WaterJPI project

SMARTControl

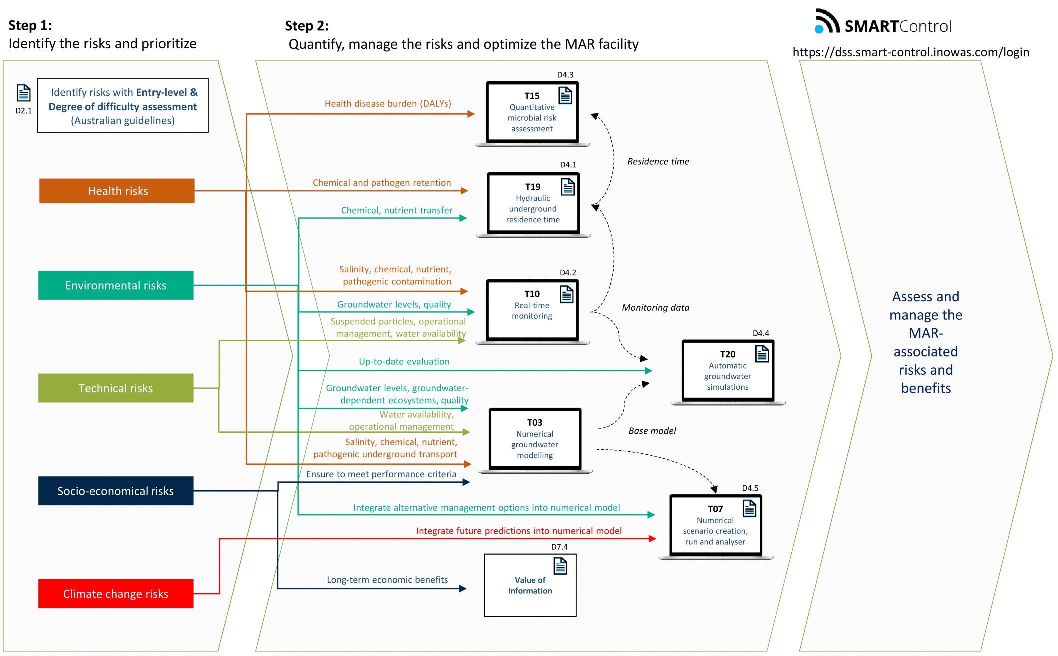
Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge (MAR) applications

Milestone D7.2

SMART-Control solutions workflow for the transfer of the approach

Author

Marie Pettenati (BRGM), Jana Glass (TUD)



https://www.smart-control.inowas.com

July 2022

Project funded by:

Milestone D7.2

SMART-Control solutions workflow for the transfer of the approach

Short summary

The present report describes the general transfer framework of the developed SMART-Control technology as a generic document to promote the SMART-Control approach and solution. The SMART-Control solutions workflow consists of two steps: first the MAR-associated risks are identified and prioritized. As a second step, the user is guided to one of the six specific web-based tools developed to quantify and manage the risks as well as to optimize the MAR facility. In addition, one methodology to quantify the long-term economical benefits arising from applying the SMART-Control approach based on the Value of Information methodology is presented.

Work package	WP7. Demonstration of approach and developed tools
Deliverable number	Milestone 7.2
Partner responsible	BRGM
Deliverable author(s)	Marie Pettenati (BRGM), Jana Glass (TUD)
Quality assurance	Catalin Stefan (TUD)
Planned delivery date	June 2022
Actual delivery date	July 2022
Dissemination level	PU (Public)
Citation	Pettenati, M., Glass, J. 2022. SMART-Control solutions workflow for the transfer of the approach. Milestone 7.2 of the SMART-Control project.

ABSTRACT

The SMART-Control solutions workflow is dedicated to guide the user in order to enhance MAR system operations and assess MAR associated risks and benefits. There are several types of MAR systems where the associated risks can arise during the planning, implementation and operation of a MAR facility. In general, operational, regulatory, business, human health, and environmental risks can occur and should be identified already during the planning and implementation stage to apply preventive measures and secure the safe and reliable operation of a MAR facility.

The solution proposed by the SMART-Control project combines the identification and characterization of MAR-associated risks with the application of the innovative web-based INOWAS DSS platform (www.inowas.com). The approach consists of an in-situ real-time monitoring system and a web-based platform for control, modelling and prediction. All developed tools can be used for free after user registration. In addition, a methodology to economically evaluate benefits brought by the SMART-Control solution was developed.

The SMART-Control workflow includes 2 Steps:

The first step comprises the identification and prioritization of the MAR associated risks based on the Australian guidelines. The risks addressed by SMART-Control include health, environmental, technical, social-economical and climate change risks (for details see Figure 1 the SMART-Control tool workflow).

After identification of the site-specific risks, the user is guided in a second step to the SMART-Control tool suit to quantify and manage the individual risks as well as to optimize the MAR facility. The developed web-based tool suit enables:

- to quantify the underground residence time,
- to conduct a quantitative microbial risk assessment,
- to setup a real-time monitoring system,
- to setup, run and evaluate a groundwater flow (and transport) model,
- to generate automatic groundwater simulations,
- to conduct a scenario analysis considering various management and climate change, and
- to evaluate the long-term economic benefits arising from using the SMART-Control solutions with the Value of Information methodology (not implemented on the web-based INOWAS platform).

The SMART-Control solutions workflow is dedicated to synthesis the way to use the developed solutions and to guide the user to enhance a MAR system operation and assess MAR-associated risks and benefits. The developed SMART-Control workflow helps to identify, prioritize the MAR-associated risks and as a second step to quantify and manage those risks. In that way, the occurring risks can be minimized, ensuring a reliable operation of the MAR facility.

CONTENT

FIGURES

1 THE SMART-CONTROL SOLUTION GUIDELINES

1.1 INTRODUCTION

1.1.1 MAR Decision Support Systems

MAR systems are resilient solutions to fight against climage change impact regarding water scarcity in terms of quantity and quality. Managing MAR systems is a challenge regarding the complexity of the natural system as such hydrosystems are constrained by climatic conditions and operational needs constantly evolving with time. The SMART-Control tool suit is dedicated to reduce the risks in the application of sustainable groundwater management techniques by developping specific tools dedicated to ensure the optimization of the management of a MAR system and water reuse related applications. During MAR life-time, the risks can arise through different pathways. Main risks ecountered by an operator are linked to water quality (pathogens, trace organic compounds, etc.) and a deacrease of MAR yield by clogging. The SMART-Control approach provides an innovative, real-time monitoring in combination with risk assessment and management tools to give an economic and environmental added value to the MAR system. The core of the SMART-Control approach consists in the web-based INOWAS platform, where various analytical and numerical tools for MAR assessment are compiled and enhanced with specific features to assess, monitor and control the occurring processes at MAR facilities (Glass et al., 2022b, 2018).

1.1.2 SMART-Control solutions for what and who?

The main objective of SMART-Control is to reduce the risks associated with the application of sustainable groundwater management techniques by developing an innovative web-based real-time monitoring in combination with risk assessment and management tools. The system consists of an in-situ real-time monitoring system and a web-based platform for control, modeling and forecasting. For this, the existing INOWAS platform was enhanced with new features.

Measurable Performance Indicators (PI) are used to assess risks focused on artificial groundwater recharge applications, such as health risks from microbial contamination, environmental risks, low recovery rates, clogging and short residence times.

The SMART-Control tool suit can be used in the planning, construction, and operation phase of a MAR system to scientifically identify, quantify and assess the site-specific MAR-associated risks and benefits.

1.2 DESCRIPTION OF SMART-CONTROL SOLUTIONS WORKFLOW

The SMART-Control solutions workflow (Figure 1) is dedicated to synthesis the way to use the developed SMART-Control solutions and to guide the user through to enhance the MAR system operation and assess MAR associated risks and benefits. There are several types of MAR systems and the associated risks can arise during the planning, implementation and operation of a MAR facility. In general, operational, regulatory, business, human health, and environmental risks can occur and should be identified already during the planning and implementation stage to apply preventive measures and secure the safe and reliable operation of a MAR facility. Unfortunately, lack of regulatory frameworks can hinder the implementation of MAR schemes (Fernandez Escalante et al., 2020; Page et al., 2020). The solution to promote safe use of MAR system is to ensure a reliable MAR implementation and operation by reducing the risk regarding human health and environmental aspects. Moreover, economic analysis of sustainable MAR operation conditions has to be included. Imig et al., 2022 point out that MAR risk management should include health, environmental, technical, economic and social risks.

The solution proposed by the SMART-Control project combines the identification and characterization of MAR-associated risks with the development of an innovative web-based, real-time monitoring system. The approach consists of an in-situ real-time monitoring system and a web-based platform for control, modelling and prediction.

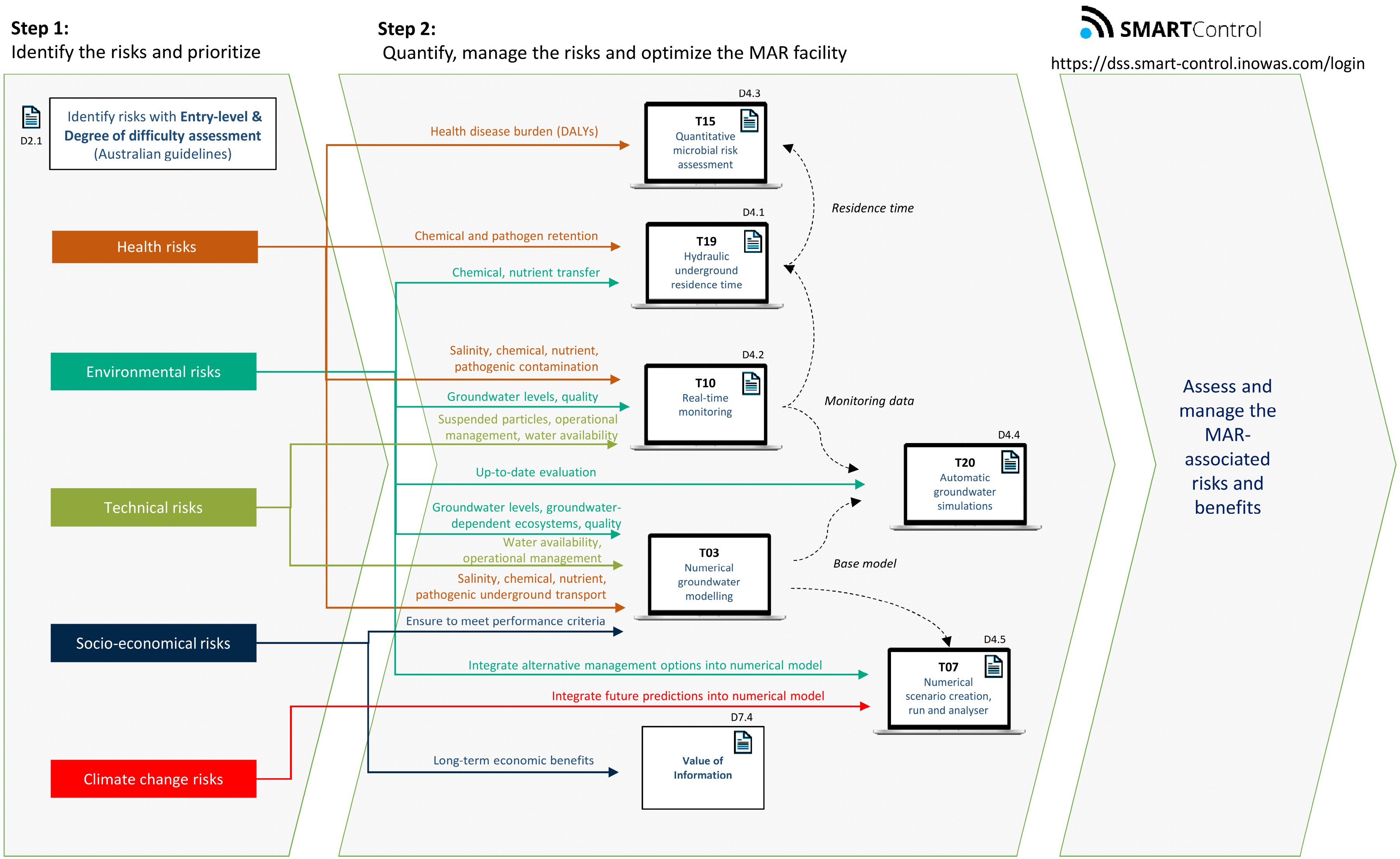


Figure 1. SMART-Control Solutions workflow to assess and manage MAR associated risks and benefits.

The **first step** of the SMART-Control workflow consists in the identification and prioritization of the risks using the integrated framework for assessing and managing MAR-associated risks and benefits (SMART-Control Deliverable 2.1). Five major risks associated to the implementation and operation of a MAR system that can be reduced using the SMART-Control tools suit were identified: health risks, environmental risks, technical risk, socio-economical risks and climate change risks.

After priorizing each kind of risk depending on the specific MAR system, the user is guided to the SMART-Control **Step 2** to choose the suitable web-based tool adapted to quantify, manage or reduce the associated risk. The tools can be accessed on the INOWAS platform (www.inowas.com), where also comprehensive tool documentations are available. The SMART-Control tool suit encompasses the following tools:

- Quantitative Microbial Risk Assessment (QMRA) is recognized as an evidence-based approach to minimize water-related infectious diseases (Deliverable 4.3, INOWAS Tool 15 "Quantitative microbial risk assessment", www.inowas.com). The QMRA tool includes hazard identification, exposure assessment, dose analysis and risks characterisation. The health risk can be assessed for selected reference pathogens such as bacterial, protozoan and viral pathogens for different hydraulic residence times during MAR.

- In order to ensure compliance with national regulations concerning trehshold values for regulated contaminants (trace metals, nitrates, trace organics, pathogens, …), calculation of subsurface travel time from the area of recharge to the point of abstraction during MAR is a critical parameter to ensure sufficient attenuation for hygienic parameters and other undesired substances (Deliverable 4.1, INOWAS Tool 19 "Groundwater residence time", www.inowas.com). With the help of Tool 19, health risks including chemical and pathogen retention as well as environmental risks such as nutrient and chemical underground transfer can be assessed.

- The real-time monitoring tool (Deliverables 3.1 and 4.2, INOWAS Tool 10 "Real-tme monitoring", inowas.com), enables the import of third-party monitoring data into the INOWAS platform and facilitates the operational management of MAR sites by collecting real-time data from the in-situ site-specific observation systems. The tool comprises data collection, pre-processing and visualisation to help identify the occurrence of health, environmental, techincal and socio-econimical risks at MAR facilities.

- The numerical groundwater modelling and optimization tool (INOWAS Tool 3 "Numerical groundwater modelling and optimization", inowas.com) can be used with the help of a hydrogeological modeler to setup a new groundwater flow (and transport) model based on MODFLOW for a study area in order to better understand the local groundwater flow system or as a basis for further scenario analysis and real-time modelling. A groundwater flow model is useful to assess health, environmental, technical and socio-economic risks of a MAR facility.

- The real-time modelling tool allows a user to extend an existing numerical groundwater flow model with new sensor data. New stress periods are automatically added to the base model using either constant values or sensor data from the last time step of the base model up until the date, the model instance is created and run (Deliverable 4.4, INOWAS Tool 20 "Real-time modelling", inowas.com). Currently, the calculation process must be initiated manually but new data can be automatically imported from the INOWAS Tool 10 "Real-time monitoring". The tool is especially helpful to assess the MAR facility in almost real-time and conduct up-to-date evaluations of the environmental risks.

- For the optimisation of MAR system operation, the Scenario analysis tool can be used to create scenarios based on an existing numerical groundwater flow model (Deliverable 4.5, INOWAS tool 7, inowas.com). It serves to evaluate various management solutions or to integrate climate, land use or urban change projections into the numerical model.

- A methodology was developed to identify and quantify the long-term technical risk and socio-economic concequences of potential risks via the Value of Information study (VoI). It helps to assess the need and benefits of implementing robust monitoring solutions to manage MAR systems regarding the risks associated to damages occuring without this solutions (Deliverable 7.4).

Going though SMART-Control Steps 1 to 2 is the best way to assess and manage a MAR facilities associated risks and benefits. This approach can be iterative: go back to Step 1 again in order to improve the management of MAR facilities and have robust feedback on actions that were made regarding the major risks identified during the first iteration and so on.

The next chapter of this document is dedicated to shortly and in a generic way describe the SMART-Control suit of tools that compose the SMART-Control methodology to reduce the risks associated to the application of sustainable groundwater management techniques such as MAR systems.

2 SMART-CONTROL SUITE OF TOOLS

2.1 STEP 1. INITIAL RISK IDENTIFICATION

SMART-Control Step 1 assessses the MAR-associated risks based on recommendations of international guidelines. It helps to clarify which actions or further investigations are required to reduce the uncertainty of risks and, if necessary, to implement remediation measures. Considering different types of MAR systems, several hydroclimatic conditions as well as many objectives of water uses after MAR, the SMART-Control Step 1 shows how site-specific hazards can be assessed to varying degrees depending upon the level of risk assessed at each project development stage (pilot stage to operational stage).

Based on recommendations of international guidelines (Alcalde-Sanz and Gawlik, 2017; NRMMC-EPHC-NHMRC, 2008; WHO, 2009, 2011), SMART-Control Step 1 identifies and characterizes potential hazards that may cause risks to human health and the environment through a two steps approach. At pilot scale, a MAR operator has to start with the entry-level assesment and with the degree of difficulty assessment. At operational MAR sites, the maximal risk assessment can be applied.

The risk assessment at MAR sites are useful to assist in clarifying which actions or further investigations are required to identify and reduce the uncertainty of risks and to implement remediation measures, if necessary. These risks can be reduced but never entirely eliminated through high quality and more detailed aquifer characterisation. Monitoring can play a key role in the risk assessment and management process. Operational monitoring systems are of particular importance as they provide timely information for use as critical control points in the risk management plan, often includes supervisory control and data acquisition and web-based reporting systems that provide near real-time data (NRMMC-EPHC-NHMRC, 2008).
Additional monitoring at the MAR sites e.g. for specific contaminants or on a more regular basis is identified as a measure to reduce the uncertainty of risks (Sprenger et al., 2019).

- ➔ *For more information see Deliverable 2.1 (Sprenger et al., 2019).*

2.3 STEP 2. QUANTIFY, MANAGE AND OPTIMIZE THE RISKS

Initial risk assessment clarifies which actions or further investigations are required to reduce the uncertainty of risks and helps to reach SMART-Control Step 2 in order to ensure water quality complience with national regulation regarding health and environmental risks and to be able to evaluate the technical risks and their socio-economical consequenses. Several monitoring and modeling tools as well as a methodology to evaluate economically the measures to take have been developed in SMART-Control in order to decrease the potential damages caused by the lack of robust online monitoring and modelling systems dedicated to MAR operations. In the following sections, an overview of the developed SMART-Control tools is given. Except the VoI methodology, all tools have been implemented on the web-based INOWAS platform and can be, after free user registration, accessed and utilized free of charge using a standard web browser.

2.2.1 Quantitative microbial risk assessment

The tool T15: Quantitative microbial risk assessment (QMRA)– INOWAS helps to quantify the pathogen occurrence in source water and their removal by various treatment steps at MAR facilities by using a probabilistic approach. The interactive web-based QMRA tool supports the evidence-based risk assessment to minimize water-related infectious diseases. The risks caused by pathogenic microorganisms can be assessed which supports decision-making related to the microbial safety of water systems. The web-based QMRA tool was developed to support the implementation of QMRA through an interactive, easy-to-use, and guided webbrowser based application. The QMRA tool allows the quantification of pathogen occurrence in source water and their removal by various treatment steps and is based on a probabilistic risk assessment.

Due to the many preset parameters, microbial risks at sites with little known information can also be calculated. Based on the findings from the model, problem and risk areas can be identified and protective measures prepared. First step is to select input parameters: Inflow concentrations of the pathogen to the treatment scheme are entered as absolute minimum and maximum concentration per liter and are required for all pathogens that are included in the QMRA. Then, for each treatment process, the log10-removals for at least one of the three different pathogen groups (i.e. bacteria, protozoa, viruses) need to be defined. Pre-defined treatments are available in the web-platform tool. After selecting the required treatment steps it is necessary to enter Log Removal Values (LRV) for each pathogen and treatment step. Treatment steps can be combined to a treatment train or treatment scheme. All selected treatment trains will be considered in the QMRA calculation.
The number of exposures per year and the ingested volume per event can be defined as fixed value or by following a pre-defined distribution. There are eight pre-defined exposure scenarios from drinking water to irrigation water and domestic end-use.
The dose-response models are based on experimental data. The dose-effect relationships can be approximated for each pathogen by exponential binomial formulae or beta Poisson distributions. Parameters for each pathogen are taken from QMRAwiki (2016). Dose-response models are defined for the pathogens that are toggled active in the inflow concentration section. For all pathogens to be used for QMRA, the infection to illness factor and the disability-adjusted life years (DALY) per case need to be defined.
The results are presented in tables and made available for download in json and csv format.

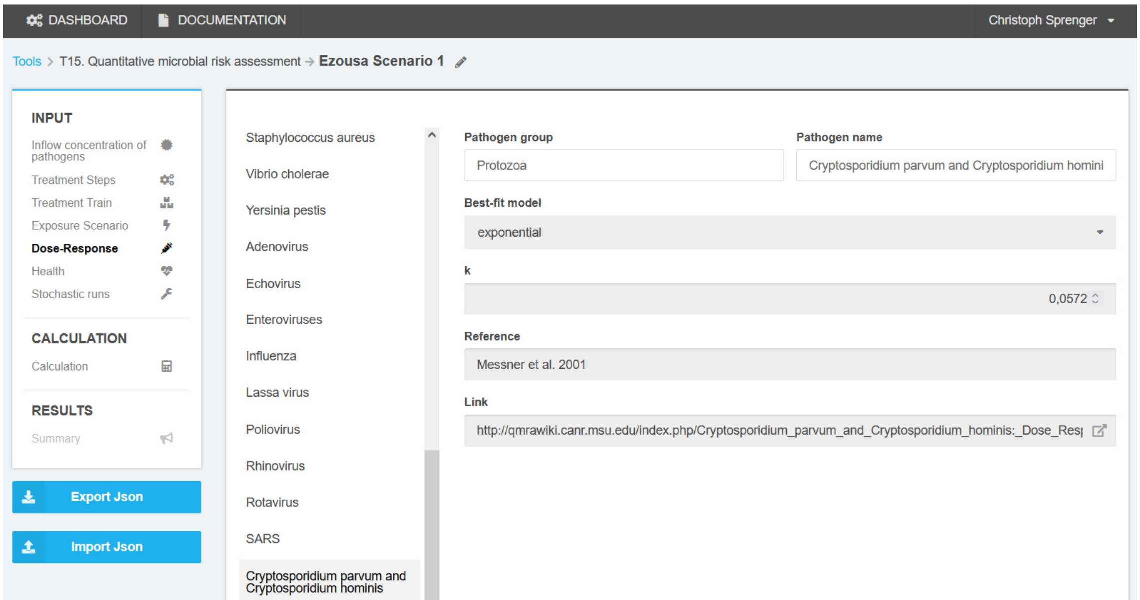


Figure 2. Screenshot of the definition of the dose-response relationship in the QMRA tool on the web-based INOWAS platform (Sprenger et al., 2021)

➔ *For more information see the SMART-Control Deliverable 4.3 (Sprenger et al., 2021)*

2.2.2 Groundwater residence time

The tool T19. Groundwater residence time – INOWAS) enables water utilities to estimate the groundwater hydraulic residence time at MAR sites by using temperature measurements in influent and recovered water.
Subsurface travel time from the area of recharge to the point of abstraction during MAR is a critical parameter to ensure sufficient attenuation for hygienic parameters and other undesired substances. The scientific background of the tool is rooted in the hypothesis that seasonal temperature variations in surface waters and abstraction wells can be used as potential tracers to estimate the groundwater hydraulic residence time during subsurface passage. At MAR sites, the groundwater temperature is directly influenced by seasonal temperature variations in the influent surface water. Under ideal conditions, these variations underlay a sinusoidal curve, with maximum values achieved in summer and lowest in winter.

This tool helps to determine groundwater hydraulic residence time (HRT) using seasonal temperature fluctuations observed in recharge water and MAR recovery wells. It represents a proxy for quick, cost-effective and reliable control of travel time during aquifer passage (Figure 3).

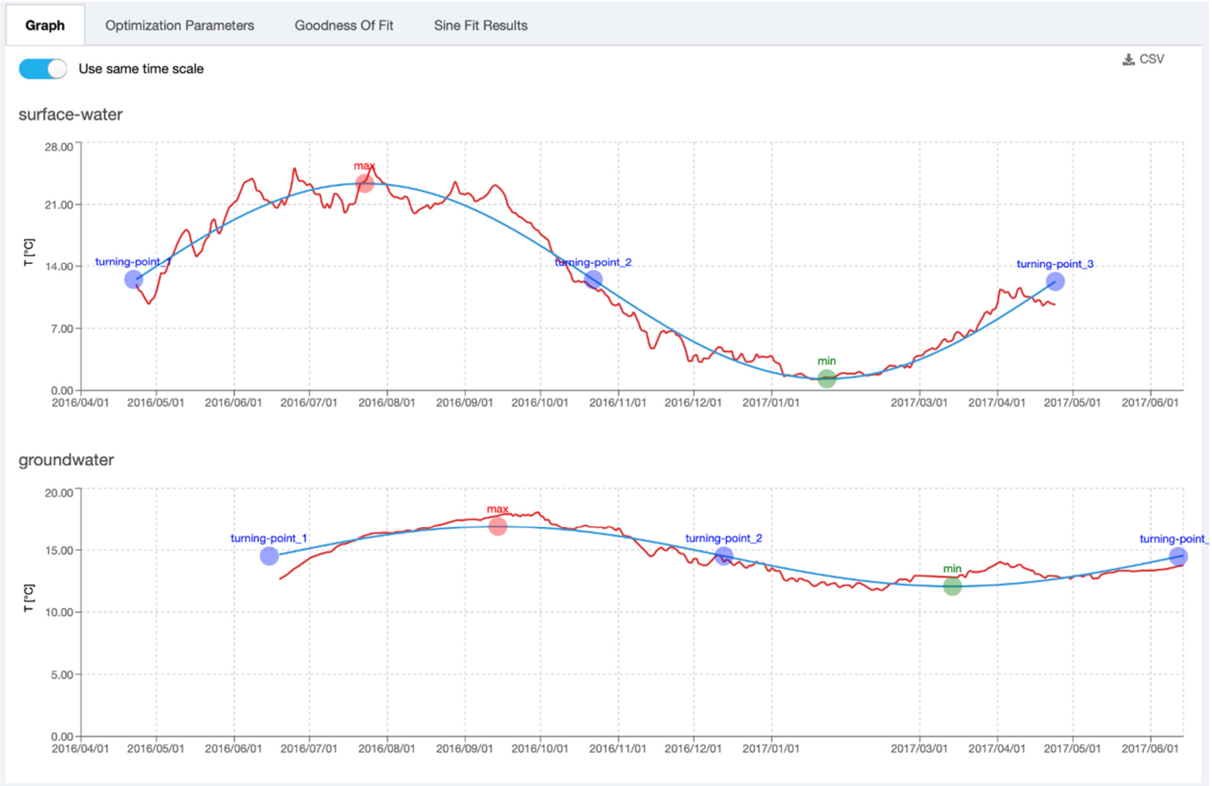


Figure 3. Calculation results: graphic visualisation of sine curve fitting with display of calculated min/max and turning points for surface water and groundwater time series

➔ *For more information, see the SMART-Control Deliverable 4.1 (Stefan et al., 2021)*

2.2.3 Real-time monitoring system

The web-based real-time monitoring tool (T10) facilitates the operational management of MAR sites by collecting real-time data from the in-situ site-specific observation system. The tool allows data collection, pre-processing and visualisation of (real-time) monitoring data to help identify the occurrence of risks at a MAR facility. The tool is divided into three main components (Figure 4): sensor setup, data processing and visualisation. Various data sources can be connected covering historical data (as CSV files) and real-time data (via FTP connection to SENSOweb, Prometheus). Real-time data is automatically updated as soon as new data is transmitted. The processing of the time series data covers value processing (e.g. filtering, mathematical operations) and time processing (resampling, filling of missing values). The visualisation allows the comparison of time series data of various sensors.

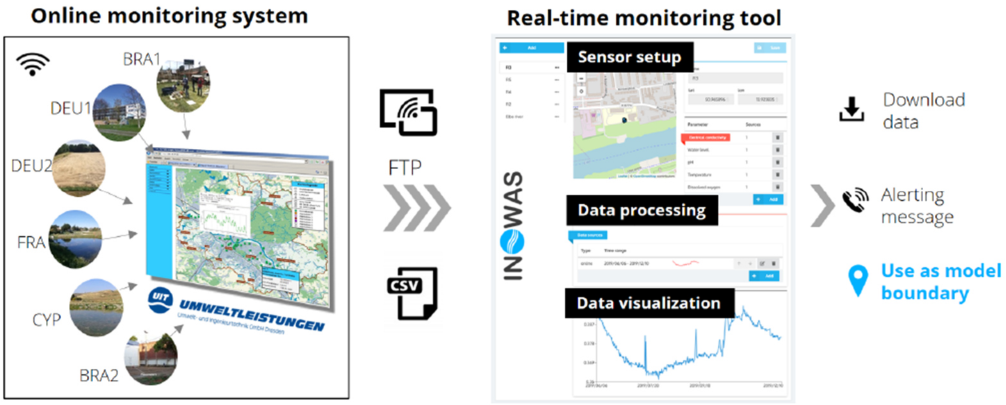


Figure 4. Concept of the real-time monitoring tool.

The developed real-time monitoring tool allows an easy observation of real-time data at MAR facilities under consideration of various data sources and processing algorithms.

➔ *For more details see the SMART-Control Deliverable D4.2* (Glass et al., 2020)

2.2.4 Numerical groudwater modelling and optimization (T03)

This tool can be used for setting up, running and visualising a new numerical groundwater flow and solute transport model based on MODFLOW (Harbaugh, 2005), the most widely applied numerical model for MAR assessment (Ringleb et al., 2016). The INOWAS tool helps to setup a new MODFLOW model for a study area in order to better understand the local groundwater flow system or as a basis for further scenario analysis (see T07. MODFLOW model scenario manager). In addition to groundwater flow, solute transport using MT3DMS can be added as well as variable-density flow based on SEAWAT.

The web interface is divided into four main components (see Figure 5):

1) model setup where all input parameters including discretization, soil layers, head observations and boundaries can be defined;
2) calculation where the MODFLOW package parameters can be set, the calculation can be run and the MODFLOW output files can be visualised;
3) results where the groundwater levels and drawdown as well as the volumetric budget can be visualised; and
4) calibration where, if observation data has been defined, the calibration statistics can be viewed and the observed versus simulated groundwater levels can be visualised.

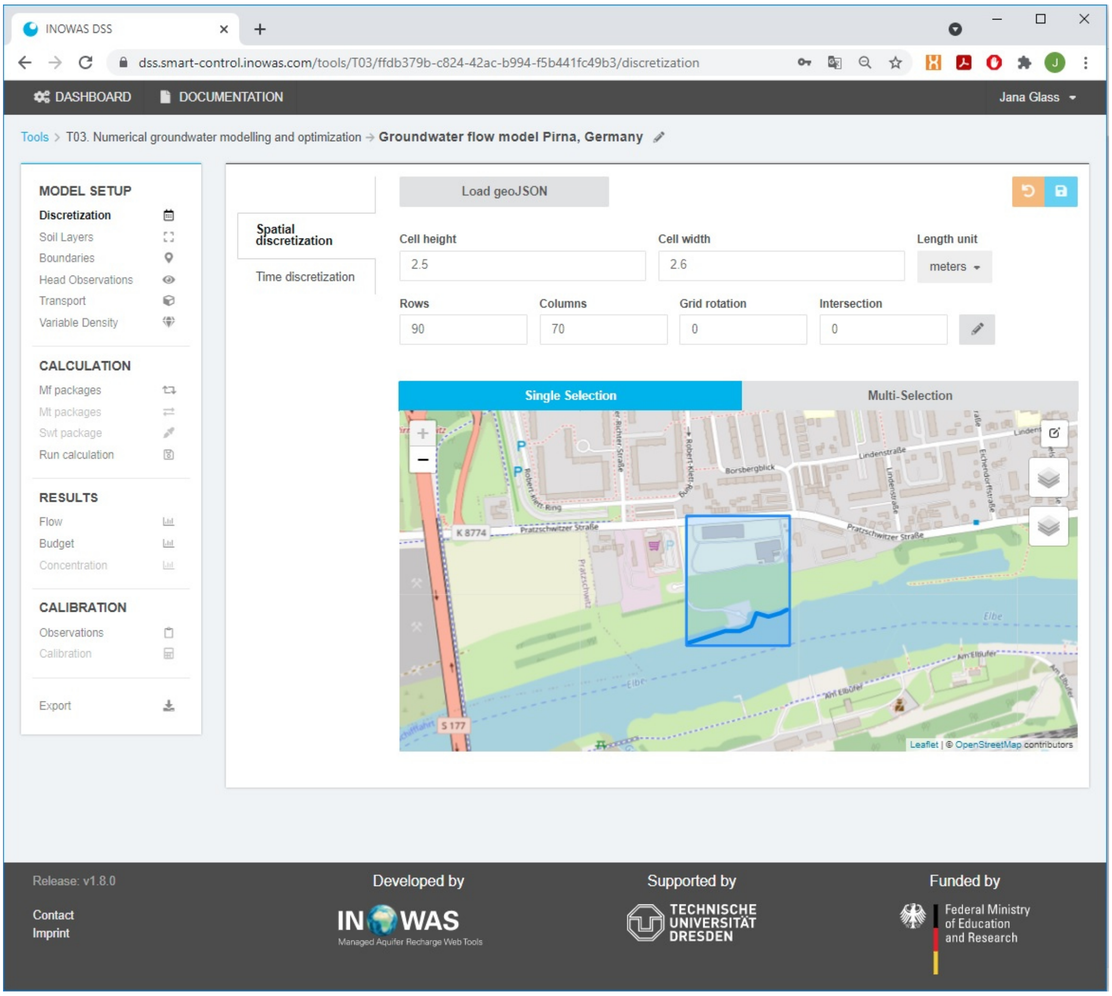


Figure 5. Overview of INOWAS-DSS tool "Numerical groundwater modelling and optimization" (Glass et al., 2022b).

➔ *For more information see the online documentation pages of Tool T03 (https://inowas.com/tools/t03-modflow-model-setup-and-editor/) or* Glass et al., 2022b.

2.2.5 Automatic groundwater simulations (T20)

The real-time modelling tool allows a user to extend an existing numerical groundwater flow model with new sensor data. By using tool T03 Numerical groundwater modelling and optimization described above, a groundwater flow model can be created, run and calibrated. The existing groundwater flow model can be actualized and rerun with new data with the help of the real-time modelling tool. New input data such as values for model boundaries are hereby imported from a sensor defined in the INOWAS tool T10 Real-time monitoring (see chapter 2.3. 1). Alternatively, the values can be also set as constant.

The main functionality of the real-time modelling tool consists thus in the utilization of real-time data to update an existing groundwater flow model (Figure 6). First, a new real-time modelling instance must be initiated based on a calibrated numerical model (T03). New stress periods are automatically added to the base model. Model boundaries and head observations can be defined using either sensor data from the last time step of the base model up until the date or constant values, then the model instance is created and run. Currently, the calculation process must be initiated manually but new data is automatically imported from the INOWAS tool T10 Real-time monitoring. After successful calculation of the real-time model, the model results including groundwater heads, drawdown, and volumetric budget can be visualized.

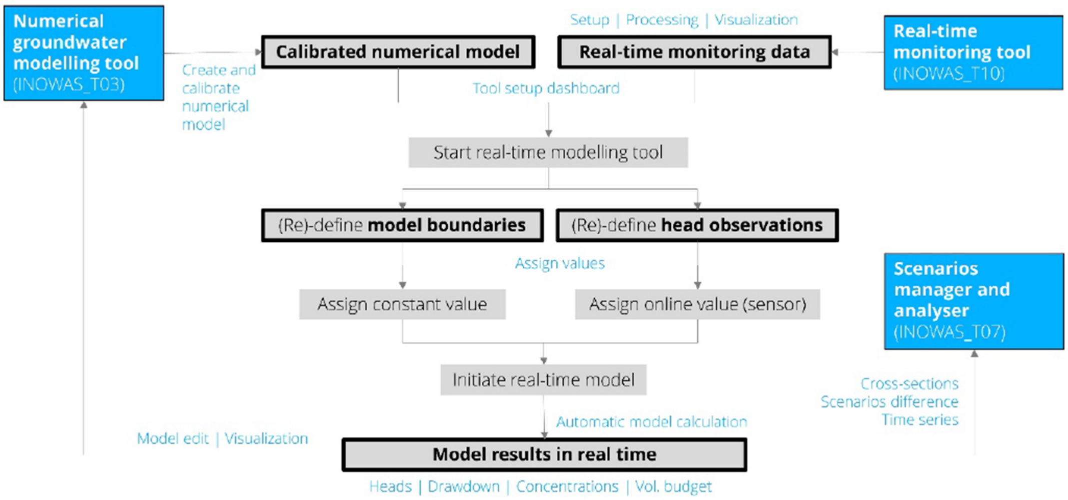


Figure 6. Concept of the real-time modelling tool (Glass et al., 2022c).

The tool represents a first step to provide an easy way to regularly update numerical groundwater flow models which are currently not updated or on a very irregular basis. Despite its (current) basic functionalities, the tool helps to analyze the relevant processes occurring during MAR operation in almost real-time, reducing the risks associated with MAR. By providing an easy way to update the numerical groundwater flow model, the up-to-date diagnostic for operators, regulators and water managers is enabled.

➔ *For more information see SMART-Control Deliverable D4.4* (Glass et al., 2022c)

2.2.6 Scenario manager (T07)

Numerical models are frequently used to plan, optimize and assess MAR facilities (Ringleb et al., 2016). Scenario analysis serves to evaluate various management solutions or to integrate climate, land use or urban change projections into the numerical model. This can be done by changing model boundaries e.g. pumping rates to represent the changing water demand, recharge rates and river discharge to reproduce climate or land use change. The implementation of MAR schemes in the study area including their impact on groundwater levels, on saltwater intrusion or their interference with other groundwater users can be assessed by building different scenarios.

The workflow is based on the existing numerical groundwater flow and transport modelling tool on the INOWAS platform, where the model can be setup, run and calibrated (see chapter 2.3.2). For scenario analysis, the Base Model can be cloned and edited to change boundary conditions by percentage. Besides that, it is possible to vary the boundary input by hand or upload CSV files. The model can be rerun and the results compared with the base model in the scenario analysis tool (Figure 7). At the moment, three possibilities to compare scenarios are available:

1) Cross-sections view;
2) Scenarios difference view; and
3) Time series view.

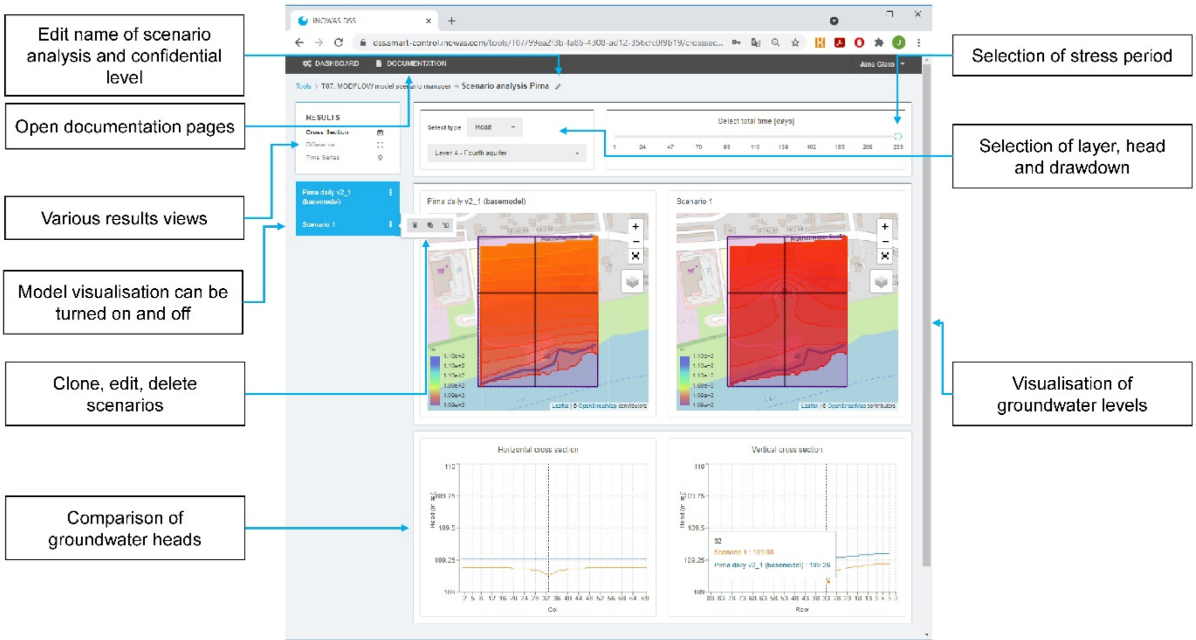


Figure 7. Scenario manager to compare various model runs (Glass et al., 2022b).

The scenario manager provides to our knowledge the unique feature to easily compare various modelling runs in one interface without the need of time-consuming calculations by hand. By comparing various management options, system operators can take scientifically-based decisions without the need to get familiar with the often complex numerical model itself. The better informed, scientifically-based decisions can help to reduce the risks associated with MAR and improve the sustainable management of water resources.

➔ *For more information see SMART-Control Deliverable 4.5 (Glass et al., 2022a)*

2.2.7 Economic evaluation of the SMART-Control improvement: value of information (VoI) methodology

MAR schemes may not always operate as expected. They may face some risks (public health risks, environmental risks) and uncertainties leading to operational issues (e.g. clogging, low recovery efficiency) that may decrease performance indicators of the systems and even threaten their long-term viability (Figure 8). Although several methods exist to incorporate potential risks and uncertainties in cost-benefit analysis (Pearce, Atkinson, & Mourato, 2006), they are still a neglected aspect of the economics of MAR (Maliva, 2014).

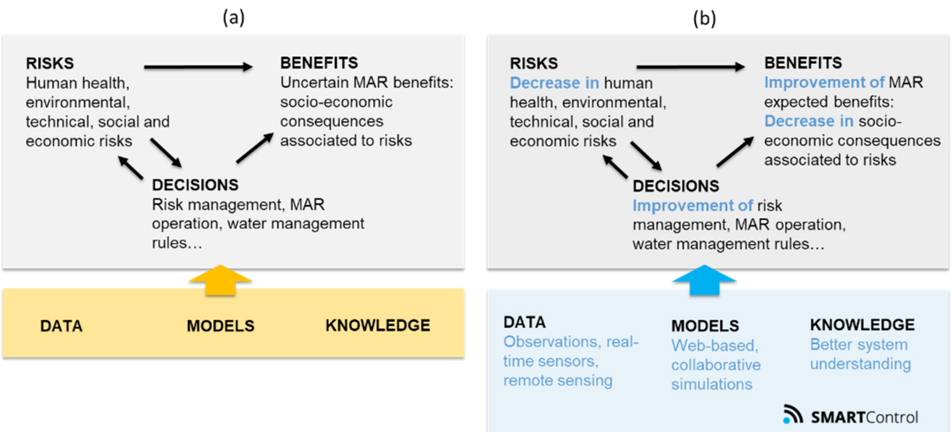


Figure 8. Benefits expected from MAR real-time monitoring and control: risks, decisions and benefits with (a) classical monitoring and (b) SMART-Control real-time monitoring and control (Hérivaux et al., 2022)

These risks can be reduced but never entirely eliminated through high quality and more detailed aquifer characterisation (Nandha et al., 2015). Monitoring can play a key role in the risk assessment and management process. SMART-Control developed an innovative web-based, real-time monitoring system (RTM) in combination with risk assessment and management tools. The online sensors measure the most common operational, chemical and biological parameters that influence the risk at MAR facilities: i.e., infiltration water volume, groundwater level, temperature, electrical conductivity, microbial content, chemical oxygen demand, nitrate, spectral adsorption coefficient, total suspended solids and dissolved organic carbon. RTM allows operators to optimize the performance of MAR systems by enhancing risk assessment and management, by increasing the probability to take the good management actions. Monitoring and data collection associated to RTM may be costly, but also brings higher benefits than classical monitoring systems.

The question then is whether the decisions related to the MAR scheme should be made on the basis of the classical monitoring system or whether it is worth investing in RTM providing additional information to reduce uncertainty. In economics, the concept of the value of information (VoI) compares the expected net benefits of collecting additional information to reduce or eliminate uncertainty associated with the outcome of a decision and the expected net benefits of a preferred uninformed alternative (Khader et al., 2013). The methodology developed in the SMART-Control project proposes to characterise and quantify the costs and benefits associated with RTM, based on the concept of VoI divided into 7 steps (Figure 9Fehler! Verweisquelle konnte nicht gefunden werden.).

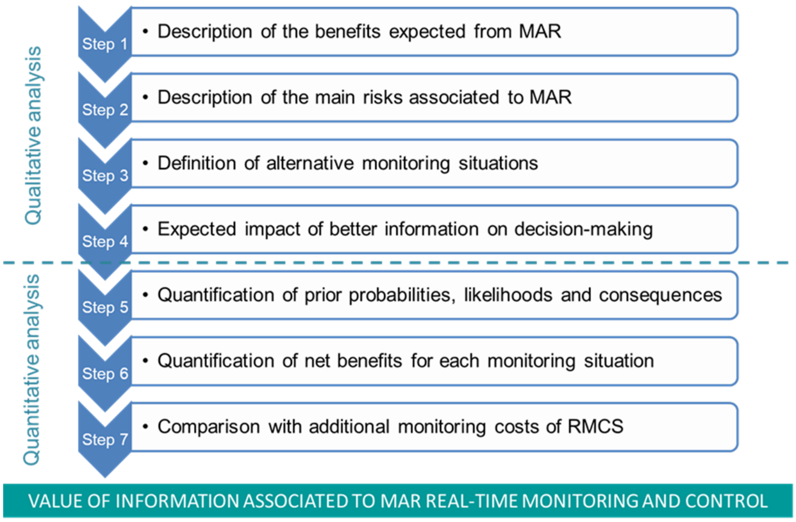


Figure 9. Proposition of a stepwise approach for SMART-Control (Hérivaux et al., 2022)

The approach first relies on a qualitative evaluation (steps 1-4) aimed at understanding the benefits, risks, and how the SMART-Control tools can improve decision-making at each study site. If better information has a potential impact on decision-making and on benefits, the quantitative analysis of the economic consequences and probabilities can be implemented (steps 5-7) to assess VoI. From Step 4, a qualitative description of the impact expected from improved information on decision and on benefits is provided. This step is decisive for the further evaluation: the quantitative analysis (steps 5 to 7) only starts if better information has a potential impact on decision-making and on benefits from MAR. This phase requires the greatest investment in working time. The steps 5-7 are dedicated to the analysis of the economic consequences and probabilities. Step 5 provides a quantification of prior probabilities π_s, likelihoods $q_{m,s}$ and consequences c_{xs}. Step 6 aggregates the expected net benefits of each monitoring situation according to the Bayesian formula (Bayesian decision theory). Step 7 compares net benefits to the additional monitoring costs. The VoI is equal to the difference between net benefits and additional monitoring costs.

➔ *For more information see SMART-Control Deliverable 7.4 (Hérivaux et al., 2022)*

3 CONCLUSIONS

The SMART-Control solutions workflow is dedicated to guide the user in order to enhance MAR system operations and assess MAR associated risks and benefits. There are several types of MAR systems where the associated risks can arise during the planning, implementation and operation of a MAR facility. In general, operational, regulatory, business, human health, and environmental risks can occur and should be identified already during the planning and implementation stage to apply preventive measures and secure the safe and reliable operation of a MAR facility.

The solution proposed by the SMART-Control project combines the identification and characterization of MAR-associated risks with the application of the innovative web-based INOWAS DSS platform (www.inowas.com). The approach consists of an in-situ real-time monitoring system and a web-based platform for control, modelling and prediction. All developed tools can be used for free after user registration. In addition, a methodology to economically evaluate benefits brought by the SMART-Control solution was developed.

The SMART-Control workflow includes 2 Steps:

The first step comprises the identification and prioritization of the MAR associated risks based on the Australian guidelines. The risks addressed by SMART-Control include health, environmental, technical, social-economical and climate change risks (for details see Figure 1 the SMART-Control tool workflow).

After identification of the site-specific risks, the user is guided in a second step to the SMART-Control tool suit to quantify and manage the individual risks as well as to optimize the MAR facility. The developed web-based tool suit enables:

- to quantify the underground residence time,
- to conduct a quantitative microbial risk assessment,
- to setup a real-time monitoring system,
- to setup, run and evaluate a groundwater flow (and transport) model,
- to generate automatic groundwater simulations,
- to conduct a scenario analysis considering various management and climate change, and
- to evaluate the long-term economic benefits arising from using the SMART-Control solutions with the Value of Information methodology.

All tool documentations and associated deliverables of the SMART-Control project are available at https://smart-control.inowas.com.

Specific implementation of the SMART-Control tool suite at the study site scale are described in the Deliverables 7.3 Technology transfer Approach.

The SMART-Control solutions workflow is dedicated to synthesis the way to use the developed solutions and to guide the user to enhance a MAR system operation or assess MAR-associated risks and benefits. The developed SMART-Control workflow helps to identify, prioritize the MAR-associated risks and as a second step to quantify and manage those risks. In that way, the occurring risks can be minimized, ensuring a reliable operation of the MAR facility.

REFERENCES

Fernandez Escalante, E., Henao Casas, J.D., Vidal Medeiros, A.M., San Sebastián Sauto, J.S.S.S., 2020. Regulations and guidelines on water quality requirements for Managed Aquifer Recharge. International comparison. Acque Sotter. - Ital. J. Groundw. https://doi.org/10.7343/as-2020-462

Glass, J., Jain, R., Junghanns, R., Sallwey, J., Fichtner, T., Stefan, C., 2018. Web-based tool compilation of analytical equations for groundwater management applications. Environ. Model. Softw. https://doi.org/10.1016/j.envsoft.2018.07.008

Glass, J., Junghanns, R., Schlick, R., 2022a. SMART-Control Deliverable D4.5: Web-based real-time modelling - Implementation of the web-based prediction analysis tool on the INOWAS platform. https://doi.org/10.13140/RG.2.2.13353.88168

Glass, J., Junghanns, R., Schlick, R., Catalin Stefan, 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. https://doi.org/10.13140/RG.2.2.16843.52007

Glass, J., Junghanns, R., Schlick, R., Stefan, C., 2022b. The INOWAS platform: A web-based numerical groundwater modelling approach for groundwater management applications. Environ. Model. Softw. 155, 105452. https://doi.org/10.1016/j.envsoft.2022.105452

Glass, J., Schlick, R., Junghanns, R., 2022c. SMART-Control Deliverable D4.4: Real-time modelling tool - Implementation of the web-based real-time modelling tool on the INOWAS platform. https://doi.org/10.13140/RG.2.2.24077.05605

Harbaugh, A.W., 2005. MODFLOW-2005, the US Geological Survey modular ground-water model: the ground-water flow process (No. 6-A16), U.S. Geological Survey Techniques and Methods. US Department of the Interior, US Geological Survey Reston, VA, USA.

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.

Imig, A., Szabó, Z., Halytsia, O., Vrachioli, M., Kleinert, V., Rein, A., 2022. A review on risk assessment in Managed Aquifer Recharge. Integr. Environ. Assess. Manag. ieam.4584. https://doi.org/10.1002/ieam.4584

Khader, A.I., Rosenberg, D.E., McKee, M., 2013. A decision tree model to estimate the value of information provided by a groundwater quality monitoring network. Hydrol. Earth Syst. Sci. 17, 1797–1807. https://doi.org/10.5194/hess-17-1797-2013

Maliva, R., 2014. Economics of Managed Aquifer Recharge. Water 6, 1257–1279. https://doi.org/10.3390/w6051257

Nandha, M., Berry, M., Jefferson, B., Jeffrey, P., 2015. Risk assessment frameworks for MAR schemes in the UK. Environ. Earth Sci. 73, 7747–7757. https://doi.org/10.1007/s12665-014-3399-y

NRMMC-EPHC-NHMRC, 2008. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2-1) - Augmentation of Drinking Water Supplies.

Page, D., Gonzalez, D., Bennison, G., Burrull, C., Claro, E., Jara, M., Valenzuela, G., 2020. Progress in the development of risk-based guidelines to support managed aquifer recharge for agriculture in Chile. Water Cycle 1, 136–145. https://doi.org/10.1016/j.watcyc.2020.09.003

Pearce, D., Atkinson, G., & Mourato, S., 2006. Analyse coûts-bénéfices et environnement. Développements récents. OECD report, http://tbauler.pbworks.com/f/OECD-Pearce+et+al-2006.pdf.

QMRAwiki, 2016 http://qmrawiki.canr.msu.edu/index.php/Dose_Response, 22.10.2021

Ringleb, J., Sallwey, J., Stefan, C., 2016. Assessment of Managed Aquifer Recharge through Modeling—A Review. Water 8, 579. https://doi.org/10.3390/w8120579

Sprenger, C., Panagiotou, K., Fernandes, L., Duzan, A., Baptista, V., Glass, J., 2019. SMART-Control Deliverable D2.1: Matrix of risks and remediation measures - Risks and remediation measures at different stages of MAR site development. https://doi.org/10.13140/RG.2.2.19884.39040

Sprenger, C., Rustler, M., Schlick, R., Junghanns, R., Glass, J., 2021. SMART-Control Deliverable D4.3: Web-based risk assessment tools - Development and implementation of a web-based tool for QMRA. https://doi.org/10.13140/RG.2.2.10552.06403

Stefan, C., Sprenger, C., Rustler, M., Schlick, R., Junghanns, R., 2021. SMART Control Deliverable 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.