CHARACTERIZATION AND BENCHMARKING OF SEVEN MANAGED AQUIFER RECHARGE SYSTEMS IN SOUTH-WESTERN EUROPE

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Abstract

The European MARSOL project includes different examples of Managed Aquifer Recharge (MAR) facilities in the Mediterranean Area. A methodical characterization of the whole recharge process has been carried out to assure that all functions and facilities are clearly comparable independently of size, budget or location. The seven selected MAR demo-sites are located in two countries. Four are in Portugal: Rio Seco and Noras (Campina de Faro Aquifer), S. Bartolomeu de Messines and Cerro do Bardo (Querença-Silves) in Algarve, and three in Spain: Llobregat (Catalonia), Santiuste and El Carracillo (Castilla y León). The systems have been defined using a form made of four sections, including alpha-numerical data, orthophotos, sketches and schedules. A first draft using bibliography was reviewed by the authors, who recorded detailed analysis and further reports to complete the characterization, shown in several tables. The article covers MAR benchmarking serial steps for infrastructure measurements (surfaces, lengths, facilities, costs), functions categorisation (transport, infiltration, treatment, restoration) and evolution in time and space (maps, sketches and calendars). MAR measuring displays contrasting interpretations depending on scale. The benchmarking process has been found difficult to apply to seven sites with so different sizes, aims, operational procedures and evolution in time. However, some parameters, such as mean infiltration rate, have shown their potential as management decision tools in the long term. Mediterranean areas, characterized by water supply irregularity, which will be amplified according to climate change models, can benefit from the use of the MAR as a water management technique and from its diverse functions, although these objectives have not been generally attached to recharge. Null energy cost and low initial investment can also play important roles to boost MAR development as a feasible alternative in water planning in the short term.

Keywords: Managed Aquifer Recharge (MAR), groundwater quality, benchmarking, Mediterranean climate, water management, climate change.

1 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 revolving 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, river bank 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 work, we have analysed seven selected MAR demo-sites located in Portugal and Spain through a methodical characterization of the whole recharge process. Thus, our goal has been to make them comparable through 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 evenness is guaranteed. This work was developed in the context of the MARSOL project (Managed Aquifer Recharge Solutions, an EU-FP7), which was aimed at demonstrating that MAR technology is a sound, safe and a sustainable strategy that can be applied with confidence.

2 Materials and Methods

2.1 Characterization of the indicators

The usage of benchmarking indicators applied to any water recharge system must evaluate above all the characterization of the framework itself, considering the broad variability of these schemes. Most of the processes that can be found in a MAR system are very diverse and interconnected (Figure 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.

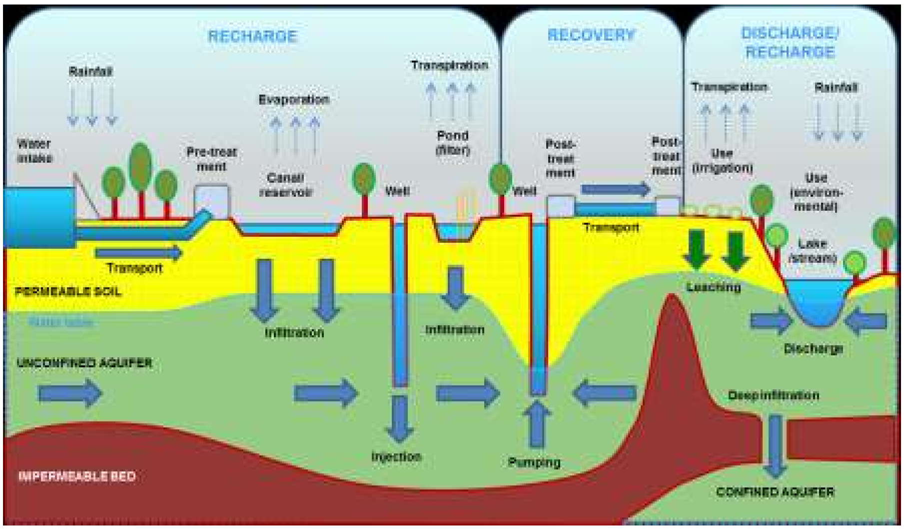

Fig. 1 Water recharge and recovery system sketch

2.1.1 Measuring water quantity

The volume of managed water should be quantified considering the different phases that this bulk has passed through from its abstraction to its final use. Parameters collected for water quantity in the MAR framework are listed in Table 1.

Table 1 Main parameters for water quantity in a MAR system covering different phases

Phase	**Quantitative parameter**	**Original source**	**Aquifer**	**End use**
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

2.1.2 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 quality control can be applied to MAR (Table 2). The general constraints are expected to be similar among the European countries although harmonization is still required (Miret and 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 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)	%
Total Dissolved Solids	TDS (mg/L)	TDS (mg/L)		TDS (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)	%

2.1.3 Comparing efficiency in terms of cost and energy

Effectiveness can be quantified in every step (Table 3) using economic or energy references. Though the cost/effectiveness ratio could be associated to the volume managed in each phase, a more objective measure is usually calculated considering the net volume of recovered water, as this is the most usual final goal of the MARSOL schemes. In the case of rising water table for energy saving as in Santiuste, water is finally pumped out for irrigation. MAR facilities dedicated to sea intrusion and wetland restoration goals step out of this efficiency concept.

An energy balance must be applied to compare passive and active systems. The economic cost should be calculated separately for the infrastructure investment and the operation and maintenance (O&M) costs. Even an Internal Rate of Return could be estimated to appraise the recharging system as a progressive investment in time.

Table 3 Parameters for efficiency in a MAR system in every possible step of the recharge recovery cycle

Phase	Efficiency parameter	Original resource	Aquifer	End use
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

2.2 General procedure

In order to gather all these data for each demo-site, a form has been designed and divided in four sections:

- Main data and big numbers are enclosed in the first section, such as MAR class, functions, geology, water cycle, water quality, soil control and benchmarking indicators as seen in Tables 5 to 7 (Figure 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 demo-site in the local and technical details. Then, functions are exposed so performance rates can be assigned.

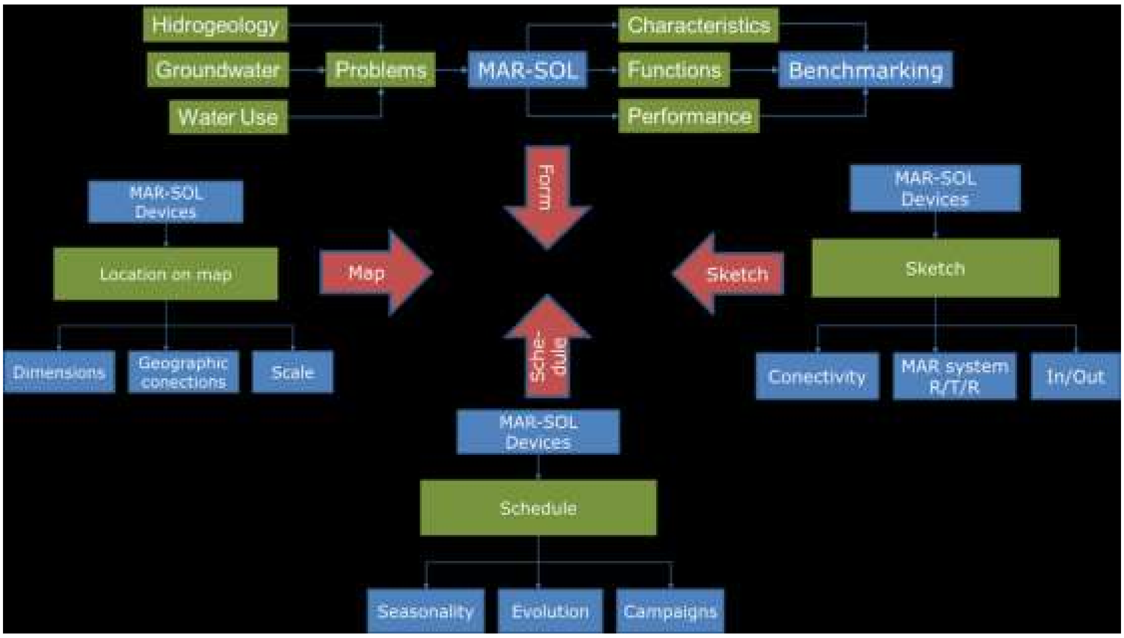

Fig. 2 Methodology applied for data gathering. From MAR characterization to indicators (R/T/R: Recharge/Transport/Recovery).

- The second section shows the location of the demo site on orthophoto using any GIS program or Google Earth. In the case of benchmarking, this process (Figure 2 left) 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).
- The third section is a sketch of the demo-site where Q_0 to Q_x represent main inlets and outlets so it can be determined which facility or stretch is playing a different role in each point of the recharge net (Figure 3). 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 2 right).

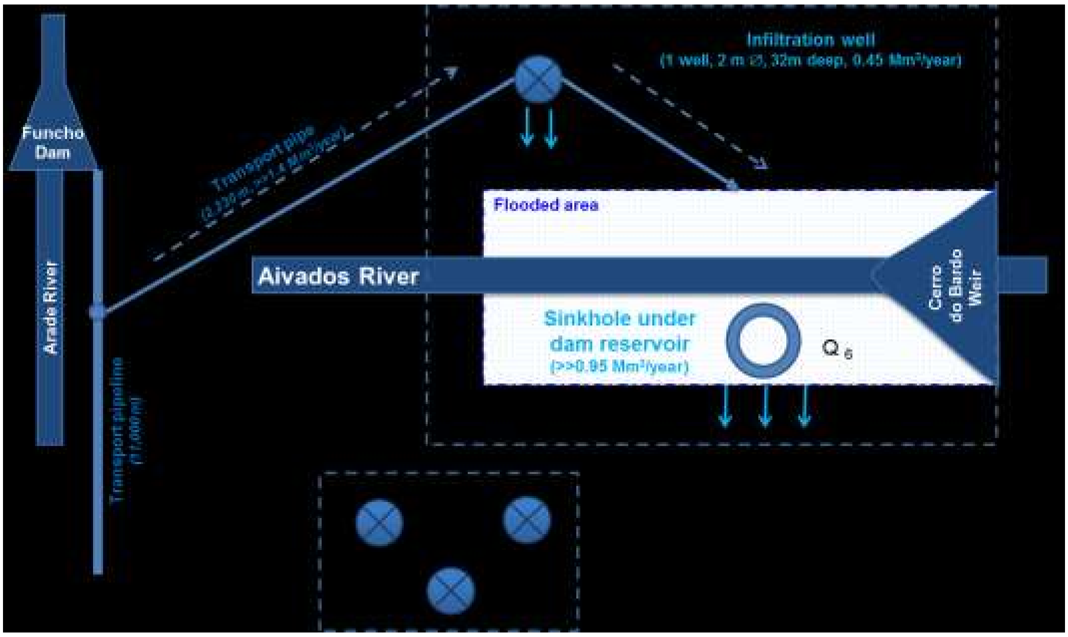

Fig. 3 Example of the Campina de Faro demo-site network sketch

- The fourth section is a calendar showing new works and changes of facilities in time (Table 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 2 down).

Table 4 Example of the Santiuste MAR system development schedule from 2002 to 2015. First column indicates the operative sections. Total number of operative facilities per year is shown in the last row. Last column shows total operative years

Operative section	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	10/11	12/13	13/14	14/15	
Diversion catchment	X	X	X	X	X	X	X	X	X		X	X	X	12
Diversion pipe	X	X	X	X	X	X	X	X	X		X	X	X	12
Infiltration pond			X	X	X	X	X	X	X		X	X	X	10
East infiltration canal (Old)	X	X	X	X	X	X	X	X	X		X	X	X	12
East infiltration canal (New)						X	X	X	X		X	X	X	7
West infiltration canal				X	X	X	X	X	X		X	X	X	9
WWTP					X	X	X	X	X	X	X	X	X	9
Biofilter					X	X	X	X	X	X	X	X	X	9
Artificial wetlands				X	X	X	X	X	X		X	X	X	9
Salt lake diversion				X	X			X	X		X	X	X	7
Salt lake restoration				X	X			X	X		X	X	X	7
	3	3	4	8	10	9	9	11	11	2	11	11	11	

3 Results

The seven demo-sites are located on four aquifers in two countries. All of them are basically surface infiltration facilities but there is a great variety because of the assorted combinations of ponds, canals, artificial wetlands or connections to WWTP (Table and Figure 4).

Table 5 Main features of the seven studied MAR demo-sites

Demo-site name	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Country	Portugal	Portugal	Portugal	Portugal	Spain	Spain	Spain
Demo location	Rio Seco (Algarve)	Campina do Faro (Algarve)	S. Bartolomeu de Messines (Algarve)	Cerro do Bardo (Algarve)	Santiuste (Segovia)	El Carracillo (Segovia)	Sant Vicenç dels Horts (Barcelona)
Aquifer	Campina de Faro	Campina de Faro	Querença-Silves	Querença-Silves	Los Arenales	Los Arenales	Llobregat
MAR class	Infiltration	Infiltration	Infiltration	Infiltration	Infiltration	Infiltration	Infiltration
MAR type	Infiltration ponds	Open infiltration wells	Infiltration / Soil-Aquifer Treatment (SAT)	Well / dam	Infiltration / SAT basins	Infiltration / SAT basins	Infiltration / SAT basins

Fig. 4 Demo-sites locations in the Iberian Peninsula

3.1 Benchmarking in Portugal demo-sites

The four Portuguese sites (Rio Seco, Noras, São Bartolomeu de Messines and Cerro do Bardo) are assessed for their preliminary benchmarking results (Table 6). Only the first site (Rio Seco) shows two-year-working-performance indicators as the rest are just estimations based on the initial tests.

The main goal in Rio Seco is to improve the groundwater quality, heavily contaminated with nitrates (vulnerable zone of Faro), mainly due to inappropriate agricultural practices. The water source will be the ephemeral stream river bed (Rio Seco) and the infiltration will be carried out using gravel filled basins in the river bed. This MAR facility shows a high potential for annual diversion (6.7 Mm^3) when the project gets totally developed, but it is only operative for a short time, no much longer than an average of 2 months (67 days) per year (Fig. 5), and infiltrating in a short section. 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 (22 m^3/h) but, considering the diverted volume, the fraction was low (0.5%) for these initial campaigns. On the other hand, mainly due to the thickness of the confining 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 (2.5 €/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.

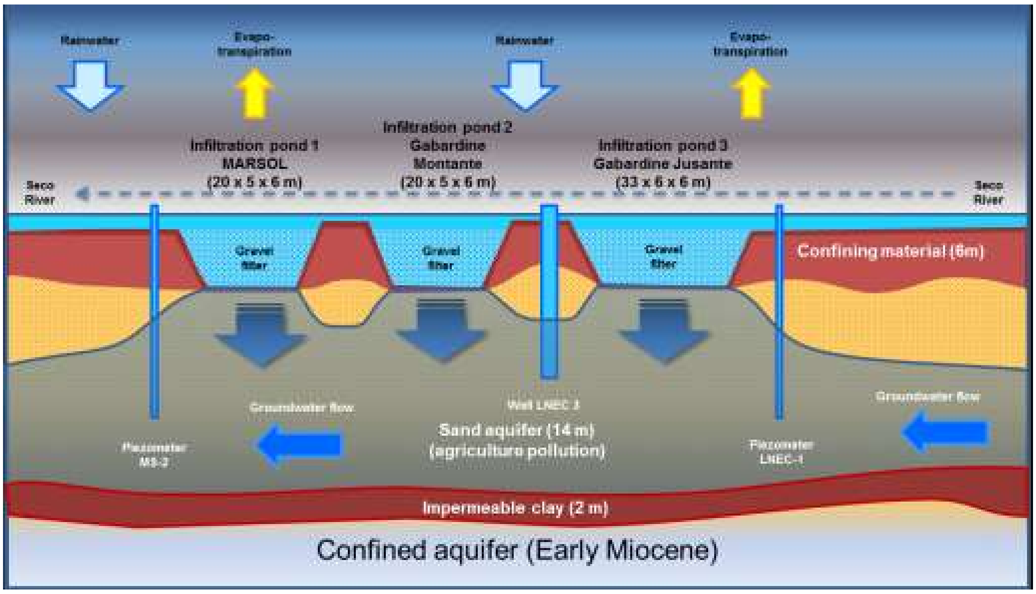

Fig. 5 Campina de Faro (Rio Seco) profile. Main processes (arrows) and MAR facilities (ponds and piezometers) are shown

Noras (Fig. 6) is an unconventional site as it is 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 (large diameter dug wells are 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 (27%). The cost of the infrastructure is very low as greenhouses and old wells were established before recharge. The O&M cost is higher than expected because of the current low intensive recharge. The availability of pre-existent wells and no water transport requirements represent good advantages for an easy replication in many other areas with greenhouses (De Pascale & Maggio 2005) in the Mediterranean coast (e.g. Almería in Spain, Ragusa in Italy or Antalaya in Turkey).

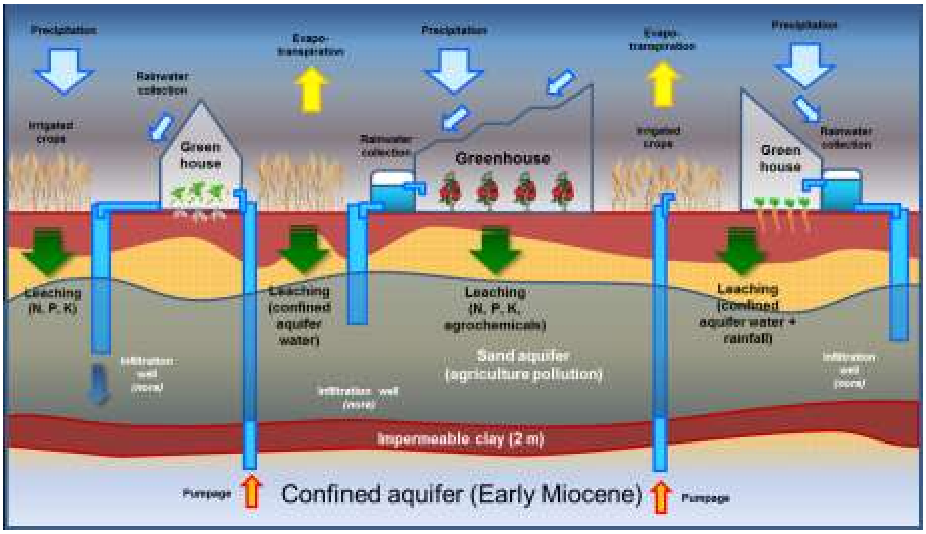

Fig. 6 Campina de Faro profile. Rain on greenhouses roofs is harvested and directed to abandoned wells (Noras) to recharge the unconfined aquifer

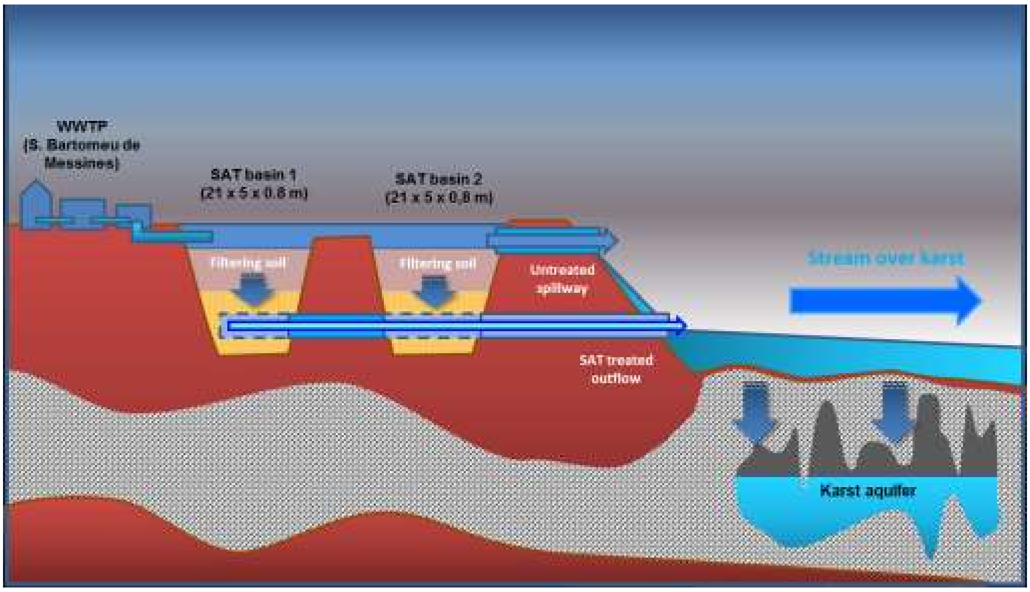

Fig. 7 São Bartolomeu de Messines MAR profile. Part of the outflow from a WWTP is infiltrated through a couple of SAT basins and spilled into a stream

S. Bartolomeu de Messines (Fig. 7) and Cerro do Bardo (Fig. 8) 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 Lobregat 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 (Fig. 7, right).

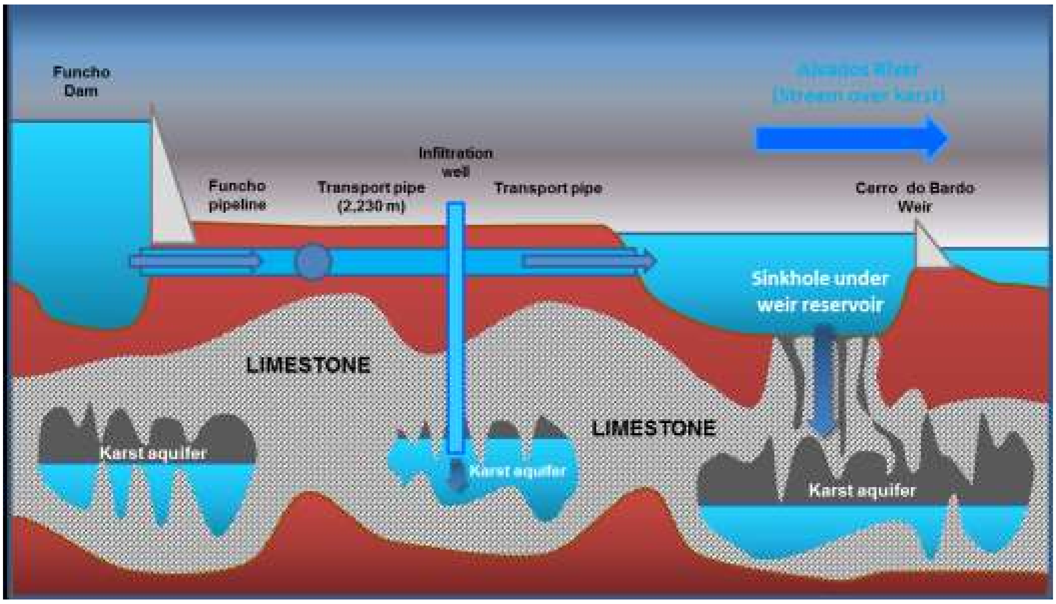

Fig. 8 Cerro do Bardo profile. Water from a dam network is diverted to an infiltration well and a weir where a submerged sinkhole recharges a karst.

Table 6 Preliminary benchmarking indicators for Portuguese MAR sites

BENCHMARKING INDICATORS	UNITS	Campina de Faro (Rio Seco +IP)	Campina de Faro (Noras + Greenhouses+Infiltration Wells)	S. Bartolomeu de Messines	Cerro do Bardo
Water diversion	Mm^3/ campaign	6.7	1.6	0.3	14
Operation time	Days/campaign	67	22	365	365
Operation campaigns	Years	2	0	0	0
Infiltration surface	m^2	401	950	210	Unknown
Infiltration volume	Mm^3/ campaign	0.035	0.4	0.03	1.7
Infiltration (volume/time) rate	m^3/h (infiltrated volume/time)	22	818	3.5	190
Infiltration efficiency (infiltrated/diverted) rate	% (infiltrated volume/diverted volume)	0.5%	27%	10%	3.4%
Infiltration area (infiltrated volume/area) rate	m^3/m^2	87	463	142	--
Average infiltration rate	m/d	1.3	21	0.4	--
Pollutants concentration decrease (Passive by dilution).	mg/L, %	50% lower nitrate concentration in a 100 m radius around the basins	Nitrate depletion (Data for future collection)	Pharmaceutics decrease in % (Active by biofilter)	--
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	2.5	0.07	0.5	0.7
O&M cost	€	4,000	4,000	1,000	15,000
O&M cost (calculated)	€/m^3 (cost/infiltrated)	0.11	0.04	0.03	0.006

In short, the main functions in the Portuguese test sites are related to quality improvement. Unfortunately, the monitoring network of such a large groundwater body is still not completely covered by sensors. Nitrogen depletion can be achieved with dilution processes thanks to the lower concentration in recharged water. Anyhow, alternatives such as pumping and treating the volume of groundwater to reduce the nitrate content from around 200 to 50 mg/L (legal limits) would be unaffordable. Pharmaceuticals resilience associated to the outflow of S. B. de Messines imply 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).

3.2 Benchmarking in Spain. Llobregat demo site (Catalonia)

The Llobregat demo site is based on two ponds: one for sedimentation processes and another one for infiltration processes (Fig. 9). The MAR system has been placed in Sant Vicenç dels Horts (10 km of Barcelona) and is a component of the artificial recharge carried out in the Low Llobregat area for decades. 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 in the bottom of the infiltration pond (Fe oxides plus reactive layer with 49% green waste 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).

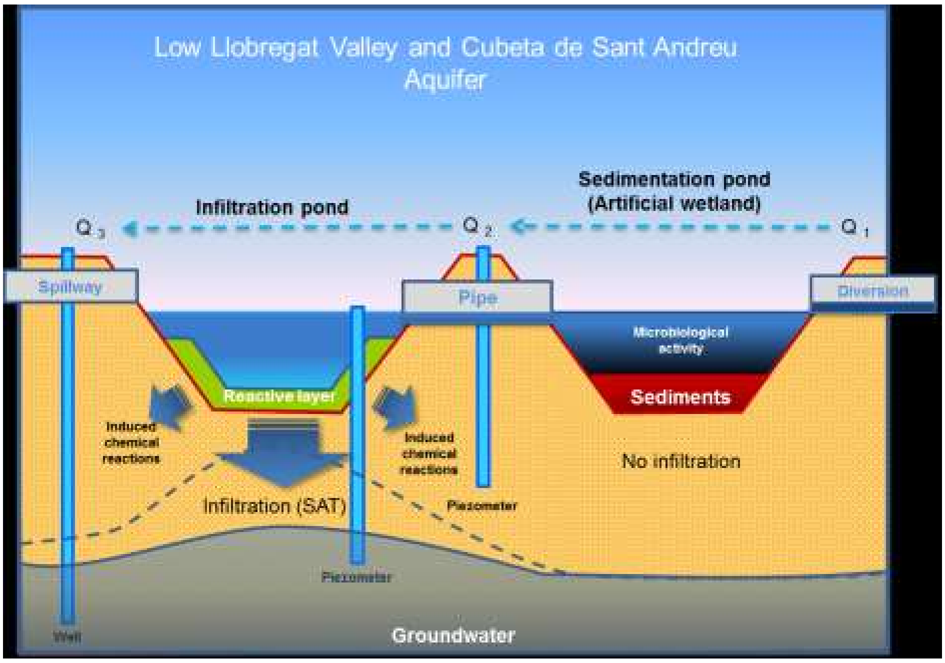

Fig. 9 Llobregat MAR demo-site profile. A pipe from a weir in Llobregat River fills a couple of ponds. The first acts as a sedimentation device and the second as an infiltrator with a reactive layer.

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). Some biological processes are probable, considering the flora and algae growing in the sedimentation pond though it has not been surveyed in the infiltration process. Some infiltration volumes show different numbers in 2011 and 2012 depending on the source (Table 7).

Having said that, a volume up to 3.74 Mm^3 has been recharged during these six years with an average of 0.6 per campaign (2010 was an exceptionally dry year). The mean infiltration rate has been around 0.75 metres per day. The decrease in the recharged volume is attributed to the increasing of clogging effects on the infiltration pond. Note that besides the total recharged volume the infiltration rate was also low and it was comparable to 2013. After the installation of the reactive layer and during the next three years the infiltration rate ranged between 0.89-0.94 m/d, in 2012 it decreased to 0.72 and in 2013 and 2014 it was between 0.48-0.5 m/d. This decrease in a benchmarking parameter could be used as a pre-alarm signal indicating the need of reactive layer renewal or the application of some counter-clogging measures.

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 recharged water passes through the reactive layer modifying redox conditions and enhancing the emerging organic compound degradation (40-75% of reduction in CEC see Table 7) 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 been irregularly used (Table 7) because of litigation linked to rights on river water supply. 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 water supply high demanding area like Barcelona City particularly during dry and tourist seasons, when surrounding WWTPs are overloaded by the increase on volume to treat, so secondary treatment cycles are usually reduced.

Table 7 Preliminary benchmarking indicators for Llobregat MAR site

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%
SO_4 decreasing %	%	5-15%
Fe (II) increasing factor	%	200-5,000 times
Mn (II) increasing factor	%	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, Chlorine concentration, interface location...	No relevant effect
Others	Microbiological active volume (m^3)	5,600
Others	Pollutant depletion	33 to 100% (see below)
Anthropogenic contaminants (Contaminants of Emerging Concern) decrease	Pharmaceuticals and personal care	% of inflow conc. (2011-2012)
	Atenolol	100%
	Cetirizine	33-77%
	Gemfibrozil	34-64%
	Carbamazepine	No (recalcitrant)

3.3 Benchmarking in Spain. Los Arenales demo site

The most important current operative demo-sites in Castilla y León are located on the same broad sandy aquifer and both have been recharging river water since 2002. El Carracillo could not get any supply for a couple of campaigns but Santiuste 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 Santiuste (Fig. 10) and El Carracillo (Fig. 11) are:

- Both sites take water from river winter surplus but Santiuste has also had a complementary water source from a lagooning WWTP since 2005.
- Canals are the main transport and infiltration facilities in Santiuste while pipeline and ponds play those roles in El Carracillo.
- 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 around 10 km far from the irrigation area, where a series of canals and ponds enhance the recharge into the sandy aquifer by direct infiltration. Transport, infiltration, purification and restoration processes take place in different sections and extents in both areas.

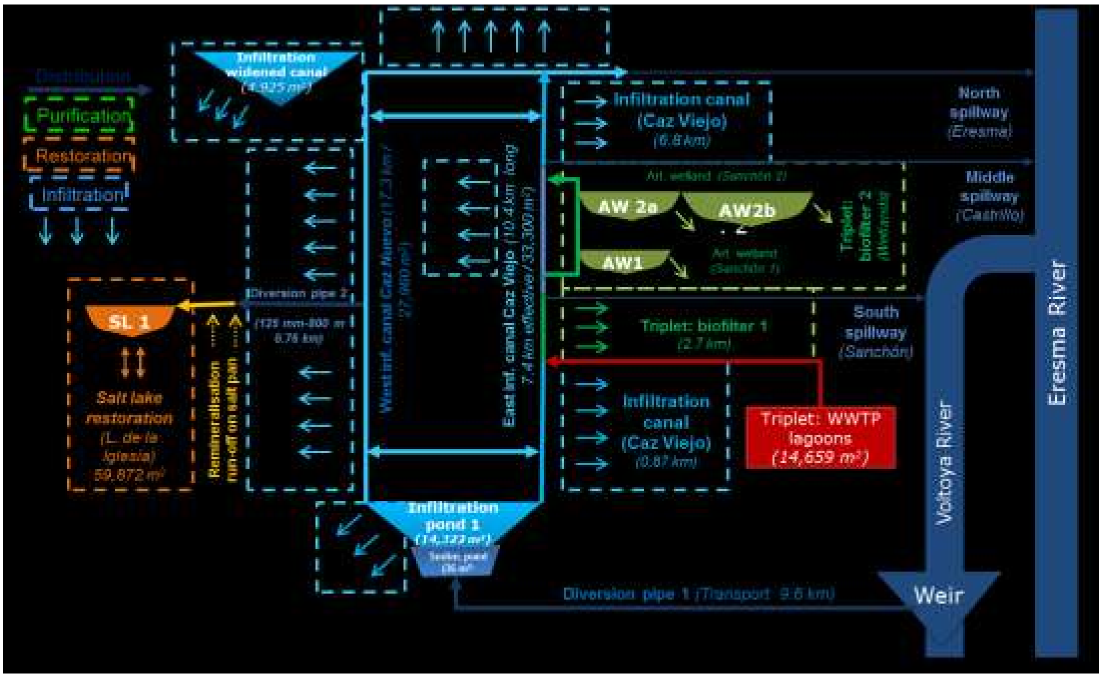

Fig. 10 Santiuste MAR sketch. A very complex MAR system conjugates up to four processes using water diverted from Voltoya River

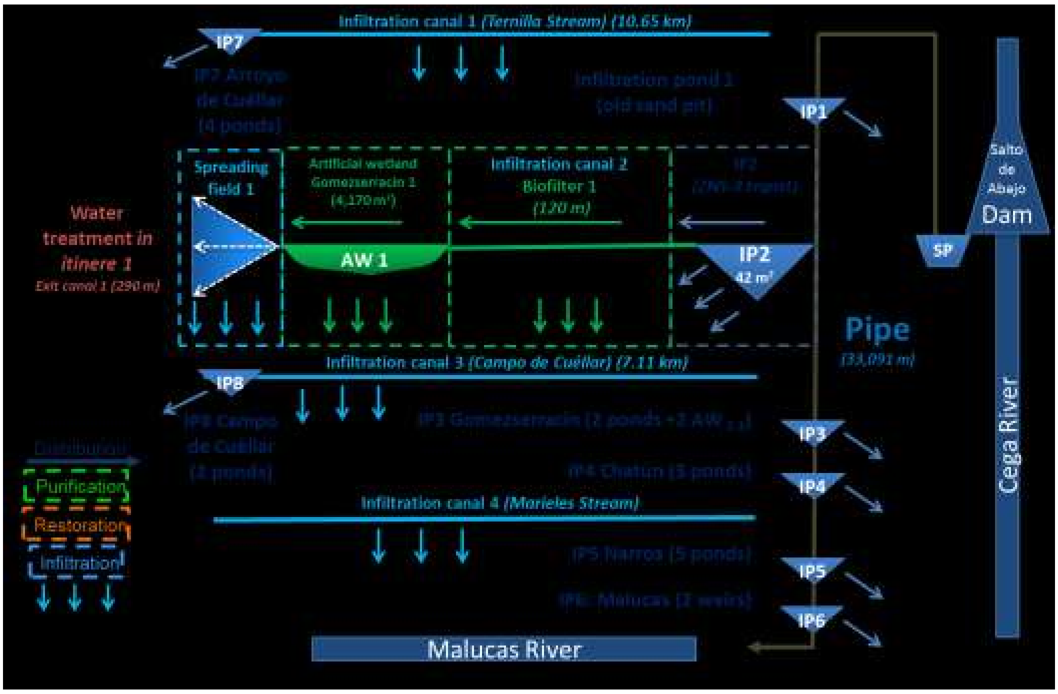

Fig. 11 El Carracillo MAR sketch. A long (33 km) pipe carries water from Cega River and supply a series of infiltration facilities in El Carracillo district

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, where current lagooning proves not to be a very effective purification method.

Benchmarking figures in Los Arenales aquifer are shown in Tables 8 and 9. The availability of more than ten cycles at both demo-sites permits to use some averages as statistics with a greater relevance for characterization in Table 9.

Table 8 Preliminary benchmarking indicators for Los Arenales MAR site (indicators dependent on campaigns). S for Santiuste and EC for El Carracillo

BENCHMARKING	DEMO-SITE	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
Water diversion (Mm^3)	S	3.5	2.3	1.3	5.1	12.7	0.5	3.9	0.7	3.1	0	3.5	2.0	3.6
	EC	1.4	5.5	0	2.4	3.2	0	1.9	5.8	4.6	1.9	7.1	1.8	0.6
Operation time (days)	S	145	175	212	137	212	7	181	43	68	0	76	57	76
	EC	149	149	0	149	149	0	149	89	90	60	119	89	27
Infiltration length (km)	S	7.2	7.2	7.2	17	17	25.7	25.7	25.7	25.7	1.1	25.7	25.7	25.7
	EC	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
Infiltration surface (ha)	S	0	0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.17	1.8	2.2	2.2
	EC	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2	60.2
Purification area (ha)	S	0	0	0	2	2.6	2.6	2.6	2.6	2.6	0.7	2.6	2.6	2.6
	EC	0	0	0	0	0	0	0	0	0	0	0	0	0
Restoration area (ha)	S	0	0	0	8.7	8.7	0	0	8.7	8.7	0	0	0	0
	EC	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Infiltration volume (Mm^3)	S	1.3	1.8	1	3.6	12.2	0.5	2.5	0.6	2.1	0	3.2	2	3.2
	EC	1.4	5.5	0	2.4	3.2	0	1.9	5.8	4.6	1.9	7.1	1.8	0.6
Infiltration rate (m^3/h)	S	374	429	191	1,083	2,396	2,738	576	620	1,305	-	1,782	1,462	1,743
	EC	391	1,538	0	685	895	0	531	2,715	2,130	1,319	2,486	836	923
Infiltration rate (m/day)	S	2.2	1.2	0.3	2.0	3.3	4.0	1.2	0.9	2.5	0.000	2.6	1.6	2.2
	EC	0.02	0.06	0.00	0.03	0.04	0.00	0.02	0.11	0.08	0.05	0.10	0.03	0.04

It is worth to mention Santiuste Basin MAR plant has been extended in different stages. Along 2004 new canal branches were built, especially in the north extreme, and minor adaptations have been conducted along the whole operative time (see Table 4). The high infiltration rate in the 2007/2008 hydrological year was due to the fact that MAR cycle was only seven days long (according to the precipitation in the area to satisfy legal constraints). In this situation, the scarce volume of water diverted easily penetrated into the aquifer. Desilting activities in the whole MAR facilities have been performed in 2005, 2010 and 2015, removing plants growing into the canals and renewing the biofilter. According to these previous conditions, there is a good correlation between the mean infiltration rate and the clogging decreasing in canals and infiltration ponds.

In contrast, Carracillo MAR plant has changed very scarcely as there has not been undertaken any general desilting campaign, so cleaning and maintenance are done according to the provisions of the irrigation community

Table 9 Preliminary benchmarking indicators for Los Arenales MAR site (constant and average indicators)

BENCHMARKING	UNITS	SANTIUSTE (CyL)	EL CARRACILLO (CyL)
Transport length	*km in pipe*	13.6	46.2
Purification length	*m in canal*	1,129	138
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/m³*	0	0
Infrastructure cost	*€*	3,948,079 €	5,273,999 €
O&M cost	*€/m³*	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	*Mm³/year*	0.21	8
Farmers	*number*	440	713
Effect of MAR in irrigation supply	*m³/ha*	853	314
Irrigated volume from MAR	*%*	28%	24%
Mean water table depth increase after MAR	*M*	1.5	2.3

BENCHMARKING	UNITS	SANTIUSTE (CyL)	EL CARRACILLO (CyL)
Energy savings	*kWh*	27.10 (per well)	28,000 (total)
Energy savings	*%*	30%	36%

3.4 Characterization of MARSOL demo-sites

The seven studied demo sites have covered 13 MAR devices out of the 25 recorded (Table 10). Infiltration ponds and open wells are the most usual facilities. The array of working services of Los Arenales sites contrasts with the specificity of Rio Seco, Messines and Llobregat.

Table 10 Types of MAR devices in the selected demo-sites. (Note: X means existent but not specified)

MAR devices	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Infiltration ponds (IP) / artificial wetlands (AW)	3 IP				5 IP +3AW	22 IP+1AW	1 (AW /SP*) +1 IP
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**		1 Dug well	3	X	
Sinkholes, collapses...				1 known sink hole			
Aquifer storage, transfer & recovery (ASTR)				X			
River bank filtration (RBF)					1		
Interdune filtration						Ditches	
Rainwater harvesting in unproductive		Greenhouse roof harvest					
Number of MAR devices	**1**	**3**	**1**	**4**	**7**	**8**	**2**

** SP: Sedimentation Pond. ** Only 11 “noras” of those 60 are considered within modelling area*

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 masses (Table 11). Llobregat and Messines have been unambiguously designed to treat only urban polluted water, not to solve supply issues in the groundwater area.

Table 11 Main problems in the aquifer under the studied demo-sites. (Note: X means existent but not specified)

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)							X
Contamination from agriculture 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**

** Organic industrial residues (1,1,2-Trichloroethane, TCA) have also been detected in Llobregat.*

The comparison between problems and functions show the different approach of specialized facilities with extended sites (Table 12). This was expected as a result of the number of facilities cited in the Table 10. Anyhow, quality improvement is a more recurrent function than storage for these recharging infrastructures.

Table 12 Attainable functions of the MAR demo-sites. (Note: X means existent but not specified)

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	NO_3	NO_3	Pharma-ceutics		NO_3	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 13). 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 13 Geological features of the MAR demo-sites. (Note: X means existent but not specified)

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

Most of the selected demo-sites are attached to other hydraulic infrastructures, such as dams, weirs and WWTP (Table 14) that can be seen as potential competitors from a benchmarking point of view. Coordination of traditional and new MAR facilities is still necessary and helps develop a more integrated network in the watershed management. Among the selected sites of this paper the only documented way to recover water is well pumping. 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 14 MAR phases of the MAR demo-sites. (Note: X means existent but not specified)

WATER SOURCE	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
River	Rio Seco			Ribeira de Aivados	Voltoya (1,000 L/s)	Cega	Llobregat
Weir/Dam				Foucho Dam	Voltoya Dam (60,000 m^3)	Cega	Weir in Molins de Rei
Sewage (WWTP)			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	900 mm / 9,824 m	33,000 m	3,200 m (pipe from Weir to first pond)
WATER RECOVERY							

WATER SOURCE	Rio Seco	Noras	S. B. de Messines	Cerro do Bardo	Santiuste	El Carracillo	Llobregat
Well		X	X	X	X	X	X
Others	*						
WATER USE							
Agriculture		X	X	X	X	X	X
Industrial							X
Ecological	X	X	X	X	X	X	
Urban				X			X

** Goal is to improve the water quality. Not so much recovery*

3.5 Benchmarking in MARSOL demo sites

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 demo-site too. Average measurements must be calculated to compare different demo-sites using a single benchmark figure.

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 15 Preselected indexes as benchmarking indicators for MAR systems. (Note: ??: probable but not measured; -: Unknown)

Country		P	P	P	P	E	E	E
Benchmarking indicators	**Units**	**Rio Seco**	**Noras**	**S. B. de Messi-nes**	**Cerro do Bardo**	**Santius-te**	**El Carraci-llo**	**Llobre-gat**
CHARACTERISTICS								
MAR Type	text	Inf. Ponds	Open Inf. wells	Infil. / SAT	Well / Dam	Inf. / SAT Basins	Inf. / SAT Basins	Sed. Pond & Inf. Pond (Reactiv e layer)
Water Source	text	River	Rainfall	WWTP	River	River+W WTP	River	River
Performance campaigns	years	2 (2014-2015)	0	0	0	12 (2002-2015)	11 (2002-2015)	6 (2009-2014)
Soil type	text	Siliceous unconfin ed	Siliceous unconfin ed	Confined Karst	Confined Karst	Siliceous unconfin ed	Siliceous unconfin ed	Siliceous unconfin ed
DIVERSION								
Annual volume water Diversion	Mm^3/yea r	6.7	1.6	0.1	14	3.2	2.4	0.6
Max potential diverted water (authorized)	Mm^3/yea r	6.7	1.6	0.3	50	8.5	14.2	1
Annual % of potential diverted water	%	100%	100%	36%	-	38%	20%	0.1-0.3%
Operation time	days	67	0	0	0	107	94	159
Max potential operational time	days	67	22	365	365	182	149	365
Annual % of potential operational time	%	100%	0%	0%	-	59%	63%	43%
Diversion rate	m^3/h	22	7,200	12	190	1,482	1,112	169
Diversion rate	L/s	6	2,000	3.5	523	412	309	47
Potential diversion rate (technical)	L/s	-	-	-	50 Mm^3	1,000	-	197
RECHARGE								
Annual recharged volume	Mm^3/yea r	0.03	0.4	0.03	1.7	2.6	2.4	0.6
Annual recharging rate	%	0.5%	27%	10%	100%	73%	63%	100%
Total recharged volume	Mm^3	0.03	0	0	0	34	31	3.7
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

Country		P	P	P	P	E	E	E
Benchmarking indicators	Units	Rio Seco	Noras	S. B. de Messi-nes	Cerro do Bardo	Santius-te	El Carraci-llo	Llobre-gat
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	$1.3*10^6$	0	0	27,778	25,803	0
Recharging area	m^2	401	950	0	??	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
Infiltration rate	m/day	1.3	21	0.4	-	1.9	0.04	0.7
COSTS								
Total investment	M€	0.086	0.032	0.015	1.15	3.9	5.2	1.1
Current investment	€/campaign	43,000	-	-		329,007	479,454	184,634
Lifespan	years	35	35	35	35	35	35	35
Lifespan investment	€/year	2,475	914	429	32,971	112,802	150,686	31,652
Relative investment (Tot. rech. vol.)	€/m^3	2.46	0.07	0.50	0.68	0.12	0.17	0.30
Relative investment (Max. pot. rech. vol.)	€/m^3	-	0.02	0.05	0.02	0.04	0.06	0.05
O&M cost	€	4,000	4,000	1,000	15,000	-	-	177,249
O&M cost per volume	€/m^3	0.11	0.04	0.03	0.006	0.050	0.080	0.05
Energy cost	kWh/m^3	0	0	0	0	0	0	0
BENEFITS								
Quality improvement	Nitrates	-50%	??	-	-	??	??	-90%
	Pharmaceutics	-	-	??	-	-	-	-100% to -33%
Total MAR population	Inhabitants	-	-	-	-	2,953	10,958	27,961
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

* Depending on Contaminants of Emerging Concern (CEC).

4 Discussion

The main troubles with benchmarking associated with recharge are related to the huge variety of demo-sites and MARSOL facilities. Apart from local conditions as pollution sources and geological background, there are some conditions that make the MAR 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, the MARSOL group needs to change from square meters to hectares as the surface used for infiltration varies from little 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 technical and environmental pros and cons.
- State of development: Some demo-sites as Cerro do Bardo are almost in the conceptual 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. None of them can be immediately tested by simple quantification of the volume of groundwater storage or water purification through the soil.
- Complexity: The demo-sites that have been selected can be as simple as an infiltration pond system in either 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 sections to get an appropriate 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 such 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 planning framework.

The benchmarking results and trends provide MAR main numbers (Table 15) 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, turbid water…). These figures may change in time depending on management operations such 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 (Max potential diverted water authorized). Infiltration is more often deduced, especially in broad areas. Global figures in extended areas are worth studying in detail to develop the best possible improvements in recharge.
    - 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 on a more solid foundation.
    - 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 sites. Nitrate reduction has been proved in-site (Llobregat) but dilution effect is hard to prove when agriculture inputs are not often monitored (Portugal, Los Arenales). Nevertheless, legal, technical (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 differ. Nevertheless, considering the maximum diverted water as the maximum recharged volume per year, the potential cost per recharged volume would be 0.06-0.02 €/m^3. O&M rates are much more variable 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 according to the current water price in the local market (especially in agrarian uses) but that also may imply many unreliable and undesirable inferences. For instance, in Los Arenales the price for water can oscillate from 0.0017 to 0.0036 €/m^3 depending on the system of application (ITA 2013). However, for Cerro do Bardo and SB Messines the pumping cost can range from 300 €/ha for citrus fruits until 700 €/ha for vegetables, according to the local Irrigation Association.
- Efficiency measures are usually limited to total recharge of water in the form of water table rise over the irrigated area, and increasing availability of groundwater supplies. More diverse and open MAR systems require a broader range of measures related to functional objectives (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 too in MAR systems assessment (San Sebastián et al. 2015) but the way they can be evaluated as a local enhancement is hard to compare with other ecosystems.

5 Conclusions

In summary, the main aims of the Managed Aquifer Recharge are the amount and the quality of the resource recovered after its pass through the system, so these two variables must be the focus of the benchmarking when matching the different cases of MAR considered. However, quantity and quality may also be measured in many ways.

To be able to compare the efficiency and efficacy of the MAR based on 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 size, budget or location.

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

- MAR functions characterization (transport, recharge, treatment, restoration) splitting into 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 demo-sites need to be studied following a more subdivided and multifaceted approach. The benchmarking system proposed and applied to medium-scale sites may best be used to compare only similar tested facilities (infiltration ponds, infiltration canals, purifying canals, artificial wetlands…) with comparable purposes.

On the one hand, and generally speaking, there is a good correlation between the mean infiltration rate and the desilting activities accomplished in Santiuste basin (with a general cleaning in 2005, 2010 and 2015 plus isolated maintenance activities). On the other hand, El Carracillo has never been desilted in its totality and the variations in the infiltration rate are rather attributable to environmental conditions.

Mediterranean water supply irregularity, amplified by climate change, can be mitigated by MAR techniques in very 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). These roles are not generally seen as goals to be solved by means of induced recharge activities and their benefits are not usually assessed when they are compared to other infrastructures. For instance, 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 their location out of riverbeds of infiltration ponds and the maintenance of biological corridors through infiltration canals of MAR are the sort of environmental advantages on behalf of recharge if they are compared to dams or canals. Unfortunately, these low impact MAR techniques are not so positively appraised during Environmental Impact Assessment (EIA) processes of infrastructures for water storage purposes.

The reuse of previous structures (sandpits in El Carracillo, wells in Noras, 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 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 demo-sites are placed near very popular tourist 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. The high price of urban land is also an issue to consider when building an above-ground water storage facility on these areas.

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

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 (as floods and droughts) are expected to happen more frequently (Giorgi and Lionello 2008).

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7 Conflict of Interest

The authors declare that they have no conflict of interest.

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