GUIDELINES FOR INTEGRATING MAR INTO THE NATIONAL RIVER BASIN PLANS AND STRATEGIES-DRAFTED

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Managed aquifer recharge

General

Managed aquifer recharge (MAR) is an intentional process by which excess surface water is directed into the ground either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration in order to replenish an aquifer (Dillon et al., 2018). MAR methods are increasingly used to maintain, enhance and secure groundwater systems under stress. The objectives of MAR commonly focus on augmenting the groundwater quantity or quality, although it can be used for various other environmental benefits (e.g. prevention of seawater intrusions, restoration of degraded ecosystems, or prevention of land subsidence). MAR has been applied in various geological and hydrogeological settings all across the world (Lluria, 2009; Grutzmacher and Kumar, 2016; Sprenger et al., 2017; Dillon et al., 2019).

Use of MAR in Europe

The catalogue presented in Sprenger et al. (2017) includes 224 MAR sites active in the year 2013, across 23 European countries. No recent adequate article on the representation of MAR sites in Europe, such as Sprenger's, has been found in the professional literature. Global MAR inventory of active and inactive MAR sites was developed by IGRAC (https://ggis.un-igrac.org/view/marportal). The largest number of sites are located in Germany, the Netherlands and France, where the most common MAR method is induced bank filtration (IBF), followed by spreading methods. MAR sites also exist in other CE countries, such as Poland, the Czech Republic, Austria, Hungary, and Slovenia, but in a significantly smaller number of sites compared to the previously mentioned ones (Sprenger et al., 2017).

MAR methods are mostly used for producing domestic water in European countries (Sprenger et al., 2017). Significantly fewer sites relate to water use for agriculture and environmental needs (Sprenger et al., 2017).

River and lake water are the most frequent sources of water for the recharge process among analyzed MAR sites utilized for domestic drinking water supply (Sprenger et al., 2017). Stormwater runoff is not found as source water for MAR in Europe, and industrial end-use is found at three sites only (Sprenger et al., 2017). Furthermore, several MAR sites utilize urban wastewater as source water.

Some of the largest MAR sites using the IBF scheme exist on the two major islands in the Danube River, upstream and downstream of the city of Budapest in Hungary. This is reflected in the fact that this city is completely supplied through bank filtration systems. The installed well capacity (indicating the operational scale) of these sites is reported to be 146 and 219 × 10^6 m^3/annual, respectively (Grischek et al. 2002). Along with all other MAR sites in Hungary included in the catalogue, the total drinking water volume derived from MAR is about 327 × 10^6 m^3/annual, making up ~50% of the public water (total public water supply 661 × 10^6 m^3/annual, EEA 2010) (Sprenger et al., 2017). According to the 3rd Hungarian River Basin Management Plan (VGT3, 2021) the total abstraction through river bank filtration was about 245× 10^6 m^3 in 2018, which accounts for about 40% of the total drinking water supply in Hungary. It has to be noted that drinking water usage has been decreased in the last decades, which is also reflected in a lower annual bank filtration abstraction.

Also, in Slovakia river bank filtration is widely used for drinking water supply, mainly from Danube River. The Slovakian public water supply relies on MAR to a large extent, i.e. it covers approximately 55% of the total public water supply (175 × 10^6 m^3/annual from a total 319 × 10^6 m^3/annual) (Sprenger et al., 2017).

Clusters of MAR sites can be seen in Germany along the rivers Rhine and Elbe, in Berlin, and along the Danube River in Austria, Slovakia, and Hungary.

In the Mediterranean region (i.e. Spain, Italy, and some parts of France) MAR sites are only marginally found, but some sites were under development at the time of their publication, e.g., in the Toscana region near Lucca, Italy (Rossetto et al. 2015). In the Mediterranean countries, mostly surface-spreading sites are found, but also in-channel modifications and point/line recharge schemes. Surface-spreading sites in this region are often designed without the point of recovery and mainly aim to replenish the target aquifer, which is often used for agricultural purposes.

A prerequisite of MAR is to have a sufficient source of water for recharge, which includes various types such as surface water, rainwater, stormwater, reclaimed water, or groundwater (Gale, 2005; Dillon et al., 2009). Depending on the initial quality of the source water and the desired final use, a phase of pre-treatment before recharge and eventually post-treatment after recovery might be necessary to bring the water to a requested (by legislation) quality standard, that ensures the protection of public health and environment (Dillon et al., 2010). The selection of specific sources primarily depends upon the availability, as well as the quality that could be achieved with at least pre-treatment effort.

MAR sites that produce water for drinking purposes underlie strict regulations according to EU and national legislation. Most of this sampling and analysis are standard procedures and often not reported in the literature.

In Italy, Legislative Decree no. 152/06 plans artificial aquifer recharge as an additional measure in water management, and Decree no. 100/2016 establishes quantitative and qualitative conditions for recharge. Many projects examine aquifer recharge, such as WADIS-MAR in the southern Mediterranean region, WARBO in Italy, and municipal wastewater treatment project in Apulia, a southern Italian region. However, aside from groundwater recharge, the community must foster a spirit of cooperation to manage groundwater as a sustainable resource (De Giglio et al., 2018).

According to German law (Groundwater Ordinance), groundwater systems including MAR sites must be reviewed every 6 years, in terms of recharge processes and connections of the groundwater body to other hydrologic systems (DEMEAU, 2012). Endangered groundwater systems must be controlled, i.e. all sources of water recharged to the aquifer (including the location, volumes of water added, chemical and physical characteristics of the water added) must be identified. Moreover, the surface land where recharge happens must be detailed planned and controlled. In the Water Management Act, MAR is not mentioned explicitly, but certain guidelines are given. No official agreement is required to infiltrate rainwater into an aquifer. Groundwater management options must ensure that the quality of groundwater is improved, not worsened (DEMEAU, 2012).

MAR in the Mediterranean aquifers

Special attention to the research of MAR in the professional and scientific literature refers to the semiarid and dry subhumid areas, which also applies to almost the entire Mediterranean.

It should be noted that Croatia is dominated by three main climatic areas: continental, mountainous and coastal, which is reflected in the different conditions of water resources. The largest shortages of water resources occur in the coastal part of Croatia as well as on the islands. This area is also located in the Dinaric karst region.

In Croatia, very little has been discussed about MAR, as groundwater reserves generally meet water needs. However, there are springs in Croatia that are used for public water supply where this technique could be applied, for example, to increase the capacity of springs, control seawater intrusion and similar.

The continental part of Croatia is dominated by alluvial aquifers of intergranular porosity formed within large sedimentation basins of the Drava and Sava rivers, which are tributaries of the Danube River. These alluvial aquifers are rich in water and represent the main water supply resource of the northern and eastern parts of Croatia. The experience of neighbouring countries, especially Hungary, in the use of MAR methods can be useful for the continental part of Croatia. According to the River Basin Management Plan 2016-2021, the average renewable groundwater reserves in the Pannonian area of the Republic of Croatia are estimated at 3,257 x 10^6 m^3 / year.

In the southern part of Croatia (i.e., the Dinaric karst region), karst basins are widespread, which are characterized by extensive catchments in mountainous areas and hinterlands with very rich precipitation and very complex spring conditions at the contacts of waterlogged carbonate aquifers and watertight clastic rocks (e.g. flysch). Additionally, seawater intrusions are common in coastal areas and islands. The estimated average annual groundwater inflow is about 13,207 x 10^6 m^3 / year for the costal part of Croatia (according to River Basin Management Plan 2016-2021). These are extremely large total annual amounts of water, which flow very quickly towards the recipient, creating high flood waves in heavy rainy periods. During summer drought periods, runoff is significantly reduced due to the relatively low retention capacity of the karst underground.

Waters that remain in the karst underground for a long time are associated with deep retention areas and are predominant during dry periods when there is no active precipitation. These are waters of very good quality, mostly without chemical pollution. Short-stay waters in the karst underground create major problems with quantity and quality, as they occur as a result of flood waves that wash away pollutants accumulated on the surface, epikarst and unsaturated aquifer zone during dry periods (according to River Basin Management Plan 2016-2021).

Significant problems are related to coastal and island aquifers, where during the summer drought periods, due to reduced inflow and pressure of fresh water and direct recharge of precipitation, the impact of the sea increases. Therefore, a large number of karst coastal springs during the dry season are salted even in natural conditions. However, the biggest problem is the springs in the coastal area and on the islands included in the water supply, where due to water exploitation there is even stronger penetration of seawater into aquifers.

Thus, a special need for artificial recharge of aquifers is present on the Croatian coast and the islands (for example islands of Vis, Korčula, and others). Generally, in the summer months when hydrological minimums are reached, numerous island and coastal water wells become saline, resulting in a reduction or disruption of water supply.

One of the few and probably the first attempt of running MAR facility in Croatia was carried out from the late 1980s to the early 2000s on the Gradola spring aquifer in the western part of Istria (Trček et al., 2007). It is the most important spring in Istria used for public water supply with an average abstraction of 0.5 m^3/s. Gradole is a typical karst spring at the contact of highly permeable carbonate rocks and Quaternary clastic deposits of low permeability.

However, due to the high costs of abstraction, as well as the unfavourable water balance of the Butoniga reservoir itself, managed aquifer recharge process was not continued. Furthermore, more activities are planned in order to maintain such a system, such as additional hydrogeological research, then the construction of additional surface reservoirs, etc. to increase water reserves.

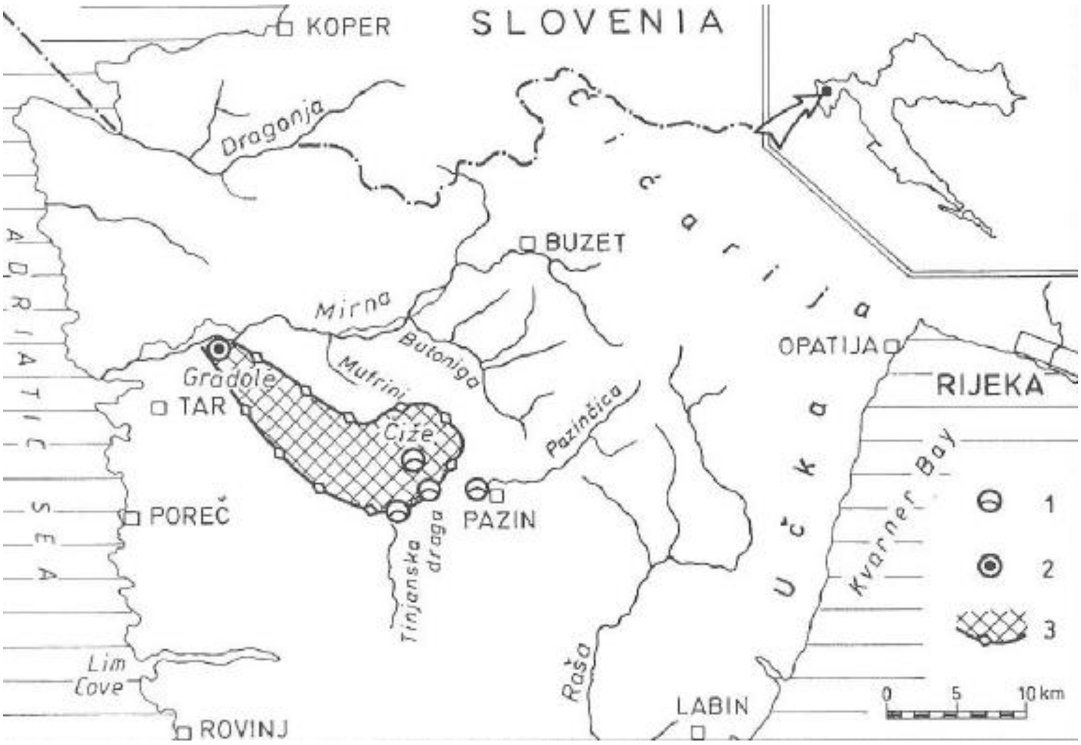


Figure 1. Location of Gradole spring (Istria, Croatia) (Magdalenić et al. 1995)

Perspective of MAR

Groundwater exploitation has grown at a rapid rate and has challenged human capability to sustain the resource. It is especially intensified in areas where the climate is dry. Managed aquifer recharge refers to a suite of methods that are increasingly used to maintain, enhance and secure groundwater systems under stress. Originally, the term "artificial feeding" was used when the focus was on increasing the amount of filling and much less attention with regard to water quality management. From today's point of view, MAR means that both components, quantity and quality, are effectively managed (Dillon et al., 2019).

In Europe, there are certain cases of application of some of the MAR techniques as early as the end of the 19th century. For example, river-bank filtration for drinking water supplies was established in Europe by the 1870s and the first infiltration basins in Europe appeared in 1897 in Sweden and 1899 in France (Dillon et al., 2019). Generally, in the middle of the last century, human intervention to increase the rate of groundwater recharge such as use infiltration zones, wells, and the like, were mainly unmanaged or accidental.

Among the first applications of artificial recharge of large-scale aquifers were the urban areas of California and New York in the United States, where MAR was used to stop the fall in groundwater levels (Dillon et al., 2019). India had the largest share in the world (31%) in the global application of MAR, in 2015, followed by the USA with a share of 26%. Germany ranked third with 9%, most of which is bank filtration for city water supplies that have been in use since before the 1870s (Sprenger et al. 2017).

The success of the aquifer recharge process is very sensitive because it depends on a number of factors and therefore requires an interdisciplinary approach to its realization in practice. In essence, it is about taking measures to increase the infiltration of water from the surface into the ground, and then about its retention (Bonacci, 2019). In general, the quality of water discharged underground should be sufficient quality in order to avoid deterioration of ambient groundwater quality. Aquifer recharge in karst basins usually involves two different processes, the diffuse (epikarst) infiltration and the point (through the sinkholes) infiltration, respectively. The amount of the two contributions in the aquifer recharge and the evolution of the processes over time are characteristic of each karst basin (Bonacci et al., 2006; Dillon et al., 2019).

In the case of coastal (karst) aquifers, groundwater retention is a particular problem (Daher et al., 2011). It is necessary to prevent the rapid outflow of water from the ground into the sea, which is a much more complex task than in granular environments, where recharge procedures have already become common while in the karst are still developing.

The climate model projections for the 21st century (Christensen ET AL., 2011; Imig and Rein, 2020; IPCC, 2021) indicate the following rainfall characteristics: decrease of the light precipitations, increase of the intensity of extremes, and increase the number of dry days. As a consequence, in the regions actually or potentially affected by water scarcity such as the Mediterranean, the stress on karst water sources is likely to grow over the next decades. Due to current uncertainties, it is very difficult to determine exactly how much potential changes in temperature and precipitation will affect water availability in karst regions (Hartman et al., 2014).

Furthermore, in karst areas with a strong anthropogenic impact, the need for aquifer management and recharge is even greater (Xanke et al., 2017). Currently, the volume of managed aquifer recharge at the global scale is estimated at 10 km^3/year, which is about 1.0% of global groundwater extraction (Dillon et al., 2019). This quantity is relatively small compared to the global water demand for all uses. But, in some countries, it is considerably higher (especially where induced bank filtration is practiced), suggesting that global opportunities are only just starting to be tapped.

However, karst aquifers are a basic source of drinking water supply to about a quarter of the world population living in densely populated areas (Hartman et al., 2017). Thus, the need to properly manage the underground drainage of natural runoff and treated wastewater should considerably increase in karst areas. The actual spreading of aquifer recharge facilities will be the result of the understanding of their capabilities and constraints, effective risk management, and the economic advantages in comparison with alternatives (Ross, 2018).

The goals of MAR

Artificial recharge of aquifers has applications in maintaining and increasing the quality and quantity of groundwater as well as in environmental management (Grutzmacher and Kumar, 2016). More detailed goals can be divided into three parts: water quality, water quantity, and environmental management (Grutzmacher and Kumar, 2016; Dillon et al., 2019).

Water quality:

• improvement of water quality in degraded aquifers (e.g. reduction of nutrients from agricultural pollutants, prevention of seawater intrusion), reduction of pollutant concentrations (e.g. arsenic),

• reduction of water treatment needs (e.g. use of natural purification).

Water quantity:

• storage of water in aquifers for future or seasonal use (e.g. water supply),

• increase in groundwater levels in overexploited aquifers.

Environmental management:

• prevention of abundant runoff and soil erosion,

• preservation of ecological flows in rivers and streams,

• flood mitigation and flood damage,

• control of seawater intrusion,

• reduction of soil subsidence,

• ensuring hydraulic conditions for the transport of pollution,

• raising groundwater levels to maintain or improve the status of groundwater ecosystems.

Although the criteria for the implementation of artificial recharge of aquifers vary from location to location, there are certain indicators that indicate this. Grutzmacher and Kumar (2016) identify the following potential areas where the following occurs:

• groundwater levels are declining,

• the availability of groundwater is inadequate, especially in the dry months,

• a large part of the aquifer is unsaturated,

• the aquifer is near a permeable fault or a semi-restricted layer containing contaminated water or water of poor quality,

• the aquifer contains water of poor quality and is very heterogeneous or has intense lateral runoff,

• aquifers show signs of seawater intrusion.

Types of aquifer recharge

The professional literature (IGRAC, 2007; Dillon et al., 2009; Sprenger et al., 2017; Dillon et al., 2019) lists five main methods (types) of aquifer recharge, some of which relate primarily to improving the infiltration of water into the ground (Table 1):

• spreading method,

• induced bank filtration,

• well, shaft and borehole recharge,

while the rest refers to techniques that affect the conditions of water runoff:

• in-channel modifications and

• runoff harvesting.

The selection of the appropriate type of managed aquifer recharge should be adapted to local specifics - hydrology, hydrogeology, type of aquifer, topography, land use, groundwater quality, and the intention to use the restored water. Among the above parameters, the knowledge and understanding of local hydrogeology still have the most important role in determining the possibilities and technical feasibility of such a project.

DEEPWATER-CE project (package 2, WP T2) addresses the development of a transnational assessment methodology for decision-making on MAR locations in Central Europe. In the framework of WP T2, methodologies for the collection and analysis of hydrogeological, geological, and climatological information relevant for selecting suitable MAR sites in Central Europe were developed (Imig and Rein, 2020).

Spreading methods

Irrigation with floodwater has been widely practiced for a long time in semi-arid regions to increase soil moisture for food production on otherwise dry cropping land, also unintentionally causing groundwater recharge.

Spreading methods refer to applications that aim to increase the infiltration of surface water into aquifers. Possible schemes include diverting water into infiltration basins or channels that will enhance infiltration through the unsaturated zone. Other possible techniques include over-irrigating crops or diverting floodwaters to specific areas to increase infiltration. Infiltrated water is stored in a basic aquifer and used during periods of high demand through wells.

In Israel, soil aquifer treatment of recycled water has contributed significantly to groundwater development over many years. In Italy, several infiltration basins have been constructed in the last few years, after accepting MAR regulations.

These spreading methods are useful for increasing the amount of groundwater, as well as for its quality due to the filtration process that occurs when water travels through an unsaturated zone.

The method of spreading can also have a negative effect in terms of quality when floodwaters are very turbid and can cause various blockages and pollution.

Induced bank filtration

Induced bank filtration is useful from the aspect of water quantity and quality, and refers to the increased infiltration of surface water into the aquifer due to its pumping. Coastal water abstraction system usually consists of a gallery of wells or a series of wells parallel to the shore of the surface water (river, lake), so that the surface water is in hydraulic contact with the aquifer. This increases or ensures the yield of the well. Bank (coastal) water can be extracted from dug, vertical or horizontal wells, drains or using other techniques.

In addition, the water collected in the wells will have better quality due to the filtration process that takes place when filtering the water from the riverbed or lake bed to the well, removing dissolved and suspended pollutants. Today in Europe, bank infiltration is mainly used for pre-treatment, the focus lying on attenuation of water quality variations and removal of turbidity, pathogens, and organic compounds (Dillon et al., 2019).

Well and borehole recharge

Recharge wells were used are used for a long time in many regions, to recharge rainwater collected in ponds to replenish shallow aquifers used as drinking water supplies (Dillon et al., 2019). Thousands of these wells still exist in coastal areas where aquifers are brackish and are used for a variety of purposes. In Israel, recharge wells started to be used in the 1950s. Aquifer storage recharge and its recovery has been applied for drinking water supply in the Netherlands, for a long time. The clogging of wells or drains has always been a hot topic in MAR systems research because of their extreme vulnerability.

In this type of aquifer recharge, water is infiltrated through wells (boreholes) directly into the aquifer or through a sink (e.g. the spring of Gradola in Istria recharged through direct injection in the sinkhole). This technique is usually applied when the unsaturated zone does not allow water infiltration, e.g., a poorly permeable layer above an aquifer is present.

Water collected in the aquifer can be captured through the same injection wells or other wells or springs depending on field conditions.

In-channel modifications

Several aquifer feeding techniques involve modifying runoff conditions within the riverbed (stream) to improve water infiltration.

For example, some techniques are based on intersecting the flow of water with dams built across the riverbed (watercourse). Such structures can be used to increase the infiltration of retained water behind the dam or to control the discharge of water according to the ability to infiltrate the underlying aquifer downstream of the dam.

In impermeable riverbeds, sand and gravel can be accumulated upstream of the dam to form an artificial aquifer to store rainwater.

Underground dams (barriers) made of low-permeability material can also be built-in riverbeds and basins in order to keep water in the alluvium (underground) for as long as possible. Thus, for example, improved underground water storage can be achieved by constructing underground injection curtains, barriers, etc., which is particularly important for coastal aquifers.

At a permanent watercourse, the river flow can be modified by building an L-shaped embankment, i.e. by widening the inundation zone, which increases infiltration and reduces the flow rate.

The design of MAR structures has changed little since the 1960s when concrete check dams and spillways for percolation tanks were introduced and standardized through technical guidelines. While there are many papers that conceptually evaluate the positioning of streambed recharge structures in relation to geomorphic variables, there is a lack of field measurement and monitoring of existing structures that would inform MAR policies for catchment-scale water sharing plans (Dillon et al., 2019).

Runoff harvesting

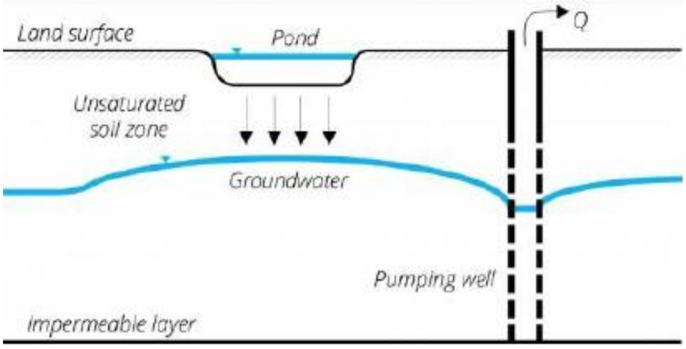
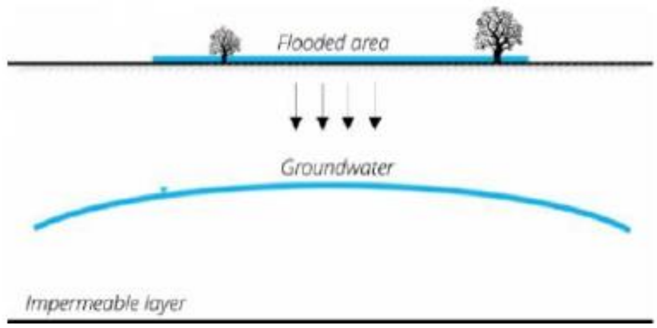
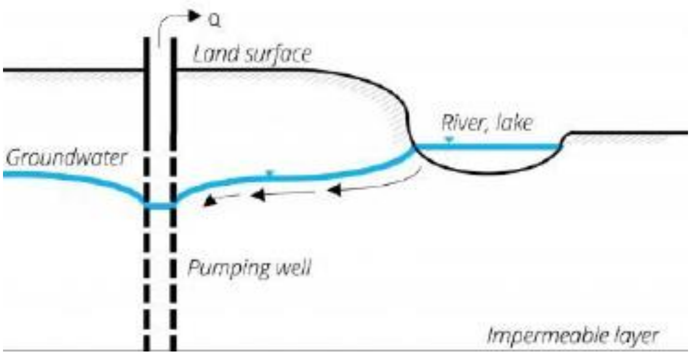
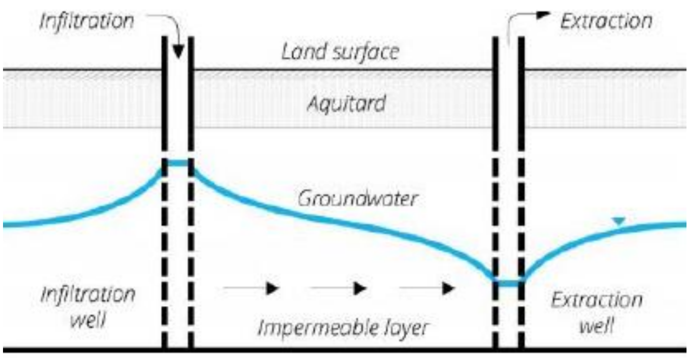
Rainwater harvesting includes MAR techniques that collect rain and surface runoff. For example, barriers and trenches can be made to reduce the surface runoff and erosion and to enable irrigation water for agriculture in hilly terrain. This MAR type increases the water contact area and provides additional recharge potential. Rooftop harvesting collects rain and stores the water in settling tanks before it is recharged through dug wells or boreholes to the aquifer (Ghanem et al., 2017, Sprenger et al., 2017).

Rainwater collection can be carried out at different levels, from households to an entire settlement or city (Ljubenkov, 2021). The collected water can also contribute to the restoration of groundwater if there is a need for it.

Rainwater collection can be reported in a number of ways, including the construction of appropriate trenches, canals or drainages, in larger areas with appropriate reservoirs, from which aquifers are further fed.

In urban areas, the most common is the collection of rainwater from roofs, which is given special attention in modern architecture. In addition, these systems can mitigate flash floods in urban areas and also help maintain groundwater levels.

Table 1. Classification of MAR techniques

	Main MAR methods	***Specific MAR methods***	***Scheme****
Techniques referring primarily to water infiltration	*Spreading methods*	*Infiltration ponds* *Flooding* *Ditches and furrows* *Excess irrigation*	 
	Induced bank filtration	*River / lake bank infiltration*	
	Well and borehole recharge	*Wells, boreholes*	

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<td rowspan="2">Techniques referring primarily to intercepting water</td>
<td>In-channel modifications</td>
<td>Dams, barriers

Artificial aquifers

Subsurface dams

Channel spreading</td>
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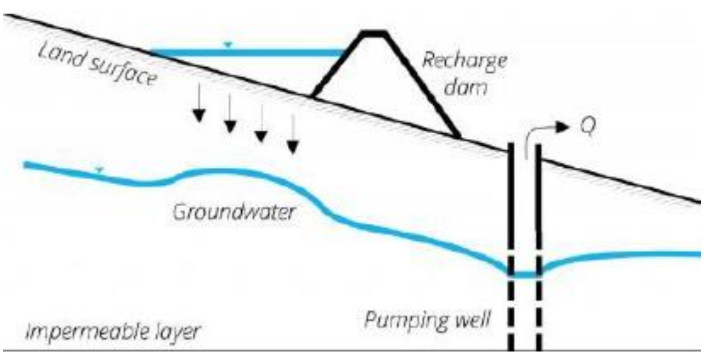

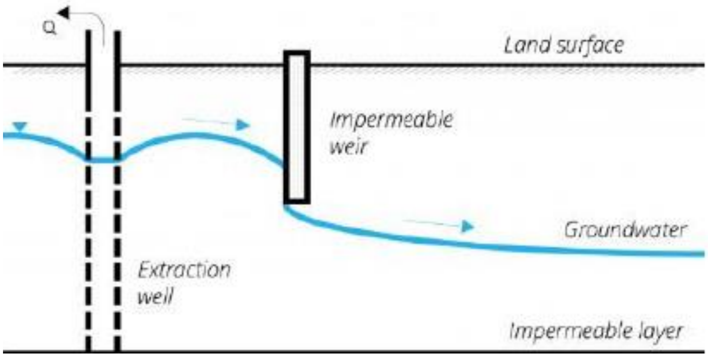

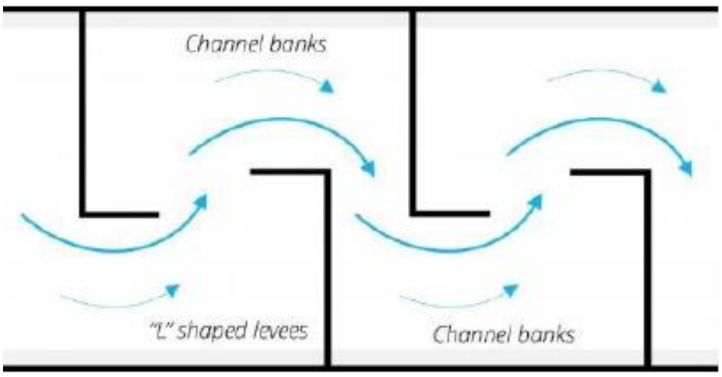

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<td>Runoff harvesting</td>
<td>Catchment area

Trenches</td>
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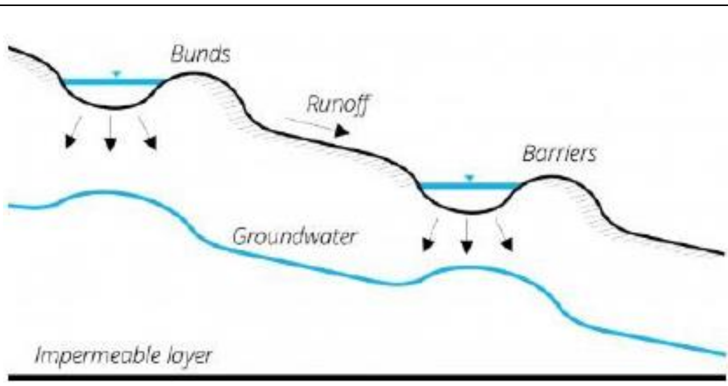

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			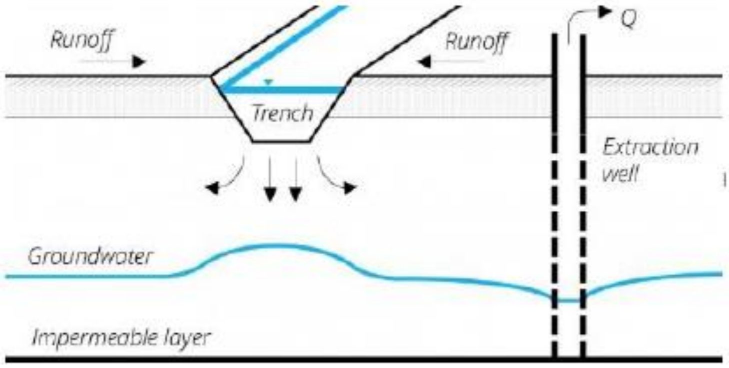

* Source: DEEPWATER-CE: Workpackage T1, Activity T1.1. (2020), based on IGRAC (2007) and Dillon et al. (2009)

According to Sprenger et al. (2017) who includes 224 MAR sites in 2013, across 23 European countries, the most widespread MAR method is induced bank filtration (IBF) with 127 sites (57% of total active sites); surface-spreading methods rank second among all MAR types with 77 sites (34% of total active sites). Well injection schemes form the third largest group of MAR types with 11 active sites (5% of total active sites) and 23 abandoned sites. Active-point or line-recharge and in-channel modification sites have been found seven and one time(s), respectively. Enhanced storage MAR types, e.g. sub-surface dams were not found in the literature for Europe.

Managed aquifer recharge (MAR) is adapted to the local hydrology and hydrogeology, and is usually governed by the type of aquifer, topography, land use, ambient groundwater quality, and intended uses of the recovered water. Figure 1 shows a variety of recharge methods and water sources making use of several different aquifers for storage and treatment with recovery for a variety of uses.

An understanding of the hydrogeology of the locale is fundamental to determining the options available and the technical feasibility of MAR projects. Recharge shown here occurs via streambed structures, riverbank filtration, infiltration basins, and recharge wells (Dillon et al., 2019).

Clearly, MAR implementation is proceeding at pace, fuelled by need and with the management aspects supported by research that improves risk assessment on resource sustainability and water quality. To ensure MAR continues to generate its intended benefits and avoids excessive piezometric pressures or waterlogging, failure during drought, and pollution of aquifers, water resources management and environment protection authorities need to be familiar with the opportunities and constraints of MAR. This is most efficiently controlled by setting soundly based policies and guidelines to ensure that MAR is undertaken in a way that protects the status of groundwater and the requirements of its receptors, including the wider environment (Dillon et al., 2019).

Water quality

The management and protection of water resources, of fresh and saltwater ecosystems, and of the water we drink and bathe in is, therefore, one of the cornerstones of environmental protection. This is why the EU's water policy over the past 30 years focuses on the protection of water resources. The last complete policy overview is provided in a document titled the "**Blueprint to safeguard Europe's water resources"** (2012) which aims at ensuring the good quality, sufficient quantity, and availability for all legitimate uses of water. Some more recent insight is offered by the fifth implementation report (2019) of the **Water Framework Directive** (2000), the central piece of environmental legislation concerning European waters.

Within the European Water Framework Directive (WFD) surface water bodies are required to meet "good ecological and chemical status" and groundwater (GW) bodies "good chemical and quantitative status" by 2015. The WFD demands that no deterioration in water status by any activity over the territory may occur. The WFD mentions artificial recharge as a possible supplementary measure and indicates that this activity will require periodic controls and previous authorization.

The **Groundwater Directive** (2006) has been developed in response to the requirements of the Water Framework Directive. The objective of the groundwater directive (GWD) is to protect groundwater against pollution and deterioration through the establishment of specific measures to protect and control GW pollution.

The **Drinking Water Directive** (98/83/EC with later additions) concerns the quality of water intended for human consumption. Its objective is to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is healthy and clean.

In general, the quality of water discharged underground should be sufficient quality in order to avoid deterioration of ambient groundwater quality. Therefore, artificial recharge must not impair the quality of groundwater. In the existing documentation, there are no clear guidelines for individual quality parameters regarding the water that enters the ground or what is the impact of MAR.

For the MAR application, it is necessary to list several ordinances from the Croatian water management that need to be taken into account:

The Ordinance on Limit Values for Wastewater Emissions (2020) (Pravilnik o graničnim vrijednostima emisija otpadnih voda, NN 26/20) is in force, which prescribes limit values for emissions of pollutants in all treated or untreated wastewater discharged into the environment and water.

The Ordinance on the health safety of drinking water (2008) (Pravilnik o zdravstvenoj ispravnosti vode za piće, NN 47/08) which provides the criteria to be met for water used for human consumption and prescribes the limit values of numerous indicators.

The Ordinance on the conditions for determining the zones of sanitary protection of springs (2013) (Pravilnik o uvjetima za utvrđivanje zona sanitarne zaštite izvorišta, NN 66/11 i 47/13) prescribes the conditions for determining the zones of sanitary protection of springs used for public water supply, as well as the measures and restrictions that are implemented in them.

These ordinances are in line with the provisions of the Water Framework Directive (WFD), as well as other directives arising from it. The application of MAR should be harmonized with these ordinances.

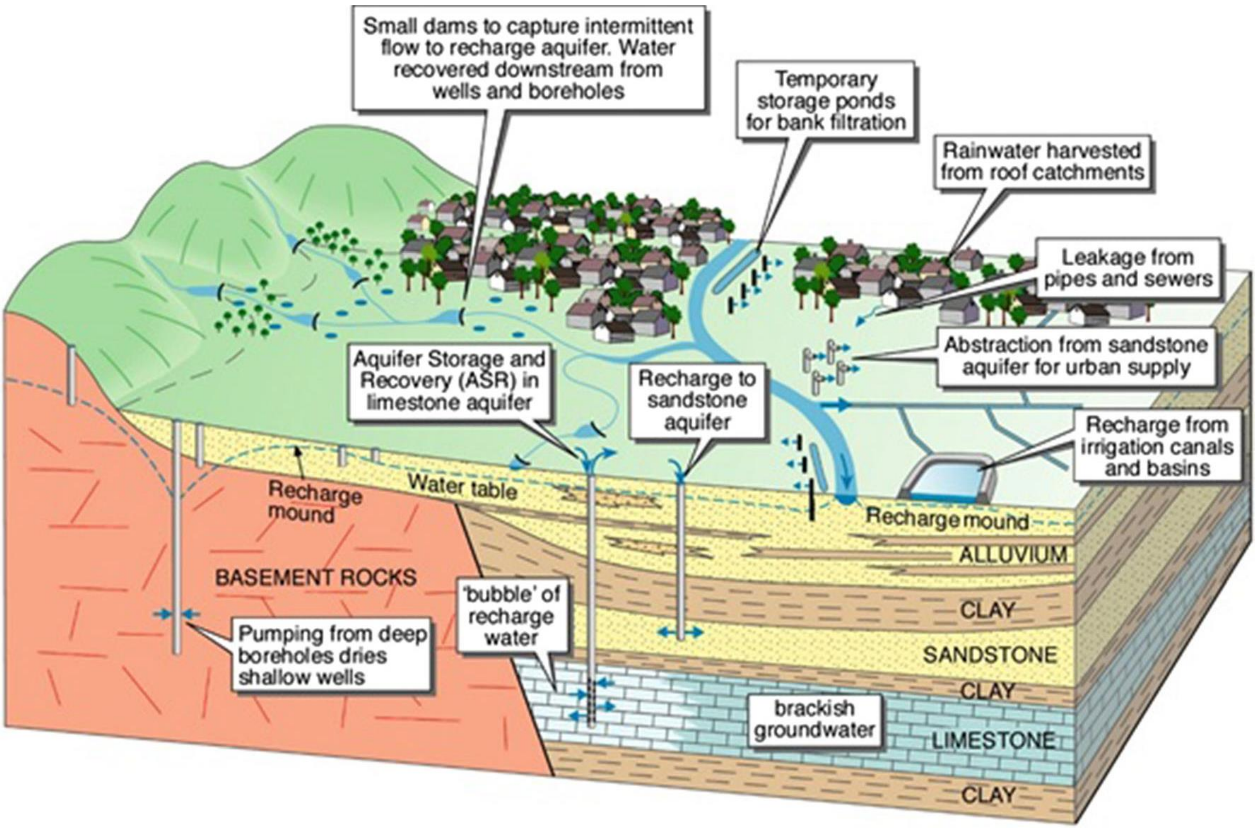

Figure 2. Different managed aquifer recharge methods (Dillon et al., 2019)

Implementation of MAR in national documents

The present European water directives do not specify requirements for MAR schemes and only define a broad frame in which MAR may be developed. At a regional or national level, some additional legislation or guidelines regulates specific concepts to achieve the protection of human health.

Since MAR has not yet been included in the existing national water management strategic and planning documents in most of the Central European countries, it should be included as soon as possible.

The most important planning documents of the Central European water management responsible bodies are the Water Management Strategy and the River Basin Management Plan.

The Water Management Strategy is a document on the basis of which water sector reforms should be implemented in order to achieve European standards in water management, and therefore forms the basis for gradual amendments to the Water Act and the Water Management Financing Act and related bylaws. The current Strategy was drafted in 2009.

A River Basin Management Plan is a document that prescribes water management plans and flood risk management plans. It is adopted for a 6-year period. The adoption of the Plan for the period 2022-2027 is underway. It is the third River Basin Management Plan.

River Basin Management Plan in terms of groundwater consists of information such as:

- Delineated and characterised groundwater bodies;
- Defining qualitative and quantitative status of groundwater, as well as of the pressures on it;
- Issuing of relevant and outstanding permits for the abstraction of groundwater;
- Acquiring valid data regarding groundwater dependent ecosystems and their mutual interactions;
- Ensuring effective protection of groundwater abstraction points intended for drinking water purposes;
- Envisioning sustainable use of groundwater resources taking into account climate change impact;
- Applying modern principles and innovative approaches in groundwater management policies.

Therefore, when drafting the updated version of RBMP, the possibilities of MAR described in these guidelines should be taken into account and included in it, taking into account all specifics (climatic, geological, hydrogeological, territorial, etc.) concerning all water management in EU countries. There are cases in Europe e.g. Italy (De Giglio et al., 2018; DEMEAU, 2012) where MAR is already included in certain planning documents

Article 5 of the Water Framework Directive requires an analysis of pressures on water bodies. Over abstraction of water from surface and groundwater bodies is a significant pressure in some areas of Europe and may be driven by wider problems of scarce water resources and increased by climate change. When, based on the Article 5 analysis, over-abstraction is identified as being a significant pressure, Member States should adopt appropriate measures to reduce the existing pressures and to prevent predicted pressures (as a means of climate change adaptation) in order to achieve a good status of surface and groundwater bodies as required by the WFD. Appropriate measures may include improved water efficiency, reducing leaks in water distribution, etc. One possible measure is managed aquifer recharge - MAR. MAR can also be a tool for management of water quality by improving water quality with artificial recharge into sensitive water bodies or to better quantity status in groundwater bodies with problems with quantities. The 2007 Communication on Water Scarcity and Droughts stresses that appropriate measures should take account of a 'water hierarchy', which emphasises the need to address water saving and efficiency as a priority. However, where this is not sufficient, additional water sources might be needed.

MAR in the Mediterranean aquifers could be such possible source. Water reuse and artificial aquifer recharged was highlighted as an important possible measure for further EU action in the 2012 Water Blueprint (EEA, 2012). One of these actions is these guidelines on Integrating MAR in Water Planning and Management in the Context of the WFD. Another is the development of a legislative proposal on quality standards for managed aquifer recharge, subject to an impact assessment.

It is important to emphasise that there is no 'one size fits all' solution to water scarcity and over-abstraction across the EU. MAR is one of the measures which can be used when deemed appropriate by individual Member States following a thorough assessment in the context of the WFD. When it is deemed to be the most appropriate measure, an analysis of risks and benefits to the environment needs to be performed. The intended audience for this document is policy makers, water resource planners, river basin managers and those in the water industry, irrigation associations, etc .

Furthermore, it stresses the importance of complying with national legislation on the quality of managed aquifer recharge where this is in place.

The second action under the Circular Economy package is for the Commission to develop a legislative instrument on quality requirements for managed aquifer recharge. If EU standards were to be adopted, the assessment and planning steps set out in this document could readily incorporate them. As a result, this document is considered as a CIS-guidance for the implementation of WFD. However, it is agreed that this document would be reviewed and possibly expanded if/when a legislative instrument is adopted in order to ensure consistency and integration between the standards, assessment and planning.

Conclusion

Groundwater exploitation has grown at a rapid rate and has challenged human capability to sustain the resource. This is particularly intensified in arid areas, but is also expected globally due to climate changes. MAR refers to a suite of methods that are increasingly used to maintain, enhance and secure groundwater systems under stress.

The present European water directives do not specify requirements for MAR schemes and only define a broad frame in which MAR may be developed. Since MAR has not yet been included in the existing national water management strategies and planning documents in most of the Central European countries, it should be included as soon as possible.

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