D.T4.3.2 ACTION PLAN FOR ADOPTION OF MAR IN CROATIA

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INTRODUCTION

The present document, a detailed, comprehensive and easy-to-follow Action Plan has been prepared to provide guidance for DEEPWATER-CE project partners and SHGs in Croatia, who are responsible for adopting MAR solutions in national water resource management schemes, policy strategic documents, water management legislation, etc.

This Action Plan proposes how, when, who, and with which resources MAR will be adopted into the water resource management plans in Croatia. Therefore, the Action Plan provide proposals and define concrete actions for the Republic of Croatia / regional level decision-makers to facilitate the application of MAR systems. Action Plan also describe the institutional settings and financial/business models necessary for the operation of MAR establishments.

GENERAL INFORMATION

Project	CE 1464 DEEPWATER_CE
Partner organisation	Split Water and Sewerage Company Ltd. PP7
Other partner organisations involved (if relevant):	Croatian Geological Survey PP8 Croatian Waters AP4
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1. BACKGROUND AND APPROACH OF MANAGED AQUIFER RECHARGE SCHEME AND ITS ADOPTION AND / OR INTRODUCTION INTO NATIONAL / REGIONAL LEVEL STRATEGIES, WATER MANAGEMENT PLANS, ETC.

D.T.1.2.1 "Collection of good practices and benchmark analysis on MAR solutions in the EU" is a thematic report within DEEPWATER-CE WP T1 – Development of transnational knowledge base on the applicability of managed aquifer recharge (MAR) in CE. The report is based on existing research papers from the domain of MAR. Furthermore, this report contains national inputs from five DEEPWATER-CE participating countries – Croatia, Germany, Hungary, Poland, and Slovakia regarding water management, priority issues, and experiences in managed aquifer recharge. It aims to provide a knowledge base for practical and theoretical aspects of MAR operation. However, to cover all existing MAR types, technologies, applied areas, and other particularities would be practically impossible and therefore, this report will focus on the most important topics in order to provide a broader understanding of the MAR concept.

The first part of this report presents a compilation of existing knowledge regarding the concept of MAR. While compiling this chapter, essential literature sources used were:

- Dillon (2005): Future management of aquifer recharge
- Casanova et al. (2016): Managed Aquifer Recharge: An Overview of Issues and Options
- Sprenger et al. (2017): Inventory of managed aquifer recharge sites in Europe: historical development, current situation and perspectives
- Dillon et al. (2019): Sixty years of global progress in managed aquifer recharge

The second part of this report focuses on experiences from existing or ongoing MAR projects from DEEPWATER-CE participating countries. A questionnaire was designed and sent to the participating project partners to provide an overview of national water management and differences between the particular EU countries. The purpose was to pinpoint underlying issues which require a MAR operation as a solution. In order to add value to the knowledge base, national case studies were presented in this report.

This report will also provide a basis for activity A.T1.3 "Capacity building to stakeholders in order to ensure integrated environmental approach on MAR", in particular, D.T1.3.2 "National training sessions on MAR topics and collection of good practices and benchmark analysis".

Managed aquifer recharge (MAR), is a term conceived by the British hydrogeologist Ian Gale, who was the founding co-chair of the International Association of Hydrogeologists (IAH) Commission on Managing Aquifer Recharge from 2002 to 2011 (IAH-MAR 2018a). Managed aquifer recharge refers to a suite of methods that are increasingly used to maintain, enhance and secure groundwater systems under stress. Simplified, 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. Whereas formerly, the term "artificial recharge", has been used when focussing on augmenting the quantity of recharge, but with much less attention given to managing water quality. The MAR term nowadays describes that both quantity and quality are managed effectively. In spite of a sound knowledge base, implementation of MAR schemes has tended to be localised and geographic expansion has been limited by a lack of understanding of hydrogeology and knowledge of MAR.

The modern history of methods covered by the term MAR begins with two techniques that are prominently represented up to the present day: induced bank filtration and surface-spreading methods. The first reported MAR site in Europe was in Glasgow (UK). The Glasgow Waterworks Company constructed a perforated collector pipe parallel to the Clyde River (Ray et al., 2003) and abstracted bank filtrated water in the year 1810. The idea of naturally filtered groundwater was born and spread to continental Europe. This method was successful at the beginning and many other cities in the UK (e.g., Nottingham, Perth, Derby, Newark; Ray et al., 2002) adopted the idea; thus, the 1860s became the first heyday of naturally filtered water in the UK (BMI 1985). However, many of these early sites experienced problems with decreasing well performance and had to be abandoned in later years (BMI 1985); nevertheless, the idea of naturally filtered underground water^ was born and spread to continental Europe, and it was soon adopted by cities in the Netherlands, Belgium, Sweden, France, Austria, and Germany. The historical development of MAR in Europe is shown in Fig. 1. Maintenance strategies and clogging aspects are known to be important to consider for MAR practices but were only rarely reported in the available literature for the European historical sites. Presumably, the main issues included turbidity, costly pre-treatments, lack of end-use water monitoring, and uncertainty in aquifer hydraulics. The progressing industrialization in the 19th century and the growing population in European cities presented the water suppliers with new challenges. The traditional water supply based on surface water was impaired by increasing contamination from the new industries and improper sanitation. At that time, based on the experiences in the UK, Adolph Thiem proposed the application of riverbank filtration to cope with degrading hygienic surface-water quality and increasing water demand (Sprenger et al., 2017). Research and development of well injection methods began in the 1960s.

The last 60 years have seen unprecedented groundwater extraction, and overexploitation as well as the development of new technologies for water treatment that together drive the advance in MAR (Dillon et al., 2019). The combined availability of deep wells, electric power, and electric submersible pumps radically escalated water withdrawal from aquifers and quickly reduced groundwater in storage. Between 1900 and 2008, 4.500 km^3 of depletion had occurred globally. Alarmingly, the depletion rate is still accelerating, reaching 145 km^3/y between 2001 and 2008 (Konikow, 2011). Although there is considerable uncertainty in estimates of annual groundwater exploitation and recharge, Margat and van der Gun (2013) report annual exploitation of groundwater of ~980 km^3/y in 2010, which is less than 8% of the estimated global mean natural recharge (which exceeds 12,000 km^3/y; Margat 2008), but nonetheless causes substantial depletion in some areas. It is clear that for sustainable-water-resource utilization, stabilization of storage decline is important and there are only two means of accomplishing this for groundwater: reducing demand (through increased water use efficiency or conjunctive use with other water sources) or increasing replenishment (Dillon et al. 2012).

Due to a wide variety of MAR types, underlying needs and conditions, socio-economical aspects, and all other factors, the concept of sustainability of MAR operation is not easy to define. There are no clear definitions, indicators, or good practices. Several efforts have been made to unite definitions, indicators, and good practices, but no conclusive document has been produced so far. Instead, efforts should be focused on individual case studies, specific guidelines, and the capitalization of existing knowledge (past projects, MAR sites) from various countries and regions. An example of such guidelines is provided by the National water quality management strategy of Australia (Natural Resource Management Ministerial Council, 2009), which addresses various sustainability factors such as:

- selection of recharge methods and areas;
- definitions of non-viable situations or areas;
- legal and institutional framework with proper assessment;
- risk characterization and preventive measures;
- monitoring and verification of water quality and environmental performance;
- operational issues and their management (e.g. clogging).

Access to full document: http://www.nepc.gov.au/system/files/resources/5fe5174a-bdec-a194-79ad-86586fd19601/files/wq-agwr-gl-managed-aquifer-recharge-final-200907_1.pdf

Another set of good examples is provided in the IAH and UNESCO document - Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas (Gale, 2005). Besides water quality issues, hydrogeological settings and control of recharge, methodologies, and institutional issues, the Strategy contains examples of various schemes implemented throughout all continents.

Further efforts are provided by the IAH Commission on Managed Aquifer Recharge (IAH-MAR). Besides organising symposia and workshops, the Commission also sets up working groups regarding various topics, such as clogging, global MAR portal (in association with IGRAC), MAR for sustainable development, economics, and so on. IAH MAR also participates in collaborative research and projects, namely:

- IGRAC MAR Portal - https://www.un-igrac.org/ggis/mar-portal

- MARSOL - Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought, http://www.marsol.eu/
- DEMOWARE - Innovation Demonstration for a Competitive and Innovative European Water Reuse Sector, http://demoware.eu/en
- DESSIN - Demonstrate Ecosystem Services Enabling Innovation in the Water Sector, https://dessin-project.eu/
- MARVI - Managing Aquifer Recharge and Groundwater Use through Village-level Intervention (India), https://recharge.iah.org/marvi
- GRIPP - Groundwater Solutions Initiative for Policy & Practice, http://gripp.iwmi.org/
- Water is essential for life, it is an indispensable resource for the economy, and also plays a fundamental role in the climate regulation cycle. The management and protection of water resources, fresh and saltwater ecosystems, and 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.

Directive 2006/118/EC on the protection of groundwater against pollution and deterioration, groundwater used for or intended for future use for the abstraction of water intended for human consumption, as referred to in Article 7 of Directive 2000/60/EC, should, in accordance with Article 7(2) of that Directive, include such measures as are necessary to ensure that under the water treatment regime applied, and in accordance with Community legislation, the resulting water will meet the requirements of Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Those measures may also include, in accordance with Article 7 of Directive 2000/60/EC, the establishment by the Member States of safeguard zones of such size as the competent national body deems necessary to protect drinking water supplies. Such safeguard zones may cover the whole territory of a Member State."

Drinking water protection zones (DWPZs) take up around 19.08% of **Croatia's** territory. Authorities responsible for water management are the **Ministry of Economy and Sustainable Development** - Administration of water management and sea protection and Croatian Waters who cooperate with regional and local government units. Criteria for delineation of DWPZ in intergranular aquifers are groundwater travel time and discharge rate, while in aquifers with fracture and fracture-cavernous porosity criteria additionally take into account groundwater flow velocity. In Croatia, there are three defined water protection zones in intergranular aquifers and four in aquifers with fracture and fracture-cavernous porosity. Legislation in Croatia also allows establishing special protected areas in the sense of water protection reserves in the remote and mountainous regions where several DWPZ can be joined together. DWPZ are implemented within the "Terms of use, development, and protection of space" of physical planning documents on the national, regional, and local level. In these documents for each established zone interdictions and protection measures are given, while the borders of zones are implemented in the cartographic representation of plans. According to the Croatian regulations for DWPZ, there are a number of limitations and restrictions in the particular sanitary protection zones. In aquifers with fracture and fracture-cavernous porosity, restrictions are more rigorous than in intergranular aquifers. According to the level of limitations and restrictions, DWPZ are divided into four zones (I-IV) of limitations which include the following activities:

IV. zone

- wastewater discharge without previous treatment,

- construction of production facilities for hazardous substances,
- construction of facilities for recovery, treatment and disposal of hazardous waste,
- construction of facilities for storage of radioactive, hazardous or oil-based fuels and materials,
- removal of topsoil,
- use of powder explosives,
- exploration and exploitation wells, except for water research,

III. zone

- all prohibitions from zone IV and additionally,
- temporary or permanent waste disposal,
- pipeline construction (hazardous fluids),
- construction of gas stations without proper technical precautions,
- surface of underground mining excluding geothermal and mineral waters,

II. zone

- all prohibitions from zone IV. and III. zone and additionally,
- agricultural production, except ecological (organic),
- cattle production (maximum 20 livestock units),
- the formation of new cemeteries and expansion of existing ones,
- construction of all industrial facilities that pose threat to water environment,
- forest clear cuts except sanitary cuts,

I. zone

- The first zone is intended to protect all the intake facilities (e.g. springs, wells, drainages, etc.) and the area which directly drains toward these facilities. First zone must be fenced. In the I. zone, all activities except those related to abstraction, conditioning, and transfer of water in the supply system are prohibited.

Furthermore, the DEEPWATER-CE project consortium prepared the handbook, i.e. a **decision-support toolbox** for the evaluation of managed aquifer recharge (**MAR**) **suitability**, with the aim of developing an integrated implementation framework for Managed Aquifer Recharge solutions to facilitate the protection of Central European water resources endangered by climate change and user conflict. It includes three major components:

i. **Climatological selection criteria,** to find out where MAR-schemes are needed or will be needed in the future
ii. **Geological and hydrogeological selection criteria**, to identify areas where MAR is possible
iii. The **sensitivity of MAR systems to** sequential and combined effects of **climate extremes**, to evaluate where and how MAR schemes can be applied if extreme climatic situations occur (such as dry or wet periods) as well as the identification of related potential risk

These selection criteria, aimed at identifying potential MAR sites, are portrayed in the form of **checklists** within a toolbox. By applying the selection criteria, suitability maps for MAR can be created. Those can be used prior to field investigations, in order to show the potential of an area or site for MAR schemes (e.g. Sallwey 2019). After a suitable area for MAR application has been identified, further aspects have to be analysed to evaluate the feasibility of MAR schemes. These aspects include, among others, water demand and supply, appropriate technical solutions, and costs and benefits – all of which will be the subject of ongoing project work.

As every MAR solution has its specific requirements or eligibility, checklists containing the selection criteria were categorized by MAR types. For example, the implementation of an induced bank filtration MAR technique is possible only if a river or lake is in proximity. In contrast, well, shaft, or borehole recharge techniques are practically independent of surface water. Since no general selection criteria for MAR can be defined, sets of selection criteria specific to MAR types are developed in this project. Based on the common practice of MAR application in Europe (e.g., Hannappel et al. 2014, BGR and UNESCO 2014, Sprenger et al. 2017) as well as local requirements identified for the project partner countries, **six promising MAR types** are selected for the evaluation:

1. Ditches (D)
2. Induced river and lake bank filtration (IBF)
3. Aquifer storage and recovery (ASR)
4. Infiltration ponds (IP)
5. Underground dam (UD)
6. Recharge dam (RD)

Detailed descriptions of the selected MAR types, and literature reviews that support this selection, are given in the public project report Collection of good practices and benchmark analysis on MAR solutions in the European Union (DEEPWATER-CE-Interreg).

The proposed MAR site selection process is based on the assessment of geological and hydrogeological conditions, current and future (modelled) climate conditions, as well as exposure and sensitivity of different MAR types to climate extremes. In order to find suitable MAR sites in Central Europe, detailed information on geological, hydrogeological, and climatological criteria have to be collected and implemented within geographical information system (GIS) databases. Data availability strongly depends on available measurements from the participating countries, on both national and regional levels.

To meet requirements for data availability, and deal with possible restrictions, a four-step procedure is developed for the decision–support toolbox. The specific steps relate to the scale, while investigations are based on the size of the screening area (different spatial resolution depending on data availability), the specific requirements of the selected MAR types, and the required order of investigations. This toolbox aims at supporting the decision process for implementing MAR systems, with a focus on the region of Central Europe.

To start the initial assessment of MAR feasibility at the designated site, a collection of preliminary information about the pilot site is recommended. The scope of this step shall be to identify, with rudimentary and readily available information, the degree of difficulty of the project and the assessment of whether the pilot site is suitable for the intended scope under the application of reasonable efforts. This shall be done with existing records in archives by the regional governments and also by field surveys. Furthermore, the objective of the MAR application can be addressed at this step, again, as already summarized in the good practice and benchmark report (DEEPWATER-CE, 2020a). It can also be helpful to interact with the general public and stakeholders to investigate their aims and objectives and hence reduce the risk of lack of public or political acceptance (Lyytimäki and Assmuth, 2014).

Therefore, the suggestion is to collect the information about:

- Climatology (precipitation patterns, temperature, evapotranspiration)
- Surface geomorphology, information on the geological history of the area
- Geological and hydrogeological settings
- Hydrological characteristics (catchment area and the drainage network) and existing water quality data.

The Australian guidelines on water recycling using MAR (NRMMC–EPHC–NHMRC, 2009) recommend to:

- assess the conformity of the MAR scheme with aquifer and catchment management plans
- talk to the regulatory institutions about the MAR project
- identify if sufficient management capabilities are available (e.g., knowledge of hydrogeology, water-quality management, monitoring).

Maliva (2014) identified different logistical and infrastructure issues that are relevant for the construction, operation, and maintenance of MAR systems. Therefore, it is recommended to analyse:

- Existing water supply infrastructure (including water quantity and quality)
- Possible linkage with MAR (implement MAR to existing infrastructure)
- Land availability for MAR infrastructure
- Site accessibility
- Site security
- Proximity to water and wastewater distribution infrastructure
- Proximity to electrical power infrastructure.

Based on the collected information, a decision shall be taken about the commencement of the project, and the implementation of pilot site characterization has to be planned.

After having conducted a desktop study (among others, including the collection of available data, the inquiry about regulatory requirements, and the identification of expertise needed for the implementation of the MAR scheme) and having obtained a positive decision about the commencement of the project, further investigation for the planning and implementation of the MAR scheme shall be carried out in form of a site characterization process.

The objectives of the site characterization shall be to answer the question, if

- there are sufficient demand and supply possibilities for water
- the aquifer is suitable for storage and recovery of the required volume of water
- there is sufficient space available to capture and treat the water

The site characterization is followed by the determination of a specific MAR design and the validation of the suitability and efficiency of this planned design with further investigations (i.e. extending information and data that have been gathered from the desktop study) (NRMMC–EPHC–NHMRC, 2009).

To answer these questions and hence identify the feasibility of a site for MAR schemes, the following investigation objectives may be chosen:

- Aquifer delineation:
  Investigation of geological structures and identification of lithological or hydro stratigraphic units in the subsurface (e.g. layer boundaries, aquifer thickness, etc.) in order to map the geometry of the target aquifer
- Characterization of aquifer properties:
  Determination of hydraulic as well as geotechnical and/or petrophysical parameters (e.g. hydraulic conductivity, storability, identification of preferential flow paths)
- Determination of groundwater dynamics:
  Measuring or modelling groundwater flow directions, recharge/discharge zones, groundwater abstractions and interaction between surface water and groundwater
- Determination of groundwater and source water quality:
  Investigating chemical composition, dissolved solids as well as geogenic and anthropogenic pollutions
- Identification of pollution sources:
  Delineation of pollutant sources (e.g. landfills or old deposits; detection of leakage in sealing systems), detection and identification of pollutants (what and where)
- Monitoring of the groundwater system:
  Monitoring of e.g. water levels, pollutant transport, water quality, etc., in order to identify and quantify temporal (e.g. seasonal) changes in the system

A suite of different methods is most likely applied for the identification of parameters needed for site characterization. Different aspects are targeted, such as:

- Water sources and water quality
- Hydrogeology, aquifer characteristics (including, e.g., storage properties)

In order to characterize the pilot site with respect to water quality (precipitation, groundwater, and surface water) and aquifer lithology, groundwater sampling and borehole analysis are performed to derive the required parameters. The chemical composition of groundwater can also provide information on the groundwater flow system. Possible methods (examples) are mentioned for identifying parameters that could be useful for MAR site characterization. Depending on the research objective, the required sampling scheme and the number of required samples have to be determined. In order to obtain reliable and comparable results from the sample analysis, it is important to stick to a defined sampling methodology.

In Croatia, the pilot area of the island of Vis has been selected. This is a semiarid karst area, which, due to its specificities, is a perfect area for establishing MAR. The available groundwater resources cover the water demand of the domestic population. However, demand increases significantly during the summer due to intensive tourism (by five to as many as six times). Vulnerable and limited groundwater resources, together with increasing seasonal demand and uncertain climate future, make this island an excellent candidate for assessing the suitability of MAR. In addition to increasing tourist activity, there is a strong need for alternative solutions in the water resources management on the island due to increased seasonal demand, climate changes, and high seasonal rainfall variability.

Desktop research results are positive and promising.

The concept of applying the MAR scheme on the island of Vis is primarily focused on the two most promising methods: the infiltration pond method and the aquifer storage and recovery (ASR) method.

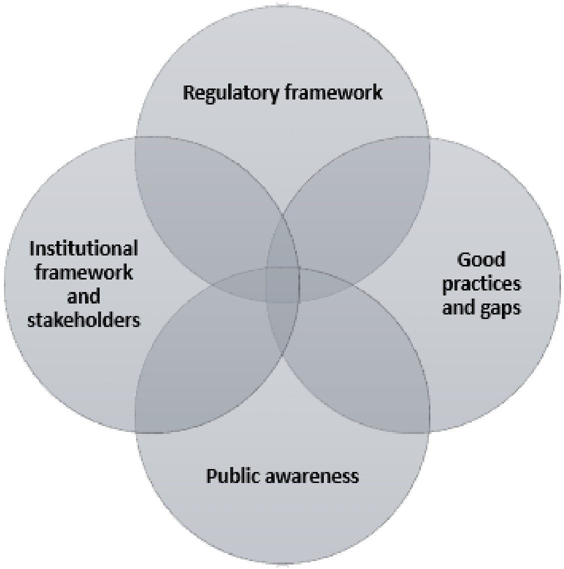
The island of Vis is suitable for the application of MAR according to all the criteria that are analysed in detail in the desktop analysis *(document D.T3.6.1 Report on the Desk Analysis of the pilot feasibility study for MAR deployment in fractured and karstified aquifers located in semiarid karst areas- https://www.interreg-central.eu/Content.Node/DEEPWATER-CE.html-)*.

Furthermore, there are other particularities of the island of Vis that make it an excellent pilot area for the implementation of the MAR pilot project in the Republic of Croatia:

- There is a significant water supply problem on the island, which cannot be solved with classic solutions (connecting the island to another water supply system), i.e., the classic solution is not necessarily the most optimal. The island of Vis is located 44 km from the nearest mainland point (Vinišće on the Trogir coast) and 53 km from Split.
- The island of Vis has its own water resources in karstic aquifers. The water level is often dangerously low in the summer months, which leads the island's water supply system to the risk of water salination. Therefore, existing aquifers need to be protected, whereby managed aquifer recharge (MAR) is definitely an option that needs to be explored.
- In the summer months of 2019 (this is the year with the highest annual water consumption on the island), the extraction of water from the existing aquifers achieved the maximum amount of water currently available on the island.
- The island's future development (mainly tourism) depends on providing additional quantities of drinking water available. On the island of Vis, there are continuous investigations to find new sources of drinking water. Connecting to the mainland water supply system is extremely expensive.

The Korita wells (5 active wells, maximum pumping quantity is approximately 42 l/s) supply the entire island of Vis. Therefore, in this pilot study, the whole island of Vis is defined as a pilot area. The Korita well field is located in the central part of the island of Vis. The Korita pumping site is conveniently located in terms of having enough land availability on-site for the potential construction of an accumulation structure, which would be utilised as a source of water for MAR. Furthermore, the availability of essential infrastructures such as roads, telecommunications, electrical power, and water distribution, and a high degree of security in terms of potential pollution sources are secured. This makes this site potentially very suitable for the application of the proposed MAR scheme.

The main pillars of the MAR policy environment are the regulatory framework, the institutional framework including stakeholders, good practices, and public awareness, which need to be established and harmonized for any MAR applications (Figure 1) as a useful tool for integrated water resource management.



A.1 Figure 1. Component pillars of MAR policy.

Regulation is required in order to control activities that might influence the quantity and quality of water resources which are the inherent components of the MAR scheme. This should be harmonized with different national environmental strategies. Due to the different vulnerability and allocation limits for water resources, recharge and recovery water for MAR are proposed to be managed separately.

The general governing instruments of the regulations are the EU Directives and EU Framework Directives, which are adopted in the national legislations of the CE countries and can relate to the different elements of MAR applications (Figure 2). The national or regional legal instruments are provided by laws and acts, government decrees, and ministerial decrees for regulation and implementation. The basic tools for the implementation of the EU Directives are the main national strategies (eg. Climate Strategy, Water Strategy). An overview of the legislation in the project partner countries has been carried out within the frame of the DEEPWATER-CE project (DEEPWATER-CE, 2021a).

The institutional arrangements for the management of MAR applications and water resources should bring clarity to the roles and responsibilities of the national and/or regional institutions responsible for water resources. The structure of the organizations with responsibilities for both surface and groundwater have to ensure a univocal background for the implementation of regulations and water resource management. This also comprises the financial actors, operators, and the authority for monitoring a MAR project. The problem of groundwater management receiving inadequate attention under this arrangement needs to be addressed in most CE countries.

In order to achieve wider applicability of MAR in CE, the integration of objectives and measures for the use of MAR systems into each country's strategic planning documents, in particular into the documents of water management, river basin management plans, and climate adaptation, is needed. It is advised to define it both on local and on regional levels. In total, five key issues are identified in this document for which policy recommendations are proposed and a short rationale is given.

Issue 1: Elaboration of a strategy on MAR applications.

Recommendation:

- Integration of the objectives and measures for the use of MAR systems into each country's strategic planning documents, in particular the documents on water management and climate adaptation.

A "National Strategic Plan for the application of MAR systems" should be prepared, which will cover the entire life cycle of a MAR scheme, including its sustainability, and risk assessment.

Rationale:

In order to provide a profound basis for the implementation of MAR solutions into legislation, the complexity of the issue needs to be accounted for. National strategies and action plans outline the strategic framework, help to establish a planning process, identify priorities, promote effective management and drive implementation of MAR schemes on a longer time scale and in a possibly wider context. They are not binding legally, though are considered important to succeed in legislation. Strategic planning should be objective, evidence-based, as much as possible, should provide a clear vision, give a forecast and compare alternative scenarios and solution possibilities.

It is suggested to set up a special working group of experts in hydrogeology, economics, and risk analysis to contribute to the preparation of national MAR strategies/action plans, as is in the case of the Water Safety Plans, for example.

Issue 2: Regulations on MAR in a comprehensive way

Recommendation:

- A detailed system of regulation and licensing of MAR methods should be established.
- The regulatory and licensing specifications for the implementation of MAR systems differ from country to country, which must be considered during this process.
- Direct and indirect incentives should also be developed.

Rationale:

Development of regulations that cover the entire life cycle of MAR activities, sustainability, and risk assessment. Regulations on water accessibility through the MAR system, entitlement, traceability, and obligations and conditions of water use should be established. The regulations for the implementation of MAR systems differ from country to country, which must be considered during this process.

Water price policies should also reward sustainable water management solutions and sanction non-sustainable solutions. Additionally, each specific sector needs direct incentives to speed up the investments.

Financial assets and resources have to work on the principle of user/polluter pays.

According to the WFD, the poor status of groundwater chemical status can be caused not only by pollutants but also by a trend change in natural background values, e.g. easily accessible in a saline area with long-lasting surface water replenishment. Therefore, the scope of the regulation should be extended to all types of discharges in addition to those containing potentially polluting substances. However, it is worth restricting the scope of the regulation according to the amount of water leaked.

MAR systems shall be installed based on extensive, detailed examination, monitoring, and experimental testing of the local conditions.

Issue 3: Suggestion of MAR incorporation into executive documents (River Basin Management Plans)

Recommendation:

- It is necessary to include the review of the applicability of MAR methods in the River Basin Management Plan (RBMP) revisions, especially in regions exposed the most to the negative effects of climate change and in the water bodies with poor conditions or at risk of contamination, as an important tool for integrated water resources management.
- Potential areas for the implementation of MAR systems can and should be determined based on the environmental assessments of the River Basin Management Plans.
- MAR systems can be installed based on extensive, detailed examination and experimental testing of the local conditions.
- During the construction of dams and reservoirs for any purpose, the possibility of unintentional groundwater recharge in the vicinity of these facilities should be evaluated to minimise evaporation and leakage.
- Focus on the design of effective monitoring of selected indicators during the operation of the MAR systems (e.g. physical-chemical properties of source water, surface water, and groundwater levels, injected yields, water treatment parameters, etc.), and regular evaluation of obtained data during the lifespan of the MAR system.

Rationale:

- The poor quantitative status of groundwater bodies is caused by groundwater overexploitation (abstracted water amount exceeds the recharge in a long term). River Basin Management Plans formulate measures for the protection of surface and groundwater-dependent ecological systems and sustainable water uses. However, groundwater systems are characterized by slow processes, therefore groundwater levels will not necessarily rise as a result of the above measures and the groundwater-dependent ecosystem will not regain an adequate amount of available water. Thus, MAR systems are suggested to be applied, in order to increase the amount of groundwater that can be extracted without further deteriorating groundwater bodies with poor quantitative status. Improvement of groundwater quality status is also a slow process, in which MAR systems can play an important role.
- MAR-specific measures should be incorporated into RBMPs.
- At present, MAR is not a supported activity to protect groundwater. In the context of groundwater vulnerability, this could be completely ruled out in some areas but permissible in others. This measure is also in the interest of surface waters.
- Indicators of the measures can be e.g.: rising groundwater levels, the quantitative status of the groundwater body, amount of wastewater recovered, amount of water replenishment, and groundwater ecosystem assessment.

Issue 4: Improving information on applicability and implementation of MAR for decision making

Recommendation:

- It is necessary to promote MAR solutions in the water sector via River Basin Management Plans (e.g. to include MAR schemes in RBMP´s revision)

Rationale:

- MAR has a vital role in managing the reduction of vulnerability and enhancement of resilience to the effects of climate change. In order to tackle these challenges, the understanding of the impacts, vulnerability, and risks needs to be strengthened through data collection, monitoring, analyses, and assessment. For the sustainable management of the available resources among competing users and also to ensure safety, promoting environmental assessment, screening, and experimental testing of local conditions are needed.

Issue 5: Education of professionals and public awareness-raising on MAR applications

Recommendation:

- The National Strategic Plans and the benefits of MAR systems must be disseminated to society, educational organisations, decision-making organisations, NGOs, and other relevant authorities. The engagement of the experts, as well as water and climate research-related institutes should be increased.

2. VISION OF ACTION PLAN

The term 'Action Plan' in water management refers to an agreed policy document that identifies political, legislative, and institutional reforms and investments needed to address water and environmental issues. The purpose of the Action Plan (AP) is to provide a framework for joint transnational management of MAR in Central European countries as they address key challenges and seize opportunities for sustainable development and use of aquifers in Central Europe in future hazardous scenarios caused by climate change and overexploitation trends. The vision of this AP is to achieve water security and sustainable socio-economic development in Central European countries through joint research and management of MAR implementation.

In Croatia, similar to many countries in the EU, MAR is not included in water-related legislation (e.g. River Basin Management Plan). Due to this fact, its investigation, focus, and potential implementation as significantly hindered. Despite the relatively abundant water resource of high quality, its distribution in Croatia is not uniform. Significant water stress, from the perspective of quality and availability, is present in the coastal and island’s areas. Most significant stressors include overexploitation of the aquifers, urban or agricultural pollution, seawater intrusions, or user conflicts. To achieve resilience and sustainability in groundwater exploitation, integrated management of water resources including MAR offers the highest potential. Solutions should be specifically tailored to meet the site-specific requirements. By drafting, promoting, and adopting this AP, MAR solutions gain increasing attention which can solve emerging or existing issues related to water management in specific areas. Additionally, due to the increasing technological potential and ever-increasing knowledge, the risks and environmental impact related to MAR implementation can be detailed, managed, and ultimately, mitigated. Therefore, MAR solutions represent holistic, sustainable, safe, cost- and environmentally friendly solutions to augment water quality or quantity. An added value of this AP is bridging the gap between the scientific community (researchers), policymakers (local, regional, and national bodies), and infrastructure providers (end users, i.e. water suppliers).

3. OBJECTIVES, PRIORITIES, TIMELINE AND POTENTIAL FUNDING PROGRAMME OF ACTION PLAN, NECESSARY INSTITUTIONAL BACKGROUND

Objectives, priorities, and actions were used to define activities that contribute to achieving the vision and addressing key issues in the AP. Actions were identified by articulating a set of objectives, priorities, and requirements, as shown in Table 1. This resulted in an initial list of actions that fall under a range of priorities. The objectives articulate broad, overarching categories for coordination, while the priorities provide more specific aims that contribute to addressing the objective. The actions provide concrete implementation steps to achieve each priority.

Table 1 Objectives, priorities and actions of AP

Objectives	Priorities	Actions
Adoption of AP in Croatia	Guideline for individual quality parameters for aquifer recharge in Croatia	Implementation of these standards in national legislation like Water quality standards in special chapter for groundwater in case for aquifer recharge
Adoption of AP in Croatia	Identified areas with problems of quality and quantity and acceptable solution with MAR to improve quality or/and quantity status	Study
Adoption of AP in Croatia	Pilot area with solution of MAR	Study
Adoption of AP in Croatia	Proposal for MAR like measure in RBMP to improve quality or quantity status	Proposal for measure in River basin management Plan
Adoption of AP in Croatia	Identification of areas with problems regarding water quality and quantity	Analyses of available data and literature for the specific area. Multidisciplinary investigations and site characterization (geology, hydrogeology, hydrology, geochemistry, microbiology, climate). Definition of the underlying problem. Definition of the desired outcome of MAR: improved quality/quantity, or other environmental benefits (e.g. aquifer remediation). Definition of benchmark conditions (e.g. water quality guidelines).
Adoption of AP in Croatia	Establishment of working groups	Definition of responsibilities and establishment of working groups, consisting of operators (e.g. water suppliers), researchers, decision-makers (e.g. water management, local, regional or national structures),

		and financial bodies (domestic or EU funded).
Adoption of AP in Croatia	Development of a conceptual model for MAR implementation	Based on exhaustive data acquired in Objective 1, the conceptual model with the selection of appropriate MAR techniques is carried out, including the definition of required construction works related to the infrastructure.
	Verification of project feasibility	Project feasibility is demonstrated by applying risk assessment methodology, cost-benefit analysis, and environmental impact assessment.
	Funding of the project	Finding and securing a funding source (EU, national, or private funding). Public procurement and contracting of infrastructure and construction work.
	Construction of MAR infrastructure	On-site works and construction, following principles of nature conservation.
	Operation of the MAR infrastructure and monitoring of performance	Active MAR facility, accompanied by strict monitoring activities. High-resolution (preferably in real-time) monitoring of pre-defined water quality parameters.
	Verification of MAR infrastructure performance	Verification of successful performance of MAR facility, e.g. achievement of water quality standards, recovery rate (ratio of injected vs. recovered water), or other environmental benefits. If the desired goal is not met (as defined in step 1), modifications of the MAR technique or other influential parameters are necessary. If MAR exhibits low performance (in the technical or economic sense) or deteriorates any component of the natural system (e.g. groundwater body), cessation and decommission of work.

4. EXPECTED RESULTS AND TRANSFERABILITY

Despite the lack of guidance documents or higher-level strategies on the EU level, the new River Basin Management Plan (RBMP) in Croatia and in similar karst areas in EU, should include MAR.

MAR can also be a tool for the management of water quality or to achieve better quantity status in groundwater bodies with such problems. The 2007 Communication on Water Scarcity and Droughts stresses that appropriate measures should take account of a 'water hierarchy', which emphasizes the need to address water saving and efficiency as a priority. However, where sufficient water resources are not available, additional water sources might be needed and considered. Karstic water resources along the Croatian coast and on the islands are highly vulnerable to overexploitation, climate change, and user conflicts, and therefore, require innovative solutions and active management efforts. In this context, MAR poses a significant potential for improving the qualitative and quantitative status of groundwater bodies. Additionally, MAR was highlighted as an important possible measure for further EU action in the 2012 Water Blueprint (EEA, 2012). One of the actions is integrating MAR in Water Planning and Management in the context of the WFD. Another is the development of a legislative proposal on water quality standards for managed aquifer recharge, subject to an impact assessment.

It is important to emphasize that there is no 'one size fits all' solution to water scarcity and over-abstraction across the territory of Croatia. MAR is one of the measures which can be used when deemed appropriate by aquifers with some problems 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, and water-related infrastructure in Croatia.

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 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. However, it is agreed that MAR 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.

4.1. Stakeholders and their influence - policy recommendation

The intended audience for this document is policy makers Government, Ministry of economy and sustainable development, water resource planners like Croatian waters, river basin managers for instance public and private water supply and those in the water industry, irrigation associations, etc in Croatia.

Stakeholders are people who participated in the DEEPWATER-CE project in any form, e.g. through training and event participation, and deliverable drafting. In Croatia, we had representatives of different target groups and institutions, and they are listed in Table 2.

Table 2. Stakeholder groups.

Stakeholder group	An example of the institution	Total number of institutions
Local public authority	City of Vis	7
Regional public authority	Split-Dalmatia County	2
National public authority	Ministry of Environment and Energy	2
Sectoral agencies	Geopark Vis Archipelago	3
Infrastructure and public service providers	Water supply and sewage company of Vis island	5
Interest groups including NGOs	Anatomy of Islands - Centre for Research and Development	8
Higher education and research	Faculty of Civil Engineering, Architecture and Geodesy	14
Enterprises	Pomak Ltd. Split	5
Business support organisations	Komiža Tourist Board	2
	In total	48

The mobilization of stakeholders was maintained by regular contact (personal and written), provision of information about the project progress, and by engaging them in the fieldwork activities. Representatives of public authorities were involved in Work package 4 through personal bilateral meetings where the topics were the policy recommendations and action plans.

Successful cooperation with the stakeholders was the key method to disseminating the results and creating an interest in the topic of the DEEPWATER-CE project and managed aquifer recharge methods. Stakeholder involvement increased the chances of involving MAR in national water management strategies as one of the possible methods used in areas where additional quantities of water are needed for water supply, agriculture, or even industry.

4.2. Transferability potentials

In general, there are four groups of transferability potentials of MAR adoption, as follows:

- Advanced knowledge/capacity requirement,
- Advanced ICT exploitation related knowledge/capacity,
- Requirement for strong access to more advanced communication channels and
- Level of synergies of SHGs required for MAR adoption

The Mediterranean region is dealing with the challenges of sustainable management of groundwater resources in karstic aquifers and therefore, the results and outputs of the DEEPWATER-CE project, especially the results derived from the Croatian pilot area, can be applied to solve that environmental challenge. The Mediterranean is regarded as a hot spot of climate change with a predicted temperature increase up to 5.5 °Celsius until 2100 and an increase in precipitation variability with a negative influence on water balance. All that is fostered by the rising anthropic pressure and a high population density which increases during the summer season.

Climate change, overexploitation, improper land use, and seawater intrusion are problems present in many countries in Europe and further, so the transferability potential is found in that aspect too.

In order to apply MAR methods in previously listed areas, it is needed to include MAR in European regulations, national water management strategies, and legislation so that those methods can even be considered as an answer to the rising problems.

Also, methods and tools developed in the project can be useful to organisations and researchers in investigations of similar situations in areas dealing with water shortage problems.

4.3. Influence on the institutional capacity of target group organisations

Croatian Waters is a legal entity for water management in Croatia established by the Water Act and its most important activities are the development of water management planning documents, the protection of water resources, and the determination of its usage.

As an associated partner, Croatian Waters was involved in all aspects of the DEEPWATER-CE project. It is therefore expected that the experience and knowledge of employees gained through trainings and similar events will influence internal protocols and increase the skills of all involved.

Higher education and research institutions were also involved in different activities of the projects so we can conclude that a transfer of knowledge occurred which will be useful in future projects and investigations.

Also, it is expected that in the future MAR methods will be mentioned more often as one of the solutions for the problem of decreased groundwater quality or quantity in different locations all over the world.

Cooperation with non-government organisations is also important since they have a certain social influence which can benefit the public acceptance of MAR methods and further prompt the dissemination of the project's results.

5. MONITORING OF THE ACTION PLAN

At which occasion / event is the AP planned to be discussed?	When will be the event organised and by whom?	What will be the aim to have a discussion about the AP?	What kind of conclusions / results will be expressed?
For new RBMP like measure	In new cycle of RBMP for 28-33 year, after the implementation of third Plan for 2022-2027, preparing new plan after 2025	Measure for areas with not good quantity status and for improving water supply on islands	MAR in the Adriatic aquifer could be such possible source for water supply in areas with problems with quantity status and scarcity of water

6. EXECUTIVE SUMMARY

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, as well in Europe too.

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.

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 sea-water 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.

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 strategic and planning documents in most of the Central European countries, it should be included as soon as possible., what is the general objective of this Action Plan.

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ANNEX I.

Declaration of intent

On behalf of the decision-making body of Split Wwter and Sewerage Company Ltd. I, the undersigned, hereby declare, that the Action Plan designed in the framework of the CE1464 DEEPWATER-CE Project was endorsed and/or accepted and/or adopted by our organisation.

Date: 22nd of April, 2022

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Director of Technical Sector

Split Water and Sewerage Company Ltd.

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(Stamp and signature)