WaterJPI project

SMARTControl

Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge (MAR) applications

Deliverable D7.3

Transfer concepts of the SMART-Control approach in Brazil and Cyprus

Authors

Anika Conrad (adelphi), Ronjon Heim (adelphi), Jan Leo Helling (adelphi)

July 2022

Project funded by:

Deliverable D7.3

Transfer concepts of the SMART-Control approach in Brazil and Cyprus

Short summary

This document provides application ideas of the SMART-Control approach at two new locations in the vicinity of the project sites in Cyprus and Brazil. The transfer especially focuses on the tools developed and tested at the project sites and is based on stakeholder interaction during the training and replication missions conducted at the project sites.

Work package	WP7: Strengthening the SMART-Control approach
Deliverable number	D7.3
Partner responsible	adelphi
Deliverable author(s)	Anika Conrad (adelphi), Ronjon Heim (adelphi), Jan Leo Helling (adelphi)
Quality assurance	Jana Glass (TU-Dresden)
Planned delivery date	July 2022
Actual delivery date	July 2022
Dissemination level	PU (Public)

ABSTRACT

PURPOSE MAR represents a viable adaptation solution for sustainable water resources management. However, MAR operators and decision makers struggle to fully exploit the benefits of MAR and to integrate MAR in their water resources management supported by the public. At many existing or planned MAR sites, the lack of adequate monitoring reduces public trust, raises questions about the impact of MAR and hinders optimal operational management. SMART-Control aims at reducing these risks, by providing an innovative web-based, real-time monitoring and control system (RMCS) in combination with risk assessment and management tools.

APPROACH In order to further optimise the MAR operation and to increase trust towards a safe MAR operation at the pilot sites in Brazil and Cyprus, the transferability of the SMART-Control approach was investigated and transfer concepts for the most promising replication sites were developed: Akrotiri basin in Cyprus and Public Market of Afogados in Recife, Brazil. These transfer concepts are based on a participatory development approach supported primarily by the implementation of replication missions at the project sites in Cyprus (October 2021 and May 2022) and Brazil (January 2022). The missions included site visits to assess the situation, bilateral meetings with key stakeholders and public workshops with a broad range of stakeholders. The mission followed a series of trainings and previous interactions and focused on selected sites by key stakeholder (Water Development Department (WDD) in Cyprus and the Federal University (UFPE) and Climate and Water Agency (APAC) in Pernambuco, Brazil). In addition to potential and active MAR operators, MAR beneficiaries and enablers were also included in the activities and discussions to consider all potential benefits for a replication project. Depending on the stage of MAR development at the potential replication site, the transfer concepts include a site-specific set of SMART-Control solutions.

CONCLUSIONS
In both Brazil and Cyprus, promising new locations have been identified where the implementation of the SMART-Control approach can contribute to sustainable groundwater management.
In the metropolitan area of Recife, permanent natural groundwater reserves have decreased by 50% in 30 years (Luna et al. 2017). While the public water supply is not able to meet the demand, ongoing industrial and urban development have increased water demand even more. Artificial recharge (MAR) of the Beberibe aquifer using the infrastructure of the public market of Afogados in combination with SMART-Control instruments represents an attractive solution safeguarding existing groundwater resources and increasing their availability for a safe public water supply in terms of both improved water quality and increased quantity. Main needs that have been identified in stakeholder workshops and which can be addressed using the SMART-Control approach are: (1) Safe water provision according to quality requirements, (2) Safe water injection, (3) maximising recovery efficiency and (4) taking the right decisions for future development.
Cyprus has been suffering from severe drought and increasing water demand for several decades, exacerbating the island's long-standing water scarcity problems. Several water management programmes and MAR projects (Ezousas, Akrotiri) have been implemented by the WDD to increase the island's water security. However, risks such as health impacts due to high nitrate and pathogen concentrations, seawater intrusion, clogging of infiltration ponds that threaten the successful operation of the MAR facility in Akrotiri have been identified and a concept has been developed to address these. Main resulting needs that have been identified in stakeholder workshops and which can be addressed using the SMART-Control approach are: reducing health impacts related to water quality, especially pathogens, overall optimisation of recovery water quality and taking the right decisions for future developments.

OUTLOOK The next steps for a successful implementation of the SMART-Control approach at the replication sites mentioned above include conducting an in-depth feasibility study together with a Cost-Benefit-Analysis, the preparation of a detailed stakeholder analysis incl. needs and contribution assessment, the identification of funding options and the development of a suitable governance approach.

CONTENT

FIGURES

TABLES

ABBREVIATIONS

APAC	Water and Climate Agency of Pernambuco
ASR	Aquifer Storage and Recovery
CBA	Cost Benefit Analysis
COMPESA	Water utility of Pernambuco
CSURB	Urban Services Company of Recife
DALYs	Disability/Disease Adjusted Life Years
GSD	Geological Survey Department of Cyprus
HRT	hydraulic residence time
IB	Infiltration Basins
MAR	Managed Aquifer Recharge
PI	Performance Indicators
RMCS	Remote Monitoring and Control System
RMR	Recife Metropolitan Region
SAT	Soil Aquifer Treatment
SBLA	Sewerage Board of Limassol – Amathus
TUD	Technical University of Dresden
UFPE	Federal University of Pernambuco
WDD	Water Development Department, Cyprus

1 INTRODUCTION

WHAT – Technology transfer concepts

This report provides concepts/options for transferring/applying the SMART-Control approach at two sites, one in Cyprus and one in Brazil. The concepts comprise of an assessment of the initial situation at the selected site, the identification of the needs and requirements regarding water resource management and the role of Managed Aquifer Recharge (MAR) and its risks in this context. Consequently, solutions based on the SMART-Control approach are elaborated.

WHY – Reducing MAR-associated risks by applying the SMART-Control approach

MAR, referring to the intentional recharge of water to aquifers (Dillon 2005), represents a viable adaptation solution for sustainable water resources management and is successfully applied worldwide for the restoration of affected groundwater-dependent ecosystem services (Stefan and Ansems 2018), including: freshwater production and availability, flood mitigation, prevention of saltwater intrusion, restoration of depleted aquifers, seasonal water storage, improvement of water quality, land renaturation, as well as increasing the aesthetic values of water bodies. Despite its financial and ecological benefits, the contribution of MAR to safe water supply at global scale is still limited. The reasons include the lack of data on the technological costs of MAR, the hydrogeological site characteristics, the associated risks and, at many sites, the lack of adequate monitoring, which reduces public trust, raises questions about the impact of MAR and hinders optimal operational management.

The SMART-Control project aims at reducing these risks in the application of sustainable groundwater management techniques, by the development of an innovative web-based, real-time remote monitoring and control system (RMCS) in combination with risk assessment and management tools. The scope of SMART-Control was and is to implement the SMART-Control approach at several selected pilot and operational MAR sites and to build capacities for the usage of the hardware and the software related to the approach like online sensors and online tools. In order to upscale the impact and increase the scope for the application of the SMART-Control approach, further sites were identified during stakeholder dialogues and desk research proven to be promising for the application of similar solutions. The transfer of the solution also showed opportunities for generalising some of the project results and making them useable for wider application. Further, the intention of the transfer concepts is to show up potential future projects and, in this way, foster the application of the SMART-Control approach beyond the project end.

HOW – The technology transfer methodology

The process for the assessment and the elaboration of the concepts started early in the project once the developed solutions at the pilot sites matured and first bilateral meetings with stakeholders were initiated. The selected sites have been jointly identified with local stakeholders. During trainings on the SMART-Control tools, first ideas for replication sites were collected. For this, transfer ideas were developed and then worked out with stakeholders in replication workshops. Site visits were conducted and further bilateral meetings organised to collect information relevant for further fine tuning the technological concept and for drafting the roadmap for a project outline. Further details of the methodology are given in chapter 3 of this document.

2 THE SMART-CONTROL APPROACH

The SMART Control approach includes research, piloting, demonstration, training and technology transfer in one framework to reduce the risks associated with MAR and promote MAR as a safe and reliable technology for water resources management. The core of the approach is the free, web-based RMCS which is composed of an in-situ real-time monitoring system (A) and the web-based INOWAS DSS platform (Figure 1) for control, modelling and prediction (B), as illustrated in Figure 2.

Figure 1. Landing page of the INOWAS DSS

Real-time data of MAR processes such as water level, electrical conductivity etc. are sent to the INOWAS platform via state-of-the-art sensors installed at MAR facilities and are processed and visualised in (A) a user-specific way for easy communication to stakeholders or for further analysis in (B). For this purpose, the INOWAS platform provides a variety of analytical and numerical tools that can be used for the planning, assessment and optimisation of MAR applications.

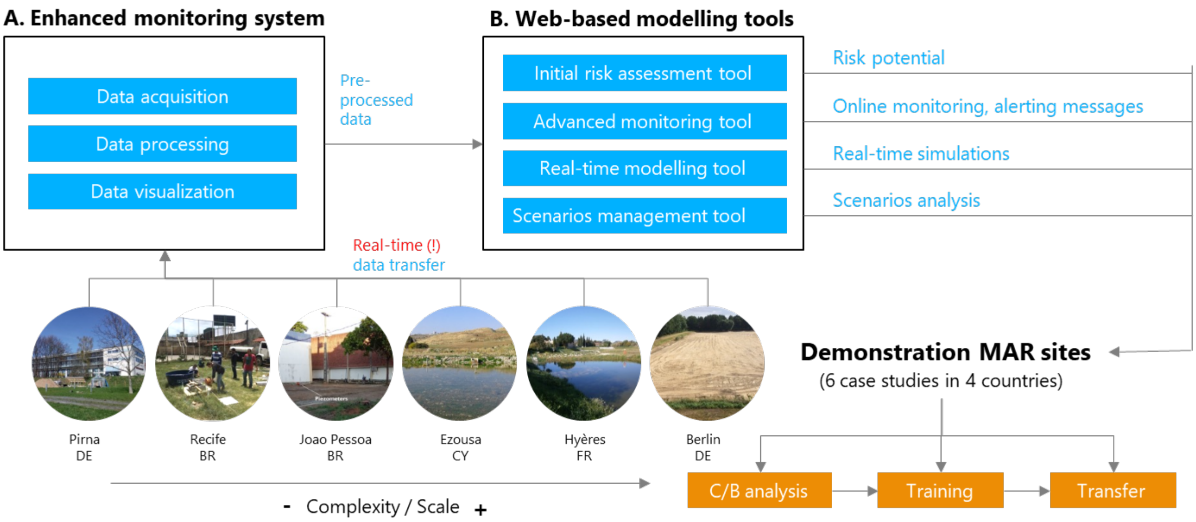


Figure 2. RMCS concept of SMART-Control at the different pilot sites

Depending on the expected risks for a safe and successful MAR operation, different tools of the platform are relevant. Figure 3 shows the web-tools developed in the SMART-Control project, mapped to the risks they address. A more detailed description of the SMART-Control web-tools is provided in section 2.1.

The SMART-Control web-tools constitute only a small part of the multitude of tools that the INOWAS platform has to offer. The platform is based on collective work resulting from previous and ongoing projects. Example applications of selected web-tools for replication sites in Brazil and Cyprus are presented in chapters 4.1.6 and 4.2.4, respectively.

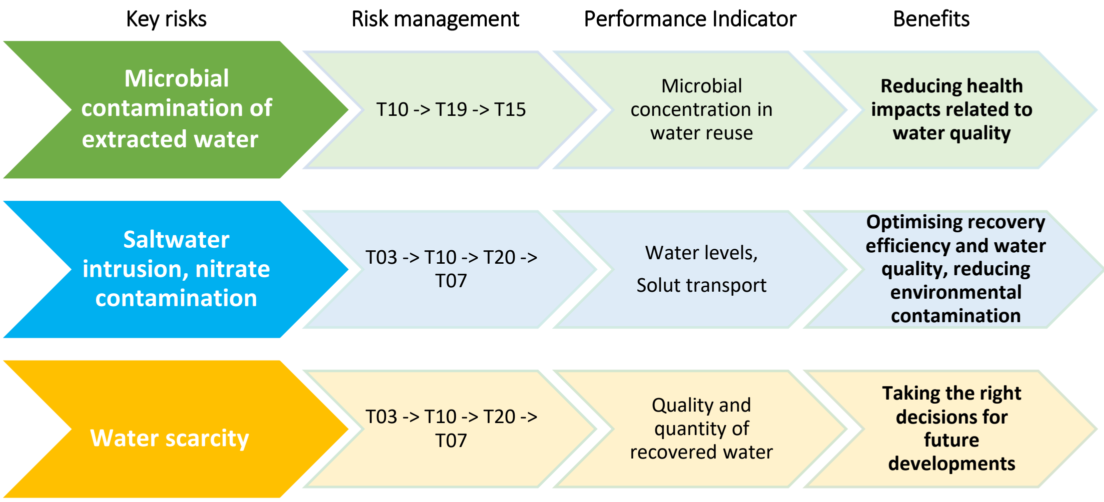


Figure 3. Key risks that are addressed by the SMART-Control approach and associated performance indicators (PI)

Legend of Figure 3

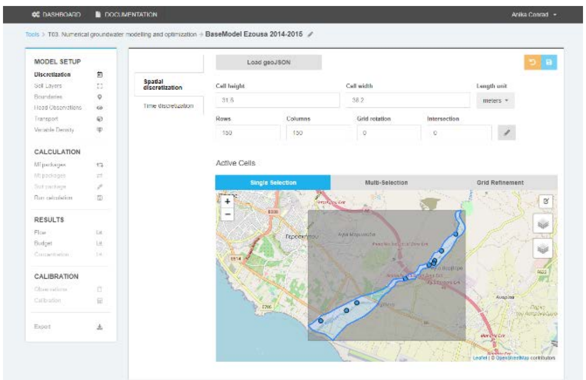
T03	Numerical groundwater modelling using MODFLOW	T15	Quantitative microbial risk assessment tool
T07	Specific Scenario Analyzer	T19	Groundwater residence time tool
T10	Real time monitoring and control	T20	Real time numerical modelling

2.1 SMART-CONTROL WEB-TOOLS

T03 Numerical groundwater modelling using MODFLOW

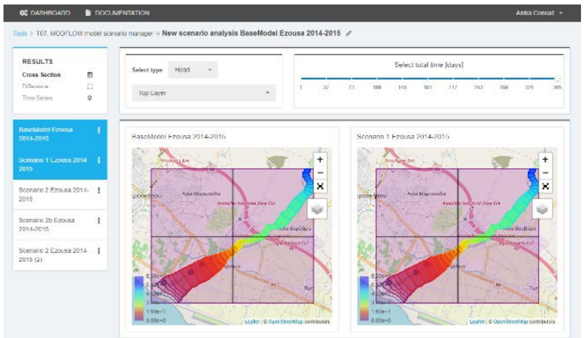
General usage and scope of specific benefits in this case: The tool enables the user to develop a MODFLOW groundwater flow model for the specific site and create, write and read input and output files of the model. In addition, solute transport using MT3DMS as well as variable-density flow can be added to the model. Furthermore, the tool provides optimization algorithms to find the best location for an infiltration well using a calibrated groundwater flow and solute transport model. (INOWAS 2022)

Required data & technical set-up: Specific knowledge on the geohydrological conditions of the site are needed in order to setup an appropriate groundwater model with the INOWAS platform. The model setup includes the configuration of the general spatial and temporal discretization of the MODFLOW model, the soil layers including different layers and zones, as well as the setting of flow and head boundary conditions (Glass et al. 2022b). The model is setup in stepwise manner. The INOWAS platform provides comprehensive tutorials for this case. (INOWAS 2022)



➔ For more information, see Glass et al, 2022 or the tool documentation on inowas.com (INOWAS 2022)

T07 MODFLOW model scenario manager

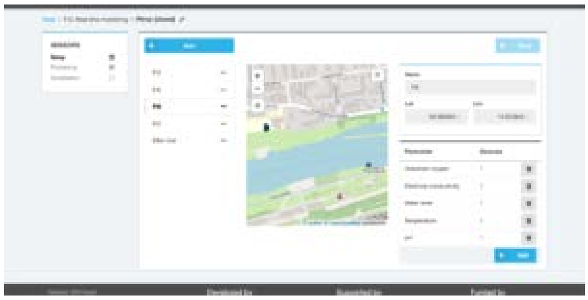


General usage and scope of specific benefits in this case: Tool 7 enables the user to analyze and compare pre-defined model scenarios with each other. Different scenarios can be evaluated to assess different management solutions or projections of climate, land use or urban development changes in the model. These can include pumping rates to simulate shifting water demand, recharge rates, or river discharge to replicate shifting climatic conditions or changes in land use. The workflow is based on the existing numerical groundwater flow and transport model tool (T03) on the INOWAS platform, where the model can be setup, run and calibrated. The Base Model can be copied and edited for scenario analysis in order to change boundary conditions manually, by hand, or via CSV upload. For evaluation, distinct results visualization options exist to enable a better comparison of the different model runs. (INOWAS 2022)

Technical requirement/Required information: The scenario analyser requires a working MODFLOW model for the area of concern and reliable information on the future scenarios in the form of available water quantities for infiltration and demand estimations. Climate projections regarding rain patterns and evapotranspiration are required if climate change scenarios are to be analysed. (INOWAS 2022)

- ➔ For more information, see SMART-Control Deliverable D4.5 (Glass et al. 2022a) or the tool documentation on inowas.com (INOWAS 2022)

T10 Real time monitoring

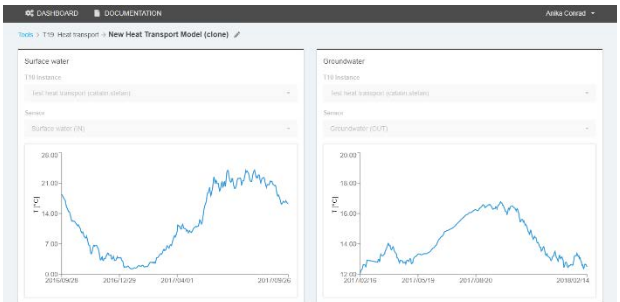


General usage and scope: Tool 10 aims at facilitating the operational management of MAR sites. The tool includes a web-based monitoring system developed for real-time integration of time series data into the INOWAS modelling platform. Sensors installed at MAR facilities worldwide can be connected to the INOWAS platform to transfer collected data in real time. The data can be visualised, processed, downloaded and prepared for further usage, e.g. as a boundary or observation point in a real-time groundwater flow model. (INOWAS 2022)

Technical requirement/Required information: For receiving online information, online sensors need to be installed. Depending on the purpose of the monitoring and control activity these can be e.g. for water balance: groundwater levels, water flow for infiltration and extraction; for water quality: nitrate, pathogens, dissolved oxygen, electrical conductivity. (INOWAS 2022)

- ➔ For more information, see SMART-Control Deliverable D4.2 (Glass et al. 2020) or the tool documentation on inowas.com (INOWAS 2022)

T19 Groundwater residence time tool

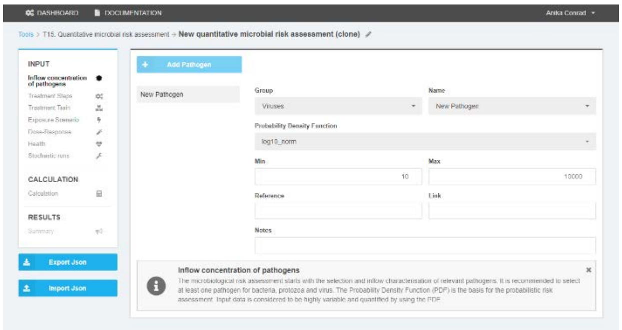


General usage and scope: Tool 19 estimates the groundwater hydraulic residence time of the infiltrated water during subsurface passage. For this, seasonal temperature fluctuations observed in recharge water and MAR recovery wells are used. The residence time is a critical parameter to ensure sufficient attenuation for hygienic parameters and other undesired substances. This tool helps to determine groundwater hydraulic residence time (HRT). (INOWAS 2022)

Required data and technical set-up: As the residence time of infiltrated water in the subsurface is calculated based on temperature measurements, online temperature sensors at infiltration well and at abstraction well need to be setup. The two sensors need to be connected to the platform with the tool 10. Further characteristics of the subsurface related to its thermal retardation factor need to be defined. (INOWAS 2022)

- ➔ For more information, see SMART-Control Deliverable D4.1 (Stefan et al. 2021) or the tool documentation on inowas.com (INOWAS 2022)

T15 Quantitative microbial risk assessment (QMRA) tool

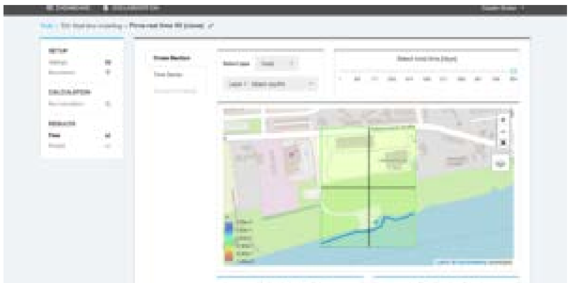


General usage and scope: Tool 15 quantitatively assesses the microbial risk of MAR schemes, including hazard identification, exposure assessment, dose analysis and risks characterisation based on measurements and sensor inputs. The risk can be assessed for selected reference pathogens such as bacterial, protozoan and viral pathogens for different hydraulic residence times during MAR. Based on the findings from the model, problem and risk areas can be identified and protective measures prepared. (INOWAS 2022)

Technical requirement/Required information: Sensors measuring the inflow concentration of the selected pathogens need to be installed. There should be an understanding in advance of the usage intention of produced water and the corresponding water quality standards. As data inputs, the involved treatment processes, the exposure and health factors need to be defined. The Exposure Scenario is based on eight pre-defined exposure scenarios from drinking water to irrigation water and domestic end-use and the health scenario includes the infection to illness factor and the disability-adjusted life years (DALY) per case. (INOWAS 2022)

- ➔ For more information, see SMART-Control Deliverable D4.3 (Sprenger et al. 2021) or the tool documentation on inowas.com (INOWAS 2022)

T20 Real time numerical modelling



General usage and scope: The real-time modelling tool allows the user to extend and update an existing numerical groundwater flow model with new sensor data and to include current measurements in the model. The new real-time modelling project can be edited and shows the results with the same functions as the T03 tool. (INOWAS 2022)

Technical requirement/Required information: An existing numerical groundwater flow model, already created and run on the INOWAS platform using tool T03. New data either set as constant or imported from a sensor defined in the INOWAS tool T10 are a prerequisite to use this tool. (INOWAS 2022)

- ➔ For more information, see SMART-Control Deliverable D4.2 (Glass et al. 2020) or the tool documentation on inowas.com (INOWAS 2022)

2.2 ADDED VALUE OF USING THE SMART-CONTROL APPROACH IN THE MONITORING AND MANAGEMENT OF MAR SYSTEMS

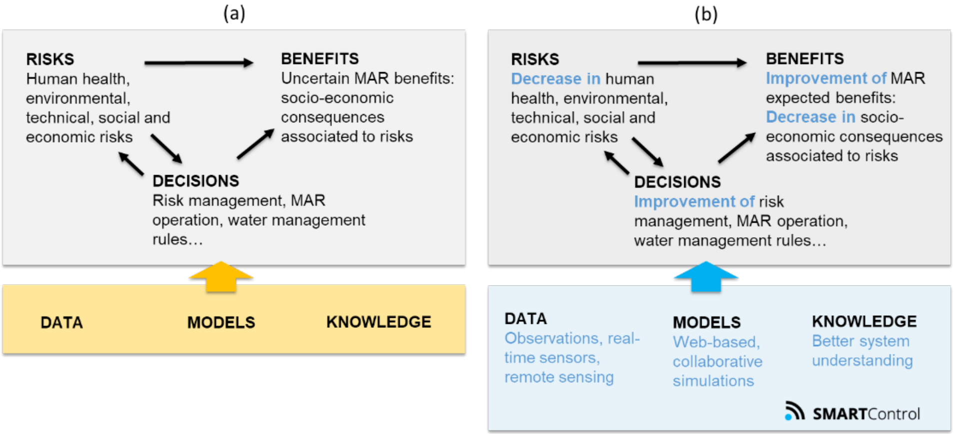


Figure 4. Benefits expected from MAR real-time monitoring and control: risks, decisions and benefits with (a) classical monitoring and (b) SMART-Control real-time monitoring and control

Using the SMART-Control approach offers many advantages for the MAR operator (see Figure 4).
The versatile range of tools allows to improve the monitoring and management of MAR systems and to minimise associated risks. The information provided by the monitoring and modelling tools helps to avoid system failures or to reduce their damages and to realize the full benefits of a MAR system. This not only allows economic savings to be achieved, but also ensures the long-term environmental and social sustainability of the system.
The INOWAS platform enables not only a versatile data analysis, but also a comprehensible visualization of this data for a simplified communication of the MAR processes to stakeholders and thus contributes to increasing stakeholder acceptance and trust towards MAR.
The INOWAS platform was developed as an open-access and free web service. Compared to desktop-based software, the entire workflow is managed directly in the web browser without the need for additional plug-ins or local storage capacity. The web-based implementation also provides researchers, MAR operators, and decision makers a platform for easy collaboration over the internet.
The INOWAS platform is a living platform, which is continuously developed in collaboration with international teams and adapted to the needs of different MAR stakeholders.

Avoidance / significant reduction of damage in case of system failures

Risk reduction through faster identification and better understanding of environmental and technical risks

1.Saving resources and time in monitoring and controlling MAR systems

2.Easier and faster assessment of operational parameters, open source, free of charge, web-based platform

Long-term economic, environmental and social sustainability

Increasing the benefits provided by the MAR system, avoiding costly damage repairs

Increase stakeholder acceptability and trust towards MAR

Easy to understand visualisations

Take better decisions for future operation and design of MAR system

Simulate climate and development scenarios

Easy collaboration between various modelers and decision makers

Option for public or private data/project storage, worldwide accessibility of data and projects

2.3 SOLUTION-SPECIFIC SUCCESS FACTORS FOR TRANSFER

There are specific resource requirements for the installation and operation of the SMART-Control approach:

1. Installation of the in-situ real time monitoring system:
   - Availability of suitable sensors and local resources for their installation and maintenance.
   - Site and target specific data to determine sensor placement
   - Network coverage of MAR sites for online data transfer
2. Application of the web-based INOWAS platform
   - Access to the internet, no large process capacities required as the platform is web-based running on the TU Dresden's own server
   - Specific requirements for applying the SMART-Control web-tools are described in chapter 2.1
3. Exploitation of the results
   - General understanding of hydrogeological and MAR processes
   - Depending on the objective, decision-making power on changing the MAR processes

3 TECHNOLOGY TRANSFER APROACH

Preparing the ground for technology transfer first involves a general definition and assessment of the exploitable results of the SMART-Control approach (Chapter 2), before site-specific activities at selected replication sites are carried out, starting with an analysis of the situation to identify the needs and requirements in terms of water resources management and current status/planned set up of the MAR site and its risks in this context. These are followed by training and awareness raising activities to build capacity of local stakeholders in the use of the INOWAS platform. Subsequently, a specific replication site is selected and a proposal for a related transfer concept based on the SMART-Control approach is co-developed together with local project partners and stakeholders. Public consultations, especially with stakeholders from politics, science and practice, finally pave the way for a mature project concept. This also includes a roadmap with the next steps developed with the identified implementers and enablers. Besides potential and active MAR operators, MAR stakeholders (of existing or planned MAR sites) are also engaged in the activities and discussions in order to consider all potential benefits for a replication project (e.g. farmers as end-users of the recovered water, water utilities as water suppliers, water agencies as decision and policy makers). More detailed information on the replication activities can be found in the project deliverable D7.5 (Conrad and Heim 2022).

Figure 5 gives an overview of the different objectives of the individual stages of the technology transfer approach.

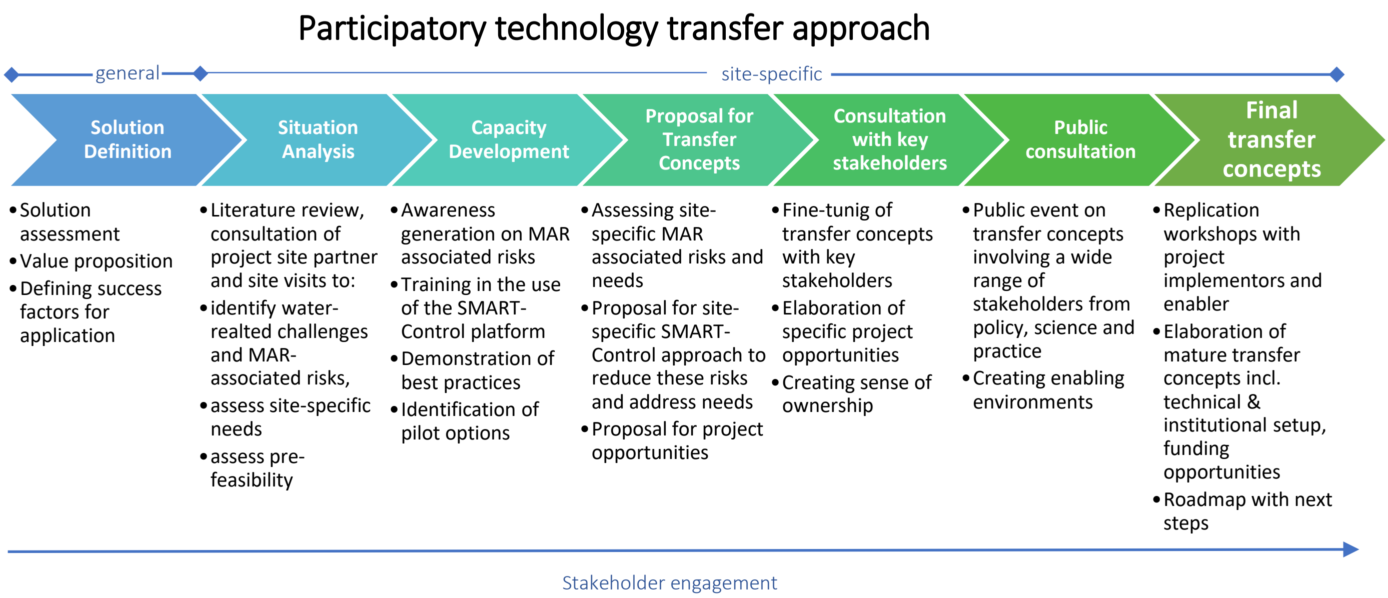


Figure 5. Steps and objectives of the participatory technology transfer approach

The described approach was carried out and transfer concepts have been developed for the Public Markets of Afogados in Recife, Brazil (chapter 4.1), and Akrotiri basin in Cyprus (chapter 4.2), both selected as most promising sites for transferring the SMART-Control approach in Pernambuco, Brazil and Cyprus, respectively. Depending on the state of development of MAR and its monitoring system at the selected sites, the chosen transfer approach differs. Four different types are differentiated in this context, whereby the selected site in Brazil belongs to catergoy 1 and the site in Cyprus to category 3:

(1) no existing MAR site yet, but MAR is planned,
(2) MAR sites without monitoring system,
(3) MAR site with existing analogue monitoring system,
(4) MAR location with existing online monitoring system.

4 TRANSFER CONCEPTS/CASE STUDIES FOR TWO SELECTED SITES IN BRAZIL AND CYPRUS

4.1 PUBLIC MARKET OF AFOGADOS, RECIFE, BRAZIL

Figure 6. Cistern of the Public Market of Afogados

4.1.1 Description of the site

The Public Market of Afogados (Figure 6, 7) is located in Recife Metropolitan Region (RMR) the capital of the state of Pernambuco in the North East of Brazil at the Atlantic Coast. The RMR is ranked as Brazil's fourth most populated urban area with nearly 4 million inhabitants and comprises an area of about 2777 km² and extents about 125 km along the coast. While the climate of whole Northeastern Brazil is considered as semi-arid with rainfall of only about 700 mm annually (WBG 2020), the RMR exhibits a tropical monsoon climate with warm hot temperatures and high relative humidity throughout the year, exceeding 2400 mm per year. Still, the precipitation is irregularly distributed throughout the year. During the rainy season from March to August, rainfall totals 1909 mm, as opposed to 549 mm in the dry season from September to February. The central area of Recife is located in the Lower Coastal Plateau, a flat low plain formed by recent sediments of coastal and fluvial origin with heights ranging from 1-10 m above sea level. It is bounded by the Coastal Tablelands that are characterized by sub-horizontal, strongly eroded, seaward dipping strata, and comprising both flat and hilly areas which rise between 80-150 m. (Leite 2000; INMET 2014)

Within the RMR there can be found five main aquifers, namely Beberibe, Cabo, Marinha Farinha, Barreiras and Boa Viagem, with only the first two being used for water supply of the region. Beberibe, formed in the Upper Cretaceous age, is the most important formation in terms of natural water storage in the RMR and is located in the Recife Plain. Its serves as a main groundwater source for the public water supply of the RMR through the Pernambuco State Water and Sewerage Company (COMPESA) and also spans below the Afogado neighbourhood. The Beberibe aquifer is composed of a sequence of sandstone with intercalations of mudstone and can be distinguished in the Upper and Lower Beberibe section with reported depths of 100 m and 200 m, respectively. The Upper Beberibe is limited to 30 m, while the lower member is 100 m thick (Leite 2000). The Beberibe on average has a hydraulic conductivity of 1,9 m/day (0,000022 m/s) and a storage coefficient of $2x10^{-4}$ (Cabral et al. 2008).

The public water supply—covering the water demand of about 6,1 m³/s for a population of 1.49 million inhabitants (Cary et al. 2015)—relies mainly on surface waters and dams, providing 5,6 m³/s in total with only 0,4 m³/s coming from groundwater. However, due to recent droughts and steady population growth, the management of groundwater resources—and thus also of the Beberibe aquifer—is becoming increasingly important for public water supply to meet the growing demand for water.

Figure 7. Location of the Public Market of Afogados

4.1.2 Needs and current solutions regarding water management

Over the last decades, droughts and the steady increase in water demand in the RMR has resulted in impacts such as groundwater depletion, deterioration of water quality and ecological status, and increased the risk of sea water intrusion and land subsidence. In 30 years, the permanent natural groundwater reserves in the Recife Plain depleted by 50 % (Luna et al. 2017). In order to secure their own water supply, many residential buildings have drilled—often illegally—private wells leading to an even greater lowering of the water table and contamination (e.g. due to salinization) of the aquifer. This is especially the case in densely populated neighbourhoods such as Afogados (Silva et al. 2021; Cabral et al. 2008). As a result, the water operator COMPESA had to cease the exploitation of some of the drying and salinized wells. The impacts of climate change and increasing demand led to water shortages that forces rationing of public water supplies. Literature sources report that COMPESA could only supply 75 % of the RMR water demand after the last severe drought period 1999-2000 (Cabral et al. 2000). In order to regulate the increasing pressure on groundwater resources, a system for zoning extraction permits was introduced which includes permit procedures for existing wells and new wells (Cabral et al. 2008). In addition, to control compliance with these restrictions, a comprehensive monitoring system was set up, under which 100 wells at selected sites in Recife were equipped with sensors to measure groundwater levels and electrical conductivity (Silva et al. 2021). However, positive effects of the measures have only been observed in some areas. The public water supply of RMR remains poor to this day (Foster et al. 2022) and groundwater levels continue to decline in critical areas, requiring the introduction of further groundwater management techniques to meet the RMR's ever-increasing water demands.

MAR of the Beberibe aquifer in combination with SMART-Control instruments represents an attractive solution safeguarding existing groundwater resources and increasing their availability for a safe public water supply in terms of both improved water quality and increased quantity. The following sections will examine the managed recharge of the Beberibe aquifer secured by the SMART-Control approach using the existing infrastructure of the public market in Afogados neighbourhood.

4.1.3 Future option of installing MAR

Table 1. Key data on the water balance of the new public market of Afogados

Water balance	Value
Annual water demand	2900 m³ (CSURB 2018)
Annual precipitation	1884 mm (APAC 2018)
Existing rain water harvesting system	Yes
Harvesting area	3,150 m²
Storage capacity	Cistern: 50 m³

MAR could help meet the local needs described above by injecting rainwater into the Beberibe aquifer, thus harnessing previously unused water resources. The existing infrastructure, including the large roof area, recently constructed rainwater harvesting system and cistern for rainwater storage, lends itself to the installation of a MAR system. This plant thus represents the replication site category 1 - no existing MAR system installed yet, but MAR is planned. Building on the cooperation with the Urban Services Company of Recife (CSUR, responsible for the public market management in Recife) in the past project SubSol, a great interest was expressed to implement MAR at this market. First rough calculations showed that with a roof area of more than 3,150 m², the collected water will be sufficient to cover the water demand of the market and additionally replenish the local aquifer. Key data on the water balance of the site are given in Table 1. The idea is, to infiltrate the surplus harvested rainwater into the Beberibe aquifer in a controlled process using nearby existing wells. In times when the storage capacity of the cistern is not sufficient to cover the amount of water needed, the water from the replenished aquifer could be extracted again through the same wells. Suitability tests of the existing wells as ASR wells are necessary before the proposed process can be operated.

Viability assessment according to Australian guidelines

In order to assess the viability of the Afogados public market as a MAR site, the first step of the entry-level feasibility assessment recommended by the Ausralian guidelines (NRMMC et al. 2009b) is carried out (see Table 2).

Table 2. Key data on replication idea for the Public Markets of Afogados

Entry-level feasibility assessment according to the Australian guidelines	
Intended water use - Is there an ongoing local demand or clearly defined environmental benefit for recovered water that is compatible with local water management plans?	**YES –** Needs of and benefits for the Public Market of Afogados: • Securing water availability in the market for hygienic purposes (currently there is only water once or twice in the week which is stored in a cistern) • Mitigating seawater intrusion/protecting existing wells in the old market Public needs and benefits: • Minimising flood events in the area • Demonstrating MAR as a safe and reliable solution with SMART-Control framework to stimulate further MAR projects in Brazil/Pernambuco
Source water availability and right of access - Is adequate source water available, and is harvesting this volume compatible with catchment water management plans?	**YES –** The harvested rooftop rainwater from the 3,150 m² large roof, would be sufficient to cover the water demand of 2,900 m³ of the market (CSURB 2018) and in addition contribute to recharge the local aquifer Beberibe for long-term benefits such as reducing risks of subsidence, providing water for other water users, ecological benefits, reducing saltwater intrusion etc. Contrary to the original plans, the currently collected rainwater is not stored in the cistern for direct use due to insufficient water quality, instead it is discharged unused into the street, from where it flows into the sewerage system and from there into the sea. The installation of a purification stage (e.g. sand filter) is desired, but the financing has not been clarified. The market management (CSURB) has the right to access this rainwater and is very interested in a cooperation for its meaningful use.
Hydrogeological assessment – Is there at least one aquifer at the proposed MAR	**YES –** The lower Beberibe aquifer serves as the main groundwater source for drinking water for the public water supply. Due to the increasing demand for

<table>
<tr><td>site capable of storing additional water?</td><td>water, the Beberibe aquifer is subject to groundwater over-exploitation, which provides capacity for recharge water.

<table>
<tr><th>Geohydrology</th><th>Value</th></tr>
<tr><td>Aquifer layers</td><td>Boa Viagem and Beberibe (Costa et al. 1998)</td></tr>
<tr><td>Electrical conductivity</td><td>751 µS/cm (Cary et al. 2015)</td></tr>
<tr><td>Salinity of the groundwater</td><td>402 mg TDS/L</td></tr>
<tr><td>Hydraulic conductivity</td><td>1.9 m/d</td></tr>
<tr><td>Groundwater table</td><td>9 m BLS</td></tr>
<tr><td>Porosity</td><td>0.1</td></tr>
<tr><td>Hydraulic head</td><td>26 m BLS (Montenegro et al. 2006)</td></tr>
</table></td></tr>
<tr><td>Hydrogeological assessment – Is the project compatible with groundwater management plans?</td><td>YES – CSURB (in charge of the management of the public markets in RMR) and the Water and Climate Agency of Pernambuco (APAC, responsible for approval of a MAR site) are supporting a MAR project at the Public Market of Afogados.</td></tr>
<tr><td>Space for water capture and treatment - Is there sufficient land available for capture and treatment of the water?</td><td>YES – The market is located in a densely populated neighbourhood of Recife, but according to the maintenance manager of the market and CSURB, there is enough space for a filter system to pre-treat the rainwater, and installtion of an ASR well. A cistern with 50m³ is already in place sufficient to store the incoming rainwater.</td></tr>
<tr><td>Capability to design, construct and operate - Is there a capability to design, construct and operate a MAR project?</td><td>NO – Local maintenance team did not yet work with MAR, would need training</td></tr>
</table>

Components of a potential MAR site

In an interactive brainstorming session with key stakeholders, the below key components of a potential MAR site were identified. These results are not final and subject to further investigation.

Table 3. Key components of a potential MAR site at the Public Market of Afogados

MAR component	Potential MAR site at the Public Market of Afogados
Capture zone	Rooftop rainwater
Storage	Cistern with capacity of 50 m^3
Pre-treatment	Probably sand filter needed to comply with regulation, reservoir for buffering heavy rain events
Recharge	ASR wells (probably existing wells can be used)
Subsurface	Lower Beberibe aquifer
Recovery	ASR well (from the same well)
Post-treatment	Depending on the type of use, disinfection with chlorine is needed (cooking purposes)
End use	Domestic or commercial use, sanitary use (except for drinking)
Hydro-geological assessment	Nearby wells to be used as observation wells for hydrogeological assessment

4.1.5 Risks of MAR operation

Local water-realted risks given by key actors:

In a brainstorming session with the project site partner UFPE and APAC, key risks for a safe, purposeful (potential) MAR operation on the site of the new Afogados public market were identified, which were validated and refined through discussions with CSURB and the market's maintenance manager during site visits:

Water scarcity
Lack of water of suitable quality is one of the most critical risks identified by key stakeholders and partners. This can be due to two reasons: (1) It is likely that the availability of infiltration water will decrease in the future due to decreasing rainfall. (2) In addition, decreasing water levels due to overexploitation and declining quality are reducing the amount of water that can be extracted for direct usage. Regarding the latter, stakeholders mentioned an increased risk of saltwater intrusion due to nearby mangroves (Cary et al. 2015; Leite 2000; Cabral et al. 2008). In addition, there is a risk of contamination from increased concentrations of nitrates, iron and pathogens in the native groundwater. As Cabral et al. (2008) point out, pollution from sewage is one of the main problems in the upper Beberibe aquifer.

Health impacts
The possible risk of microbial contamination of the recovered water due to pathogens in the native groundwater can also have critical effects on human health. On the market, the water is used for cooking and cleaning dishes, for example. Accordingly, quality requirements specific to the purpose must be met.

Contamination of the groundwater used for drinking water purposes by COMPESA
The planned MAR facility will infiltrate pretreated rainwater into an aquifer that serves as the main source of public drinking water. Accordingly, the impact of potential groundwater contamination through infiltration is particularly serious and reducing this risk is all the more important. Existing legal regulations for Pernambuco for MAR sites regulating the quality of the infiltrated water are very weak, which should by no means give reason to become careless in this respect. However, the risk posed by rooftop water is manageable. The Australian guidelines mention critical, possible concentrations of metals originating from the roofing material and pathogens in this context (NRMMC et al. 2009a). The former is not relevant to the case of the public market, as the roof and rain catchment system are made of plastic. A risk, on the other hand, could be pathogen concentrations, from faeces of birds and small animals. The guidelines recommend direct pathogen monitoring, focusing on the main pathogens commonly detected in roof water (e.g. Campylogacter).

Space constraints
As is typical for a public market, there is little space in the new Afogados market. However, judging by the statements of the maintenance manager, space is being made for a filter system. Nevertheless, care should be taken when dimensioning the MAR system, including the filter, to ensure that it takes up as little space as possible. This aspect, however, is outside the scope of the SMART-Control approach and will not be discussed further below.

Possible future scenarios that influence these risks

Changing climate and less precipiation, but heavier rain events
Climate change projections for the RMR show a risk of worsening water scarcity in the dry season and an increase in extreme rain events in the rainy season. These developments are expected to increase the need for additional water storage and thus for a MAR system that is able to store water in times of surplus and deliver water in times of demand. In addition, an increased water demand due to decreasing rainfall could be compensated by using additional water sources (e.g. through greywater, stormwater reuse) or the additional purchase of COMPESA water could be considered. This could possibly make the construction of a second cistern necessary. The planning of the MAR system should take into account the corresponding developments inlcuding possible future increasing infiltration and abstraction patterns.

Stricter regulations
More stringent requirements for MAR will only increase the need for real-time monitoring systems and thus increase the need for an application of the SMART-Control approach.

4.1.6 SMART-Control approach suitable for addressing risks and their expected benefits

With regard to the previously identified MAR-associated risks, related needs have been determined and specific SMART-Control solutions were selected that are able to address the needs and reduce the identified risks (see Figure 8). The selected SMART-Control solutions are focused on selected tools developed within the SMART-Control project and provided by the INOWAS platform. They include a model-based approach in the SMART-Control platform with online sensors for an improved real-time data management for risk reduction and MAR system optimization. The specific benefits of using each of the recommended SMART-Control tools for the specific need are described below. A detailed description of the tools with their data and technical set-up requirements is given in chapter 2.

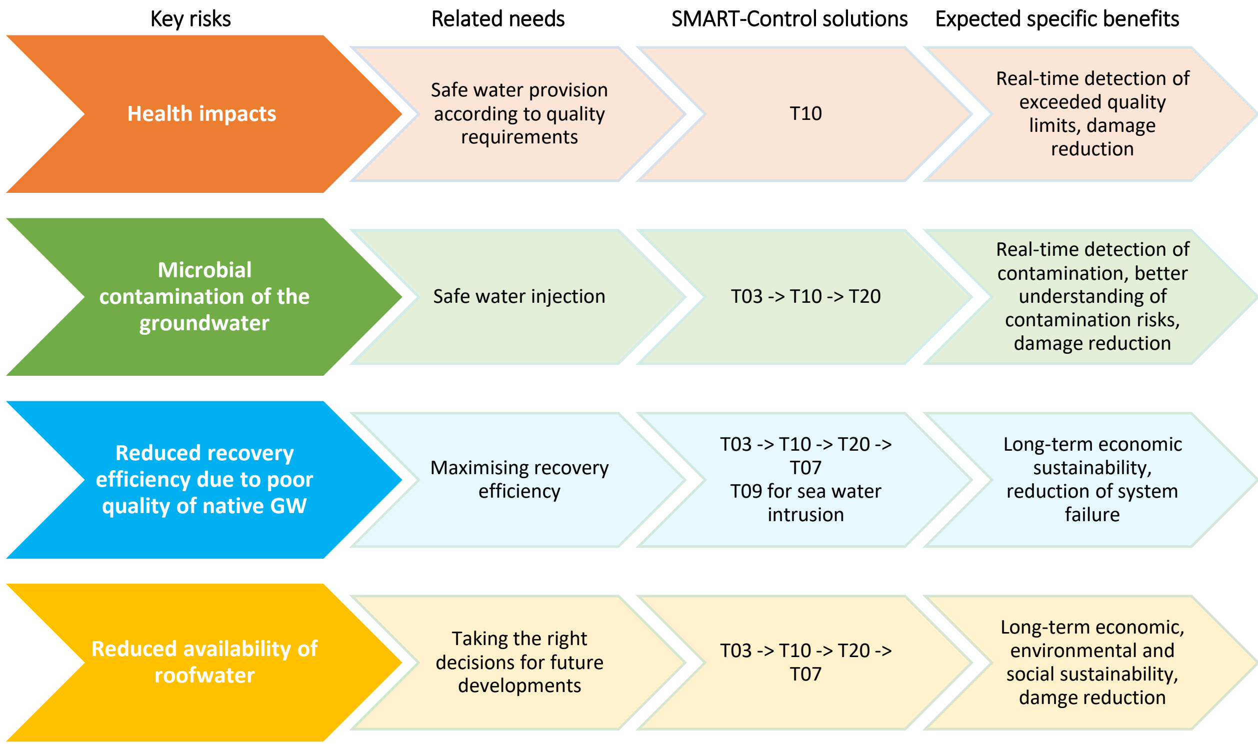


Figure 8. SMART-Control solutions to address identified key risks for a future MAR site at the public market of Afogados and expected benefits

1. Safe water provision according to quality requirements

With its **Real-Time Monitoring Tool 10**, the SMART-Control approach offers an optimal possibility not only to detect data in real time, but also to process and visualise them in a user-specific way. This offers optimal risk management of e.g. groundwater extraction in the case of the public market of Afogados. All that is required is the installation of online sensors to detect contaminations of concern at the extraction well and data upload to the INOWAS platform. Data storage can be public or confidential under desired security conditions. In the further course, MAR operators or decision makers can access their data from anywhere on the internet and check the status of the MAR system. The fast and easy insight into the MAR operational status increases stakeholder's acceptability and trust towards the safety of the MAR facility. Appropriate alert functions are in the planning stage.

2. Safe water injection

Even though the risk from roof water injection is low (Australian guidelines), appropriate monitoring is advisable in line with the motto: trust is good, control is better. The SMART-Control approach offers an optimal and simple solution to ensure safe water injection and hence the integrity of the groundwater resources, which in the case of the public market serves the public drinking water supply. In addition to the real-time monitoring of the target values (see **T10 Real-time monitoring**) and thus the detection of limit value exceedances in real time before the injection of the contaminated water, **T20** allows **real-time modelling**, thus to update an existing numerical groundwater flow model of the case study area on the INOWAS platform (created with **T03 Numerical groundwater modelling and optimization**) with these real-time sensor data. Using the groundwater model, it is possible to theoretically estimate the impact and the risk of infiltration. This helps both in setting the limit values in advance and in rapid remediation in the event of damage. A research project at the market site under a comprehensive SMART Control real-time monitoring system is well suited to test and update existing regulations applying for Pernambuco for MAR using roof water.

3. Maximising recovery efficiency

The SMART Control approach includes several tools to maximise recovery efficiency in groundwater recharge, combining both real-time data and future scenarios. These include, for example, the previously described interaction of **T10, T03 and T20**, which provide real-time insights into the interaction and impact of infiltration and abstraction patterns on the aquifer (e.g. water levels, solute transport) and, vice versa, the impact of aquifer contamination on recovery efficiency allowing for improved MAR planning and optimization. This includes contaminants from high nitrate or pathogen levels or saltwater intrusion and their effects on the injected freshwater bubble (see also the description of the **T09 equations for simple saltwater intrusion** below). The additional use of the **T07 Scenario Analyser** allows comparison of the status quo with different scenarios.

T09 Simple saltwater intrusion equations (not part of SMART-Control approach but implemented on the INOWAS platform)

Seawater intrusion poses a threat to the Beberibe aquifer as the overextraction is shifting the interface between salt- and freshwater. It is crucial to analyse the process which can influence the intrusion to determine whether extraction is feasible.

Tool 9 contains analytical equations that can be used to analyse or predict the location of the interface between sea water and fresh water in a groundwater system (Glass et al. 2018).

<u>General usage and scope of specific benefits in this case:</u> This tool can be used to determine the location, shape and extent of the interface between the freshwater aquifer and saltwater. Based on widely used equations, the tool helps in estimating critical abstraction rates to prevent increased sea water intrusion and upconing. In addition, the effects of sea level rise on sea water intrusion can be calculated.

<u>Required information/technical setup:</u> To calculate the interdependencies between the fresh- and saltwater bodies, basic knowledge of the aquifer and seawater properties are needed. Among others, these can include the thickness of the freshwater body, the different water densities, interface distances, the hydraulic conductivity and inflow/outflow and pumping rates.

<u>Specific benefits in this case:</u> This tool is especially helpful as it provides the user with specific knowledge on the interface between the fresh- and saltwater based on simple measurements. Furthermore, it can help in estimating the influence of pumping or recharging wells on the saltwater intrusion processes.

4. Taking the right decisions for future developments

In addition to the real-time monitoring and modelling of the MAR processes and site (**T10-T03-T20**), **T07 Specific Scenario Analyser** allows to view, analyse and compare user-defined scenarios of the MAR system. Operators and decision makers are provided with a kind of prediction of the future situation of the MAR system in terms of its performance under changing conditions. This enables them to make the right decisions to either plan a further increase in the amount of water available for MAR or to adapt the technical set-up or operation of the MAR system in accordance to future developments such as climate or demographic changes. This enables evidence-based planning and optimization of infiltration and abstraction patterns, water storage tank volume or location of the ASR wells.

Below described tools, implemented on the INOWAS platform are useful for taking the right decisions during MAR planning:

The appropriate selection of the applied MAR method and model are crucial to implement the MAR technology in a right way and profit from it. The INOWAS platform provides for both cases tools which can easily be implemented and guide the path towards the selection of the right method and model.

T06 MAR Method Selection (not part of the SMART-Control approach, but implemented on the INOWAS platform)

Choosing the suitable MAR method based on the given circumstances of the MAR site is necessary to develop, operate and maintain an efficient and economic MAR project. The selection of the appropriate MAR method for given conditions is often driven by two main factors: a suitable aquifer and an available suitable water source. Based on the classification system developed by IGRAC (2015), the tool helps in producing a first overview of suitable possible MAR methods.

General usage and scope of specific benefits in this case: This tool is giving the user a very rough first idea about which MAR methods can be applied to a site with certain characteristics. The selection of a MAR method is influenced by hydrologic and hydrogeologic factors such as geology, soil infiltration capacity, available water quantity and quality as well as the available land and costs. Based on the selected five criteria water source, soil type, land use, purpose, and the scale of the project the tool helps in determining the most suitable MAR methods for the specific case (INOWAS platform 2022).

Required information/technical setup: For this tool, very general information is required which should be available before planning to implement MAR technology. The source of water at the site can include river, groundwater, runoff, and waste-water and their respective reliability, quality and quantity. The soil type is classified in four schemes to determine roughly the infiltration capacity. The land use type based on the Corine classification should be known as well as the purpose of the MAR application (maximize storage capacity, prevent saltwater intrusion, restore groundater levels, improve water quality, etc.). Lastly, the amount of people that the user wants to supply with the water stored by applying MAR should be known to estimate the quantity of water to be stored.

Specific benefits in this case: The tool gives a basic overview about which techniques are feasible and provides a very rough analysis on the costs and land need for each MAR method that is applicable to the specified situation.

T11 MAR Model Selection

Models are being used during the design, implementation and optimization stage to evaluate the processes occurring at MAR schemes. As the selection of a suitable model suite for a particular problem is often a challenge, the tool facilitates interactive filtering and model comparison (Glass 2019).

General usage and scope of specific benefits in this case: This tool provides a comprehensive overview of suitable models which have already been applied to asses MAR-related topics and is based on a review of modeling MAR case studies. A limited list of suitable models can be created which helps the user to select a suitable model to evaluate his MAR-specific issue. In addition, a list of case studies of model applications with regard to the user-defined filter criteria is provided. Further information about the commonly used software codes such as equations used, dimensions, licenses and model homepage is given if the models were used previously in at least two published case studies.

Technical requirement/Required information: Basic information on the main MAR method (in-channel modifications, induced bank filtration, rainwater & runoff harvesting, spreading methods, well shaft and borehole recharge), the general objective of the modelling study (geochemical processes, Impact on groundwater, optimization or recovery efficiency), and the processes considered such as groundwater or unsaturated flow, solute or reactive transport or watershed management are needed to determine a limited list of suitable models. If the user needs further filtering of the suitable models, e.g. if the list of models is still too long, more specific filter criteria can be set for the specific objective of the modeling study and the specific MAR method used.

Specific benefits in this case: A correctly selected model for the MAR specific issue aids in evaluating the occurring processes during design, implementation and optimization of the selected MAR scheme. The tool facilitates interactive filtering and model comparison and gives detailed information on the models and application cases as the selection of a suitable model for a particular problem is often a challenge.

4.1.7 Potential implementation constellations (institutional set-up, financial aspects, etc.)

The State Agency for Water and Climate (APAC) is responsible for planning and regulation of water resources in Pernambuco. The Urban Services Company of Recife (CSURB) and the water utility of Recife (COMPESA) could be responsible for setting up and managing the system. CSURB has already installed the rainwater catchment system at the new market and has pointed out its interest in the possibilities which the MAR solution brings with. They are interested in looking at the feasibility of this system in the framework of a research project. The Federal University of Pernambuco (UFPE), who is the coordinator of the SMART-Control pilot system in the Pina neighbourhood, could be the right partner institution for the implementation of such a research project. The well driller and maintenance company Aqua Poços can be an experienced partner to install further wells in the area.

4.1.8 Roadmap for project development

The next steps for an implementation of the Transfer Concept and the application of the SMART Control tools for the identified replication site in RMR would be, as suggested by the local partners, a more in-depth feasibility study for the technical set-up and the exact specification of the equipment needed for each of the approaches, as well as a comparison of different options. As part of the feasibility study, it would be useful to carry out a cost-benefit analysis comparing the investment and operating costs with the expected benefits to decide which measures are worth investing in, using e.g. the value of information methodology applied in the SMART-Control project (Hérivaux et al. 2022). While there is an initial idea from the relevant authorities and interested and competent stakeholders, a detailed stakeholder analysis, including a needs assessment and willingness to contribute, would be essential. For this feasibility study to be carried out, financing options and supportive programmes need to be identified and a project proposed. In addition to technical and economic feasibility, legal and operational feasibility should also be ensured.
Also useful and recommended is the development and implementation of a governance approach to ensure fair and equitable access to the benefits of the MAR system and equitable sharing of costs. This would enable APAC to monitor and prevent illegal well drilling and groundwater abstraction and maximise the overall benefits of using the valuable but scarce water resources despite sustainable and limited use.

- In-depth feasibility study with cost-benefit analysis
- Detailed stakeholder analysis incl. needs and contribution assessment, funding options
- Development of governance approach

4.1.9 Further MAR sites of interest

Due to very high-water demand and saltwater intrusion into well fields, there is an urgent need for sustainable water management solutions. Not only the Beberibe aquifer, but also the Cabo aquifer suffered great declines in water storage as its water table lowered by 90m between 1975 and 2015 (Luna et al. 2017). As Coelho et al. (2018) demonstrate, the application of MAR systems via ASR/ASTR may be considered feasible in the RMR Area due to the great variability of deep wells drilled for private and public uses and the large rainfall amount during rainy season. Currently, there are no further MAR sites in the RMR, which means that the search for replication sites is limited to type 1 “no existing MAR site yet, but MAR is planned”. Two “hotspots” with a high density of wells have been identified in the RMR: (i) Boa Viagem avenue in the Cabo aquifer; and (ii) Northwestern “Bacia do Pina”, in Espinheiro neighbourhood above the Beberibe aquifer (Coelho et al. 2018). Especially in these areas, the illegally drilled wells could be used to apply MAR. During assessment studies and meetings with local stakeholders within the SMART-Control and prior projects such as the SUBSOL project, potential MAR sites were identified, which are listed below (Chakrabarti et al. 2017):

- **Roofed public markets:** Taking the Afogados market as an example, the roofs of other public markets in Recife could as well be used for harvesting rainwater and applying MAR. Some examples of other public markets include: Cais de Santa Rita (mentioned by CSURB), Mercado publico de Beberibe (Northern region, next to Beberibe river), Mercado de Casa Amarela (North), Mercado Público de Nova Descoberta

(North-West), Mercado da Madalena, Mercado Público do Cordeiro (Center-North), Mercado Público Cavaleiro (West)

- Residence buildings: Large residential complexes (condominiums) could be used to harvest rainwater as they have a great roof area and often already possess water tanks and well systems. As proposed by the manager of a well drilling company, old wells, which were once closed due to high salt water concentrations in the groundwater, could be reopened for recharge purposes. This would be a cost-effective method to enable individual solutions and create a well field in a short period of time. Furthermore, most of the residence buildings have large water tanks that could be used for rainwater storage. According to NBR 5626, typical residence buildings in the RMR provide space for 48 apartments and should have a water tank of approximately 130 m³, allowing water storage that would cover consumption needs for two days (Chakrabarti et al. 2017). However, those responsible should bear in mind that many roofs in Recife are already equipped with water reservoirs, but these are used to ensure hydraulic pressure and public water shortages (Coelho et al. 2018). The Conjunto Habitacoes is one example of a large residential complex which could be a potential target site.
- Large resort complexes: Especially in Porto de Galinhas, many wells have already had to be abandoned because of saltwater intrusion. This also accounts for the hotel resort Enotel which started to implement a desalinisation system in addition to drilling new wells. The old wells could be used as recharge systems. Other possible sites could be the Nannai in Porto de Galinhas or further resorts in Multo Alto as recommended by APAC.
- Industrial complexes: The Port of Suape, a 30,000 hectare industrial complex near the largest regional port is looking for immediate solutions to meet its water needs. Implementation there would also be interesting, as the roofs of the large administrative buildings could be used for rainwater collection. The AmBev-brewery could be another possibility to use the rainwater runoff from roof areas for ASR implementation.
- Other large buildings in the RMR: Several buildings with large roof areas exist in the RMR and are as such attractive for ASR implementation. Examples are the Public Convention Centre (Teatro Guarapes), the airport and large shopping complexes. The public convention centre (Teatro Guarapes) has a huge roof and lies in an area where groundwater is under stress and could benefit from recharge. Although the shopping center RioMar already covers its water needs by harvesting rainwater and water reuse, aquifer recharge practices could still be an attractive solution for them in case financial incentives are provided that could foster a more sustainable water use.

4.2 AKROTIRI BASIN, CYPRUS

2.1.1 Description of transfer site

Akrotiri Basin lies in the south of Cyprus westwards from the city of Limassol (see Figure 9). The region of the Sovereign Base Area of Akrotiri has a subtropical and semi-arid climate with mild winters and hot summers with temperatures between 7°C and 34°C and with little rainfall during the winter from November to March with an average rainfall between 400 and 500 mm/a while the annual precipitation has been observed to have decreased by 100 mm in the last 85 years and the annual distribution has changed considerably with extremes in rainfalls and droughts alternating (WBG 2022).

The Akrotiri aquifer is the third biggest aquifer in Cyprus, which has been fed by the rivers Kouris and Garyllis prior to building the dams Kouris (1987) and Polemidia on the Gyrylis river (1965). Since then, the recharge depends on overspills from the dams and the controlled releases. Overall the mainly unconfined phreatic aquifer has an extend of 52 km², with a hydraulic conductivity ranging between 30 and 300 m/day and a specific storage between 8 to 20 %. In the coastal area of the MAR site, the aquifer has a thickness of around 100 m ranging up to 140 m. Around 400 boreholes in the region have yields between 20 to 200 m³/hour. Between 1990 and 2000 10.8 Mm³ were extracted in average whereas only 3.3 Mm³ were recharged artificially. (WBG 2022)

Main economic activities in the region requiring from apart domestic water consumption and tourism are irrigation for agriculture which is partly directly irrigated with tertiary treated water from the Lemesos Sewage System. The intensive use of fertilizers has led to high nitrate contamination up to 200 mg/l and due to low recharge and illegal over pumping salt water has intruded into the coastal aquifer which is partly below 3 m below sea water level (Georgiou 2002).

© TomTom, Maxar

Figure 9. Location of Akrotiri MAR system

4.2.1 Needs and current solutions regarding water management

Cyprus suffers from several decades of severe drought and an increasing demand of water, which in combination aggravates the critical long-standing water scarcity problems of the island. Several aquifers along the coast are at risk of drying out and due to saline contamination, many wells had to be abandoned because of seawater intrusion, irrigation-induced salinization (Milnes 2011), and nitrate contamination (Georgiou 2002). The authorities in Cyprus have put water scarcity at a high priority topic and examine regular monitoring and research programs. Numerous measures taken by WDD to counteract the sinking fresh water availability have improved the situation over the past years.
The measures though had limited success in water management due to several factors such as decreased annual rainfalls, an overall increased water demand especially due to increase of population and tourism and pertaining partial overexploitation of aquifers due to illegal pumping activities.
In the 1960s, local authorities started a rainwater collection program with the aim of "Not a drop of Water to the Sea". As a result, the storage capacity of the dams has been increased from 6 Mm³ to 300 Mm³, which also lead to the fact that no perennial streams exist on the island anymore (Hochstrat and Kazner 2009). In addition, Cyprus started to overcome water shortages by implementing desalination plants (four in the Republic of Cyprus). For instance, 90% of Lefkosia's domestic water supply is generated by desalination and almost 50% of the overall domestic water is produced by desalination plants since 2001.
In 2016, Turkey supported Northern Cyprus's water supply through a water pipeline. In addition, the southern part of the Island had to attain additional water shipped-in from Greece during this time.

Besides dams and desalination, groundwater bodies remain important water sources on the island. The Akrotiri aquifer is one of the most important porous aquifers in Southern Cyprus with an area of 45 km². The average annual extraction rates dropped from 14 Mm³/year to only 8 Mm³/year after 1990, due to saving measures by the authorities and salinization of wells. The Cyprus WDD studies the islands water scarcity and operates MAR sites in Cyprus reusing reclaimed water for many years. Artificial recharge of natural water bodies proved to be one of the promising instruments to counteract the continuously growing water stress. With positive experiences at the Ezousas aquifer, where an ASR site operating since 2005 achieves promising results on water storage, a similar project started in 2017 at the Akrotiri aquifer. The new site at the Akrotiri aquifer is still in its optimization phase and has great potential for improvement.

4.2.2 Current status of MAR installation

At the Akrotiri MAR system, the WDD infiltrates tertiary treated water from the Limassol Amathus Wastewater Association into the Akrotiri aquifer in winter via artificial ponds along the riverbed (see Figure 10, 11) and recovers the same mixed with groundwater via wells in summer at times of higher demand for irrigation needs. For this purpose, 17 recharge ponds have been constructed along the Kouris Riverbed, covering a total area of 56,000 m^2 (Achilleos et al. 2019). The volumes of water recharged into the Akrotiri aquifer were 0.8 Mm^3 in 2016 and 1.5 Mm^3 in 2017. As for the scope of available water for infiltration in 2021 almost 10 Mm³ of tertiary treated waste water were available from the Limassol Sewage treatment Board (SBLA 2022). The treated wastewater is partly directly used for irrigation, its quality could be further enhanced in a SAT process with MAR, thus there is the potential and need for improving the MAR installation at Akrotiri. Currently, there are also plans for setting up an additional waste water treatment plant near to the site, so that more treated waste water could be available in near future.

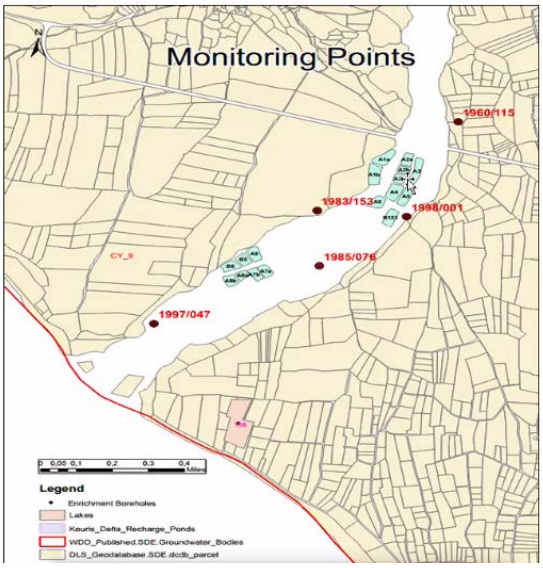


Figure 10. Akrotiri MAR system overview

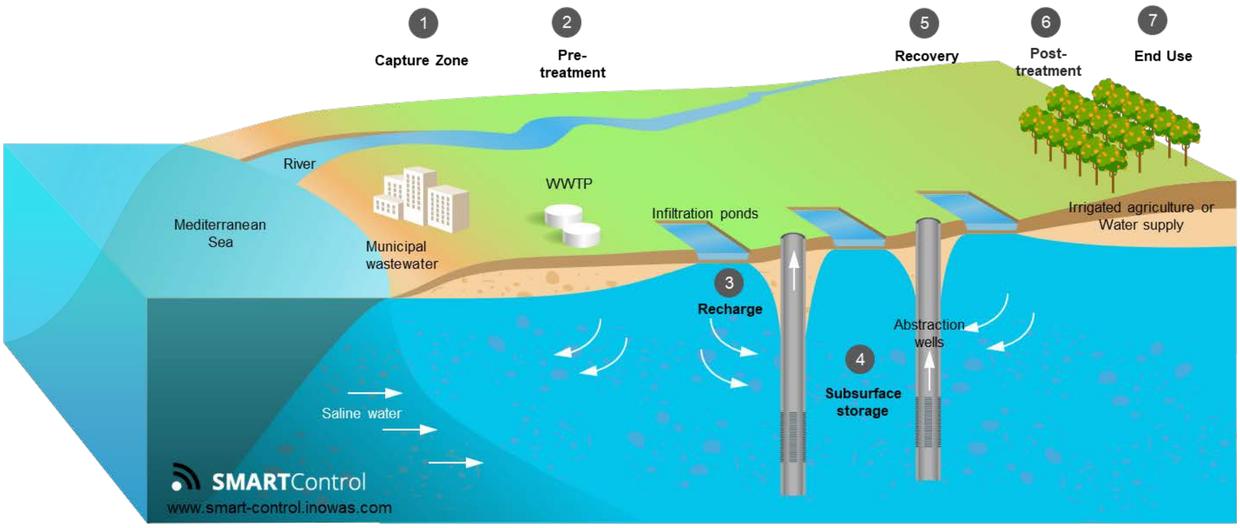


Figure 11. Technical Setup of the MAR scheme at Akrotiri (INOWAS 2022)

Existing monitoring system

The operation of the MAR system at Akrotiri is regularly monitored through offline, laboratory-based measurements by WDD. However, these measurements are time-consuming and the intervals are long, serving more long-term observation and for research purposes than as an alert system to minimize risks. Water levels are measured 6 times per year. Quality parameters are measured 4 times per year at 6 sites in the recharge period (October-April) covering a wide measurement range of heavy metals, pesticides, pharmaceuticals, etc. (Achilleos et al. 2019). Meteorological data are provided by the Cyprus Meteorological Survey. The Geological Survey Department has an online monitoring system with two monitoring wells in the Akrotiri aquifer which provide information on water level and salinity.

The tertiary treated waste water which is used for infiltration is monitored by the Sewerage Board of Limassol (SBLA). Quality and Quantity of Tertiary Treated Waste Water, Digested Sludge and Raw Sewage are given on the website with monthly values from the year 2008 onwards till date (2021) in yearly tables (SBLA 2022). SBLA also has an online nitrate sensor which monitors the effluent water quality continuously.

4.2.3 Risks of MAR operation

Local water-related risks given by key actors

The MAR system at the Akrotiri site is operating in a fragile area. Due to high agricultural activity in the area, the aquifer suffers from **high nitrate concentrations**. Overexploitation of the groundwater resources promotes **seawater intrusion**. Some wells near the coast had to be closed due to their water level being below the sea-level leading to **salinization**. This process is believed to increase in the future. The use of treated wastewater carries the risk of **increased concentrations of pathogens and pharmaceuticals** in the infiltrated and recovered water. Likewise, **clogging** of the recharge ponds is a constant risk that the WDD is striving to better monitor. (Source: replication workshop and bilateral stakeholder meetings)

Measures in place to reduce the risks

The WDD has already enacted several measures to prevent the risks associated with MAR and to counteract high pollution concentrations in the aquifer. Restriction of drilling new wells should regulate over pumping and allow water levels to slowly recover. The installation of a MAR system could already increase the water levels and thus reduce seawater intrusion. To minimize the risks from wastewater seepage, water from a nearby dam is used to dilute the infiltrate. Moreover, an offline monitoring system controls the safety of the MAR plant and the reclaimed water for irrigation purposes. Several parameters are measured, however, only at long intervals. A plan for the purification of the infiltration pond beds addresses the risk of clogging. (Source: replication workshop and bilateral stakeholder meetings)

Possible future scenarios that influence risks and MAR system

With regard to increasing water consumption, a new wastewater treatment plant is planned in the area providing more wastewater to operate a MAR system. It is expected that water-intensive agriculture will increasingly relocate from the area, giving space to less water-consuming new settlements. In addition, recent years in Cyprus have shown a decrease in rainfall towards more extreme weather events. Heavy rain events have the disadvantage of allowing less water to infiltrate naturally into the aquifer, resulting in more surface runoff lost to the sea. MAR provides one solution to counteract this process.

4.2.4 SMART-Control approach suitable for addressing risks and their expected benefits

In the replication workshop the participants matched SMART Control tools with the identified risks and the MAR operator's and end users' needs and discussed the scope of the installation of a RCMS system at the Akrotiri site. With regard to the previously identified and analysed risks, it was discussed which objectives could be achieved and questions could be answered with the SMART-Control Approach and its tools. The results of these discussions were further verified in bilateral meetings. The final approach can be grouped into three main objectives, see Figure 12.

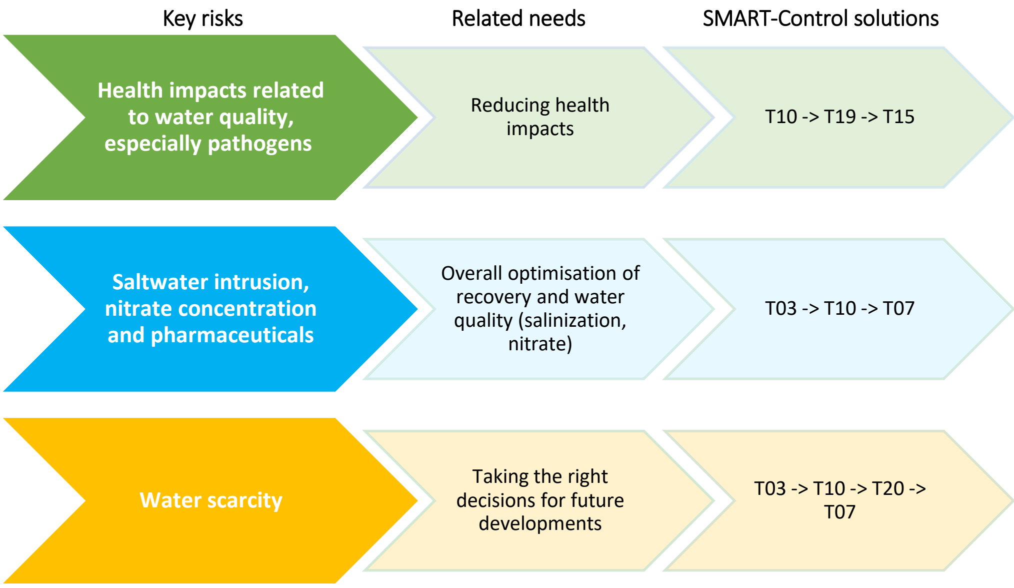


Figure 12. SMART-Control solutions to address key risks identified for the Akrotiri basin and expected benefits

1. **Reducing health impacts related to water quality, especially pathogens**

The SMART-Control platform can support in reducing health related risks by giving an indication for the assumed treatment during the soils passage with the assessment of the groundwater residence time and with assessing the quantitative microbial risk for different usage purposes of the recovered water.

T19 Groundwater residence time tool

<u>Specific benefits in this case:</u> The HRT tool provides information about the scope of removals of contaminants through the passage of the soil layers. This information can be used as early alert system for microbial risk assessment during MAR operation. Depending on the result a more suitable setup regarding the location of the infiltration and/or extraction well can be identified. The information can also be used for the QMRA tool in order to assess the risk of pathogen concentration for the entire treatment process as well the requirement for further treatment steps depending on the intended usage of the produced water.

T15 The QMRA tool

<u>Specific benefits in this case:</u> The QMRA tool provides information on the impacts of the final water quality in the unit of disability/disease adjusted life years (DALYs) depending on the water usage aim. With this tool it can be

decided in which way the water can be used while complying with an aim of a tolerable disease burden. E.g. the WHO uses a tolerable disease burden of 10^{-6} DALYs pppy (WHO 2011). This can protect the water users from unwanted negative health impacts.

2. **Overall optimisation of recovery and water quality (salinization, nitrate)**

The INOWAS platform provides many tools to optimise MAR operation. The SMART-Control approach focussed on optimising recovery efficiency of the MAR system while maintaining good water quality of the recovered water.

T10 Real time monitoring and control

Specific benefits in this case: The real time monitoring could provide constant information about the status of **salt water intrusion** and the impact of MAR for providing an effective barrier against the intrusion. The monitoring system could optimise the amount of water required for the prevention while further making it possible to extract the optimal amount without loosing precious freshwater unnecessarily flowing into the sea. The optimisation of operation with online control based on online monitoring could further upscale the MAR process and produce more water treated with the soil passage during the MAR process and in this way **secure the availability of water** for irrigation. According to the data of the Limassol Sewerage Board almost 10 Mm³ of treated waste water were available in 2021 (SBLA 2022). In comparing to the direct usage of the treated effluents, the MAR process would additionally act like a SAT system and could **remove pollutants** of concern like suspended solids, organic and inorganic materials, bacteria and viruses. Even nitrogen concentrations can be greatly reduced by adsorption and denitrification, and possibly by the anaerobic oxidation of ammonia (anammox) deeper in the vadose zone during the wet-dry cycles (Christodoulou et al. 2007). The water quality sensors of the infiltrated water and the water level sensors of the infiltration ponds could also help to monitor clogging and **optimise clogging management** of the infiltration ponds.

3. **Taking the right decisions for future developments**

The circumstances and conditions for water resource management change in the course of time, thus it is important to consider these in any future planning and also the dimensioning of any system to be setup. To assess the overall scope of the MAR system considering the future scenarios, the SMART-Control project has implemented a tool on the INOWAS platform which supports in producing information on the impact of different changing conditions to MAR systems considering future scenarios.

T07 Application Specific Scenario Analyzer

Specific benefits in this case: Operators and decision makers are provided with a kind of **prediction of the future situation** of the MAR system with regard to its performance capacities under changing circumstances. This enables them to take the right decision to either plan for further increasing the amount of water being made available for MAR or for choosing the best suitable locations for the infiltration and the extraction in order to make the **maximum usage of the existing aquifer system**. Further external impacts like climate change can be considered and required adaptation activities planned for long-term operational management. Given the rising amount of available treated waste water in Limassol as well as the changing rainfall pattern in Cyprus, future scenarios could show up the scope for **upscaling the MAR system in Akrotiri.**

4.2.5 Potential implementation constellations (institutional set-up, financial aspects, etc.)

The WDD is responsible for the water resource management on the island, operates the MAR facility and thus would be responsible for installing and implementing a comprehensive monitoring program. However, they could very well imagine following a co-creation and citizen science approach. Possible partners would be Cyprus Geological Survey Department, University of Cyprus, Technical University of Cyprus and end-user of the recovered water such as farmer organisations as well as possibly international research organisations. In addition, views and needs of other beneficiaries affected by an optimized MAR system such as end consumers of the food production should be included in certain decision-making processes.

4.2.6 Roadmap for project development

The next steps for possibly implementing the approach and applying the tools for the Akrotiri case would be to look into a more in-depth feasibility study for the technical setup and specify the exact equipment and their location required for each of the approaches, comparing different options. As part of the feasibility study it would make sense to conduct a cost benefit analysis comparing the capex and opex costs with the expected benefits for each stakeholder in order to decide on the measures which are worth investing in. While the responsible authorities and interested and competent stakeholders are assessed a detailed stakeholder analysis including a stakeholder specific needs assessment and willingness to contribute would be essential to be conducted. For conducting this feasibility study funding options and supporting programmes and schemes have to be identified and a project proposal submitted.

In addition to the technical and economic feasibility a legal and operational feasibility also has to be assured. As reports have mentioned illegal pumping activities a governance approach would need to be elaborated for providing just and equitable access to the benefits of the MAR system and sharing the costs accordingly. In this regard potential results might be expected from the upcoming PRIMA project AGREEMAR which looks into developing an agreement for the Akrotiri region to share the benefits among the different stakeholders.

4.2.7 Further MAR sites of interest

This report has focussed on the Akrotiri case. In the interactions with the stakeholders in the region there were two main sites of interest: Akrotiri basin and Germasoyeia basin. The former was selected as it has a running MAR system similar to the setup in Ezousas based on treated effluents and the potential applicability of the SMART Control approach could directly be assessed and discussions with stakeholders could be held at a more specific level. However, Germasoyeia is more interesting for the local stakeholders (WDD) in regards to looking into optimising the MAR system which is based on infiltration of surface water from the Germasogeia reservoir. This MAR system is also used for securing drinking water supply and should thus also be considered in further works in this field.

In addition to the two sites many other aquifers in Cyprus are overexploited and could possibly be assessed for improved MAR operation. Many aquifers are in the coastal zone and suffer from overexploitation and sea water intrusion. Possibly many of the tools on the INOWAS platform could be useful for assessing MAR feasibility.

It was also brought up in the meetings with the stakeholders that there are further sites in Cyprus, which could be explored for their suitability for MAR in the light of having the assessment and modelling tools at hand. Initial studies showed that various aquifers in Cyprus are facing problems related to overexploitation and thus could potentially look into MAR. Among these sites specifically mentioned were Kokkinochoria, Kiti, Peyeia, Polis Chrysochou and also the various aquifers connected to Cyprus biggest catchment Troodos. It was decided that the general assessment of these sites would not be covered in detail in this report but the second replication mission to Cyprus at the end of the project would conduct site visits for assessing the general needs regarding MAR setups. According to information from the WDD (Figure 13), various aquifer are observed to have been overexploited very strongly over a period of more 20 years with a ratio of over pumping to recommended extraction higher than 1 and have capacities for being recharged. (WDD 2019)

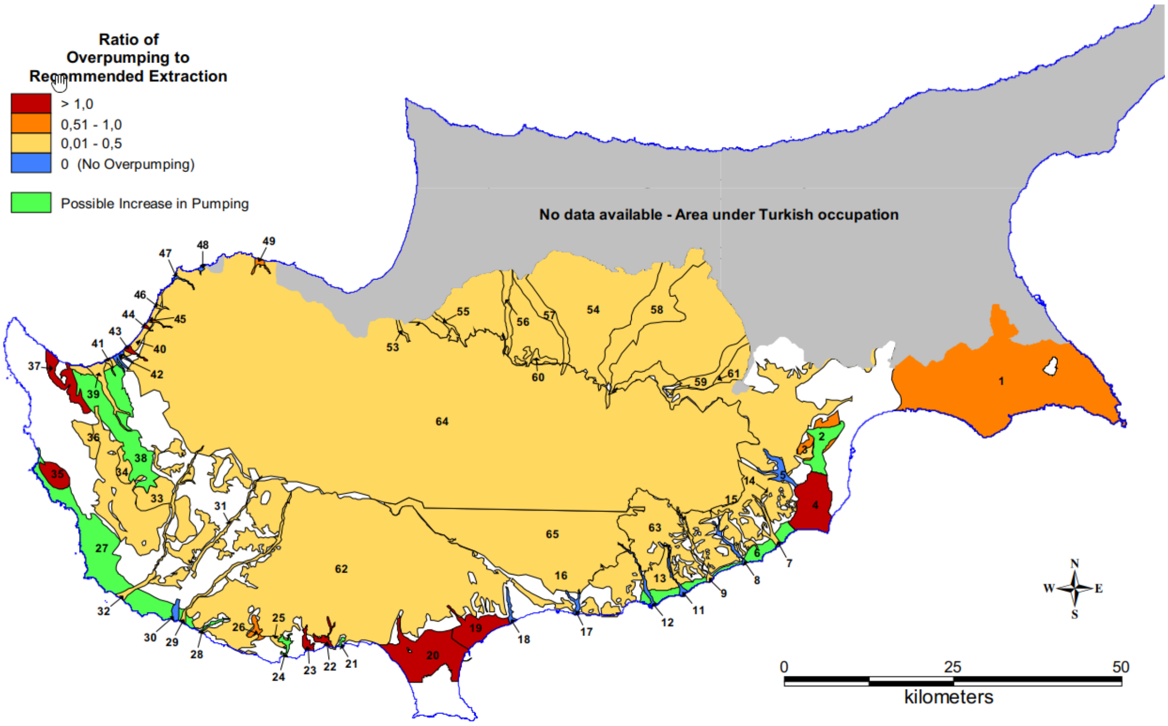


Figure 13. Aquifers of Cyprus – Ratio of Overpumping to Recommended Extraction (Georgiou 2002)

Sites with very strong over pumping >1 are: 4: Kiti Perivolia, 19: Lemesos Town (Garyllis), 20: Aktrotiri, 22: Paramali, 23: Avdimou, 35: Pegeia Limestone, 37: Androlikou Limestone, 43: Argaka – Makounta Riverbed, 44: Xeropotamos Riverbed

Sites with strong over pumping of 0,51 – 1,0 are: 1: Kokkinochoria, 3: Aradippou Gypsum,
26: Pissouri West Gypsum, 45: Gialia Riverbed, 49: Pyrgos

Several of these and other suggested sites were visited during the second replication mission for having first hand impressions. These were Kokkonochoria area, Dipotamos reservoir, Western Mesaoria basin, Pegeira Limestone, Mavrokolympos reservoir, Argaka – Makounta riverbed, Evretou Damn, Adrolikou Limestone, Xeropotamos riverbed and Asprokemnos Damn.

In the visit to Kokkinochoria the situation in Ormidia, Liopetri, Agia Napa, Paralimni and Deryneia region assessed. While the first two regions seemed to be in urgent need of groundwater recharge the latter three seemed to have sufficient groundwater. An interview held with the operator of the waste water treatment plant in Paralimni for assessing the availability of treated waste water for MAR as groundwater level in this region seemed sufficiently saturated (Figure 8). The operator mentioned that currently all the treated water is being used for direct irrigation and he does not see any scope for providing additional water for MAR. He further suggested to contact the sewage board at Paralimni for further discussing about the policy of distribution of treated waste water, which was though not possibly to be organised during the mission.

In general, none of the assessed additional sites apart from Germasogeia and possibly Kokkinochoria were assessed to be suitable for improving MAR systems on the first glance. While various factors like the general requirement for more, better and timely varying requirement of water, current status of the aquifer, the potential availability of water for infiltration seemed favourable for MAR solutions in some cases, other factors like the factual availability of water, the geological suitability and the assumed resources involved in setting MAR systems seemed rather not to be in favour. The first glance assessments are planned to be further assessed in detail in upcoming project activities in a follow up project (AGREEMAR).

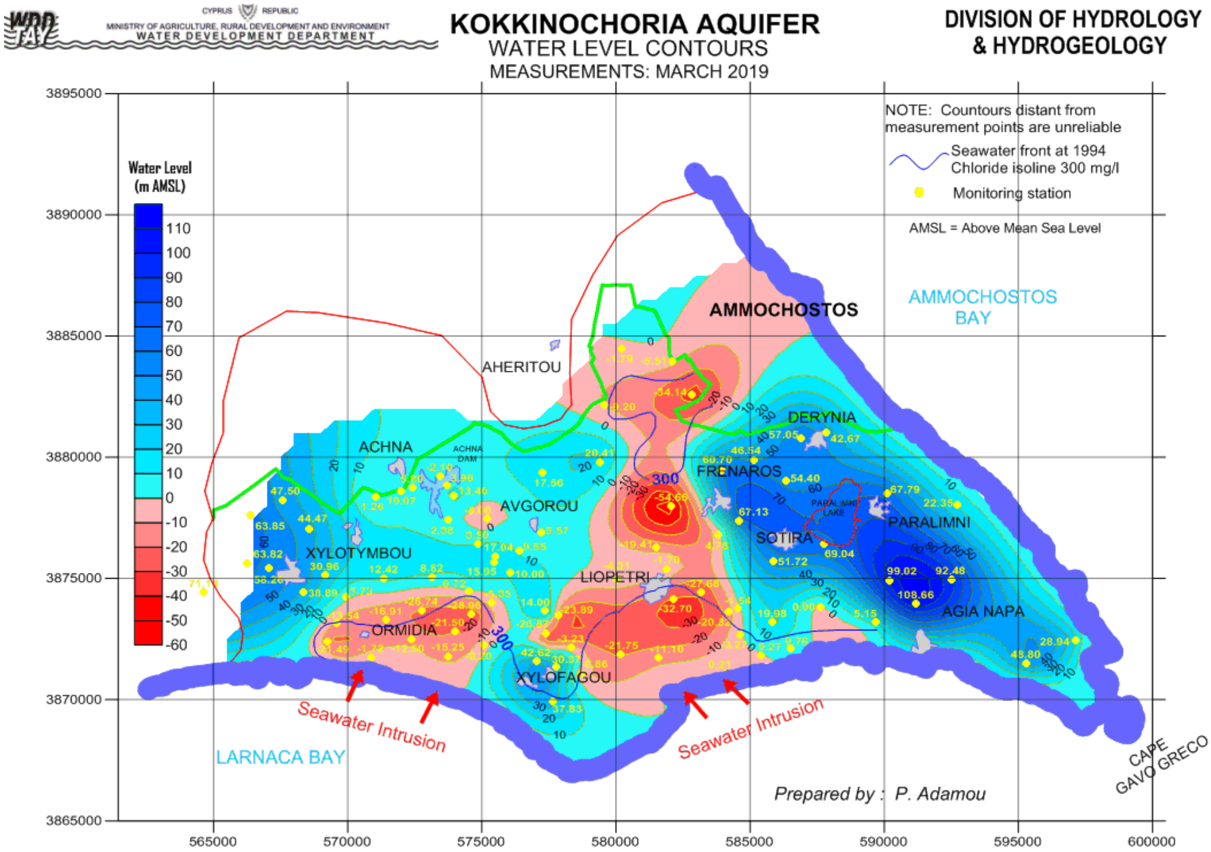


Figure 14. Groundwater level and salinity at Kokkinochoria (WDD 2019)

5 CONCLUSIONS

In the context of this report, two promising new locations close to the project sites were identified and further analysed for their replication potential of a web-based real-time monitoring and control system in combination with risk assessment and management tools—the SMART-Control approach: the Akrotiri basin in Cyprus and the Public Market of Afogados in Recife, Brazil. At both replication sites, it is found that the implementation of the SMART-Control approach could help to sustainable manage the groundwater. Due to the different conditions and requirements at the two sites, different SMART-Control solutions are recommended:

At the location of the public market of Afogados, Recife many of the necessary infrastructure and prerequisites for a MAR site are in place (e.g. rainwater collection system installed on large roofs, cistern for rainwater storage, wells etc.). The local authority CSURB, in charge of the market management in Recife, is interested in the installation and use of a MAR facility to increase local water security, however, a lack of information, accurate guidance and certainty of success hinders an actual MAR implementation. Identified key risks associated with a potential MAR operation include health impacts, microbial contamination of the groundwater, reduced recovery efficiency due to poor quality of native groundwater and reduced availability of roofwater. Based on stakeholder workshops and site assessments, the application of the following specific SMART-Control solutions showed particular promising in reducing these site-specific MAR associated risks: T10 (Real time monitoring and control) for real-time detection of exceeded quality limits to reduce damages, the combination of T10 with T03 (Numerical groundwater modelling using MODFLOW) and T20 (Real time numerical modelling) for a better understanding of contamination risks and T07 (Specific Scenario Analyzer) for ensuring an optimal operation and set-up of the system adapted to future development, increasing the long-term economic sustainability of the system.

At the Akrotiri basin in Cyprus, a MAR system is already in place, but further potential in managing and evaluating the implementation of the technology was identified. Risks that threaten the successful operation of the MAR facility are health impacts due to high nitrate and pathogen concentrations, seawater intrusion, and clogging of infiltration ponds. The following selection of SMART Control solutions has shown particular promising and is recommended for ensuring the continued success of the MAR system and for regaining stakeholder trusts: The combination of T10, T19 (Groundwater residence time tool) and T15 (Quantitative microbial risk assessment tool) is well suited to ensure the provision of safe water for agricultural irrigation. The real-time modelling approach along with T07 also provide ideal solutions to optimise water quality during water reuse and to make the right decisions for future developments. The INOWAS platform with its easy-to-use management, assessment and forecasting tools can perfectly contribute to solving site-specific risks and needs.

The next steps for a successful implementation of the SMART-Control approach at the replication sites mentioned above include conducting an in-depth feasibility study together with a Cost-Benefit-Analysis and the identification of funding options.

The transfer approach used in this report, presented in chapter 3, is applicable to other sites to determine the application potential of the SMART-Control approach beyond the project activities. The description and value proposition of the approach presented in chapter 2 supports the initial assessment. In this sense, the authors also recommend the use of the more detailed Transfer Guide (Pettenati 2022), developed within the SMART-Control project, for step-by-step guidance on the use of the SMART-Control approach.

6 REFERENCES

Achilleos, M.; Tzoraki, O.; Antunes, M. (2019): Monitoring of the managed aquifer recharge (MAR) system by treated wastewater reuse in Akrotiri Limassol Cyprus. Conference proceedings: ISMAR 10: International Symposium on Managed Aquifer Recharge. Available online at https://www.researchgate.net/publication/332523124_MONITORING_OF_THE_MANAGED_AQUIFER_RECHARGE_MAR_SYSTEM_BY_TREATED_WASTEWATER_REUSE_IN_AKROTIRI_LIMASSOL_CYPRUS?channel=doi&linkId=5cb96ad5299bf120976fa14d&showFulltext=true.

Cabral, Jaime J.S.P.; Farias, Veronilton P.; Sobral, Maria do C.; Paiva, Anderson L.R. de; Santos, Renata B. (2008): Groundwater management in Recife. In *Water International* 33 (1), pp. 86–99. DOI: 10.1080/02508060801927648.

Cabral, Jaime J.S.P.; Santos, S.M.d.; Demetrio, J.G.A.; Montenegro, S.M.G.L. (2000): A groundwater information system for Recife metropolitan region. Management Information Systems 2000, Lisboa, Portugal.

Cary, Lise; Petelet-Giraud, Emmanuelle; Bertrand, Guillaume; Kloppmann, Wolfram; Aquilina, Luc; Martins, Veridiana et al. (2015): Origins and processes of groundwater salinization in the urban coastal aquifers of Recife (Pernambuco, Brazil): A multi-isotope approach. In *The Science of the total environment* 530-531, pp. 411–429. DOI: 10.1016/j.scitotenv.2015.05.015.

Chakrabarti, R.; Semmling, E.; Bunsen, J.; Conrad, A.; Campos, J.C.S.; Lhoir, J. (2017): Lessons learned from trust building activties. Deliverable 4.3 of the HORIZON 2020 Project SUBSOL. Available online at http://www.subsol.org/uploads/deliverables/D4.3_revised_version_.pdf.

Christodoulou, G. I.; Sander, G. C.; Wheatley, A. D. (2007): Characterization of the Ezousas aquifer of SW Cyprus for storage–recovery purposes using treated sewage effluent. In *Quarterly Journal of Engineering Geology and Hydrogeology* 40 (3), pp. 229–240. DOI: 10.1144/1470-9236/06-031.

Coelho, Victor Hugo R.; Bertrand, Guillaume F.; Montenegro, Suzana M. G. L.; Paiva, Anderson L. R.; Almeida, Cristiano N.; Galvão, Carlos O. et al. (2018): Piezometric level and electrical conductivity spatiotemporal monitoring as an instrument to design further managed aquifer recharge strategies in a complex estuarial system under anthropogenic pressure. In *Journal of environmental management* 209, pp. 426–439. DOI: 10.1016/j.jenvman.2017.12.078.

Conrad, A.; Heim, R. (2022): SMART-Control Deliverable D7.5: Two replication workshops at transfer sites. Available online at http://smart-control.inowas.com/wp-content/uploads/D7.5-Two-replication-workshops-at-transfer-sites_final.pdf.

Costa, W.; Manoel Filho, J.; Santos A. C.; Brito, A. M.; Souza, F. J.; Lopes, A. V. (1998): Estudo hidrogeológico da região metropolitana do Recife: Hydrogeology study of the RMR (Tech. Rep. Recife: Projeto HIDROREC - Convenio IDRC-UFPE/FADE).

Dillon, Peter (2005): Future management of aquifer recharge. In *Hydrogeol J* 13 (1), pp. 313–316. DOI: 10.1007/s10040-004-0413-6.

Foster, Stephen; Hirata, Ricardo; Eichholz, Michael; Alam, Mohammad-Faiz (2022): Urban Self-Supply from Groundwater—An Analysis of Management Aspects and Policy Needs. In *Water* 14 (4), p. 575. DOI: 10.3390/w14040575.

Georgiou, A. (2002): Assessment of Groundwater resources of Cyprus, Water Development Department.

Glass, Jana (2019): New advances in the assessment of managed aquifer recharge through modelling. PhD thesis, Technische Universität Dresden, Dresden. Available online at https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-360564.

Glass, Jana; Jain, Ramandeep; Junghanns, Ralf; Sallwey, Jana; Fichtner, Thomas; Stefan, Catalin (2018): Web-based tool compilation of analytical equations for groundwater management applications. In *Environmental Modelling & Software* 108, pp. 1–7. DOI: 10.1016/j.envsoft.2018.07.008.

Glass, Jana; Junghanns, Ralf; Schlick, Robert (2022a): SMART-Control Deliverable D4.5: Web-based real-time modelling - Implementation of the web-based prediction analysis tool on the INOWAS platform: Technische Universität Dresden. Available online at http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_5.pdf.

Glass, Jana; Junghanns, Ralf; Schlick, Robert; Stefan, Catalin (2020): SMART-Control Deliverable D4.2: Web-based real-time monitoring and control capabilities -Implementation of web-based real-time monitoring tool on INOWAS platform: Technische Universität Dresden. Available online at http://smart-control.inowas.com/wp-content/uploads/2020/06/SMART_Control_D4_2.pdf.

Glass, Jana; Junghanns, Ralf; Schlick, Robert; Stefan, Catalin (2022b): The INOWAS platform: A web-based numerical groundwater modelling approach for groundwater management applications. In *Environmental Modelling & Software* 155, p. 105452. DOI: 10.1016/j.envsoft.2022.105452.

Hérivaux, C.; Panagiotou, K.; Sprenger, C.; Stefan, C. (2022): SMART-Control Deliverable D7.4: Value of information associated to MAR real-time monitoring and control. Available online at http://smart-control.inowas.com/wp-content/uploads/SMART-Control_D7_4.pdf

Hochstrat, R.; Kazner, C. (2009): Case study report Cyprus. Flexibility in coping with water stress and integration of different measures.

IGRAC (2015): Global Inventory of Managed Aquifer Recharge (MAR) Schemes. International Groundwater Resource Assessment Centre. Available online at https://ggis.un-igrac.org/ggis-viewer/viewer/globalmar/public/default.

INMET (2014): Temperatura Máxima (°C) (in Portuguese). 1961–1990. Edited by Brazilian National Institute of Meteorology (INMET). Brazil. Available online at http://sisdagro.inmet.gov.br/sisdagro/app/balancoHidrico, updated on 6/28/2022, checked on 6/28/2022.

INOWAS (2022): INOWAS Platform - Free web-based modeling platform for planning, management and optimisation of Managed Aquifer Recharge. Edited by Technische Universität Dresden. Research Group INOWAS. Available online at https://inowas.com/, checked on 7/28/2022.

Leite, Betty (2000): Preliminary Evaluation of Aquifer Storage and Recovery in the Recife Metropolitan Region, Pernambuco, Brazil. In *Águas Subterrâneas*.

Luna, Rejane Maria Rodrigues de; Garnés, Silvio Jacks dos Anjos; Da Cabral, Jaime Joaquim Silva Pereira; dos Santos, Sylvana Melo (2017): Groundwater overexploitation and soil subsidence monitoring on Recife plain (Brazil). In *Nat Hazards* 86 (3), pp. 1363–1376. DOI: 10.1007/s11069-017-2749-y.

Milnes, Ellen (2011): Process-based groundwater salinisation risk assessment methodology: Application to the Akrotiri aquifer (Southern Cyprus). In *Journal of Hydrology* 399 (1-2), pp. 29–47. DOI: 10.1016/j.jhydrol.2010.12.032.

Montenegro, Suzana M. G. L.; Montenegro, Abelardo A. de A.; Cabral, Jaime J.S.P.; Cavalcanti, Giancarlo L. (2006): Intensive exploitation and groundwater salinity in Recife coastal plain (Brazil): monitoring and management perspectives. In *1st SWIM-SWICA - Joint Salt Water Intrusion Conference*. Available online at http://www.swim-site.nl/pdf/swim19/pages_079_088.pdf.

NRMMC; EPHC; NHMRC (2009a): Australian guidelines 23 for water recycling: managing health and environmental risks (phase 2). Stormwater harvesting and reuse. Available online at https://www.waterquality.gov.au/sites/default/files/documents/water-recycling-guidelines-stormwater-23.pdf, checked on 7/19/2022.

NRMMC; EPHC; NHMRC. (2009b): Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2). Managed Aquifer Recharge. Available online at http://www.waterquality.gov.au/guidelines/recycled-water, checked on 7/19/2022.

Pettenati, Marie; Glass, Jana (2022): SMART-Control solutions workflow for the transfer of the approach. Milestone D7.2 of the SMART-Control project.

SBLA (2022): Sludge & Waste Water quality and quantity control | SBLA | Sewerage System of Limassol – Amathus. Sewerage Board of Limassol – Amathus. Available online at https://www.sbla.com.cy/en/content/sludge-waste-water-quality-and-quantity-control, updated on 7/14/2022, checked on 7/14/2022.

Silva, Thyego R.; Leitão, Teresa E.; Lima, Mariucha M.C.; Martins, Tiago N.; Oliveira, Manuel M.; Albuquerque, Mateus S.C.; Costa, Waldir D. (2021): Hydrogeochemistry and isotope compositions of multi-layered aquifer systems in the Recife Metropolitan Region, Pernambuco (NE Brazil): An integrated approach using multivariate statistical analyses. In *Journal of South American Earth Sciences* 109, p. 103323. DOI: 10.1016/j.jsames.2021.103323.

Sprenger, Christoph; Rustler, Michael; Schlick, Robert; Junghanns, Ralf; Glass, Jana (2021): SMART-Control Deliverable D4.3: Web-based risk assessment tools - Development and implementation of a web-based tool for QMRA: Kompetenzzentrum Wasser Berlin. Available online at http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_3.pdf.

Stefan, Catalin; Ansems, Nienke (2018): Web-based global inventory of managed aquifer recharge applications. In *Sustain. Water Resour. Manag.* 4 (2), pp. 153–162. DOI: 10.1007/s40899-017-0212-6.

Stefan, Catalin; Sprenger, Christoph; Rustler, Michael; Schlick, Robert; Junghanns, Ralf (2021): SMART Control D4.1: Web-based real-time monitoring and control capabilities - Development and implementation of a web-based tool for the calculation of groundwater hydraulic residence time. Available online at http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_1.pdf.

WBG (2020): World Bank Climate Change Knowledge Portal: Brazil - Current Climate. Edited by World Bank Group. Available online at https://climateknowledgeportal.worldbank.org/country/brazil/climate-data-historical, checked on 6/28/2022.

WBG (2022): World Bank Climate Change Knowledge Portal: Cyprus - Current Climate. Edited by World Bank Group. Available online at https://climateknowledgeportal.worldbank.org/country/cyprus/climate-data-historical, checked on 7/14/2022.

WDD (2019): Qualitative and quantitative status of groundwater. Maps of ground water contour of underground water level (iso piezometric maps) of coastal aquifers. Edited by Ministry of Agriculture, Rural Development and Environment, Republic of Cyprus. Water Development Department. Cyprus. Available online at http://www.moa.gov.cy/moa/wdd/Wdd.nsf/All/8F2E8B15E9B03742C22583D20031DD9B?OpenDocument, checked on 7/5/2022.

WHO (2011): Guidelines for drinking-water quality. 4th edition: Geneva.