to be assigned to each element among five options (Figure 3).

Results: Table presents the frequency of the elements obtained in Exercise two. There was the introduction of new elements, considered important by stakeholders.

[4] Google forms is a free online service to create forms (https://www.google.com/forms/about/)

Figure 3. Photo of the group working during Exercise two.

Table 3. Elements used by stakeholders to build their constellations

	ELEMENTS	FREQUENCY (f) 1-3			
		M1	M2	M3	F
NATURAL	WATER SCARCITY	X			1
	ECOSYSTEM SERVICES	X		X	2
	CLIMATE CHANGE	X		X	2
	EVAPORATION			X	1
	SOIL	X	X	X	3
	PRECIPTATION	X	X	X	3
	AQUIFER	X	X	X	3
TECHNICAL	ENVIRONMENT MONITORING 3rd GENERATION		X		1
	MONITORING ALERT SYSTEM		X		1
	LOCAL NUMERICAL MODEL	X	X	X	3
	VIABILITY MAP	X	X	X	3
	WASTEWATER TREATMENT 3rd LEVEL	X	X	X	3
	TECHNOLOGIES METHODS MAR/INDICES	X		X	2
	CONSTELLATION ANALYSIS			X	1
	PURIFICATION	X		X	2
INSTITUTIONAL	C.T.M (MONITORING)	X			1
	COUNTIES			X	1
	DRAP			X	1
	LARGER USERS		X		1
	LARGE PRODUCERS IN AGRICULTURAL SECTOR	X			1
	CCDR/FINANCING		X	X	2
	RESEARCH INSTITUTION /IAD/LNEC	X	X	X	3
	AdVT-AdP	X			1
	AgdA-AdP	X		X	2
	APA	X	X	X	3
GOOD GOVERNANCE	DIRECTIVE 91/271/CEE	X			1
	DL 69/2023	X		X	2
	AGREEMENTS				
	PGRH	X	X	X	3
	ENVIRONMENTAL EDUCATION	X		X	2
	PARTICIPATIVE METHODOLOGIES	X		X	2
	ENVIRONMENTAL LICENSING	X		X	2
	HUMAN CONSUMPTION			X	1
	DQA/2000/60/CEE	X	X	X	3
	STUDY OF EVOLUTION		X		1
	DARU		X	X	2

7.1.3 Exercise 3 – Individual

This exercise was disregarded because it generated a dubious understanding of the issue and, but it was understood that at this stage of the analysis (implementation CA) and with all the other data that was available, it would not be detrimental to this discussion, analysis and realization of the exercises four and five.

7.1.4 Exercise 4 – Small groups

Materials: laminated cards with the four colors required in the CA methodology and plastic surface (one square meter) reusable; black water pen for each stakeholder; paper napkin; glue tape all available for each of the three tables. Printed, each stakeholder received the list of elements used in exercise two and Table.

Methodology: The large group was divided into three small groups to cooperatively build one constellation to each group using the appropriate material disposed in each table (Figure 4).

Methods of analysis:

1. Facilitator and observer
2. Discourse Analysis

3. Content Analysis[5]

Figure 4. Photo of the group working during Exercise four.

Results: Three constellations build (Figure 5), cooperatively, in parallel, about the same issue by the stakeholders - each group was formed by multi sectors, multi-level, different scales to ensure the diversity of interests and to prepare for consensus in future agreements.

[5] Discourse Analysis is characterized not only by a theoretical reorientation of the relationship between the linguistic and the extralinguistic, as well as a change in the observer's stance towards the research object. Language, from a discursive point of view, cannot just represent something already given, being part of a social construction that breaks with the illusion of naturalness between the limits of the linguistic and the extralinguistic. Language is not dissociated from social interaction.

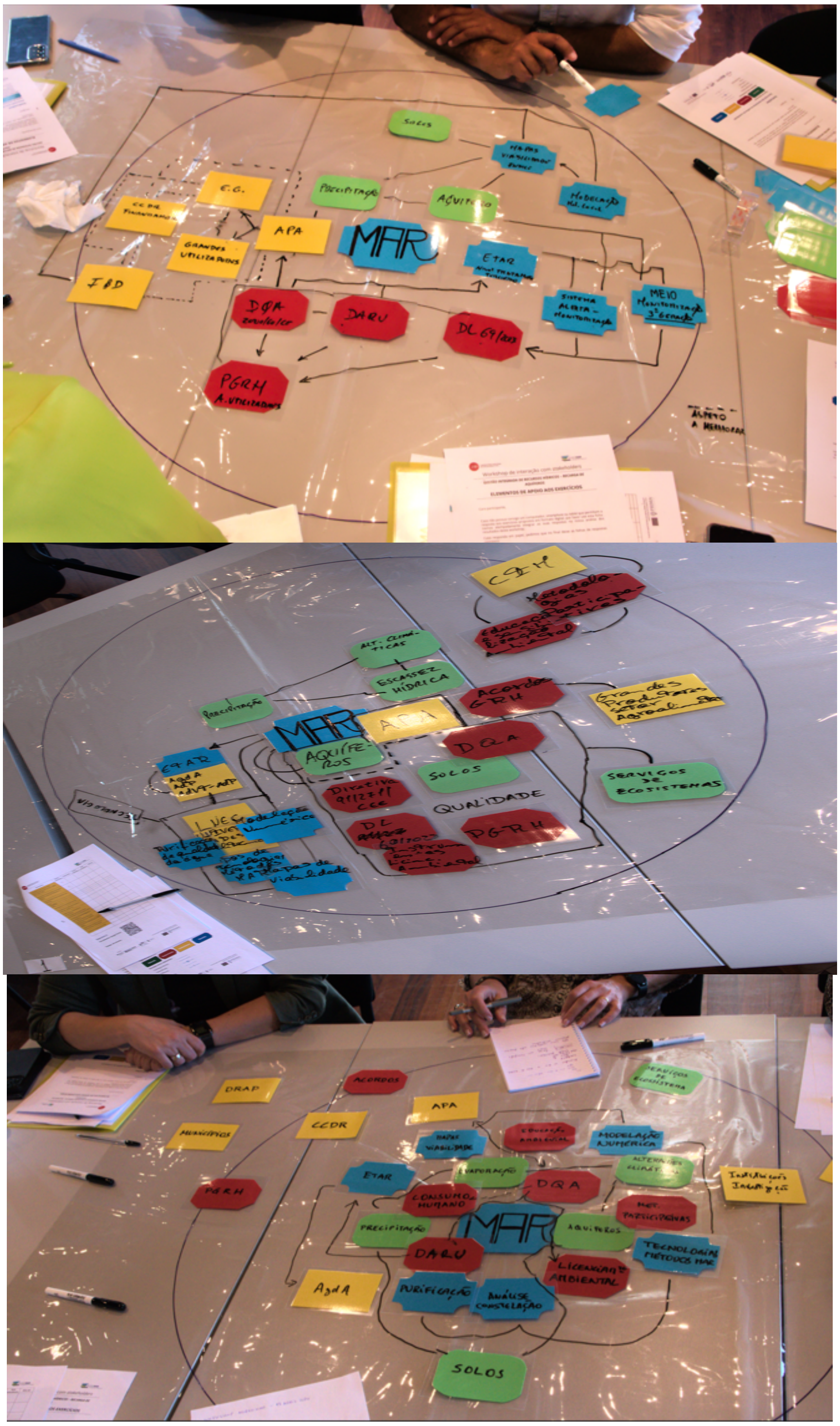


Figure 5. Photos of the 3 constellations resulting from the exercise four.

Discourse Analysis from the speech of one of the stakeholders, at the end of exercise four, when looking at the other two constellations built (Figure 5) by the other two groups:

> "I was so sure of the structure I had built together with my group, but now looking at what other colleagues built, I wondered if their view of the issue was not more correct."

It is evident in this speech, at the end of exercise four, the facilitating character of CA to diversify, deepen and interrelate the understanding of water resources management in Comporta and in Portugal. By deepening, in a participatory and collaborative way, the obstacles and possibilities related to MAR establish firm bases for agreements and Good Governance, as they are constituted from an intentional, consensual, human commitment so that such a method can be implemented and implemented.

7.1.5 Exercise 5 – Large group – final plenary session

Material: the three CA and record

Methodology: Plenary – presentation of the CA by stakeholders and joint analysis (Figure 6).

During the presentations an audio was recorded for further Discourse Analysis.

Methods of analysis

1. Facilitator and observer
2. Discourse Analysis

Results: MAR implementation discussion between stakeholders using the cocreated constellations analysis.

In the "Discourse Analysis" of exercise five, through the speech of one of the stakeholders - who was present when a first presentation on CA was made at another time - it is possible to perceive the validation of the methodology as an important facilitating instrument for communication and joint analysis for co-created and participatory decision-making. In this way, an intentional commitment, willpower and responsibility for the implementation of MAR is built.

"... I confess that I didn't believe in these methodologies... But we notice and learn."

This same stakeholder at the time of this reflection gave as an example of the facilitating character of a joint learning and deepening of the issue, the fact that he did not consider ecological services on his own constellation, but added to what he perceived in his colleague's constellation.

Considerations of the defined dimensions and scales:

Spatial dimension –local - perimeter under the influence of Comporta/PT

Time dimension – MAR implementation phase

Social dimension: Multi level; different scales; cross sectors.

Institutions represented: APA; AgdA-AdP; LNEC; large users of the agri-food sector; CCDR; Municipalities.

Public and private sector.

Configuration of the three subgroups:

As the purpose of the process was to broaden the individual and collective view of the issue to generate understanding and consensus that could enable future agreements a diverse composition in the formation of subgroups (three tables) was a fundamental requirement.

Dynamics:

Distributed in three tables, the stakeholders developed three constellation analyses (Figure 5) that, in a second moment, when a large group was formed, a representative from each table explained (Figure 6) the co-created constellations.

Figure 6. Photos of the presentations of the results during Exercise 5.

A6. Result and Discussion

A6.1. Constellation Analysis

The Institutional constellation analysis of MAR implementation/ Comporta-Portugal cocreate

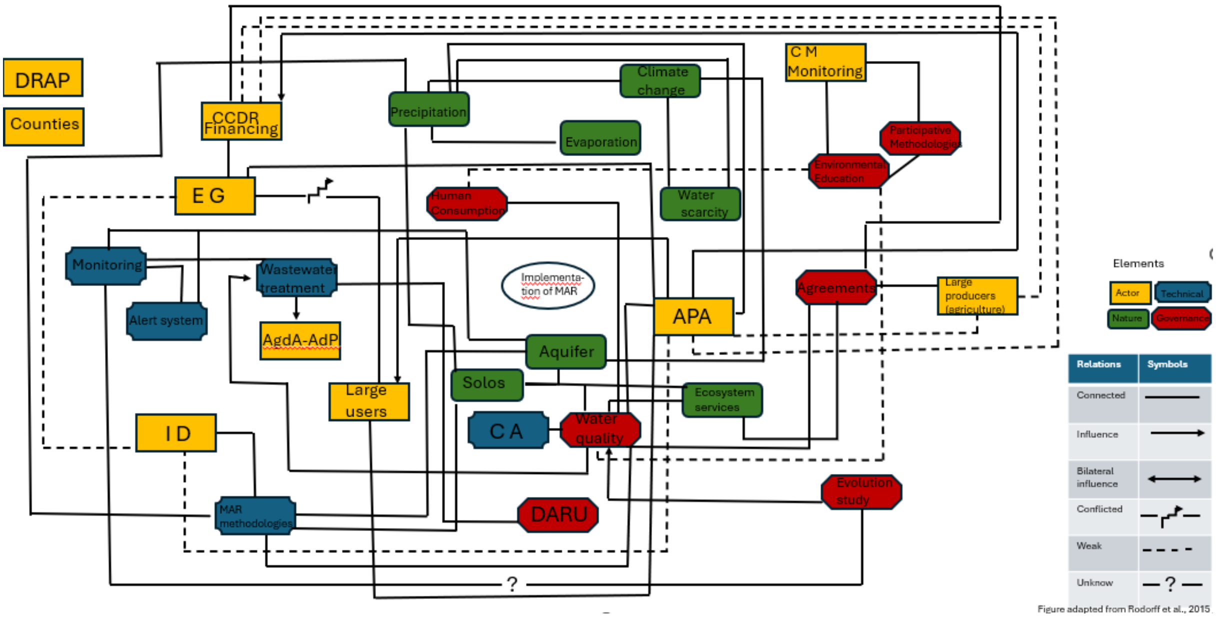


Figure 7. Institutional Constellation Analysis of the MAR System – Comporta/PT.

A6.2 The methodological approach

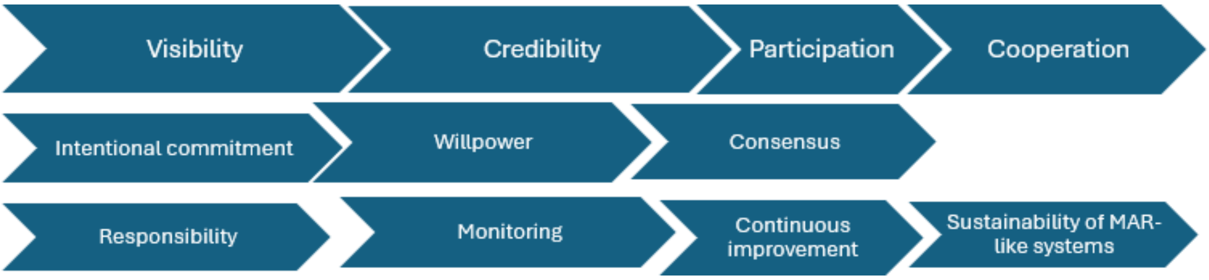
The methodological approach to build the CA (Figure 7) is based on the other three CA resulting from the workshop.

A6.2.1 Path to decision in relation to constituent elements:

Based on table 3, all elements with frequencies 3 and 2 are now included in the resulting AC; Regarding the elements whose frequency value was 1, the decision was made based on the expertise of the experts. The criterion used for the decision to include all the elements suggested by the stakeholders and which were not initially included in the table of elements (this possibility was foreseen in the methodology) provided for the realization of exercise 2, two criteria were used to justify the inclusion of all the elements suggested by the stakeholders:

Valuing (visibility) and credibility of knowledge (local/regional knowledge) - based on Boa Ventura de Sousa Santos' theory on the sociology of absences and emergencies[6] - an essential factor for the intentional commitment of stakeholders to future agreements and to the implementation and development of MAR type technologies in Portugal.

The second criterion was the principle of participation as a fundamental to the AGREEMAR project. In the social dimension, unlike the physical dimension, the conditions conductive to the implementation of MAR systems are created. In view of Portugal case study, it is possible to suggest the following flowchart (at each stage the use of CA can be very useful) for the favorable social construction for such implementation:



<u>A6.2.2 Path to decision on the placement of elements:</u>

The decision criterion was based on the observation of the very arrangement of the elements defined by the stakeholders in the three constellations (central or peripheral) in relation to the central issue, namely, the implementation of MAR type technologies in Portugal.

The following logic was then followed:

All elements with frequency 1 were positioned in their original places, when they did not conflict with other elements of frequency 2 or 3, a situation that did not occur in this study.

The elements that presented frequency 2 or 3, when possible, were positioned in the same place, when in the three constellations the same element had been positioned in a very similar place. If the same element is in a very different position, the decision as to its position was based on the expertise of the experts.

<u>A6.2.3 Path to the decision as to the connections (relationships) between the elements:</u>

A study was made of each and every relationship contained in the three constellations built by the stakeholders, a two-way relationship. Based on this study and the expertise of the specialists, the relationships were transposed to the CA of implementation of MAR – Comporta.

A6.3 Discussion

The constellation resulted from the three other CA co-created by the stakeholders (Figure 7) expresses not only the current state of the MAR/Comporta regarding additional elements considered essential for the implementation and development of MAR-type systems in Portugal, mainly regarding governance instruments and technologies.

This perception was also reflected in the categories mentioned in Table 2, the social/human category that presents the feeling of distrust and insecurity is directly related to two other categories: the technology category (that presents the issue of guaranteeing good quality of water for infiltration as a fundamental factor

[6] The wider the credible reality, the wider the field of credible signs or clues and possible futures. The greater the multiplicity and diversity of available and experiences (knowledge and agents). Applying this theory to MAR means build agreements involving different scales, cross sector and multi-level.

in making the decision to do MAR) and the category of education (that presents the issue of knowledge about the MAR system, understanding of the prejudice of water quality for further acceptance).

Still in terms of the technological elements added by interested parties, considering the development phase of MAR systems, in the end there was consensus on the need for an alert and monitoring system in constant and direct communication with the public. the wastewater treatment plant (it was even suggested the governance element called "evolution/study" which, through the monitoring of the alert and monitoring system, would not only prove the effectiveness of the MAR method, but would also enable continuous improvement of the method.

Once the quality of the water to be infiltrated was proven and trust was established between those involved and between them in relation to the system itself and, knowledge in relation to the system and the quality of recycled water was disseminated, it was almost consensual among stakeholders that MAR-type technologies could be a good alternative as one of the ways to mitigate the issue of water scarcity in Portugal and for this purpose it is necessary that it is foreseen in the Basin Plans and that the establishment of agreements for MAR should be an integral instrument in the Management of Water Resources in Portugal.

Other governance instruments added by stakeholders concern the provision of environmental education and awareness and the use of participatory methodologies as an important factor in overcoming water scarcity, considering among others the use of MAR Methods. In relation to social actors, relations between APA and CCDR (MAR financiers) should be strengthened, as well as between APA and innovation and development institutions and that the conflict relationship between large resource users water issues, such as large farmers, and the Golfs need to be resolved so that the benefits generated by MAR no longer generate conflict but are a way of resolving them.

One of the conclusions reached was that in order to reach agreements for the implementation of MAR-type systems in Portugal, it is necessary to pay special attention to social and human issues, as well as to technological issues that guarantee the quality of infiltrated water and its constant monitoring as it has been proven in Table 2.

A7. Final considerations

- The need to improve social relations and water quality as the main prerequisite for the implementation of MAR in Portugal prevents the practice of an "*end-of-pipe-technology*" in the national territory and ensures that the implementation takes place from the beginning in the standards of an environmentally and socially more advanced technology, as the Theory of Ecological Modernization (EMT) explains.
- Based on the results obtained and based on the TME, a general governance framework for the implementation of MAR methods should start from the exercise of a new role of the State in environmental policies capable of aligning it with ecological reform, thus evolving from a palliative and reactive action to an active, preventive and, regenerative way; from a closed and bureaucratic politics to a participatory, capable political activity; from a centralized action to a more decentralized one and from a dirigiste government direction to a more contextualized one, based on Olivieri (2009).
- The framework of environmental sociology includes the Theory of Ecological Modernization, which analyses the transformations of social practices and institutions in modern society when confronted with the environmental crisis and its gradual evolution towards what TME calls Reflexive Modernity[7]. This Reflexive Modernity has been occurring mainly in the societies of late modernity, in which, conceptually, Portugal can be inserted. In this sense, the MAR method falls - or has all the potential to do so - in the

[7] Reflexive Modernity or Later Modernity is a concept that refers to the social, cultural and technological transformations that have occurred since 1960s. In contrast to postmodernity, this approach highlights the continuity of modern institutions transitions and cultural developments, while seeking to adapt to the new realities of contemporary world (Olivieri, 2009).
Late Modernity is so designated due to an enormous deferral between the causes of environmental degradation (since the Industrial Revolution, and before that by the Agricultural Revolution and deforestation for the conquest of arable land) and its consequences: this deferral between cause and consequence makes the accumulation of the evils of industrialization (in its density and severity) much later than the accumulation of goods.

category of the most environmentally advanced technologies (the one that constantly examines and monitors its practices through the new informational inputs of this same practice). That said, it was noticed, in the practice of constellation analysis (exercises: 1 to 5) that the institutions present their wish to make agreements, and establish a governance for MAR, in which the quality of the infiltrated water is proven to be guaranteed, as well as the knowledge of the ongoing processes and mutual trust.

- And last but not least, when it comes to the issue of contextualizing MAR for Good Governance[8], it is important to pay attention to the fact that it is not a methodology that can simply be copied from one location to another, but implemented in an environmentally and humanly responsible way, with attention to the needs and particularities of each place. To this end, the appropriate use of natural and social technologies in an integrated and complementary way, in MAR implementation processes, are essential to ensure their adequate, long-lasting and environmentally sustainable use.

A8. Further steps

- Next, in a face-to-face interview or by video conference with a member of each group participating in the workshop, the "Institutional Constellation Analysis of the MAR System – Comporta/PT" for considerations, improvements, and validation as a facilitative method for agreements in MAR systems implementation.
- The results from exercise four – the three CA (three layers) built cooperatively by stakeholders – represent the stage of MAR system implementation. For the MAR system development stage another CA (one more layer) should be cooperatively built with the participation of MAR beneficiaries, and named, "constellation analysis of MAR system development – Comporta – Portugal".

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[8] Good Governance - the multiplicity of use of the term governance ended up emptying its original meaning and, also, in the sense of process, governance can serve for good or bad, so it was necessary, necessary to adjective this term to Good Governance, rescuing its original meaning and delimiting its action in good. to rescue its original meaning and delimit its action aimed at achieving the common good. Based on Rodorff (2015) and the dialogical three-dimensional perception of space according to Lefebvre (1974), in this work, Good Governance of water resources was defined as being one that focuses on the public use of water resources and from a geosystemic perspective it would be achieved by following different forms of social regulation, beyond a hegemonic model dictated by market forces, and viewing the State not as a supplier, but rather as a partner in its different levels of government; rehabilitating the site as a place for economic and environmental action, as well as valuing the civic dimension as a promoter of change in the society-nature relationship; all of this under a dialogical and three-dimensional perception of territorial spaces - starting from the local, regional, national to the global - capable of accounting for the perceived, planned and apprehended space (your life).

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