MARSOL

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

Benchmarks evolution, pooling and practical results

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Author(s)	Enrique Fernández Escalante, Rodrigo Calero Gil, María Villanueva Lago (Tragsa) Jon San Sebastián Sauto (Tragsatec)
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1. EXECUTIVE SUMMARY

This report is part of the EU-funded MARSOL project (www.marsol.eu, Grant Agreement Number 619120).

The main objective of this deliverable is to report the benchmarking results and to study and analyse the evolution of the diverse sets of benchmarks adopted for each demonstration site, in order to compare all of them so as to obtain some series of settings and common circumstances willing to be applied in other Managed Aquifer Recharge (MAR) schemes as practical recommendations.

The deliverable includes all the different benches and indicators adopted and evaluated and their pooling, with specific trends obtained for the main groups of indicators and benchmarks evaluated during the project´s development.

Regarding the envisaged objectives, the report presents how the different industry branches for some demonstration sites have been involved and mobilized and their degree of dependence on MAR technique in their water supply related schemes. The results demonstrate that MAR represents a strategic solution, in some cases unique, to combat water scarcity and extreme water related events adverse effects, paying special attention on droughts (the key is the storage). Objective 4 (to evaluate implemented technologies at the MARSOL demonstration sites) is performed by means of benches and indicators; objective 5 (to propose effective strategies to integrate MAR techniques and associated designs into water system) has been developed essentially in deliverables D13.1 and D13.3, and the appraisal and comparison are carried out in Sections 5 and 6 where the evaluation of implemented technologies are considered, proposing elements to be taken into account in future Integrated Water Resources Management (IWRM) plans.

According to the tasks exposed in the DoW, Task 13.2 (Analysis of technical solutions at the MARSOL demonstration sites and evaluations of their advantages and shortcomings towards benchmarking) was initiated in the deliverable D13.2 and is updated along this report, and also Task 13.3 (testing protocols for different exemplary MAR schemes and their benchmarking) in the same way, exposing techniques and methods applied and their indicators pooling according to the proposed classification and considering a vast diversity of sources. Task 13.5 refers to the advance of each demonstration activity in the different pilot sites from a practical point of view; Task 13.6 was started in the report D13.2 and is updated now, and Task 13.7 exposes the pooling of the benchmarking system designed for each of the demonstration sites.

The annexes include some facts and figures regarding industry mobilization and evolution for some specific demonstration sites, in special Los Arenales.

After this summary and the introductory paragraphs, Section 3 focuses on benchmarking background and update of the schemes characterized, Section 4 study the pooling evolution for each demonstration site, and, lastly, Section 5 summarizes the most important conclusive remarks regarding benchmarking from a practical point of view; to finalise with references and annexes.

2. INTRODUCTION

Benchmarking is a question of comparison. It deals with the process of comparing one's business procedure and performance metrics to either industry bests or best practices from other firms (Camp 1989). Typically measured parameters are quality, time and cost. In benchmarking, management identifies the best facilities in their sector and compares the results and processes of those "targets" to one's own results and processes. Thus, they learn how well the targets perform and, more significantly, the business processes that clarify why these “firms” are so successful (Larsson et al. 2002).

Specific indicators (cost per unit of product, productivity per unit of time) are used to measure performance, resulting in a metric of performance that is then compared to other ones (Fifer 1989). In conclusion, the goal of MAR (Managed Aquifer Recharge) can be as apparently unrelated as water storage, water treatment or habitat rehabilitation. These key aims should also be measured in terms of indicators spinning around water quantity, quality and efficiency.

Also referred as "best practice benchmarking" or "process benchmarking", this procedure is used in management and particularly strategic management, in which organizations evaluate various aspects of their processes in relation to best practice companies' ones, usually within a peer group defined for the purposes of comparison (Scanlon et al. 2002).

That strategic dimension of recharge should be considered whenever it is intended to look for the role that a recharge facility can play in the basin planning. Their different uses for winter water surplus storage, seawater intrusion barrier or sewage treatment could be appraised in comparison to the other standard water management infrastructures as dams, reservoirs and Waste Water Treatment Plants (WWTP) (Levantesi et al. 2010). Therefore, effectiveness should also consider the multipurpose capability of many MAR systems (Dillon et al. 2010). The broad variability of MAR facilities (e.g. infiltration pond, riverbank filtration and deep injection), their different purposes and the local geological context complicate the task of comparison. Consequently, it is imperative to begin with an exhaustive benchmarking analysis and characterization of those different roles that a MAR system can simultaneously play. Only true comparable facilities should be assessed, so that the evaluation can be considered technically correct.

In this report, we have analysed the eight Mediterranean MAR demonstration sites with special attention to those allocated in Portugal and Spain through a methodical characterization of the whole recharge process. Thus, our goal has been to make them comparable by means of a benchmark analysis. Furthermore, we have used detailed diagrams of those systems and their separated recharging facilities or sections can be clearly submitted to the same conditions, considering their common characteristics so that evenness is guaranteed. This work has been developed in the context of the MARSOL project which is aimed at demonstrating that MAR technology is a sound, safe and a sustainable strategy that can be applied with confidence, statements in full accordance with the results obtained in this deliverable.

2.1 Objectives

The MARSOL project aims at providing scientists, practitioners and end-users with an engineering-enabled set of technical solutions to improve Managed Aquifer Recharge (MAR) efficiency in areas where it is applied, and therefore, on general water management, "bench-marking" can be considered as a set of tools directly linked to assess those technical solutions.

The main targets of this report are:

1. Describe the benchmarking background: what benchmarks are, how they work and which available types are applicable (benchmarking definition, procedure and classes), and how they can be adapted for MAR.
2. Explain a properly designed methodology, starting by an "initial characterization of the schemes" (according to the classical benchmarking procedure) and design/selection of the indicators for the trend study evolution.
3. Propose a template to insert the benches and indicators (form sheets 1 to 4) including a general sketch of each demonstration site including cartographic systems, ending by the initial evolution for this stage of the project. So that, the interaction between users, smart solutions, demonstration sites infrastructures and water management techniques is guaranteed, ensuring a repository of experiences which trends will help to design the best technical solution for each case.
4. Present a proposal for specific indicators designed or adopted for Managed Aquifer Recharge operations in some of the MARSOL project demonstration sites.
5. Detail the application of benchmarks for each demonstration site, taking into consideration the preliminary data for benchmarking: all the measurable characteristics have received a number so as to study their evolution and future trending changes.

Through the text, reader can see how the benchmarking evolution process took place during data collection and how it was finally led to the close connection between benchmarking and technical solutions.

3. BENCHMARKING BACKGROUND AND UPDATE OF THE CHARACTERIZED SCHEMES

3.1 Basics on benchmarking and MAR

No single benchmarking methodology can be considered as universally adopted. The wide appeal and acceptance of benchmarking has led to the emergence of benchmarking methodologies. A classical proposal developed a 12-stage approach to benchmarking (Camp 1989), that could be applied to the MAR in the next steps:

1. Select subject: Managed Aquifer Recharge.
2. Define the process: Intake, transport, pre-treatment, recharge, storage, recovery, distribution and use.
3. Identify potential partners: Water authorities, farmers, town halls, water treatment plant managers, environmental institutions…
4. Identify data sources: Water management authorities, water users associations, universities…
5. Collect data and select partners: Technical figures from other demonstration sites: Diversion, flow, infiltration, investments, operation and maintenance costs.
6. Determine the gap: Where we are and where we want to arrive. From pilot areas to establish managed aquifers.
7. Establish process differences: Variability of MAR devices: Dispersion, canals, wells, filtration, rain.
8. Target future performance: Development of a more relevant MAR role in water resources management.
9. Communicate: Informal reunions, meetings, congresses, papers, public information and participation.
10. Adjust goal: Specific aims for each local site or device: Irrigation, water treatment, environmental restoration…
11. Implement: Calculation of internal rates through different years and comparison between similar devices and conditions (source, objective, climate, hydrochemistry…).
12. Review and recalibrate: Feedback process about specific and overall indicators to check their availability and significance.

Efficiency is related to multi-functionality so benchmarking should be used to compare only tested similar devices and that implies parting systems into homogeneous operational stretches or facilities.

Benchmarking can be internal (between devices forming a whole recharge system) or external (comparing performance of similar recharge devices in different local cases). Within these broader categories, there are three specific types of benchmarking (Bogan & English 1994):

1. Process benchmarking.

2. Performance benchmarking.
3. Strategic benchmarking.

These can be further detailed, as applied on MAR, as follows:

- Process benchmarking: The initiating local site researcher should focus its observation and investigation of recharge processes with a goal of identifying and discerning the best practices from one or more similar local sites (infiltration ponds, for instance). Activity analysis should be necessary whenever the aim is to benchmark not only total infiltration volumes but also water quality improvements or cost and efficiency rates.
- Financial benchmarking: Performing a financial analysis and comparing the results in an effort to assess your overall feasibility, especially when compared to more hydraulically classic solutions as superficial storage or pipe transportation. Benchmarking in the public sector: Functions as a tool for improvement and innovation in public water management administration (Wisniewski 2000).
- Benchmarking from an investor perspective: The collaboration of farmers in irrigated areas, tourism sector near high visited wetlands or local waste water treatment plants managers can be summoned to demonstrate the multiple goals of a recharge device and call their attention to invest in MAR devices.
- Performance benchmarking allows different demonstration sites to assess their competitive position by comparing devices and services with those of other locations and countries.
- Product benchmarking: That involves the process of designing new MAR systems or upgrades to current ones, considering their similarities and variances.
- Strategic benchmarking: involves observing how other water management infrastructures compete (dams, canals, WWTP…) within this sector when trying to achieve the same kind of objectives (storage, transport, treatment…).
- Functional benchmarking: A local site researcher will focus its benchmarking on a single function to improve the operation of that particular function: Infiltration rates, water storage, suspended solids precipitation, nitrogen removal...
- Best-in-class benchmarking: Involves studying the leading demonstration site that best carries out a specific function as cited: storage, infiltration, transport…
- Operational benchmarking: Embraces everything from maintenance and productivity to analysis of procedures performed (Cunha & De Witte 2010).
- Energy benchmarking: Process of collecting, analysing and relating energy performance data of comparable activities with the purpose of evaluating and comparing performances between or within entities (Ratjen 2013). Entities can include processes, infrastructures or sites. Benchmarking may be internal between parts within a single demonstration site (canal branches, infiltration reservoirs) or external between sites with comparable parameters.

3.2 Analysis of technical solutions at the MARSOL demonstration sites and evaluation of their advantages and shortcomings towards benchmarking

3.2.1 Evolution of the initial characterization of the schemes

The usage of benchmarking indicators applied to any water recharge system must consider above all the characterization of the framework itself, considering the broad variability of these schemes. The processes that can be found in a MAR system are very diverse and interrelated (Figure 3-1). The benchmark indicators can be divided in those for evaluating the water quantity and its quality, and those for evaluating the cost and the energy of the MAR facility.

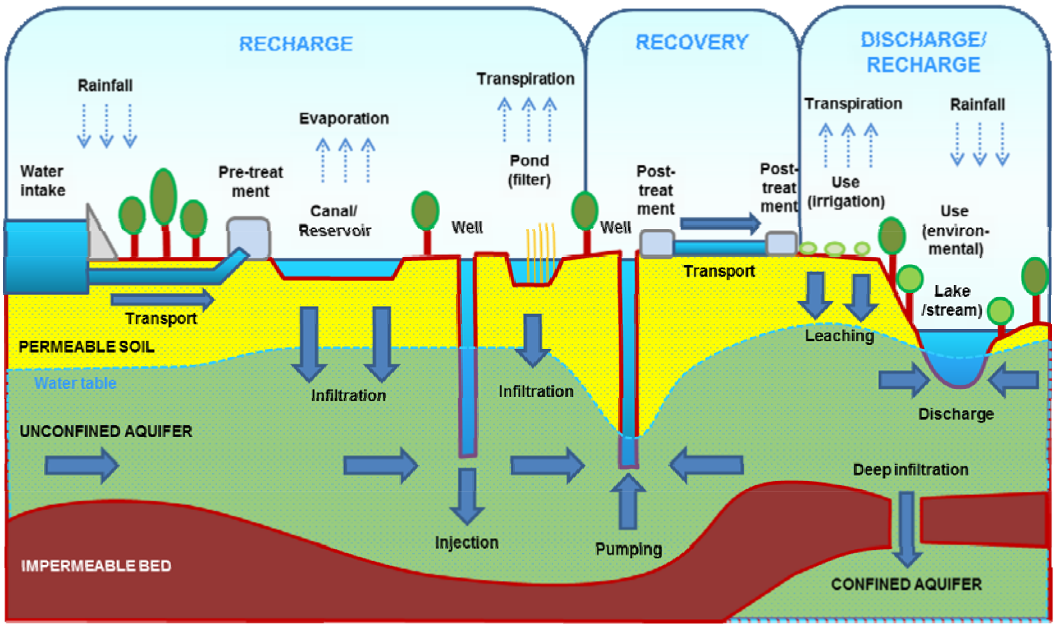

Figure 3-1: MAR squeme: Water recharge and recovery system sketch

- SOURCE: Source of water used for recharging. The origin of capture indicates the water availability and quality that are going to determine the rest of the steps. The distance to recharge area has to be considered: Superficial (River, lake, sea, rainfall), groundwater (well, aquifer), recycled: Sewage (WWTP), brackish (SWTP), drainage (Irrigation, storm tanks)…
- ABSTRACTION: The way the water is abstracted or collected from the source, before transport or storage in a different site: Direct pumping, dam, weir, reservoir, collector, wells, filtration system (dunes, RBF)…
- RELOCATION: OPTIONAL. Transport of water from the source to the recharge site is non-compulsory. Sometimes, water abstraction and recharge points could be so near that transport should be considered irrelevant: Canals, ditches, pipes, aquifer (horizontal flow), streams…
- PRE-TREATMENT: OPTIONAL. In some cases, water can undergo some kind of pre-treatment that can induce physical or chemical changes in the water volume before the recharge occurs: Filtering, decantation, gravitational sedimentation, chemical addition (Al, Cl, O_3), activated sludge, Up-flow Anaerobic Sludge Blanket Reactor (UASB)…

- RECHARGE: All kind of available techniques for MAR, from passive to active devices can be enlisted: Pumping, drilling, filtration, Soil Aquifer Treatment (SAT)…
- STORAGE: The aquifer characteristics will define the possible changes in physics and chemistry of the groundwater: Type of aquifer (unconfined, confined), geological structure (karst, sand), pore size, depth, water table, transmissivity, infiltration rate…
- RECOVERY: As it was defined in the step of water abstraction or recharge, the method of recovery can affect physical and chemical characteristics as far as flow rate, energy cost or availability in time: Well, spring, wetland…
- POST TREATMENT: OPTIONAL. As in the pre-treatment process, the diversity of devices or systems is connected to the potential use as much as the final quality after storage: Filtering, deposition, chemical addition, activated sludge, Up flow Anaerobic Sludge Blanket Reactor (UASB)…
- END USE: The possible usages of water affect the economic and ecologic effectiveness of the whole system. Wherever aquifers are brackish or not highly transmissive, water needs to be recovered close to the point of recharge requiring some distribution systems: Agriculture: (irrigation, water table control), industrial (coolant, raw material, solvent, energy source), ecological (wetland restoration, environmental flows, and flood control), urban (drinking water, garden and street watering)…

3.3 Benchmarking evolution and pooling components

3.3.1 Measuring water quantity

The volume of managed water should be quantified taking into account the different phases that this bulk has passed through from its abstraction to its final use. Once again the relative measure of the water recovered could be very significant to judge the usefulness of the MAR framework. Parameters for water quantity in a MAR system are listed in Table 3-1.

Table 3-1: Main parameters for water quantity in a MAR system.

Phase	Quantitative parameter	Original source	Aquifer	End use	% of total
Resources	Water availability	m^3			%
Abstraction	Water abstraction	m^3			%
Pre-treatment	Pre-treated water	m^3			%
Recharge	Recharged volume		m^3		%
	Recharge rate		m^3/year; L/s		%
	Volume/surface rate		m^3/ha		%
Storage	Incremented store		m^3		%
	Water table		m		%
Recovery	Water availability			m^3	%
	Water recovery			m^3	%
Use	Water use			m^3	%

Even though quantity is one of the main figures in MAR, it can be measured in a very different way depending on the site, the state of project and the type of facility. The sites in their initial phases are still quantifying the litres per second or the metres per hour as permeability and transmissivity experiences are in progress yet. Meanwhile the long-time operational sites tend to quantify square metres per cycle (operation time). On the other hand, recovery volume is not so easy to get for comparison when there are many different uses in the aquifer (Llobregat), or when the dedicated target is not systematically quantified (nitrate dilution or seawater barrier).

3.3.2 Measuring water quality

Once the flow pattern has been identified in every stage, the changes in quality must be monitored to check any possible (desired or undesired) change that could affect not only the final use, but also the chemical evolution of the collected water or the aquifer stability (Sedighi et al. 2006).

The same parameters that are used in any water treatment can be applied (Table 3-2). The general constraints are expected to be similar among the European countries although harmonization is still required (Miret et al. 2012). The list could be larger depending on the kind of pollution (industrial, agrarian, urban…) and the expected role of the MAR facility (storage, dilution, filtering…).

Table 3-2: Parameters for water quality in a MAR system. The change (in terms of %) is referred to the relative change of quality in different water stages (before abstraction; aquifer and before use).

Qualitative parameter	Recharging water	Aquifer	Recovered water	Change
pH	pH	pH	pH	%
Biological Oxygen Demand	BOD (mg/L)	BOD (mg/L)	BOD (mg/L)	%
Chemical Oxygen Demand	COD (mg/L)	COD (mg/L)	COD (mg/L)	%
Total Suspended Solids	TSS (mg/L)	TSS (mg/L)	TSS (mg/L)	%
Dissolved Organic Carbon	DOC (mg/L)	DOC (mg/L)	DOC (mg/L)	%
Ammonia	NH_3 (mg/L)	NH_3 (mg/L)	NH_3 (mg/L)	%
Total N	N (mg/L)	N (mg/L)	N (mg/L)	%
Phosphorus	P (mg/L)	P (mg/L)	P (mg/L)	%
Emerging Organic Compounds, Pesticides	(ppm)	(ppm)	(ppm)	%

In case the availability of water analysis cannot be obtained as often as desired in time and space because of budgetary restrictions, at least original resource and final end water quality should be compulsorily stated. Before and after management net figures are important but sometimes the percentage of change is essential to assess the viability of the recharge (as related to WWTP analysis legal prescriptions). This percentage should be expressed as a fraction of the annual available resource for recharge or the maximum established by the authority in charge. Other possibility could be relating every figure to the maximum obtained in the series of campaigns.

The main quality parameter has been nitrates as most of the demonstration sites are associated to agricultural areas. Water extraction from wells, water consumption for irrigation and nitrogen leaching from soil form a vicious cycle in rural areas where drinking use gets compromised by non-point pollution. The industrial pollution in Llobregat (Spain) or Lavrion (Greece) implies that the number of parameters to consider gets broader. Although WWTP effluents are one of the most guaranteed supplies they show a too impaired quality and pharmaceutics and urban pollutants multiply the list of compounds to be analysed.

3.3.3 Comparing efficiency in terms of cost and energy

Though the cost effectiveness could be related to the volume managed in each phase, a more objective measure could be calculated considering the net volume of recharged water as this is the final goal of the whole scheme. Effectiveness can be measured in every step (Table 3-3) using economic or energy references.

An energy balance must be applied to compare passive and active systems. The economic cost should be calculated separately for the infrastructure and for the operation and maintenance. Even an *Internal Rate of Return* could be estimated to value the recharging system as an investment in time. These monetary aspects have been covered in depth in work package 16 which regards economic issues of the MARSOL project, where alternative scenarios have been used to assess the feasibility of MAR related to other infrastructures.

Table 3-3: Parameters for efficiency in a MAR system.

Phase	Efficiency parameter	Original resource	Aquifer	End use	% of total
Abstraction	Energy cost	kWh/m^3			%
	Infrastructure cost	€/m^3			
	O&M cost	€/m^3			
Pre-treatment	Energy cost	kWh/m^3			
	Infrastructure cost	€/m^3			%
	O&M cost		€/m^3		%
Recharge	Energy cost		kWh/m^3		%
	Infrastructure cost		€/m^3		%
	O&M cost		€/m^3		%
	Recharging rate		%		
	Filtration rate		m^3/ m^2		
Recovery	Energy cost			kWh/m^3	%
	Infrastructure cost			€/m^3	%
	O&M cost			€/m^3	%
Use	Energy cost			kWh/m^3	%
	Infrastructure cost			€/m^3	%
	O&M cost			€/m^3	%

3.4 Techniques and methods applied and their indicators pooling

In order to collect all these data for every demonstration site, the MARSOL demonstration sites leaders have been contacted to fill in a complete data form to characterize their aquifer recharge system. The template was divided in four sections and shared via a cloud server:

- Main data and big numbers are covered in the first section as MAR class, functions, geology, water cycle, water quality, soil control and benchmarking indicators as seen in further tables (Figure 3-2, up). The first sheet is the most important table where the main data reside, showing the approach of MAR to solve water management problems. The upper part of the table reveals the features that illustrate the demonstration site in the local and technical details. Then, functions are exposed so performance rates can be assigned.
- The second section shows the location of the demonstration site on orthophoto using any GIS program or Google Earth (Figure 3-3). In the case of benchmarking (Figure

3-2, left) this process is not simply used to get location maps but also to get operational dimensions, e.g. the size of the recharging facilities (pond surface) is greater than their active dimensions (pond infiltrating bottom area).

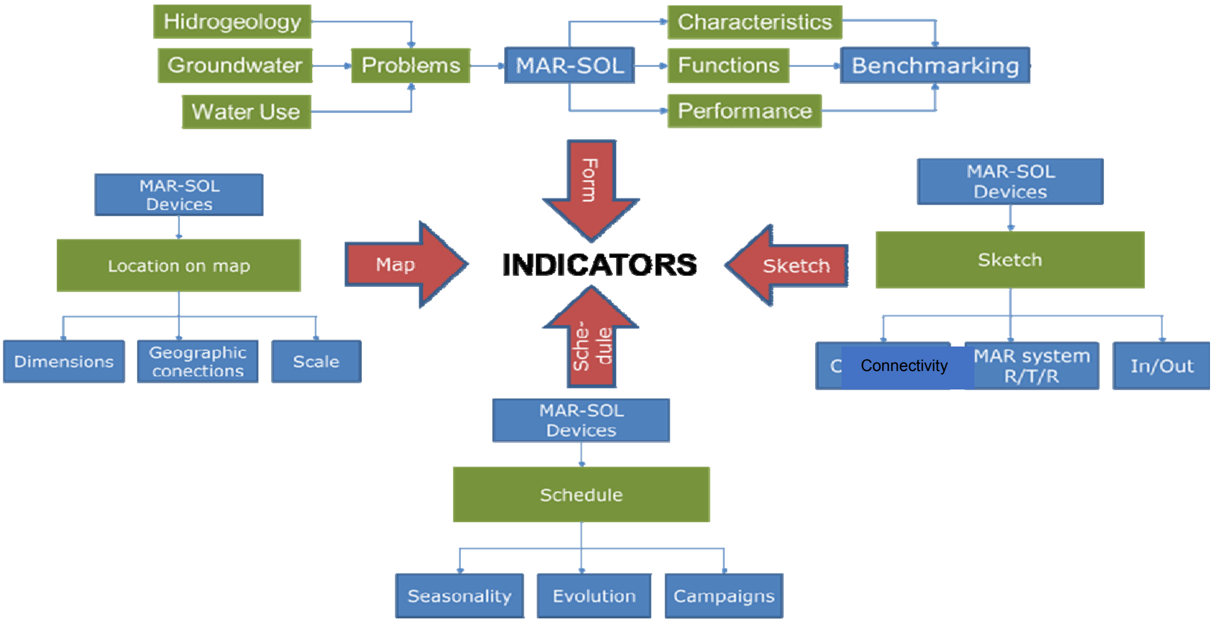

Figure 3-2: Methodology applied for data gathering. From MAR characterization to indicators.

Figure 3-3: LLobregat demonstration site location on orthophoto.

- The third section is a sketch of the demonstration site where Q_0 to Qx represent main inlets and outlets, so it can be made out which device or stretch is playing a different role in each point of the recharge net (Figure 3-4). The main aim is focused on identifying in and out flow directions (available points for future monitoring network), main functions (transport, recharge, recovery…) and connectivity (leaks) for benchmarking design (Figure 3-2, right).

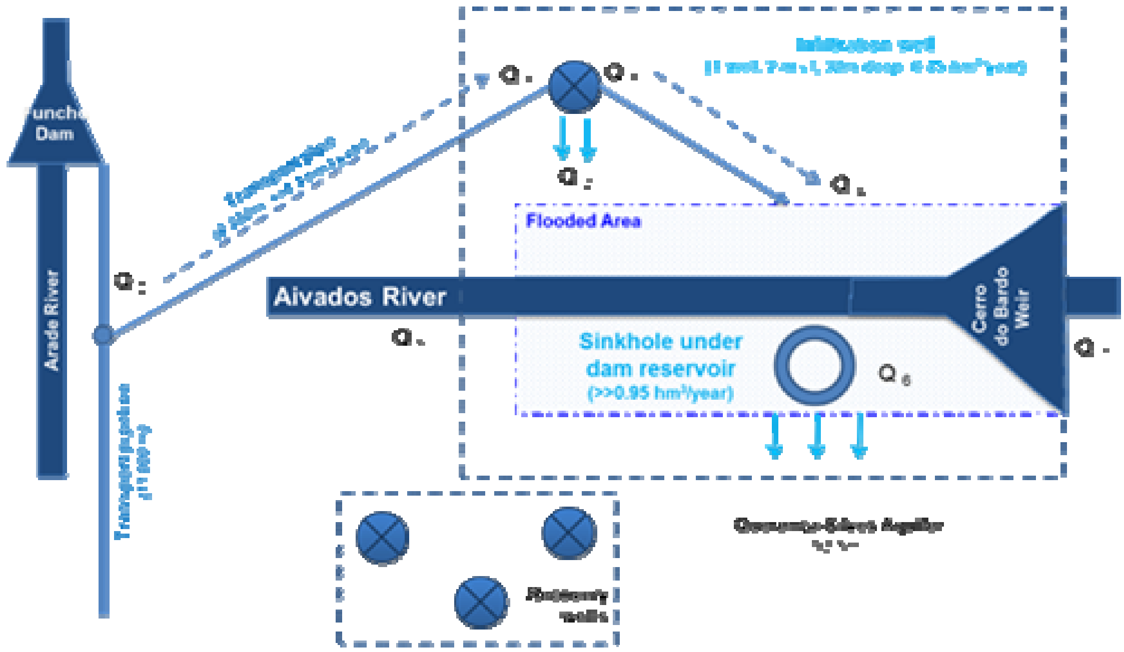

Figure 3-4: Example of the Campina de Faro demonstration site network sketch.

- The fourth section is a calendar showing new works and changes of facilities in time (Table 3-4). As shown below, some of them can be enlarged as other ones can start from zero so functionality is not constant every season (Figure 3-2, down).

Table 3-4: Example of the Santiuste MAR system development schedule from 2002 to 2015. Total number of operative facilities per year is shown in the last row.

	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	Total
Diversion catchment	1	1	1	1	1	1	1	1	1		1	1	1	12
Diversion Pipe	1	1	1	1	1	1	1	1	1		1	1	1	12
Infiltration Pond			1	1	1	1	1	1	1		1	1	1	10
East Infiltration Canal (Old)	1	1	1	1	1	1	1	1	1		1	1	1	12
East Infiltration Canal (New)						1	1	1	1		1	1	1	7
West Infiltration Canal				1	1	1	1	1	1		1	1	1	9
WWTP					1	1	1	1	1	1	1	1	1	9
Biofilter					1	1	1	1	1	1	1	1	1	9
Artificial Wetlands				1	1	1	1	1	1		1	1	1	9
Salt Lake diversion				1	1			1	1		1	1	1	7
Salt lake restoration				1	1			1	1		1	1	1	7
	3	3	4	8	10	9	9	11	11	2	11	11	11	

In order to have a guide to follow, a completed version of the form was sent to the people in charge of the eight MARSOL demonstration sites. The first section was filled with the data obtained from bibliography for every demonstration site. The other three sections were filled in with the pattern of Santiuste (Los Arenales, Spain), so that the researchers in charge of every demonstration site could see and apply a practical example. Further revisions and meetings permitted to correct and adapt the fields, units and figures according to the current state of each MAR facility.

The main troubles to benchmarking associated to recharge are related to the huge variety of demonstration sites and MAR facilities. Apart from local conditions as pollution sources and geological background, there are some conditions that make the MARSOL sites hard to evaluate for benchmarking:

- Scale: The sites that have been compared using benchmarking indicators present a great difference of extent. From the infiltration ponds of Llobregat or Rio Seco to the broad areas of canals in Santiuste or the infiltration area in Menashe, the MARSOL group needs to change from square meters to hectares as the surface used for infiltration turns from pond bottoms to kilometres of channels. This change of size goes further than simply using different units of measure. It is also a different approach from intensive to extensive systems, each with their own pros and cons.
- State of development: Some demonstration sites as Lavrion are almost in the experimental stage, while others have been working for decades. Consequently, the availability of data and the consistency of those figures are very unequal. This initial stage is an important inconvenient when the aim is a long term target as nitrate dilution or seawater intrusion barrier effectiveness, that cannot be immediately tested by simple groundwater storage or water purification through the soil.
- Complexity: The demonstration sites that have been selected can be as simple as an infiltration pond system in Portugal or Spain or as complicated as a network of canals, ponds and wetlands in Santiuste basin in Los Arenales. Those connected facilities need to be valued as their separated items to get a comparison based on similar aims and processes instead of an appraisal as a whole.
- Main target: The array of recharging facilities covers many different aims, from nitrate dilution to environmental recovery. Although complexity and multifunctionality are usually linked, even the basic sites as Rio Seco can play different roles at the same time (infiltration, nitrate dilution and flood control). That flexibility and multiplicity of roles are perfect examples of the reasons why recharge could be easily used as a water management tool adapted to different situations within a basin.

According to these previous conditions, the characterization of each demonstration site has been carried on in order to identify each comparable item before a global judgement could be established.

4. POOLING EVOLUTION FOR EACH DEMONSTRATION SITE

The original eight MARSOL demonstration sites have been separated in 15 locations in order to characterize the MAR facilities so the implementation of benchmarking could be easier (Table 4-1).

Table 4-1: Increasing number of operational demonstration sites and forms.

#	CODE	SHORT NAME	COUNTRY	DEMO LOCATION
1	1	LAVRION	Greece	Lavrion Technological & Cultural Park (LTCP)
2	2a	ALGARVE & ALENTEJO	Portugal	Rio Seco
3	2b	ALGARVE & ALENTEJO	Portugal	Campina de Faro
4	2c	ALGARVE & ALENTEJO	Portugal	Ribeiro Meirinho
5	2d	ALGARVE & ALENTEJO	Portugal	Cerro do Bardo
6	2e	ALGARVE & ALENTEJO	Portugal	Melides Lagoon
7	3a	LOS ARENALES	Spain	Santiuste (Segovia)
8	3b	LOS ARENALES	Spain	Carracillo (Segovia)
9	3c	LOS ARENALES	Spain	Alcazarén (Valladolid)
10	4	LLOBREGAT	Spain	Sant Vicenç dels Horts (Barcelona)
11	5a	BRENTA	Italy	Schiavon (Vicenza)
12	5b	BRENTA	Italy	Loria (Treviso)
13	6	SERCHIO	Italy	Lucca (Tuscany)
14	7	MENASHE	Israel	Menashe
15	8	SOUTH MALTA	Malta	South Malta

4.1 Greece. Lavrion demonstration site

Lavrion Technological & Cultural Park (LTCP) is located at the coastal area of Lavrion, Attica, within the wider area of Athens. The Region of Attica covers an area of 3,207 km^2, containing more than half the population of Greece. Attica Water District involves the entire Region of Attica, the islands of Aegina, Salamina and Makronisos and small parts of Sterea Ellada and Peloponnese. That means high population water supply demand combined with summer tourism is linked to increasing need of sewage treatment during the driest season.

The case study combines all typical Mediterranean coastal water problems (i.e. seawater intrusion, water scarcity, irrigation water demand, etc.) and MAR application has been envisaged to combat all those.

Two types of aquifers are developed, one in the Quaternary alluvial deposits (granular aquifer) and one in the Upper Marble formation (karstic aquifer). The total water availability is about 450 hm^3 and this amount consists of 260 hm^3 of surface water and 190 hm^3 groundwater. There are four major water reservoirs, four major water purification plants, two major wastewater treatment plants and several clusters of wells in the area.

The pilot site will involve the employment of infiltration basins, which will be using waters of impaired quality as a recharge source, hence acting as a Soil-Aquifer-Treatment (SAT) system.

This structure is complemented by new technological developments, which will be providing continuous monitoring of the quantitative and qualitative characteristics of infiltrating groundwater through all hydrologic zones (surface, unsaturated and saturated zone). This will be achieved through the adaptation and installation of an integrated system of prototype sensors installed on-site, offering a continuous monitoring and evaluation of the performance of the SAT system.

4.1.1 Advance of the demonstration activity

This demonstration site has been mainly devoted to technological development of hardware and software for recharging monitoring. After local hydrogeological studies and the search of the best infiltration points by means of GIS have been completed, main tasks have been focused on piezometer design and operation in field around the selected infiltration spot and a software program that can be as affordable as reliable.

Nevertheless, as it is indicated in Table 4-2, it is situated in a very promising zone where MAR can show the flexibility of this kind of water management solution to such a wide-ranging problems and sources. Six water problems have been detected and WWTP seems to be a promising source of water of impaired quality. The soil processes and chemistry evolution during infiltration must be monitored in order to avoid pollution of the aquifer. Infiltration trough a karst and the risk of industrial pollution are also challenging conditions but as long as seawater intrusion and overexploitation occurs in the zone, the sewage option should not be neglected. Mediterranean extreme circumstances, especially in summer, help to force more inventive solutions.

Table 4-2: Lavrion preliminary characterization.

Indicator	Observations on indicator	LAVRION
Country		Greece
Demo LOCATION	Main location: Province, county, villages…	Lavrion Technological & Cultural Park (LTCP)
AQUIFER	Aquifer or Groundwater body	Lavrion
MAR Class	Main classes: Infiltration/Injection	Infiltration
MAR Type	Subclass	Infiltration Basin (SAT)
OBSERVATIONS	Any remarkable characteristic of the site	Impaired q source: q_0, q_r, q_f
MAR devices (According to table)		
3 DISPERSE	RIDGES/ SOIL AND AQUIFER TREATMENT TECHNIQUES (SAT)	X
4 DISPERSE	INFILTRATION FIELDS (FLOOD AND CONTROLLED SPREADING)	X
PROBLEMS	Main troubles on the aquifer area	
Scarcity (Overexploitation)	Quantitative issues because of overconsumption	X
Scarcity (Climate Change)	Drought, rising temperatures trend, lower precipitation cycles…	X
Salinity (Seawater intrusion)	Associated to coastal aquifers	X
Heavy metals (Mining, Industry)	Metals from agrochemicals, urban, industrial sources: Pb, Fe, Al, Cr, Cd, Hg…	X
Agriculture contamination (mainly N)	Agriculture diffuse contaminants: N, P K…	X
Organic pollution (agrochemicals and antibiotics)	Toxic pollutants as pesticides and antimicrobials	X
FUNCTIONS	Current recharge applications	
Irrigation Supply		X
Drinking water supply		X
Seawater barrier		X
GEOLOGY		
Multi-aquifer		X
Coastal		X
Alluvial		X
Karst		X
WATER SOURCE		
Sewage (WWTP)		X
WATER RECOVERY		
Lake / wetland	Lake, lagoon, pond…	X
WATER USE		
Agriculture	Irrigation, water table control	X
WATER CONTROL	Available and comparable analysis	
QUANTITY (Q)		
Water table level	m (monthly change), beginning vs. end of recharge campaign	X
Soil Moisture	% (regular change around wells)	X

4.1.2 Pooling of its specific benchmarking system

Benchmarking for Lavrion has not been possible as this is still in a very preliminary phase. However some indicators should be taken into account in order to design, in advance, a convenient follow up.

- The lack of a detailed mapping of wells in the area is a problem to be solved as soon as possible as recharge effects on water quantity and quality can be misjudged. This fact is due to undetected extractions or abandoned wells that can become unexpected points of pollution.
- Seawater intrusion combat is a kind of recharge consequence that needs a long-term monitoring to be tested, so that might be postponed for later phases.
- Scarcity and nitrate pollution are also problems hard to fight against, but local effects are easier to measure, particularly when the demonstration site has been as devoted to monitoring technical solutions as this one.
- The opportunity of reusing WWTP effluents in a Mediterranean coast is an important advantage to be remarked. The damage of sewage pipes on underwater seagrass meadows (*Posidonia oceanica, Zostera marina, Zostera noltii, Cymodocea nodosa* and *Halophila stipulacea*) could be contrasted to the potential use of this volume in more productive uses as groundwater recharge. Even more, when the same coastal aquifer is suffering seawater intrusion, a positive barrier is urgently needed.

4.2 Portugal. Algarve and Alentejo demonstration site

4.2.1 Advance of the demonstration activity

Up to five demonstration sites were characterized in this country. Unfortunately one of them has been deleted from the next table, Melides Lagoon, as its preliminary stage of development complicates the possibility of establishing indicators based in a solid design. This site was an infiltration facility that used a polluted return flow from rice fields into a lagoon as a source of recharge by improving water quality through a SAT device. Unluckily, the project has not been technologically advanced for the MARSOL calendar yet so the number of demonstration sites in Portugal has been reduced to four as shown in Table 4-3.

Table 4-3: Preliminary characterization and benchmarking indicators for Portuguese MAR sites.

Indicator	*Observations on indicator*	ALGARVE - Campina de Faro (Rio Seco +IP)	ALGARVE - Campina de Faro (GH+IW)	ALGARVE - S. Bartolomeu de Messines	ALGARVE - Cerro do Bardo
Country		Portugal	Portugal	Portugal	Portugal
Demo LOCATION	*Main location: Province, county, villages…*	Rio Seco	Campina do Faro	S. Bartolomeu de Messines	Cerro do Bardo
AQUIFER	*Aquifer or Groundwater body*	Campina de Faro	Campina de Faro	Querença-Silves	Querença-Silves
MAR Class	*Main classes: Infiltration/injection*	Infiltration	Infiltration	Infiltration	Infiltration
MAR Type	*Subclass*	Infiltration Ponds	Open Infiltration wells	Infiltration / SAT	Well / Dam
MAR devices	*Main devices*	3 Infiltration Ponds	Infiltration dug Wells "Noras" (1 tested, 60 inventoried)	2 Infiltration ponds for SAT	1 Dug Well; 1 Weir (dam); 1 pipeline 2,230 meters long from the Arade reservoir pipeline

Indicator	*Observations on indicator*	ALGARVE - Campina de Faro (Rio Seco +IP)	ALGARVE - Campina de Faro (GH+IW)	ALGARVE - S. Bartolomeu de Messines	ALGARVE - Cerro do Bardo
MAR dimensions	*Length, width (depth when available). Applicable to each device*	2 Ponds 20 m long*5m wide*6 m deep; 1 basin 33 m long*6,1 m wide* 6 m deep; total 401 m^2 * 6 m deep	Total of 60 infiltration dug wells; diameters range from 2 to 5 meters; Depths of around 20 meters	2 ponds; 21 m long * 5m wide * 0,80 m deep; SAT system with a depth of 0.30 m	Dug well: 2 m diameter; 32 meters deep; Weir with 26 meters width and 1.30 high
MAR devices (According to table)					
DISPERSE	*Infiltration ponds/ wetlands*	3 Infiltration Ponds			
DISPERSE	*Ridges/ soil and aquifer treatment techniques (SAT)*			2 SAT Ponds	
DISPERSE	*Accidental recharge by irrigation return*		X		
CHANNELS	*Reservoir dams and dams*				1 Weir
WELLS	*Open infiltration wells*		60 dug wells (11 within modelling area)		1 Dug Well
WELLS	*Sinkholes, collapses...*				1 known sink hole
WELLS	*Aquifer storage, transfer & recovery (ASTR)*				X
RAIN	*Rainwater harvesting in unproductive*		Green House roof harvesting		
PROBLEMS	*Main troubles on the aquifer area (Changed into specific problems dealt by the MAR devices)*				
Scarcity (Overexploitation)	*Quantitative issues because of overconsumption*			X	X
Scarcity (Climate Change)	*Drought, rising temperatures trend, lower precipitation cycles...*			X	X
Agriculture contamination (mainly N)	*Agriculture diffuse contaminants: N, P K…*	X	X		
Organic pollution (agrochemicals and antibiotics)	*Toxic pollutants as pesticides and antimicrobials*	X	X		
Wastewater discharge	*Insufficiently treated effluents, point of discharge*			X	
Floods	*Flooding events caused by CC, extreme rain…*	X			
FUNCTIONS	*Current recharge applications*				
Irrigation Supply					X
Drinking water supply					X
Seawater barrier			X		
Water Quality improvement		X	X	X (Pharmaceutic s)	
Seasonal storage					X
GEOLOGY					
Multi-layered aquifer		X	X		
Mono-layered aquifer				X	X
Coastal		X	X		
Inland				X	X
Alluvial		X	X		
Karst				X (Querença-Silves Aquifer)	X (Querença-Silves Aquifer)
Confined				X	X
Unconfined		X	X		
WATER SOURCE					
River	*Diversion with no horizontal building*	X (Rio Seco)			X (Ribeira de Aivados)
Weir/Dam					X (Arade Dam)
Sewage (WWTP)				X (Sao Bartolomeu de Messines)	

Indicator	Observations on indicator	ALGARVE - Campina de Faro (Rio Seco +IP)	ALGARVE - Campina de Faro (GH+IW)	ALGARVE - S. Bartolomeu de Messines	ALGARVE - Cerro do Bardo
Rainfall			X (collected in the GH roofs towards the infiltration wells)		
WATER TRANSPORT	*Mean of transportation when available*				
Pipe	*Buried or not*		X	X	X
Others	*To be specified when completing*	No transport for Infiltration Ponds			
WATER RECOVERY					
Well			X	X	X
Others	*To be specified when completing*	X (Goal is to improve the water quality, not so much recovery)	X (Goal is to improve the water quality, not so much recovery)		
WATER USE					
Agriculture	*Irrigation, water table control*		X	X	X
Ecological	*Wetland restoration, environmental flows, flood control*	X	X	X	X
Urban	*Drinking water, garden and street watering*				X
WATER CONTROL	*Available and comparable analysis*				
QUANTITY (Q)					
Discharge volume	*Water abstraction (m^3/year)*	X	X	X	X
Water table level	*m (monthly change), beginning vs. End of recharge campaign*	X	X		X
QUALITY (q)					
EC	*(mhoms/cm; dS/m)*	X	X	X	X
pH		X	X	X	X
BOD	*Biological Oxygen Demand (mg/l)*			X	
COD	*Chemical Oxygen Demand (mg/l)*			X	
TSS	*Total Suspended Solids (mg/l)*			X	
NO_3	*Nitrates (mg/l)*	X	X	X	
P	*Phosphorous (mg/l)*			X	
K	*Potassium (mg/l)*			X	
Heavy metals	*Fe, Cu, Cr, Al, Hg…*			X (B, Zn, Cu)	
Pesticides	*Pesticides according to main uses*			X	
Others	*To be specified when completing*			X (Pharmaceutics, Colif., Cl, SO_4, NO_2, NH_4; Temperature)	

4.2.2 Pooling of its specific benchmarking system

The four selected Portuguese sites (Rio Seco, Noras, São Bartolomeu de Messines and Cerro do Bardo) are going to be assessed for their preliminary benchmarking results (Table 4-4). Only the first site (Rio Seco) shows two-year-working-performance indicators as the rest are just estimations based on initial tests.

The main goal in Rio Seco is to improve the groundwater quality heavily contaminated with nitrates (vulnerable zone of Faro) due to inappropriate agricultural practices. The water source is the ephemeral stream river bed (Rio Seco) and the infiltration is carried out using gravel filled basins in the river bed. This MAR facility shows a high availability for diversion (6.7 hm^3) but it is only operative for a short time, no much longer than an average of 2 months (67 days) per year (Figure 4-1), corresponding to the stream water availability. The site had been partially active since 2007 until it was made fully operational in October 2014. The space was limited as the three infiltration ponds were located in the very narrow and ephemeral river bed (Costa et al. 2015). The average infiltration rate was quite good (21.6 m^3/h) but, considering the diverted volume, the fraction was low (0.52%) for these initial campaigns. On the other hand, mainly due to the thickness of the confined material, the cost of the infrastructure was 86,000 €, which despite not being too high it is second in Portugal and almost twice the budget of the third one. Considering the costs and the corresponding infiltrated volume, the Rio Seco ponds are the most expensive facilities (2.46 €/m^3). However, this is expected to change in future campaigns as the long lifespan and low operation and management (O&M) charges of these infrastructures tend to flatten the annual investment.

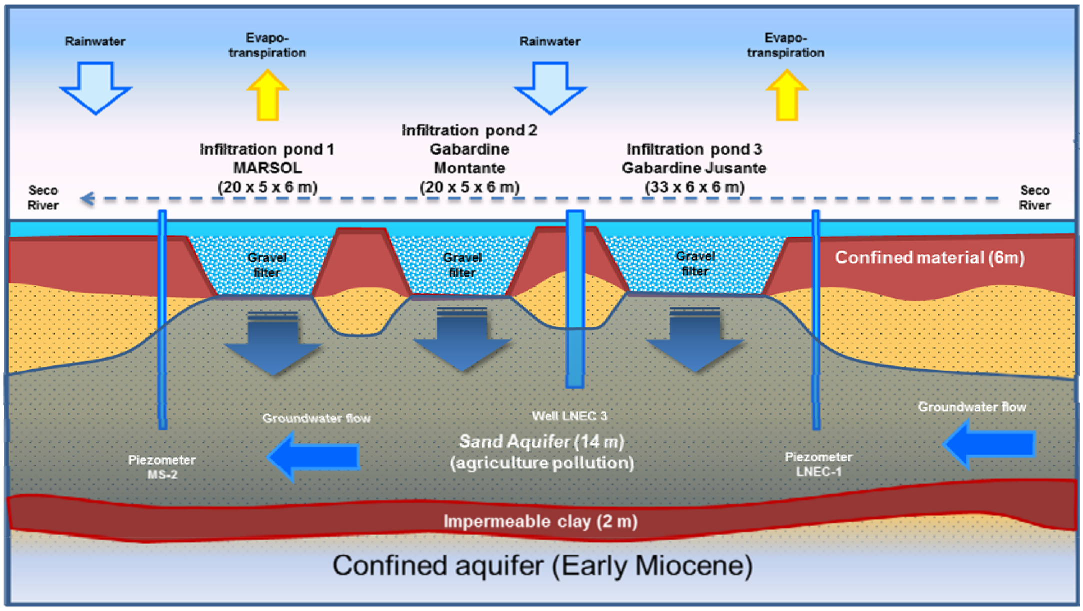

Figure 4-1: Campina de Faro (Rio Seco) profile. Main processes (arrows) and MAR facilities (ponds and piezometers) are shown.

Noras (Figure 4-2) is an unconventional site as a rainwater harvest system in a rural area. Its huge gathering capacity (1,300,000 m^2) comes from the surface of the greenhouse rooftops and the old abandoned wells (named *"noras"* in Portuguese) are the actual infiltration facilities (Lobo Ferreira and Leitão 2014). The infiltration speed is very high (max. 7,200 m^3/hour, annual average 818 m^3/hour) for such short water availability. Consequently, a very good infiltration area rate (463 m^3 per m^2, considering the large "noras" area) makes its efficiency good enough (26.99%). The cost of the infrastructure is very low as greenhouses and old wells were established before recharge. The operation and management (O&M) estimated cost is one of the lowest in Portugal but its calculated cost is four times higher. The availability of pre-existent wells and no water transport requirements represent good advantages for an easy replication in many other areas with greenhouses (Leonardi and De Pascale 2010) in the Mediterranean coast such as Almería in Spain, Ragusa in Italy or Antalaya in Turkey.

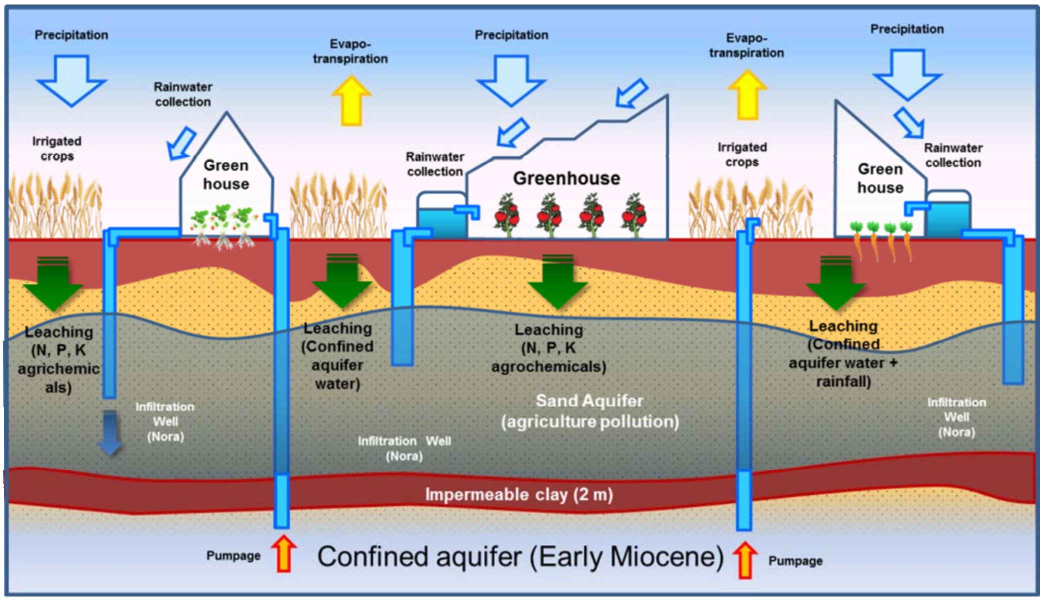

Figure 4-2: Campina de Faro GH profile. Rain on greenhouses roofs is harvested and directed to abandoned wells (noras) to recharge the unconfined part of the aquifer.

S. Bartolomeu de Messines (Figure 4-3) and Cerro do Bardo (Figure 4-4) benchmarking are just based on projects in their preliminary states, so their results cannot be commented in detail yet. The most remarkable facts are the low O&M cost for both sites and the high price of the infrastructure of Cerro do Bardo, due to its long water transport pipe (2,230-meter-long pipe). S. Bartolomeu and Llobregat share some similarities in influent quality (urban polluted water) and design (biofilter in the bottom of a pond) although infiltration in Portugal takes place later, after discharge on a stream running on a karst (Figure 4-3, right).

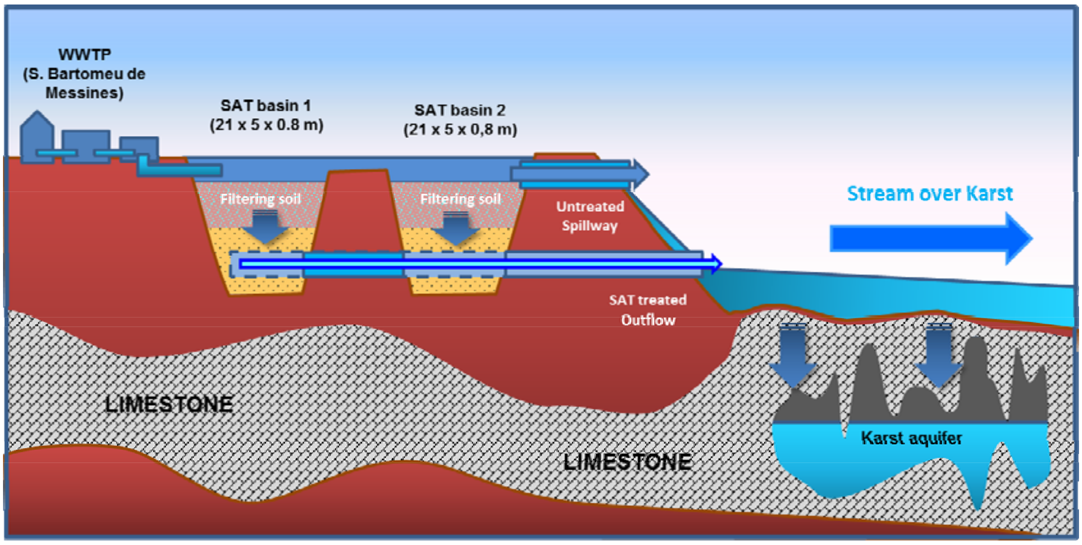

Figure 4-3: São Bartolomeu de Messines MAR profile. Part of the outflow from a WWTP is infiltrated through a couple of SAT basins and spilled into a stream.

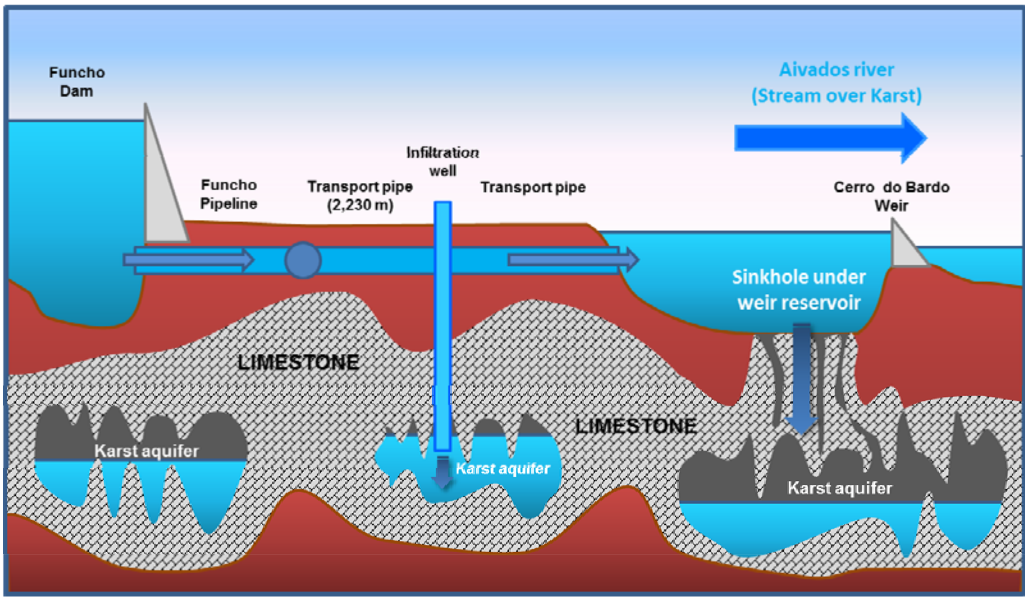

Figure 4-4: Cerro do Bardo profile. Water from a dam network is diverted to an infiltration well and a weir where a submerged sinkhole recharges a karst.

Table 4-4: Preliminary benchmarking indicators for Portuguese MAR sites.

BENCHMARKING INDICATORS	UNITS	Campina de Faro (Rio Seco +IP)	Campina de Faro (Noras GH+IW)	S. Bartolomeu de Messines	Cerro do Bardo
Water Diversion	hm^3/ campaign	6.7	1.63	0.3	14
Operation time	Days/ campaign	67	22.25	365	365
Operation campaigns	Years	2	0	0	0
Infiltration surface	m^2	401	950	210	Estimated surface of weir (no sinkhole measures)
Infiltration volume	hm^3/ campaign	0.035	0.44	0.03	1.7
Infiltration speed (V/t) rate	m^3/h	21.6	818	3.5	190
Infiltration efficiency (R/D) rate	% (infiltrated /diverted)	0.52%	26.99%	10.00%	3.40%
Infiltration area (V/A) rate	m^3/m^2	87.28	463.15	142.86	--
NO_3 concentration decrease	mg/L, %	50% lower nitrate concentration in a 100 m radius around the basins	Quality improvement data: % depletion (Data for future collection)	Pharmaceutics decrease in %	--
Energy cost	kWh/m^3	0	0	0	0
Infrastructure cost	€	86,000	32,000	15,000	1,154,000
Infiltration Infrastructure cost	€/m^3	2.46	0.07	0.50	0.68
O&M cost	€	4,000	4,000	1,000	15,000
O&M cost (estimated)	€/m^3	0.133	0.010	0.033	0.006
O&M cost (calculated)	€/m^3 (cost/infiltrated)	0.114	0.041	0.033	0.006

In short, the main functions in Portugal are related to quality improvement whose measurement is not completely covered by sensors and analyses in such a large groundwater body.

Nitrogen depletion must be estimated considering the lower concentration in recharged water or a more general and long-term water table decline in the whole aquifer. Anyhow, the alternative of pumping and treating the volume of groundwater to reduce the nitrate content from 200 to 50 mg/L would be unaffordable. Pharmaceuticals resilience associated to the outflow of S. B. de Messines implies very expensive and specific analyses, but they are also an emerging concern related to urban pollution and WWTP outflow (Drewes et al. 2003; Clara et al. 2004).

4.3 Spain. Los Arenales demonstration site (Castilla y León)

4.3.1 Advance of the demonstration activity

The most important current operative demonstration sites in Castilla y León (CyL) are located on the same broad sandy aquifer and two of them have been recharging river water since 2002. Alcazarén (Figure 4-5) had legal problems to maintain water supply from Pirón River so it is going to be considered only for characterization purposes. El Carracillo (Figure 4-7) could not get any supply for a couple of campaigns and Santiuste (Figure 4-6) only failed in 2011-2012 for the same period so, there are 11-12 recharging cycles to compare and get consistent results (Fernández Escalante 2005; Fernández Escalante et al. 2015). The main differences between, are:

- The three sites take water from river winter surplus but Santiuste and Alcazarén has also had a complementary water source from WWTP.
- Canals are the main transport and infiltration facilities in Santiuste (and in El Carracillo too) while pipeline and ponds play those roles in El Carracillo and Alcazarén.
- Works in Santiuste have been constantly evolving since 2002, lengthening and broadening some facilities (canals) and building new ones (ponds, artificial wetlands), while El Carracillo has remained more stable with only minor changes.

Summing up, these sites use a long pipe to transport water by gravitation from a river between 5 and 18 km far from the irrigation area, where a series of canals and ponds enhance the intentional recharge into the sandy aquifer by direct infiltration. Transport, infiltration, purification and restoration processes take place in different sections and extents in the three areas (Table 4-5).

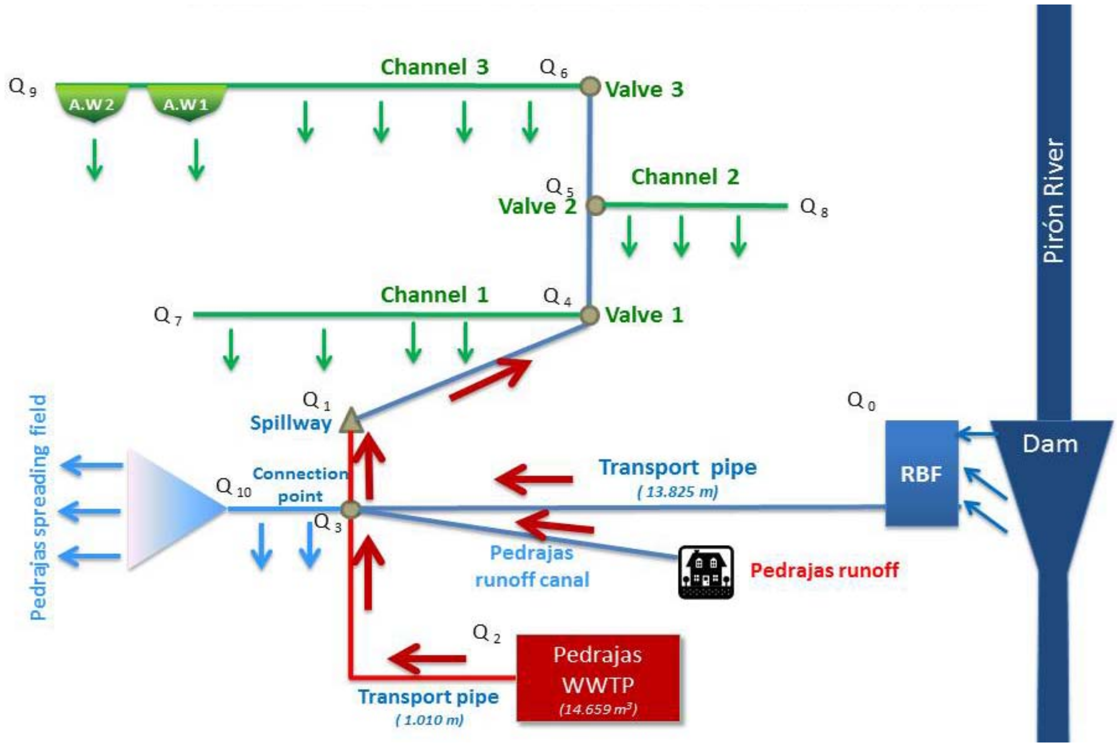

Figure 4-5: Alcazarén MAR sketch. Main water source comes from a River Bank Filtration system that can be compared to that in Serchio but also from a WWTP effluent.

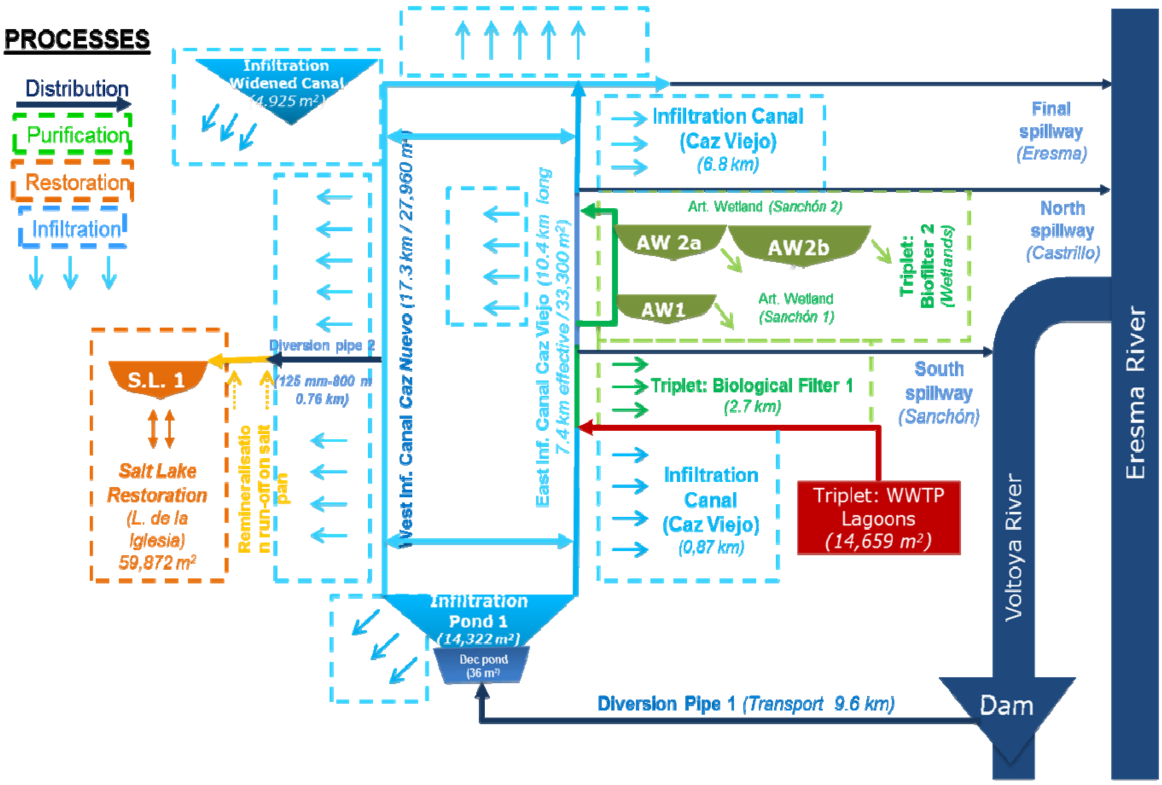

Figure 4-6: Santiuste MAR sketch. A very complex MAR system conjugates up to four processes using water diverted from Voltoya River.

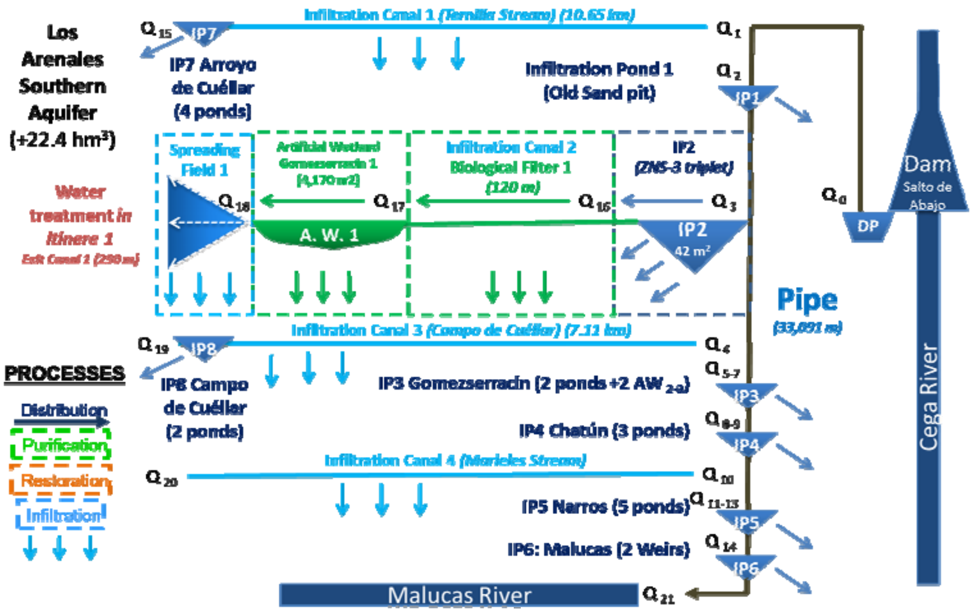

Figure 4-7: El Carracillo MAR sketch. A long (33 km) pipe carries water from Cega River and supply a series of infiltration facilities in El Carracillo district.

The biofilter process in Santiuste is carried out by a vegetated canal and three artificial wetlands that improve water quality of the WWTP sewage flow before infiltrating in the next canal section. El Carracillo has a similar little scale triplet formed by a stagnation pond, a vegetated canal, an artificial wetland and a spreading infiltration field at the end. However, water quality is still better than in the previous site as no water from a WWTP is inserted into the system and current lagooning proves not to be a full effective purification method. On the other hand, Alcazarén WWTP effluent has a much better quality so infiltration does not show any important collateral clogging effect by now.

Table 4-5: Preliminary benchmarking indicators for Los Arenales MAR sites.

Indicator	*Observations on indicator*	Santiuste	El Carracillo	Alcazarén
Country		Spain	Spain	Spain
Demo LOCATION	*Main location: Province, county, villages…*	Santiuste (Segovia)	El Carracillo (Segovia)	Alcazarén (Valladolid)
AQUIFER	*Aquifer or Groundwater body*	Los Arenales	Los Arenales	Los Arenales
MAR Class	*Main classes: Infiltration/Injection*	Infiltration	Infiltration	Infiltration
MAR Type	*Subclass*	Infiltration / SAT Basins	Infiltration / SAT Basins	Infiltration / SAT Basins
MAR devices	*Main devices*	Ponds/Canals/AW	Ponds/Canals	Ponds/Canals
OBSERVATIONS	*Any remarkable characteristic of the site*	Complex irrigation area with infiltration, water treatment and restoration functionality	Extended infiltration pond network connected by pipe from a river dam	Infiltration canals connected to RBF from a dam and a WWTP
MAR devices (According to table)				
DISPERSE	*Infiltration ponds/ wetlands*	5+1	22+1	X
DISPERSE	*Channels and infiltration ditches*	27 km	40.7 km	X
DISPERSE	*Ridges/ soil and aquifer treatment techniques (SAT)*	X		
DISPERSE	*Infiltration fields (flood and controlled spreading)*		1	1
DISPERSE	*Accidental recharge by irrigation return*	X	X	X
DAMS	*Reservoir dams and dams*	1	1	X
WELLS	*Qanats (underground galleries)*		X	
WELLS	*Open infiltration wells*	3	X	

Indicator	*Observations on indicator*	Santiuste	El Carracillo	Alcazarén
FILTRATION	*River bank filtration (RBF)*	1		X
FILTRATION	*Interdune filtration*		X (ditches)	
PROBLEMS	*Main troubles on the aquifer area*			
Scarcity (Overexploitation)	*Quantitative issues because of overconsumption*	X	X	X
Agriculture contamination (mainly N)	*Agriculture diffuse contaminants: N, P K…*	X	X	X
Organic pollution (agrochemicals and antibiotics)	*Toxic pollutants as pesticides and antimicrobials*	X	X	X
Wastewater discharge	*Insufficiently treated effluents*	X		
Wetland desiccation	*Deterioration by water Table decline, run-off shortage….*	X		
Floods	*Flooding events caused by CC, extreme rain…*			
FUNCTIONS	*Current recharge applications*			
Irrigation Supply		X	X	X
Drinking water supply		X		
Wastewater treatment		X		X
Wetland restoration		X	X	X
Water Quality improvement		X (NO_3)	X (NO_3)	X (NO_3)
Seasonal storage		X	X	
GEOLOGY				
Mono-aquifer		X	X	X
Inland		X	X	X
Alluvial		X	X	X
Unconfined		X	X	X
WATER SOURCE				
River	*Diversion with no horizontal building*	Voltoya River (1,000 L/s)	Cega	Pirón
Weir/Dam		Voltoya Dam (60000 m3)	Salto de Abajo Weir	Pirón Dam
Sewage (WWTP)		Santiuste de San Juan Bautista		Pedrajas
Irrigation return flow		X	X	X
Others	*Returning river*	Eresma	Pirón	
WATER TRANSPORT	*Mean of transportation when available*			
Canal	*Canal of water (concrete or ground)*	X		X
Ditch	*Irrigation channel*		X	
Pipe	*Buried or not*	9,823.63 m (PRF 900 mm)	33,000 m	13,825 m
WATER RECOVERY				
Well		X	X	X
WATER USE				
Agriculture	*Irrigation, water table control*	X	X	X
Ecological	*Wetland restoration, environmental flows, flood control*	X	X	X
WATER CONTROL	*Available and comparable analysis*			
QUANTITY (Q)				
Discharge volume	*Water abstraction (m3/year)*	X	X	X
Water table level	*m (monthly change), beginning vs. End of recharge campaign*	X		
Soil Moisture	*% (regular change around wells)*	X		
QUALITY (q)				
EC	*EC* | *(mhoms/cm; dS/m)*	X	X	
pH	*pH*	X	X	
Temperature sensors	*ºC in depth*	X	X	
HCO_3	*HCO_3* | *Bicarbonate (mg/l)*	X	X	

4.3.2 Pooling of its specific benchmarking system

As Alcazarén has not been able to maintain a similar operative rhythm, it has been removed from the current benchmarking process. Benchmarking figures in Los Arenales aquifer are shown in Table 4-6. The availability of more than ten cycles at both demonstration sites permits to use some averages as statistics with a greater relevance for characterization in Table 5-6.

The main effect of MAR has been measured as their consequences in the main use in the area: irrigation: irrigated area has grown, culture production has risen, agroindustry has been developed and rural demography has positive statistics (Fernández, San Sebastián & Villa-nueva 2016). These encouraging facts have been responded by local population with a good social acceptance in the villages where recharge takes place.

Table 4-6: Los Arenales demonstration sites benchmarking pooling.

BENCHMARKING	UNITS	SANTIUSTE (CyL)	EL CARRACILLO (CyL)
Water Diversion	***Campaigns***	**hm^3**	**hm^3**
	2002/2003	3.5	1.4
	2003/2004	2.25	5.5
	2004/2005	1.26	0
	2005/2006	5.11	2.45
	2006/2007	12.68	3.2
	2007/2008	0.52	0
	2008/2009	3.87	1.9
	2009/2010	0.7	5.8
	2010/2011	3.13	4.6
	2011/2012	0	1.9
	2012/2013	3.48	7.1
	2013/2014	2.04	1.786
	2014/2015	3.58	0.598
Operation time	***Campaigns***	**Days**	**Days**
	2002/2003	145	149
	2003/2004	175	149
	2004/2005	212	0
	2005/2006	137	149
	2006/2007	212	149
	2007/2008	7	0
	2008/2009	181	149
	2009/2010	43	89
	2010/2011	68	90
	2011/2012	0	60
	2012/2013	76	119
	2013/2014	57	89
	2014/2015	76	27
Transport length	*m in pipe*	13,598	46,192
Infiltration length	***Campaigns***	**m**	**m**
	2002/2003	7,238	17,765
	2003/2004	7,238	17,765
	2004/2005	7,238	17,765
	2005/2006	17,027	17,765
	2006/2007	17,027	17,765
	2007/2008	25,720	17,765
	2008/2009	25,720	17,765
	2009/2010	25,720	17,765
	2010/2011	25,720	17,765
	2011/2012	1,129	17,765
	2012/2013	25,720	17,765
	2013/2014	25,720	17,765
	2014/2015	25,720	17,765
Infiltration surface	***Campaigns***	**m^2**	**m^2**
	2002/2003	0	602,416
	2003/2004	0	602,416
	2004/2005	18,047	602,416
	2005/2006	18,047	602,416
	2006/2007	18,047	602,416
	2007/2008	18,047	602,416
	2008/2009	18,047	602,416
	2009/2010	18,047	602,416
	2010/2011	18,047	602,416

BENCHMARKING	UNITS	SANTIUSTE (CyL)	EL CARRACILLO (CyL)
	2011/2012	0	602,416
	2012/2013	18,047	602,416
	2013/2014	22,342	602,416
	2014/2015	22,342	602,416
Purification length	*m in canal*	1,129	138
	Campaigns	**m^2**	**m^2**
	2002/2003	0	0
	2003/2004	0	0
	2004/2005	0	0
	2005/2006	19,538	0
	2006/2007	26,066	0
Purification area	*2007/2008*	26,066	0
	2008/2009	26,066	0
	2009/2010	26,066	0
	2010/2011	26,066	0
	2011/2012	6,528	0
	2012/2013	26,066	0
	2013/2014	26,066	0
	2014/2015	26,066	0
	Campaigns	**m^2**	**m^2**
	2002/2003	0	27,838
	2003/2004	0	27,838
	2004/2005	0	27,838
	2005/2006	86,654	27,838
	2006/2007	86,654	27,838
Restoration area	*2007/2008*	0	27,838
	2008/2009	0	27,838
	2009/2010	86,654	27,838
	2010/2011	86,654	27,838
	2011/2012	0	27,838
	2012/2013	0	27,838
	2013/2014	0	27,838
	2014/2015	0	27,838
	Campaigns	**hm^3**	**hm^3**
	2002/2003	1.3	1.4
	2003/2004	1.8	5.5
	2004/2005	0.97	0
	2005/2006	3.56	2.45
	2006/2007	12.19	3.2
Infiltration volume	*2007/2008*	0.46	0
	2008/2009	2.5	1.9
	2009/2010	0.64	5.8
	2010/2011	2.13	4.6
	2011/2012	0	1.9
	2012/2013	3.25	7.1
	2013/2014	2	1.786
	2014/2015	3.18	0.598
	Campaigns	**Q (m^3/h)**	**Q (m^3/h)**
	2002/2003	373.56	3,91.50
	2003/2004	428.57	1,538.03
	2004/2005	190.64	
	2005/2006	1,082.73	685.12
	2006/2007	2,395.83	894.85
Infiltration rate	*2007/2008*	2,738.10	
	2008/2009	575.51	531.32
	2009/2010	620.16	2,715.36
	2010/2011	1,305.15	2,129.63
	2011/2012	-	1,319.44
	2012/2013	1,781.80	2,485.99
	2013/2014	1,461.99	836.14
	2014/2015	1,743.42	922.84
NO_3 concentration decrease	*mg/L, %*	NO_3 reduction by dilution with river source (not measured)	NO_3 reduction by dilution with river source (not measured)
Energy cost	*kWh/m^3*	0	0
Infrastructure cost	*€*	3,948,079 €	5,273,999 €
O&M cost	*€/m^3*	0.05	0.08
Irrigable area	*ha*	3,061	7,586
Original Irrigated area	*ha*	515	3,000
Current Irrigated area	*ha*	790	3,500
Increased irrigation land	*ha*	275	500
Mean annual aquifer extraction	*hm^3/year*	0.21	8
Farmers	*number*	440	713
Effect of MAR in irrigation supply	*m^3/ha*	852.6	314.3

BENCHMARKING	UNITS	SANTIUSTE (CyL)	EL CARRACILLO (CyL)
Irrigated volume from MAR	*%*	27.84%	23.8%
Mean water table depth increase after MAR	*M*	1.47	2.3
Energy savings	*kWh*	27.10 (per well)	28,000 (total)
Energy savings	*%*	30.4%	36%

4.4 Spain. Llobregat demonstration site (Catalonia)

4.4.1 Advance of the demonstration activity

Though salinity is a general problem in the aquifer, this MAR device is located 13 km far from the coast and the recharged water has no evident impact on seawater intrusion. This topic will be further discussed in the Malta review.

The proximity to an industrial area gives us the opportunity to deal with pollution from this use that increase the interest on any SAT process that could let contaminated water to be used for recharge even in those circumstances. During the last decades, industrial and irrigation consumptions have severely fallen to 5 hm^3 per year as urban supply has grown to 40 hm^3.

The Irrigation Association is called C.U. Delta Riu Llobregat, with 1,500 irrigated ha within 2,150 ha total area and 465 associated farmers (Spanish Ministry of Agriculture MAPA, 2001). The area has risen to 2,336 ha according to the Catalonian Water Agency (ACA, 2009).

As water quality improvement is one of the main goals, its measurement as depletion in % of main monitored substances (pharmaceuticals) should be available for benchmarking. Drinking use is also declared so possible data to compile and could be a percentage of recharged water for drinking supply performed by the Basin Authority (ACA).

Table 4-7: Llobregat preliminary data for benchmarking.

Indicator	Observations on indicator	LLOBREGAT
Country		Spain
Demo LOCATION	*Main location: Province, county, villages…*	Sant Vicenç dels Horts (Barcelona)
AQUIFER	*Aquifer or Groundwater body*	Llobregat
MAR Class	*Main classes: Infiltration/Injection*	Infiltration
MAR Type	*Subclass*	Infiltration / SAT Basins
MAR devices	*Main devices*	Decantation Pond (A.W.) & Infiltration Pond
MAR dimensions	*Length, width (depth when available). Applicable to each device*	28,000 m^2
MAR devices (According to table)		
DISPERSE	*Infiltration ponds/ wetlands*	2 (A. W. /Dec. Pond + Inf. P)
DISPERSE	*Ridges/ soil and aquifer treatment techniques (SAT)*	X
PROBLEMS	*Specific troubles on the aquifer area dealt by the MAR devices*	
Scarcity (Overexploitation)	*Quantitative issues because of overconsumption*	X
Scarcity (Climate Change)	*Drought, rising temperatures trend, lower precipitation cycles...*	X
Heavy metals (Mining, Industry)	*Metals from agrochemicals, urban, industrial sources: Pb, Fe, Al, Cr, Cd, Hg….*	Industrial residues 1,1,2-Trichloroethane (TCA)
Agriculture: agrochemicals and antibiotics for livestock	*Toxic pollutants as pesticides and antimicrobials*	X
Mistreated sewage discharge	*Insufficiently treated effluents (N, P, K, POP like pesticides, solvents, pharmaceuticals, industrial chemicals...)*	X
FUNCTIONS	*Current recharge applications*	
Irrigation Supply		X

Indicator	Observations on indicator	LLOBREGAT
Drinking water supply		X
Water Quality improvement		X
GEOLOGY		
Monolayer -aquifer		X
Coastal		X
Alluvial		X
Unconfined		X
WATER SOURCE		
River	*Diversion with no horizontal building*	Llobregat
Weir/Dam		Weir in Molins de Rei
Water diversion (% per year)		0.11-0.32
WATER TRANSPORT	*Mean of transportation when available*	
Pipe	*Buried or not*	3200 m (pipe from Weir to first pond)
WATER RECOVERY		
Well		X
WATER USE		
Agriculture	*Irrigation, water table control*	2,6
Industrial	*Coolant, raw material, solvent, energy source*	7,5
Urban	*Drinking water, garden and street watering*	22,5
Total		58,9
WATER CONTROL	*Available and comparable analysis*	
QUANTITY (Q)		
Discharge volume	*Water abstraction (m3/year)*	422568-592760
Water table level	*m (monthly change), beginning vs. End of recharge campaign*	5.44-11.89
Soil Moisture	*% (regular change around wells)*	5-45
Others	*To be specified when completing*	6 piez+1multilevel piez+1well
QUALITY (q)		
EC	*(mhoms/cm; dS/m)*	1.2-2.1 dS/m
pH		6.9-7.2
Temperature sensors	*ºC in depth*	15-22
HCO_3	*Bicarbonate (mg/l)*	310
COD	*Chemical Oxygen Demand (mg/l)*	<5
TSS	*Total Suspended Solids (mg/l)*	80±15 %
NO_3	*Nitrates (mg/l)*	5.1-15
NH_4	*Ammonia (mg/l)*	1.5
P	*Phosphorous (mg/l)*	<0.25
K	*Potassium (mg/l)*	25
Turbidity	*NTU*	25NTU
Heavy metals	*Fe, Cu, Cr, Al, Hg… (mg/l)*	4,6 (Fe)
Pesticides	*Pesticides according to main uses*	0.1-0.3 mg/l
SOIL CONTROL	*Available and comparable analysis*	
Perforations upstream	*Sand (%)*	73-83
	Clay (%)	3-11
	Silt (%)	13-14

4.4.2 Pooling of its specific benchmarking system

The Llobregat demonstration site is based on two ponds: one for sedimentation processes and another one for infiltration purposes (Figure 4-8). The MAR system has been placed in Sant Vicenç dels Horts (10 km from Barcelona). The recharged water comes from the Llobregat River and the main goal is to increase the water storage in the aquifer as well as to improve the quality of recharged water. A reactive layer made up of organic matter was installed at the bottom of the infiltration pond (Fe oxides plus reactive layer with 49% vegetal compost, 49% sand and 2% clay) (Valhondo et al. 2015). The objective of this reactive layer was to enhance the redox processes of the aquifer through the release of organic matter (acting as a potential electron donor). Previous lab studies concerning the dynamics of physical and biological processes concluded that microorganisms could reduce the infiltration rate as the flow patterns affect the special distribution of biological parameters (Rubol et al. 2014; Freixa, et al. 2016). The alternation of short wetting and drying cycles permits to maintain microbial activity, to recover the infiltration rate and to minimize bio-clogging respectively (Dutta et al. 2015; Rodríguez-Escales et al. 2016).

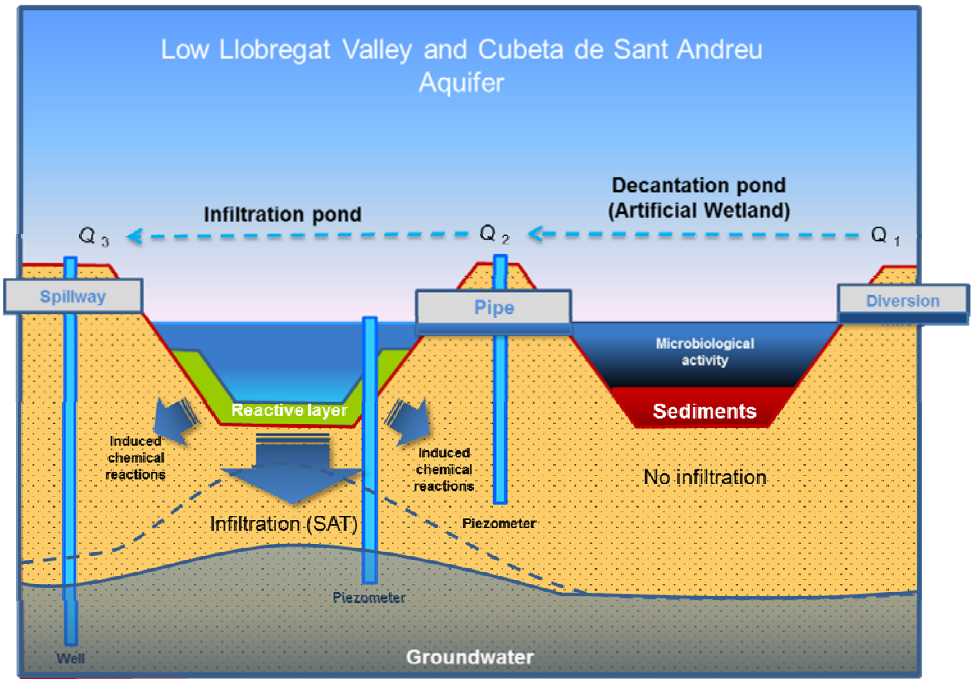

Figure 4-8: Llobregat MAR demonstration site profile. A pipe from a weir in Llobregat River fills a couple of ponds. The first acts as a decanter and the second as an infiltrator with a reactive layer.

The available data for benchmarking comes from the last six years, when the MAR facility has been operative for 952 days with an average of 159 days per campaign. The infiltration pond covered an area of 5,600 m^2, although there are some discrepancies about such data (see CETaqua 2013 and Valhondo et al. 2015). There is no measured infiltration under the first sedimentation pond. Some infiltration volumes show different numbers in 2011 and 2012 depending on the bibliographic source (Table 4-8).

Table 4-8: Llobregat demonstration site benchmarking pooling.

BENCHMARKING	UNITS	LLOBREGAT (Catalonia)
Water Diversion	m^3/h	710 (maximum)
Operation time	Days	952 days in 6 operative years
Operation flow	m^3/h	200-500
Operation campaigns	Year	days/year
	2009	80
	2010	14
	2011	170
	2012	258
	2013	211
	2014	219
Infiltration surface	m^2 in ponds	5,600
Sedimentation (microbiological active) surface	m^2 in ponds	4,000
Infiltration volume	Year	m^3/year
	2009	422,568
	2010	49,950
	2011	898,401
	2012	1,038,295
	2013	739,643
	2014	592,760
Infiltration rate	Year	m/d
	2009	0.94
	2010	0.89
	2011	0.94
	2012	0.72
	2013	0.50
	2014	0.48
NO_3 concentration decrease	%	>90%
SO4 decreasing rate	%	5-15%
Fe (II) increasing rate	%	200-5,000 times

Mn (II) increasing rate	%	80-1,500 times
Energy cost	kWh/m^3	No E consumption
Infrastructure cost	€	1,107,807
O&M cost	€/m^3	0.047
Seawater barrier effect	Change in meters, Cl concentration, interface location...	No relevant effect
Others	Microbiological active volume (m^3)	5,600
Others	Pollutant depletion	33 to 100% in CEC
Anthropogenic contaminants (Contaminants of Emerging Concern) decrease	Pharmaceuticals and personal care	% of inflow concentration (2011-2012)
	Atenolol	100%
	Cetirizine	33-77%
	Gemfibrozil	34-64%
	Carbamazepine	No (recalcitrant)

Having said that, a volume up to 3.74 hm^3 has been recharged during these six years with an average of 0.6 per campaign (2010 was an exceptionally bad year), the mean infiltration speed calculated has been around 0.75 metres per day and still the rate has greatly changed over the years.

The most important indicators are related to the removal of pollutants. Nitrate and Sulphate decrease whereas Fe (ferrous iron) and Mn (manganese II) increase as water passes through the reactive layer searching for the right chemical atmosphere that permits the elimination of a series of pollutants (40-75%) present in the river flow (atenolol, cetrizine, gemfibrozil) (Valhondo et al. 2014, 2015). Only carbamazepine stays imperturbable to the effect of the reactive layer. Denitrification (>90%) is one of the most relevant achievements (Valhondo et al. 2014, 2015).

The investment seems to be too high bearing in mind the recharged volume and rate but the ponds have not been permanently used (Table 4-9). Nevertheless, the effects of persistent pollutants should be considered in order to assess the real cost-benefit rate of this MAR system, especially in a high demanding area of water supply like Barcelona City and particularly during the dry and touristic seasons.

Table 4-9: Llobregat facilities development calendar.

	2008	2009	2010	2011	2012	2013	2014	2015
Ponds construction	X							
Piezometers construction	X		X					
Operation start		X						
Reactive layer implementation				X				
Hydrochemistry sampling campaign				X	X	X	X	X
Microbiology sampling campaign		X					X	X
Infiltrometry test		X					X	

4.5 Italy. Brenta Schiavon demonstration site (Vicenza)

The Brenta demonstration site is divided in two different facilities: Schiavon Forested Infiltration Area (FIA) and Loria Flood Retention and Infiltration Basin. Both of them are in the Veneto Region. Vicenza Upper Plain is very important from the hydrogeological perspective; it is the recharge area of the springs that are the primary potable water resource for large portions of the Region plain.

- Schiavon: The watering of the pilot area in Schiavon (Vienken et al. 2016) takes place generally during non-irrigation periods, using the existing irrigation water conveyance system (ditches, underground pipelines). The surface of infiltration covers about 2 hectares on an undifferentiated aquifer with high-medium permeability. The water infiltration rate has been estimated in 20-50 L/s/hectare and the groundwater table level is around 3 m below ground level. The plot has been planted with fast growing tree species.

- Loria: This site (Tippelt 2015) shows a higher permeability than the other and groundwater is much deeper here (-40 m.b.g.l.). The plot infiltrates water from the Lugana Stream with 10 m^3/s of maximum discharge in a period of 30 years. The basin has a stock capacity up to 40.000 m^3 and it is filled up three/four times in a year.

4.5.1 Advance of the demonstration activity

Brenta Schiavon has connected the availability of biomass as a secondary product of recharge as far as a little landscape restoration as shown in Figure 4-9.

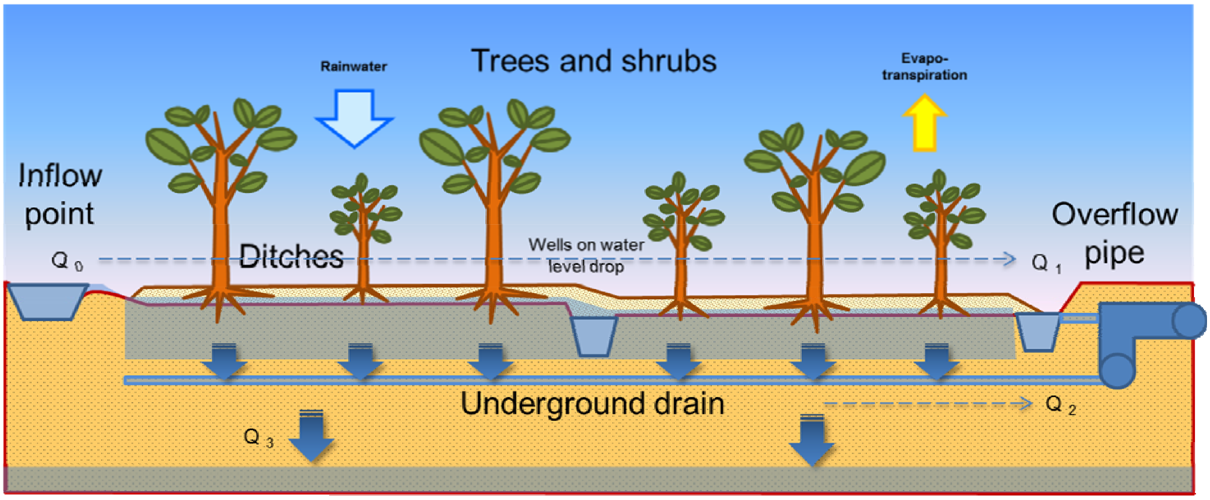

Figure 4-9: Brenta-Schiavon MAR demonstration site profile. A ditch from a canal let water run through a forested area.

The recharge flow at the Schiavon site (0.019 m^3/s) does not seem to produce relevant increases in groundwater table level and aquifer storage.

Nitrates concentration results are quite low during all monitoring time period (3-11 mg/l) due to:

- Physical filtration process of surface water from Roggia Comuna.
- Purification process through the microorganisms that live in symbiosis with the roots of the Forested Infiltration Area (Brix 1987).

The Loria flood retention area has been activated only for a short time period (few days) and with very low water levels (about 10-20 cm). This condition did not allow evaluating the recharge effects through flood retention area in terms of water quantity and in terms of improved water quality.

Table 4-10: Brenta preliminary data for benchmarking.

Indicator	*Observations on indicator*	BRENTA Schiavon	BRENTA Loria
Country		Italy	Italy
Demo LOCATION	*Main location: Province, county, villages…*	Schiavon (Vicenza)	Loria (Treviso)
AQUIFER	*Aquifer or Groundwater body*	NE Alpine system	NE Alpine system
MAR Class	*Main classes: Infiltration/Injection*	Infiltration	Infiltration
MAR Type	*Subclass*	Infiltration Field	Infiltration / Basins
MAR devices	*Main devices*	Forested Infiltration Fields	Reservoirs dams

Indicator	Observations on indicator	BRENTA Schiavon	BRENTA Loria
OBSERVATIONS	Any remarkable characteristic of the site	2 ha Fast growing trees for paper and biomass	Flood storage area
MAR devices (According to table)			
DISPERSE	Ridges/ soil and aquifer treatment techniques (SAT)	Furrows	
DAMS	Reservoir dams and dams		40,000 m^3
DISPERSE	Accidental recharge by irrigation return	X	
WELLS	Aquifer storage & recovery (ASR)	X	
PROBLEMS	Main troubles on the aquifer area		
Scarcity (Overexploitation)	Quantitative issues because of overconsumption	X	X
Scarcity (Climate Change)	Drought, rising temperatures trend, lower precipitation cycles...	X	X
Wetland desiccation	Deterioration by water Table decline, Run-off shortage….	X	X
FUNCTIONS	Current recharge applications		
Irrigation Supply		X	X
Wetland restoration		X	X
Water Quality improvement		X	X
GEOLOGY			
Mono-aquifer		X	X
Unconfined		X	X
WATER SOURCE			
River	Diversion with no horizontal building	X	
Irrigation return flow		X	
WATER TRANSPORT	Mean of transportation when available		
River			X
Ditch	Irrigation channel	X	
WATER RECOVERY			
Well		X	X
WATER USE			
Agriculture	Irrigation, water table control	X	X
Industrial	Coolant, raw material, solvent, energy source	X	X
WATER CONTROL	Available and comparable analysis		
QUANTITY (Q)			
Discharge volume	Water abstraction (m3/year)	X	X
Water table level	m (monthly change), beginning vs. End of recharge campaign	X	X
QUANTITY (Q)			
EC	(mhoms/cm; dS/m)	X	X
pH		X	X
COD	Chemical Oxygen Demand (mg/l)	X	X
TSS	Total Suspended Solids (mg/l)	X	X
NO_3	Nitrates (mg/l)	X	X
Heavy metals	Fe, Cu, Cr, Al, Hg…	X	X

4.5.2 Pooling of its specific benchmarking system

As in other cases, the preliminary stage of development does not let us consider both sites to a benchmarking process with a minimum reliability. Nevertheless some interesting conclusions can be taken out of these experiences:

- The financial analysis shows that 75 ha infiltrating facility could be enough to recharge 20 hm^3 per year with an average increase of 1.5% in the municipal tariffs for users. Passive infiltration with limited space, low maintenance and high environmental and landscape integration are feasible at a low cost.
- The most relevant phase is the selection of the best spots for recharge. Investment in previous researching phases deserves special attention as compared to other more expensive methods of water storage or purification, that can be more independent of location but more expensive in terms of construction and operation.
- Apart of economic reasons, several environmental functions could be achieved by these simple recharging devices: increase of groundwater, regeneration of springs, renewable energy (e.g. wood to biomass), reduction of greenhouse gas emissions; enhancement of the landscape; increase in biodiversity…

- Nitrate concentration is becoming an increasing concern. Tests show that recharge NO_3 content is about 10 mg/L during recharge but content goes up to 18 during the time recharge is off. Dilution occurs but it cannot be a long-term solution. Preventive measures on agriculture input sources must be carried out to guarantee that recharge accomplish its mission.

Table 4-11: Brenta demonstration site benchmarking pooling.

BENCHMARKING	Units	BRENTA Schiavon
Water Diversion	m^3; L/s/, %, % EFR	27.55 l/s
Operation time	days, hours, months	116 days
Infiltration volume	m^3/campaign	276,000 m^3
Infiltration rate	L/s*m2; hm^3/year; m^3/month; m^3/day…	2 m^3/day
Energy cost	kWh/m^3	0
Infrastructure cost	€/m^3	0.397
O&M cost	€/m^3	0.037

4.6 Italy. Serchio demonstration site (Tuscany)

4.6.1 Advance of the demonstration activity

The Sant' Alessio demonstration site is an induced River Bank Filtration (RBF) scheme, in which the bank of the Serchio River is used to improve the quality of the running water by simple groundwater flow across the alluvia (Rossetto et al. 2015). A river weir raises groundwater table up to 3 metres so water availability to the vertical wells and general storage capability get increased.

The uses are double, the direct urban supply and the storage in the aquifer, increasing the available groundwater storage and resources.

The designed monitoring system includes sensors in surface and groundwater. The experimental groundwater monitoring system consists of a set of four sensors in the piezometers drilled around the reference well (well 5) of the Pisa-Lucca pipeline.

Some specific figures of this scheme are displayed in Table 4-12.

Table 4-12: Serchio preliminary data for benchmarking.

Indicator	*Observations on indicator*	SERCHIO
Country		Italy
Demo LOCATION	*Main location: Province, county, villages…*	Lucca (Tuscany)
AQUIFER	*Aquifer or Groundwater body*	
MAR Class	*Main classes: Infiltration/Injection*	Infiltration
MAR Type	*Subclass*	RBF
MAR devices	*Main devices*	Dams, wells
OBSERVATIONS	*Any remarkable characteristic of the site*	MAR monitoring and Decision Support System
	MAR devices (According to table)	
WELLS	*Open infiltration wells*	X
WELLS	*Deep wells and boreholes*	X
FILTRATION	*River bank filtration (RBF)*	X
PROBLEMS	*Main troubles on the aquifer area*	
Scarcity (Overexploitation)	*Quantitative issues because of overconsumption*	X
Others	*To be specified when completing*	Originally no overexploitation just storage
FUNCTIONS	*Current recharge applications*	
Drinking water supply		X
GEOLOGY		
Mono-aquifer		X
Alluvial		X
Unconfined		X

Indicator	*Observations on indicator*	SERCHIO
WATER SOURCE		
River	*Diversion with no horizontal building*	Sechio river
Weir/Dam		1.5-3 m over river natural level
Well		10 extraction wells
WATER TRANSPORT	*Mean of transportation when available*	
Aquifer	*Horizontal flow (The T in ASTR)*	X
Pipe	*Buried or not*	X
Others	*To be specified when completing*	X
WATER RECOVERY		
Well		20 wells (25m deep)
WATER USE		
Urban	*Drinking water, garden and street watering*	X
WATER CONTROL	*Available and comparable analysis*	
QUANTITY (Q)		
Discharge volume	*Water abstraction (m^3/year)*	600 L/s
Water table level	*m (monthly change), beginning vs. End of recharge campaign*	X
QUALITY (q)		
EC	*(mhoms/cm; dS/m)*	X
pH		X
HCO_3	*Carbonate*	X
BOD	*Biological Oxygen Demand (mg/l)*	X
COD	*Chemical Oxygen Demand (mg/l)*	X
TSS	*Total Suspended Solids (mg/l)*	X
NO_3	*Nitrates (mg/l)*	X
Total N	*Total Nitrogen (mg/l)*	X
P	*Phosphorous (mg/l)*	X
K	*Potassium (mg/l)*	X
Heavy metals	*Fe, Cu, Cr, Al, Hg…*	X
Pesticides	*Pesticides according to main uses*	X
Others	*To be specified when completing*	6 piezometers for river and utility Q and q
SOIL CONTROL	*Available and comparable analysis*	
Transmissivity	*m^2/s*	0.01

4.6.2 Pooling of its specific benchmarking system

Serchio has shown a long reliability and the new monitoring campaigns have proved that RBF is a passive, cheap but solid way of enhancing water quality, even in such a multi-faceted area where urban, industrial and agriculture pollutants come from dispersed sources into the aquifer.

- The number of inhabitants served by Sant Alessio is huge (300,000 inhabitants) with a potential of 15 hm^3/year. The site has been working for 30 years and alarming event has never happened.
- The effect of soil filtering has been tested by the simple comparison of the extracted water with the samples obtained in the river and in the wells located near the sources of pollution. Emerging pollutants are issues of concern but WWTP are facing similar problems with higher cost, but similar effects.
- Microbiological analyses have exposed very effective results of soil-matrix filtering in order to remove Coliforms and *E. coli* as in Brenta experiences.
- Even a MAR passive system in a periurban area (with multiple sources of pollution) is able to provide drinking water the use that must get the highest quality. The tests illustrate that river source has greater amounts of some pollutants than the water filtered through the bank.
- Monitoring has shown that pollution issues exist in the river and in the aquifer but MAR contributes to remove pollutants from water supply. Further natural processes in the soil and water bodies must be surveyed in order to avoid unexpected peaks of

pollutants discharges (leaking, dissolving). Surveillance is a "must" for any catchment management.

- The use of vegetated areas and WWTP effluents in MAR are the next steps so many financial, legal, social and institutional issues need to be handled in advance.

Table 4-13: Serchio demonstration site benchmarking pooling.

BENCHMARKING	Units	Serchio
Water Diversion	m^3; L/s/, %, % E.F.R.	500 L/s
Operation time	days, hours, months	365 days/24h
Operation campaigns	years, days/year…	30 years
Infiltration volume	m^3/campaign	15 hm^3
Served population	inhabitants	300,000

4.7 Israel. Mehashe demonstration site (Hadera)

4.7.1 Advance of the demonstration activity

The Menashe plant was constructed 50 years ago to capture runoff from the hills, infiltrating and storing the water into the coastal aquifer for drinking purposes. The size and the dimensions of the infiltration ponds were design according to the flooding event data-sets. Infrastructures include ancillary dams, channels, a pipeline, a sedimentation pond, three infiltration ponds, monitoring facilities and about 20 recovery wells.

Table 4-14: Menashe preliminary data for benchmarking.

Indicator	*Observations on indicator*	MENASHE
Country		Israel
Demo LOCATION	*Main location: Province, county, villages…*	Menashe
AQUIFER	*Aquifer or Groundwater body*	
MAR Class	*Main classes: Infiltration/Injection*	Infiltration
MAR Type	*Subclass*	ASR
MAR devices	*Main devices*	Infiltration ponds and production water
MAR dimensions	*Length, width (depth when available). Applicable to each device*	150 m^2
OBSERVATIONS	*Any remarkable characteristic of the site*	Desalinated and chlorined water source. Injection wells subject to consideration
MAR devices (According to table)		
WELLS	*Aquifer Storage & Recovery (ASR)*	X
PROBLEMS	*Main troubles on the aquifer area*	
Scarcity (Climate Change)	*Drought, rising temperatures trend, lower precipitation cycles...*	X
Floods	*Flooding events caused by CC, extreme rain…*	Winter Floods
Observations		Demineralized desalinated water plant discharge
FUNCTIONS	*Current recharge applications*	
Drinking water supply		X
Water Quality improvement		X
Seasonal storage		X
Others	*To be specified when completing*	Remineralisation
GEOLOGY		
Mono-aquifer		X
Coastal		X
Alluvial		X
Others	*To be specified when completing*	In-between Mono and multilayer (model in development)
WATER SOURCE		
River	*Diversion with no horizontal building*	Torrential waters
Sea (Desalination Plant)		X
WATER TRANSPORT	*Mean of transportation when available*	
Canal	*Canal of water (concrete or ground)*	X
Pipe	*Buried or not*	X

Indicator	*Observations on indicator*	MENASHE
Observations		Dikes and canals for streams and pipe for DSWP
WATER RECOVERY		
Well		X
WATER USE		
Urban	*Drinking water, garden and street watering*	X
WATER CONTROL	*Available and comparable analysis*	
QUANTITY (Q)		
Discharge volume	*Water abstraction (m^3/year)*	X
Water table level	*m (monthly change), beginning vs. end of recharge campaign*	X
QUALITY (q)		
EC	*(mhoms/cm; dS/m)*	X
pH		X
HCO_3	*Carbonate*	X
BOD	*Biological Oxygen Demand (mg/l)*	X
COD	*Chemical Oxygen Demand (mg/l)*	X
TSS	*Total Suspended Solids (mg/l)*	X
NO_3	*Nitrates (mg/l)*	X
Total N	*Total Nitrogen (mg/l)*	X
P	*Phosphorous (mg/l)*	X
K	*Potassium (mg/l)*	X
Heavy metals	*Fe, Cu, Cr, Al, Hg…*	X
Pesticides	*Pesticides according to main uses*	X
		Applicable to the pilot

4.7.2 Pooling of its specific benchmarking system

The demonstration site in Israel has several details that can be very interesting for benchmarking: remineralisation as a goal, winter floods control in a Mediterranean coast, and a long period of working time. The fact that here the water coming from the desalination plant needs to recover a mineral content to be drinkable faces the opposite technical problems of places such as Llobregat or S. Bartolomeu, where the aim is to reduce the concentration of some undesired elements from water. The SAT process is adding compounds from soil instead of removing them while water passes through the soil column.

Table 4-15: Menashe demonstration site benchmarking pooling.

BENCHMARKING	Units	MENASHE
Water Diversion	m^3; l/s/, %, % EFR	585 hm^3/year
Operation time	days, hours, months	365 days/24h
Infiltration rate	L/s*m^2; hm^3/year; m^3/month; m^3/day…	5,000 m^3/h

- Another passive infiltrating and storing facility that has been working for decades whose cost has been paid off long time ago with a very limited surface consumption in a very space demanding area.
- MAR flexibility in Israel has been exposed by the adaptation to a new source of water; from run-off to desalinated water. Using the infiltration ponds of Menashe plant to infiltrate surplus desalinated water is profitable due to its low construction expenses.
- Additional water (eventual surplus of desalinated seawater) increases the overload on the infiltration ponds when the demand of desalinated water supply is lower. The worst case would occur if there was simultaneously a high flood event together with a large excess of desalinated water. It is not clear if it is feasible to recharge floodwater and surplus desalinated water simultaneously. This case is comparable to the flood event during the peak of a recharging campaign in Santiuste (Los Arenales). If Spanish solution was to build three spillways back to the rivers, in Israel additional wells would be required to overcome the total pumping capability.

4.8 Malta. Malta South demonstration site

The overall objective of Maltese demonstration site (Sapiano, Schembri & Micallef 2016) is the assessment of the development of a seawater intrusion barrier by means of highly polished treated effluents from a WWTP. Groundwater abstracted from the southern region of the Malta Mean Sea Level aquifer system exhibits characteristically high chloride contents, as a result of the intrusion of saline waters in response to the historically high groundwater abstraction for irrigation. The project involved the use of a barrier of aligned coastal bore-holes.

4.8.1 Advance of the demonstration activity

The pilot system is currently formed by six recharge boreholes and four more for monitoring purposes. All of them have been drilled around the perimeter of the WWTP that supplies the water to be injected. The WWTP keeps on generating effluents during the whole year, even if there is no place where they could be stored out of irrigation season. Eventually, this high quality water surplus after treatment can be pumped into the coast wells to counteract the seawater intrusion. Clogging and unexpected pollution (especially from persistent organic pollutants) are the main troubles to be monitored.

Table 4-16: Malta preliminary data for benchmarking.

Indicator	*Observations on indicator*	MALTA SOUTH
Country		Malta
Demo LOCATION	*Main location: Province, county, villages…*	South Malta
AQUIFER	*Aquifer or Groundwater body*	Southern Malta
MAR Class	*Main classes: Infiltration/Injection*	Injection
MAR Type	*Subclass*	Boreholes
OBSERVATIONS	*Any remarkable characteristic of the site*	Injection of WWTP effluent
MAR devices (According to table)		
WELLS	*DEEP WELLS AND BOREHOLES*	6 (recharge) +4 (monitoring) boreholes
PROBLEMS	*Main troubles on the aquifer area*	
Scarcity (Overexploitation)	*Quantitative issues because of overconsumption*	X
Salinity (Seawater intrusion)	*Associated to coastal aquifers*	X
FUNCTIONS	*Current recharge applications*	
Seasonal storage		X
GEOLOGY		
Coastal		X
Karst		X
WATER SOURCE		
Sewage (WWTP)		X
WATER RECOVERY		
Well		X
WATER USE		
Agriculture	*Irrigation, water table control*	X
WATER CONTROL	*Available and comparable analysis*	
QUANTITY (Q)		
Discharge volume	*Water injection(m^3/year)*	X
Water table level	*m (monthly change)*	X
QUALITY (q)		
EC	*(mhoms/cm; dS/m)*	X
pH		X
TOC	*Total Organic Carbon (mg/L)*	X
BOD	*Biological Oxygen Demand (mg/L)*	X
COD	*Chemical Oxygen Demand (mg/L)*	X
TSS	*Total Suspended Solids (mg/L)*	X
NO_3	*Nitrates (mg/L)*	X
Total N	*Total Nitrogen (mg/L)*	X
Microorganisms	*Bacteria and virus*	X
Environmental compounds	*Taste & odour-causing compounds, NDMA, Pharmaceuticals and Personal care products (PPCP's), Pesticide and herbicides, 1,4 Dioxane, Fuels and fuel additives, VOCs, Endocrine disruptor chemicals*	X

4.8.2 Pooling of its specific benchmarking system

- The most notable feature of the Malta site is the use of injection of high quality treated effluents. Injection requests good quality water not commonly associated with standard WWTPs, so sewage is usually infiltrated through SAT. In this case, the pre-treatment of recharging water is included in the WWTP processes so that MAR devices can take advantage of the high recharging rate of the injection.
- The Maltese site has offered recharge as a way to solve the impossibility to store the surplus of a water plant (in this case a WWTP) out of the irrigation season (from August to February). Annual recharge (water storage increase by infiltration) capacity has been estimated at one million m^3.
- The South Malta plan cannot be considered as only a recharge proposal, but a whole strategy that will imply many other interlaced actions, as water extraction control and monitoring network.
- For future surveillance, water quality monitoring should be a key element, but it shows a scenario that could be used as an example for many coastal Mediterranean cities, where tourism involves a high pressure on water resources during the summer time. These spill problems might be changed into resource opportunities in the form of reuse of reclaimed water.

5. RESULTS OF BENCHMARKING

Considering the availability of data and the time of operation, only the four Portuguese and three of the Spanish demonstration sites have been selected to develop a comparison based on benchmarking indicators. Though the rest of demonstration sites have not been used in this section, some remarks and conclusions can be easily extended to some of them, as has been mentioned in the discussion.

5.1 Characterization of MAR demonstration sites

The seven studied demonstration sites have covered 13 MAR devices out of the 25 recorded methods (Table 5-1) as detailed in the list taken from the MAR catalogue included in the deliverable 13.1 (MARSOL, 2015). Infiltration ponds, canals and open wells (in this order) are the most usual facilities. The array of working services of Los Arenales sites contrasts with the specificity of the rest in the Iberian Peninsula (Rio Seco, Messines and Llobregat).

Table 5-1: Types of MAR devices in the selected demonstration sites.

MAR devices	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Infiltration ponds/ wetlands	3 Infiltration Ponds				5+1	22+3	2 (A. W. /Dec. Pond + Inf. P)
Channels and infiltration ditches					27 km	40,7 km	
Ridges/ soil and aquifer treatment techniques (SAT)			2 SAT Ponds		X		X
Infiltration fields (flood and controlled spreading)						1	
Accidental recharge by irrigation return		X			X	X	
Reservoir dams and dams				1 Weir	1	1	
Qanats (underground galleries)						X	
Open infiltration wells		60 dug wells (11 within modelling area)		1 Dug Well	3	X	
Sinkholes, collapses...				1 known sink hole			
Aquifer storage, transfer & recovery (ASTR)				X			
River bank filtration (RBF)					1		
Interdune filtration						X (ditches)	
Rainwater harvesting in unproductive		Greenhouse roof harvest					
Number of MAR devices	**1**	**3**	**1**	**4**	**7**	**8**	**2**

The main problems reported on each aquifer area are similar and repetitive. Overexploitation and nitrate pollution from agriculture sources are common to most of the groundwater bodies (Table 5-2).

Llobregat and Messines have been unambiguously designed to treat only urban polluted water, not to solve supply issues in the groundwater area.

Table 5-2: Main problems in the aquifer under the studied demonstration sites.

PROBLEMS	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Scarcity (Overexploitation)			X	X	X	X	X
Scarcity (Climate Change)			X	X			X
Salinity (Seawater intrusion)							
Heavy metals (Mining, Industry)							Industrial residues 1,1,2-Trichloroethane (TCA)
Contamination from agri-culture source (mainly N)	X	X			X	X	
Organic pollution (pesticides and antibiotics)	X	X			X	X	X
Wastewater discharge			X		X		X
Wetland desiccation					X		
Floods	X						
Total number	**3**	**2**	**3**	**2**	**5**	**3**	**5**

The comparison between problems and functions show the different approach of specialized facilities with extended sites (Table 5-3). This was expected as a result of the number of structures cited in the Table 9. Anyhow, quality improvement is a more recurrent function than storage for these recharging devices.

Table 5-3: Attainable functions of the MARSOL demonstration sites.

FUNCTIONS	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Irrigation Supply				X	X	X	X
Drinking water supply				X	X		X
Seawater barrier		X		X			
Wastewater treatment					X		
Wetland restoration					X	X	
Water Quality improvement	X (NO_3)	X (NO_3)	X (Pharmaceuticals)		X (NO_3)	X (NO_3)	X
Seasonal storage				X	X	X	
Total number	**1**	**2**	**1**	**4**	**6**	**4**	**3**

Considering their geological features, the seven sites have been located on aquifers that can be as different as their solutions (Table 5-4). Unconfined ones are still the most habitual kind as the vadose zone is going to play an essential role in water purification during the infiltration process.

Table 5-4: Geological features of the MAR demonstration sites.

GEOLOGY	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Multi-aquifer	X	X					
Mono-aquifer					X	X	X
Coastal	X	X					X
Inland					X	X	
Alluvial	X	X			X	X	X
Karst			X	X			
Confined							
Unconfined	X	X			X	X	X

Most of the selected demonstration sites are attached to other hydraulic infrastructures, such as dams, weirs and WWTP (Table 5-5) that can be seen as potential competitors from a recharger point of view. Coordination of traditional and new MAR facilities is still necessary and helps developing a more integrated network in the watershed management. Among the selected sites of this report, the only documented way to recover water is pumping from wells and boreholes. This is not a disadvantage as the private energy cost becomes the best control mechanism to avoid overexploitation, as far as water pricing policies have proved not to be enough (Kajisa and Dong 2015).

Table 5-5: MAR phases of the MAR demonstration sites.

WATER SOURCE	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
River	X (Rio Seco)			X (Ribeira de Aivados)	Voltoya (1,000 L/s)	Cega	Llobregat
Weir/Dam				X (Foucho Dam)	Voltoya Dam (60,000 m^3)	Cega	Weir in Molins de Rei
Sewage (WWTP)			X (S. B. de Messines)		Santiuste de S. Juan Bautista		
Irrigation return flow					X	X	
Rainfall		X					
Outflows (Spillways)					Eresma River	Pirón River	
WATER TRANSPORT							
Canal					X		
Ditch						X	
Pipe		X	X	X	PRF 900 mm / 9,823.63 m	33,000 m	3,200 m (pipe from Weir to first pond)
Others	No transport for Infiltration Ponds						
WATER RECOVERY							
Well		X	X	X	X	X	X
Others	X (Goal is to improve the water quality. Not so much recovery)						
WATER USE							
Agriculture		X	X	X	X	X	X
Industrial							X
Ecological	X	X	X	X	X	X	
Urban				X			X

5.2 Indexes for MAR Benchmarking

Long experience permits managers to try and test a range of techniques so benchmarking can show comparison in time (performance/internal benchmarking) within the same demonstration site, too. Average measurements must be calculated to compare different demonstration sites using a single benchmark figure (Spanish demonstration sites are the most mature ones).

The main challenge is to achieve a good method to value the economic effect of MAR. Different sites show dissimilar uses, water markets or demands so, even monetary calculations could be incomparable among diverse MAR systems.

Most of the time the prominence of recharge must be assessed as the percentage of improvement in some of the important features for users, such as pumping energy reduction, water table lift, irrigated area expansion, vegetable production increase, standard water purification cost, groundwater nitrate content dilution, etc.

Table 5-6: Preselected indexes as benchmarking indicators for MAR systems.

Country		P	P	P	P	S	S	S
Benchmarking indicators	**Units**	**Rio Seco**	**Noras**	**S. B. de Messines**	**Cerro do Bardo**	**Santiuste**	**El Carracillo**	**Llobregat**
CHARACTERISTICS								
Location	text	Rio Seco	Campina de Faro	S. Bartolomeu de Messines	Cerro do Bardo	Santiuste (Segovia)	Carracillo (Segovia)	Sant Vicenç dels Horts (Barcelona)
MAR Type	text	Infiltration Ponds	Open Infiltration wells	Infiltration / SAT	Well / Dam	Infiltration / SAT Basins	Infiltration / SAT Basins	Dec. pond & Inf. pond (reactive layer)
Water Source	text	River	Rainfall	WWTP	River	River+WWTP	River	River
Performance campaigns	years	2 (2014-2015)	0	0	0	12 (2002-2015)	11 (2002-2015)	6 (2009-2014)
DIVERSION								
Annual volume water Diversion	hm^3/year	6.7	1.63	0.11	14.00	3.24	2.40	0.623
Max potential diverted water (authorized)	hm^3/year	6.7	1.63	0.3	50.00	8.5	14.2	1.03
Annual % of potential diverted water	%	100%	100%	36%	-	38%	20%	0.11-0.32%
Operation time	days	67	0	0	0	106.85	93.77	158.67
Max potential operational time	days	67	22.5	365	365	182	149	365
Annual % of potential operational time	%	100%	0%	0%	-	59%	63%	43%
Diversion rate	m^3/h	21.6	7,200	12.5	190	1,481.63	1,111.56	169.24
Diversion rate	L/s	6.00	1,999.95	3.5	52.78	411.56	308.77	47.01
Potential diversion rate (technical)	L/s	-	-	-	50 hm^3	1,000	-	197.22
RECHARGE								
Annual recharged volume	hm^3/year	0.035	0.44	0.03	1.7	2.61	2.40	0.623
Annual recharging rate	%	0.51%	26.99%	10%	100%	73.29%	62.76%	100%
Total recharged volume	hm^3	0.03	0	0	0	33.98	31.16	3.74
DIMENSIONS								
Transport length	m	0	3,000	20	2,230	13,598	46,192	3,200
Recharging length	m	0	0	0	0	25,720	17,765	0
Purification length	m	0	0	0	0	1,129	138	0
Restoration length	m	0	0	0	0	0	0	0
Diversion area	m^2	0	1,300,000	0	0	27,778	25,803	0
Recharging area	m^2	401	950		Unknown	22,342	602,416	5,600
Purification area	m^2	0	0	210	0	26,066	0	4,000
Restoration area	m^2	0	0	0	0	86,654	27,838	0
COSTS								
Total investment	€;	86,000	32,000	15,000	1,154,000	3,948,079	5,273,999	1,107,807
Current investment	€/campaign	43,000	-	-		329,006.58	479,454.36	184,634.50
Lifespan	years	35	35	35	35	35	35	35

Country		**P**	**P**	**P**	**P**	**S**	**S**	**S**
Benchmarking indicators	**Units**	**Rio Seco**	**Noras**	**S. B. de Messi-nes**	**Cerro do Bardo**	**Santius-te**	**El Carraci-llo**	**Llobre-gat**
Lifespan investment	€/year	2,475.14	914.29	428.57	32,971.43	112,802.26	150,685.69	31,651.63
Relative investment (Tot. Rech. V.)	€/m^3	2.46	0.07	0.50	0.68	0.12	0.17	0.30
Relative investment (Max. Pot. Rech.)	€/m^3	-	0.02	0.05	0.02	0.04	0.06	0.05
O&M cost (estimated)	€	4,000	4,000	1,000	15,000	-	-	177,249
O&M cost per volume (estimated)	€/m^3	0.133	0.010	0.033	0.006	0.05	0.08	0.047
Energy cost	kWh/m^3	0	0	0	0	0	0	0
BENEFITS								
Quality improvement	Text	50% lower nitrate concentration in a 100 m radius around the basins	Quality improvement data: % depletion (Data for future collection)	Pharmaceutics decrease in %	Salt water intrusion reduced	Lower nitrate concentration by dilution and biofilter	Nitrate reduction by dilution with river source (not monitored)	-90% NO_3; -5-15% SO_4: +200-5,000 times Fe; +80-1,500 times Mn; -100% atenozol; -33-77% cetirizine; -34-64% gemfibrozil
Total MAR population	Inhabitants					2,953	10,958	806,249
Served population (farmers)	Inhabitants/year					440	713	230
Served irrigation area	ha		130			3,061	7,586	1,383
Irrigated area	ha		130			1,520	3,500	254

The benchmarking results and trends provide MAR main numbers (**Table 5-6**) showing different features, such as:

- Operational dimensions should not always be inferred from geometrical measurements (real metre ≠ operative metre). The infiltration surface or length is limited by clogging and/or other processes (clay layers, high turbidity in the water…). These figures may change in time depending on management operations as weeding or soil ploughing. Consequently, canals are divided in stretches with high or low infiltration/ distribution rate (Santiuste) or ponds can be used as wetlands for environmental or purification purposes (Santiuste and El Carracillo) rather than as infiltrating spots.
- Diversion flow/volume is usually the most reliable datum based on flowmeters and volume/flow legal limitations (Maximum potential diverted water authorized). Infiltration rate and storage differences are more often deducted, especially in broad areas. Global figures for extended areas are worthy to be studied in detail so as to develop the best possible improvements in recharge management.
- Flows through canals or infiltration rates are usually deduced (transpiration, lateral and deep losses are inferred or neglected). It is necessary to install more control points to develop mathematical models to analyse quantitative and qualitative MAR performances in a more solid ground.
- Water quality enhancement (S. Bartolomeu, Llobregat, Santiuste) has a very interesting and contrasted role (Maeng et al. 2011), as reclaimed water could play an

essential part in the future during the dry seasons in the Mediterranean countries. Nitrate reduction has been proved in-site (Llobregat) but dilution effect is hard to prove when agriculture inputs are not often monitored (Algarve and Los Arenales). Nevertheless, legal, technical (in special clogging) and sanitary issues should be solved before sewage could be generally accepted as a standard recharging source by water authorities.

- Costs should be shared through the whole operational lifespan (unfinished, refurbished…) and compared to their analogue facilities' costs (dams for storage, WWTP for purification, injection wells for recharge). Some experiences seem to sustain MAR positive results (Khan et al. 2008). However, these calculations imply sometimes too many deductions as not many MAR facilities have been running for long enough to check their profitability (Maliva 2014).
- Relative investment is very variable (mean: 0.613 €/m^3) as the scale and state of the development of each site are very unequal. Nevertheless, considering the maximum diverted water as the total recharged volume per year, the cost of that recharged volume would be 0.06-0.02 €/m^3. Operation and maintenance (O+M) rates are much more changeable, with a wide range from 0.13 to 0.006 €/m^3.
- The best economic indicator would be the cost of recharged cubic metre of water related to the current water price in the local market, especially in agrarian uses, but that also implies many inferences that could be not as reliable as desired. Another approach is to compare MAR costs of storage or treatment with those ones of current similar facilities as dams and WWTP in the same zone (see WP15 on Water to Market results).
- Efficiency is usually too limited to total recharge of water in form of water table rising, irrigated area, and increasing availability. The more diverse and opened the system is, the more functional it results (Santiuste and El Carracillo). Multi-functionality must be considered to assess the whole MAR system performance, especially when they are compared to dams and reservoirs.
- Environmental functions as habitat restoration or passive water quality improvement should be considered in MAR systems assessment too (San Sebastián et al. 2015) but the way they can be evaluated as a local enhancement is hard to compare with other wider variety and large scale ecosystems.

6. LINKING TECHNICAL SOLUTIONS AND BENCHMARKING

Benchmarking deals with comparison among similar facilities, but it is also a way to value their own performances. In MARSOL a main aim is to know how well the goals are being fulfilled. According to the variety of devices shown in previous pages, it has been well established that some conditions are commonly shared (infiltration, WWTP sources, winter surplus, green filters) but every demonstration site has a main target, a bull's-eye, that is compelled to achieve by designing advanced schemes. The problem is that at the same time that MARSOL efforts are focused on that particular purpose, many other forces operate around and on the MAR system under surveillance. Some of them are just pulling in the other direction and trying to make us miss the objective.

The touchstone is the statement proposed by the MARSOL Steering that "MAR is a sound, safe, and sustainable strategy for climate variability preparedness that can be used with great confidence, and through MARSOL and its demonstration sites the awareness and the acceptance among stakeholders for MAR solutions has been greatly increased".

6.1 Topics for guidelines and benchmarking

The next sections are going to be dedicated to topics for MAR guidelines. These leaflets should try to be focus on the best practices offered by the Technical Solutions and the indicators that can be supported by real benchmarking indexes extracted from the different MAR demonstration sites under permanent tracking.

6.1.1 Water storage

The main objective of any recharging device has always been to increase water storage as much as possible. This achievement can be measured by many direct and indirect methods. The water level in wells, the abstracted water volume or flow from any source, or the rising irrigated plots in a traditionally rain-fed area, even infiltrated water monitored through piezometers, are just some examples of measurements of the successful recharge…. But this recharge can often let you lose perspective of the real problem. Water level decrease is a consequence of an overexploitation of groundwater resources and the control of those uses should not be ignored because it could bring up a vicious cycle. In Los Arenales (Spain) the aquifer is being refilled for maintaining the same use that declined the water table level in wells so deep that irrigation was jeopardized and close to disappear 30 years ago. Nowadays, irrigation is flourishing, but no planning has assumed the challenge of deciding how far this intensive agriculture can go without threatening the irrigation once again. Modern techniques and farmers' new mentality about sustainable development can help to a more rational agricultural growth, but no authority seems to be considering as of now how to connect this kind of rural water management with some specific tool.

From the benchmarking point of view this MAR storage figure can be expressed as an annual volume, a percentage of the water consumption in the area, a share of the monthly precipitation… All figures should be focused on the increasing availability of water, what allows a wider adoption or design of indicators as well as the process to monitor is carefully watched

The other face of the coin is shown by the donor. Somebody must pay for the improvement of water resources and that is the downstream basin whose water is being abstracted. It can even mean a reduction in natural recharge (or the impossibility of any potential MAR device instalment in those inferior lands) for any aquifer that could be supplied by the river. In some cases in Italy and Spain winter surpluses in rivers have been used as a recharge water resource, but the strict application of the Water Framework Directive could imply the reconsideration of the existence of all those redundancies in a planning that must watch over the guarantee of wetlands connected to shallow groundwater levels, estuaries and coastal habitats. For this reason MAR is one of those projects subjected to a thorough EIA process, as the use of any flowing water should be very soundly discussed in order to avoid future impacts in the hydrology, hydrogeology and ecology. Some River Basin Plans even forbid any recharging project. Dams and dykes never received such a treatment when they flourished in the former times, but this should not be a lament but an incentive for recharging projects to be appraised with all their potential effects in mind.

Regarding benchmarking MAR versus the preference for surface reservoirs, MAR indexes should use that comparison with other sorts of storage: water stored in aquifers as related to that in dams/reservoirs, increase of water quantity in groundwater bodies…

Consequently, reclaimed water is becoming a key element in a Global Climate Change scenario that seems to increase the occurrence of droughts and floods and no water can be easily considered as a surplus any more, especially in the Mediterranean basin. But the chance of transforming a spill into a source should not be forgotten, even when quality issues, flourish and threaten MAR feasibility. The event of a surplus coming from an overproduction of a treatment plant (Malta, Menashe) is much more probable to be available for recharge in the near future than a unsecured winter river surplus (Los Arenales).

Some benchmarking indexes on water source are the percentage of reclaimed or desalinated water used for recharge, saved cost of the recharged water considered as a spill fee, rate of recharging cost versus spilling cost…

6.1.2 Nitrate dilution

The Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources) has been applied long before WFD appearance. It has been determining groundwater masses affected by nitrates all over Europe. Some MARSOL sites have been conceived for the purpose of diluting high polluted waters with better quality inputs (Rio Seco, Portugal).

The obvious figure to follow should be the evolution of the concentration of this compound in the groundwater, but this is the consequence of many other processes operating on the aquifer evolution. At the same time that any MAR device is infiltrating some water with lower nitrate content, other processes are simultaneously occurring on the aquifer. One of them is the constant overuse of fertilizers by the farmers as stated in Portuguese demonstration sites. The leaching over-irrigation, the relatively low prize of irrigation water and nitrate products as manure, the non-negative farmer's view of the second ones as potential water pollutants and sometimes little details as the low cost of big packs of an apparently harmless and biological product as manure help to maintain to overdose as a rule. The existence of underground septic tanks attached to intensive farms (El Carracillo, Spain) can, accidentally or not, aggravate the situation. The leaching of nitrates that had been fixed in the current non saturated zone during infiltration, and their re-dissolution when groundwater level rises back again, are common problems to be taken into account in MAR demonstration sites when their devices are conceived to fight against non-point agriculture pollution.

Considering this disheartening scenario it could seem hard to keep on. Anyway, the MAR device is still a *driving force* whose efforts, if not results, can be measured. The effect of better quality water into the soil can be monitored using wells and piezometers surrounding the selected MAR device during infiltration or injection phase (Llobregat, Spain or Lavrion, Greece). Theoretical water balances and mass balances could be calculated to watch the role of recharge in the final nitrogen concentration in the groundwater storage variation.

Talking about benchmarking on Nitrogen, the balance of N_2 influent from recharge and N_2 content in the aquifer (volume and concentration), results of nitrogen processes in the vadose zone compared to agriculture leaching. Nitrification and denitrification processes are still difficult to predict in natural soils. The generally expected dilution effect (mg/L of NO_3) is hard to check in the short or middle term.

6.1.3 Seawater intrusion

Whenever near a coast all freshwater, even one of a poor quality, helps as a barrier against the salt water intrusion when sea flow becomes dramatic (Malta). Nevertheless it does mean that a 3D model is necessary to visualize the uneven groundwater flows (Menashe). Efforts should be designed to avoid overpressure in zones where freshwater can be lost in a coastal spill while a saline wedge gets into another point within the same aquifer. In that way, all the recharged water may be not playing the pushing role is supposed to play. Recharged volume does not equal functional barrier.

The location of the barrier is also an issue to consider. There are some wells in the coast that must be sacrificed as recharging devices in order to guarantee that the next inner line of wells can get an appropriate quality for the selected use (urban or agrarian). The best location, quality of recharging water and final use are three parameters to balance, so, MAR can be used as a feasible counteraction against seawater intrusion more widely.

Once again, as soon as a new recharge cycle begins, either some new or re-encouraged users renew the water extraction. The potential encouraging effect on irresponsible consumers once a first solution is set up implies a detailed surveillance of the extraction in order to avoid recharge to end in a useless result. Monitoring is as important as active recharge so benchmarking can proficiently quantify the final effects.

With respect to benchmarking and saline water intrusion, recharged water (as a response indicator), depth and variation of the freshwater limit in the interface, extension of salt front inside the coast, salt content in samples, EC evolution in coastal wells, number of abandoned wells… are also solid intrusion benches.

6.1.4 Water quality improvement

This general aim has been proposed for some demonstration sites in Portugal, Italy and Spain. For instance, in Catalonia, an infiltration pond is using a designed filtering and reactive layer system to remove industrial, agrarian and urban pollutants from a near river water, so that volume increases the available groundwater in the basin whilst improves its quality. The possibility of changing that layer composition is an advantage to check different sensitivity for different pollutants. But at the end either layer or the bed of the pool gets clogged with the removed elements, becoming a new waste to be managed. The comparative cost of this management as related to current water price in the area is yet unbalanced; so, cleaning water is not worthy by now, even though Water Framework Directive principles or Climate Change scenarios could support the contrary. As far as defective WWTP are acceptable, no matter how many Persistent Organic Pollutants (POPs) pass through their filters and digesters, the cleaning-recharging scheme has no future but in experimental and passive devices.

Specialization could show a promising future scenario in areas where pollution comes from natural sources (e.g. Santiuste and the arsenic WPP). Drinking water is a primary use so purification cost is usually assumed by the same authorities that would not accept a post-treatment of sewage that could help to increase the available resources for the former use. Mediterranean touristic hot-spots (Barcelona, Cyprus, Greece) may become the next client for this sort of MAR where high income from visitors, exorbitant prizes of surface square metre and salinization combine to push these new proceeds of groundwater management as an asset. Financial analysis in WP15 has revealed that the percentage of taxes or fees that should be raised in order to fund most of the MAR facilities is not an exorbitant figure.

A more outstanding example is Sant' Alessio (Italy) as the RBF has been tested for decades and the soil filter is acting so well that all parameters seem to be under any regulated quality threshold. Obviously, monitoring should keep on the alert but it should be observed that all quality water sources must follow the trend with the same scrupulousness as non-point pollution is a rising concern.

Problems with persistent organic pollutants are undeniable during filtration but they show a similar behaviour in nature (Hamman et al. 2016) and after WWTP processes (Petrovic at al. 2009); so, it is a common issue for all procedures, not just a MAR restraint. On the other hand, the small land use and the reduction of dispersal barriers of MAR are the sort of environmental advantages on behalf of this technique if they are compared to surface dams or canals. Unfortunately, these low impact MAR activities are commonly not so positively appraised during Environmental Impact Assessment (EIA) processes of infrastructures for water storage purposes.

Regarding benchmarking and water treatment and considering the effects of SAT, the change in percentage of any element content after recharge is as important as the total decrease in concentration (% versus mg/L). Thresholds and elements should be applied depending on the final use (irrigation, drinking, restoration…). Comparison with more technological systems can be based in terms of cost-benefit rate (€/m^3), energy consumption (kW/L), maintenance costs (€/month), public investment ((€/year), lifespan (years)… as recommended bench indicators.

6.1.5 Environmental restoration

Although it is obvious, local environment features are items that cannot be forgotten during recharging. Not only by the consequences of water relocation in a catchment area but also by the opportunity to rebuild former natural landscapes related to old higher groundwater levels. Bringing up some examples, in Santiuste there are a couple of experiences to be considered. Sanchón artificial wetlands have been built following the local structure of previous ponds in the area (called “bodones”). The recharging flow is forgotten for a while in order to attain a couple of advantages. As quality is improved by natural processes (some water from WWTP has been mixed with the river flow within the connecting canal), fauna and flora settle in these ponds. Finally, even loosing part of the volume, recharging is reassured back in the infiltration canal. Not a big price for the double feature of three swallow pools built in a lateral branch of a huge recharging network. Something similar could be said about Brenta where orchards or meadows play de role of biofilters as they get integrated in the local rural landscape.

The example of the salt lake in Santiuste is a little different. Here, the quality that could be threatened is the one of the lagoon by the freshwater. The high value of this kind of endorheic systems that seem to be fed by old deep underground streams could be spoiled by an excessive supply of freshwater. Even a more serious risk could come from the invasion of the near cereal plots surrounding the pan. During these years, as the freshwater flow maintained the use of the lake as a reservoir for birds in winter time, the summer did its work drying the outer ring. Apparently, the input of recharging water in winter seems to balance the reduction of natural suppliers as rain and the interception of surface flows by the near cultures. The highly vulnerable species adapted to these uncommon conditions stay in place, so mission seems to be accomplished. Despite this success, some sort of EC control should be recommended to trigger a valve to cut inflow when dilution might become excessive. More research is indispensable to go further.

What is the price of this natural treasure? It is hard to say, especially because any wetland restoration by definition depends more on the water supply than in any other man activity as earthworks on geomorphology restoration or vegetal planting on the shores.

Some of the benchmarking indicators proposed for these environmental issues are the restored surface (ha), indirect recharging efforts (m^3/m^2), number of protected species affected, percentage of recharging supply dedicated to environmental functions (%)…

6.1.6 Landscape refurbishment

The possibility of using former structures for recharge is one of the most attractive characteristics of MAR: *"the recycling spirit"*. With that inner Diogenes syndrome, MAR collects old infrastructures for reusing and colonizing new territories, former structures have been reused such as sandpits (Carracillo), mine hollows (Seville), old quarries (Baleares), mineral cleaning ponds (Andalusia) and abandoned wells (noras, Santiuste) *"do not close a well, reuse it".* The simple positive effect of transforming an industrial ruin or a useless device into a restored working element is undeniable. Infiltration ponds in Menashe or El Carracillo turn into an attractive water body for birds and local population.

The saved money in earthwork budget during the construction phase is evident as it can be easily compared with a mechanical excavation rate. For instance, at the Los Arenales demonstration site some ponds were refurbished to build some infiltration ponds so most of the digging was voided.

Some benching indicators for benchmarking and landscape assets are: Area of restored landscape (ha), percentage of landscape restored by recharge (%), recreative resources (visitors/year), recharging volume dedicated to landscape restoration (m^3/ha)…

6.1.7 Going underground

Another attraction of recharge comes from its underground feature. This water storage does mean minimum surface space so that invisibility means no big investment in plots, no stops in running rivers and usually a supply role that provide users without the disturbance of canals and pipes, using the same aquifer as a distribution system.

Evaporation, eutrophication and pollution from aerial sources or accidental spills are usual problems in superficial storing facilities, as dams and reservoirs. More issues to be remarked when surface and underground systems are compared.

On the other hand, undetected polluted inputs are easier to happen in aquifers. Karsts have not the advantage of an unsaturated column to filter those pollutants.

Distribution network does not occupy any precious surface in irrigated areas or very expensive plots in urban areas. Maintenance and operation costs are attached to every user of a well instead of to the constantly discussed annual or monthly fee; even when the users do not use the MAR infrastructures or maybe they consider that the sharing system is not fair.

The lack of biological barriers for local fauna or the spreading systems for exotic species is a good question to consider during water management planning. Canals and ditches can be changed by aquifer horizontal transmissivity when the water table is high enough.

Proposed indicators for benchmarking and "invisibility" are related to the relative capacity to reduce the need of space when compared to other infrastructures: needed space/ stored volume rate (m^2/m^3), relative reduced cost (€/year), plot cost/treated volume (€/m^3)…

6.1.8 Flood control

In Menashe, Santiuste and Lucca, MAR facilities are ready to absorb extreme episodes. This feature is one to be applied in Mediterranean areas as a climate change adaptation measure, as the occurrence of extreme water-related events indicates that the upsurge of extreme episodes is a problem associated to all the scenarios.

At the same time, as explained in previous paragraphs, this potential feature can risk the main aim of storage. When flood and recharge coincide the recharging device has a very limited operability. Shallow groundwater can be dangerous during a heavy rain episode but this hazard could also happen in natural situations when there is no MAR facility in the zone.

Some proposed benchmarking indicators for flood control are: Potential volume of water to be infiltrated (vadose volume in m^3), potential flow to be diverted (L/s), volume of water provisionally stored (m^3, when turbidity or flow avoids recharge), decrease of time of rain concentration (L/h)…

6.1.9 Multifunctionality

Evidently, a sort of summary brochure could be devoted to illustrate that multiplicity of functions as one of the most attractive features of MAR as a water management tool. Flexibility, adaptability and a basin holistic vision are the kind of features that can make MAR a technique that deserves to be considered in watershed planning.

In this context, some indicators for benchmarking and multifunctionality are: Countries, environments and local conditions where MAR has been installed, functions covered by a single MAR facility, potential uses of existing MAR demonstration sites, cost/benefit balance…

6.2 Benchmarking as an EIA tool: MAR as null hypothesis

As it has been previously established, benchmarking is based on indicators. Indicators show how the MAR device performs and attains the target it is designed for. Simultaneously indicators can be used to confront MAR with other technical solutions depending on the objective to reach.

Impacts are also associated to these indicators as they are attached to active human actions in the environment. Where some can see indicators of projects that show good opportunities, others can see nothing but potential problems. Those complications can rise from the source of managed water or the way water penetrates into the soil. Technical constraints and legal requirements prompt and MAR might face an unpropitious atmosphere where it seems hard to prosper.

Measures are needed to reduce those impacts. As in any other project appraisal, measures and monitoring techniques are proposed to diminish the global effect until the balance of technical, social, economic and environmental aspects, guaranteeing the sustainability of the alternative.

The array of technical solutions offers many different ways of adapting MAR to a precise hydrogeological area and deal with the associated problems. In fact, many of the problems produced by recharge can be also solved by MAR solutions and variations. Recharge correspondingly offers tools to deal with its own ordinary problems: filtering against leaching, reuse against new infrastructures, reclaim against clean sources, wetland restoring against riverside occupation, soil management practices against clogging…

An example about water storage has been illustrated in the Figure 6-1, but other uses could be discussed in a similar way: nitrate dilution, water quality improvement, saline water barrier effect…

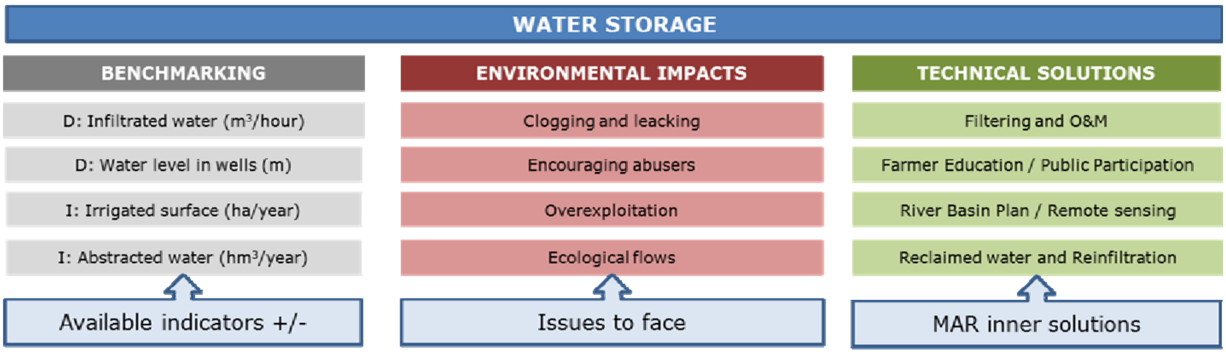

Figure 6-1: Water storage aim: Benchmarking indicators, associated impacts and MAR associated technical solutions.

Passive and natural soil processes, low (or null) energy cost, underground location or recycling features should aid to push MAR as an alternative not to be neglected. If there is a final objective to be attained by MARSOL, that is MAR to be considered as any other standard technique or infrastructure for water management during selection process. For instance, whenever a dam project is assessed as a water storage device, MAR alternatives should be taken into account and their characteristics should be subjected to a parallel comparison to those of the dike before final decision. Same process could be applied to wastewater treatment plants appraisal. Budgetary shortages, final water use or scattered rural location could transform an apparent low profile infiltrating pond into the amazing winner of the race.

Nonetheless European directives, national laws enforcement and precaution principles (that seem to be not so aggravating to other potential competitors up to now), are not very proactive for MAR these days. Frontal confrontation against well-established standards as concrete dams or the black image of people on WWTP product is not a good advising strategy. Those windmills could be too big and strong for our humble Don Quixote figure, so that it is not the best path to show the full potential and capacity of this technique. It does not mean running away the battlefield, but facing those competitors in a positive way, trying to fill those gaps where MAR can offer advantages out of reach to the standardized facilities.

Features related to transparency, modernity, sustainability, green touch, invisibility, recycle, economy, locality, adaptability, ecological … these are the keywords to be linked with MAR in order to gain technical respect and Media visibility for MAR. The task is to obtain all those figures, statistics, graphs, plans, maps and tables to feed the Media with reliable material that can give MAR a public boost.

Evidently, research and science are not fields that should be deserted but maybe focus should be unbalanced to a more general view. Technicians, decision makers, stakeholders, civil servants and politicians are the kind of people better placed to help MAR to get a place under the sun in the water management, but in the modern world that never stops looking for quick and constant communication, MARSOL must be able to offer material for popular Media: leaflets and not only articles, images and not only texts, indicators and not only raw tables, newspapers and not only journals…

Time has come for proselytism and the stress must be placed on SOL. MAR is an actual technique that deserves to be treated at least as an alternative solution in many different problems associated to water management.

In a similar way, to that null hypothesis that requires a compulsory reasoned answer in all EIA process, MAR is something to be debated with arguments and seriously considered before refusing (or not) one of that catalogue of 25 affordable facilities and solutions.

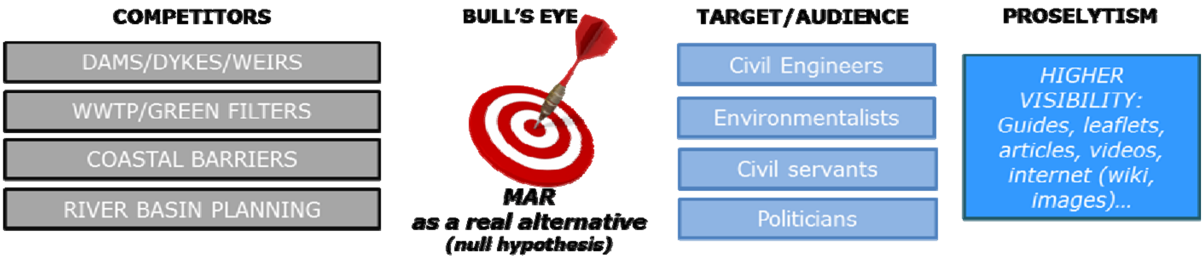

Figure 6-2: MARSOL bull's eye: To be considered as a cutting-edge alternative.

Consequently, MARSOL main bull's eye (**Figure 6-2**) should be not to give up achieving the prerogative of MAR as an alternative solution in the hydrological field that cannot be neglected. Benchmarking indicators based on real facts and sites must be used to compose those materials for the Media to make recharge a more affordable technique for general public and stakeholders.

7. SUMMARY AND CONCLUSIVE REMARKS REGARDING BENCH-MARKING FROM A PRACTICAL POINT OF VIEW

The overall aim of Managed Aquifer Recharge technique is the increase the amount and quality of the water resources recovered after its pass through the underground system, so that this couple of variables must be the focus of the benchmarking when matching the different cases of MAR considered. However, quantity and quality may also be monitored in many ways.

To be able to compare the efficiency and efficacy of the MAR based systems in terms of energy balance or cost/benefit, a methodical characterization of the whole process must be carried out to assure functions and facilities are clearly comparable, independently of their size, budget or location.

Benchmarking MAR facilities should take a series of steps. This report proposes at least three:

- MAR functions characterization (transport, infiltration, treatment, restoration) splitting homogeneous operational sections.
- MAR infrastructure measurements (surfaces, lengths, facilities, costs).
- MAR evolution in time (data series and schedules) and space (maps and sketches).

Measuring MAR could be relatively easy on a small scale with a specific function (Llobregat, S. Bartolomeu), but not in open extended multi-purpose areas (Los Arenales, Noras). This is the reason why the biggest MARSOL demonstration sites must be studied following a more subdivided and multifaceted approach. The benchmarking system proposed and applied to medium-scale sites should be used to compare only similar and tested facilities (infiltration ponds, infiltration canals, purifying canals, artificial wetlands…) with comparable purposes.

Mediterranean water irregularity, amplified by climate change previsions, can be mitigated by MAR techniques in many different ways, such as sea water intrusion barrier (Reichard and Johnson, 2005), sewage treatment (Bekele et al. 2011) or ecological restoration (Esteban and Dinar 2013) to mention some. These roles are not generally seen as goals to be solved by means of inducted recharge activities and their benefits are not usually assessed when they are compared to other infrastructures.

The reuse of previous structures (sand pits in El Carracillo, abandoned wells in Noras and Santiuste, dry stream beds in Santiuste and Weir in Cerro do Bardo), its adaptability to local usages (agricultural, rural, urban) and consequent savings provide a broader variety of solutions within a MAR *"recycling spirit"*. The design of passive systems (no energy costs are required after the initial construction in the seven sites) and their low initial investment (minimized by means of refurbishing former infrastructures such as sand pits for artificial wetlands…) seem to be key factors to boost MAR acceptance (Fernández Escalante and San Sebastián 2012).

Some demonstration sites are placed near very popular touristic destinations like Barcelona and Algarve, where the increasing population requires large amounts of drinking water in summer (dry season) and simultaneously produces high discharge rates of sewage (Gössling et al. 2012). The high price of urban land is also an issue to consider when building a superficial water storage facility on these areas.

MAR must play a central role in the recycling process (Dillon et al. 2010) as an affordable option in a Climate Change scenario where extreme episodes (such as floods and droughts) are expected to happen more frequently (Giorgi and Lionello 2008).

Benchmarking indicators can help to assemble a series of didactic material for the print and social Media, as guidelines on points of interest in water management issues (Escalante et al. 2013), so MAR technique may become a performance of common knowledge in both technical and inexperienced circles (Lyytimäki & Assmuth 2015).

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