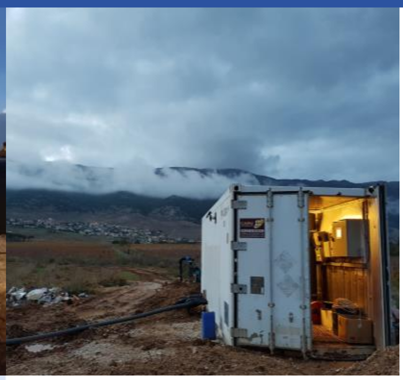
Jan 31, 2019

Managed Aquifer Recharge in Lebanon

Component 3 of SLWAAS program

Synthesis report



Deltares Enabling Delta Life

KWR Watercycle Research Institute

ELARD

ACACIA WATER

1866 AUB American University of Beirut الجامعة الأميركية في بيروت

Executive summary

As part of the project "Strengthening the Lebanese Water and Agricultural Sector" a Managed Aquifer Recharge (MAR) pilot system was implemented in the western Bekaa Valley. This report summarizes the site selection process, the design, installation and monitoring of the pilot system, and the economic upscaling potential of MAR in Lebanon. The course of the project is evaluated and recommendations for future MAR projects are given.

Colophon

Document title	.	Managed Aquifer Recharge in Lebanon
Client	.	Ministry of Energy and Water, Lebanon
Status	.	Final version
Datum	.	Jan 31, 2019
Project number	.	160740
Author(s)	.	L. Rolf, A. Wiersma, S. Burger, T. te Winkel
Reference		
Collegiate review		
Released by		A.C. de Vries

Table of contents

Technical reports
Report 1: Framework for assessing the site suitability of MAR projects in karst aquifers
Report 2: Pilot site selection for MAR in unconsolidated sediments
Report 3: Design, installation and monitoring of a MAR system in Miocene sediments
Report 4: Economic analysis

1 Introduction

1.1 About this report

This report summarizes the technical reports that were produced during the project of implementing a Managed Aquifer Recharge (MAR) pilot system in Lebanon. The project is part of the program "Strengthening Lebanese Water and Agriculture Sector" (SLWAAS) and was carried out during January 2017 and January 2019.

During the inception phase of the project a framework for assessing the site suitability of MAR projects in karst aquifers was developed, which is summarized in Chapter 2. Based on these findings, it was decided to concentrate on unconsolidated sediments for a pilot MAR system. The site selection process is laid out in Chapter 3. Chapter 4 gives an overview of the design and installation of the MAR system. Throughout the project an economic analysis regarding the upscaling potential of agricultural MAR systems in Lebanon was carried out, which is presented in Chapter 5. The course of the project is evaluated in Chapter 6, including an assessment of the factors that resulted in the withdrawal of the project support of MoEW in Lebanon. Finally, conclusions and recommendations are given in Chapter 7.

Figure 1: Drilling of the MAR well at the pilot site in western Bekaa Valley (March 2018)

1.2 The SLWAAS program and the MAR pilot

The Dutch government has funded the program "Strengthening Lebanese Water and Agriculture Sector" (SLWAAS). This program consists of 6 projects:

1. Water operator partnership (WOP) with the Bekaa Water Establishment (BWE)
2. Water quality monitoring stations Litani River for Litani River Authority (LRA)
3. Small-scale storage / Managed Aquifer Recharge (MAR)
4. Land reclamation and water reservoirs
5. Adaptable greenhouses
6. Netherlands Water and agriculture expertise facility

The third project "small scale storage /artificial recharge" aims to showcase the method of using the subsurface as a water reservoir. This is done by artificially bringing water in the subsurface during the wet season where it is stored, and using it when the demand is there to irrigate crops in the dry growing season. This method is called Managed Aquifer Recharge. The advantages are plenty, such as:

- There is no water loss due to evaporation
- It does not take up any valuable space
- No expensive dam has to be built
- No water quality problems
- The ground water system can partially recover

Lebanon has a positive annual water balance, however during the year water shortages occur. This is where groundwater storage can be a useful solution. MAR has been on the table in Lebanon for a long time, but was piloted only once in the 70's with insufficient monitoring. Therefore, the aim of this project was to implement a MAR installation that could serve as a demonstration project and assess the potential to upscale such installations in Lebanon.

This project is implemented by the Dutch companies Acacia Water, Deltares, KWR, and Broere Hortitech together with the Lebanese partner Elard in cooperation with the American University of Beirut (AUB) and in coordination with the Ministry of Energy and Water (MoEW), the Bekaa Water Establishment (BWE), and the Litani River Authority (LRA).

Specific objectives:
To choose one location where water buffering MAR interventions can be implemented based on bio-physical criteria (geology, geohydrology, soil, slope, rainfall, evapotranspiration, etc.), while also taking into account other criteria such as stakeholder involvement, security at the site and source water quality.

1.3 MAR in karstic limestone

Lebanon has a geology that is typical for many countries around the Mediterranean. Most of the rocks are limestone, which are deeply weathered by the dissolution of the calcium carbonate making up the limestone. This dissolution results in bare rough rocks at the surface and a maze of underground caves and fractures. The features related to this limestone dissolution are called "karst".

Globally, there have been successful applications of MAR in karstic limestones. However, due to the unpredictability of the underground fractures and caves, the chance of success is highly uncertain and therefore also many failures of MAR application are reported in similar settings. In these MAR systems, water can be successfully injected, but it is not always clear where the water is going.

Previous studies in Lebanon identified potential MAR sites in karstic limestones based on a GIS analysis of local conditions such as fresh water availability etc. This study did not touch on the conditions for good aquifer properties for successful MAR implementation. Since the approach of the present study was to continue where the previous work had stopped, the first deliverable was a report providing a framework for MAR implementation in karstic limestone. However, it was decided not to continue to pursue a MAR installation in the limestone aquifers for the following reasons:

- The drilling in the hard rock is expensive
- The chance of success is too uncertain
- MAR in karstic limestone is not a Dutch expertise

The framework provided can serve as the starting point for future studies that do intend to apply MAR in karstic limestone.

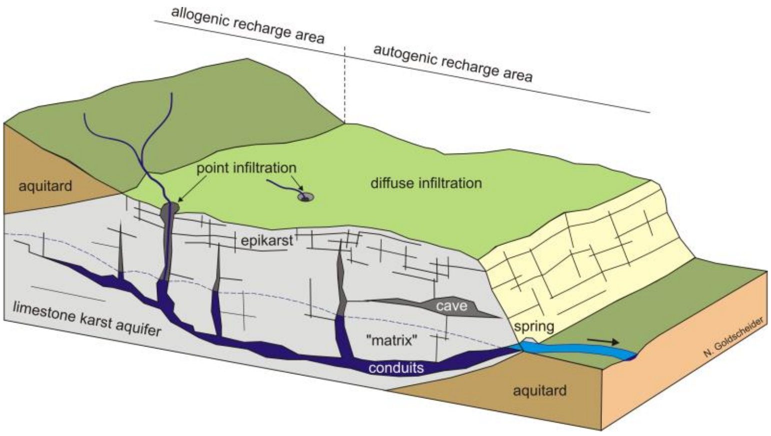


Figure 2: Hydrogeological function of karst (Goldscheider & Drew 2007)

1.4 MAR in Lebanon

Artificial recharge aiming to control seawater intrusion has been carried out in many places around the world. In the Lebanese context however, the focus is on the karstic aquifers. The karstic aquifers have low residence time and fast flow. Therefore, controlling intrusion in karstic aquifers, should have a constant slow percolation of water into the phreatic zone, this can be achieved in epikarstic areas. A method to assess the rechargeability of karst was applied in the Damour area and the results showed that artificial recharge is not feasible using infiltration ponds there due to lack of free space, however, it reportedly would be more feasible if the water is injected in a sub-horizontal well, or gallery of wells. Although the latter concept was not tested, a proposed site was suggested for a field experiment in the village of Mechrif.

In Hadat-Hazmieh feasibility studies have been carried out for artificial recharge. Between 1968 and 1975 an artificial recharge pilot was carried out. Water from the Daychounieh Spring mixed with treated water from the Beirut River were injected via a well into the aquifer. The infiltration of this water (varying between 7.75 and 660 m3/hr), resulted in a limited decrease of chlorine levels, and a seaward retreat of the fresh-saline water interface. During periods of high spring discharge, water is still infiltrated in the wells with estimated rates of 500 m3/hr in Chiyah. Due to expansion of urban areas and the large number of illegal wells, it has become impossible to make an accurate estimation of the impact of the recharge.

1.5 MAR in unconsolidated sediments

Karstic and fractured limestone is characterized by a solid matrix with low hydraulic conductivities, and large fractures and conduits through which water can flow at high velocities. Water-bearing voids are distributed unevenly throughout the rock and drilling a borehole into one of them for constructing a successful well might be pure chance. A MAR system in which the injected water is also recovered is even more uncertain.

Determining the hydrological characteristics of a karst aquifer at a given point is very difficult because of the heterogeneity. Transmissivities and yields observed at one well might not be achievable at a well close by because fractures and conduits are not distributed uniformly. For a MAR system this implies that the karst aquifer must be thoroughly tested at the potential MAR well, especially with regards to the aquifer's ability to hold the water in the vicinity of the well for the entire recharge period. If not known, it is unclear where the infiltrated water flows to, which makes it hard to determine the impact.

Implementing a pilot MAR system seems therefore more promising in unconsolidated sediments of the Quaternary and Miocene than in the Cretaceous and Jurassic karstic limestones.

2 Site suitability framework for MAR in karst aquifers

Report 1 "Framework for Assessing the Site Suitability of MAR Projects in Karst Aquifers" presents the findings of a comprehensive desk study carried out at the beginning of the project to scan the potential for MAR on a national scale in Lebanon and to develop a framework for assessing site suitability for MAR in karst regions. Most of Lebanon's aquifers are karstic, but global experience with MAR in karst is rather scarce. A thorough literature review and expert interviews were carried out which contributed to the compilation of criteria that can indicate the suitability of a location for a MAR system. In a multi-criteria analysis, a selection of eight potential MAR sites in Lebanon that were previously proposed by a UNDP study were compared, and the sites' suitability regarding different aspects was analysed.

The central part of the site suitability assessment framework is the multi criteria analysis. Its core is a newly developed criteria catalogue which provides a wide range of aspects that the plausible MAR sites can be compared across. Depending on the objective of the MAR project and the focus of the decision-making process, criteria from different domains can be chosen. Data availability will also affect the selection of criteria from the catalogue. The criteria catalogue (Figure 4) is divided into eight themes which contain 52 categories which, in turn consist of 141 criteria. For example, criteria that can be evaluated to rate site suitability in the category "level of aquifer stress" include: Groundwater balance; decrease of groundwater levels; but also increase of salinity.

Figure 3: Karstified limestone in Lebanon. Large voids in the rock have been filled with bricks.

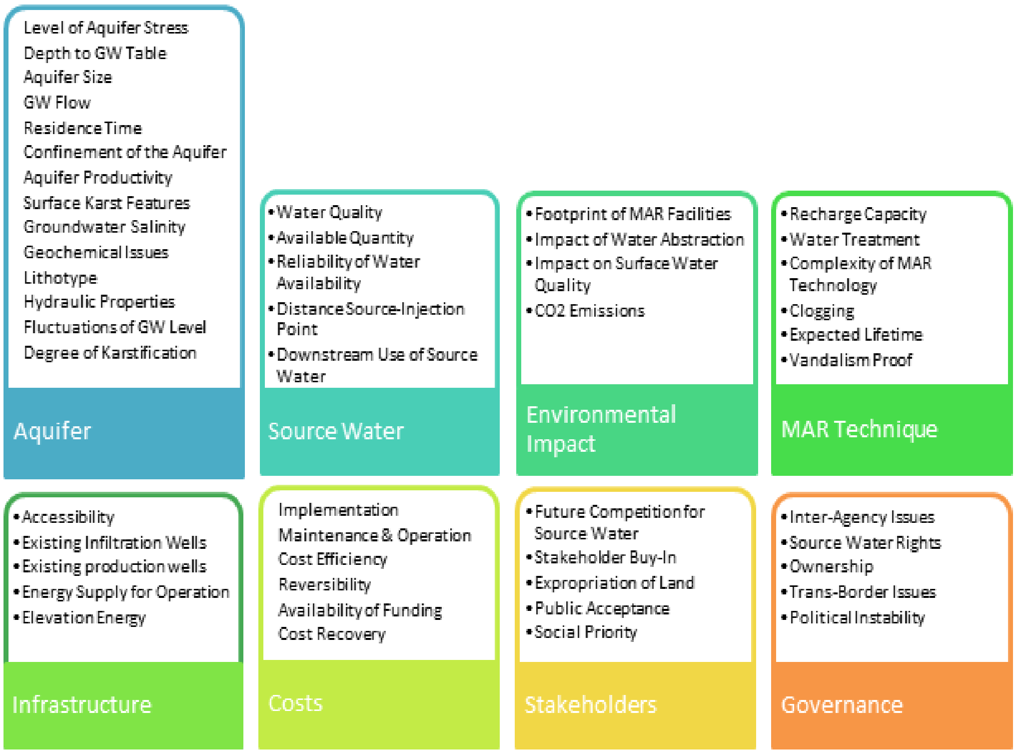


Figure 4: Themes and categories of the criteria catalogue for assessing the MAR site suitability in karst

An important finding of this desk study was that the hydrogeological challenges of storing water in highly permeable karstic aquifers add an extra layer of uncertainty to a MAR pilot project. To this end, the project subsequently focused on potential MAR sites in alluvial sediments where the behaviour of infiltrated water is more predictable.

The MAR pilot project will help in quantifying the upscaling potential of MAR in Lebanon. In addition, it acts as a great opportunity for capacity building in the Lebanese water sector and helps to shift the paradigm that only high-yielding but vulnerable karst aquifers are productive water reservoirs towards the possibility of actively managing the groundwater reserves in sedimentary aquifers with lower productivity.

In a later upscaling of the technique MAR systems may also be implemented in karstic aquifers. To achieve this, the developed framework can help in determining promising locations. This study also outlines what data is necessary to determine suitable sites and design the MAR scheme. The framework is not exclusively applicable in Lebanon but is a useful starting point for other projects that aim at implementing managed aquifer recharge systems in karst aquifers worldwide.

3 Selection of MAR pilot site

The second report "Pilot site selection for MAR in unconsolidated sediments" presents the process and results of the selection of suitable pilot sites. The first decision made after the previous phase was to focus on locations with unconsolidated sediments, such as sand or gravel. This choice was made because the feasibility of a pilot for the application of MAR in karstic limestones was considered too expensive and risky. In the Netherlands, the involved parties have an extensive track record with MAR in these unconsolidated sediments. In Lebanon there are three areas with unconsolidated formations that have been identified during the inception mission with field investigation and associated desk studies to have potential for the MAR pilot. These are:

- Akkar Plain
- Damour
- Bekaa valley

First, a number of requirements were defined that the MAR pilot site should fulfil. The main requirements were:

- Geology: soil properties should be suitable for the application of MAR
- Water: a water source with clear unpolluted water needs to be available for infiltration. The project needs to have the approval to use this water
- Landowner: if a pilot is implemented a cooperative and enthusiastic land owner is necessary: for making the pilot possible on his land, for arranging practical things around the farm and to be a strong ambassador of the pilot

Other requirements are power supply, telecommunication service, security, accessibility and water demand.

A team from the Beirut based consultancy firm ELARD carried out a desk study and a field investigation in the three designated areas. Based on these studies, two specific locations in the Damour area and the Bekaa valley were identified that met most of the criteria and were worth investigating further for suitable soil properties using geophysics. These geophysical (electrical-resistivity) surveys can provide information on whether the local soil properties are suitable for MAR. The Akkar plain dropped out as a promising site in this phase because of water quality issues and the lack of secure locations with clear land owner that would be willing to adopt the pilot.

Figure 5: Geophysical survey at Edde Estate

The electrical resistivity surveys in the Damour area and Bekaa Valley provided preferred locations based on the soil properties at the sites. For the most promising site in the Damour area, however, it was impossible to contact the land owner. In addition, the local irrigation canals were often closed in the wet season as otherwise they clog up with sediment. This is not favourable for a successful MAR pilot.

In the Bekaa Valley, the landowner and the executing manager of Edde Estate were very enthusiastic and cooperative. The Edde farm promotes a sustainable approach to farming, and they see MAR as a technology that closely matches their approach. In addition, unpolluted water is available nearby in a ditch on the premises, which can serve as water source. Hence, the Edde Farm in the Bekaa Valley was chosen to implement the MAR.

Necessity of MAR in the Bekaa Valley

The Bekaa Valley is flanked by the Lebanon and Anti-Lebanon mountain ranges. It is drained to the south by the Litani river, that feeds the Lake Qaraoun reservoir. The river is fed by the many springs that flow from the foot of these limestone mountain ranges. The valley is underlain by a series of aquifers, which are alluvial unconsolidated sediments at the top, and older karstic limestones below. All of these aquifers are overexploited by the many, partly unlicensed, wells that withdraw water, mostly for irrigation purposes. Hence, the groundwater levels decline at an alarming rate – the situation is unsustainable.

A side effect of this overexploitation is that the springs coming from the mountains diminish. In addition, the river, that used to be naturally draining the Bekaa Valley, now is or will soon become a loosing stream, infiltrating and losing water to the subsurface. This leads to a lower availability of surface water, and lowering of the water table of Lake Qaraoun.

Successful application and upscaling of underground water storage in the form of MAR could result in reduced extraction of the deeper aquifers. This results in partial recovery of the natural groundwater system and facilitates recovery of spring discharge and therefore the surface water availability.

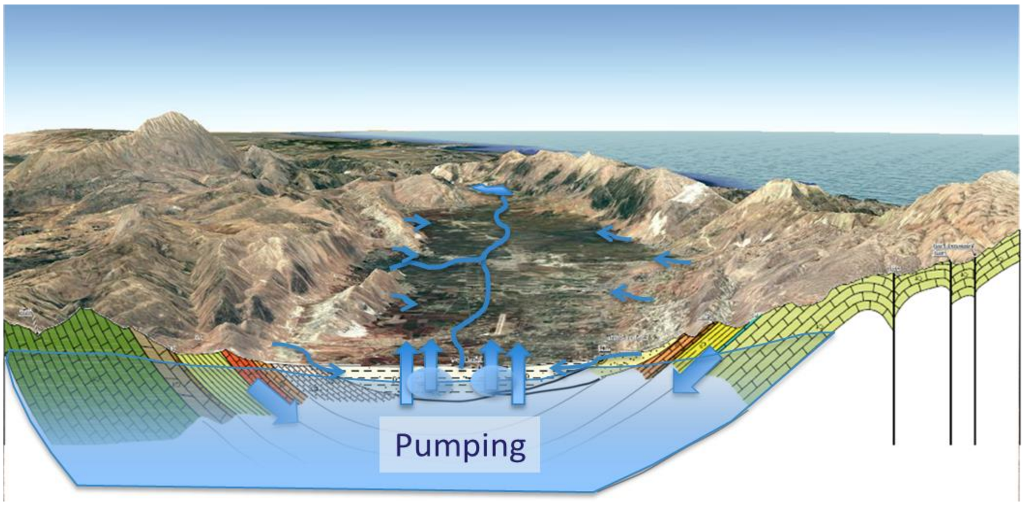


Figure 6: Schematization of the geology and (ground-)water system in the Bekaa Valley, looking south. Recharging the groundwater in the unconsolidated sediments in the valley plain (white) would take pressure off the underlaying limestone aquifers, thereby benefitting spring discharge

4 Design, installation and monitoring of the MAR system

The MAR system was designed as an off-grid solution with low operation and maintenance requirements. Its functioning can be schematized in three processes (Figure 7): During **capturing** surface runoff that is generated by the winter rains and snow melt is abstracted from a ditch. It is piped to the operation unit where it is filtered. The clean water then enters the **storage** phase during which it is infiltrated in the aquifer via MAR well. Due to the low permeability of the aquifer the infiltrated water stays close to the well. In the summer, when the surface water has dried up the stored groundwater is **used** for irrigating vineyards.

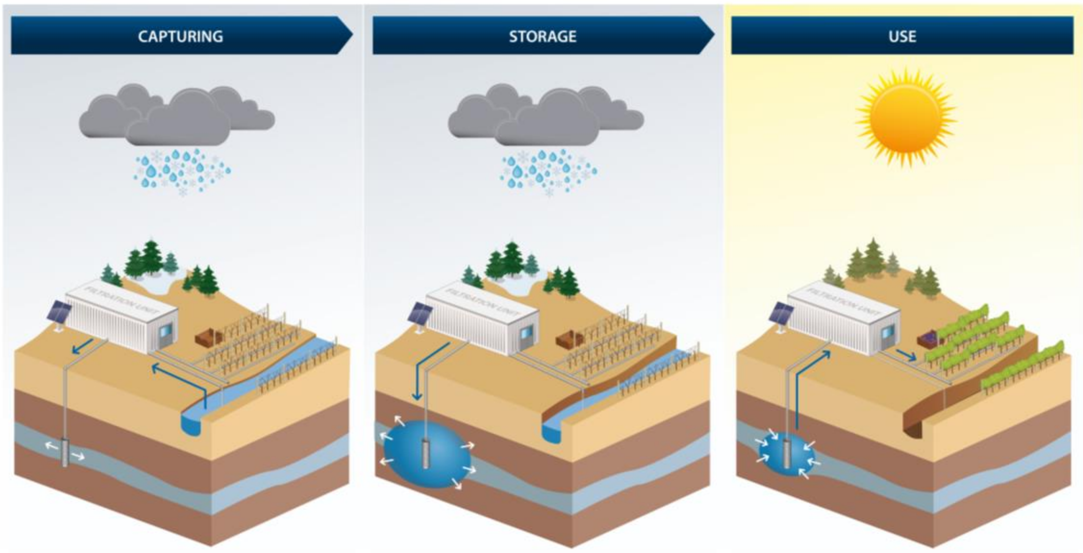


Figure 7: Schematization of the operation processes of the MAR system

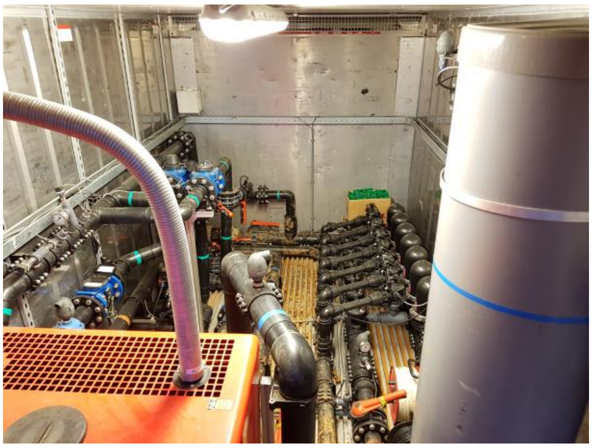
Report 3 lays out the system design in more detail and describes the installation process, including borehole drilling, well installation, setup of the operation and filtration unit, as well as construction of the source water abstraction scheme. Furthermore, a monitoring campaign is outlined that should be setup (and partially already is installed) if the operation of the MAR pilot is continued.

The outcome of the site selection led to the decision to install the MAR system on the property of Edde Estate and drill the MAR well in Miocene sediments (consolidated and unconsolidated). While the geophysical investigation suggested a maximum depth of these sediments of 80 – 120 m, during the drilling down to 230 m no underlying hard rock was found, which gives important new insight into the geology of the area. Suitable unconsolidated layers for storing water were found in the section of 156 – 198 m depth.

The MAR scheme, which can be operated energy neutral and off-grid, consists of three main components:

1. Source water intake point: Consists of a small abstraction weir in a drainage ditch which gathers the surface runoff and return flow of a 3 km2 catchment area. From the abstraction point the source water flows through 800 m of pipeline to build up pressure for filtration using elevation difference of the landscape.

2. Operation and filtration unit: A container houses 8 filters to treat the source water before infiltration. It also contains the controls and water monitoring equipment which can be accessed online. A generator in the container acts as a backup in case the field of solar panels do not produce enough energy to power the abstraction pump.



3. Dual-purpose well: 200 m deep well with one filter column for infiltration during the winter and abstraction during the irrigation season using a submersible pump which is solar-powered.

During the technical implementation of the MAR system a number of important lessons were learned which a future MAR project in Lebanon can benefit from. Recommendations in report 3 include aspects regarding well siting, drilling, well design, well development, and time planning of the project.

5 Economic feasibility

5.1 Introduction

The driver to assess the economics of MAR originates from the negative economic consequences of groundwater depletion. This is especially true for the agricultural sector, which is highly dependent on water resources. Furthermore, the technology needs investments which is a drive to create understanding of which sector segment has most growth opportunities. The aim of the economic study was to investigate which sectors in Lebanon form an economically attractive climate for investments in MAR.

5.2 Economic developments in Lebanon

Lebanon had a GDP of US$ 52,646 million in 2017 with a GDP growth of 1,8%. The economy relies on real estate, tourism, retail and financial services for growth. The total agricultural sector counts for 3,53% of the total economy in 2017. 63% of the country is occupied by agricultural land and 60% of the total water withdrawals are used for crop cultivation (FAO.org). The economic value of water in the agricultural sector is high, since much of the sector depends on water for irrigation. Even though agriculture makes up only a small portion of the country's GDP, from a socio-economic perspective agriculture is considered important because of rural development, employment and the cultural value.

5.3 Agriculture in Lebanon and the value chains

658.000 ha of Lebanon are covered with agricultural land, which is 63% of the total surface area of the country (FAO.org). Most of these are small farms, 73% of the farms are smaller than 1 ha. The middle and large-scale farms are mostly focused on cultivation of table and wine grapes, citrus, potatoes and avocados.

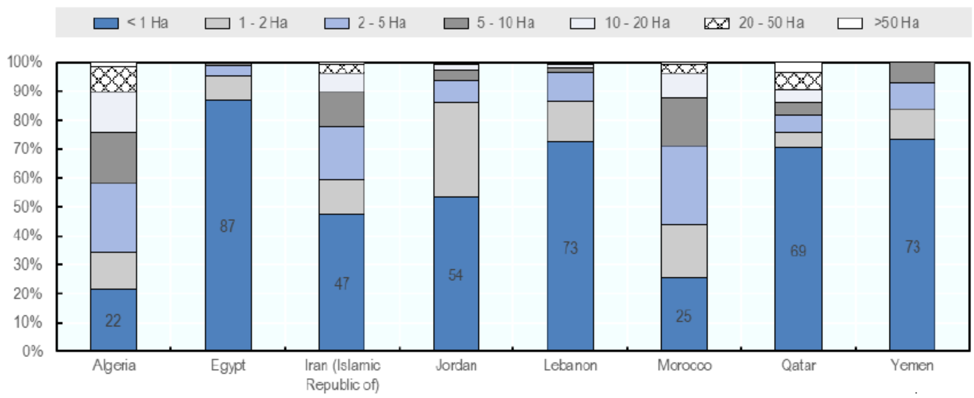


Figure 8. Farm size distribution in selected MENA countries, 1996-2003 (source: OECD/FAO)

In the most important value chains a set of drivers, trends and future scenario's influence the sector developments. Introducing MAR in terms of these influences provide a window of opportunity for introduction. The most important drivers are over abstraction of groundwater resources, climate change, geopolitical unrest, a negative trade balance and an unstable financial sector.

5.4 Value chains

The value chain analysis provides a more detailed understanding of the different agricultural activities in Lebanon. From this it can be concluded that implementation of MAR systems in a private business environment should focus on large-scale farmers and exporting table grape, wine grape and avocado growers. Investing in their own water security will support sustainable farming practices in future and act as a business insurance for their capital and outstanding loans. The recommendation is to continue working on the business case, specify and monetize the benefits and determine the financial payback time.

5.5 Identification of the benefits, costs and governance of MAR

Before applying MAR at a farm level an analysis of the costs and benefits is required. As this study is a first step towards describing the economic feasibility of MAR in Lebanon and there is no real focus sector for MAR yet, the costs and benefits are roughly estimated. The total investment costs of the pilot are not representative for the eventual realization after upscaling. The main benefits of MAR implementation are irrigation water availability, avoided investment costs for future groundwater abstraction, groundwater recharge, countering salinization and improving water efficiency by using MAR.

5.6 Water governance

For a successful implementation of MAR in Lebanon, the governance of water resources plays an important role. Despite the important number of water related projects the resources are still depleting fast. More attention should then be given to the governance of those resources. With the impulsion from the public sector to sustainably manage water resources, the implementation of MAR can guarantee the availability of water and the recharge of depleted groundwater resources. To ensure durable and successful results, the governance of water resources must be strengthened.

Groundwater resources in Lebanon can be considered as common pool resources involving a large range of users. Investment in recharging and using those resources can be threatened by poor water management and can minimize the rate of return. Governing groundwater resources on a community level allows to avoid the vicious circle that individual strategies bring. This is even more relevant in the context of agriculture in which the resources are used for irrigation purposes by many actors. To implement a MAR system, involving the users at all stages and ensuring their commitment will constitute most of the work. Such application must follow appropriate design principles for sustainable water management.

5.7 Cost reduction

The majority of Lebanese agriculture takes place on small scale plots. Even though the size of the farms seems small, the impact on water management is high because of the cumulative effect of abstraction. In order to have an impact and to achieve scale-up for small-scale farmers, further development of simpler methods is important. These methods must be cheap and technically simple. It is highly recommended to start this development with a financial economic analysis, answering the question: What are the maximum investment costs per specific crop and in which way can the reduction be realized in technical terms? In this way it is possible to pilot MAR in Lebanon and simultaneously prepare introduction of the technology in the Lebanese market.

6 Course of the project

The project ran for about two years. As often with projects that involve a field component in a challenging country, not everything went as planned. In this chapter an overview of the course of the project is provided, and some of the issues that that were faced are summarized. To do so, first the chosen approach is explained that was chosen to make the project a success. Then the important milestones in the project are discussed, and the actual way the project developed.

6.1 Project approach

The objective of the project was to find solutions for small-scale groundwater storage with upscaling potential to bridge the gap of low water availability during the irrigation months. It was important to implement a tangible pilot system, rather than only producing a feasibility study.

To this end, a funnelling approach was chosen: During the inception phase a scan of the entire country was carried out, then the site selection was focused on a number of potential locations in sedimentary aquifers. The final MAR site was selected so as to make optimal use of the landscape to achieve minimal energy consumption. The MAR system was then designed according to the site conditions. The project was accompanied by an economic assessment to determine the agricultural sectors and preconditions for upscaling the technology. Throughout the project stakeholder involvement was ensured by frequent meetings and joined activities of the Dutch and Lebanese partners, and by close communication with all parties involved in the implementation process. Much attention was paid to improving gender equality during the project: Two workshops were organized for raising awareness for gender equality and gender balance was ensured among the staff of the different organizations involved in the project.

6.2 Project development

1. Inception phase (February – May 2017)
    a. Establish collaboration with local partners
    b. Determine focus areas for site selection
    c. Gender equality workshop
2. Implementation phase (June 2017 – November 2018)
    a. Find potential sites in focus areas
    b. Assessing site suitability
        i. Geophysics
        ii. Questionnaires
    c. Site selection
    d. System design
    e. Installing MAR system
        i. Import of equipment
        ii. Drilling of MAR well
        iii. Installation of MAR system

3. Economic assessment (throughout entire project)
    a. Economic analysis of Lebanese agricultural sectors
    b. Cost-benefit analysis of MAR
4. Project ending (January 31, 2019)

6.3 Involved institutions and organizations

Institutions and organizations	Role
Dutch governmental institutions	
Ministry of Foreign Affairs (MoFa)	Donor
Dutch Embassy in Beirut	Representative of Dutch MoFa
Dutch implementing organizations	
Acacia Water	Project lead
Deltares	Expert (hydro-)geology
KWR	Expert MAR and water chemistry
Broere Hortitech	Provider of MAR equipment
Lebanese project partners	
Elard	Local consultant
American University of Beirut (AUB)	Local scientific partner
Edde Estate	Land owner and beneficiary
Lebanese governmental institutions	
Ministry of Energy and Water (MoEW)	Overarching water authority
Bekaa Water Establishment (BWE)	Responsibilities (i.a.): Monitoring of groundwater in the Bekaa
Litani River Authority (LRA)	Responsibilities: Irrigation, hydropower, management of Lake Qaraoun

6.4 Project conclusion

At the point of writing this concluding project report the MAR system is not operational. Despite a very tight time schedule and various geological, logistical, and engineering challenges it was possible to build a functional pilot system. However, in very recent developments the permission to operate the system was revoked. It remains unclear whether the project will be able to operate or if the site will have to cleared of all equipment. Furthermore, the request for a budget-neutral half-year extension of the project was not approved, so that proper testing of the MAR system could not be carried out.

6.4.1 The role of Litani River Authority

Responsibilities of the Litani River Authority (LRA) include the management of Lake Qaraoun, Lebanon's only large-scale reservoir. This lake is used for energy production and to feed irrigation schemes in the south of the Bekaa Valley. In a normal year there is not enough inflow into the reservoir to fill it to full capacity. The constructed MAR project lies in the upstream catchment area of the Litani River which feeds Lake Qaraoun. LRA's concern is that an operational MAR system upstream of the reservoir will further diminish the inflow into the reservoir, thereby decreasing the capacity for energy production and irrigation. This was discussed at an early stage in the project. After meetings with LRA officials in Lebanon and a visit to operational MAR systems in The Netherlands Acacia

Water was under the impression that LRA was convinced of the benefits of MAR. In short, these are:

- Storing water without contamination risk (Lake Qaraoun is heavily polluted)
- Storing water where it is needed (transportation via irrigation canals from the reservoir is energy intensive)
- Storing water without evaporation losses (annual evaporation from Lake Qaraoun is 1.5 – 2 m)
- Counteracting the deteriorating groundwater levels, thereby improving baseflow of the Litani River because less irrigation water has to be abstracted from springs

Furthermore, MAR has a prominent position as “projected additional water resources” in the National Water Sector Strategy 2010 – 2035 developed by the Ministry of Energy and Water (MoEW). Accordingly, MoEW officially supported the project.

In the last half year of the project LRA voiced concerns about the MAR system. An expert workshop was planned in November 2018 to discuss the project as well as the impact of a potential upscaling of the MAR technique on the water resources in the Upper Litani River Basin, including Lake Qaraoun. This workshop was cancelled by LRA three days before the event. Subsequent talks between Dutch project partners and LRA could not resolve the concerns; LRA had taken the standpoint that MAR should not be implemented in the Bekaa Valley. In a further development, MoEW followed LRA’s request and discontinued its support for the project after the official end date of January 31, 2019.

6.4.2 Budget-neutral extension

The SLWAAS project was scheduled to run for two years. Like other consortium members, Acacia Water faced many difficulties to achieve the ambitious goals within this timeframe and proposed a budget-neutral extension of the project duration until July 2019. This would have allowed for a proper testing of the MAR system and optimization of the system during a full cycle of infiltration (winter) and irrigation (summer) – at no additional costs. This proposal was not approved by the donor institution, the Dutch Ministry of Foreign Affairs (MoFA). It should be noted that, at the beginning of the project, it was communicated that there was a fair possibility for the project to be extended after two years. While it is understandable from an organizational perspective for MoFA and the Dutch embassy to discontinue the project due to changed core business and regional priorities, this decision severely undermines the impact of the project, including potential reputational damage to the Dutch water sector in Lebanon.

Figure 9: Lake Qaraoun and the snow covered Mt. Hermon in the background

7 Conclusions and recommendations

7.1 General evaluation

To implement a pilot MAR project in Lebanon in two years, including an extensive site selection process and establishment of collaborations with different organizations, proved to be a challenge. Nevertheless, the project approach of building a tangible pilot project based on sound scientific research and with state-of-the-art technology was the right decision. In Lebanon, many projects of international cooperation to improve e.g. the water or agricultural sector are carried out, but too often the results remain concealed in reports or workshops. Implementing a tangible pilot project that can be operated, studied and monitored beyond the project duration was therefore much appreciated by most of the Lebanese project partners.

Needless to say, it is disappointing that the project has ended not according to plan; it remains unclear whether it will ever be possible to operate the MAR system. To the Dutch and Lebanese implementing project partners it remains unclear what precisely would have convinced LRA of the obvious benefits of MAR and how the ministry's support for the project could have been extended. A longer project duration would have probably helped to build a stronger relationship with the Lebanese institutions, in order to be more effective within the Lebanese context. Furthermore, a financial contribution by MoEW (e.g. 20% of the installation costs) could have ensured continued support and better engagement of the Lebanese water authorities.

One of the major successes of the project is the good cooperation between Dutch implementing organizations (namely Acacia Water and Deltares) and the Lebanese project partners Elard and American University of Beirut (AUB), resulting in mutual learning (e.g. capacity building during well drilling) and development of new scientific insight (e.g. site geology). It is important that AUB is able to continue the planned research beyond the duration of the project even if the project itself is discontinued.

7.2 Lessons learned

A number of important lessons were learned during the course of the project and future MAR projects in Lebanon might be able to profit from these recommendations:

- **Siting:** The more hydrogeological data is available, the better the design of the MAR well can be made. This consists data regarding geological properties, hydraulic aquifer properties, and quality of the groundwater. Without reliable data of the aquifer, exploration drilling is necessary.

- **Source water:** Source water measurements, both quality and quantity should be done at a early stage, so that the design of the MAR system can be adjusted accordingly (e.g. how much water is available for infiltration, what type of filtration is necessary).

- **Stakeholder cooperation:** One of the selection criteria for the site was good stakeholder cooperation; the enthusiasm of the land owner and farm manager have contributed to the successful construction of the pilot system.

- **Drilling technique:** Mud drilling is not a standard drilling technique in Lebanon. The only method available for drilling in sedimentary formations is straight flush rotary drilling. This method creates a mud cake on the borehole walls and artificially clogs the aquifer, which requires complex well cleaning after drilling. In order to have good infiltration wells in sedimentary formations, it is vital that improved drilling techniques (such as reverse flush rotary drilling or airlift drilling) are made available for Lebanon. This also makes sampling of cuttings easier.

- **Well development:** The local drilling industry is not yet familiar with more advanced well development techniques that are necessary after mud drilling. It is strongly advised to use biodegradable bentonite as drilling mud, or a professional bentonite remover chemical. Also, suitable well development techniques, such as air plunging, intermitted pumping and section pumping are necessary.

- **Well lining material:** Much of the material for the pilot MAR well was imported (e.g. PVC casings, filters, gravel). For efficient construction of new infiltration wells a supply chain of well lining material needs to be set up in Lebanon.

- **MAR system:** The applied Dutch MAR technology, delivered as a single operation and filtration unit, can be installed off-grid and in short time (plug and play). It should be investigated if similar solutions can be made locally.

- **Time:** In order to achieve good cooperation with local partners, to do all needed field investigations, to select the best site, and to do a full cycle (infiltration & abstraction) of operation and monitoring a timeframe of at least 3 years is needed.

- **Economic feasibility:** Most promising investors in MAR are the middle and large scale farmers, who grow high value crops such as table grapes, wine grapes and avocados. Further piloting of MAR is recommended to gain an improved understanding of the benefits and risks, and to eventually develop the most suitable MAR-system in relation to both cost-benefit and water use in the Lebanese context.

- **Water governance:** Groundwater should be governed as a common pool resource and water authorities need a strong mandate to manage them in a sustainable way. Public investments in MAR can help to recharge the deteriorating groundwater reserves. This can include implementing MAR in karst aquifers with the aim to benefit groundwater users at a regional level. At the same time, more efficient water well licensing mechanisms need to be in place and abstraction points need to be regulated and monitored.

- **MAR expertise:** To develop more understanding of the feasibility of MAR in Lebanon more pilot schemes should be implemented and monitored. Next to larger MAR schemes (possibly in karst) much potential lies in small-scale and low-cost systems that utilize existing (dry) wells. Subsidizing MAR systems for smallholders would help to improve the resilience of the rural population. For this, an important precondition is to simplify the MAR system (especially the filtration unit) and make it available on the local market at a lower cost.

- **Stakeholder mapping:** The importance of stakeholder involvement cannot be overstated. To target the most important institutions, organizations, and individuals, stakeholder mapping should be carried out at an early stage of the project. It is important to understand the local political situation and the relationship between the stakeholders including official and unofficial power differences. Ideally, each stakeholder's interest in the project as well as its power to support or prevent the project are mapped.

van Hogendoornplein 4
2805 BM Gouda

Telefoon: 0182 – 686 424
Internet: www.acaciawater.com
Email: info@acaciawater.com