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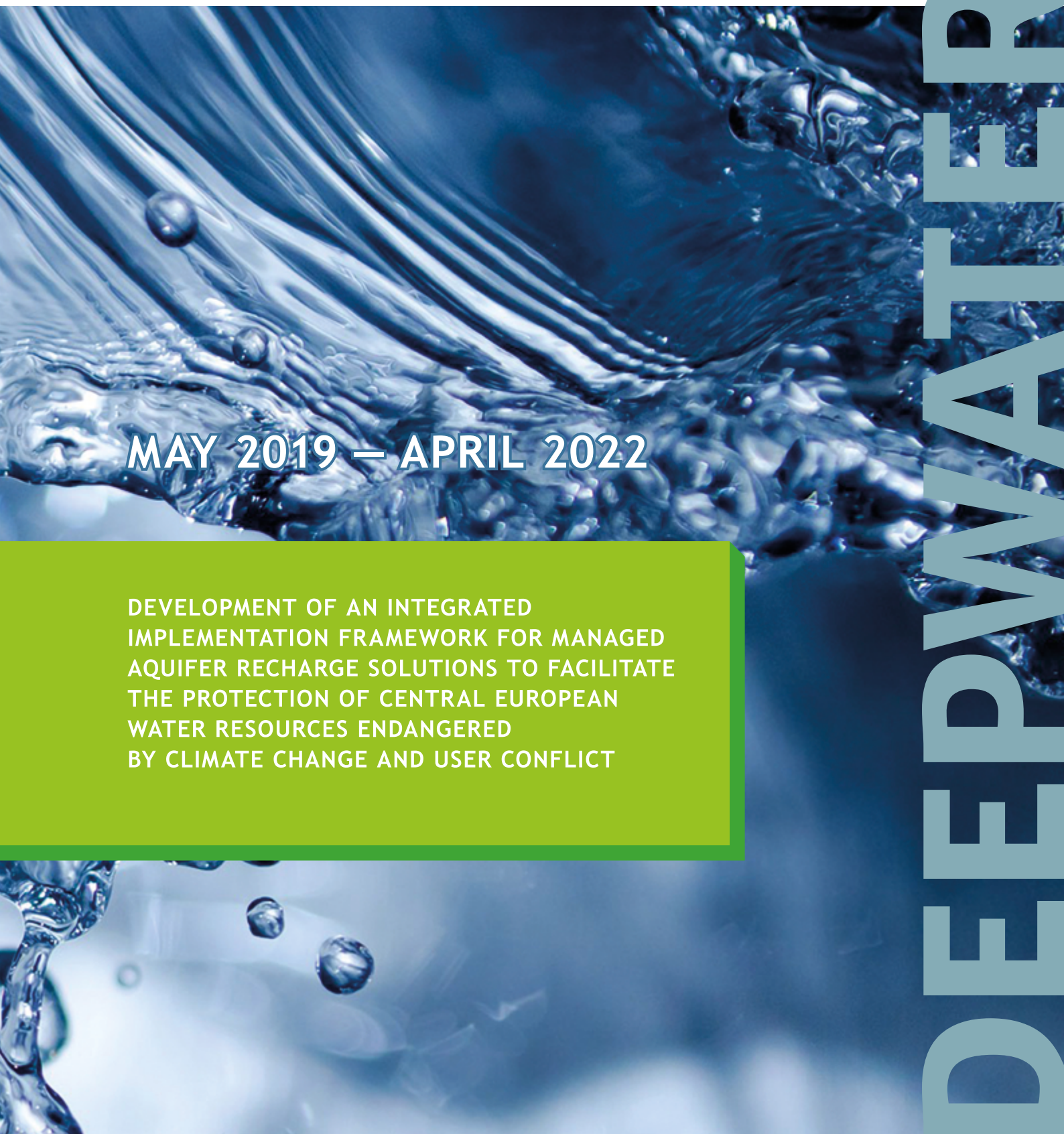
DEEPWATER-CE



MAY 2019 – APRIL 2022

DEVELOPMENT OF 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

DEEPWATER-CE

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Interreg CENTRAL EUROPE
European Union European Regional Development Fund
DEEPWATER-CE

7 PROJECT PARTNERS

5 COUNTRIES

€ 1.771535,96 BUDGET

01.05.2019—30.04.2022 TIMELINE

Brochure content

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Introduction

Project Outline

DEEPWATER-CE is a project that has brought together seven partners from five central European countries: Hungary, Germany, Poland, Slovakia and Croatia.

The main aim of this cooperation was to develop a comprehensive and integrated approach to implementing solutions for Managed Aquifer Recharge (MAR).

Partners have tackled a growing problem that affects more and more people, which is a lack of sufficient and, in places, good quality ground-water. The methods they have used involve managed aquifer recharge techniques. In case of prolonged droughts or general water shortages, this enables groundwater to be abstracted for human consumption, agriculture or industry.

As a result of the DEEPWATER-CE project, different MAR solutions are now better known to a larger audience thanks to trainings and collaboration with international stakeholders.

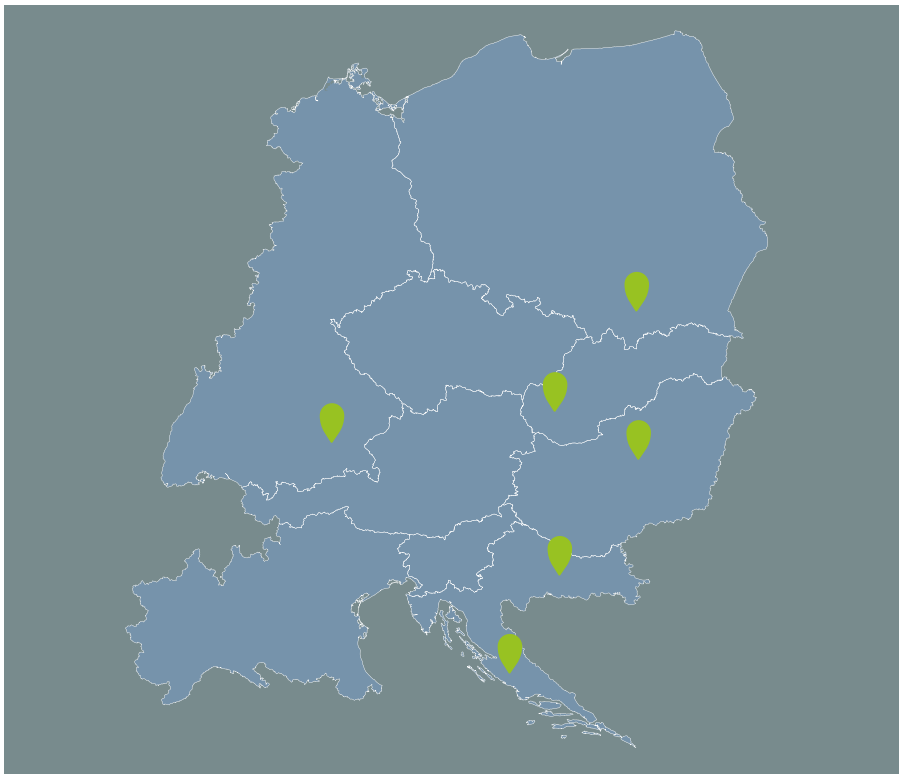
Our team has developed a Transnational Decision Support Toolbox in the form of a handbook, in which a methodology designed to help stakeholders select the appropriate location for a MAR facility is proposed. This handbook is a set of selection criteria to support the suitability of a given region for the chosen MAR type.

On the Global Groundwater Information System (GGIS) online platform of the International Groundwater Resources Assessment Centre (IGRAC), you can explore the MAR suitability maps and climate exposure maps produced on the basis of the methodology tested in the four partner countries.

The results of the pilot actions, tools and proposals were developed for the implementation of MAR, an overview of the relevant legislative acts was made and the conclusions were presented to the decision-makers and stakeholders in the partner countries, where we received a lot of interest and positive feedback.

In a broader, long-term perspective, this innovative project will help to increase the security of our and future generations' access to drinking water and irrigation water resources in the face of constantly changing climatic conditions in Central Europe.

The DEEPWATER-CE projects have contributed significantly to achieving INTEREEG CENTRAL EUROPE's aim of integrating and sustaining the management of natural heritage.



HUNGARY

- Mining and Geological Survey of Hungary
- Geogold Kárpátia Ltd.

GERMANY

- Technical University of Munich

POLAND

- University of Silesia in Katowice

SLOVAKIA

- Water Research Institute

CROATIA

- Croatian Geological Survey
- Split Water and Sewerage Company Ltd.

Project Partners

Mining and Geological Survey of Hungary

Mining and Geological Survey of Hungary (MBFSZ) is a central governmental body supervised by the Ministry of Innovation and Technology, and at the same time, a nationally recognized geoscientific knowledge and competence centre. It performs national administrative and research activities related to mining, geology, geophysics, and climate policy.

Geogold Kárpátia Ltd., Hungary

GeoGold Kárpátia Ltd. is a private, small-sized, profit-making enterprise, whose core businesses are environmental protection, geology, hydrogeology, geophysical surveys and water management. The company started its activities in 2005 with highly experienced geologists and geophysicists. GeoGold has experience in industrial and public water supply research, water vulnerability diagnosis, engineering geophysics and landfill verifications.

Technical University of Munich, Germany

The Technical University of Munich (TUM) is a higher education and research institution. As part of the Chair of Hydrogeology, the Hydrogeology and Biogeochemistry Group has experience in hydrogeological and biological investigations within the unsaturated zone and in groundwater.

Working fields include, the identification of subsurface water flow and contamination using stable water isotopes and modeling. Other fields of research include microbial biodegradation and coupled processes in the groundwater soil-plant system.

University of Silesia in Katowice, Poland

The University of Silesia in Katowice is a higher education and research institution.

The role of the University in the project is to act as project communication coordinator and participate in work packages.

A team of hydrogeologists actively study aquifers in areas heavily transformed by human activity (industry, urbanization) where unintentional and managed aquifer recharge is part of research activity, whose main aim is to identify the level of groundwater recharge using modern modeling techniques and the impact of urban-industrial areas on water resources and exploitation of groundwater utilization, based on the example of Tarnów.

Project partners during the periodic meeting in Poland

Water Research Institute, Slovakia

The Water Research Institute (WRI), established in 1951, is a public organization under the supervision of the Ministry of Environment of the Slovak Republic.

The WRI is the only organization in Slovakia conducting comprehensive water management research, e.g. drafting fundamental national conceptual documents and legislation in the field of water management, executing activities related to implementation of the Water Framework Directive, expertise and consulting services, water analyses, proposals for flood protection facilities, hydraulics, hydrology and river morphology, research on drinking water supply and wastewater treatment and collection as well as cooperation on cross-border rivers.

The WRI manages the National Water Reference Laboratory for Slovakia and is responsible for technical standardization in the field of water supply.

The WRI actively participates in international projects.

Croatian Geological Survey

Croatian Geological Survey (HGI-CGS) is the largest public research institute in the field of geosciences and geological engineering in Croatia. It is a unique scientific institute performing systematic and standardized geological, hydrogeological, and engineering geological surveys to acquire geoscientific data for the entire territory of the Republic of Croatia. The Department of Hydrogeology and Engineering Geology at HGI-CGS has centennial experience in a wide spectrum of hydrogeological research, ranging from identification and intake of potable and thermal groundwater, groundwater protection, quantitative and chemical status monitoring and assessment, fluid and heat flow modeling, geophysical investigations, complex hydrochemical research, as well as interaction of groundwater with construction (hydroelectric power plants, highways and railways, tunnels, quarries). Researchers are actively engaged in popularizing and promoting geoscience through workshops for all age groups, science fairs, professional and scientific lectures.

Split Water and Sewerage Company Ltd.

This infrastructure and (public) service provider is a regional water supply company operating in the territory where the pilot area will be established, provides water in four cities and nine municipalities. The installations for four towns include conveyance from the River Jadro, 5 km from the center of Split, a supply and water distribution network of 1400 km, 57 reservoirs and 50 pumping stations. Some municipalities have different sources of drinking water. For example, the municipality of Marina receives drinking water from a drilled well, and the island of Šolta receives it from the River Cetina.

As experts, they deal with the problems of water salinity caused by lowering the underground fresh water level in Marina's water supply system during the summer period.

Associated Partners

- General Directorate of Water Management (Hungary)
- International Groundwater Resources Assessment Centre (IGRAC, The Netherlands)
- Tarnów Waterworks Ltd. (Poland)
- Veneto Regional Agency for Environmental Protection (APRAV, Italy)
- Croatian Waters (Croatia)

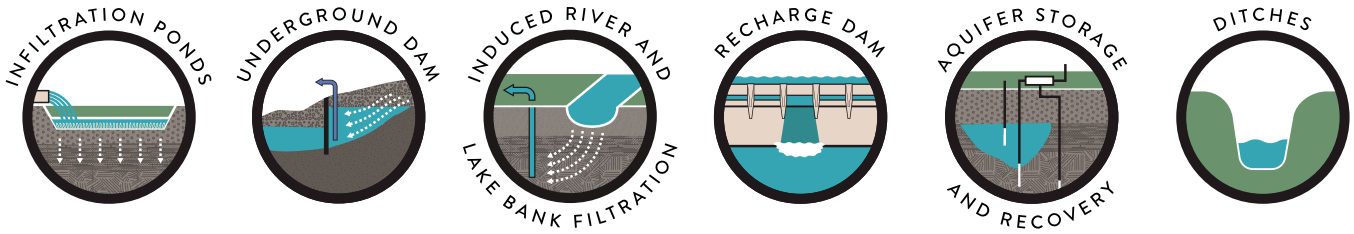
What is MAR?

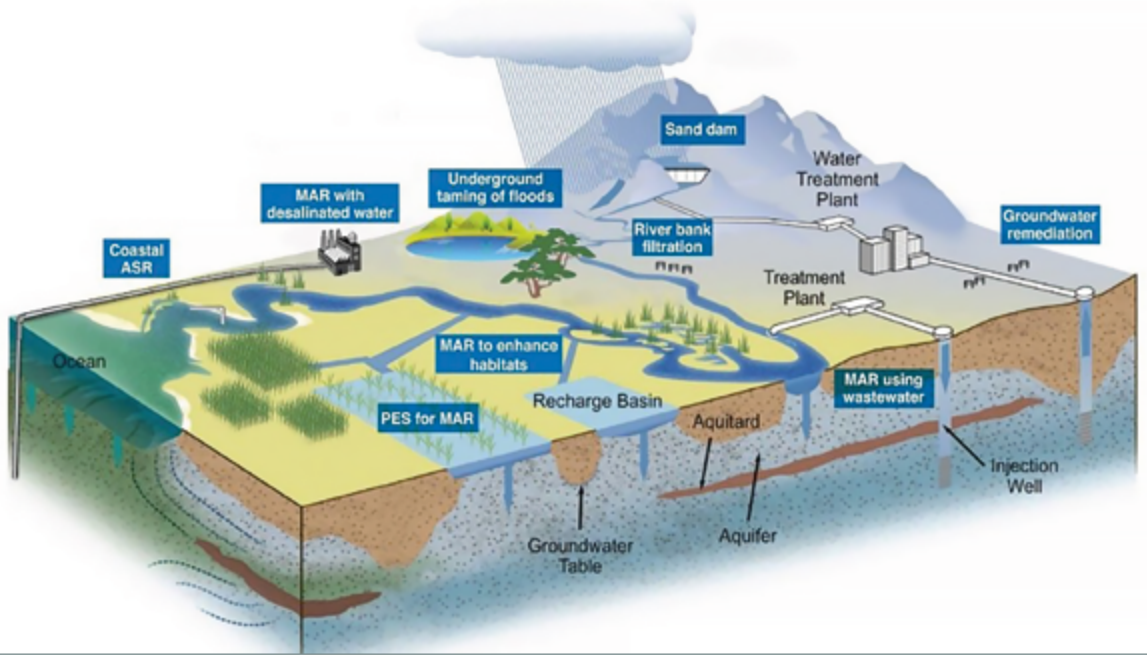
Managed Aquifer Recharge (MAR) is a purpose-built (human controlled) system for recharging groundwater, originating from different sources, into suitable aquifers from which it is extracted in case of emergency (e.g. during a drought) or used for environmental or human health benefits. Sources of water for recharge may include a surface water, treated municipal wastewater or desalinated water.

MAR comprises a variety of techniques. In the DEEPWATER-CE project, we focused on six of them: induced bank filtration (IBF), infiltration ditches, infiltration ponds, aquifer storage and recovery (ASR), recharge dam and underground dam. These techniques are increasingly being used in order to maintain, improve and secure the groundwater systems exposed to various levels of risk on a local or basin scale.

One of the main advantages of MAR is that it can play a crucial role in improving groundwater quality or tackling the effects of environmental changes and extreme weather events such as drought or flood. The quality of recharged water can be enhanced when the water infiltrates through an unsaturated zone. Infiltrated water, as a special kind of a hydrodynamic barrier, can also prevent seawater intrusions or reduce the inflow of polluted groundwater from industrial zones.

Globally, since the 1960s the number of MAR measures implemented has been accelerating at a rate of 5% every year.





https://fennerschool.anu.edu.au/news-events/events/public-seminar-managed-aquifer-recharge-water-banking-we-can-trust

Project work packages

THEMATIC PACKAGES

Development of a transnational knowledge base on the applicability of MAR in CE

- involvement of stakeholders on a national and transnational level
- collection of good practices and benchmark analysis of existing MAR solutions
- trainings for stakeholders via webinars

Development of a transnational assessment methodology for decision-making on MAR locations in CE

- identification of the most appropriate sites in CE for implementing MAR
- selection of areas most directly affected by climate change and where MAR may be needed most
- development of a common decision supporting tool for locating MAR sites

Feasibility assessment for establishing MAR schemes in CE

- common methodology for conducting feasibility studies
- pilot feasibility studies carried out in four countries
- preliminary assessment of the environmental impact of potential MAR implementation

Development of policy recommendations and national action plans

- development of policy recommendations in line with current legislations and regulations
- technical guidelines for incorporating MAR in river basin management plans and strategies
- roundtable discussions with relevant stake-holders to ensure their support and receive their suggestions
- roundtable discussions with decision makers

PROJECT OUTPUTS

The project results will emerge in the following outputs:

1. **Training in knowledge transfer on MAR solutions and their environmental and economic benefits (sets of webinars, training sessions).**
2. **A transnational decision support toolbox for designating potential MAR locations in Central Europe, in the form of a handbook including a set of checklists for the selection of MAR location in CE.**
3. **A pilot feasibility study for MAR schemes with an integrated environmental approach in four pilot areas, under porous hydrogeological conditions in Hungary, Poland and Slovakia and in karst geological conditions in Croatia.**
4. **Policy recommendations and national action plans for adopting MAR solutions as part of national water resource management schemes in CE, prepared as specific technical guidelines.**

WORK PACKAGE 1

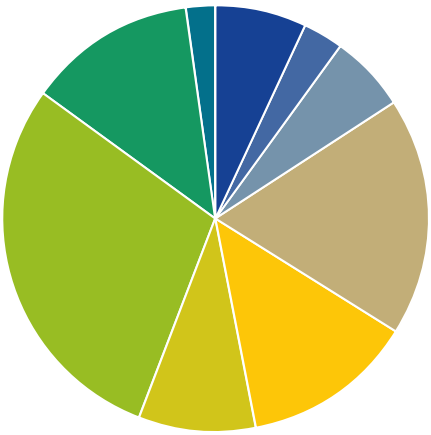
Development of a transnational knowledge base on the applicability of MAR in CE

The main objectives of WP T1 „Development of a transnational knowledge base on the applicability of MAR in CE" were (i) to create transnational cross-sector stakeholder groups (CSSGs) to support project implementation and share MAR-related experiences, (ii) to analyze the status-quo of good practices and benchmark analyses related to MAR in the EU and beyond, and (iii) to increase opportunities for the relevant stakeholders through a series of stakeholder workshops. The development of a comprehensive MAR knowledge base and the CSSGs also set the foundations for the successful implementation of other DEEPWATER-CE work packages and activities.

One particularly important milestone in this work package was the development of the report called: "Collection of good practices and benchmark analysis on MAR solutions in the EU". This report provides a historical overview of MAR development and its various objectives, types of technological solutions and various sources of water, factors and risks associated with MAR, as well as the European and global perspective. Additionally, five partner countries (Croatia, Germany, Hungary, Poland and Slovakia) provided a legislative framework and the most important geological and hydrogeological characteristics related to water management in order to show „the big picture" as to why MAR is needed in these countries. Furthermore, each country provided a case study of a previous or existing MAR site, highlighting good practices or lessons learnt from this operation. Since the DEEPWATER-CE project began, 277 potential stakeholders have been recognized and compiled into a database. Some were involved in project implementation, some in trainings, while others were informed about the main project results. The composition of the CSSGs according to target groups is shown in the figure below.

As part of our activities, we have launched the National Virtual Square on LinkedIn

The Virtual Square (VS) is an internet platform using LinkedIn possibilities to facilitate cooperation within Cross-sectoral Stakeholder Groups (CSSGs). It is a place for everyone interested in hydrogeology and wishing to share their opinion and knowledge about MAR systems with us.



Project stakeholders

7%	Local public authority
3%	Regional public authority
6%	National public authority
18%	Enterprises
13%	Business support organisation
9%	Sectoral agencies
29%	Infrastructure and public service providers
13%	Interest groups including NGOs
2%	Higher education and research

National Virtual Squares

HUNGARY GERMANY POLAND SLOVAKIA CROATIA

Transnational Virtual Square

TRAINING SESSIONS

Training sessions, advertised through national fora, were carried out via sets of online webinars in the local language and tailored to suit local needs.

Three training sessions conducted as part of the DEEPWATER-CE project addressed stakeholders from different sectors in order to transfer the knowledge on MAR solutions and their environmental and economic benefits. Each training sesion had a different subject in order to cover all aspects of the methodologies developed, including processes and checklists involved in the assessment of potential MAR site locations, searching for the benefits of implementing MAR schemes and preparing feasibility studies based on pilot site investigations.

The purpose of the trainings:
The main purpose of the trainings was to disseminate the knowledge on the basic principles of the MAR schemes, practical information on their usage, reasons of which they are needed in the future due to climate change impacts, technical information on their installation and benefits followed by practical installation examples. Additionally, a specific information on the national pilot site, including planned investigations, and activities of a project partner, were presented. Furthermore, training provided a platform for discussion of specific problems, exchange of experience, knowledge share. Also, networking and earning new contacts with colleagues involved in the same field played crucial benefits of the trainings and contributed to achieving the project's goals.

All trainings are intended for relevant stakeholders listed in the national Cross--Sectoral Stakeholders Groups (CSSG). The groups are being continuously updated by newcomers due to new emerging issues. The invitations to attend each training were differentiated in order to reach the specific group of the target audience.

1st training session
MAR principles and collection of good practices and benchmark analysis

The training was focused on explaining MAR principles, the conditions for its implementation, the best practice examples in Europe and national case studies. The content originated from a report dealing with a collection of good practices and a benchmark analysis of existing MAR projects in Central Europe.

2nd training session
Toolbox, selection criteria and checklist for MAR location

This training provided information on the toolbox assisting in the decision -making process for selecting the appropriate sites for implementing MAR schemes in Central Europe. Within the assessment process summarised in the toolbox, general and specific criteria were considered, e.g. geological and hydrological conditions, climatic models and scenarios, and the sensitivity of MAR schemes to extreme climate s. Pilot sites were chosen from related checklists for the above selection criteria.

3rd training session
Pilot feasibility studies to prepare policy recommendations

As part of project implementation, four pilot sites were selected for applying the MAR methodologies tested during the project.

This training briefly presented the selection of the pilot sites using the decision support toolbox as well as the content of the feasibility study. Moreover, it provided detailed information on recent geophysical, geological, hydrogeological, geochemical surveys carried out on the pilot sites and the optional numerical modeling. Additional information on pilot sites was also given, including information on water supply and demand, risk management, cost-benefit analysis and the regulatory and legal framework.

Based on the results of feasibility studies for all four pilot sites, policy recommendations for incorporating MAR solutions into water management were prepared.

If you missed our training sessions, we encourage you to listen to the recordings!

Training recordings and materials are available for download here:

https://www.interreg-central.eu/Content.Node/DEEPWATER-CE.html#TRAININGS

WORK PACKAGE 2

Development of a transnational assessment methodology for decision-making on MAR locations in CE

The main output of Work Package 2 was the creation of a handbook presenting a decision-support toolbox to evaluate Managed Aquifer Recharge (MAR) suitability. Three major components were investigated: climatological selection criteria, geological and hydrogeological selection criteria as well as the sensitivity of MAR schemes to extreme climates. These selection criteria, aimed at identifying potential MAR sites, are displayed in the form of checklists within a toolbox.

Every MAR solution has its own specific requirements depending on the site in question, the checklists containing selection criteria are categorized by MAR types. Based on common MAR application practice in Europe as well as local requirements for the project partner countries, six promising MAR types were selected for evaluation:

- Ditches,
- Induced riverand lake bank filtration,
- Aquifer storage and recovery,
- Infiltration ponds,
- Underground dam
- Recharge dam.

The first step of the tooolbox is the identification of areas where MAR is needed, based on climate change exposure maps for Central Europe.

These maps result from a calculation of the future water balance by modeling temperature, precipitation and evapo-transpiration change under different climate change scenarios. Depending on a surplus or deficit in the water budget, compared to the reference period, the four categories – *"slightly, moderately, highly and extremely exposed"* – were assigned to the study region of Central Europe.

Climatological selection criteria

Hydrogeological/geological selection criteria

Analysing sensitivity of MAR to climatic extremes

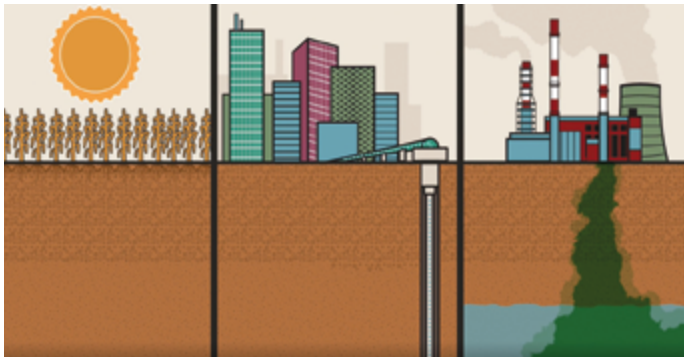
DECISION SUPPORT TOOLBOX
including checklists (sets of selection criteria), specific to MAR types

MAPS OF THE SUITABLE AREAS FOR IMPLEMENTING MAR

Development of a transnational knowledge base on the applicability of MAR in CE

The second and third step provide for each MAR type specific hydrogeological criteria (e.g. rock type) that allow the user to create GIS based maps that first exclude unsuitable areas (general mapping 2nd step) and then classify the remaining areas into "low", "moderate" and "high suitability" (specific mapping 3rd step).

Once a highly suitable pilot site for a MAR type has been chosen, a detailed feasibility study for this location is carried out as the fourth step. Therefore, the first part is a climate sensitivity analysis with the goal of identifying possible threats (e. g. flood, pollution) to the suggested MAR system and possible preventive or mitigation measures. Checklists with impact chains for each MAR type are provided for evaluation. The further steps of the feasibility study are described in the Work Package 3.



Link to VIDEO TUTORIAL:
https://www.youtube.com/watch?v=s5i9jR5EdP4

WORK PACKAGE 3

Feasibility assessment for establishing MAR schemes in CE

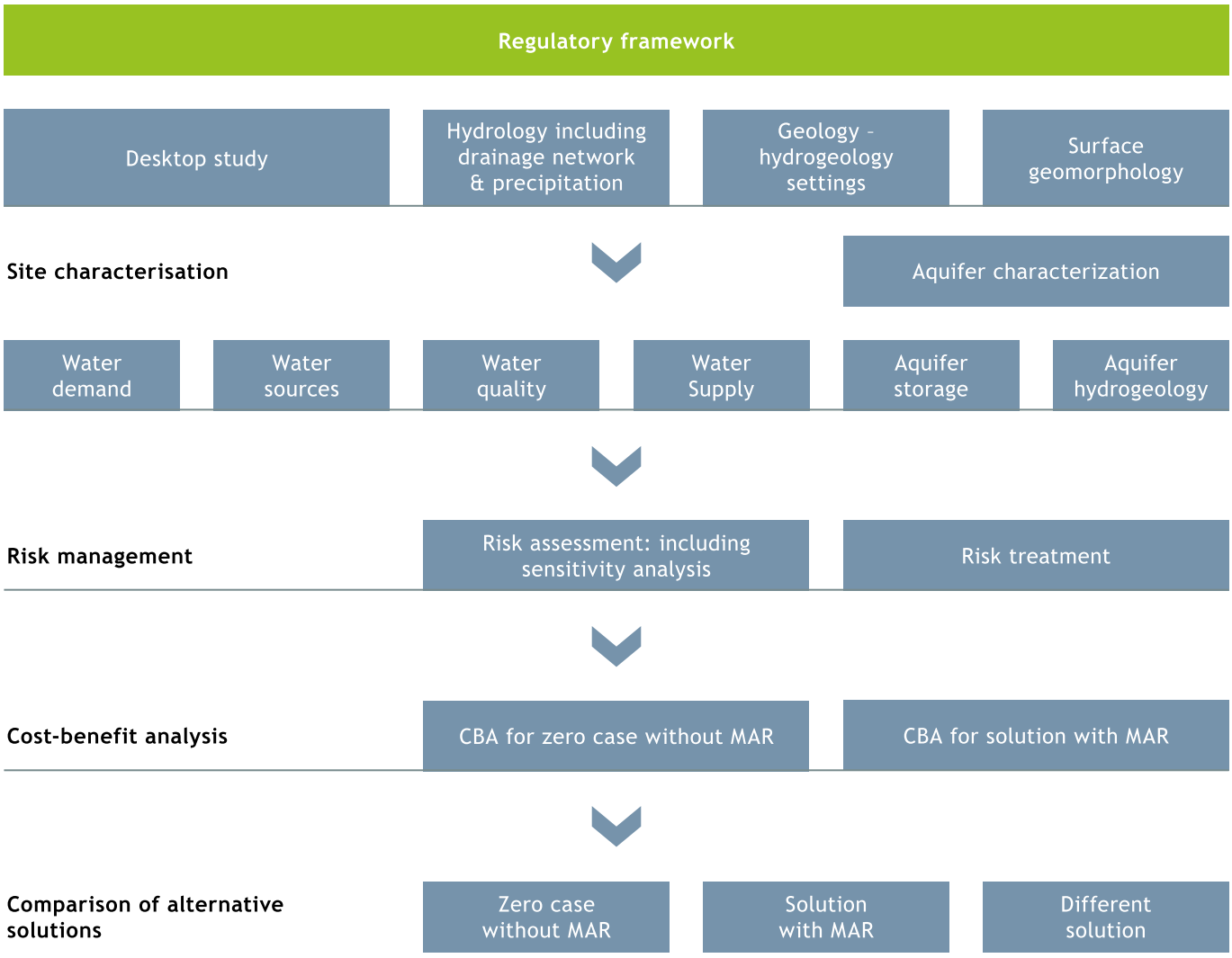
In the Work Package 3, we developed a common methodological guidance for DEEPWATER-CE MAR pilot feasibility studies in order to assess the actual feasibility of the potentially suitable MAR site identified for a specific MAR type.

The common methodological guidance for DEEPWATER-CE MAR pilot feasibility studies (deliverable D.T3.2.5), is composed of six components (see figure). Within the methodological guidance, literature studies concerning suited approaches for the components are given.

At the chosen pilot sites, different hydrological, hydrogeological and geophysical measurements were carried out. The data collected were used to identify the technical and economical feasibility of the MAR scheme. Detailed information about the water quality was collected and possible sources of pollution were identified by the partners. Work included suggestions for risk treatment and monitoring as well as a cost-benefit analysis.

The results of the pilot feasibility studies are used to prepare policy recommendations with a view to implementing MAR solutions into national river basin management plans and water management strategies in WP 4. Policy recommendations will be drafted with the support of cross-sector stakeholders to ensure that the documents mirror the integrated environmental needs, including social, economic and ecological aspects.

Guidance for MAR pilot feasibility study



The set of prepared GIS data and Global Groundwater Information System (GGIS) of IGRAC

Within the DEEPWATER-CE project, the decision support toolbox was developed to facilitate the identification of locations suitable for implementing Managed Aquifer Recharge (MAR) in Central Europe.

The methodology chosen for the investigation of potentially suitable locations for MAR sites, is based on specific climatological, hydrogeological and geological criteria, archive data and on opinions of the experts. These criteria are spatial and can be depicted on maps.

As part of Work Package 3, a set of 62 maps for the four partner countries (HU, HR, SK, PL) was created. It contains climatological maps and MAR suitability maps, representing areas potentially suitable for implementing MAR methods.

The suitability maps were created at two levels of detail: general and specific.

The general maps include spatial representations of potentially suitable MAR sites in the partner countries, at the national or regional level, with a subdivision into suitable and non-suitable sites.

The specific maps go one step further and focus in greater detail (with a subdivision into low, moderate and high suitability), on hydrogeological and geological aspects of regions identified as potentially suitable during the general mapping.

In order to provide sustainability and disseminate the work of our project, all the climate exposure, general screening and specific screening maps were included in the Global Groundwater Information System (GGIS) database of IGRAC (https://ggis.un-igrac.org/).

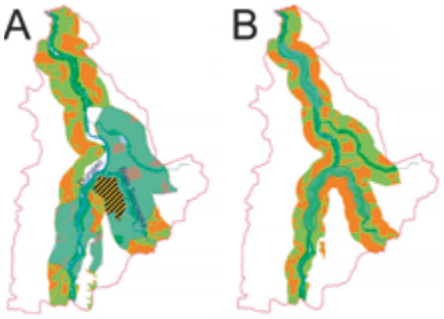
The GGIS is an interactive portal for sharing data and information on groundwater resources around the world.

Based on these solutions, and thanks to our fruitful cooperation with IGRAC, all the maps are easily accessible for the stakeholders from Central Europe and other countries interested in MAR, via an easy-to-use, free access web portal.

HOW TO BROWSE OUR MAPS?
Simply paste https://ggis.un-igrac.org/maps/2171/embed in the browser!

Specific maps

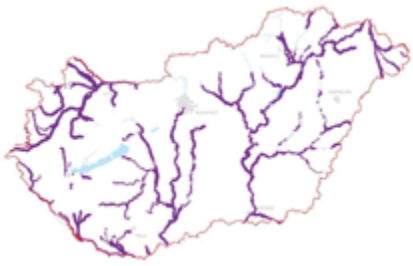
Potentially the most promising areas to implement MAR. [A] Ditches, [B] IBF



- high suitability
- moderate suitability
- low suitability
- the most promising areas for implementing MAR
- premises of Grupa Azoty S.A

General maps

Potentially suitable areas for the infiltration ditches MAR scheme



- potentially suitable areas

Potentially suitable areas for the "infiltration ponds" MAR scheme

- potentially suitable areas

Climate exposure maps

- slightly exposed
- moderately exposed
- highly exposed
- extremely exposed

Pilot actions

Based on the transnational decision support toolbox for identification of potentially suitable MAR locations in Central Europe (output of Work Package 2), four pilot sites with applicable MAR types were identified in four countries. At these sites, pilot feasibility studies were carried out according to the guidance for DEEPWATER-CE MAR pilot feasibility studies.

At the 4 pilot sites, various hydrological, hydrogeological, geological and geophysical measurements were carried out.

The collected data were used to identify the technical and economical feasibility of the MAR schemes. Detailed information about the water quality was collected and possible sources of pollution were identified by the partners. The work included preparation of suggestions for risk treatment and monitoring as well as a cost-benefit analysis.

The results of the pilot feasibility studies will be used to prepare policy recommendations with a view to channeling MAR solutions into national river basin management plans and water management strategies.

Policy recommendations will be drafted with the support of cross-sector stakeholders to ensure that the documents mirror the integrated environmental needs, including social, economic and ecological aspects.

Research areas:

Maros alluvial fan, Hungary
Studies in this region showed porous geological conditions in alluvial floodplain systems. The area of interest was the covered paleo-channels of the Ancient Maros River.

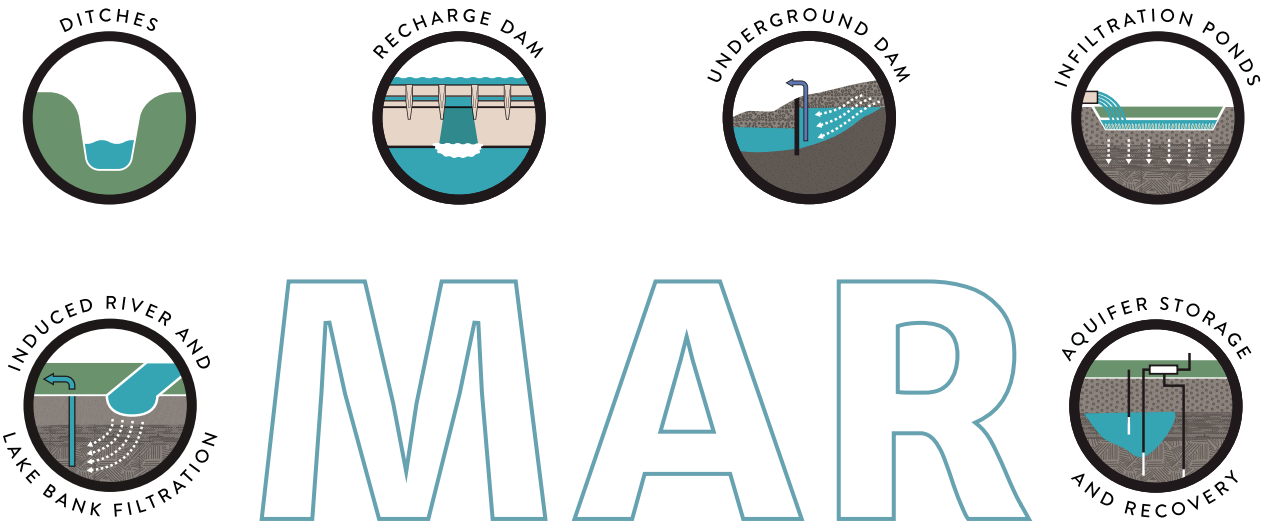
Tarnów Waterworks, Poland
The research focused on a working infiltration well field exploiting the shallow porous aquifer near the industrial zone, which poses a serious threat to groundwater quality.

The Žitný ostrov, Slovakia
Study on porous aquifers in an agricultural area. The pilot site area is demarcated by channels providing technical opportunities for water flow control by creating a Recharge Dam MAR type.

Island of Vis, Croatia
The study took place in a region with complex karst hydrogeological conditions, in the Mediterranean coastal area on the island of Vis.

Pilot sites

Poland Świerczków well field	Slovakia Žitný ostrov	Hungary Vicinity of Medgyesbodzás and Csanádapáca	Croatia Vis Island



Aerial photograph of the pilot site

The pilot feasibility study for MAR schemes with integrated environmental approach in porous geological conditions in Maros alluvial fan, HUNGARY

The Hungarian pilot area is situated in the south-eastern part of the Great Hungarian Plain (in Békés County between the two largest tributaries of River Tisza (the Körös River and the Maros River).

The pilot site is located in the Quaternary and Holocene fluvial fan of the Ancient Maros River, which forms a flat area slightly protruding from its surroundings. The water network of the Maros alluvial fan is sparse and shows a low level of surface runoff. Most of the watercourses are temporary, except those channels which are artificially maintained. The Holocene--Pleistocene fluvial sediment series of the alluvial fan form a unique hydrological system which shows an intensive groundwater flow and is recharged from the extensive hilly regions beyond the national border.

Given the exceptionally suitable conditions for agriculture, this is the main economic activity in the area. Since the area is highly exposed to extreme weather conditions, especially droughts during vegetation periods, there is a great demand for irrigation water.

Irrigation is mainly supplied from groundwater. According to experiences, unregistered wells are often used for irrigation purposes. These wells are usually drilled with no regard for any regulations or technological guidelines. Therefore, they may endanger the drinking water aquifers nearby. Considering this situation, applying MAR systems to irrigation may bring significant environmental benefits. The main objective of the investigated MAR scheme is to secure the supply of irrigation water and support sustainable water management during periods of water scarcity, while at the same time providing increased security for adjacent drinking water reserves.

Geophysical Cone Penetration Test and groundwater sampling

Based on a desk analysis, the area between Csanádapáca and Medgyesbodzás was chosen as the final pilot site for further surveys.

MAR IN AQUIFERS NEAR INDUSTRIAL SITES

Results from pilots – HUNGARY

Based on the archive data, supported by new surveys, a feasibility study for an underground dam MAR scheme was carried out for the selected pilot site as part of the DEEPWATER-CE project.

In order to obtain accurate information on the geological-geophysical characteristics of the pilot site a complex field survey was performed, including electrical resistance measurements, geophysical cone penetration tests, groundwater samples and groundwater level measurements.

The integrated evaluation provided a detailed geological and hydrogeological conceptual model. A direct connection could not be identified between the near surface layers and drinking water resources at pilot sites, although an indirect hydraulic connection cannot be excluded.

Different local infiltration conditions are reflected by the hydro-chemical composition in the upper two sand horizons. Based on isotope data, the first sand horizon shows a Holocene origin, while the third one and the deeper aquifers clearly show Pleistocene infiltration origin. The groundwater residence time for the second aquifer may be of Pleistocene infiltration origin but it is influenced locally by direct recharge.

A 3D hydrogeological numerical modeling tested the potential effects of different hypothetical construction plans for an underground dam. Results showed that a dam inserted in the uppermost aquifer would increase the position of the groundwater table on the upstream side of the dam.

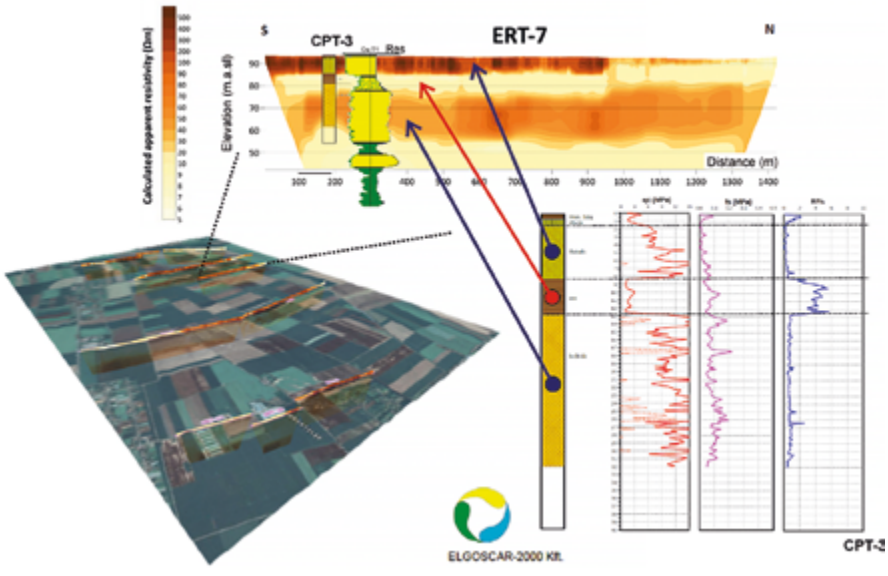
"Modeling a deeper dam resulted in increasing both the volume of abstractable water and the extent of the affected area.

Based on the Preliminary Environmental Impact Assessment, the proposed MAR system is not expected to make a significant impact on climate, geology, soil and surface waters, biodiversity or the ecological network.

In the framework of risk analysis, 111 potential risks have been identified, and risk treatment methods have been suggested for all.

An overview of the water demand was performed, but only licensed and abstracted water amounts for settlements were available, although the abstracted amount from unregistered wells is supposed to be significant too. Therefore, a rough estimation could be made for the real need for irrigation water. While hydrogeological modeling was performed for different scenarios, a cost benefit analysis has been carried out for one option, which is an underground dam built in the uppermost aquifer. The surveys show that the local farmers and agricultural companies are not keen to invest their own money but they do expect governmental support.

The results based on the feasibility study show that the pilot site is potentially suitable for underground dam MAR scheme but it would be socio-economically feasible only in a long term.



Integrated evaluation of field measurements and archive data

The pilot feasibility study for MAR schemes with an integrated environmental approach to porous geological conditions Świerczków well field, POLAND

The aim of a pilot feasibility study in Poland was to investigate the effects of applying the MAR technique to a porous aquifer located near industrial site, which poses a serious threat to groundwater quality. The Świerczków well field in Tarnów was selected because of its location in the vicinity of one of the largest nitrogen plants in Europe (Grupa Azoty S.A.) and because it applies two MAR types: the surface spreading method (infiltration ditches) and induced induced bank filtration (IBF).

Research area of detailed investigation in Tarnów

Tarnów Waterworks are responsible for supplying the Tarnów agglomeration (200 000 inhabitants) with drinking water based on surface and ground-water resources. At the Świerczków site, groundwater is extracted from the Quaternary unconfined porous aquifer of an average thickness of 4-6 m. The average hydraulic conductivity is $3x10^{-4}$ m/s. The static water level is approximately 3.5^{-5} m below the ground surface. Nearly 7,500 m^3 of groundwater per day is extracted from the aquifer, which represents about 25% of total water production for the Tarnów agglomeration. The small thickness of the aquifer, a need to increase the efficiency of the well field, and improve groundwater quality by reducing the inflow of water from the industrial site made it necessary to use MAR system.

The Świerczków well field consists of 17 wells recharged by a system of 3 infiltration ditches, with a total length of about 620 metres, and by the riverbank filtration.

During the pilot feasibility study, the PP4 research team investigated the possibility of adapting an appropriate MAR method to increase groundwater resources in Tarnów, but also aimed at developing an early warning monitoring system that would ensure safety and good quality water for the city's inhabitants. Using the Świerczków well field in Tarnów as an example, PP4 attempted to prove that additional water supplies could also be used in areas threatened by deteriorating groundwater quality due to neighboring industrial plants.

Świerczków well field, Tarnów

Results from pilots – POLAND

The field campaign started in December 2019, and the survey was completed in the end of 2021.

During that period, we carried out the following works:

- shallow hand probe drilling,
- drilling new piezometers,
- installation of data loggers for continuous measurement of groundwater table fluctuations, temperature and electrical conductivity,
- monthly measurements of the water table in the abstraction wells, piezometers and infiltration ditches using an electric water level meter,
- field measurements of physicochemical parameters of precipitation, surface water and groundwater carried out on a monthly basis in conjunction with water sampling for isotopic analyses,
- chemical analyses of water including ionic composition, occurrence of pharmaceuticals and personal care products (PPCP), surfactants, microplastic and organic compounds,
- chemical and mineralogical analyses of soil samples and sediments collected from ditch beds,
- geophysical survey using the Electrical Resistivity Tomography method (ERT).

In addition to field studies, we also collected a number of archival data including, among others, environmental maps, detailed climatic data, hydrogeological documentations, and archival chemical analyses.

Based on the research performed, we have obtained a lot of valuable data about the pilot site, which has helped us properly understand the conditions of groundwater flow and formation of groundwater quality.

Drilling of piezometers to collect water and soil samples

Cleansing pumping of a piezometer

Periodical water sampling for chemical and isotopic analyses of groundwater and surface water

The pilot feasibility study for MAR schemes with an integrated environmental approach to porous geological conditions in the Žitný ostrov area, SLOVAKIA

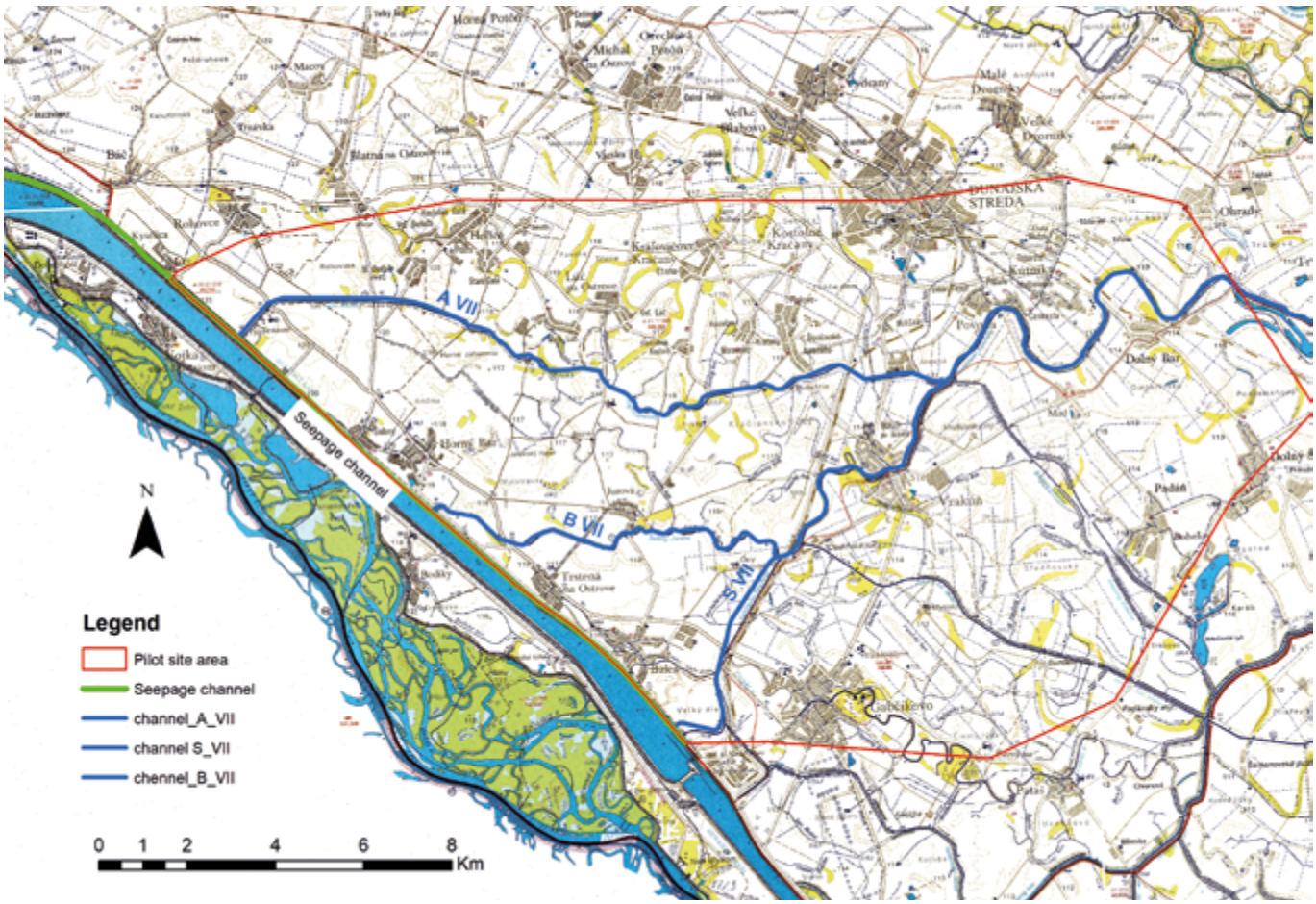
The location of the pilot site was chosen on the basis of general and specific screening criteria developed as part of the DEEPWATER-CE project. The pilot site is located in porous conditions in the agricultural area of the Podunajska Lowland, in the Žitný ostrov area.

The pilot area is characterised by a dense network of irrigation channels with technical tools (weirs, gates). The possibility to regulate the flow in channels is a crucial issue in the process of creating a MAR type recharge dam and revealing interaction between surface water and groundwater.

The Danube River created an extensive branch system on the territory of the Žitný ostrov. The pilot area is roughly delineated by the towns of Šamorín, Dunajská Streda and Gabčíkovo, bordered by primary channel S VII (Gabčíkovo-Topoľníky channel) and secondary channels A VII (Vojka-Kračany,) and B VII (Šuľany-Jurová,). From a geological viewpoint, it is located in the Slovak part of the Danube Basin, in the north-western part of the Pannonian Basin System. The sedimentary in-fill of the depression is represented by Neogene and Quaternary sediments (the latter up to 320 m thick). The average hydraulic conductivity coefficient of Quaternary gravels and sandy gravels of the pilot area is $2.91*10^{-3}$ ms^{-1} and the transmissivity coefficient is $2.96*10^{-2}$ m^2s^{-1}. The Quaternary sediments have mostly the phreatic groundwater table. Groundwater in Quaternary sediments can generally be described as fluviogenic water, which chemical composition originates from infiltrating water from surface water courses. The main cations are calcium and magnesium, while iron and manganese contents are also often increased. The main anions are bicarbonates with lower values of sulphates. The presence of nitrites and nitrates indicates anthropogenic pollution. Groundwater has from middle to high mineralization.

The investigation work performed at the pilot site was started by a desktop analysis followed by fieldwork. The desktop analysis summarised the relevant available archive data used to descrine the pilot site area, e.g. geomorphology, climatic conditions, land use, hydrology, geology and hydrogeology.

The field measurements aimed at investigating infiltrated surface water volume from a MAR type recharge dam scheme. The aims of field measurements were to assess and quantify the scope for aquifer recharge by (i) assessing the lateral range of infiltrated surface water impact on the groundwater level based on data obtained from research on the hydraulic conductivity of soil; (ii) modeling surface water and groundwater interaction and (iii) drafting scenarios for technical regulation of water flow in channels to ensure groundwater recharge at the pilot site.



Location of the pilot area in Žitný ostrov

Results from pilots – SLOVAKIA

Representative soil samples were measured in a laboratory to obtain data on soil hydraulic conductivity. The results vary depending on silty/clayey particles content. In general, the top surface soil is less permeable than deeper parts of Quaternary sandy gravels. The following distribution of hydraulic conductivity was revealed: in aquifer (350,20 cm/day); sediment in channel (2,88 cm/day) and soil (6,24 cm/day).

Water supply was assessed by numerical modeling. The MODFLOW model enabled calculating the potential amount of water infiltrated into groundwater. The modeling was applied in two scenarios (Prognosis 1 – existing weirs closed; Prognosis 2 – three new weirs added) compared to the Zero variant (natural conditions, i.e. open weirs). The results of modeling showed the potential amount of surface water infiltrated into groundwater. In Prognosis 1, it corresponds to 37910 [$m^3.d^{-1}$] in a wet year and 23598 [$m^3.d^{-1}$] in a dry year; in Prognosis 2, it corresponds to 41213 [$m^3.d^{-1}$] in a wet year and 32789 [$m^3.d^{-1}$] in a dry year. It is evident that the amount of water infiltrated into an aquifer can be increased in Prognosis 2 by up to more than 50% (as in the wet year 2010) and more than 75% (as in the dry year 2018) in comparison with the natural surface water level regime (the Zero variant). The new operation mode was proposed to the manager of the channels (the Slovak Water Management Enterprise).

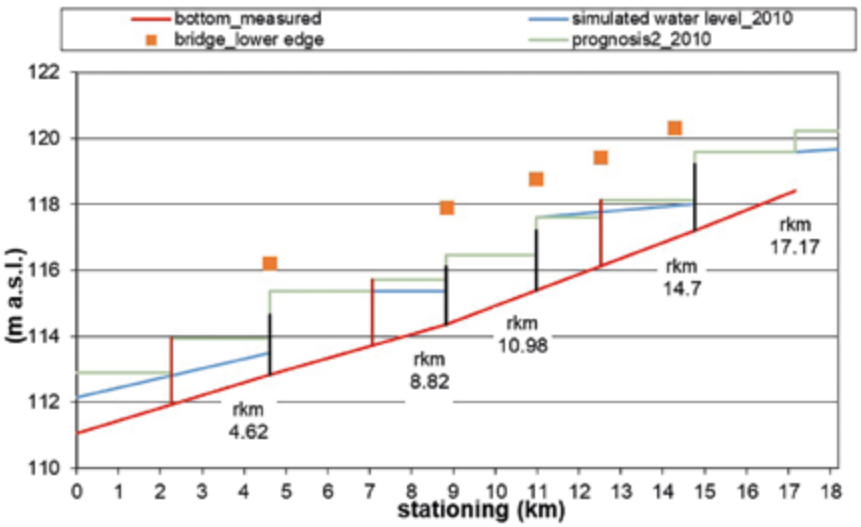
Similar results were received by model HYDRUS-2D, in which the channel is located in the upper layer of quaternary sediments. In a quasi-steady state, the infiltration rate is between 100 – 350 $m^3.km^{-1}.day^{-1}$. The length of the channel system in the pilot area is 100.86 km, which means that the total inflow into aquifers is between 10,000 and 35,000 $m^3.day^{-1}$. This corresponds to the data estimated by the simulation model MODFLOW.

The projected water demand in 30 years is evaluated from a mininum of 8,699,090 m^3 to a maximum of 15,004,000 m^3, while the expected water supply is 11,967,985 m^3 in a dry year and 15,042,745 m^3 in a wet year. The range of values for annual irrigation water demand is estimated on the basis of long-term climate forecasts.

Risk assessment for the pilot site identified non-technical risks during the design and construction phase. These were: a lack of private/public funding (very high risk); and low price of water and high installation cost (high risks). An evaluation of technical risks revealed high risk of occurrence during the design and construction phase. The risks identified were: technical difficulties during construction, risk of low water storage and hydrogeological setting. During the operational phase, high risks are represented by swelling clays, nutrients, periodicity of droughts and rainfall, changes in water demand and supply. To ensure the effective functioning of the MAR system, a thorough risk monitoring system must be brought into operation.

A costs-benefit analysis of a MAR type recharge dam applied a financial discount rate of 4% to obtain a discounted value for the stream of direct benefits and the present value of future costs and initial capital costs over a 30 year project horizon. The positive differences between direct costs and benefits suggest that the MAR scheme is economically feasible, having a positive expected Net Present Value (NPV) over 30 years of its project lifespan in 3 scenarios (max, average, min). Calculations showed positive results for project feasibility in all cases.

Field measurements



Longitudinal profile of the A VII drainage channel - simulated water level and prognosis 2 (2010), proposed weirs - vertical red lines

The pilot feasibility study for MAR schemes with an integrated environmental approach to karst geological conditions on the island of Vis, CROATIA

Vis is a small remote island in the Adriatic Sea. It is one of the Middle Dalmatian Islands. With an area of 89.7 km^2, the island is mostly composed of karstified carbonate rocks and belongs to the Dinaric karst region, a locus typicus for karst landforms. The main morphological and structural elements on the island have W-E orientation, or Hvar strike, which differs from Dinaric strike (NW-SE).

The island's relief could be described as three hilly chains separated by two valleys. The northern valley is relatively narrow, tectonically predisposed, and this is where the island's most important water supply spot – the Korita well field – is located. The southern valley is wider, and karst poljes are developed.

The climate on the island of Vis can be classified as a "Hot-summer Mediterranean climate" with dry and hot summers and mild winters. Due to its position in the open sea, there is a strong maritime influence which is reflected in the mitigation of climate extremes and air temperature variations. There are no surface water bodies on the island of Vis. Karst poljes, covered by low permeability Quaternary deposits, are prone to periodical flooding during heavy rain.

Vis is not connected to the mainland by a submarine water pipeline as it has an autonomous water supply due to favourable geological and hydrological conditions. This has enabled the formation of excellent karst aquifers.

All populated places on the island are connected to the public water supply. The island of Vis derives its water supply from its karst aquifer (drilled wells in Korita, the Pizdica coastal spring and the K-1 well). The pumping capacity of Pizdica is 3.3 L/s. At the Korita pumping site, the capacity is around 40 L/s. The K-1 well is the newest well and its pumping rates are up to 1.5 L/s. This well taps the dolomite aquifer of relatively low permeability behind the volcanic-sedimentary-evaporitic barrier. The main problem concerning water supply from the island's karst aquifers is the high possibility of seawater intrusion. However, karst poljes, together with karstic rock mass below them, serve as a barrier to groundwater flow and also as a protection of the central island karst aquifer from seawater intrusion from the south. The western boundary is geologically clear and represented by a total volcanic--sedimentary-evaporitic barrier. The prevention of seawater penetration from two major sides is one geological reason for such a high-quality aquifer on this karstic island.

The type of MAR will incorporate well/basin infiltration into the karst aquifer from accumulation structure on the surface. To assess suitability and technical feasibility, further aquifer characterization was needed, hence, the research included geophysics, hydrochemistry, monitoring of salinity and water levels, modeling of the fractured zone of the aquifer, and structural-geological research.

In situ alkalinity measurement at Pizdica spring

Results from pilots – CROATIA

Between September 2019 and September 2021, a broad variety of different research was conducted on the island of Vis, namely hydrogeochemical, hydrogeological, structural-geological, geophysical, and hydrological surveys.

Hydrogeochemical analyses were used to establish long-term trends and dynamics for the karstic aquifer on the island of Vis, which shows extremely high heterogeneity. By conducting monthly sampling, almost all potential hydrological scenarios were covered. The main aquifer on the island (Korita aquifer, where a pumping site is present) displayed long-term stability despite record-low precipitation in 2020 and 2021, with a slight increase in chloride and EC concentration. This indicated relatively large groundwater reserves that have shown resilience to over-pumping and are protected from seawater intrusion, making the Korita aquifer an ideal candidate for implementing IP and/or ASR. Additionally, the site is known for excellent groundwater quality. However, with the utilization of MAR, an even higher level of security in case of extreme hydrological events, such as prolonged droughts, could be achieved.

Geophysical surveys focused on the southern side of the island, where little hydrogeological data exists due to the absence of boreholes and wells. The main goals were to investigate the Quaternary deposits and their thickness. Generally, rock mass and aquifers below these karst poljes showed very low productivity and low transmissivity, because the rock mass and fractures are infilled by the products of dolomite weathering and clayey Terra rossa particles. Hence, karst poljes on the southern side of the island provide an excellent barrier for seawater intrusion into the central Korita aquifer.

Climatological analyses showed evidence of rapidly increasing trends in annual air temperature and relatively stable annual precipitation until 2100. Results for the regional climate models Aladin, RegCM3, and Promes showed, a potentially significant loss of water resources until the end of the 21st century. This could significantly reduce the availability freshwater at the Korita site, emphasizing the importance of alternative solutions (e.g. MAR). Additionally, a seasonal redistribution of precipitation, i.e. an increase in summer precipitation and a decrease in winter precipitation, is expected to negative impact on aquifer recharge.

The Korita aquifer, at the existing pumping site, seems to be the most promising location for the implementing IP and ASR systems. However, further research should be conducted to reduce uncertainty and obtain more detailed insights into the hydraulic properties of the aquifer. Proposed future research includes a well pumping test (assessment of transmissivity), tracer tests (to obtain apparent groundwater velocity and connectivity), thermal imaging (detection of coastal discharge zones), rainwater sampling at the Korita site, and test operations (e.g. monitoring groundwater level response and groundwater chemistry to artificially infiltrated/recharged water), as well as the continuation of detailed hydrogeochemical research.

Structural-geological investigations

Groundwater sampling from deep borehole in karst polje

WORK PACKAGE 4

Development of policy recommendations and national action plans

Work Package 4 of the DEEPWATER-CE project is designed to collect and analyse current legislation in Central Europe (CE) relevant to the MAR and frame and present policy recommendations supported by the scientific outcomes of the project iin order to facilitate implementation of MAR schemes throughout the CE region. By carrying out the actions proposed in WP4, the project aims to develop concrete, ready-to-implement measures and define a path of adoption for the benefit of the whole CE region. The main objective is to develop a policy framework for MAR with a view to facilitate the long-term sustainability of water supply within the region. The expected results of the project are improvements to the integrated environmental management capacities of competent bodies for protection and sustainable use of water resources in Central Europe, through transnational cooperation. This is expected to be achieved by providing better knowledge of technical solutions and legal requirements and also the social, ecological and economic impact of what MAR schemes would bring to the target areas.

The European Union's water regulations provide the framework for water governance, and thus also for the introduction of purposeful recharge of water to aquifers. However, MAR specific recommendations need to be elaborated and further developed. Therefore, to promote MAR methods more widely – among governing bodies, policymakers, professional organizations, users and society in the CE region – a brief, comprehensive description of MAR systems developed so far and adopted in many parts of the world is needed.

To help achieve the goals of WP4, various tools are applied, such as questionnaire templates, comparative analyses to learn and understand current policy instruments relevant to MAR schemes in a transnational context, guidelines in a general handbook format for transnational applicability, technical guidelines, policy recommendations, country specific action plans and discussions with relevant stakeholders to ensure their support and obtain their suggestions.

The collection of national legislation and policies on MAR was carried out first, during which a questionnaire was compiled for the project partners. This template contained detailed questions about the regulatory framework, institutional framework and stakeholders, as well as good practices and gaps. The project partners provided their responses to the online questionnaire. Furthermore, the Italian associate project partner prepared an overview of their existing legislation practices for MAR.

The comparative transnational report was finalised on the basis of an analysis of the partners' responses to the questionnaires. The conclusions, together with a comparison of national legislation systems, served as input into the comprehensive guidelines. This report was also intended to highlight possible best practices which can be adopted by the other participating countries.

The transnational guideline report is compiled as a handbook for broader further use. The handbook describes the complex and lengthy process of a recharge system and the aspects expected to present the most difficulties. It also summarises the technical, environmental and regulatory challenges to project implementation and formulates the key issues on the basis of the results of pilot feasibility studies for which policy recommendations are to be outlined.

The set of policy recommendations report translates the scientific results obtained in the DEEPWATER-CE project, including the peculiarities of each country, to develop a policy framework for MAR. Policy recommendations are drafted, with the support of cross-sectoral stakeholders, to ensure that they satisfy integrated environmental needs, including social, economic and ecologic variables and are negotiated in accordance with political agendas.

In addition, guidelines for integrating MAR into the national river basin plans and strategies have been drafted, with the support of the project partners. This draft contains technical guidelines for integrating MAR into national river basin management plans and strategies for the use of technical commissions.

Finally, the common transnational action plan is to be developed on the basis of a common template for adopting MAR in CE countries. Guidelines for country-specific action plans contain steps needed to incorporate MAR into the relevant national plans and policies.

The Action Plans include national policy recommendations which are tailored to local conditions at national level and are to be presented to the decision makers. Action Plans propose how, by whom, when and with which resources MAR shall be adopted according to the regulations.

Thus, supported by the above achievements, the project is to be concluded by initiating the process of adopting action plans. It's expected to provide a better MAR policy framework aimed at facilitating the long-term sustainability of water supply in the countries involved and targeted within the Central European region.

Other selected activities

LOCAL COMMUNITY MEETINGS IN PILOTS

Hungary

Poland

Slovakia

Croatia

PRESS CONFERENCES ABOUT PILOT STUDIES & THE JOURNALIST'S ON-SITE VISIT

Press conference in Medgyesbodzás, Hungary

Journalists' visit to pilot site, Poland

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Also ResearchGate platform
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https://www.researchgate.net/project/DEEPWATER-CE

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