MARSOL

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

MAR Technical Solutions Review and Data Base

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1. Executive summary

This report is part of the MARSOL (www.marsol.eu) FP7 founded EU project (Grant Agreement Number 619120).

The main purpose of this deliverable is to provide several sets of “technical solutions” based on the current state-of-the-art, and as a repository for storing all types of activities applied or up to be deployed in the different demo site scenarios. The different techniques applied have been aggregated into a data base, offering different problem-solution binomials. Some of the technical solutions will be tested in the next future in the MARSOL platform.

After the summary and the introductory paragraphs, Section 3 provides the state-of-the-art, i.e. a hydrogeological literature overview on past technical solutions applied to improve the efficiency of Managed Aquifer Recharge (MAR) activities in different worldwide contexts conducted in the last years.

Section 4 details the activities and results carried out in the diverse demo sites and the structure of the MARSOL database, defined in terms of problem-solutions models, along with a list of different techniques. So that, the interaction between the users, the smart solution, the demo-sites infrastructure and the repository of experiences is guaranteed. The database structure has a simplified design and has been deliberately kept open and flexible to integrate additional future inputs, either coming from the interaction with the several agents involved in the water management activity or from specifically constructed pilot-devices.

The technical solutions have been classified, according to their scopes, in **three different groups**, related to:

- ✓ Design and construction
- ✓ Operation
- ✓ Management.

Section 5 develops, in parallel, a final corollary of Soil and Aquifer Treatment (SAT) techniques, as the main contribution from this WP´s results, distinguishing **four sorts of operations**:

- ✓ Applied to water from its original source (in both quantity and quality)
- ✓ To the receiving medium (in both soil and aquifer)
- ✓ Management parameters plus cleaning and maintenance operations.
- ✓ To the combination of all of them

Section 6 pays attention to dissemination, technology transfer, stakeholder awareness and publications activities plus other dissemination efforts.

Section 7 and 8 include conclusive remarks and references.

An appendix has been included with the screenplay of the specific movie on technical solutions presented with this deliverable as an alternative way to expose info accessible to a broader band of target groups.

2. Introduction

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 consequently, on general water management.

They will rely on a shared understanding and test performed in the different demo sites, with the objective of achieving maximum infiltration rates at the minimum cost and without compromising environmental aspects.

MARSOL has built a bi-directional communication channel between partners and end-users. Behavioural data are collected by means of sensors in most of the demo-sites, in order to study how to increase the efficiency of the different devices and facilities. End-users provide hints about problems to be solved by technical solutions, being the social participation a very important source of inspiration to accomplish improved activities.

Within the MARSOL project, Work Package 13 tries to summarize and evaluate technical solutions for different MAR scenarios. Specific technical solutions to meet seasonal, long-term or emergency demands are being elaborated in order to achieve a sustainable water supply through aquifer storage. The general work progress of WP13 requires a detailed knowledge and characterization of the state-of-the-art and from the different demo-sites where activities are being performed, as well as actions accomplished in parallel scenarios.

The specific objectives of this work package are:

- ✓ To mobilize industry and promote innovative solutions for water-related challenges by means of tackling issues of real innovation, practical importance, relevance and viability regarding MAR.
- ✓ To demonstrate that MAR represents in some cases the only strategic solution to face water scarcity and extreme water related events, especially droughts *("the key is the storage"*).
- ✓ To present the current state-of-the-art for technical solutions at existing MAR sites.
- ✓ To deploy new technologies at the MARSOL DEMO sites.
- ✓ To propose effective strategies to integrate MAR techniques and associated designs into water system expansion plans to meet water supply needs.
- ✓ To prepare guidelines for the selection of appropriate MAR technical solutions under various boundary and environmental conditions.

In order to fulfil the WP13's objectives, it is essential to:

- ✓ Summarize and analyze the technical solution currently active in MAR sites, to define the background techniques and their impact on water availability.
- ✓ Analyze the technical solutions at the MARSOL DEMO sites and evaluate their performance in terms of advantages and shortcomings towards benchmarking.
- ✓ Develop new designs and propose construction criteria, testing protocols for different exemplary MAR schemes by means of benchmarking.
- ✓ Develop technical guidelines for the implementation of MAR under various boundary conditions.
- ✓ Set up benchmarks regarding the advance of each demonstration activity in the different pilot sites, as well as the technical solutions reached capable to increase the expertise from a practical perspective.

Starting from a literature review on the “solutions” applied in the last decades; this deliverable fulfils the first objective, whilst the others will be resolved in the 13.2 to 13.4 reports.

Mainly two out of eight demo-sites (Menashe in Israel and Arenales in Spain), have provided relevant insights to face the key steps mentioned above. Furthermore, taking inspiration from the state-of-the-art solutions and the expertise of the partners, we have identified a preliminary set of designs relevant to achieve the most appropriate structure to be used in the MARSOL project.

2.1. Project background

The objective of WP 13 and the structure of this deliverable has been three folded:

- There is an explanation of the challenges to be solved in the most active demo sites, so as to develop the different tasks and objectives.
- The improvements in each pilot site are described, not only dealing with constructive details, but also in relation to the communication with stakeholders.
- The actions to achieve the public participation and deeper education of the farmer groups are defined. These activities, directed to bring MAR technique to the market (in special agro-industry) and to solve stakeholder’s problems by means of technical solutions, have been taken on from initial stages of the project.

This deliverable's description, according to the Description of Work (hereinafter DoW), states:

D13.1 MAR technical solutions: Report on problem-technical solution binomials and the best applied criteria obtained from the experience at the DEMO sites; data base on technical solutions tailored for MAR sites.

And the associated milestone points out: *MS8, MAR technical solutions review and technical solutions data base completed.*

This deliverable relates, in special, to tasks 13.1 and 13.2, both lead by Tragsa Group (as is the whole WP 13). Table 2.1 exposes a timetable with the planned dedication for this WP leading partner.

Table 2.1. Proposed timetable for WP 13 and other related WPs where Tragsa Group participates

CRONOGRAM

OBJECTIVES WP	YEAR / QUARTER / MONTH	TASK	PERSONS /MONTH
WP 1 Project Management	Task 1.2: Operational Project Management	1.2	2
	Task 1.3 Quality Assurance	1.3	
WP 2 Dissemination, Exploitation & Training	Task 2.4: List of relevant regional funding opportunities and related water projects	2.4	1
	Task 2.7: Training activities	2.7	
	Task 2.8: Advanced Study Course (ASC)	2.8	
WP 5 DEMO Site 3: Los Arenales Aquifer, Castile and Leon, Spain	Task 5.1: Site operation	5.1	24
	Task 5.2: Conductions and piping	5.2	
	Task 5.3: Studies for trapped air (gas clogging)	5.3	
	Task 5.4: SAT-MAR studies	5.4	
	Task 5.5: Artificial wetlands	5.5	
	Task 5.6: Modelling	5.6	
WP 13 Technological solutions and benchmarking	Task 13.1: MAR technical solutions	13.1	10
	Task 13.2: MAR techniques at the MARSOL DEMO sites	13.2	
	Task 13.3: Technical parameters and benchmarking	13.3	
	Task 13.4: MAR implementation guidelines	13.4	
	Task 13.5: Benchmarking (supporting partners LCTP, LNEC, UPC, SGI, SSSA, MEK, MRA)	13.5	
	Task 13.6: Benchmarks adoption	13.6	
	Task 13.7: Benchmarks evolution and pooling (supporting partners LCTP, LNEC, UPC, SGI, SSSA, MEK, MRA)	13.7	

3. State of the art. Overview of “technical solutions” on MAR

It is important to state, since the beginning, that “technical solutions” are not related to Managed Aquifer Recharge (MAR) technique as if it was the problem to solve, but rather the group of activities to increase MAR effectiveness, being MAR the solution to many related water management dysfunctions.

One of the main problems that have arisen in most of the MAR facilities is how to get an effective and rapid infiltration rate in high water availability for inducted recharge conditions. The difficulty presents a technical character: *How to increase the water infiltration speed into the aquifer?*.A possible solution to this issue is the adoption of Soil and Aquifer Treatments (SATs)[1] and other complementary techniques, such as design and management improvements applicable to existing devices

In this context, this overview relates the availability of techniques to be adopted from specific MAR sites around the world, specifically designed to provide technological improvements willing to:

- Increase the rate of infiltration in MAR operating areas,
- Improve the effectiveness of the already existing facilities,
- Make accessible design criteria to be applied in future MAR devices.

In this chapter multiple international references have been reviewed and consulted, collecting a vast amount of already existing *“tech sols“* in the hydrogeological and engineering literature. The diverse groups of actions might be grouped in three different classes, either if they are specific design criteria to be applied in the constructions works, if they are related to the operation of the facilities, in general adapting their organization to the environmental conditions, or if the are related to management, including regulations, norms and Decisions Support Systems as a whole. In short:

- Design and construction
- Operation
- Management

The next paragraph will study their existence in the eight different MARSOL demo-sites, the new TECH-sols emerging from the project and their applicability in analogous sceneries, taking into account spatial variability premises.

1- It must be remarked that in this report it is used the classic Dutch connotation for SATs (Krul & Liefrinck, 1946), as techniques to be applied to increase infiltration rate by means of operations on soils, aquifers and “artificial recharge” water; despite in the last years there is a tendency to apply this term to managed aquifer recharge operations with reclaimed water from waste water treatment plants.

3.1. Some technical solutions for the design and construction of MAR facilities

MAR is a water management technique, considered “special“ or “alternative“ in many countries, but especially suitable for specific areas where other conventional systems cannot be applied. There are many advantages in its use, and one of the most important is its willingness to interfere in the water cycle without any electricity consumption, what is called a “passive“ system.

In order to avoid energy consumption, there is a criterion considered as a *common denominator* for most of the facilities, which is the use of the gravity as propeller for MAR water, in special for infiltration ponds, channels and wells. In flat landscape areas, it is required to perform accurate micro-topography studies so as to get MAR water flowing without any pumping.

The microtopography is also a determinant asset in the quality of the water. Some research done in Minnesota *(Delin & Landon, 2002)* to determine the relation between the topography and chemical compounds of agriculture origin, has revealed that some agro-chemical mixtures move quickly with water so they get concentrated into low basin areas and are the most affected by localized recharge. This experience was conducted in a sandy aquifer, similar to some of the demo sites.

Regarding the aquifer knowledge and potential behaviour, geophysical techniques and, in special, geoelectric prospections have been widely used.

For MAR applications a good knowledge of the subsoil infiltration potential is a key issue. In this way, geophysical techniques play an important role, especially the resistivity method, since this process is based on the propagation of electrical current, governed mainly by the presence of clay, water and/or brine (water and mineral salts) in the subsoil.

In the FP6 GABARDINE project, a tracer test (with salt) was performed using, besides the classical hydrogeological tools, the resistivity method in a time-lapse mode, in order to assess among others the preferable groundwater pathway. The results obtained with the profile installed along the major axis of the infiltration basins are presented in the figure 3-1.

Surface runoff carries an advective movement of chloride; nitrate-nitrogen and sulphate willing to move towards depressions rather than to higher areas, with an annual average of even 5 times more in basins with respect to areas topographically elevated 1.4 m.

Other factors that influence the flow rate are the type of soil, the presence of organic carbon and hydrogeological thresholds. All of them have a direct influence on the vertical flow rate of water (FAO, 2000).

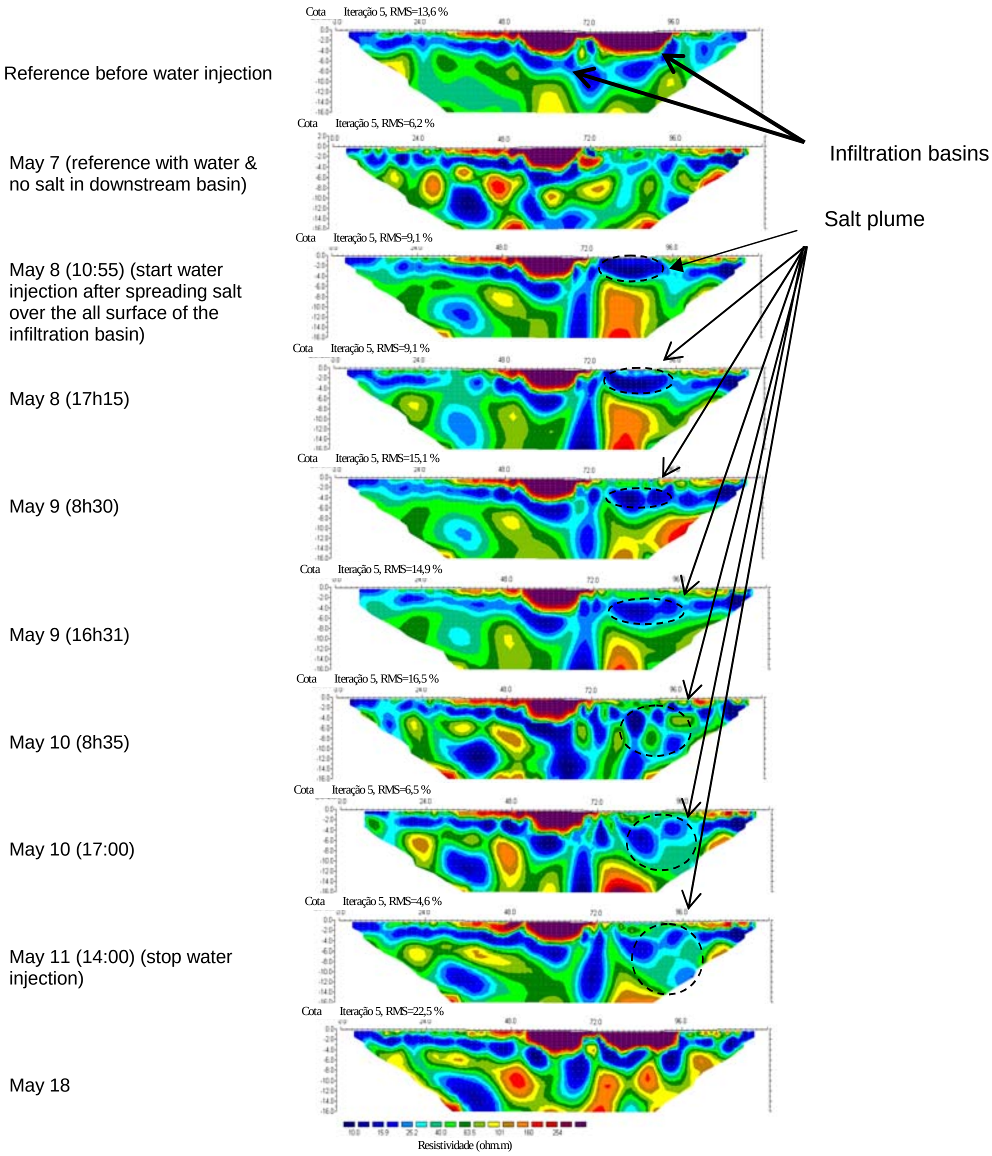


Figure 3-1. Salt tracer test with resistivity in time-lapse mode, performed at Rio Seco Algarve, Portugal (adapted from Mota, 2007, Diamantino *et al.*, 2007 and Diamantino *et al.*, 2008.

Some elements directly related to the topography to be considered during the design and construction of MAR facilities are (modified from Fernández, 2009):

- Possibility of pipe-laying connecting a river or the main source of water and the target aquifer without any pumping (passive system).
- Control of the aquifer base level by means of a dam to raise the groundwater table in the upper groundwater flow wells.
- Possibility of inserting filters in the circuit for water pre-treatment and/or to control pH by means of mudstone gravel filters. The slope must be enough to avoid pumping, despite the head loss occurring inside the pipeline or canal.
- MAR water pre-treatment by means of piping filters (at the heading and in intermediate positions).

Figure 3-2 a) and b). Detailed studies of micro-topography in MAR channels in order to achieve a passive system in Adelaide (Australia) and Phoenix (USA).

Other very important feature to be taken into account, apart from micro-topography, is the possibility of electricity supply for the MAR system. The design criteria will be absolutely different for a passive system or for a connected one (DINA-MAR, 2011).

Figures 3-3 a) to c). Actions carried out on the morphology of infiltration ponds and channels. Studies of topography (a) and micro-topography to bring MAR water to infiltration wells by gravity, Castellón, Spain (b) and use of pumps to move water into an infiltration pond (active system) in the North of Thailand (c).

DESIGN CRITERIA FOR MAR INFILTRATION PONDS

There are specific design criteria available in the hydrogeological literature about the design of infiltration ponds, slopes depending on the sort of materials, depth… (DINA-MAR, 2011, Peyton, 2001 and Martin & Dillon, 2002).

One of the most important technical solutions to be studied carefully is the morphology of the bottom, either flat or ploughed with furrows, and, in the second option, what the furrows pattern should be In order to improve the infiltration rate in a sandy aquifer, the contact surface between the water and the receiving medium was increased by means of the ploughing of furrows.

Furrows increase the infiltration rate when compared with flat-bottom basins, with higher values in the ridge of the mounds than at the bottom of them. Silts are deposited in the bottom of the furrows due to gravity while the ridges remaining higher up and relatively cleaned (Fernández & Martínez, 2012). Although it is not possible to set a defined trend, furrows with 80 cm spacing perform better, in general terms (for the conditions the authors conducted their test). In order to quantify the differences between a flat and a ploughed bottom, infiltration tests must be carried out. Results confirmed that, according to the test place and conditions, it is a good practice to open furrows with disc ploughs, which proves to be less harmful for the soil than a mouldboard plough (Fernández & Senent, 2012).

Figures 3-4 a) & b). Furrows plugged with different width at the bottom of a decantation and infiltration pond. Headwater of the Santiuste´ MAR device in Spain (a) and Phoenix infiltration pond (b).

DESIGN CRITERIA FOR MAR CHANNELS

The main lines of action to increase the infiltration rate and the total infiltrated volume in the channels bottom and walls are focused on the channel morphology itself (DINA-MAR, 2011). They also focus on flow regulation and filtering of silt in the AR water (Fernández *et al.*, 2009), as well as the construction of a single furrow along the channel or the employ of a geofabric, in order to make the cleaning and maintenance planning and operations easier (Fernández & Senent, 2012).

Figure 3-5. Geofabric installation in the bottom of the AR channel at Santiuste basin, Arenales demo site, in 2008.

The surface conditioning of the receiving environment through "*furrows*" or grooves on the bottom of the surface recharge structures are usually covered with a waterproof membrane or specific geofabric. The result is that walls are still sparsely silted, while most of the viscous processes are addressed and deposited on the bottom (Groove) by gravity, currents, the effect of waves and rain (Peyton, 2001).

In the case of infiltration wells, most of the designs must be tailor made, according to the aquifer characteristics, to the volume to inject and the origin of the water (DINA-MAR, 2011).

Figures 3-6 a to c). Specific designs for a huge infiltration pond in Shafdam, Israel (a); a MAR high diameter well (Maribor, Slovenia) and a dual system injection borehole (Madrid, Spain).

3.2. Operative technical solutions

Some authors have concentrated their efforts in the study of actions to improve MAR water previous contamination and general treatment, either focussed into the attenuation of any specific compound, such as, e.g. dissolved organic matter (Leenheer, 2002; De los Cobos, 2002) or pre-treatment as the most effective measure to improve MAR systems effectiveness (Bouwer, 2002).

MAR WATER PRETREATMENT

Recharge water pre-treatment is usually complicated and expensive. They are desirable standards to be achieved, such as the elimination of nutrients and organic matter from the water, to get the longer service life of the MAR well (Bouwer, 2002; MIMAM, 2002).

The Total of Dissolved Solids (TDS) determines largely the chemical and biological clogging. The standards found in the bibliography are fixed at 150 ppm for superficial devices (Pyne, 1995: CSIRO, 2002) and 100 ppm in deep injection devices (ASR) (Dillon & Pavelic, 1996); and for suspended matter, the quality requirement is below 2 or 3 mg/l (Bouwer, 2002).

The quality standard for Total Organic Carbon (TOC) varies within wide limits in the consulted regulations. For example, the desirable limit is set to 10 mg/l In California (Mills, 2002); other studies set the threshold between 8 and 18 ppm (Rinck-Pfeiffer *et al.*, 2002). In deep injection devices interval ranges between 3 and 12 ppm for South Australia (Dillon & Pavelic, 1996), etc.

The main parameters to be taken into account and its qualitative limit have been the target of numerous research works. To mention a few of them, the Total of Solids in Suspension (TSS) and Turbidity has been established in 10 ppm from certain MAR experiences in California (Aiken, 2002; Cozzarelli, 2002). Other experiences in Colorado have demanded a greater severity, reducing the standard for fluvial origin recharge water from 8 down to 2.8 mg/l (Mills, 2002). Experiences in Texas have determined the limit in 20 mg/l, with a qualitative optimal limit inferior to 10 mg/l (Fryar, 2001). For deep injection devices a 2 mg/l concentration may be sufficient to significantly reduce the infiltration rate in wells and boreholes (Pyne, 1995).

The addition of disinfectants in MAR water, known as DBPs technique (Disinfection By Products) is used on all around the world experiences, although there have been various cases positive and negative as a result of – among others - chlorination (Pyne, 1995 and 2002; Bouwer, 2002; Tsuchihashi *et al.*, 2002); microfiltration (Pyne, 2002); iodination (Fox, 2002); ozonification and UV radiation (Cushing et al., 2003); the pH control additives (Pyne, 1995; Stuyfzand & Mosch, 2002); the combination of different techniques at the same time (Dillon & Pavelic, 1996); control of the temperature of the water (Pérez-Paricio *et al.*, 2001; Olsthoorn & Mosch, 2002); shortage of dissolved gases (Bouwer, 2002).

SATS TECHNIQUES APPLIED DURING THE OPERATION OF A MAR SYSTEM

There is a group of techniques, integrated under the generic name SAT (Soil and Aquifer Treatment), constitute a set of essential methods for the correct design and operation of any MAR integrated system. His application requires a deep knowledge of the natural processes which allow either removing or minimizing certain contaminants out of the recharge structures, especially organic and nitrogen compounds *(Fox, 2002)*.

Its development requires specific engineering designs and the use of multifactor control systems in each annual or multi-year cycle (Kopchynski *et al.,* 1996). Some SAT techniques found in the literature, that have been applied and tested in different parts of the world, include the implementation of dual systems in space, allowing the use of a part of the device while the other is subjected to processes of cleaning and restoration (Fox, 2002); the control of the distance between the injection and extraction wells (Moorman *et al.*, 2002); the chemical attack on calcite using acids so as to control the pH of the aquifer too (Rinck-Pfeiffer, 2002); the control of the concentration of Dissolved Organic Carbon (DOC) and trihalomethanes (Rostad, 2002; Salameh *et al.*, 2002).

SAT techniques also include the best selection of the period to perform MAR in intermittent devices and the most appropriate flow rate to be recharged at each moment. In both cases it is very important to control the inflow of air into the aquifer, which usually is aligned with the Blaxejewski's "average" curve for temporal and passive devices (Blaxejewski, 1979). According to this author's studies, his graph shows that the infiltration rate increases continuously since the MAR cycle starts, reaching its peak point around a month later, when the receiving medium is close to the air saturation and the air trapped in the aquifer pores and the low temperature trigger its infiltration rate decrease for approximately fifteen days.

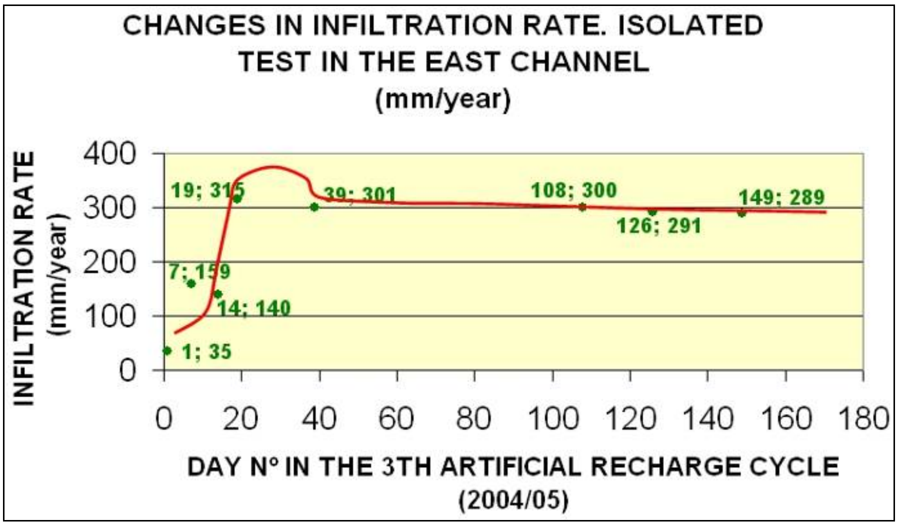


Figure 3-7. Infiltration rate evolution due to air trapped into the aquifer along the MAR cycle (from November to May) in Arenales aquifer, aligned with Blaxejewski's "average" curve (taken from Fernández *et al.*, 2009).

Then, it shows a slightly decreasing tendency during the winter (freezing periods cause a delay in the infiltration rate). At some point slightly after half of the period, the aquifer has already trapped significant amounts of air (up to 35% according to references (e.g., Stuyfzand, 2002) which may also be accompanied by Lisse effect (Krul & Liefrinck, 1946), with a direct negative effect on the recharge effectiveness (DINA-MAR, 2011). When spring comes closer, bringing deaeration, the curve shows a more or less constant morphology. The final result is a decrease in the infiltration rate, with an accumulative effect in successive cycles (Fernández *et al.,* 2009).

Operating aspects derived from this study are aimed at practising manual control of the inlet valve according to the circulating flow, which should be shut off during frost cycles (Fernández & Senent, 2012). This control is carried out manually by stakeholders, receiving an expert advice (DINA-MAR, 2011).

There are also SAT techniques to choose the best volume to be recharged in each date. Some works for surface MAR devices are performed in Fernández *el at.* (2009) and DINA-MAR (2011)

Figures 3-8 a) & b). Diversion from a river catchment directed at an infiltration pond (Chihuahua, Mexico) and control of the water thickness in an infiltration pond (Phoenix, USA).

Other SAT techniques willing to be applied in potential MAR facilities are:

- Avoid gas clogging produced by “cascading” effect, water shaking… (Stwifzand, 2002).
- Installation of over-spilling control valves and spillways in surface canals and infiltration ponds (Fernández, 2005).
- Pay attention to the “depth of alert”, recommended between 1.5 and 5.0 m depending on the aquifer´s characteristics (Fernández, 2005; Pyne, 1995).
- Avoid water thickness in infiltration ponds over 140 cm (DINA-MAR, 2011) to 4.0 m (Martin &Dillon, 2003).
- Manual management depending on rainfall and freezing conditions (DINA-MAR, 2011).
- Maximum infiltration rates (%) with flow rates about 200 L/s in canals (Fernández *el at*., 2009).
- Ploughing infiltration ponds bottom with furrows (80 cm) (Fernández & Martínez, 2012).

A broader compilation of SAT techniques may be found in Fernández (2005) who collects a vast amount of references.

CLEANING AND MAINTENANCE CRITERIA

Within the "healing" techniques it is worth mentioning the use of specific devices to reduce the clogging processes. Such vehicles, known as "Basin Cleaning Vehicles" (BCV), must be designed in function of the characteristics of the area to be cleaned. Its operation is continuous and its purpose is to remove materials that cause or contribute to form viscous processes. (Mills, 2002; Woodside & Hutchinson, 2001).

A BCV must be equipped with a guidance system that allows it to be used without operator, a jet set and a suction device for the extraction of the turbid water and the sediments from the most superficial layer. It also requires a system to remove the hardened filter cake (Mills, 2002).

Figure 3-9. Example for a Basin Cleaning Vehicles (BCV) in Holland.

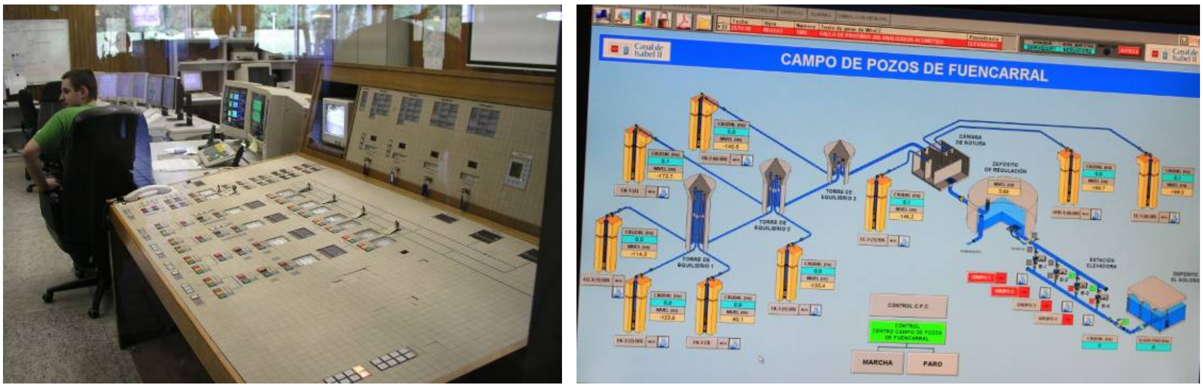
3.3. Technical solutions related to management

In addition to the availability of water for managed aquifer recharge, there is a management parameter, known as "safe yield". It's a technique, even a philosophic principle (Lluria, 2011), consisting of extracting from the aquifer an amount of water matching the full recharge simultaneous volume (Pérez-Paricio, 2001; Fox, 2002). This technique is obligatory in certain places, as it is the case of Phoenix (USA), ensuring a certain environmental protection of the aquifer.

Other technical solutions related to management, according to different authors, are:

- Aquifer as a huge water store and a pipeline (Pérez-Paricio, 2001).
- Surface deposits of sandy materials, in zones with very thin surface sand layer (Stephen, 2004).
- Buried fishbone pipelines in zones with very thin sand layer and according to the aquifer properties (Macías *et al.*, 2014; Lobo *et al.*, 2014).

- Wells used as water stores in low permeability areas (Gale, 2005; Fernández, 2006).
- Wells drilled in aquifer drainage areas (MIMAM, 2002; Fernández, 2005).
- Detailed register of end-users of the aquifer (MIMAM, 2002).
- Minimize perching flow rates from the upper to the depth aquifer in multilayer systems (Fernández, 2005).
- Users management´ organization, in order to improve the effectiveness (Fernández, 2009; Lobo *et al.,* 2014)



Figures 3-10 a) & b). Management techniques in MAR systems, control panel in the Berlinesse water supply company (Spandau, Germany) and remote real time monitoring of the MAR process in Madrid (Spain).

3.4. Corollary of "Technical Solutions"

The corollary is a list of options to solve problems affecting to MAR facilities by means of SAT techniques, new designs, and changes in the management practices and other procedures considered as "others" (Fernández, 2005).

As rules of general application for all methods and MAR, it is worth to mention:

- Appropriate pre-treatment of recharge water and/or employ of excellent water quality for this purpose (Pérez-Paricio, 2001).
- Minimize the aeration of the water and the Lisse effect (Stuyfzand & Mosch, 2002; Fernández, 2005).
- Recharge speeds waters, avoiding mixing of them, the cascading, etc. (Fernández *et al.*, 2009).
- Minimize corrosion of structures, and hyper-oxygenation of the water, controlling the oxidizing conditions, recharging with water at temperatures above the average aquifer temperature, etc. (Stuyfzand, 2002).
- Control of certain chemical parameters, avoiding exceeding the water quality standards applicable under the legislation of each country where the operations performed. In some parameters there is quorum at the global level, e.g. recharge water should have less than 10 ppm of turbidity or solids in suspension (TSS) (Pyne, 1995; Aiken, 2002; Cozzarelli, 2002).
- Appropriate design of structures with warning and alarm devices in case the depth of alert is exceeded (Christen et al, 2001).

The different options put together in the hydrogeological literature to solve problems affecting MAR facilities by means of the exposed techniques are found in the next "corollary", proposed by Fernández (2005) (figure 3-11).

Some activities are questionable in different situations according to different authors (Pérez-Paricio *et al.*, 2001; De Vries & Simmers, 2002), such as:

- Reduction of bacterial colonies, nutrients and minimization of OCD in the recharge water using disinfectants. Possibility of chlorination as a pre-treatment technique.
- Reduction of algae colonies using chemicals.
- Cleaning of the infiltration surface in the summer period accompanied by an acidification treatment.
- Addition of chemicals to control the pH of the medium (calcium), recharge waters treatment (chlorine, iodine), chemical treatment of the surface of the receiving medium subject to physical clogging processes (polyphosphates, deflocculants), elimination of calcareous crusts (by means of acids) and other chemical clogging processes (by means of chlorine, hydrogen peroxide for the inactivation of bacteria), etc.

In this context, the alternatives of improvement to increase the effectiveness of MAR facilities are high and constitute a wide range of possibilities which application must have a solid and reliable technical foundation. These rules are eminently practical guidelines that should be taken into account before building MAR facilities. The construction of recharge structures must count on adequate studies of the physical environment.

In spite of many experiences collected in the corollary come from isolated examples, spatial variability must not represent substantial changes to the scale of work considered (De Vries & Simmers, 2002).

The objective also extends to later stages, when it may be necessary to carry out cleaning and maintenance activities, and/or monitor the evolution of the aquifer and the effectiveness of the actions. In this sense, it is important to design and/or adopt environmental indicators of response, specific programs of surveillance and control and specific benchmarks for MAR activities.

Recharge water (quantity)

- Temporary store in surface reservoirs
- Control of the flow velocity of recharged Waters
- Avoid operations in freezing weather /season /cycles
- Use of thermostatic cameras/Chambers
- Selective criteria at origin
- **Cleaning and maintenance**

Recharge water (quality)

- **Preselecting:** selective criteria for the origin of recharge waters: Filtering and decantation waters **AR**, etc (membranes, mud lines, filters, packets?
- **Overflow/run-off** tramps and decantation structures and stagnation structures
- Anticorrosion **devices**
- **Design** and preservation of **slope** (rubble works, gabions...)
- **Design of channel bottoms** (furrows), use of geofrabrics
- **Limitation of the water layer height: Pretreating** type ***DBP*** *(Desinfection by Products)*:Cl, I, O3, H2O2, UV rays, etc.
- Cleaning **vegetation** during AR / Specific plantation during summer season
- **Avoid aireation** on AR waters: communicating vessels, open structures, velocity / reduce the speed of waters in channels
- **Deaireation** using piezometers, increase distance between injection-extraction points
- **Dual systems**: Algae drying, natural bed drying, cryotreating, cracking (cake), scarification od silting zones and cleaning /replacement
- **Isolation** from atmosphere/sunlight
- **Specific fishes (e.g. medaka)**.
- **Filtering beds and chemical additives**, to eliminate clogging layers
- Avoid recycling effect
- **Denitrification** (e.g. anammox): irrigation / watering tuning the deep of pump placement
- **Avoid natural salinization**: Induced recharge. Barriers in salty areas

Receiving medium (soil and aquifer)

- **Pretreating of water for MAR**
- **Natural drying** of bed, and cracking
- **Cryotreating**
- Use of **dual systems** allowing cleaning of one of them whilst the other is operating
- **Inverse pumping** in wells pits close to canal
- **Alternate normal and inverse pumping**
- **Backwashing** in geo fabrics, membranes and filters
- **Use of jet type** cleaning techniques
- Mechanical (wall brushing and scratching) and chemical (use of chemical additives) techniques for the **regeneration** for recharge **wells**
- **Cleaning** techniques with the highest possible frequency
- **Injection well daily pumping**
- **Use of Basic Cleaning Vehicles (BCVs)**

Management/good Practices/Use criteria and codes

Management parameters and ex situ techniques

- Choosing the most adequate **period** and place
- Initiate '**soft' MAR cycles**
- Input **flow** and **speed control**
- **Monitoring chemical properties** of MAR water during recharge cycles
- Use of **protection devices** for fauna and people
- Early adoption of the **best available techniques**
- Design and adoption of a proper Watching and **Control Program**
- Specific protocol for **clogging control**
- Protocol for proper **hydro-mechanical** aspects in space and time
- **Integral systems**: all elements are interconnected
- Limit fertilizers
- Promote participation of farmers in water management
- Installation of adapted waste water treatment plants and decrease untreated spilling
- Protected perimeter
- Public use regulation

Figure 3-11. Corollary. Lists of options to solve problems affecting to MAR facilities by means of SAT techniques, new designs and changes in the management practices. The operations can affect either recharge water´ quality and quantity or the receiving medium (soil and aquifer). Management parameters plus cleaning and maintenance operations are also considered. Taken from Fernández, 2005.

4. Technical Solution on MAR applied in the different demo-sites

After an introductory and necessary chapter to know better the background regarding “technical solutions”, in the next chapters the different improvements applied in the different MARSOL demo sites are going to be studied, so as to achieve MARSOL targets. The procedure adopted has the following phases:

- Proposal for a new inventory of types of MAR facilities around the world and specifically present in the demo sites.
- Study some binomial of the problems and dysfunctions affecting some specific facilities studied in MARSOL demo sites, by means of an example.
- Inventory all the technical solutions applied in all the MARSOL demo sites.
- Finally, expose some possible solutions designed and willing to be applied in parallel scenarios, with some applicability criteria (in the next chapter)

4.1. MARSOL inventory for MAR facilities

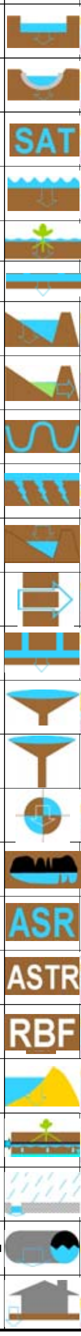
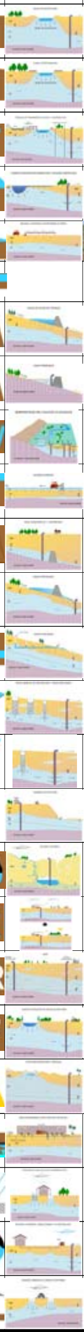
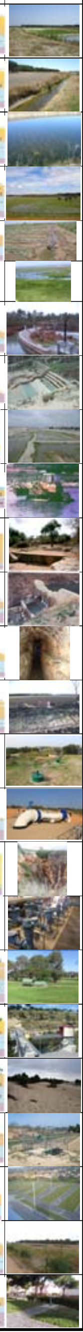
The different typologies of MAR devices have been collected and put together in a new inventory.

The starting point was an inventory of devices available for Managed Aquifer Recharge at a global scale to create a catalogue of practical experiences. These were grouped according to the Gale (2005) classification. To these original 15 classifications, eight more were defined (DINA-MAR, 2011) introducing some slight changes. Those new devices were generally based on variations of irrigation systems in order to increase water return to aquifers from the different irrigation systems, and the implementation of MAR techniques in urban zones.

The proposed inventory includes two new typologies and counts on examples and photos, most of them taken from the demo sites (figure 4-1).

The description of the specific facilities considered of bigger importance due to the technical solutions applied will be exposed in the chapter 4.

Regardless the fact that this chapter might result a bit generic, it compiles much summarized results from all around the world, hence some pieces of information may require to be extended with the references.

Nº	SYSTEM	MAR DEVICE	LOGO	FIGURE	PHOTO	LEGEND	1: Lavrion, Greece	2: Algarve and Alentejo, Portugal	3: Los Arenales, Spain	4: Llobregat River, Spain	5: River Brenta, Italy	6: Serchio River, Italy	7: Menashe, Israel	8: South Malta, Malta
1	DISPERSSION	INFILTRATION PONDS/ WETLANDS				Artificial wetland to recharge in Sanchón, Coca, Arenales aquifer		✓	✓	✓				
2		CHANNELS AND INFILTRATION DITCHES				Artificial recharge channel of the Basin of Santiuste, Segovia, Spain, operative since 2002.			✓					
3		RIDGES/ SOIL AND AQUIFER TREATMENT TECHNIQUES	SAT			Furrows at the bottom of a infiltration pond in Santiuste basin (Arenales)	✓	✓	✓	✓	✓			
4		INFILTRATION FIELDS (FLOOD AND CONTROLLED SPREADING)				Infiltration field in Carracillo, Arenales aquifer	✓		✓		✓			
5		ACCIDENTAL RECHARGE BY IRRIGATION RETURN				Artificial recharge by irrigation return. Extremadura, Spain. Photo: Tragsa		✓			✓			
6		BOFEDALES WETLANDS				Bofedales (Colombia)								
7	CHANNELS	RESERVOIR DAMS AND DAMS				Artificial recharge dam in Arenales. Segovia, Spain.			✓					
8		PERMEABLE DAMS				Permeable dam in Huesca, Spain. Photo: Tragsatec.								
9		LEVEES				Levees in Santa Ana river, Orange County, California, USA. Photo: A. Hutchinson.								
10		RIVERBED SCARIFICATION				Scarification at Besós riverbed, Barcelona, Spain. Photo: J. Armenter.								
11		SUB-SURFACE/ UNDERGROUND DAMS				Sub-surface dam in Kitui, Kenya. Photo: Sander de Haas.								
12		DRILLED DAMS				Drilled dam. Lanjarón, Granada, Spain. Photo: Tragsatec.								
13	WELLS	QANATS (UNDERGROUND GALLERYS)				Qanat at Carbonero el Mayor, Segovia, Spain. Photo: E.F. Escalante			✓					
14		OPEN INFILTRATION WELLS				Passive infiltration well. Santiuste basin		✓	✓					
15		DEEP WELLS AND BOREHOLES				Artificial recharge well. Menashe. Israel. Photo: EFEscalante								✓
16		BOREHOLES				Borehole in Israel. Photo: EFEscalante								
17		SINKHOLES, COLLAPSES...				Sinkhole called"El Hundimiento". Alicante, Spain. Photo: DINA-MAR								
18		ASR	ASR			ASR device in Scottsdale, Arizona, USA. Photo: DINA-MAR					✓		✓	
19		ASTR	ASTR			ASTR device in California, USA.				✓				
20	FILTRATION	RIVER BANK FILTRATION (RBF)	RBF			MAR RBFsystem in Villeguillo, Arenales, Spain		✓				✓		
21		INTERDUNE FILTRATION				Interdune filtration in Carracillo Eastern site. Arenales, Spain			✓					
22		UNDERGROUND IRRIGATION				Underground irrigation in Andalucía, Spain. Photo: Tragsa.								
23	RAIN	RAINWATER HARVESTING IN UNPRODUCTIVE				Rainwater harvesting in unproductives for MAR techniques.			✓					
24	SUDS	ACCIDENTAL RECHARGE PIPES AND SEWER SYSTEM				Artificial recharge from sewer system in Arenales, Spain			✓					
25		SUSTAINABLE URBAN DRAINAGE SYSTEMS				SDUS. Gomeznarro park. Madrid, Spain. Photo: E.F. Escalante.								

Figure 4-1. MARSOL inventory for the different existing MAR devices. Summary and MAR schemes inventory grouped by typologies (Modified from Fernández and San Sebastián, 2012 inspired on Gale, 2005). Clicks indicate the different typologies available in each demo-site.

4.2. Problem-solution binomials

The problems and dysfunctions affecting some specific facilities studied in MARSOL demo sites, according to the main impacts affecting each aquifer area, are shown in the table 4-1. The identification of problem-technical solution binomials have been based on:

- Engineering criteria
- Risk assessment
- Environmental impact

Table 4-1. Main impacts on the aquifer area detected in each demo site, and grouped according to some stablished categories.

PROBLEMS	Main impacts on the aquifer area	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
Scarcity (Overexploitation)	Quantitative issues because of overconsumption	X	X	X		X	X		X
Scarcity (Climate Change)	Drought, rising temperatures trend, lower precipitation cycles...	X				X	X	X	
Salinity (Seawater intrusion)	Associated to coastal aquifers	X							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	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		X			
Floods	Flooding events caused by CC, extreme rain...								
Others	*To be specified along the rest of the project*								

Some of the proposed solutions could be grouped into the following categories:

- Scarcity (Overexploitation)
- Scarcity (Climate Change)
- Salinity (Seawater intrusion)
- Heavy metals (Mining, Industry)
- Agriculture contamination (mainly N)

- Organic pollution (agrochemicals and antibiotics)
- Wastewater discharge
- Wetland desiccation
- Floods
- Others

Other classifications for each demo-site of high relevance for the improvement of the existing facilities are based on their Water origin, considering up to 12 different sources (table 4-2).

Table 4-2. Water source for each demo-site MAR facilities.

WATER SOURCE		1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
River	No horizontal building diversion		X	X	X	X	X		
Weir/Dam			X	X					
Lake / wetland									
Canal									
Ditch									
Spring									
Well			X						
Sewage (WWTP)		X		X					X
Sea (Desalination Plant)								X	
Irrigation return flow				X		X			
Rainfall			X						
Others	*To be specified when completing*								

Also the final use or function for the MAR water, distinguishing eight different current recharge applications (table 4-3).

Table 4-3. MAR Water final use or functions for each demo-site.

Current recharge applications	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
Irrigation Supply	X		X		X			
Drinking water supply	X		X	X		X	X	
Seawater barrier	X	X						
Wastewater treatment		X	X					
Wetland restoration			X		X			
Water Quality improvement		X	X (NO3)		X			
Seasonal storage		X	X					X

5. Results. MARSOL´s "corollary" for technical solutions

After an introductory and necessary chapter to know better the CURRENT state-of-the-art regarding technical solutions, as they have been interpreted in this project, this chapter introduces the improvements and new experiences performed in the different demo-sites, in order to achieve MARSOL targets and to reach the envisaged outcomes.

The SAT techniques most used in the demo sites which undergo permanent research are:

- Study on the biggest impact that affects the MAR facilities: Clogging.
- Influence of the period and flow volume of artificial recharge on the infiltration rate and effectiveness of the facilities.
- Actions applied on the morphology of the receiving medium (recharge wells, channels and infiltration ponds).
- Reduction of air inflow into the aquifer around the MAR facilities.
- Management, cleaning and maintenance operations.

The results of all the trials and the study of art at a global level have enabled the following operational corollary to be proposed, which has been designed with the aim to present a catalogue of options that can be applied in equivalent scenarios to combat the problems and impacts that affect recharge management mechanisms. It is therefore a system for decision making support (DSS).

All the solutions not present in any of the demo sites but tested in the references have been also proposed increasing the scope of the corollary as an asset.

5.1. MAR technical solutions data base structure

The data base on technical solutions has been tailored to include all the relevant information from the MAR sites.

There have been distinguished four sorts of operations:

1. Applied to water from its original source (quantity).
2. Applied to water from its original source (quality).
3. Applied to the receiving medium (in both soil and aquifer).
4. Applied to management parameters plus cleaning and maintenance operations.
5. Applied to the combination of all of them (integrated system).

The different categories utilized to classify the different sort of operations and the specific technical solutions (elements) included in each are:

1.1. Water quantity aspects (T.S. 1 to 5).

2.1. Pre-treatment-treatment (T.S. 6 to 12).

2.2. Surface facilities (T.S. 13 to 16).

2.3. Deep injection (T.S. 17 to 19).

2.4. Receiving medium (T.S. 20 to 24).

2.5. Others (T.S. 25).

3.1. Previous studies (T.S. 26 to 27).

3.2. Surface facilities (T.S. 28 to 35).

3.3. Injection facilities and piezometers (T.S. 36 to 41).

3.4. Operative aspects (T.S. 42 to 46).

4.1. Operation (T.S. 47 to 53).

4.2. Maintenance (T.S. 54 to 56).

4.3. Decision support systems (T.S. 57 to 63).

4.4. Management (T.S. 64 to 70).

4.5. Reuse (T.S. 71 to 73).

Currently there have been **collected and/or designed 73 real technical solutions**. These lists might change after the development of the ongoing activities. According to the exposed structure, the **data base elements** are:

RECHARGE WATER (QUANTITY)

1-Preselecting: selective criteria for the origin of recharge water when several sources are available
2-Temporary storage of MAR water in surface reservoirs
3-Control of the flow velocity of MAR Water (stopping devices…)
4-Manage/avoid operations during specific events/periods, e.g. freezing weather, heat waves…
5-Security structures for overflow events, run-off tramps, spillways, etc.

RECHARGE WATER (QUALITY)

6-Pretreating of water for MAR in origin: (WWTP, membranes, mud lines, filters, packets…) (specify)
7-Pretreating of water for MAR in the heading of the structure: Filtering beds, decantation/stagnation structures, deaeration, etc.
8-Pretreating of MAR water using unsaturated zone as a pretreatment natural filter
9-Treatment structures intercalated along the construction for surface facilities, e.g. control of pH by means of mudstone gravel filters (specify)
10-Pretreating by Disinfection By Products (DBPs), e.g. Cl, I, O3, H2O2, UV rays, etc. (specify)
11-Chemical additives to eliminate clogging layers (specify)
12-Combination of different MAR facilities to improve the MAR water quality, e.g. a "triplet scheme" (WWTP, green biofilter, artificial wetland)?
13-SURFACE FACILITIES: Design and preservation of slope (rubble works, gabions...) (specify)
14-Limitation/control of the water layer thickness
15-Denitrification processes/additives (e.g. anammox)
16-Mechanisms to force the mixture of the different layers of MAR water, e.g. for canals let the water jump over or below stopping devices alternatively
17-DEEP INJECTION FACILITIES: Employ of anticorrosion materials in the MAR devices
18-Changes in the depth of the pump for wells/boreholes
19-Induced changes in water quality for irrigation. Fertilizers… (specify)

20-RECEIVING MEDIUM: Avoid aeration on AR waters: communicating vessels, open/buried structures, velocity control (specify)
21-Deaeration techniques: piezometers, increase distance between injection-extraction points… (specify)
22-Isolation from atmosphere/sunlight structures (specify)
23-Avoid natural salinization: Induced recharge, e.g. barriers in salty areas (specify)
24-Recycling effect of water in the MAR system (describe)
25-OTHERS: Specific fishes/exotic species introduced to reduce clogging (e.g. medaka)

RECEIVING MEDIUM (IN BOTH SOIL AND AQUIFER)

26-PREVIOUS STUDIES: The knowledge of the environmental conditions for the receiving medium might be considered sufficient? (describe)
27-Regarding the selection of the site, are there "natural fences" to avoid water to leave the system?
28-SURFACE FACILITIES: Changes in the receiving medium design. Furrows in the bottom, width, shape... (describe)
29-Changes in the receiving medium design. Geofrabrics in the bottom/slopes (specify)
30-Inverse pumping in wells pits close to a MAR canal or pond
31-Backwashing in geo fabrics, membranes and filters
32-Use of jet type cleaning techniques
33-Chemical cleaning (use of chemical additives) (describe)
34-Operations in the bottom: Algae drying, natural bed drying, cryotreating, cracking (cake) (specify)
35-Mechanical cleaning (scarification or silting zones and cleaning /replacement) (specify)
36-INJECTION FACILITIES AND PIEZOMETERS: Alternate normal and inverse pumping and frequency
37-Mechanical cleaning (wall brushing, scratching...)
38-Chemical cleaning (use of chemical additives) techniques for the regeneration of recharge wells
39-Selection of casing materials for wells according to groundwater characteristics (quality, quantity, durability...)
40-Employ of water level control automatic systems (alarm systems, buoys…)
41-Employ of clogging preventive systems, e.g. cathodic protection…(specify)
42-OPERATIVE ASPECTS: Use of dual systems allowing cleaning of one of them whilst the other is operating
43-Cleaning of the vegetation in the MAR facilities (specify)
44-Specific plantation during any season
45-Cleaning techniques frequency (specify)
46-Use of Basic Cleaning Vehicles (BCVs) (describe)

MANAGEMENT PARAMETERS AND EX SITU TECHNIQUES (INCLUDING MANAGEMENT, GOVERNANCE...)

47-OPERATION. Management parameters and ex situ techniques related to water management, governance... (describe)
48-Election of the most appropriate period and place to MAR water / obligation due to administrative concessions
49-Initiate 'soft' MAR cycles (start gradually)
50-Input flow and flow water speed control (automatic, manual) (specify)
51-Dual systems: duplicated MAR facilities to alternatively manage MAR and cleaning activities

52-Alternative sources of MAR water and management (describe)
53-Monitoring chemical properties of MAR water during recharge cycles
54-MAINTENANCE. Specific protocol for clogging control
55-Protocol for proper hydro-mechanical aspects in space and time. e.g. pressure inside a pipeline circuit (describe)
56- Specific cleaning and maintenance programs or decisions made "on the go"?
57-DECISION SUPPORT SYSTEMS. Integrated system design: all elements are interconnected
58-Promote participation of farmers or other social agents or stakeholders in water management
59-Limit fertilizers use
60-Decrease untreated spilling in the area
61-Protected perimeter around the MAR facilities
62-Use of protection devices for fauna and people in MAR facilities
63-Public use regulation
64- MANAGEMENT. Early adoption of the Best Available Techniques (to what extent new BATs are tested prior their application?)
65-Design and adoption of a proper Watching and Control Program
66-Construction of dams specifically designed for MAR
67-Construction of WWTP specifically designed for MAR
68-For those devices constructed due to a R&D specific project, is there any guaranteeing mechanism to operate the system after the end of the project
69-Are there already specific operative guidelines? (specify)
70-Use of sensors to monitor turbidity, dissolved oxygen, temperature… either inlayers or installed in surface facilities
71- REUSE. The wells used for MAR were specifically designed or previous wells/shafts were used (change of use)?
72-Use of existing natural previous elements to improve MAR efficiency, e.g. River Bank Filtration (RBF direct or inverse), use of dolines, sinkholes…
73-Use of pre-existing artificial previous elements for MAR e.g. rivers dams, meander scarfs…

The demo sites, with their catalogue number and name, are:

1- Lavrion

2- Algarve & Alentejo

3- Arenales

4- Llobregat

5- Brenta

6- Serchio

7- Menashe

8- Malta South

Tables 5-2 to 5-5 expose the technical solutions applied in all the MARSOL demo sites and those obtained from external references.

TECHNICAL SOLUTIONS DATABASE STRUCTURE

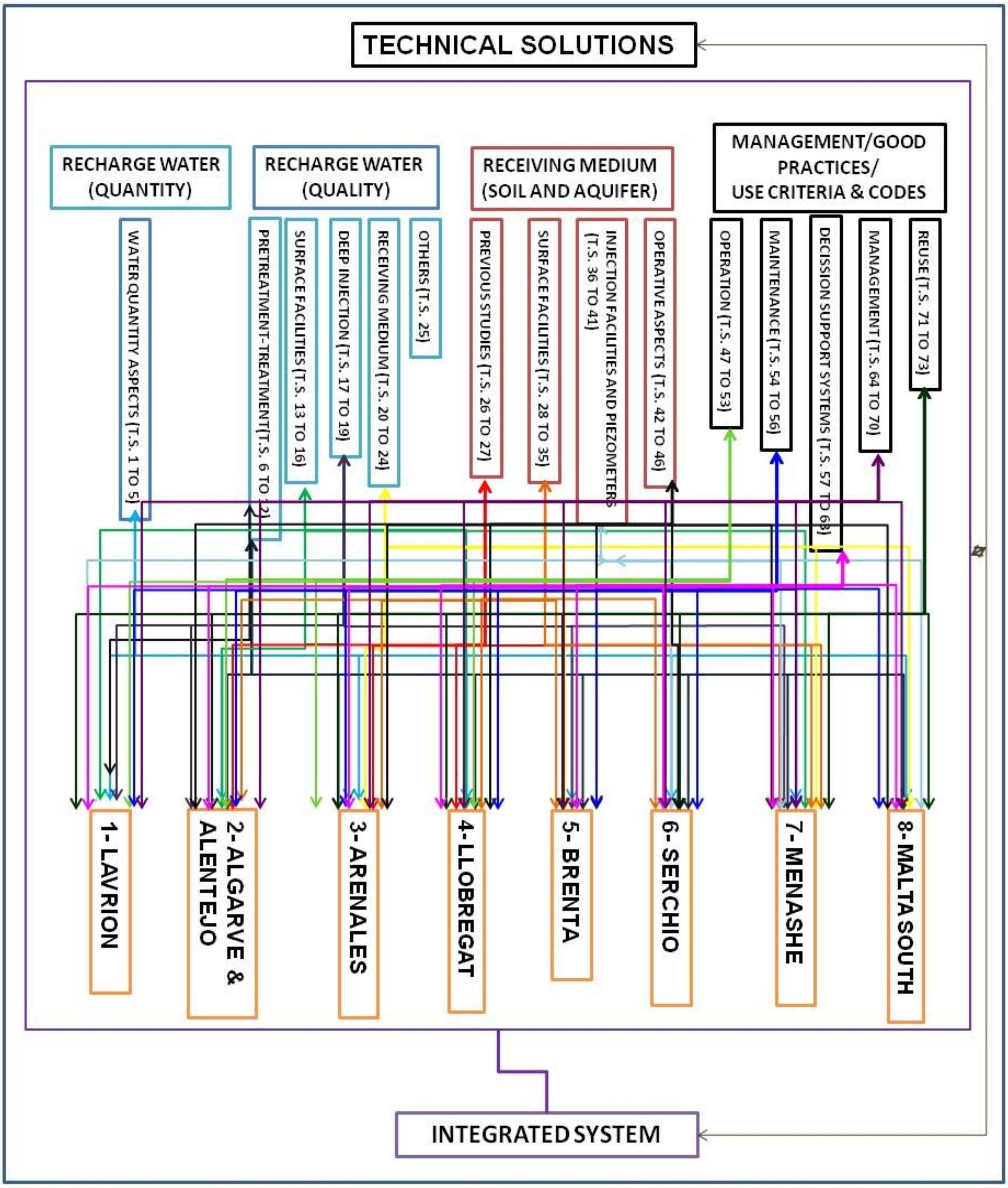


Figure 5-1. MARSOL Technical solutions database structure, relating the sort of T.S., the category, the specific T.S. applied and the demo-site where it is being tested and deployed. Notice: This figure might change after the development of the ongoing activities.

5.2. MAR technical solutions. New corollary and description of the different methods

On the basis of the previous corollary exposed in chapter 3 and the surveys carried out in all the demo sites involved in MARSOL project, it is developed, according to the technical solutions database structure, the best activities to be applied and recommended in analogous sceneries, fulfilling the target of the milestone MS8.

Four types of activities have been differentiated (based on activities related to MAR water quantity, quality, on the receiving medium and related to management, governance…), with the aim of responding the following question: **“How to best MAR Water?”**

Tables 5-2 to 5-5 expose the different technical solutions applied in each demo site, indicating how this *tech. Sol.* is applied and the results and improvements obtained along the project. Some of them have been collected from previous hydrogeological references.

Table 5-1. Legend for the degree of development for each technical solution (T.S.) appiel at each demo site.

X	**Currently in operation**
F	**To be developed shortly**
I	**Intended to be deployed in the future**
S	**In study**
C	**Technical solution taken from references**

Below each table, the main activities which deserve further details are explained.

5.2.1. Techniques applied to water from its original source (both quantity and quality)

SAT techniques applied to MAR water related to quantitative aspects are listed in table 5-2..

Table 5-2. Data base for SAT techniques applied to MAR water related to quantitative aspects. Legend: X - Currently in operation; F - To be developed shortly; I - Intended to be deployed in the future; S - In study; and C - Technical solution taken from references.

SORT OF TECHNICAL SOLUTION		DEMO SITE							
	Recharge water (quantity)	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
WATER QUANTITY ASPECTS	*1-Preselecting: selective criteria for the origin of recharge water when several sources are available*	only WWTP		X	I	Single	Single	X (rain, WWTP, desalinatio n)	two sources
	2-Temporary storage of MAR water in surface reservoirs	X tanks, lagoon	F (Cerro do Bardo)	X				X (settlemen t)	X agricult ure plant
	3-Control of the flow velocity of MAR Water (stopping devices…)			X		X heading gate		X (gates, valves…)	
	4-Manage/avoid operations during specific events/periods e.g. freezing weather, heat waves…	X		X	x	use during irrigation period		according to rainfall	Supedi ted to high deman d
	5-Security structures for overflow events, run-off tramps, spillways, etc.		X (huse spillway in Cerro do Bardo and Rio Seco)	X	x			spillway	
	To be specified in latter stages								

WATER QUANTITY ASPECTS (T.S. 1 to 5):

1 - Preselecting: selective criteria for the origin of recharge water when several sources are available

In most of the cases there is a unique source (Lavrion, Llobregat, Brenta, Serchio). When several sources are available the use is either integrated combining water from different sources (Arenales, Malta), or seasonally depending on availability (Menashe).

2 - Temporary storage of MAR water in surface reservoirs

This technique is applied in most of the demo sites, in general used as a pre-treatment measure (Lavrion, Algarve, Arenales and Menashe). In case of storage purposes, it is merely temporal (Malta).

Figures 5-2 a) & b). Temporary storage of MAR water for decantation pre-treatment and recharge (heading infiltration pond) in Carracillo, Arenales Aquifer, Spain.

3 - Control of the flow velocity of MAR Water (stopping devices…)

The most frequent device is the *"heading gates"* present at Arenales, Brenta and Menashe demo sites.

It is an important an useful technique that requires to pay an intense attention, as it is to increase the infiltration volume in areas with a bigger infiltration rate (specially for MAR canals); to avoid the dissolution of oxygen from the atmosphere and to mix layers of water stratified due to thermal or hydrochemical dissociation.

In the case of initial valves (figure 5-3) the volume of water to be "*MARed*" is controlled either manual or automatically (figures 5-3 and 5-29) for manual operation in Arenales aquifer.

Figures 5-3 a) & b). Valves for manual control of the water volume diverted from the river to the canal for MAR activities in Santiuste basin, Arenales Aquifer, Spain.

4 - Manage/avoid operations during specific periods; e.g. freezing weather, heat waves…

The environmental circumstances that have a direct effect on MAR managing are the rainfall, option considered in almost all the demo sites with spillways, infiltration ponds and measures to palliate this sort of extreme water event.

The water temperature must be between specific limits to be “MARed”. Previous studies have demonstrated that during freezing conditions the infiltration rate decreases considerably (DINA-MAR, 2011). Thus, until now, the applied measures have been to interrupt (manually) the recharge cycle when these environmental conditions occur.

It is necessary to find appropriate procedures to increase the effectiveness of recharge during these freezing cycles.

Other “specific period” with a direct influence on MAR facilities management is the demand for water supply for urban use or for irrigation.

5 - Security structures for overflow events, run-off tramps, spillways, etc.

Some diversion from the canals and surface storage structures counts on spillways for the eventual case of over floods concurring when the MAR facilities are at full work. In most of the cases these little canals or pipes go straight to rivers or infiltration areas. In a case (Algarve) there is a hose spillway which also allows evacuating water in the pumping tests performed in the wells.

5.2.2. Techniques applied to the receiving medium (in both soil and aquifer)

The SAT techniques applied to MAR water by means of modifying their water quality are listed in table 5-3.

Table 5-3. Data base for SAT techniques applied to MAR water to affect their water quality.

SORT OF TECHNICAL SOLUTION		DEMO SITE							
	Recharge water (quality)	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
PRETREATMENT-TREATMENT	*6- Pretreatment of water for MAR in origin: (WWTP, membranes, mud lines, filters, packets…) (specify)*	X (WWTP)	X (SB Messines WWTP)	X pipeline filter				X	X
	7-Pretreating of water for MAR in the heading of the structure: Filtering beds, decantation/stagnation structures, deaeration, etc.		X (Campina de Faro - Noras, Cerro do Bardo and SB Messines)	X stagnation estructure	x	single chamber for decantatio n		X (only according to turbidity measures)	X
	8-Pretreating of MAR water using unsaturated zone as a pretreatment natural filter		X (Cerro do Bardo and Rio Seco)	S					
	9-Treatment structures intercalated along the construction for surface facilities, e.g. control of pH by means of mudstone gravel filters (specify)			X gravel canalbeds	x (organic reactive layer)			filters in the concrete channel	
	10-Pretreating by Disinfection By-Products (DBPs), e.g. Cl, I, O3, H2O2, UV rays, etc. (specify)			S			hypochlo rite	hypochlori te, H2O2	H2O2
	11-Chemical additives to eliminate clogging layers (specify)							hypochlori te	
	12-Combination of different MAR facilities to improve the MAR water quality, e.g. a "triplet scheme" (WWTP, green biofilter, artificial wetland)?		X (SB Messines)	X	x			X	

SURFACE FACILITIES	***13- Design and preservation of slope (rubble works, gabions...) (specify)***		**X (Rio Seco) - filling with gravel**	**X gabions in stopping devices and passes**	**x**			**concrete**	
	14-Limitation/control of the water layer thickness	**X 50 cm**	**S**	**x (140 cm)**	**x**			**X**	
	15-Denitrification additives (e.g. anammox)								**No needed**
	16-Mechanisms to force the mixture of the different layers of MAR water, e.g. for canals let the water jump over or below stopping devices alternatively			**X (water flows up and down consequtive stopping gates**					
DEEP INJECTION FACILITIES	***17- Employ of anticorrosion materials in the MAR devices***	**X**						**X**	**X**
	18-Changes in the depth of the pump for wells/boreholes					**Fixed 50 m**		**surface pumping**	
	19-Induced changes in water quality for irrigation. Fertilizers... (specify)	**F (regulated)**	**X (Campina de Faro has specific regulations (Vuln Zone)**	**F (proposal for regulation)**					
RECEIVING MEDIUM	***20- Avoid aeration on AR waters: communicating vessels, open/buried structures, velocity control (specify)***			**X (avoid cascading and flow speed control)**		**laminar flow**		**laminar flow**	**laminar flow. Closed circuit**
	21-Deaeration techniques: piezometers, increase distance between injection-extraction points... (specify)			**S (wells)**				**specific own system (patented)**	
	22-Isolation from atmosphere/sunlight structures (specify)	**X**		**only in the pipeline**		**X initial chamber protected**	**pipeline circuit**		

	23-Avoid natural salinization: Induced recharge, e.g. barriers in salty areas (specify)			**X (natural barriers)**				**X**	**X**
	24-Recycling effect of water in the MAR system (describe)	**C**							
OTHERS	***25- Specific fishes/exotic species introduced to reduce clogging (e.g. medaka)***	**C**							
	To be specified in latter stages								

X	**Currently in operation**
F	**To be developed shortly**
I	**Intended to be deployed in the future**
S	**In study**
C	**Technical solution from references**

PRETREATMENT/ TREATMENT (T.S. 6 to 12):

6 - Pretreatment of water for MAR in origin: (WWTP, membranes, mud lines, filters, packets…)

Practically all de demo sites with water proceeding from a WWTP have the specific treatment required by their respective regulations (Lavrion, Messines Algarve, Menashe, Malta S).

In Arenales demo site, the water catchment has two specific devices to pre-treat water taken from the river consisting on a system of filters and a stagnation initial structure attached to the MAR dam (figures 5-4).

Figures 5-4 a) to c). Initial grid and filtering system in the diversion dam inlet valve in Santiuste basin and structure for stagnation in Carracillo council´s catchment dam, Arenales Aquifer, Spain.

7 - Pretreating of MAR water in the heading of the structure: filtering beds, decantation/stagnation devices, deaeration, etc.

In most of the cases the most applied solution is a decantation or stagnation structure in the heading of the MAR system, minimizing the occupation of terrain (Algarve, Arenales, Llobregat and Malta South). In Brenta there is a single chamber for decantation, and in Menashe the system has a bypass and the decantation is only carried out if needed according to turbidity measures.

In Llobregat there is a first infiltration pond to reduce the suspended solids which works as an artificial wetland as well.

Figures 5-5 a) & b). Some examples for technical solutions already deployed in Carracillo council. Stagnation systems in the heading of some infiltration ponds; Arenales Aquifer, Spain.

Another important Technical solution developed by Mekorot co. in Menashe demo site is an air entrainment pilot to pre-treat MAR water at the heading of the circuit.

The gas binding is an impact with a large-scale intensity. The recharged water from canals is losing about 1 ppm of dissolved oxygen through the aquifer after 25 m long circulation in the horizontal layer. Much of this increase is trapped in the pores of the aquifer. It is advisable to perform recharge at slow rates, since air entering the aquifer occupies about 25% of the temporarily effective porosity (estimated by indirect methods in Fernández, 2005).

The prototype is being tested currently and a new patent has been proposed (figures 5-6), thus no detailed information may be reported in a public document.

Figures 5-6 a) to c). Aspect of the air entrainment pilot to pre-treat MAR water in the heading of the circuit by means of a specific patent developed by Mekorot to reduce TOD (taken from Mekorot, 2015).

8 - Pretreating of MAR water using unsaturated zone as a pretreatment natural filter

It is a usual measure to convert the aquifer into a pipeline as well as treating the water along its natural flow until it reaches the final destiny.

The volume recharged in a specific place can be recovered even kilometres "down groundwater flow". Some specific examples are in Algarve Cerro do Bardo demo site for a karst system and Arenales for a detritic one.

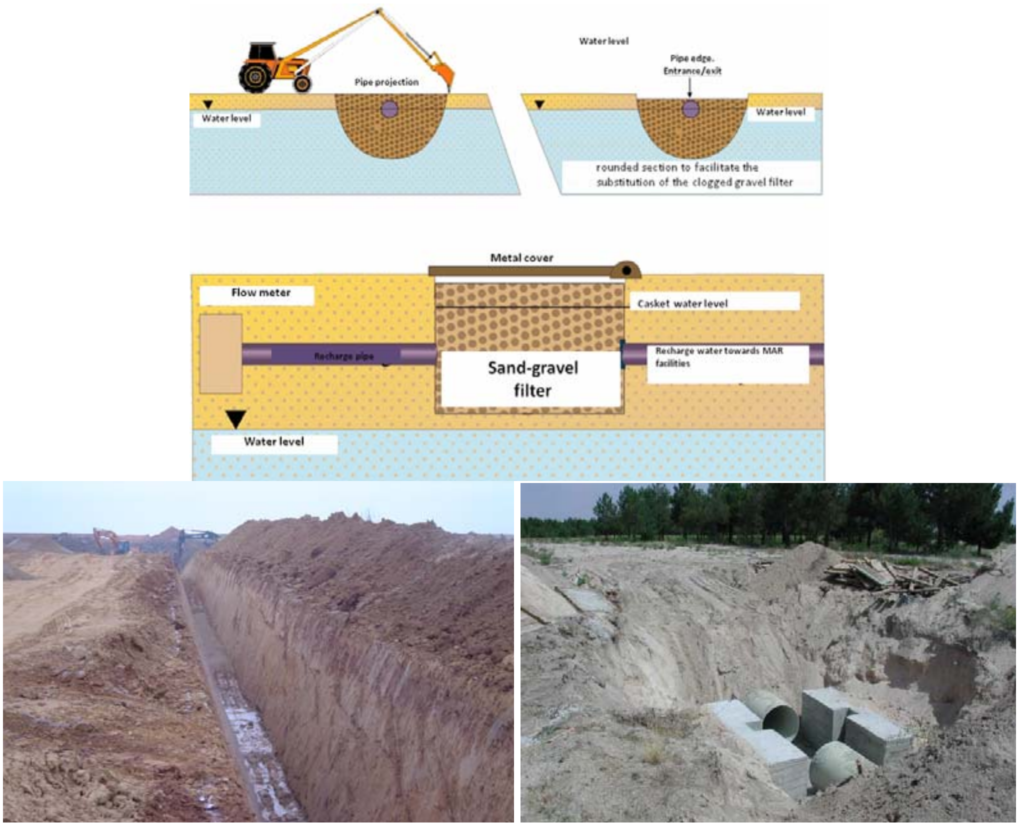
9 - Treatment structures intercalated along the construction for surface facilities, e.g. intercalated filters, control of pH by means of mudstone gravel filters…

In Arenales the MAR water quality is improved *"in itinere"* by means of different systems, such as sand or gravel filters embedded along the pipeline or circuit (figure 5-7) and run-off traps (figures 5-8).

Actions have been taken in the receiving environment where pH in the recharge water is considerably different from the native water due to the fact that the chemical imbalance contributes to the clogging processes. The technique used for pH balancing has been the inclusion into the design of calcareous gravel beds and acid stone breakwater (figures 5-9). This construction technique allows small corrections of pH on predefined sectors while giving durability and ruggedness to the infiltration channels.

In Llobregat an organic reactive layer has been deployed to reduce the suspended solids, the total dissolved solids and the air dissolved in the MAR water.

In the case of Menashe there are filters in the concrete channel.



Figures 5-7 a) to c). Pipe installation in sand soil and pipes sealed across MAR zones allowing a casket to be filled up with a gravel filter in Arenales aquifer.

Figures 5-8 a) to c). Run-off traps, stagnation and decantation structures to pre-treat runoff water prior reaching MAR facilities

Another type of *in itinere* treatment structures that, in this case, are not usually buried are, e.g., the gravel canal beds (figures 5-9) what brings up the pH about 0.2 units for a slow flow rate (DINA-MAR, 2011, Fernández, 2013).

Figures 5-9 a) to d). Mudstone gravel filter to result in pH corrections as well as provide stability to some MAR facilities such as ponds (examples for Arenales and Menashe) and canals (Arenales).

In most of the cases is an “invisible” solution and requires little or none surface terrain.

10 - Pretreating by Disinfection by Products (DBPs), e.g. Cl, I, O3, H2O2, UV rays, etc.

DBPs allow the reduction in the presence of bacteria and nutrients content in the recharge water through the use of disinfectants, insulation from direct solar radiation...

In the demo sites there are some specific treatments by means of hypochlorite (Serchio and Menashe) and H_2O_2 in Menashe and Malta South demo sites.

The addition of chemical products is a very controversial activity due to indirect and deferred impacts, such as the production of THMs after chlorination or even N-Nitrosodidietilamide (Tsuchihashi et al., 2002). It also increases considerably the pre-treatment costs, thus it has not been applied in most of the demo sites.

11 - Chemical additives to eliminate clogging layers

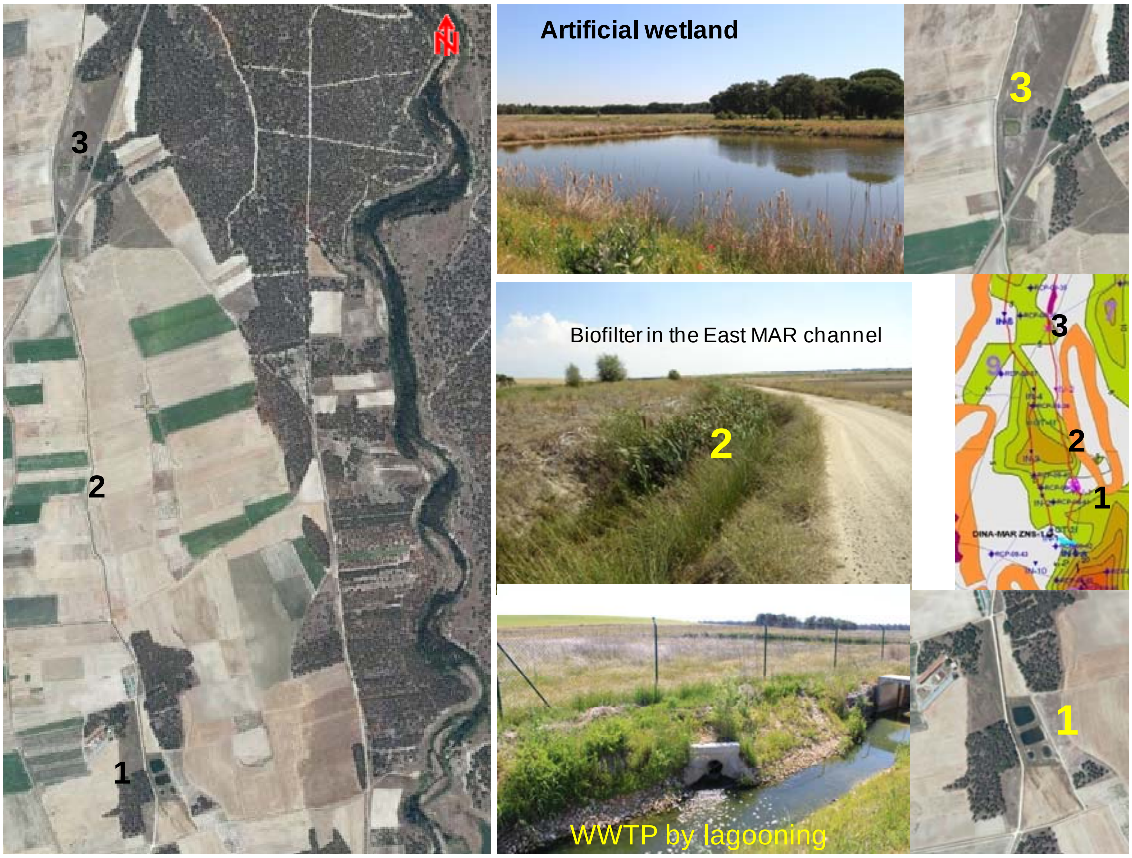
In order to avoid clogging development, in Menashe demo site it is being tested the addition of hypochlorite, line of action currently opened.

12 - Combination of different MAR facilities to improve the MAR water quality, e.g. a "triplet scheme" (WWTP, green biofilter, artificial wetland)”

The use of green biofilters and the purification by means of artificial wetlands are being tested in Algarve Messines, Arenales, Llobregat y Menashe.

There have been constructed two different schemes called *“Triplets”* in Arenales aquifer, which are a combination of elements to purify MAR water during the recharge process.

In Santiuste basin, it consist of two km long structure along a MAR canal starting at the junction WWTP-MAR canal with water from fluvial origin. This SAT-MAR structure is integrated by three elements, WWTP, green biofilter and an artificial pond to finish the purification process. Later the water returns to the MAR canal (figures 5-10).



Figures 5-10 a) to c). Santiuste basin “*Triplet*” scheme.

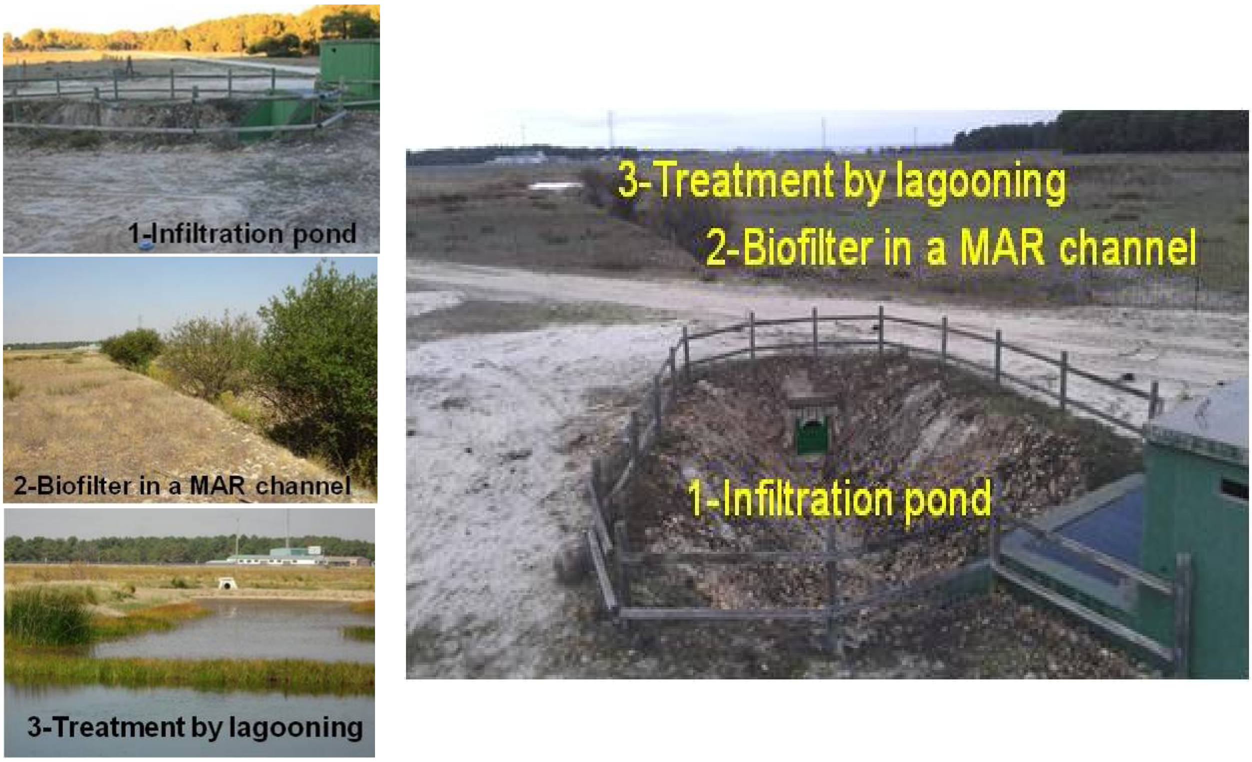
1 - WWTP lagooning
- Volume of reclaimed water / fluvial water: below 5%.
- High concentration of biological processes at the bottom.

2 - Green biofilter. Double function:
- Purifying activity on the potential pollutants by plants.
- Roots pierce and break the clogging in the canal, increasing the infiltration rate (despite their direct consumption of water).

Most inventoried species are hydrophilic herbaceous with an annual cycle, rapid growth, high root expansion and ease of extraction with roots (Fernández, 2005).

3 - Artificial wetlands, with a double function:
- Purification of the water stored in the vessel.
- Environmental function, as a shelter for wild fauna.

The Carracillo biofilter has 150 m and induces a very slight change of water quality properties, but its main target is to decrease the gas dissolved in the MAR water prior it is recharged after the infiltration pond in a spreading area (figures 5-11). The effect on water quality is an opened line of action.



Figures 5-11 a) to c). Carracillo shield "*Triplet*" scheme.

SURFACE FACILITIES (T.S. 13 to 16):

13 - Design and preservation of slope (rubble works, gabions...)

Slopes in MAR canals and ponds are protected, in general, by means of gravel (Algarve Río Seco), gravel and gabions (Arenales, Llobregat) or concrete (Menashe).

In the case of Arenales (figures 5-12), at the beginning 1:1 slopes were opted in fine sands for a greater durability and smaller clogging concentration, due to their higher tilt. After some slides and several trials (figures 5-14 a-b); 2V:3H were built in the channels (c) and after 3H/2V, what has increased the observed infiltration rate across the walls but also their clogging development, with even carbonates lenses. Some of the locations especially vulnerable are dotted with rubble works and gabions (in Fernández, 2013). This line of action is still opened.

In the Algarve (Rio Seco) test site, the geotechnical characteristics of the terrain above the aquifer, allow the construction of vertical slopes during the dry season, allowing maximum contact area with the aquifer, thus enabling higher infiltration flows. The pond structural integrity was assured with filling of 3-5 mm of siliceous gravel. Use of calcareous mean was avoided to avoid undesirable reactions.

Geofabrics have not been used yet in the demo site, but some specific cases are available in the literature. In the Algarve (Messines) test site it is intended to be used in SAT ponds to avoid aquifer contamination.

Figures 5-12 a) to f). 1/1 slope with potential slices due to desiccation processes (a, b); 2H/3V initial design (c); 3H/2V as the most common slope in the channels and ponds walls (d,e); and eventual gabions protections (f).

14 - Limitation/control of the water layer thickness

The recommended water layer thickness to get the highest infiltration rate is a hot topic. It oscillates between 0.50 m (Lavrion) and 1.40 m (Arenales), depending on the environmental conditions. Some references mention up to about 4 m (Martin & Dillon, 2002), what depends on several constraints.

In some of the demo sites, studies on this line of action have been developed for years, generally by means of the trial and error methods; e.g. in Fernández el at, 2009 it is explained the preferred thickness in the infiltration ponds constructed above a sandy aquifer, which is 140 cm.

The selection of the best water thickness, apart from achieving the higher efficiency, reduces the compaction of the substrate. That is why it is so important to determine the water depth according each aquifer´s characteristics (Custodio, Llamas, 1983).

The line of action is opened and new tests are being performed in five out of eight demo sites.

15 - Denitrification processes/additives (e.g. anammox)

The addition of chemical compounds to reduce and minimize the concentration of nitrogen in groundwater is another important topic. Some demo-sites show that this action is not needed according to their chemical quality (e.g. Malta).

When surfing the hydrogeological literature there are some references referred to encouraging denitrification processes and creating enabling environments in the aquifer by means of additives. Some experiences mention the use of "*anammox*", to enhance the aerobic oxidation of ammonium (Van de Graaf *et al.,* 1995; Kuenen & Jetten, 2001).

This technical solution is not being tested in MARSOL currently.

16 - Mechanisms to force the mixture of the different layers of MAR water, e.g. for canals let the water jump over or below stopping devices alternatively

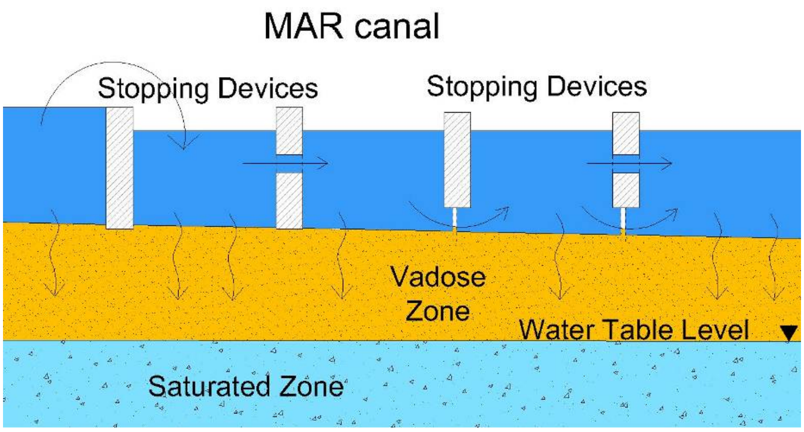
The damming devices placed along the channels usually produce a rise in the dissolved oxygen concentration of MAR water and a corresponding reduction in infiltration rates due to the Lisse effect (Krul & Liefrinck, 1946). There is also a thermal and hydrochemical stratification, avoiding the permanent mixture of MAR water along the canal and favoring undesirable conditions.

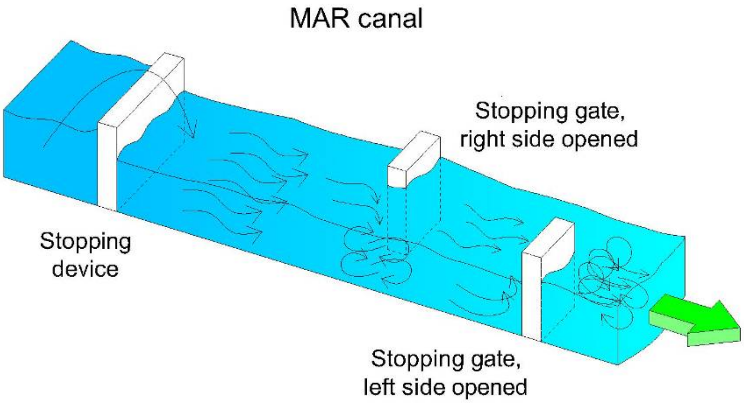
According to estimations, the infiltration volume decreased by 25% from the first to the second MAR cycle (2003-2004), a fact attributable to the air entrainment (Fernández, 2013). The evolution of the entrapped air into the aquifer below a MAR system along a single MAR cycle has been exposed in the figure 3-7 (taken from Fernández *et al.*, 2009).

The oxidizing conditions are developed in the contact with the atmosphere, whilst at the bottom there are the biggest TDS and organic matter content concentration.

The measures implemented and under permanent test aim at reducing the dissolution and gaseous particles incorporated in the recharge water through changes in the design of the devices at the stopping devices in the canals and their operation. Tests carried out so far in Arenales are based on facilitate the flow either below or in the middle of the weirs and precast concrete (figures 5-13 b and c and figure 5-14 a), and toggling the double stopping devices, by means of alternate gates, to enhance the mixing of water also laterally (figures 5-14 b to d).

Figures 5-13 a) to d). Stopping and damming devices MAR evolution in Arenales experiences. Original design (a), The locks (gates) are raised so the water flows underneath and holes drilled halfway let water flow through the middle of the canal depth (b), the central steps are equipped with a gate to regulate the flow along the channel, that tends to occur below the contact area with the air (c). Metal screw holes practiced to remove or raise the concrete gates with a bulldozer or tractor (d).





Figures 5-14 a) to d). Structure and system to facilitate the flow either below or in the middle of the weirs and precast concrete in order to mix the water stratification (a) and alternate opened gates in the double stopping devices to induce the mixing of water also laterally.

Improvements in the design must be accompanied by improvements in the operation; hence the floodgates management has remained in the hands of farmers who have been duly advised of these impacts and how to reduce them.

DEEP INJECTION FACILITIES (T.S. 17 to 19):

17 - Employ of anticorrosion materials in the MAR devices

Use of metal components made of anti-corrosion materials are implemented for elements such as surface gates, pipelines and boreholes. The employ of these materials is practised in Lavrion, Menashe and Malta South.

18 - Changes in the depth of the pump for wells/boreholes

The depth of the pump in the MAR wells is not usually changed due to the heavy cost that it represents. The usual depth where the pump is installed stays about 50 m (fixed) in Brenta, whilst in Menashe and Mata South is close to the surface and above 20 m, respectively.

19 - Induced changes in water quality for irrigation. Fertilizers…

The survey conducted about the addition of agro-chemical products for irrigation is carried out in Lavrion, Algarve and Arenales. There are specific regulations for each area. Thus, the technical solution should be related to review the local regulated limits, especially for fertilizers.

RECEIVING MEDIUM (T.S. 20 to 24):

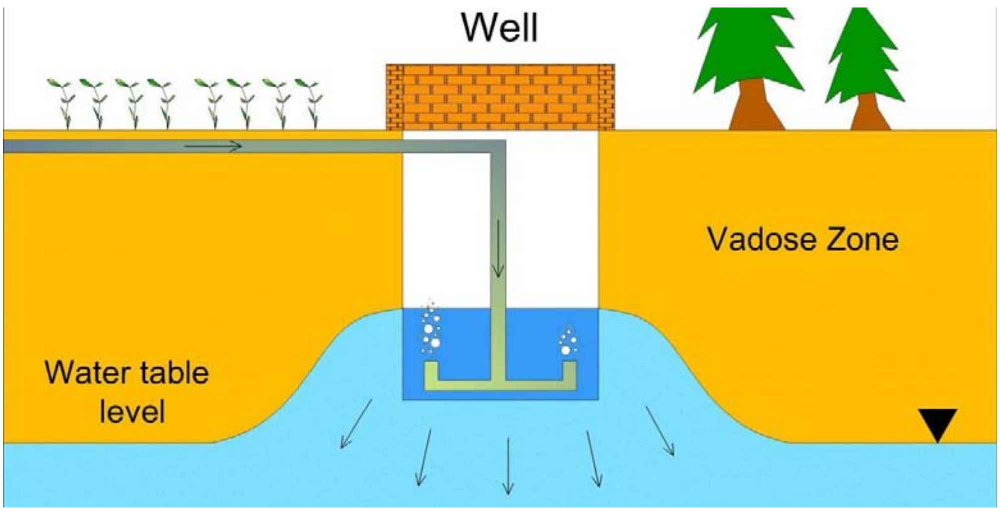
20 - Avoid aeration on MAR waters: communicating vessels, open/buried structures, velocity control

The measurement of the storage variations in the aquifer has allowed detecting the presence of an important Lisse effect (Krul and Liendfrich, 1946), which has reached up to 25% of air trapped in the aquifer capacity, according to indirect measures and estimations mentioned in T.S. 16 and references.

It is important to avoid the entrance of oxygen into the system and the generation of gas by means of an appropriate design of structures and devices. This fact is largely originated by the design of the devices, which cause agitation, cascading and mixing of water in contact with the atmosphere, increasing its gas concentration.

Some activities have been developed in Brenta, Menashe and Malta south to get a laminar flow. Most of the measures are based on avoiding positive partial pressures of the gases in the fluid.

A good example for recharge wells has been developed in Menashe. The free water fall is avoided by means of a closed pipeline with a SAT design and water is poured below the groundwater table, avoiding shaking and cascading effects (figures 5-15).



Figures 5-15 a) to c). Well design to minimize the entrance of air in the aquifer by means of a closed pipeline circuit and injection below the water table. Menashe, Israel.

In Arenales the techniques applied are based on the mix of waters of higher temperature than the aquifer´s native water, prevent cascading devices as presented in the T.S 16 and in figures 5-16, 5-17, etc.

Figures 5-16 a) to c). Recharge water with 7.5 ppm of total dissolved oxygen, *in situ* determinations and sample collection.

Figures 5-17 a) to c). Stopping and damming devices evolution in Arenales MAR experiences to mix water and to avoid its oxygenation.

Apart from the air measured directly in the MAR water (figures 5-16), the study of the air inflow into the aquifer around the MAR devices and the monitoring is accomplished with humidimeters, termometers and tensiometers at MARSOL ZNS stations.

The set of technical solutions to be applied in order to avoid or decrease theses impacts are currently under development, being the most important the preventive measures and the deaeration techniques.

21 - Deairation techniques: piezometers, increase distance between injection-extraction points…

Regarding dissolved oxygen, the measurements collected throughout a cycle manifest, in general, that the oxygen concentration exceeds the desired limits, with a different evolution in the demo sites. e.g. in Arenales the concentration values in the header have been around 8.8 ppm, whilst in the area of the artificial wetlands exceed the 10 ppm, reaching values of up to 12 ppm in the Northern sector (CHD, 2003).

When the green biofilter had a great development, the tendency was inverted due to the direct consume of dissolved oxygen and carbon dioxide (CO_2 and OD) by the plants.

Other deaeration techniques are based in the use of wells, piezometers and leaning piezometers to allow the escape of air from the aquifer to the atmosphere, as well as to increase the distance between the injection and the extraction points in case a field of wells is set between… (Arenales). For the Menashe case a particular specific system has been deployed (see T.S. 7 for pre-treatment).

Figures 5-18 a) & b). Some examples for technical solutions already deployed in Arenales Aquifer, Spain. Stagnation system in the heading beside the river dam, modified design to avoid the shake of the water increasing the DO content (a) and systems to evaluate the evolution of gas clogging entrapped in the aquifer.

22 - Isolation from atmosphere/sunlight structures

The measures applied to avoid the contact between MAR water and the atmosphere are based in the use of closed pipeline circuits (Arenales, Serchio) and the presence of initial and protected chambers (Brenta).

23 - Avoid natural salinization: Induced recharge, e.g. barriers in salty areas

In order to avoid salinization processes two sort of measures have been applied, either related to the design using natural barriers to isolate the MAR area and the high salinity area (impermeable marl hills) as has been done in Arenales, or artificial barriers disconnecting the induced recharge area from salty soils (Menashe and Malta South).

24 - Recycling effect of water in the MAR system (describe)

This measure is referenced in the bibliography (Fernández, 2014) and is based in the reuse of recharged water, especially for irrigation areas. The infiltrated water has been used for irrigation and the leaching recharges the aquifer again, creating a loop or a recycling effect.

OTHERS (T.S. 25):

25 - Specific fishes/exotic species introduced to reduce clogging (e.g. medaka)

It is worth studying actions to decrease dissolved organic carbon and oxygen, for example endemic fishes when possible, nitrophylic plants barriers to reduce nitrates concentration in groundwater, etc.

This line of action is facing serious constraints due to the introduction of alien species in the medium, being more appropriate the use of endemic plants, as described in T.S. 43rd.

5.2.3. Techniques applied to the combination of both (water and soil)

SAT techniques applied to the combination of MAR water and the receiving medium (soil).

X	**Currently in operation**
F	**To be developed shortly**
I	**Intended to be deployed in the future**
S	**In study**
C	**Technical solution from references**

Table 5-4. Data base for SAT techniques applied to the combination of MAR water and the receiving medium (soil).

SORT OF TECHNICAL SOLUTION		DEMO SITE							
	Receiving medium (soil and aquifer)	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
PREVIOUS STUDIES	*26- The knowledge of the environmental conditions for the receiving medium might be considered sufficient? (describe)*		X (geological hydraulic & chemical knowledge)	X	x (saturated and unsaturated media monitored)			S	
PREVIOUS STUDIES	*27-Regarding the selection of the site, are there "natural fences" to avoid water to leave the system?*			X				S	
SURFACE FACILITIES	*28- Changes in the receiving medium design. Furrows in the bottom, width, shape... (describe)*		X furrows	X (furrows, slope control)		earth canal. Slope preservation	river slope preservation		
SURFACE FACILITIES	*29-Changes in the receiving medium design. Geofrabrics in the bottom/slopes (specify)*		F (WWTP of SBM)	S					
SURFACE FACILITIES	*30-Inverse pumping in wells pits close to a MAR canal or pond*			X				X	
SURFACE FACILITIES	*31-Backwashing in geo fabrics, membranes and filters*	C							
SURFACE FACILITIES	*32-Use of jet type cleaning techniques*	X alluvial piezometers						X	
SURFACE FACILITIES	*33-Chemical cleaning (use of chemical additives) (describe)*							hypochlorite	
SURFACE FACILITIES	*34-Operations in the bottom: Algae drying, natural bed drying, cryotreating, cracking (cake) (specify)*			Xcryotreatment, cracking, bed drying	x (algae removal)				

	35-Mechanical cleaning (scarification or silting zones and cleaning /replacement) (specify)		X (Seco river)	X scarification /replacement	x(scarification of the surface after period of activity)	X		x	F
INJECTION FACILITIES AND PIEZOMETERS	*36- Alternate normal and inverse pumping and frequency*	X alluvial piezometers						x	
	37-Mechanical cleaning (wall brushing, scratching...)	X piezometers					X	x	
	38-Chemical cleaning (use of chemical additives) techniques for the regeneration of recharge wells						X	x	F
	39-Selection of casing materials for wells according to groundwater characteristics (quality, quantity, durability...)		x		X	X	X	x	
	40-Employ of water level control automatic systems (alarm systems, buoys...)			X (singular sites)			X	x	
	41-Employ ofclogging preventive systems, e.g. cathodic protection...(specify)						X		
OPERATIVE ASPECTS	*42- Use of dual systems allowing cleaning of one of them whilst the other is operating*		X (WWTP of SBM)				multiple wells system		
	43-Cleaning of the vegetation in the MAR facilities (specify)		X (Rio Seco)	X (allowance of natural plants in the green biofilter)		X cleaned canals	cleaned river	X cleaned canals	
	44-Specific plantation during any season			S					
	45-Cleaning techniques frequency (specify)		on demand (annual)	X (biannual)	periodic	seasonal	yearly	3-4 years	periodic
	46-Use of Basic Cleaning Vehicles (BCVs) (describe)			F (in development)				Tractor	
	To be specified in latter stages								

PREVIOUS STUDIES (T.S. 26 to 27):

26 - The knowledge of the environmental conditions for the receiving medium might be considered sufficient? (Describe)

According to references, most of the successful MAR cases are stablished in areas with depth knowledge of the aquifer characteristics, being the poor knowledge one of the biggest constraints for the unsuccessful cases.

Four out of the eight demo sites have declared to have dedicated vast sums of resources to carry out specific studies prior MAR activities (Algarve, Arenales, Llobregat, Menashe). E.g., in order to assess the groundwater pathway on MARSOL Algarve demo site 2, a tracer test similar to the one performed for GABARDINE project (in Mota, 2007) was performed with Cerro do Bardo water well. On three profiles centred in the well, with an N-S, W-E and SW-NE directions, a survey was performed during one week. A resistivity reference for each profile was established and daily readings were performed at each one. After data processing for the production of the 2D resistivity models, 2D section of the resistivity difference between each day section and the reference one was calculated. As an example, the results obtained after 5h 30m and after 3 days and 2 hours are presented on Figure 5-19.

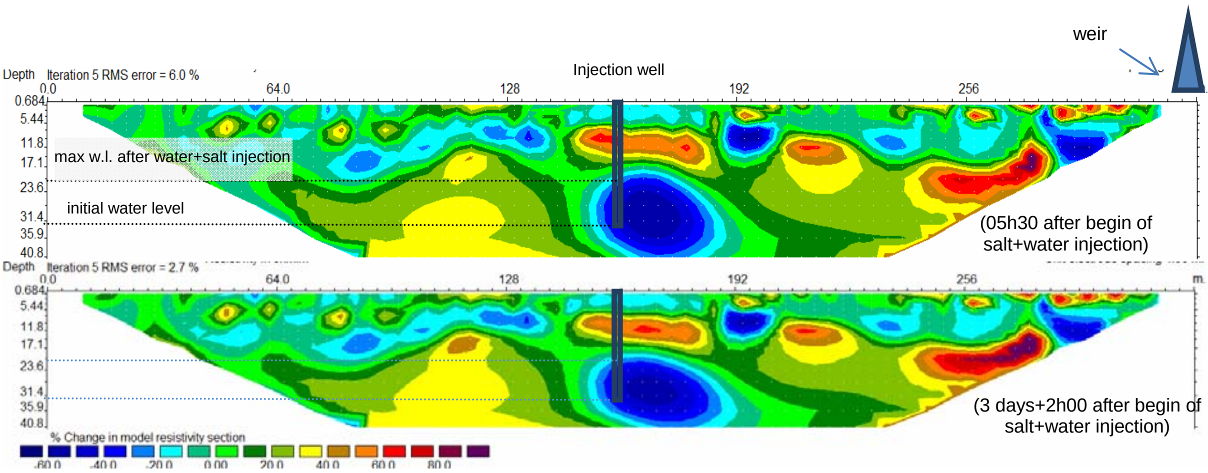


Figure 5-19. Salt tracer test with resistivity in time-lapse mode, performed at Cerro do Bardo DEMO site, Algarve Portugal (see Lobo-Ferreira *et al.*, 2015, for further information).

27 - Regarding the selection of the site, are there "natural fences" to avoid water to leave the system?

According to the degree of knowledge, the position of the MAR facilities must be decided in line with some features, being one of them the presence of “natural fences” which retain the stored water in the aquifer avoiding its movement. This criterion was taken into account for the design and construction of Arenales and Menashe facilities, where there are impermeable marl outcrops which refrain the groundwater natural flow.

SURFACE FACILITIES (T.S. 28 to 35):

28 - Changes in the receiving medium design. Furrows in the bottom, width, shape...

Human intervention on the receiving medium so as to improve MAR efficiency is being practiced in at least four of the demo sites In Arenales it is controlled the slopes stability in canals and ponds and the furrows design, with some experiences about the best distance between the respective furrows, being 80 cm the most successful for those specific conditions. In Brenta the earth canal is preserved and the Serchio river counts also on a slope preservation program.

29 - Changes in the receiving medium design; e.g. geofrabrics in the bottom/slopes

There have been detected sudden changes in the aquifer hydrochemical conditions in the channels MAR structures. E.g. in Arenales aquifer and there is a zone nearby Coca village where the groundwater hydrochemical environment is clearly reducing. This sector, corresponding to the central part of the basin aquifer, has also strong concentrations in free iron, manganese and silica, so that, conditions for the precipitation of calcite and iron are conducive... Therefore, it is necessary to carry out actions to counteract quality hydrochemistry of water of artificial recharge on its way through this sector. By the moment the flow speed along the canal is increased in this area, by removing the stopping devices in this sector.

30 - Inverse pumping in wells pits close to a MAR canal or pond

This sort of RBF in which the well is dug in the river has been practiced in Santiuste North with good results, what represent a modification from the usual RBF systems, such as Serchio River. The use of wells close to a canal so as to develop the system efficiency is also being performed in Menashe demo site.

31 - Backwashing in geo fabrics, membranes and filters

In those devices provided with geofabric membrane or filtration systems, it is appropriate the reverse washing of these filters (backwashing technique), and the dewatering of the viscous processes previously applying dry cleaning practices. Some isolated experiences have been driven in Arenales (figures 5-20), being a line of action currently under development.

Figures 5-20 a) & b). Geofabrics installed in the bottom of the MAR canal to facilitate the cleaning of clogging processes with minor changes in the infiltration rates in Santiuste basin.

32 - Use of jet type cleaning techniques

The maintenance of wells by means of a jet or pressurized water is being done for piezometers in Lavrion (only in those drilled in alluvial materials) and in Menashe for all. This cleaning technique is expected to be applied also in Malta South in latter stages. None of the demo sites is employing this technique to clean canals or infiltration ponds.

33 - Chemical cleaning (use of chemical additives)

Reduction of the chemical clogging processes by means of acidification, periodic removal of the superficial cake layer in surface devices. The most used products are acids such as acetic, oxalic and chlorhidric. The surface facilities are cleaned with products only in Menashe demo site, where hypochlorite is applied eventually.

34 - Operations in the bottom: e.g. algae drying, natural bed drying, cryotreating, cracking (cake)

This sort of SAT techniques is being used in Arenales and Llobregat. For the first case, the cleaning and maintenance program recommends to apply some unclogging procedures, such as:

- Let the recharge facilities to dry up eventually, counteracting the expansion of the clays and thus restoring part of the previous permeability. This is a temporal and ineffective measure if it is not combined with other actions.
- Use the freezing periods to crack the clogging layer with a very thin layer of water, especially in dual systems (an infiltration pond is working whilst the other receives the SAT.

At the Llobregat demo site, algae colonies tapestries are removed in the summer time.

35 - Mechanical cleaning (scarification or silting zones and cleaning /replacement)

The scarification of the clogged layer is the most applied technique when the cake is over the surface and the penetration capacity is rather short. This operation is usually achieved during the summer period. This measure is complex in case of the facilities count on geofabrics.

The clogging extraction lends itself to different alternatives such as extraction, washing and reintegration prior the new recharge cycle begins, or removal to specific dumps and replacement by natural terrain (figures 5-21), etc.

Mechanical cleaning is carried out in Algarve (Seco River), Arenales (scarification and replacement), Llobregat, Brenta y Menashe (scarification). In Malta South it is envisaged to be done in the next stages.


Figures 5-21 a) & b). Cleaning and maintenance operations in ponds and canal by means of excavators (sand and clogging replaced by clean sand, a) and scarification by means of tractors with adapted accessories (b).

INJECTION FACILITIES AND PIEZOMETERS (T.S. 36 to 41):

The technical solutions performed in injection wells and boreholes, as well as piezometers are:

36 - Alternate normal and inverse pumping and frequency

It is usual the daily pumping of the MAR injection wells (backwashing). This activity is done usually in Menashe demo-site.

For piezometers it is also used as a cleaning procedure and is applied eventually in Lavrion for those drilled in alluvial formations. Stakeholders avoid this technique for those piezometers drilled in mudstone bodies.

37 - Mechanical cleaning (wall brushing, scratching...)

The production wells and boreholes are cleaned when efficiency indicators recommend it. These series of indicators will be exposed in the deliverable 13.3., improving the Rödl *et al.*, 2008 proposal.

The action of mechanical cleaning is being tested in Serchio and Menashe demo sites catchments and in Lavrion for piezometers.

There are some references about the design of specific tools to clean MAR boreholes (Fernández, 2014) tested in other living labs.

38 - Chemical cleaning (use of chemical additives) techniques for the regeneration of recharge wells

The addition of chemical compounds type polyphosphates, weak acids is a technique employed worldwide. This addition must be combined with hydraulic methods to facilitate their incorporation into the environment and improve their effectiveness (Perez-Paricio & Carrera, 1998b). Chemical products are combined with mechanical actions in Serchio and Menashe demo sites. In Malta South it is expected to be needed shortly and planned in the maintenance program.

39 - Selection of casing materials for wells according to groundwater characteristics (quality, quantity, durability...)

The injection wells in the demo-sites are usually equipped with metal casing, considering other options depending of the chemical characteristics of the native groundwater.

Some partners have used alternative materials such as PVC, FVRP in other sites such as Algarve, Llobregat, Brenta, Serchio and Menashe.

Figures 5-22 a) & b). GRP and Johnson casing for injection wells casing.

According to the Menashe demo site experience, Mekorot co. considers to use either GRP or Johnson stainless steel casing in the new injection wells. According to the literature, the development of bio fouling and biological clogging on GRP are lower than on any other casing material. The problem is the low percentage of the open slot space in comparison to Johnson stainless steel screen (Mekorot, 2015). The larger the open space for an injection well, the better. Flow speeds of 1.5 cm/s are advisable.

40 - Employ of water level control automatic systems (alarm systems, buoys…)

The installation of alarm systems in the MAR facilities and in the observation piezometers in continuous recording to monitor the „depth of alert“ evolution, the thickness of the water layer for surface devices, the incoming flow rate, etc. has been done in Arenales (singular sites), Serchio y Menashe at least. These systems are equipped with inlayers and accessories for the real time data transfer.

41 - Employ of clogging preventive systems, e.g. cathodic protection…

Boreholes preservation requires preventive techniques in order to delay clogging development. There are some complementary techniques, such as cathodes of sacrifice which minimize electro-kinetic reactions willing to facilitate clogging growth, applied, e.g. in Serchio demo site.

As an example, some of the on-site techniques applied in Menashe demo site have driven to propose some draft guidelines in designing new MAR wells, as follows (Mekorot, 2015):

- The main clogging problem c from air entrainment.
- The best construction is larger outside diameter (26”-30”) and casing + screen of 14-16” diameter. Using Johnson stainless steel screen or GRP.
- Drilling with water or biodegradable mud.
- To have several piezometers to measure the changes in the water level during the recharge (for clogging rate and operational protocol).
- The water level should be at a level that will prevent any air entrainment.
- The injection pipe should be without air (full with water).
- The injection water should be clean from turbidity (NTU ~ 0.1).

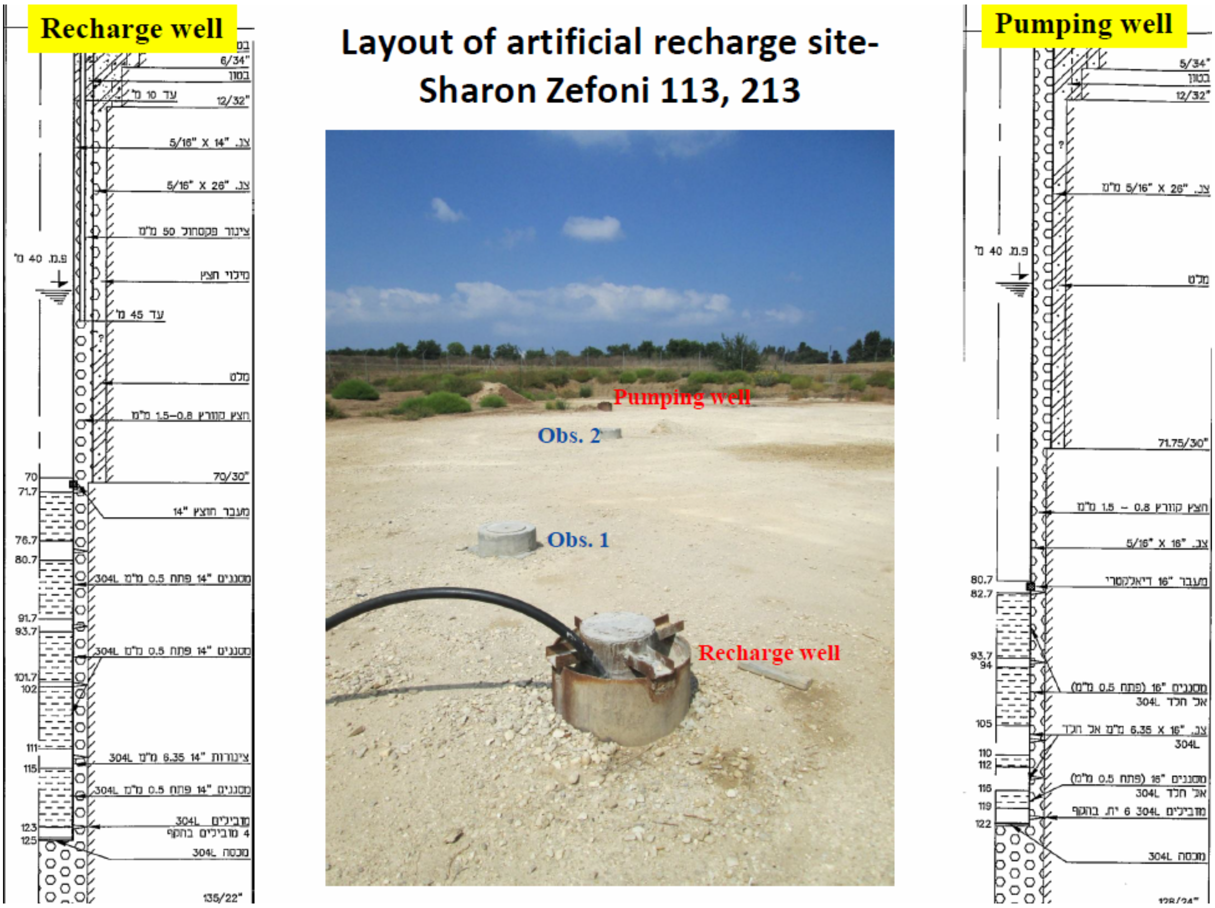


Figure 5-23. Example for an ASTR design aspect in Sharon Zefoni, demo site Menashe, taken from Mekorot, 2015. Column for the injection and extraction wells.

Some schematic designs specific for Arenales aquifer can be found in the literature (figure 5-24).

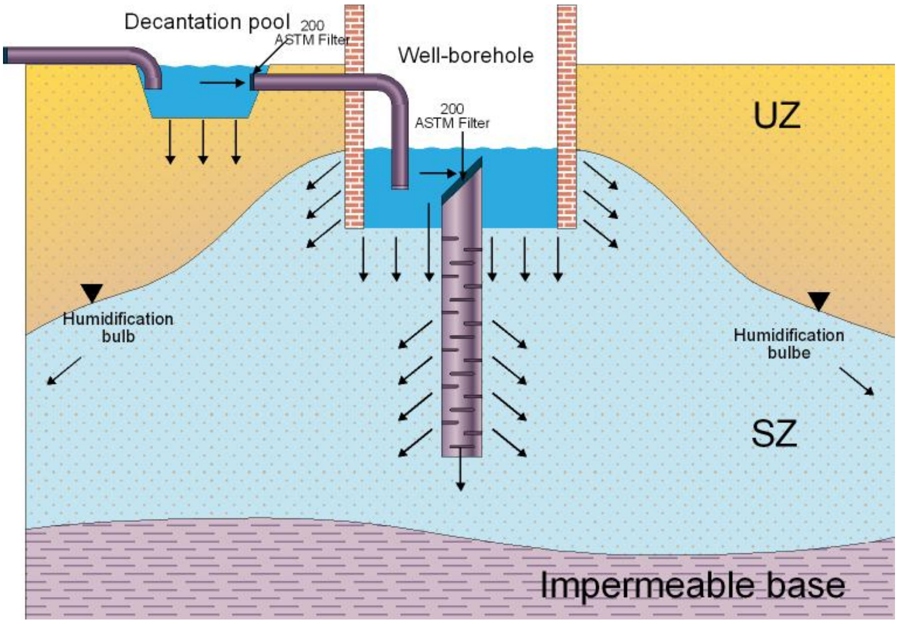


Figure 5-24. Sandy or fine gravel filter in open well (a); building scheme and equipment for MAR wells medium depth (b & c). Modified from Fernández, 2005.

OPERATIVE ASPECTS (T.S. 42 to 46):

42 - Use of dual systems allowing cleaning of one of them whilst the other is operating

The duplication of some facilities allows some operative or management possibilities, what drives to a higher efficiency but might even duplicate costs. Some dual systems examples are tested in Algarve and Serchio RBF catchment.

43 - Cleaning of the vegetation in the MAR facilities

For surface facilities it is a common argue to allow the growth of vegetation or to clean vegetation periodically. Some roots pierce and break the clogging layer, with the subsequent increase in the infiltration rate, the decrease of nutrients from the soil and the reduction of the dissolved oxygen, as direct consequences, but they require certain water consumption.

The experience in the demo-sites is not conclusive by now. In Algarve the vegetation is removed eventually (Seco River, Alcantarinha, figures 5-25). In Brenta, Serchio and Menashe the facilities are cleaned “when needed”.

Figures 5-25 a) & b). Removal of plants in the Alcantarinha infiltration pond, Algarve.

In Arenales it has been removed traditionally, nevertheless, some areas respect the vegetation growth lately, so as to allow studying its effect on the infiltration rate. One example is the green biofilter in the “*Triplet*” scheme (T.S. nº 12).

Cleaning activities are carried out at the end of each cycle of MAR. Most listed species are those hydrophilic herbaceous with a short annual cycle, rapid growth, high root expansion and ease of extraction with roots. Some species that can meet these requirements inventoried in Arenales demo site are:

- *Dactylis glomerata*
- *Agrimonia eupatoria*
- *Althaea officinalis*
- *Althaea hirsuta*
- *Carum verticillatum*
- *Elymus hispidus subsp. hispidus*
- *Galium palustre*
- *Iris pseudacorus*
- *Lolium rigidum subsp. rigidum*
- *Sparganium erectum*
- *Tetragonolobus maritimus var. hirsutus*
- *Triglochin palustris*
- *Ranunculus repens*

The plants must be specific to each area of action, depending on the climate conditions, the substrate, the salinity, etc.

44 - Specific plantation during any season

The technical solution is based on the plantation of appropriate species, due to the fact that roots prepare the soil for a higher infiltration rate [apart from those growing up naturally (see previous T.S.)].

Figures 5-26 a) & b). Some specific species are planted along the spring season as a soil treatment measure.

The use of mulches is only applied in Arenales demo site and it is variable within the area (not every member in the irrigation community respect this measure). The technical solution is based on performing a selective cleaning along the “Triplet“.

45 - Cleaning techniques frequency

At the end of the MAR cycle, it is usual to rake the surface cake, chemical baths of acid, adding calcium, drying or freezing, employment of the BCV, etc. (Pérez-Paricio career, 1998b). The action can be performed during the cycle if the device is equipped with a dual system, which allows recharge on one side while the other is subjected to cleaning.

In the different demo-sites the frequency varies between seasonly and every 3-4 years, being on demand (Algarve), seasonaly (Brenta), yearly (Serchio), biannually (Arenales), every 3-4 years (Menashe), periodicly (Llobregat, Malta S).

46 - Use of Basic Cleaning Vehicles (BCVs)

According to the general experience, it seems absolutely recommended the periodic cleaning of the clogging bed in the different MAR devices, some of them simultaneously with operations. Given the specific conditions of each area (the sort and morphology of the MAR facilities, the presence of bridges, stops, the existence of a service road parallel to the canals, it is therefore recommended the design and construction of a specific BCV prototype, initially at small scale.

This BCV must have a blade or scraper to remove the cake from the bottom, a long and swing arm that allows operating on the canal from the service road, and its articulated withdrawal when reaching bridges, stops, etc. Clogging processes extracted must be stag-nated by gravity. It is possible to carry out either a chemical treatment of the material before its relocation, or their replacement by clean sand, designing the main vehicle of a towing system.

Generic BCVs will be tested in some of the demo sites. In Arenales is in development, introducing slight modifications to tractors or excavators and in Menashe the BCV is a single tractor with selected accesories.

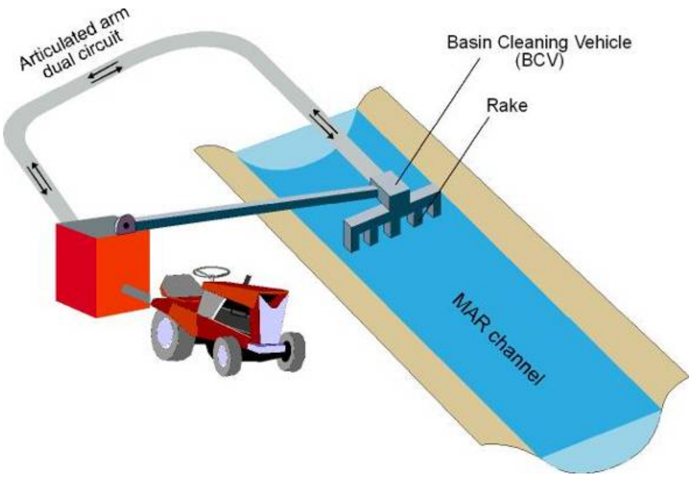


Figure 5-27. Schematic design for a Basin Cleaning Vehicle (BCV) (Woodside & Hutchinson terminology) adapted to the morphology of the canal and based on the use of traditional machinery with easy assembly and disassembly structural modifications. Modified from Fernández, 2005.

In case of positive results should be making BCVs on a larger scale. The design must be „tailor made" and it is recommended the integrated chemical and mechanical attack on clogging layers. Each BCV must be tested and improved along different MAR cycles.

5.2.4. Techniques related to management parameters, good practices plus cleaning and maintenance operations

SAT techniques applied to MAR facilities regarding management, good practices, criteria use and codes.

Figures 5-28 a) to c) Some examples for technical solutions already deployed in Arenales Aquifer, Spain. MAR Well connected to the canal used for water management (a), water layer thickness controlled in infiltration ponds (b), and MAR management by valves / flow meters (c).

Table 5-5. Data base for SAT techniques applied to MAR facilities regarding management, good practices plus cleaning and maintenance operations.

SORT OF TECHNICAL SOLUTION		DEMO SITE							
	Management/good Practices/Use criteria and codes	1-LAVRION	2-ALGARVE	3-ARENALES	4-LLOBREGAT	5-BRENTA	6-SERCHIO	7-MENASHE	8-MALTA S
OPERATION	*47-Management parameters and ex situ techniques related to water management, governance... (describe)*			X (irrigation community regulations)		based on downstream piezometers monitoring	X	5 m3/s for recharge Max 10 m3/s	
OPERATION	*48-Election of the most appropriate period and place to MAR water / obligation due to administrative concessions*		X	X conditioned by administrative concession		Internal organization (Brenta consortium)		Winter. Recharge all the year	X according to availability
OPERATION	*49-Initiate 'soft' MAR cycles (start gradually)*			X		X		According to runoff	
OPERATION	*50-Input flow and flow water speed control (automatic, manual) (specify)*	X manual	X manual	X Manual	X Manual	X Manual	X Automatic	manual - automatic gate	X Manual
OPERATION	*51-Dual systems: duplicated MAR facilities to alternatively manage MAR and cleaning activities*	C							
OPERATION	*52-Alternative sources of MAR water and management (describe)*			X river and WWTP (only at Santiuste)				X (see 1)	
OPERATION	*53-Monitoring chemical properties of MAR water during recharge cycles*	X	X	X only in Carracillo ZNS3 and Alcazarén WWTP	X	X		X	
MAINTENANC	*54-Specific protocol for clogging control*		S	F					

	55-Protocol for proper hydro-mechanical aspects in space and time. e.g. pressure inside a pipeline circuit (describe)								F
	56- Specific cleaning and maintenance programs or decisions made "on the go"?	on demand	on demand (only once)	X (according to budget)	on demand and according to budget				
DECISION SUPPORT SYSTEMS	*57-Integrated system design: all elements are interconnected*	For monitoring, not for use		X		X	I	X	X
	58-Promote participation of farmers or other social agents or stakeholders in water management		X	X					
	59-Limit fertilizers use	X (regulation)	X (Campina de Faro has specific regulations (Vuln Zone)	F (proposal for regulation)		X (regulation)			
	60-Decrease untreated spilling in the area								no needed
	61-Protected perimeter around the MAR facilities			X	X	X Internal (Brenta cons.)	X	2 km	not allowed
	62-Use of protection devices for fauna and people in MAR facilities	Fence		wood fence		Fenced		Fenced	Fenced
	63-Public use regulation			Wetlands only			X	Not opened	F
MANAGEMENT	*64- Early adoption of the Best Available Techniques (to what extent new BATs are tested prior their application?)*			I				previous tests on new techniques are done	
	65-Design and adoption of a proper Watching and Control Program			C	X	X Internal (Brenta consortium)	X	X	stakeholders

	66-Construction of dams specifically designed for MAR		X (Cerro do Bardo Weir)	X			X (RBF)		
	67-Construction of WWTP specifically designed for MAR								x
	68-For those devices constructed due to a R&D specific project, is there any guaranteeing mechanism to operate the system after the end of the project	own activities		X donation to irrigation community	own activities			Mekorot	own activities
	69-Are there already specific operative guidelines? (specify)			C			I	F	
	70-Use of sensors to monitor turbidity, dissolved oxygen, temperature… either inlayers or installed in surface facilities	X	X (for temp. & cond.)	X (ZNS stations)		X	I	X	X Utility control
REUSE	*71- The wells used for MAR were specifically designed or previous wells/shafts were used (change of use)?*		X (reuse of Noras and Cerro do Bardo Well)	X (*Do not close a well, reuse it!*)					
	72-Use of existing natural previous elements to improve MAR efficiency, e.g. River Bank Filtration (RBF direct or inverse), use of dolines, sinkholes…		X (Cerro do bardo)	X inverse RBF, wells in Santiuste			X (RBF)		
	73-Use of pre-existing artificial previous elements for MAR e.g. rivers dams, meander scarfs…			X Alcazarén dam			S		
	To be specified in latter stages								

X	Currently in operation
F	To be developed shortly
I	Intended to be deployed in the future
S	In study
C	Technical solution from references

OPERATION (T.S. 47 to 53):

47 - Management parameters and ex situ techniques related to water management, governance...

In addition to the techniques applied on-site, a series of management parameters and techniques off-site are complementary, such as the most appropriate choice of the period and the most suitable location for the various in-situ techniques.

Management parameters are decided by the irrigation community with expert advice (Arenales), decided after receiving information from downstream piezometers monitoring (Brenta and Serchio), or infiltration volumes between certain limits (from 5 to 10 m^3/s in Menashe).

48 - Election of the most appropriate period and place to MAR water / obligation due to administrative concessions

The period for MAR is related either to environmental conditions or obligations related to regulations. In Algarve, Arenales is conditioned by administrative concession, in Brenta the decision is made by internal organization (Brenta consortium), in Menashe the activity increases in the winter time and in Malta is directly related to availability.

49 - Initiate 'soft' MAR cycles (start gradually)

For those cases with intermittent recharge, some demo sites start the activity gradually (Arenales, Brenta) and other have no option due to they are submitted to environmental conditions such as runoff (Menashe).

Those demo sites with a complex machinery require start gradually to test that the different elements are working well. The progressive start or „soft“ cycle includes:

- Guarantee a permanent water flow input and speed control, either on-site or through remote control.
- In some specific cases some real time water quality control stations allow to interrupt or paralyze the action automatically from the distance if it is neccesary (overfloods...).

50 - Input flow and flow water speed control (automatic, manual)

A recharge program has also been designed with manual valve control, which management depends on climatic circumstances. In general, MAR is minimized on frosty days to prevent the formation of carbonated crusts. It is also stopped in those cases when there are storms and the water turbidity increases considerably in the river's outlet. In that case has been considered preferable to avoid recharging during a period to increase the clogging and silting processes.

All the MARSOL demo sites have manual control, except Serchio and Menashe, where the controls are automatized.

Figures 5-29 a) & b). Manual operation: Manual control of the inlet valve by farmers advised. Close on flood, storms, frost, etc.

51 - Dual systems: duplicated MAR facilities to alternatively manage MAR and cleaning activities

None of the demo site is that big and complex to permit this situation, solution rather appropriate for huge MAR facilities.

52 - Alternative sources of MAR water and management

The management is related to the source of water. In some cases it might be combined (river and WWTP origin, such as Arenales, or runoff, WWTP, desalination plant (Menashe). This solution is closely related to T.S. nº 1. Most of the decisions are made “on the go” according to environmental conditions.

53 - Monitoring and correction of chemical properties of MAR water during recharge cycles

Water characteristics are corrected by means of a proper monitoring in almost real-time. Most of the demo sites count on monitoring networks.

It is recomendable a permanent monitoring of the MAR water at the begining of each cycle. A recommendable alternative is the use of a bio/monitoring laboratory during the initial period. It is also recommended the use of multiparametric probes to control the most relevant parameters, such as TSS, TDS, TOC, conductivity, nitrates concentration, temperature and pH.

Some measures to correct certain parameters have already been presented, as the reduction of total dissolved solids (TDS) in the MAR waters using devices of haven and filtration (TS 8); control of the pH of the receiving environment through the addition of acids or bases depending on the conditions of the environment (calcium, acids, bases, etc.) with special care to avoid the generation of precipitates (TS 9); to avoid the increase of dissolved oxygen in MAR water (TSs 20 & 21).

MAINTENANCE (T.S. 54 to 56):

54 - Specific protocol for clogging control

Series of activities to reduce clogging formation and a permanent incidence on them are under permanent study. Some draft guidelines have been already proposed by some partners, e.g from Menashe demo-site (Mekorot, 2015):

- Clogging in the recharge well is the main problem in maintaining its recharge capacity.
- The right rehabilitation method should be determine for each well according to the clogging source and to the rate of the clogging phenomena.
- The desalinated water in Israel have very low suspended solid and organic matters. The clogging may come from air bubbles during the injection (air entrainment clogging).
- Periodic backwashing (re-pumping) of the recharge wells at specific times of volumes recharged. The frequency may determine after running a pilot.
- We found only one hydraulic instrument that enable to inject and to pump from the same instrument (Baskiflow control valve-FCV).
- Mekorot are running a pilot to study the air clogging problem and to design her own pumping/ injection system.

In Algarve this process is „in study“ and in Arenales it is expected to be deveoloped shortly.

55 - Protocol for proper hydro-mechanical aspects in space and time; e.g. pressure inside a pipeline circuit…

Apart from monitoring water quality evolution, hydro-mechanical aspects should be under permanent control in closed circuits and pipelines. Some examples of application have been found in Israel (figure 5-30 in Tel Aviv area). In the case of Malta demo site, it is expected to be developed shortly.

Figures 5-30 a) to c). Control of pressure devices for a MAR closed pipeline circuit.

Flow-rate measures are being collected automatically in some demo sites, such as Arenales and Serchio (figure 5-35a).

Figures 5-31 a) & b).Sand filter *"in itinere"* equipped with a flow meter.

In cases of having a little space availability, a new technical solution under development is to intercalate slotted pipes along the recharge pipeline. This design is currently being tested in Carracillo region to recharge the aquifer below pine forests, very often in that area (figure 5-32).

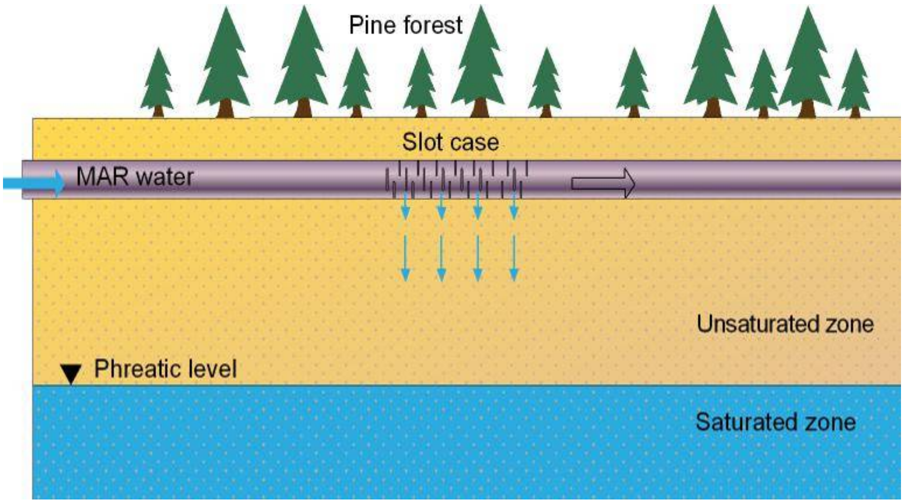


Figure 5-32. Slotted case pipeline intercalated in the recharge circuit (modified from Fernández, 2005).

56 - Specific cleaning and maintenance programs or decisions made "on the go"?

The most usual programs are either on demand or depending on the budget available for cleaning and maintenance. In Lavrion and Algarve are done “on demand”, in Arenales and Llobregat “according to the budget” and in other cases there is an internal organization and decision are made “on the fly” (Brenta).

DECISION SUPPORT SYSTEMS (T.S. 57 to 63):

Any applicable code designed for an area in which MAR operations are carried out should consider, at least, the following issues:

57 - Integrated system design: all elements are interconnected

Interoperability is an usual technique to achieve the highest facilities´efficiency. It allows a rapid replacement or improvement of damaged key elements. An integrated system also allows the detection of ecological or environmental sites requiring a restoration, etc.

For this purpose, enhanced or inducted integrated MAR is emerging as a appropriate alternative, what allows a greater control on the receiving medium. Some of the main alternatives and operations to be considered are:

- Use of dry and abandoned wells for MAR.
- Use of trenches for water conduction.
- Creation of closed circuits between the shaft and the recharge area, equipped with a peristaltic pump.
- Joint construction alternatives.
- Permanent monitoring.

58 - Promote the participation of farmers or other social agents or stakeholders in water management

On the one hand, to involve stakeholders and key population more capacited to manage processes related to MAR activity is giving good results with more pros than cons (personnel availability, greater flexibility, rapid intervention in case of remote monitoring, etc.). In the other hand, stakeholders are the main beneficiaries of their own conduct, they adquire a certain reputation are are appreciated by the community, etc. The participation of stake-holders is only present in Algarve and Arenales demo sites.

59 - Limit fertilizers use

The limitation on the manures/fertilizers/pesticides... application is regulated in Labrion, Algarve (declared vulnerable zone for diffuse nitrates pollution) and Brenta. In Arenales there is a specific proposal for regulation apart from the compulsory water quality guidelines.

60 - Decrease untreated spilling in the area

The presence of untreated spilling is a problem for groundwater what is reduced by means of the installation of water treatment plants and awareness to minimize the dumping and spilling of uncontrolled effluents in teh areas.

In the demo sites and in general stakeholders are aware of these sort of impacts and there is no need of measures to prevent spills.

61 - Protected perimeter around the MAR facilities

The establishment and zonification of a perimeter of protection ordenating the activities in the related area have not been done yet. There are different scenarios such as an internal organization (Brenta, Arenales); and in some cases it is unfeasible due to the shortage of terrain (Malta). In only one case, Menashe, there is a two kilometer ratio perimeter around the MAR plant, what is the best technical solution beyond any doubt.

62 - Use of protection devices for fauna and people in MAR facilities

In general there are physical barriers around MAR facilities to avoid potential incidents with animals and men. Most of the MAR facilities are surrounded by a fence.

63 - Public use regulation

There is not any regulation of the public use, except for some wetlands related to MAR activity, e.g. Arenales, where some activities related to promote scientific, educational and environmental activities have already been done. In Malta is envisaged to design a rapid regulation.

MANAGEMENT (T.S. 64 to 70):

64 - Early adoption of the Best Available Techniques (to what extent new BATs are tested prior their application?)

According to references, the Best Available Techniques (BATs) should be adopted promptly as soon as new discoveries can be considered of proven effectiveness. The survey for the demo site leaders has driven to the conclusion that BATs must be tested for each specific conditions prior any indiscriminated application.

65 - Design and adoption of a proper Watching and Control Program

The design and establishment of a surveillance and control system, to monitor the evolution of MAR facilities, such as the installation of a continuous/real time system to register the main parameters evolution in remote is a good thing. The systems employed by now apply an operating Center via GSM (Arenales, Llobregat, Brenta, Sechio, Menashe and Malta South).

Some specific measures are usually proposed, such as early overflood warning systems, depth of alert alarms, measures to minimize the visual impact of some facilities, etc.).

The surveillance and control program should take into consideration:

- Specific Protocol to study the clogging evolution based on the monitoring of simple parameters.
- Design of protocols and hydro-mechanical aspects combinations correct in the space and in the time.
- Treatment of the system as an „integrated system" in which all the elements are interrelated.

66 - Construction of dams specifically designed for MAR

In the cases of river divertion, the dam design plays an important rol in the effectiveness of the MAR structure. In Algarve Cerro de Bardo the catchment was specifically designed, as well as in Arenales. In Serchio river the RBF system has also an adapted and specific design.

The main technical solution must reside in the possibility of pretreating the MAR water in the own dam.

A singular case deployed in Arenales demo site was the construction of one specific dam just in the river where Carracillo aquifer is drained (figure 5-33). The water level in the river has been raised and consequently the water table in all the wells located in the area close to the river has risen accordingly. This action has represented energy saving of up to 40% (MARenales movia, annex 1).

Figure 5-33. Technical solutions already deployed in Arenales Aquifer, Spain. This dam is controlling the Carracillo aquifer base level, raising the water table depth in more than 100 close wells.

67 - Construction of WWTP specifically designed for MAR

In contrat with the previous case, most of the WWTP used in the demo sites were present before MAR activities begun, expect for the Malta case, where the WWTP was designed according to the expected use. The connections, junctions, by-passes, etc. were specifically designed for MAR avoiding potential flaws.

68 - For those devices constructed under a specific R&D project, is there any guaranteeing mechanism to operate the system after the end of the project?

This is a usual problem in most of the experimental facilities. The measures adopted to avoid the abandonement of the facilities are no other than the donation to stakeholders and local population, in case they have received the awareness of the advantages of having it during the project duration.

In Lavrion, the facilities are used for own activities with consequtive projects, in Arenales the construction was transferred to the irrigation community, who are responsible of maintenance and propoer use; in Llobregat the ponds are used for own activities as well as in Malta south. In Menashe, the Mekorot company takes care of the successive devices deployed.

69 - Are there already specific operative guidelines?

The operative guidelines should be an essential part of MAR projects and include bench-marks and indicators related to the economic scope and the savings accomplished by the MAR technique application. For example, for Arenales aquifer, where guidelines have been adopted from a private proposition (Fernández, 2005) it has been calculated a reduction in pumping cost until 48% in about 100 wells due to the risen groundwater table (see MARenales movie, 2015, Fernández et al., 2015).

In Serchio and Menashe this guidelines are expected to be implemented shortly.

70 - Use of sensors to monitor turbidity, dissolved oxygen, temperature… either inlayers or installed in surface facilities

This TS is closely related to TS 53 and considered of the biggest importance for all the partners in the consortium. All the demo sites have sensors to monitor different parameters, except Serchio, where they are in implementation process.

The measures are complemented by those from the utility control, what makes the data set collection huge, requiring an interoperability effort.

The main TS is based, consequently, in the standardization of the collected datasets; they must be uniform and their procurement and interpretation must be easy. There is a whole Work Package (11) in the project to study the different datasets origin and to make them compatible.

Figures 5-34 a) to c). Infiltration ponds in Tel Aviv surroundings equipped with sensors to monitor specific parameters.

It is recommendable to install anti-vandalism designs to protect data collection and communication systems (figures 5-35).

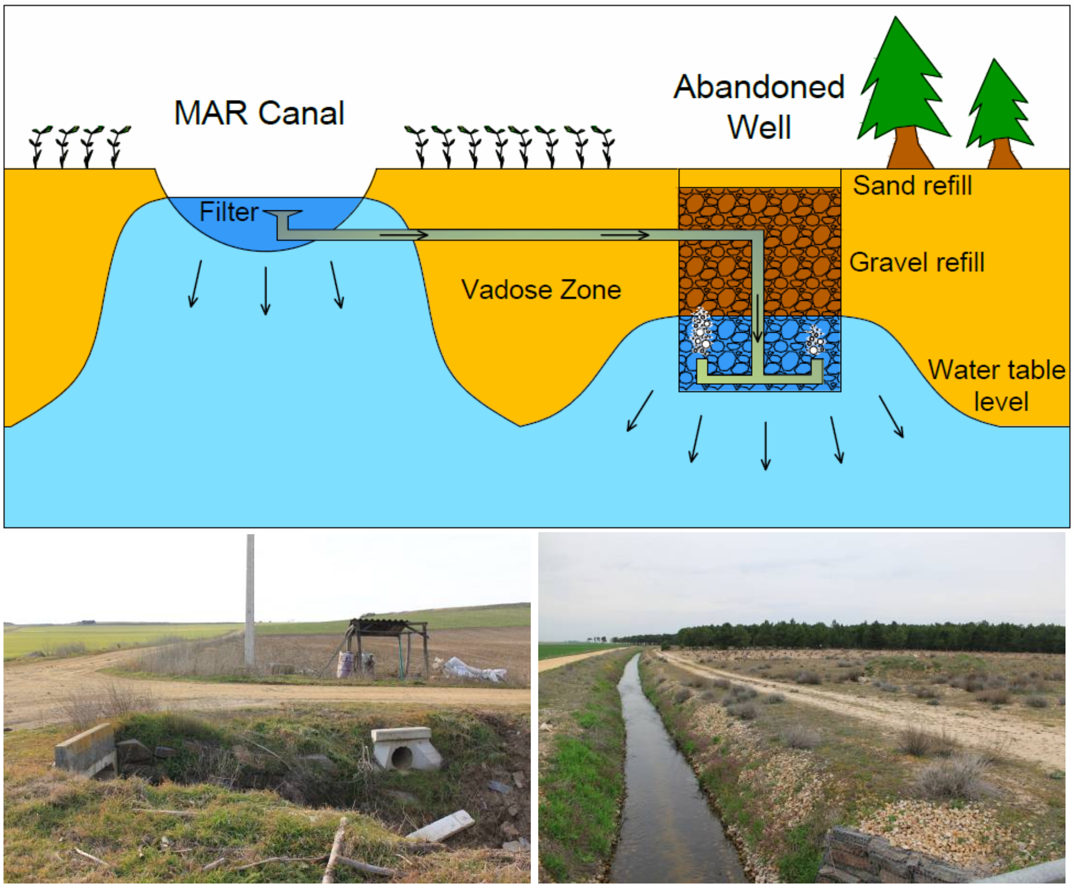
Figures 5-35 a) & b). Examples for anti-vandalism systems to protect data collection and communication elements (Serchio demo-site).

REUSE (T.S. 71 to 73):

71 - The wells used for MAR were specifically designed or previous wells/shafts were used (change of use)?

Some wells that have become unproductive or got dry due to the groundwater table decline can be “reused”. The accomplished example has been by means of a connection with the surface MAR system. In Arenales demo site two old wells were connected to the MAR system (reuse) by means of a pipeline and the well was refilled in gravel and sand, counting with a cheap and productive invisible MAR device which increases the efficiency of the MAR system (figure 5-36a and photos 5-36b&c). Two wells more have been “reused” in Algarve demo site (Cerro do Bardo and Noras).

This specific case has brought up a new slogan: **“do not close a well, reuse it”**.



Figures 5-36 a) to c). Scheme for a “reused” well (invisible MAR structure connected to canals or to infiltration ponds) by means of a pipeline with the surface MAR system. Example implemented in Arenales aquifer.

72 - Use of existing natural previous elements to improve MAR efficiency, e.g. River Bank Filtration (RBF direct or inverse), use of dolines, sinkholes…

There are a few examples of pre-existing structures used for MAR apart from wells, in special related to river bank filtration systems, using well dug in the river bank for the Serchio and Arenales cases (figures 5-37a and 5-37b, respectively).

Figures 5-37 a) & b). Direct and inverse RBF systems in Serchio and Arenales demo sites.

The use of sinkholes to access the aquifer directly is a practice not used in any demo site, but there are some examples in the hydrogeological literature, e.g. in DINA-MAR (2011).

73 - Use of pre-existing artificial previous elements for MAR, e.g. rivers dams, meander scarfs…

This line of action is intended to be deployed in the future for a meander scarf in Serchio river area. The TS applied is expected for latter reports.

The experiences obtained in the demo sites after several years of operation drive to the same conclusion reported by different authors and experiences distributed all over the world, which, in general, can be considered feasible, positive (Martin & Dillon, 2002), economically satisfactory (Dillon, 1996), etc. Any alternative to be chosen should take into consideration two basic objectives (Dillon *et al.*, 1999):

- Maintenance of the current resource of the aquifer in the best conditions of quality and quantity as a water management element.
- Ensure the provision of water supply to end-users avoiding any risk on the precedent target.

Further improvements and designs collected along the rest of the project will be presented in coming deliverables such as 13.3 (Month 35).

5.3. Proposal for a MAR integrated system design applying technical solutions. An example for Arenales aquifer

This example is eminently **practical** and based on the main problems that have been detected during years of activity in Arenales aquifer (Santiuste basin) MAR activities, and the actions and new lines of research undertaken to resolve them. Some of these solutions have already been applied by either the Spanish Ministry of Agriculture or the irrigation communities in charge of the devices. Other must be solved yet.

This example has been selected due to its maturity, it is one of the demo-sites that firstly started, or even the oldest. The binomials have been numbered according to the carto-graphies displayed in the figures 5-38 and 5-39.

STEPS FORWARDS A HIGHER WATER MANAGEMENT EFFICIENCY (CONSIDERING, IN SPECIAL, IRRIGATION USE)

Some of the dysfunctions detected along the operability of the device have been:

1 Pipe instalation in sand soil
2 Pipes sealed across MAR zones
3 RBF system besides a damm
4 High diameter MAR well
5 Stopping devices affected by cascading effect
6 Hydric restoration of wetlands by means of MAR and SAT techniques
7 Furrows designs for infiltration ponds
9 Improvement of MAR boreholes designs
10 Tests in channels equiped with geofabrics.

1-2. Some alternatives have been analysed for the superficial recharge in areas with a large occupation of land and pine groves, where it is not possible to implement superficial type devices. For this reason, studies and testing have been undertaken on methods for inserting sub-superficial devices inserted into the pipes themselves that direct the water coming from the intake rivers towards the MAR systems.

3. The original dams require to be modified in order to facilitate water purification through the river alluvial and later captured in nearby wells, thus facilitating River Bank Filtration (RBF) systems.

4-5. In all the cases, there have been detected problems caused by air inflow into the aquifer together with physical clogging (in high diameters infiltration wells and at the bottom of infiltration ponds and canals). The stopping devices emplaced at the channels headings and in the connections with the supply pipes, produced a rise in the dissolved oxygen concentration of MAR water and a reduction in infiltration rate and total amount due to Lisse effect (Krul & Liefrinck, 1946).

6-8. Variations were experienced in some aspects related to the hydrogeological operation of the system, such as changes to the water quality in adjacent wetlands, changes in the flows of springs, etc. These problems are requiring specific studies, usually based on special induced recharge designs.

7. Clogging problems in infiltration ponds at different depths, as well as the generation of carbonated crusts in sectors of the aquifer with a reducer chemist of subterranean waters or originating from recharge during frost cycles.

9. Inadequate well designs and recharge probes that enable fines to enter, abundant intake of air in the aquifer and limited infiltration, usually to take advantage of pre-existing abandoned wells.

10. The unbalanced distribution of clogging processes was detected in the slopes, which made it necessary to modify the morphology of the canals and ponds, to apply specific cleaning techniques and/or to install geofabrics.

SOME SOLUTIONS PROPOSED FOR THE DESIGN AND IMPLEMENTATION OF SATS TECHNICAL SOLUTIONS

The solutions proposed for the environmental impacts and dysfunctions mentioned have involved several years of research and progressive improvements, Related to Soil and Aquifer Treatment Techniques and structural designs.

Generally speaking, the initiatives have been a reiterative process, up to the point that there are still several problems that are not adequately resolved and designs are pending construction. However, the current devices present notable quantitative and qualitative improvements over the initial design built 13 years ago. The main activities undertaken, presented in the same order of the statement of reasons, include:

1. Pretreatment filters and slot pipe devices inserted along MAR pipelines “in itinere”
2. Invisible conductions and filters
3. Adoption of River Bank Filtration mechanism in new areas

4 Newly constructed artificial recharge wells with decanters and filters
5 Ideas to avoid cascading effect (gas clogging)
6 divertions from the MAR device to degraded wetlands
7 Complementary facilities to increase water salinity for salt lakes restoration
8 Ploughed furrows designed for higher infiltration values at the bottom of channels and infiltration ponds
9 Wells reused and new specific design for medium and depth wells and boreholes
10 Modify the morphology of the canals and ponds, and design specific cleaning techniques

1-2. The recharge devices inserted into pipelines with pieces of slotted case and filtration sections allow an “in itinere” recharge. These sorts of tests are accompanied by filters for pre-treatment of the water inside of the same pipe. The stretches are surrounded with gravel in a “drainage trench” type device. There is also a maintenance programme for periodic replacement of the gravel.

3. The construction of dams for the intake of water from the river has been accompanied by initiatives of well perforation in the river banks. This River Bank Filtration system (RBF) is becoming productive and broadly deployed in the area.

4, 5-9. The newly constructed infiltration ponds and wells have a specific design, based on the insertion of decanters and filters, elevated diameter and perforation of a probe inside it. Many of the designs applied are inspired from the works of Bouwer, 1999 and 2002 and Olsthoorn, 1982. Communicating vessel systems are also being tested in some detention devices, as well as chutes to minimise aeration. It is becoming a priority technique minimising the cascading effect in the constructions and avoid the air burbles entrapment, what brings, as a consequence, a reduction of the amount of fines and air what is introduced into the aquifer and, consequently, greater infiltration rates.

6-7. Some devices have been designed for the induced modification of the quality of MAR water destined for environmental purposes. In the case of regeneration of La Iglesia salt lake, located at the edge of the aquifer, a chute has been constructed, which forces the interaction of natural salts that lie in the area with the recharge water, preserving its quality. In this manner, with high surface interaction and little time, much residence time is reduced, increasing the contact surface MAR water-salty soil and undersoil.

8. The activities in the infiltration ponds have involved studying the formation and distribution of clogging processes on the horizontal and vertical. Ploughed furrows have been tested in pilot ponds with different wavelengths, and several infiltration trials undertaken with annual frequency. In general the 80cm equidistant ridges have provided higher infiltration values. In the case of canals, there are replaceable geofabrics in the furrows, which facilitate the harvesting of fines and replacement with clean natural sand. A recharge programme has also been designed with manual valve control, depending on climatic circumstances. In general, recharge rate is minimised in freezing days, so as to prevent the formation of carbonated crusts.

10. After several trials, slopes with a 2:3 incline have been built in the channels, with a higher rate of infiltration in the walls observed. In fine sands 1:1 slopes have chosen for a greater

durability. In order to improve cleaning and maintenance operations, a specific Basin Cleaning Vehicle (BCV) has been designed, which is adapted to the morphology of the canal and based on the use of traditional machinery with easy assembly and disassembly structural modifications. This design has not been definitively implemented yet.

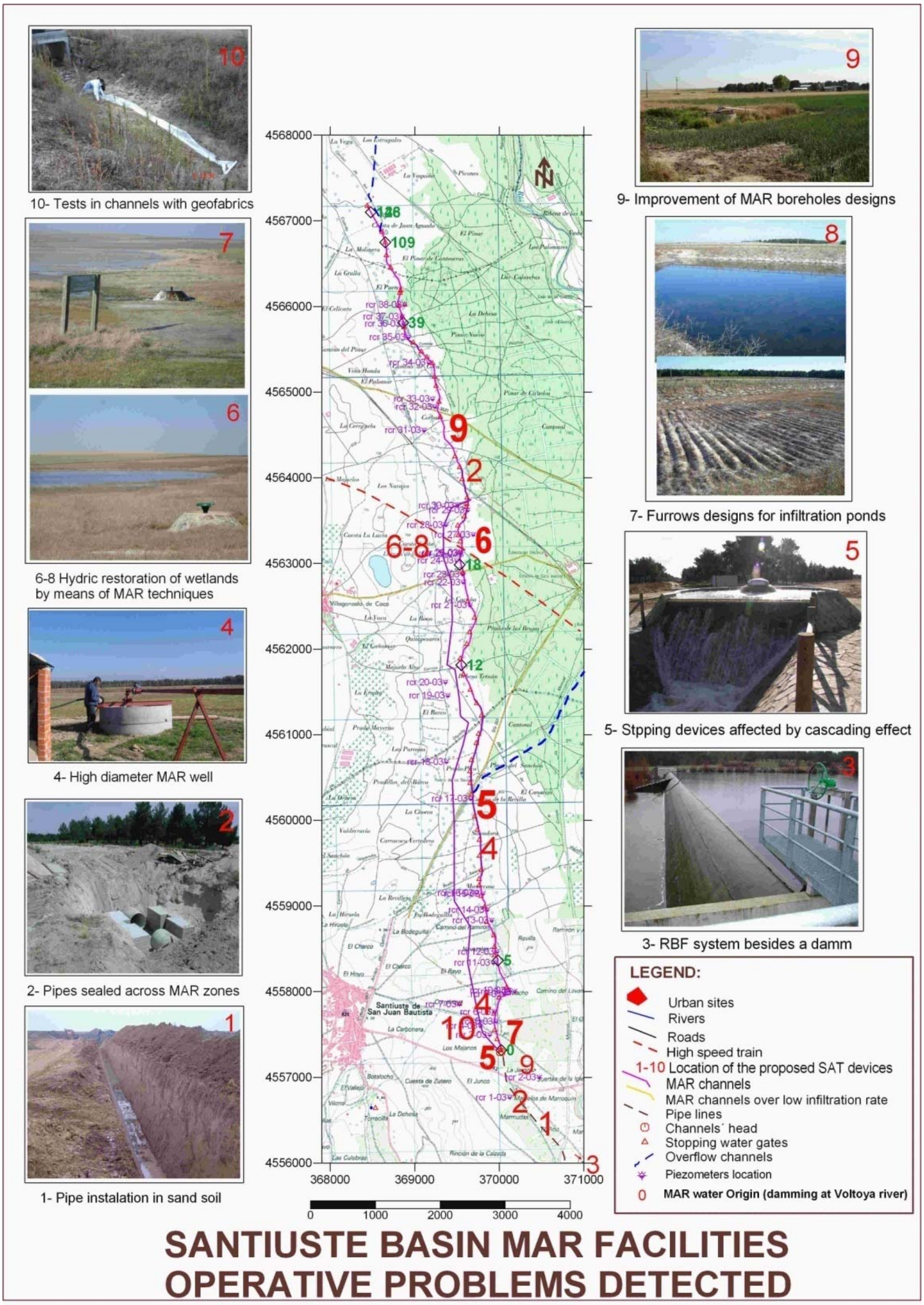


Figure 5-38. Examples and position of the biggest impacts and inadequate designs that affect the MAR facilities in Santiuste basin (Arenales Aquifer, Spain) and some actions proposed or performed to solve them (modified from Fernández and Senent, 2012).

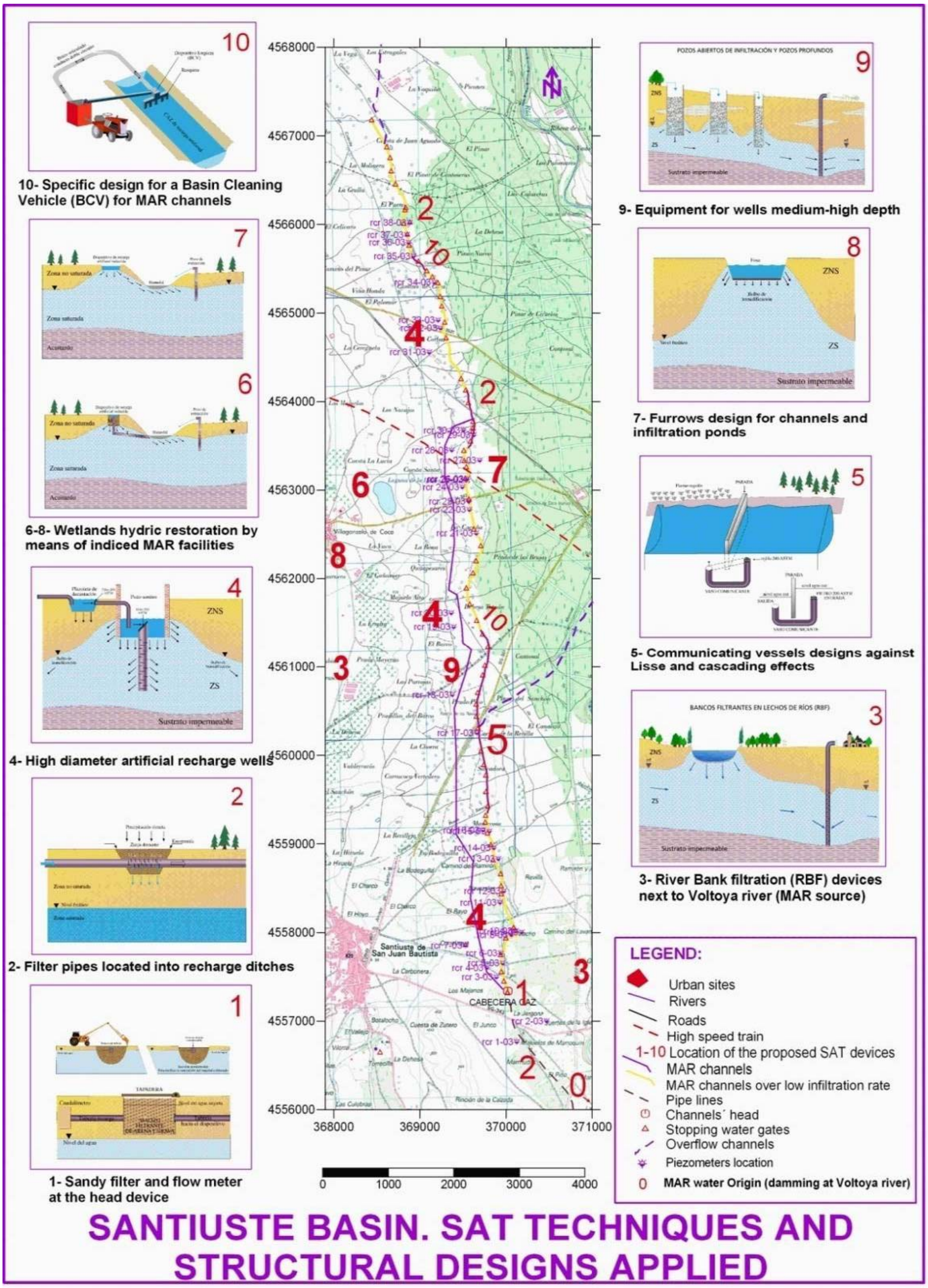


Figure 5-39. Proposal of solutions based on SATs techniques and structural designs to solve the biggest impacts and inadequate designs that were affecting MAR facilities. Example for Santiuste basin (the results from the rest of the pilot MAR sites are also enclosed in these techniques): 1-2. Filters intercalated along the pipeline crossing sandy aquifers (for areas with a short availability of superficial terrain). 3- Proposals for RBF systems close to MAR dams. 4- Designs for high diameter artificial recharge wells. 5- Devices to avoid the increase of dissolved oxygen in recharge waters. 6-7- Environmental restoration of wetlands by means of induced recharge. 8-9. Designs to minimize the clogging and Lisse effect in wells, channels and infiltration ponds. 10. Specific BCV design. Modified from Fernández & Senent, 2012.

6. Activities for dissemination and stakeholder awareness

The relations between the MARSOL researchers and Los Arenales stakeholders, specially related to agroindustry is close and cooperative. There are three different types of relations within this framework to improve water management by public participation and working on a deeper education of the farmers groups involved in the irrigators communities.

Within these objectives, two training workshops have been done specially dedicated to farmers and MARSOL partners: MAR4FARM and MARenales.

6.1. MAR4FARM WORKSHOP: MAR IN "LOS ARENALES" AQUIFER.

On the 29th and 30th of October briefing workshops called MAR4FARM, were held at Santiuste de San Juan Bautista and Gomezserracín (Segovia), respectively. Sessions were especially aimed to farmers and the general population in these rural areas, so, technical language was eluded in presentations. The irrigation communities collaborated actively in its organization and dissemination.

Figures 6-1 a) to c). MAR$_4$FARM workshops logos.

Final programs (Santiuste de San Juan Bautista, 29/10/2014 and Gomezserracín, 30/10/2014) and presentations

29th and 30th October 2014 (2 days)

<u>Santiuste de San Juan Bautista, 29/10/2014</u>

1-Innovative groundwater artificial recharge techniques and experiments. Schemes to solve WR problems in the Mediterranean Region. Dr. João Paulo Lobo Ferreira

2- *La masa de agua subterránea Los Arenales. Valoración de su estado (Los Arenales groundwater body).* D. Víctor del Barrio Beato

3- *Regadío con agua regenerada. La experiencia de Alcazarén (Reclaimed water Irrigation: Alcazaren case).* D. José Luis Sevilla Portillo

4- *Funcionamiento del acuífero de la Cubeta de Santiuste (Santiuste basin aquifer in operation).* Dr. Enrique Fernández Escalante

5- *Descripción de las obras (Works description).* D. Roberto Fernández García

6- *Impacto ambiental de la actuación (MAR environmental impact).* Dr. Jon San Sebastián Sauto

7- *Técnicas de gestión hídrica a escala de usuario. Recomendaciones. Presentación del libro: 2002-2012. Una década de recarga gestionada. Acuífero de la Cubeta de Santiuste (Castilla y León)*

(Water Management Techniques at user level. Recommendations. Book Presentation: 2002-2012 : A decade of managed recharge: Santiuste Basin Aquifer). Dr. Enrique Fernández Escalante

8- *Eficiencia energética y uso de energías alternativas en el regadío. Técnicas practicas. (Energy efficiency and alternative energy power use for irrigation. Technical practices).* D. José Manuel Omaña Álvarez

<u>Gomezserracín, 30/10/2014</u>

1-*Innovative groundwater artificial recharge techniques and experiments. Schemes to solve WR problems in the Mediterranean Region.* Dr. João Paulo Lobo Ferreira (similar presentation in both cases)

2- *La masa de agua subterránea Los Arenales. Valoración de su estado (Los Arenales groundwater body).* D. Víctor del Barrio Beato (similar presentation in both cases)

3- *Estudios y trabajos previos y futuros. Funcionamiento del acuífero de "El Carracillo", Segovia Preliminary and future studies and Works: "El Carracillo" aquifer fuctioning).* Dª Carmen Macías Antequera

4- *Impacto ambiental de la actuación, en especial sobre las masas forestales (MAR environmental impact, focused on woodlands).* Dr. Jon San Sebastián Sauto

5- *Historia y descripción de la obra del Carracillo. Presentación 2014. (History and descrption of El Carracillo Recharge Works).* D. Roberto Fernández García

6- *Recomendaciones de gestión hídrica a escala de usuario de Los Arenales (Water management advices at user level in Los Arenales).* Dr. Enrique Fernández Escalante

7- *Regadío con agua regenerada. La experiencia de Alcazarén (Reclaimed water Irrigation: Alcazaren case).* D. José Luis Sevilla Portillo

8- *Eficiencia energética y uso de energías alternativas en el regadío de los Arenales. Técnicas practices (Energy efficiency and alternative energy power use for irrigation. Technical practices).* D. José Manuel Omaña Álvarez (similar presentation in both cases)

Final presentations are available on the Internet at MARSOL website, MAR to MAR-K€t site and the IAH MAR sister page: http://www.dina-mar.es/post/2014/11/17/MAR4FARM-PRESENTACIONES-PRESENTATIONS-AVAILABLE-FREELY-ON-THE-INTERNET.aspx

Figures 6-2 a) & b). Leaflet cover with the program of both workshops. Final presentations are available on the Internet at MARSOL website, MAR to MAR-K€t site and the IAH MAR sister page: http://www.dina-mar.es/post/2014/11/17/MAR4FARM-PRESENTACIONES-PRESENTATIONS-AVAILABLE-FREELY-ON-THE-INTERNET.aspx

Lessons learnt and conclusions from the conference itself

- The conference has been addressed with a broad approach, from a general and global perspective, to the specific area, being the first part less interesting for the attendance than the second one. In future sessions, it would be desirable to reduce preliminary and general aspects, strengthening on unambiguous concepts.
- The stakeholders seemed to be more interested in the current situation and, specially, in the future evolution of the project and the area, and how they will be affected as individuals. They payed little attention to past events.
- Speakers must make a greater effort to avoid technical language.
- The purpose of the workshop has been successfully achieved, as knowledge has been brought to groundwater users related to these MAR activities, who welcomed the workshop with satisfaction and gratitude. That is why this kind of workshops should be periodically repeated

Remarkable/ innovative aspects from the presentations

- It is important to highlight the need of considering the management and maintenance of MAR facilities as one of the most important aspects to ensure appropriate operation and preservation, as well as to improve its visibility.
- MAR is essential to ensure a good irrigation water quality (less nitrates and arsenic)and quantity to be applied by farmers. The extraction is more or less equal to the infiltration rate: aprox, 62 hm3/year, according to the hydrogeologist Mr. Victor del Barrio. And this

situation is expected to get worse in the future according to climate change previsions. The rise of the water table level for the irrigation period has a direct impact in a lower energy consumption of irrigation water pumping from wells, and therefore, in a reduction in the electricity or fuel bill.

- Good MAR water quality ensuring for irrigation purposes brings an added value for farmers in the shape of better quality crops with higher yields, further higher incomes and an easier marketing.
- In short, the higher crop yields and lower costs (by reducing the electricity bill), could impact in a more optimal economic return to farmers who consume groundwater from MAR devices.
- Assuring sustainability of irrigation will allow to fix population in the area.

Specific conclusions and recommendations

- In the main sectors of Los Arenales aquifer, the irrigated surface has doubled in 10 years.
- It might be important to advise users and the population in general, related to future water management: “Do not close a well, reuse it”. Those old wells that have been abandoned due to diverse reasons might be included in the MAR system. It can be accomplished by connecting the old excavation to ponds or channels by means of a single pipe (passive scheme with no energy consumption), and refill it with coarse gravel. This sort of actions is affordable and increases the groundwater storage. Some particular experiences in Santiuste Basin are improving the effectiveness of MAR devices.
- Another key element within this framework might be: “Association as a fortress”. Communities operate MAR facilities more effectively than individuals.
- Irrigation communities must be part, and even the main contributor to the operation and conservation of MAR devices. It is important to count on expert advice, too.
- Groundwater users and practitioners should monitor water authorities, due to changes in the MAR permits, changes in allowances depending on environmental conditions, potential calls to obtain some support mainly those related to changes in environmental conditions.
- The public-private partnership (PPP) schemes must be approached, as well as the schemes based on innovation and multi-level governance applicable for MAR zones.
- It is endorsed to include in the dissemination material, such as map panels or brochures informing groundwater users, data about estimation of the amount of money saved by means of MAR in irrigation since the beginning of the activities (electricity, pumping cost, etc., and the additional incomes after converting a rain-fed area into an irrigation area).
- It is also imperative to disseminate the results and practical criteria obtained in another demo sites and international experiences.
- The slogan based on the info exposed in INPRESS report: “MAR is a driving force” must be defended permanently.

General conclusions

- MAR technique is developing a strong practical potential that should be broaden.
- It is important to walk steps towards the general awareness that induced recharge increases the groundwater quantity as well as the quality. The concept of MAR as a "driving force" must be remarked permanently.
- The current state of the MAR facilities must be adapted to new MARSOL and MAR TO MARK€T objectives (demo sites).
- It is important to perform MAR activities without interfering in the farmers' work, so as to facilitate their cooperation.
- Blue print datasets have huge differences among Spanish regions, what is due to, in a certain measure, their industrial activity. So, industries involved in MtoM AG should be carefully chosen.
- The "green water" is becoming more and more important in the Spanish economic activity, and its connection to MAR is becoming more important in order to avoid environmental negative impacts.
- Lower energy consumption due to water table raise, and the consequent reduction of pumping cost, is, beyond any doubt, profitable for farmers, due to the lower electricity bill.
- SAT-MAR activities, understood as irrigation with reclaimed water, brings a good opportunity for future rural development, but requires a very careful and expert management, as well as permanent improvements, in order to avoid negative experiences with a direct influence in the public perception.
- The dissemination of R&D advances to users is a key element for "future MAR". It is important the cooperation of the receivers. This can be achieved by means of increasing their interest in the project. Providing advice on their economical savings plays an important role in this issue.
- It is necessary to maintain and increase the channels of communication for the exchange of international experiences, with the aim of sharing criteria, results, experiences... It is convenient to transfer both, the negative and the positive experiences.
- The water balance used by the 9 industry branches considered by MtoM AG must be solved when possible for different countries. It is important to point out the most relevant aspects for each:

    1. AGRO-INDUSTRY
    2. WATER SUPPLY INDUSTRY
    3. WASTE WATER TREATMENT PLANTS
    4. DESALINATIONS AGENTS
    5. BOTTLED COMPANIES
    6. GOLF COURSES
    7. PUBLIC ADMINISTRATION BRANCHES
    8. BALNEARIES & SPAS (SALLUS PER AQUAM)
    9. HOTELS AND TOURIST FACILITIES (MARKET UPTAKE)

6.2. MARenales TRAINING WORKSHOP

From March 9th to 11th the training Workshop “MARenales” was held in the vicinity of the Arenales aquifer, Castilla y León, Spain, organized by Tragsa. MARSOL members working in the field of water management in large irrigation areas have shared their expertise with regional stakeholders as well as other experts from the MARSOL project and invited experts from Korea, Israel and from the Spanish Geological Survey. The main objectives of this training workshop were:

- To expose the technical solutions applied by the partner’s expertise regarding each demo-site, studying the applicability to be used in other equivalent environments.
- Exposition of successful construction criteria (specific designs, materials…)
- Exposition of successful water management criteria, mentioning the "musts to" as well as the "mustn’ts to".
- Criteria for cleaning and maintenance of the existing structures lengthening the infiltration capacity and the life-span of the structures.
- Other criteria that the expert speakers could include in their presentations regarding technical solutions, benchmarking, indicators and dissemination procedures.
- Response to all the questions that could arise along the full workshop.

The workshop had two sessions, one project-internal session and one open session involving farmers from the irrigation community and other end-users. Sessions were held in Coca Castle (Segovia), and Gomezserracín (Valladolid). The field trip, apart from visiting MAR facilities, included visits to agro-industries related to MAR, such as a vegetables packaging and exportation factory.

There have been in total 50 participants from seven European countries, plus Korea and Israel, including technicians from the regional river basin authorities and from the regional government as well as invited guests from other, thematically related European projects. The organizers of the workshop have received written congrats from participants, outlining the good example of technical solutions deployment from the theoretical background, the excellent participation of farmers in the water management schemes and relation to MAR activities, and the excellent framework between researchers and end-users.

Figure 6-3. MARenales workshops logo.

Final program and presentations

Coca village, Segovia, 9/3/2015. Internal workshop with external technicians. English as official language.

Technical Solutions and benchmarking presentations:

1. *"Effective MAR performance in water-curtain insulated greenhouse complex: technical solutions and problems unsolved"*. Kim Yongcheol, EAP, Kigam, Korea
2. *"Los Arenales aquifer: description and Managed Aquifer Recharge (M.A.R.) facilities. Explanation of the Los Arenales aquifer, demo site description and hydrogeological functioning"*. Enrique Fernández Escalante, TRAGSA, Spain
3. *"Technical solutions for MAR facilities construction. Detailed description for building works, design and materials employed"*. Roberto Fernández García / Francisco de Borja González Herrarte, TRAGSA, Spain
4. "*An Environmental approach to MAR Technical Solutions and benchmarking"*. Jon San Sebastián Sauto, Tragsatec, Spain
5. *"MARSOL Portugal: Constructions and site investigation techniques"*. Tiago Carvalho, TARH, Portugal
6. *"Demonstrating managed aquifer recharge as a solution for climate change adaptation: experiences from LNEC Portugal"*. Teresa Leitão & Manuel Oliveira, LNEC, Portugal
7. *"Managing technical solutions for MAR in Los Arenales aquifer. Practical advises"*. Enrique Fernández Escalante / Roberto Fernández García, TRAGSA, Spain
8. *"Demoware invited presentation"*. Elisenda Taberna, Veolia, Spain.
9. *"Novel technical method to monitor temporal change of FW-SW interface for a MAR site in coastal area"*. Kim Yongcheol, EAP, Kigam, Korea
10. Premiere of MARenales short film (to be criticized by partners).

Notice: Despite its closed door character, all the interested people who requested to attend were finally invited to be present at the meeting.

Gomezserracín, Segovia, 11/3/2015. Open-door training workshop. Spanish as official language with presentation slides in English.

Training and dissemination to end-users presentations:

1. *"MAR and water footprint/ Recarga gestionada de acuíferos (MAR) y huella hídrica"*. Ms. Elvira del Pozo Campos. Agricultural Engineer (TRAGSATEC)
2. *"Methodology for probabilistic risk evaluation linked to MAR activities based on fault tree analysis. / Metodología para la evaluación de riesgos ligados a actividades de recarga gestionada de los acuíferos"*. Dr. Xavier Sánchez Vila. Civil Engineer (UPC, MARSOL)
3. *"Practical technical solutions for Managed Aquifer Recharge facilities. / Soluciones tecnológicas prácticas para dispositivos de recarga gestionada*". Dr. Enrique Fernández Escalante. Hydrogeologist (TRAGSA, MAR to MAR-k€t)

4. "Urban rain water harvesting and infiltration. Architectonical designs and solutions / MAR y cultivo de agua en la edificación. Diseños y soluciones arquitectónicas. D. Ignacio Prieto Leache. Architect (Tragsatec, DINA-MAR)
5. "Low impact MAR activities and benchmarking / El bajo impacto en las actividades asociadas a MAR y "benchmarking". Dr. Jon San Sebastián Sauto. Biologist (Tragsatec, DINA-MAR)
6. *"MAR, energy efficiency and use of alternative energy systems for irrigation. Tech. solutions / MAR, eficiencia energética y energías alternativas en el regadío. Soluciones tecnológicas*". D. Francisco de Borja González Herrarte. Agricultural Engineer (TRAGSA)
7. *"ICTs solutions for MAR activities / Soluciones TICs para las actividades de Recarga Gestionada de Acuíferos (MAR)"*. Dª. María Eugenia García de Garayo y Millán. Engineer. (TRAGSA-WIRE AG)
8. *"Technical solutions for MAR experiences in Spain. State of the art and future panorama / Soluciones técnicas de las experiencias en MAR en España. Perspectiva future"*. Dr. José Antonio de la Orden Gómez. Mining Engineer (Instituto Geológico y Minero)
9. Premiere of the short film *"MAR Technical solutions in Los Arenales aquifer"* / Estreno del corto: *"Soluciones tecnológicas en MAR en el acuífero de los Arenales".*

Figures 6-4 a) to c). MAR4FARM workshop hold at Santiuste and Gomezserracín city councils, Segovia province.

Lessons learnt and conclusions

Door-closed meeting: 2015/09/03. 29 attendants

- It is important to strengthen the cooperation with other EC supported projects. In the next MARSOL conferences participants from DESSIN, DEMOWARE, etc. and experts of recognized prestige in the field of water management and MAR will be invited.
- The training workshops must include a balance of members from the industry and from the academia, in order to expose the scientific background as well as the practical application of the outcomes.
- The technicians implicated in the irrigation community operations should receive the results of the project, as an agent to provide some help in the dissemination for farmers and the population in the rural area in general.

- The exposure of some successful cases of cooperation among stakeholders, scientists and regional authorities is important in order to provide some inputs and possible changes related to the current regulations.
- The cooperation with local agents is imperative in order to involve the industry more and more in the water management techniques.

Open-door meeting: 2015 March 11th. 50 attendants

Specific conclusions and recommendations

- The president of the irrigation community commented that there are more MAR experiences in Spain than he expected, remarking his good impression. He even mentioned people are not aware of the intensive use of MAR technique for water management related to irrigation in his closest circle.
- Farmers in the area who attended the training workshop brought up the importance of how convenient the support of these agents has been, bringing the general knowledge into practical advises, either from the public administration or from R&D projects…
- Some attendants expressed their interest for the potential affection of over-pumping and utter recharge, in short, water table oscillations, on the edifications and buildings foundations. This fact could bring a differed damage and geotechnical problems on the edifications structure. Technical solutions on MAR should also consider this potential affection as a problem to solve in MAR operations, design and management. A question was debated in the meeting: who should pay any damage generated by MAR operations when farmers are sued though not all the population are farmers? A possible solution might be contracting specific insurances of civil responsibility derived from MAR activities.
- River basin authorities should emit a technical report justifying where the regular undisturbed water level must stand for each specific area in the aquifer, clarifying possible future responsibilities.
- The assistants shared the feeling that MAR is being profitable for farmers respecting their economic incomes. This profit should be included in the awareness campaigns for some related areas in order to trigger a “contagious” effect on those areas’ farmers.
- Some farmers are receiving different benefits from MAR technique in their area, bringing out some imbalance. Some compensation measure should be established in order to compensate these variances.
- Social problems in relation to MAR deployment are being more serious than the technical challenges. Some specific problems requiring a quick solution in the area are related to the minimum flow rate in the river. to allow the diverting recharge water volumes and the urgent solutions to be performed when MAR devices are stopped no matter the climatic conditions are appropriate to have the facilities working.
- Some farmers wanted to know how the help, if available, is provided by the river basin authorities for MAR. Competency transference to the irrigation community should imply the respective sanctioning regime too. The main advantage remains in the internal management within the irrigation community, which seems to be better to solve conflicts than any external decision.

- River basin authorities cannot make any decision about energy production or MAR as a water preferential use. The final solution is nowadays in the hands of the court of Justice.
- The competence problem between energy production and MAR is coming from the origin of the activity. In 1998, when MAR works began, the permission characteristics required a further development of the legal aspects, documentations and conflict resolution normative.

Remarkable/ innovative aspects from the presentations

- New focus on: water-energy nexus, alternative energy systems for irrigation, risks and hazards, benchmarking calculation, water footprint, technical solutions from the rest of the world, ICT use and implementation of remote sensors and connectivity despite poor or inexistent mobile phone coverage and previous experiences related to R&D projects carried out by the Spanish Geological Survey.
- Most of these activities were not presented in the previous end-users workshop held in October 2014.
- One of the most relevant presentations for farmers was that related to water-energy nexus: how much energy is saved with groundwater elevation and how much the savings might grow installing solar energy facilities.
- It is remarkable mentioning the increasing demand for solar energy facilities applied to irrigation pumping.
- Opinion from water users is essential for technicians. That is why explanatory panels have been located next to the MAR recharge points, so, feedback is expected.
- It’s important to work in low-cost innovation, simple, collaborative aiming global solutions to MAR.
- MAR could be internalized and implemented in so many regular decision processes, as urbanism. The objective is to increase the infiltration in cities and villages for not only recharging the aquifer, but also to reduce floods and surface run-off.
- MAR has positive social and environmental impact.

General conclusions

- Speakers must make a greater effort to avoid technical language. Also, it would be interesting to ask to the irrigation community which aspects and itemsare interested in. In general, talking about solutions to its common problems, as solar energy for decrease its costs in electricity, will be appreciated, as the president of the community expressed.
- It is important to disseminate encouraging examples and successful cases from other experiences around the world among those stakeholders who provide some help in the MAR facilities management.
- Social problems in relation to MAR deployment are becoming more serious than the technical challenges.
- Although there is a certain agreement on MAR as a profitable service for population in the irrigated area, some other people disagree because they don’t earn their own living

from the agriculture. There is also a rising concern about the potential problems related to geotechnical effects of the terrain, future deferred impacts and even social conflicts.

- The profits overcome the inconveniences as a general rule. That is the main reason why successful schemes should be exported to equivalent areas, promoting a “domino effect”.
- The purpose of the workshop has been successfully achieved, as knowledge has been brought to groundwater users related to these MAR activities again. They also welcomed the training workshop with satisfaction and gratitude. That is why this sort of workshops should be repeated at least once again along MARSOL project.

Figures 6-5 a) & b). MARenales-training-workshop-program (a) and field trip guide cover (b).

Final presentations are available on the Internet at MARSOL website and the IAH MAR sister page: http://goo.gl/dIqhQz

6.3. Publications

The following publications have been released:

MARSOL Project article

- LOBO FERREIRA, J.P., ESCALANTE, E., SCHÜTH, C. and LEITÃO, T.E., 2014 - Demonstrating Managed Aquifer Recharge (MAR) as a Solution for Water Scarcity and Drought in Portugal and Spain. "12º Congresso da Água /16. ENASB/XVISILUBESA", organized by APRH, APESB e ABES, Lisbon, 5-8 de março de 2014, 15 pp.

- Tragsa MARSOL partners. Los Arenales field trip guide. 2015 March. Presented in MARenales workshop and available in Internet (MARSOL website) and in Researchgate.

- Fernández Escalante, E., González Herrarte, F.B. & San Sebastián Sauto, J. (2015): Recarga Gestionada de Acuíferos: Multifuncionalidad en la Zona Regable de Santiuste. - XXXIII Congreso Nacional de Riegos, Valencia, 16.-18. June 2015, 10 p.

Project related background publications

Book collecting a high amount of information for Los Arenales demo site since 2002:

- Book: “2002-2012, una década de recarga gestionada. Acuífero de la Cubeta de Santiuste (Castilla y León)”. Edited by Tragsa. April 2014. ISBN 84-616-8910-0. 298 pg.

Figures 6-6 a) & b). Project related background book: 2002-2012, una década de recarga gestionada. Acuífero de la Cubeta de Santiuste (Castilla y León). Cover (a) and back (b).

SCI article. Journal Water, published with results from DINA-MAR project but containing info very important for future MARSOL actions:

- Practical management to minimize the effects of clogging in Managed Aquifer Recharge Wells at two sites in the Guadiana Basin, Spain. Enrique Fernández Escalante. Journal of Hydrologic Engineering, Vol. 20, issue 3, March 2015. American Society of Civil Engineers (ASCE) ISSN 1084-0699. DOI: 10.1061/(ASCE)HE.1943-5584.0001047.

- Fernandez Escalante, A.E., San Miguel Fraile, M.Á. & Sánchez Serrano, F. (2014): El hidrogeoportal DINA-MAR. Aplicación en soporte GIS para determinar zonas susceptibles de aplicar técnicas de recarga gestionada en España. - Boletín Geológico y Minero, 125 (3), 341-368.

- Macías, C., Martínez, R. & Martínez, J. (2014): Estudios preliminares para el diseño de una instalación de recarga artificial en la zona oriental del acuífero de “El Carracillo, Segovia”. - Boletín Geológico y Minero, 125 (2), 187-202.

- Macías, C., Martínez, R. & Martínez, J. (2014): Determinación de volúmenes de agua a gestionar en las infraestructuras de la fase II del proyecto de recarga artificial del acuífero cuaternario de la comarca de “El Carracillo”, Segovia (sector occidental). - Boletín Geológico y Minero, 125 (2), 173-186.

- Fernandez Escalante, A.E., Calero Gil, R., San Miguel Fraile, M.A. & Sánchez Serrano, F. (2014): Economic Assessment of Opportunities for Managed Aquifer Recharge Techniques in Spain Using an Advanced Geographic Information System (GIS). - Water,6, 2021-2040; doi:10.3390/w6072021.

Metal dissemination posters (installed in the Demo Site)

Figures 6-7 a) to d). Metal dissemination posters installed in Arenales Demo Site.

6.4. MARSOL Project movie

MARenales Movie. TECHNICAL SOLUTIONS FOR MANAGED AQUIFER RECHARGE AT ARENALES AQUIFER, CASTILLE AND LEON (SPAIN).

A new short film has been performed directed specially to technicians and student, explaining the aquifer and specially the technical solutions applied. This movie shares the objectives of WP-5 and WP-13 (technical solutions and benchmarking).

- DINA-MAR: http://www.dina-mar.es/videos/MARenales-Film_v7.6.mp4

The movie is also available in the IAH-MAR sister website www.dina-mar.es with links from marsol and MAR to MAR-k€t sites. In order to make it more accessible, it has been uploaded in other mirror sites:

- YouTube: https://youtu.be/Dw22rcEQdiw
- The Water Channel: http://thewaterchannel.tv/media-gallery/6139-managed-aquifer-recharge-at-los-arenales-aquifer-castille-and-leon-spain

The script and screenplay have been aggregated in the annex 1.

Figure 6-8. MARenales movie screenshot.

6.5 Other dissemination activities

- 23-24/01/2014. EIP Water, European Commission. Joint Kick-off meeting in Brussels. Presentation to our project officer, Severina Markova.
- 21/03/2014. Internal presentation of MARSOL project to the R&D subdirectorate, researchers and board, within Tragsa Group.
- 02/04/2014. Presentation of the project in the workshop “Agua e I+D+i” organized by the Spanish Water Technological Platform.
- 28/04/2014. Presentation of the project in the conference: La técnica MAR en el arco mediterráneo imparted in the University of Malaga, announcing the project, its objectives and the creation of a parallel action group called MAR to MARk€t.
- 11/04/2014. Posts announcing the project in DINA-MAR and Spanish Water Technological Platform websites:

  http://goo.gl/T5wpqf
  http://goo.gl/wtoI7a

- Participations and presentation in two workshops of other EC funded related projects:
- 29and 30th September 2014. MAR4FARM workshop in Los Arenales aquifer.
- 02/10/2014. DEMEAU project, Barcelona, Spain.
- 08/10/2014. Warbo summer school course, Lisbon, Portugal, with the participation of six MARSOL members.
- Announce in Radio Nacional de España Castilla-León, program “Contrastes” by D. Celestino Lobato. March 5th, 12h. RTVE “A la carta”: http://www.rtve.es/alacarta/audios/informativo-de-castilla-y-leon/.
- 9-11/03/2015. MARenales training workshop in Los Arenales aquifer.
- Announce of the project in the International Association of Hydrogeologist, Managed Aquifer Recharge Commission Forum, list with about 400 recipients.

- Periodic meetings with Santiuste & Carracillo irrigation communities, to planning the future celebration of two consequtive workshops directed to farmers already exposed in this chapter.
- Spanish Water Technological Platform or Plataforma Tecnológica Española del Agua (PTEA). News and links published in their monthly bulletin nº 22, April 2015. http://www.plataformaagua.org/
- MASE. MARSOL oral presentation. Soluciones Tecnológicas para gestión eficiente: Dispositivos de recarga en Santiuste (Segovia). Jornada sobre "La explotación intensiva de reservas de agua de acuíferos en España: retos y soluciones tecnológicas para su gestión eficiente". Madrid, 2015 April 21th; 150 attendants.
- FESCET. MARSOL oral presentation. Móstoles, Madrid, 2015 April 08th; 80 assistants. Mentioned in wordpress.com: https://goo.gl/9VKEwF
- MARenales workshop announced in EIP Water Innovation News May 2015, 12th. May 2015. Newsletter

7. Conclusive remarks

Living in a time when the availability of water resources is an issue of general interest, managed aquifer recharge devices are presented as a serious alternative for water management plans, to be combined with more traditional systems.

“You don´t need to be a scientist to deploy a MAR project” (outcomes of the Algarve training workshop, 2015 June).

Before implementing a MAR activity, it is necessary to choose the most appropriate method, either by surface recharge, in depth systems or mixed. It is preferable the surface infiltration systems, since they facilitate the application of the majority of SAT techniques.

The availability of water for MAR is not guaranteed in long periods of drought in most of the demo sites. Alternative sources as WWTP or reuse should be considered.

Although some of these devices have been used for years, most of them are being object of intense research, in order to establish parameters of design, inspection and maintenance that will facilitate its use widely.

Although some MAR devices deployment can be a complex process and present some problems during the construction and operation stage, the majority of these problems can be avoided or reduced conducting prior detailed technical studies.

Despite some failures have occurred in this topic, the vast majority of MAR devices succeed and fulfil expectations. However, MAR technique is frequently employed in less favourable areas, such as karstic and fractured aquifers, what can predictably increase the number of failures of these actions.

A joint strategy for the conservation of water, which would include in their plans both, regeneration and reuse of water, as MAR technique involves, would be an important improvement to satisfy the water growing demand. For example, in areas where there is a significant seasonal demand variation, such as coastal zones, the joint use of the systems of storage and regeneration/recuperation is having a great success, not only for supply of the population but also for environmental uses, as the fight against salt intrusion is.

The design changes and management parameters must be created “a la carte”, depending on the climate and characteristics of each system.

A corollary has been proposed with the aim to present a series of options to be considered when implementing a solution (DSS instrument).

The competent authorities should include during the planning, development, and implement-tation of MAR projects, the joint integration of MAR systems, at national, regional and basin level, as part of the set of strategies to be adopted for modern water management.

The process is opened. Each improvement applied becomes a new element to improve.

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9. APPENDIX

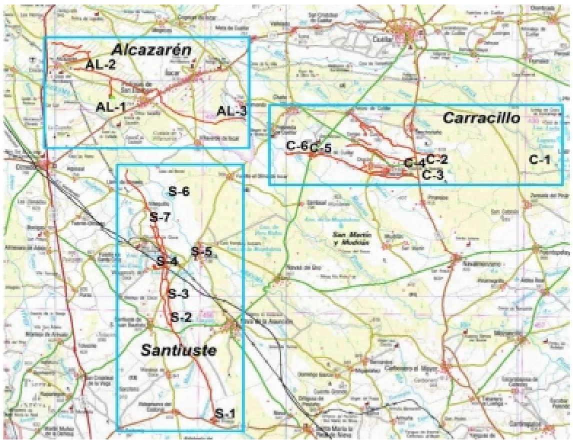
ANNEX I: NEW MAR MOVIE: TECHNICAL SOLUTIONS FOR MANAGED AQUIFER RECHARGE AT ARENALES AQUIFER, CASTILLE AND LEON (SPAIN)

ABSTRACT

"Los Arenales" aquifer is a sandy groundwater store over 7,500 square kilometres located in the Autonomous Region of Castilla y Leon, Spain. Since the mid-20th century, the expansion of irrigation has led to a decline in groundwater level of more than 20 meters. This Aeolian sand aquifer, with basins up to 55 metres thick, is also very vulnerable to drought. In order to mitigate this impact, the Spanish Ministry of Agriculture developed Managed Aquifer Recharge (MAR) facilities in three pilot zones. The project, building works, tracking and further monitoring was entrusted to Tragsa Group, a MARSOL project partner.

After more than a decade of operation, MARSOL intends to provide technical solutions for MAR technology, in order to improve the facilities efficiency and nearing the MAR technique to agroindustry, the principal activity in this area.

The movie script is in English, subtitled in Spanish.



Mirror sites:

The movie is also available in the IAH-MAR sister website www.dina-mar.es with links from marsol and MAR to MAR-k€t sites. In order to make it more accessible, it has been uploaded in other mirror sites:

DINA-MAR: http://www.dina-mar.es/videos/MARenales-Film_v7.6.mp4
You Tube: https://youtu.be/Dw22rcEQdiw
The Water Channel: http://thewaterchannel.tv/media-gallery/6139-managed-aquifer-recharge-at-los-arenales-aquifer-castille-and-leon-spain

SCREENPLAY

"Los Arenales" aquifer is a sandy groundwater store over 7,500 square kilometres located in the Autonomous Region of Castilla y Leon, Spain. Since the mid-20th century, the expansion of irrigation has led to a decline in groundwater level of more than 20 meters. This Aeolian sand aquifer, with basins up to 55 metres thick, is also very vulnerable to drought. In order to mitigate this impact, the Spanish Ministry of Agriculture developed Managed Aquifer Recharge (MAR) facilities in three pilot zones. The project, building works, tracking and further monitoring was entrusted to Tragsa Group, a MARSOL project partner.

After more than a decade of operation, MARSOL intends to provide technical solutions for MAR technology, in order to improve the facilities efficiency and nearing the MAR technique to agroindustry, the principal activity in this area.

Due to variable river flows, annual volumes recharged in the two main pilot zones ranged between 0.5 and 12.2 hectometres (hm^3) at Santiuste basin and between 0.5 and 5.5 hm^3 in Carracillo council between 2002 and 2012. The river water was supplemented with 0.5 hm^3 per year of treated sewage effluent since 2005.

From a bird's eye view, the main *“Living Labs"* currently operative in Los Arenales aquifer are three.

Most of the facilities and MAR devices are integrated into the “hydrogeological routes“ called „Caminitos de Agua“ for „Little paths of water“ in Spanish), proposed by DINA-MAR project in 2009, strengthening the demo site character of Los Arenales aquifer.

TECHNICAL SOLUTIONS AT SANTIUSTE BASIN: HYDROGEOLOGICAL ROUTE

Pioneer system at Los Arenales aquifer includes about 850 hectareas (ha) of irrigated fields, a surface that increases every year.

There is an isolated sector in the aquifer of about 50 km^2 , what grants a living lab to study processes and facilities efficiency. It has also become a good example of sustainable use of groundwater in rural zones.

STOP S-1. DAM OF DERIVATION FOR MAR FROM VOLTOYA RIVER

At the Santiuste basin site, Voltoya river water is diverted for recharge by gravitational flow through 9 km of buried pipes to the heading recharge device. The dam has a specific design with filters, diversion and decantation structures on its west side. It has also been equipped with fish back racks.

STOP S-2. HEADER OF THE MAR FACILITIES. DECANTATION POND AND MARSOL ZNS-STATION 1.

The header consists of a big decantation pond with the size of a football field after a flow rate counter, a filtering system and some high diameter buried wells in the heading of the aquifer. This sort of wells are useful and invisible, providing a technical solution slogan: *“Do not close a well, reuse it“*.

STOP S-3. TRIPLET: WASTE WATER TREATMENT PLANT BY LAGOONING, BIOFILTER AND ARTIFICIAL WETLANDS

The WWTP poures treated water into the channel, which conserves the natural vegetation in this stretch, working as a biofilter, until the point where the canal has a spillway, used in case of floods or extreme precipitations.

The presence of the base of the aquifer close to the shallow water table permitted the construction of two artificial wetlands, with an interesting vegetation evolution that helps finishing the water purification process along the triplet.

STOP S-4 LA IGLESIA, AN EXAMPLE OF A DEGRADED WETLAND RESTORED BY MEANS OF MAR TECHNIQUE

This dried salt pond was restored by means of a specific MAR solution. The salinity is achieved by the interaction between recharge water surface flow and the salty sediments of the salt lake pan, allowing the permanence of an endemic bacteria colony and a shelter for waterfowl. The use of biominerals and salt deposits have also been studied in this area.

STOP S-5. GAUGING STATION IN VOLTOYA RIVER CLOSE TO COCA VILLAGE

The recharge is allowed as far as the river maintains an ecological flow. That condition is attained by means of a real-time flowmeter in a gauging station connected to the Duero river basin authorities.

STOP S-6. RANNEY WELL IN THE ERESMA RIVER BANK (INVERSED RBF)

In the north of the basin there is an inverse River Bank Filtration (RBF) system. Water is collected by a Ranney well using the bank as a filter and transported to a treatment plant that supplies seven villages with drinkable water, hence, involving these industrial agents in the MAR system management too.

STOP S-7. VILLEGUILLO MARSOL INFILTRATION POND. PRETREATMENT AND FILTERING (SATS)

An extra infiltration pond was performed by MARSOL project and the irrigation community to recharge an area intended to be irrigated in the next future. There are different organic and inorganic filters to monitor the water quality evolution and clogging processes, specially gas clogging.

Infiltration rates are measured in different slopes too. Therefore, this living lab allows important action lines to research.

TECHNICAL SOLUTIONS AT ALCAZARÉN HYDROGEOLOGICAL ROUTE

The newest facility, based on the capture of reclaimed water from the waste water treatment plant complements the irrigation of over 800 ha.

STOP A-01. ALCAZARÉN WWTP

The waste water treatment plant has been re-designed in order to divert a part from the reclaimed water to the MAR operative scheme, together with a “water harvesting” canal, which collects and provides the runoff water from the village.

STOP A-02. FILTRATION DEVICES. INFILTRATION PONDS, CANALS AND DITCHES

The small scale infiltration ditches and ponds can be managed by the farmers, according to groundwater level in their own wells and piezometers.

Without the farmers, this smart recharge would not be feasible.

Thus, the “win-win” scheme is ensured, as they are the main beneficiaries of the groundwater storage.

STOP A-03. DIVERSION DAM & RBF

This is a single dam in a river close to irrigation areas. Its location converts the river, which receives water from the aquifer, in a located recharge system through the banks, as the dam is over the water table, far from any superficial MAR facility. That way, watertable rises in near wells.

TECHNICAL SOLUTIONS AT CARRACILLO SHIELD HYDROGEOLOGICAL ROUTE

Carracillo is the biggest MAR area in Los Arenales aquifer. There are over 7,500 ha of irrigated land and a promising related agroindustry, specially dedicated to the package and exportation of vegetables. The main crops are strawberries and vegetables.

MAR is managed by Carracillo irrigation community, responsible of the collective activity.

STOP C-1. DAM OF DERIVATION FOR MAR FROM CEGA RIVER

The dam in the Cega river was specifically designed for MAR, with a direct divertion to the stagnation pond. At the end of a gravity-fed pipe, there is a fish bone shaped structure with 9 different valves, pouring into sump pits by gravity.

No energy is consumed to move the recharge water in this passive system.

STOP C-2. INFILTRATION POND IN AN OLD SAD-PIT AND ARTIFICIAL WETLAND

The presence of a sand extraction site used for construction, and a complex dune system, allows the decantation pond to act as an artificial wetland and also an interdune filter. These are examples for the adaptation of pre-existing structures into the MAR scheme.

STOP C-3. INFILTRATION FIELD FOR CONTROLLED SPREADING. MAR-SOL ZNS-3 STATION AND PIEZOMETRIC BULB

The second “exit” from the back fish structure is used as an infiltration pond in the main storage area. This device has been complemented with a data set collector station with multiple sensors for the vadose zone and 10 crossed piezometrers, in order to monitor the wet bulb shape and advance.

An extra volumen is used for flood and controlled spreading (infiltration field) by means of dead-end canals, after a detailed study of the topography.

The infiltration rate is measured using the sensors in the ZNS-3 station, allowing the real-time monitoring of the recharge in the aquifer.

The whole system can be considered as a “triplet”, integrated by three elements: stagnation filter and infiltration pond, biofilter canal and artificial wetland. This design shows a good performance and an advance tech solution arised from MARSOL project.

STOP C-4. GOMEZSERRACÍN, DECANTATION AND INFILTRATION PONDS AND CANALS

The next exit is close to a village in a pIne area sorrounded by irrigation land. A multi-decantation design allows an extra water quality improvement. Concrete vessels allow an easy cleaning of fine sediments and clogging materials, showing another important Tech Sol.

STOP C-5. NARROS DE CUÉLLAR. CHANNELS AND INFILTRATION PONDS FOR IRRIGATION AND ENVIRONMENTAL PURPOSES

The water pipe located in Narros ends at a big infiltration pond, used as a wildlife refuge and at the same time a recharging device. Extra volume is driven to a channel.

Furthermore there are little infiltration ponds among several pig farms connected with the supply wells, though linking "directly" the MAR activity with the agroindustry in the area.

STOP C-6. NARROS DE CUÉLLAR. MALUCAS RIVER DAM TO CONTROL THE WATER TABLE

This dam has a double function: on the one hand, water is stored for its direct use. On the other hand, and the most important, the water table is mantained locally at a level higher than its peak. Thus, groundwater is closer to the surface in the near wells and the energy consumption for pumping gets lower, allowing important savings in irrigation (up to 48% of energy consumption), a higher energy efficiency and another example of sustainability.

This is one of the most important tech solution in Los Arenales aquifer concerning the increasing cost of energy in agriculture.

CONCLUSIONS

After a detailed characterisation of Los Arenales aquifer, in Castille and Leon, Spain, different building works were performed in a permanent improvement, converting the demo site into a living lab whose evolution is monitored by means of benchmarking and indicators.

Once commissioned and constructed, the works were transferred to the communities of farmers, pointing the need of collaboration of people directly involved in management, cleaning and maintenance as a key of success for MAR activities.

The demo site has become an example of MAR technique to combat groundwater over-exploitation. The storage of water would allow the irrigation in the area for three years with no precipitation, minimizing the risk for the associated agroindustry.

Initially some farmers resisted the new organizational structures but this was solved through negotiation and informing the respective communities on sustainable development, environmental awareness and hydrogeological processes, including the applications of MAR, with the subsequent decline in the price of water and in the costs of pumping.

Apart from the agro-industry, the activity also mobilizes water supply and treatment agents, environmental groups, the public administration in care of water and wildlife, Municipalities (playing an important role in MAR management) and Public Private Partnership (PPP) schemes, as well as plenty of industries and SMEs whose wells exploit MAR groundwater resources.

The MAR methodology has driven to a tested "know-how" for general "rural development" through technical guidelines for the implementation of MAR under various boundary conditions, plus a permanent modernization. The examples of success are quickly shared with the commoners.

MAR maintains and increases the industry, which depends on groundwater availability within the assembled network.

The living lab provides examples of Public Private Partnership and Decision Support Systems, involving different agents and administrations.

There are still many issues to solve and research to be done to mobilize industry and SMEs in this area, especially related to vegetables packing and exportation, for MAR technique to reach the front line that deserves in water management.