WaterJPI project

SMARTControl

Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge (MAR) applications
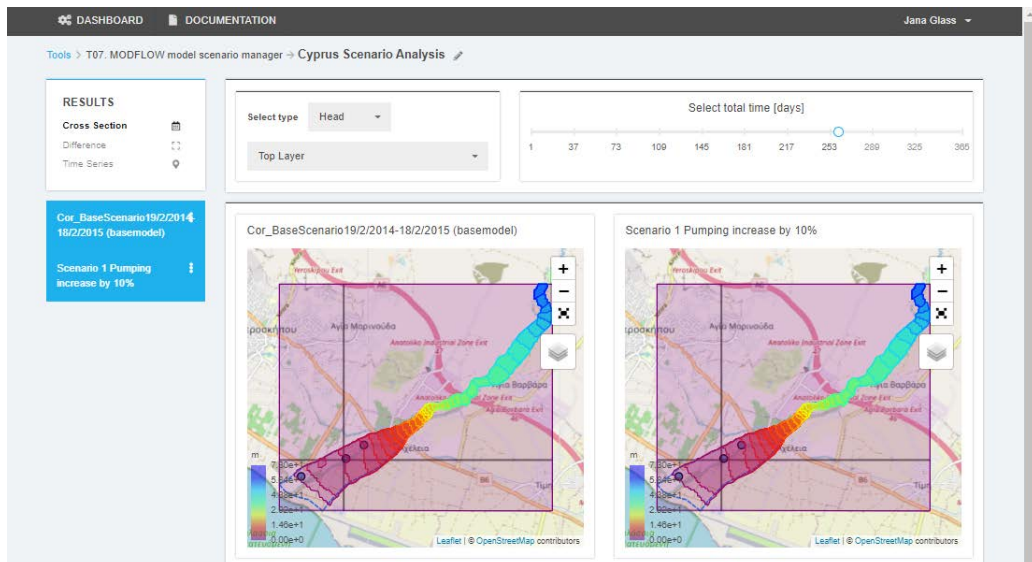
Deliverable D4.5

Web-based real-time modelling
Implementation of the web-based prediction analysis tool on the INOWAS platform

Authors
Jana Glass (TUD), Ralf Junghanns (TUD), Robert Schlick (TUD)

Deliverable D4.5

Web-based real-time modelling
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Short summary

Scenario analysis serves to evaluate various management solutions or to integrate climate, land use or urban change projections into the numerical model. This report describes the main functionalities of the web-based tool "T07 MODFLOW model scenario manager" where various model runs can be easily compared with each other by distinct results visualization options. The developed web-interface provides new possibilities for easy transfer of modelling results to MAR operators, local stakeholders and decision-makers, independent of location and software to help take better informed, scientifically-based decisions with regard to MAR.

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ABSTRACT

This report describes the successful implementation of a web interface for scenario management and analysis of numerical groundwater flow (and transport) models on the INOWAS platform. 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 or river discharge to reproduce climate or land use change. The workflow is based on the existing numerical groundwater flow and transport model tool on the INOWAS platform, where the model can be setup, run and calibrated. For scenario analysis, the Base Model can be cloned and edited to change boundary conditions by percentage, by hand or CSV upload.

The scenario management tool offers the unique possibility to compare two or more model runs with each other. For this, distinct results visualization options have been developed. The cross section view provides the comparison of multiple scenarios via groundwater heat maps as well as horizontal and vertical cross sections along selected rows and columns. The difference view enables the calculation of groundwater head or drawdown differences at selected time steps and locations for two scenarios. The time series view provides feature to visualize the groundwater head or drawdown evolution at a selected location for one or more model runs. In that way multiple scenarios can be evaluated in one project, where the visualization of model results can be turned on and off for each of the models which allows an easy comparison and evaluation of the occurring changes between the scenarios.

The web-interface provides new possibilities for easy transfer of modelling results to MAR operators, local stakeholders and decision-makers, independent of location and software. 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. The presented tools were specifically developed to solve MAR-related issues but can also be used to solve other, general groundwater-related questions.

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1. INTRODUCTION

1.1 BACKGROUND

Managed aquifer recharge (MAR) is used worldwide for sustainable management of water resources. MAR implies the storage of surface water in the underground and its utilisation for different purposes such as domestic and agricultural use, or for ecological benefits. What differentiates MAR from other groundwater recharge practices (i.e. leakage from sewerage networks) is the intentional recharge of the aquifers by injecting water under controlled conditions. In order to safeguard and protect the good status of the aquifers, a monitoring system provides qualitative and quantitative data necessary for the safe operation of the MAR scheme.

Depending on site-specific requirements, the monitoring system contributes to the optimisation of the operational scheme in order to reduce the MAR-associated risks. The role of monitoring systems consists in assessing the water quality parameters of the influent water, native groundwater and recovered water in respect to existing regulations. Automatic monitoring systems consisting in multi-parameter probes can deliver continuous measurements of most relevant parameters and deliver the values in near-real time conditions. The system can be equipped with additional control functionalities that have the capability to intervene in the operational management and, for example, to stop the water inflow when the water quality does not meet the desired quality thresholds.

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. An intuitive interface to compare the various models with each other to easily visualize the occurring changes in the scenarios is presented that could help decision makers to make better informed, scientifically-based decisions. In that way, numerical model results can be optimal used which can help to reduce the risks associated with MAR since it allows the system operators to take scientifically-based decisions without the need to get familiar with the often complex numerical model itself.

1.2 ABOUT THE SMART-CONTROL PROJECT

"SMART-Control" is an international research project funded through the Water Joint Programming Initiative (WaterJPI) and implemented by nine institutions from Germany, France, Cyprus and Brazil. The main objective of the project is to reduce the risks associated to MAR by the development of an innovative web-based real-time monitoring and control system (RCMS) in combination with risk assessment and management tools. The SMART-Control approach relies on coupling a real-time in-situ observation system consisting of state-of-the-art online sensors and a web-based groundwater monitoring and modelling platform. The resulting system shall provide operators and managers of MAR schemes with automatic decision support tools for monitoring, controlling and prediction of processes occurring during MAR. The approach will be tested and validated at six MAR sites under different environmental and operating conditions. More information about SMART-Control is available on the project website: https://www.smart-control.inowas.com.

1.3 SIMULATION TOOLS

The SMART-Control software infrastructure is based on the free groundwater modelling platform developed by the Research Group INOWAS at Technische Universität Dresden, Germany. The platform contains a collection of empirical, analytical and numerical tools for assessing groundwater flow processes with focus on managed aquifer recharge applications (https://www.inowas.com). The INOWAS platform was amended in the SMART-Control project by four additional simulation tools (more info and the complete documentation of the tools is available at: https://www.smart-control.inowas.com/tools):

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Table 1. **Short description of simulation tools developed in the SMART-Control project**

No.	Tool name	Tool description
T1	**Initial risk assessment**	The tool represents an easy-to-use instrument to evaluate the viability of a MAR project and the preliminary assessment of human health and environmental risks. The tool has two parts: A) a component for the estimation of groundwater hydraulic residence times during subsurface passage (see Deliverable D4.1, http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_1.pdf); and b) a component for quantitative microbial risk assessment (QMRA) of MAR schemes, including hazard identification, exposure assessment, dose analysis and risks characterization (see Deliverable D4.3, http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_3.pdf). The risk is assessed for selected reference pathogens such as bacterial, protozoan and viral pathogens for different hydraulic residence times during MAR.
T2	**Real-time monitoring and control**	This tool aims to facilitate 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 visualized, processed, downloaded and prepared for further usage (see Deliverable D4.2, http://smart-control.inowas.com/wp-content/uploads/2020/06/SMART_Control_D4_2.pdf).
T3	**Automatic groundwater simulations**	Real-time observations collected from MAR sites can be integrated into a web-based modelling workflow. The system relies on the existing groundwater modelling capabilities of the INOWAS platform, which were expanded by additional features. The integration of real-time monitoring data into the simulation workflow enables fast response time and optimized management, which helps to minimize and control the associated risks (see Deliverable D4.4, http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_4_Real-time-modelling_tool.pdf)
T4	**Predictions for advanced system management**	The tool allows building climate change and development scenarios for groundwater flow models to predict future boundary conditions and compare them to the present situation using the INOWAS Scenario Analyser. The tool provides a novel way of using real-time, web-based groundwater models to assess the effects of climate change, urbanisation, land use change (irrigation demand) and population growth on spatial and temporal water availability.

This report describes the main functionalities of tool **"T4. Predictions for advanced system management"**. For the description of the other tools see the SMART-Control Deliverables D4.1, D4.2,D4.3 and D4.4 or the project website: https://www.smart-control.inowas.com where also a detailed documentation of the tools is available.

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2 TOOL CONCEPT AND TECHNICAL INFRASTRUCTURE

2.1 TOOL CONCEPT

The web-based tools implemented on the INOWAS platform in the frame of SMART-Control are based on each other: results of one tool can be used in another tool or as input data for further calculations (Figure 1).
By using tool T03.Numerical groundwater modelling and optimization (https://inowas.com/tools/t03-modflow-model-setup-and-editor/), a groundwater flow and transport model can be created, run and calibrated.
New input data such as values for model boundaries or observations can be imported from a sensor defined in the tool T10 Real-time monitoring (https://inowas.com/tools/t10-real-time-monitoring/). The monitoring system covered by tool T10 integrates (real-time) monitoring data into the INOWAS platform. For that, a connection to a sensor that transmits data needs to be setup. Monitoring data could include e.g. groundwater heads, recharge rates in infiltration basins, or electrical conductivity. If no sensor is available, also data upload via CSV or a connection to a public WSV service can be established. The raw data can be visualized, processed with a set of simple statistical tools, and downloaded for further usage. For more details see Deliverable D4.2 (http://smart-control.inowas.com/wp-content/uploads/2020/06/SMART_Control_D4_2.pdf).
The calibrated numerical model can be used in a second step either to be actualized by real-time data in the tool T20 real-time modelling (see D4.4, http://smart-control.inowas.com/wp-content/uploads/SMART_Control_D4_4_Real-time-modelling_tool.pdf) or serves as a basis for scenario analysis. For this, the tool T07 MODFLOW model scenario manager has been implemented on the INOWAS platform and extended in the frame of SMART-Control.
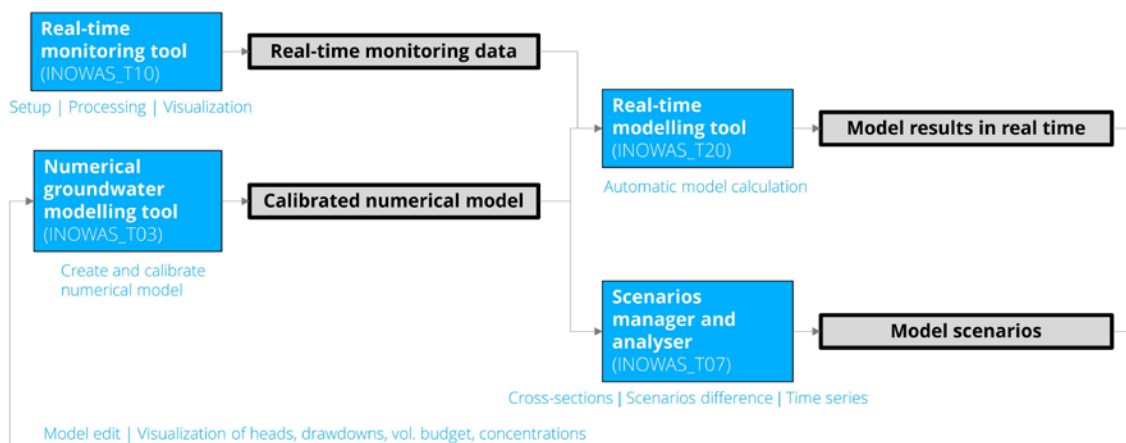The documentation of the tool can be found on the following link: https://inowas.com/tools/t07-application-specific-scenarios-analyzer/

Figure 1.   **Tool communication on INOWAS platform.**

As a prerequisite to use the Scenario Manager tool, a groundwater flow (and transport) model must be setup, run and (optionally) calibrated in tool T03 Numerical groundwater modeling and optimization (Figure 2). As a next step, a scenario analysis can be initiated. For this the Base model can be cloned. The cloned model can be then edited with the help of tool T03 (e.g. by changing pumping rates), rerun and the results compared with the base model in the scenario analysis tool. At the moment, three possibilities to compare scenarios are available (see chapter 3 for details):
1) Cross-sections view
2) Scenarios difference view
3) Time series view.

The scenario manager provides to our knowledge a unique feature to easily compare various modelling runs in one interface without the need of time-consuming calculations by hand.

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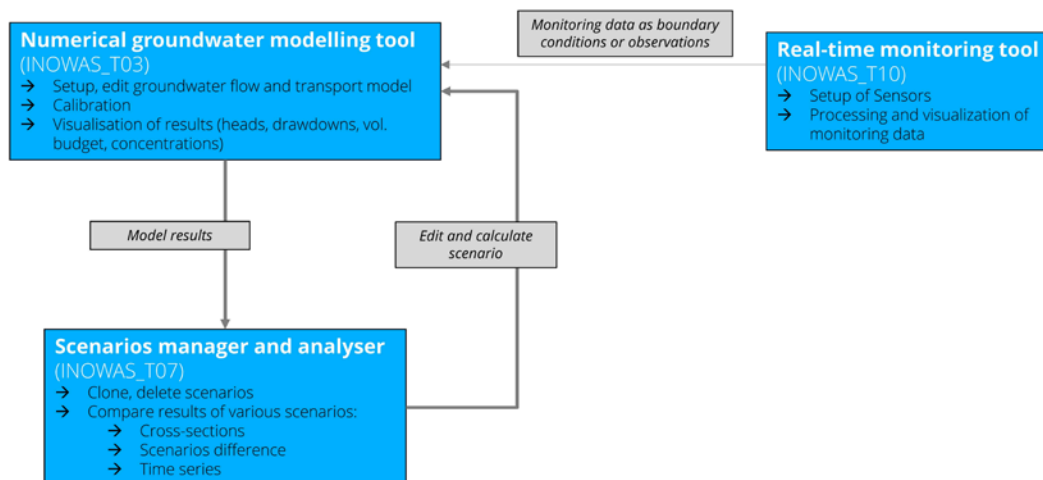
Figure 2. Scenario manager tool workflow.

2.2 TECHNICAL INFRASTRUCTURE

The technical infrastructure of the tool includes a client component (user web browser), a webserver and a set of worker microservices (Figure 3). The client application is programmed in JavaScript and TypeScript and includes feature-rich frameworks such as React, Redux and Leaflet to create a modern, user-friendly interface. The webserver is used for user authentication and for storing the state of the web-application. The microservices aim at solving highly specialized tasks like geoprocessing, time-series processing or running numerical models. The system can integrate additional microservices written in different programming languages with the aid of dedicated APIs. For more details see Deliverable D4.2 (http://smart-control.inowas.com/wp-content/uploads/2020/06/SMART_Control_D4_2.pdf).
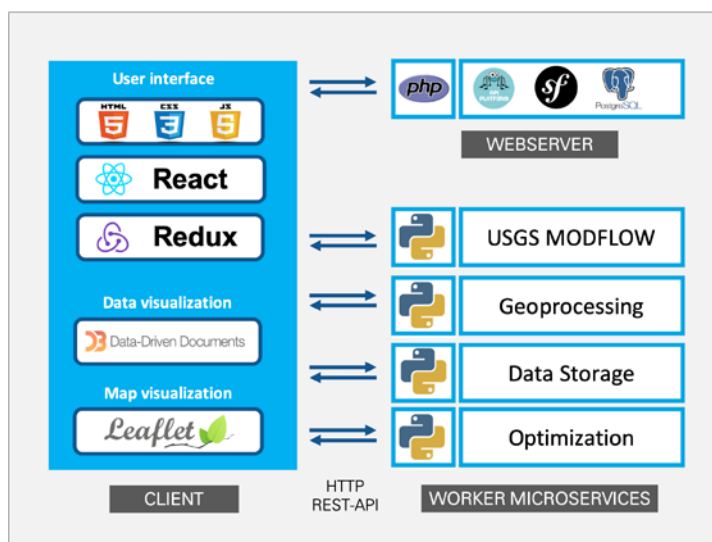
Figure 3. Technical infrastructure of the INOWAS DSS utilized by the real-time modelling tool.

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3. TOOL UTILIZATION

3.1 SETUP AND MANAGEMENT OF SCENARIO ANALYSIS

There are two options available to start a new scenario analysis:
The first option is to go to tool T07 in the dashboard, create a new tool instance and pick the model that serves as basis for the scenario analysis from the drop down list (Figure 4). Be aware that only a model owner can start a scenario analysis and subsequently edit the model. If the model is not in the list, the model first needs to be cloned before the scenario analysis can be initiated. For this, go to T03 in the dashboard and click "Clone" for the model that should be edited and a scenario analysis be created.
In the second option, the scenario analysis can be directly initiated in the results section of T03. For this, go to the flow results of the model and click "Scenario Analysis". A new scenario analysis is automatically created and the user will be directed to tool T07 MODFLOW Scenario manager.
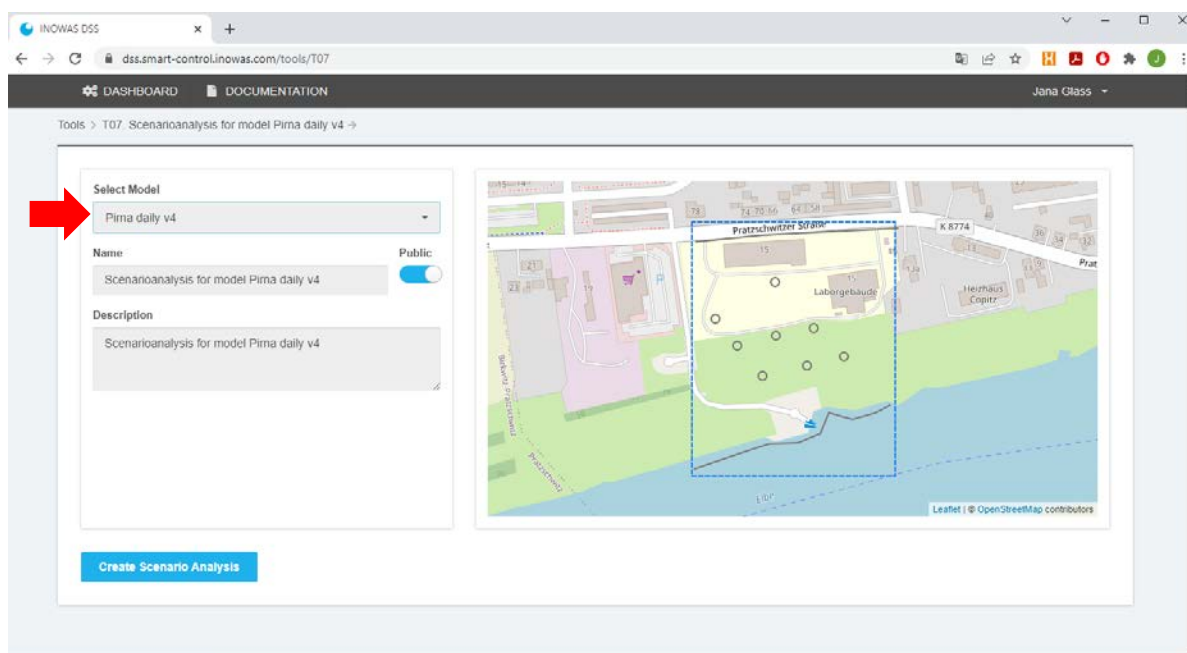
![SMARTControl logo]

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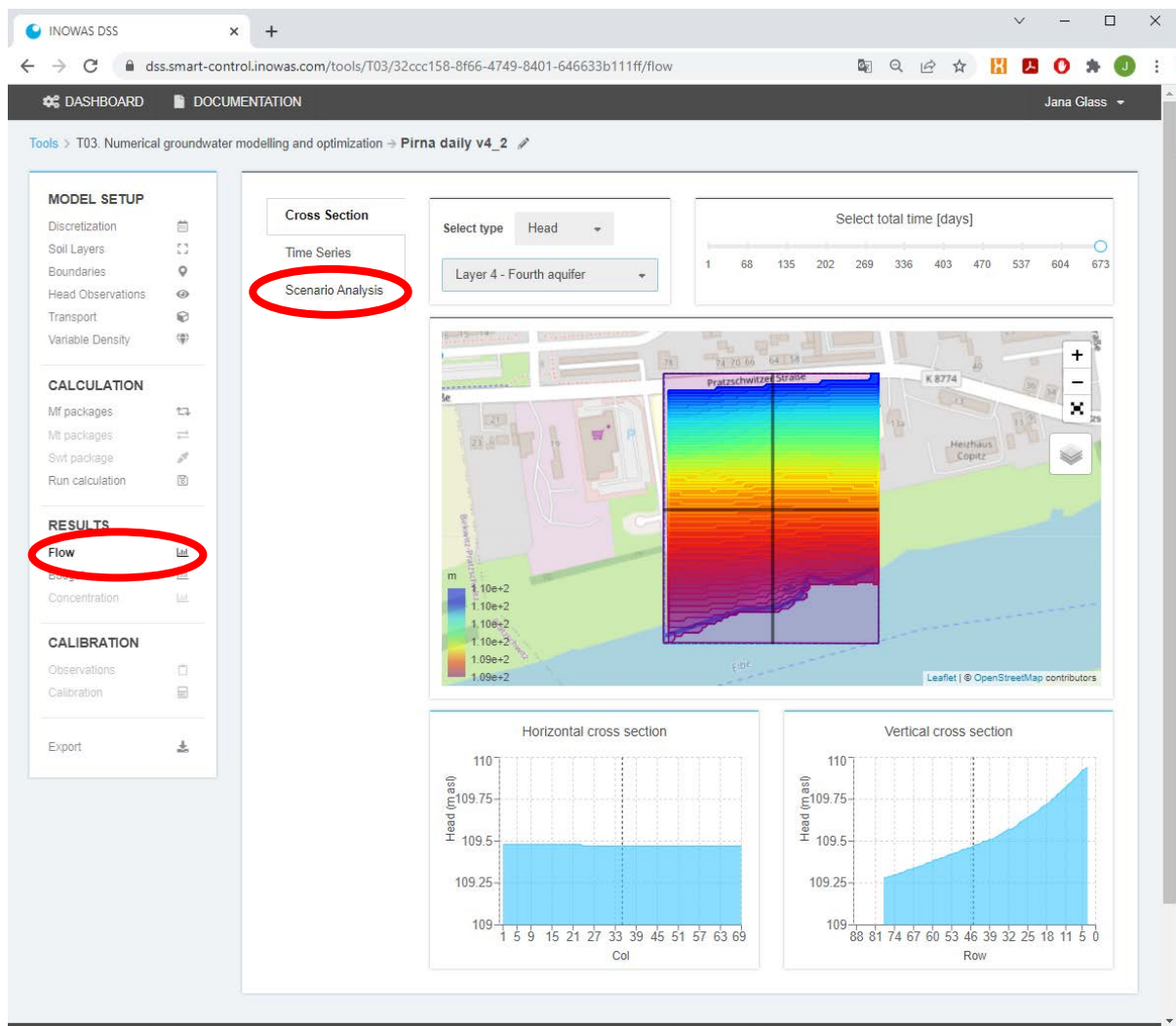

Figure 4.   **Initiation of scenario analysis: through the dashboard (top) or directly from the groundwater flow model on the web-based INOWAS platform (bottom).**

The landing page of tool T07 Modflow Scenario Manager provides various features (Figure 5):
-      Edit of the name and confidential level of the scenario analysis.
-      Open of the documentation pages.
-      Turning on and off the model / scenario visualisation.
-      Cloning, editing and deleting a model or scenario.
-      Selection of the results view. As default the Cross Section View is displayed.

In the right panel of the user interface, the model results are displayed. For the cross section view, the layer, head and drawdown can be selected as well as the stress period using the slider. Below a 2D map of the groundwater levels is displayed for the selected settings followed by horizontal and vertical cross sections for the rows and columns which can be selected in the 2D map.
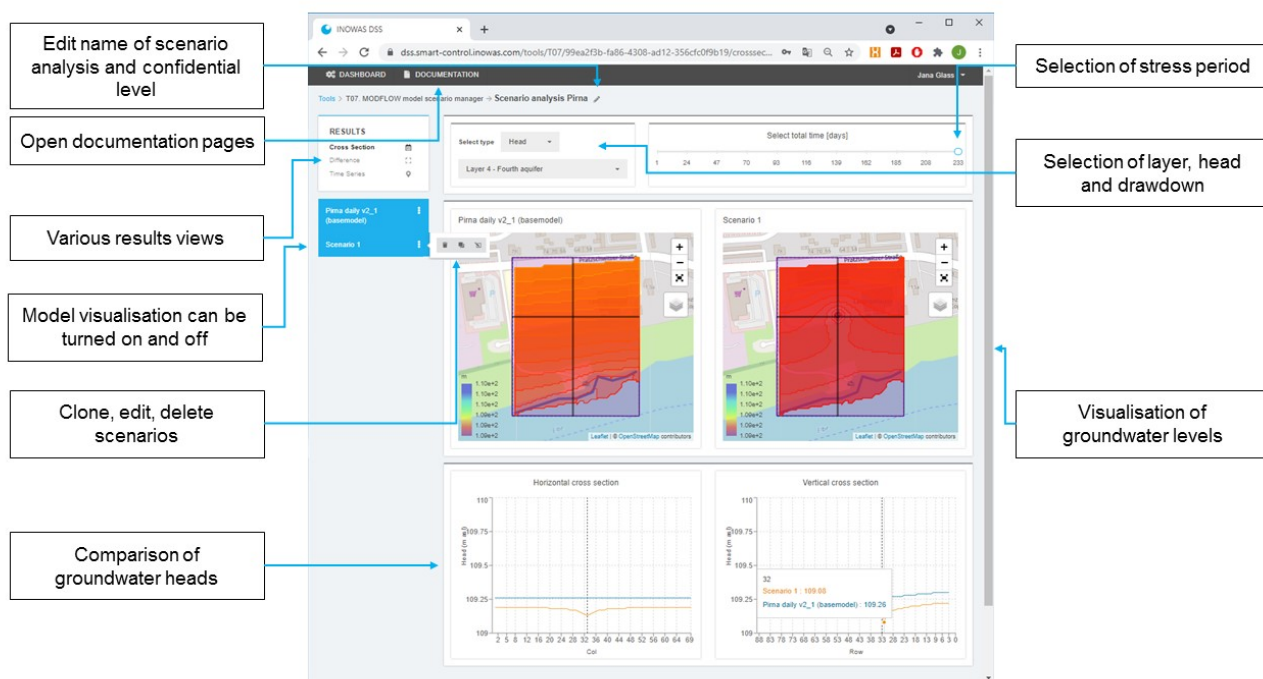
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Figure 5. **Features of tool T07 MODFLOW model scenario manager (Glass et al., 2021).**

The chosen numerical groundwater flow model is handled as "Base Case" in the scenario analysis and cannot be changed. To create a new scenario, the user needs to click on the groundwater flow model that should be edited and choose clone. A second model is appearing in the list with the addition "(clone)".

3.2 (RE-)DEFINITION OF BOUNDARY CONDITIONS IN THE MODEL EDITOR

The cloned model can be changed by clicking on "edit". The user is re-directed to tool T03, where all functionalities of Tool T03 can be used to edit the model. This includes the possibility to change the name, boundaries and re-calculate the model.

A special feature that is only available through the Scenario Manager is to change model boundaries by percentage. This is especially handy if there is only approximate data for the scenario available or a quick estimate is required what happens e.g. with the groundwater levels if pumping is increased by 10%. For this, the desired percentage needs to be typed in the field "Change by %" (Figure 6). As soon as it is clicked outside of the field, the percentage is automatically applied to all values of the boundary. After validation of correct value input, the changes can be saved.
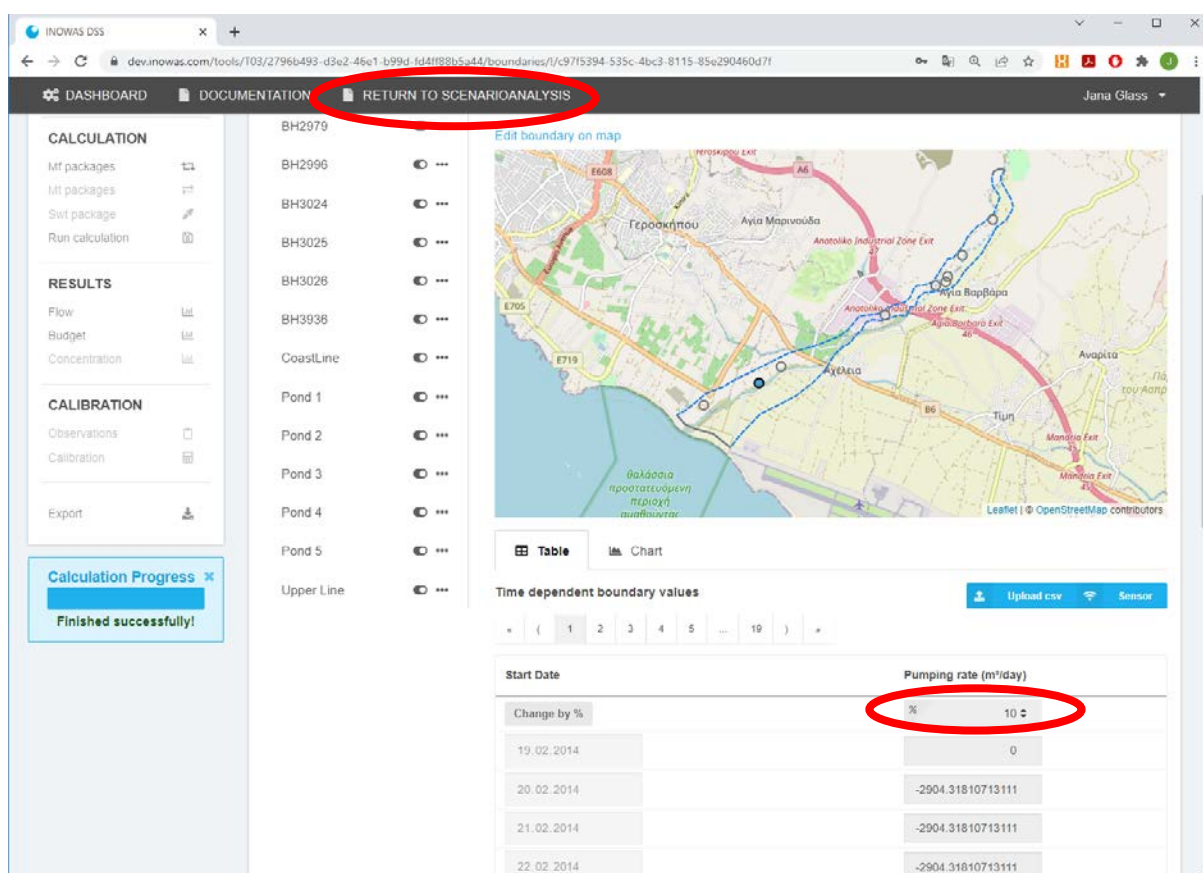
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Figure 6.   **Edit of model boundaries by %-change for scenario calculation and return to scenario analysis.**

After editing all boundaries, the scenario can be calculated in the run calculation menu. The calculation can be initiated using the "Calculate" button. Once the calculation has terminated, the calculation logs and model files can be viewed. The user needs to make sure that the calculation of the model scenario terminates normally. In the results section, the groundwater heads or drawdown can be displayed for each layer and time step. In addition, the budget can be visualized either as volume per time step or cumulative volumes.

To go back to the scenario analysis, click "return to scenario analysis" at the top of the interface as shown in Figure 6.

3.3 COMPARISON OF RESULTS IN THE SCENARIO MANAGER TOOL

The tool T07. MODFLOW model scenario manager provides distinct features to compare and evaluate various model scenarios in one application without the need of time-consuming hand calculations. The tool also allows the easy transfer of modelling results in an interactive web interface to non-modellers such as decision-makers, MAR operators or stakeholders. Currently, the easiest way to export the scenario results as images for reports and presentations is to use the screenshot function of your computer.

3.3.1 Cross section view

Cross sections at user-specified locations allow the comparison of simulation results for the selected model layer at a specified time step (Figure 7).

The user can decide which scenarios should be compared and can choose multiple scenarios for comparison.

The map shows the groundwater heads or drawdown for the selected scenarios. In the bottom a horizontal and a vertical cross section are displayed comparing the drawdown or groundwater head for the chosen scenarios. The precise groundwater heads can be visualized by moving the mouse cursor over the graph.
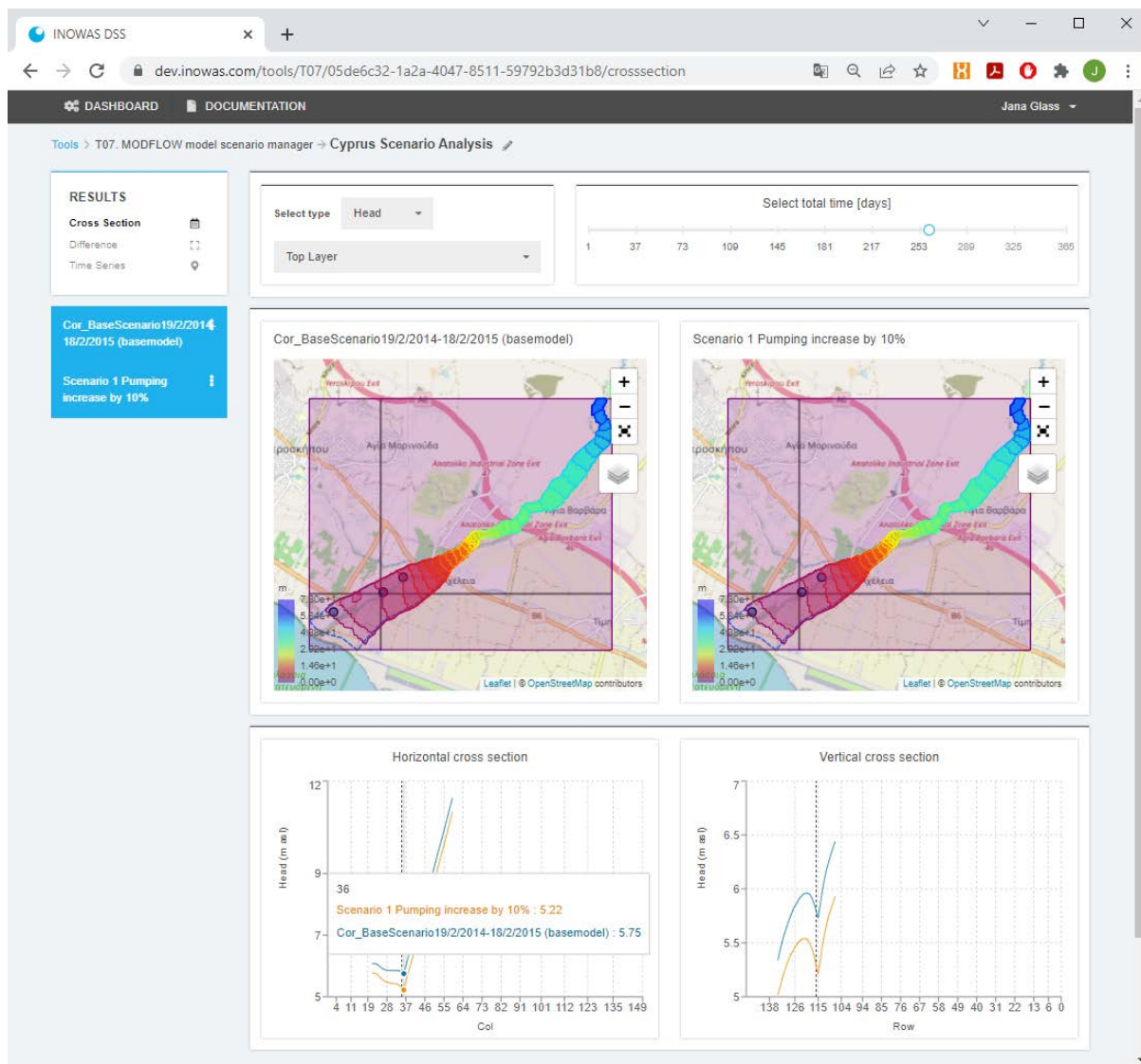
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Figure 7.   Cross section view to compare various scenarios.

3.3.2 Scenario Difference View

The scenario difference view allows to display the groundwater level changes or the change in drawdown between two models for a chosen layer at a specified time step (Figure 8). The user needs to choose two models from the drop down list as well as the time step for which the models will be compared.
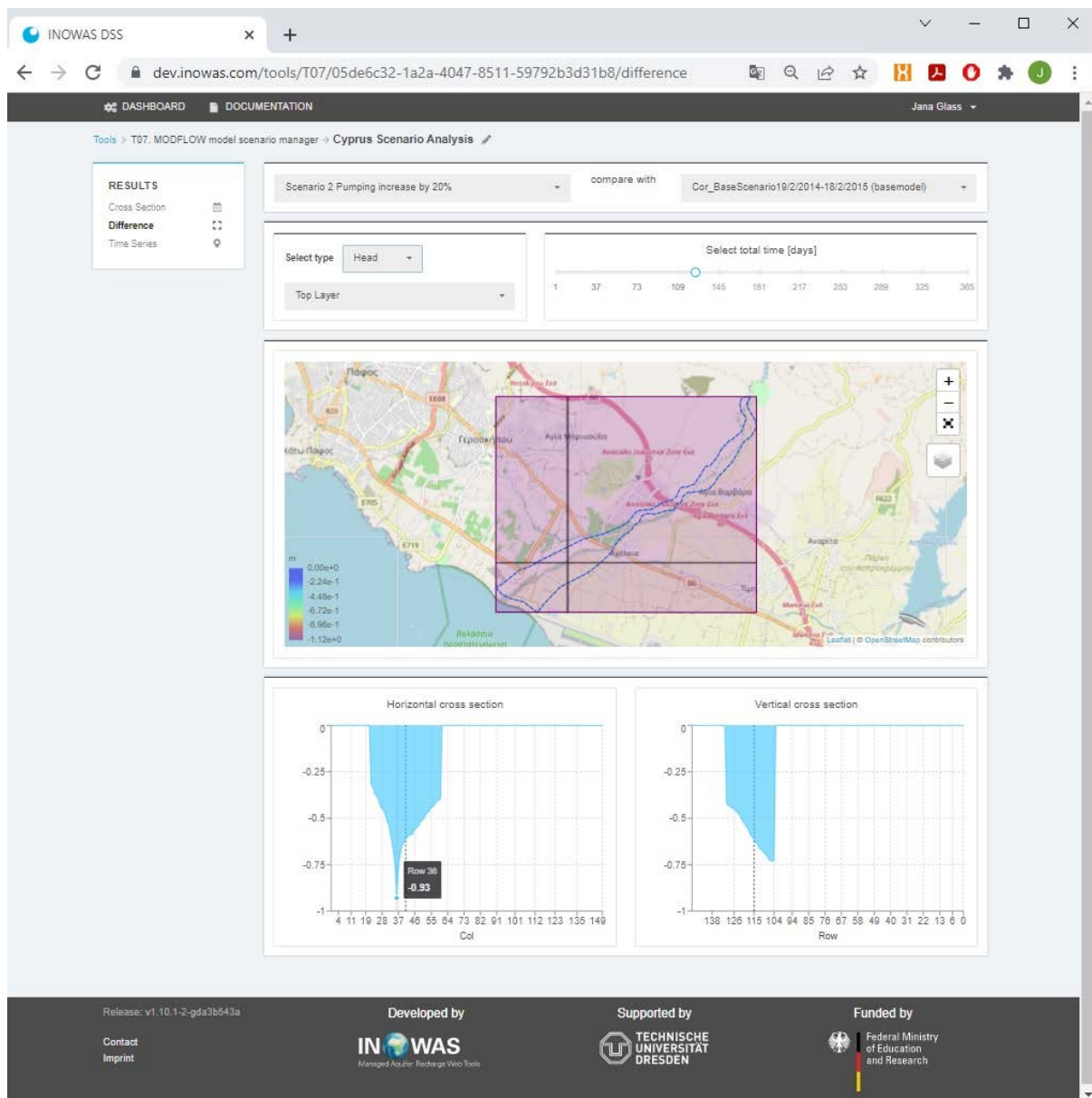
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Figure 8. Scenario difference view to visualize the difference between two selected model runs.

3.3.3 Time series view

The time series view was developed to display the groundwater head over time at user-specified locations for various scenarios (Figure 9). The user can choose various model runs for comparison. The precise groundwater heads can be visualized by moving the mouse cursor over the graph.

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Figure 9.   Time series view to compare various scenarios over time.

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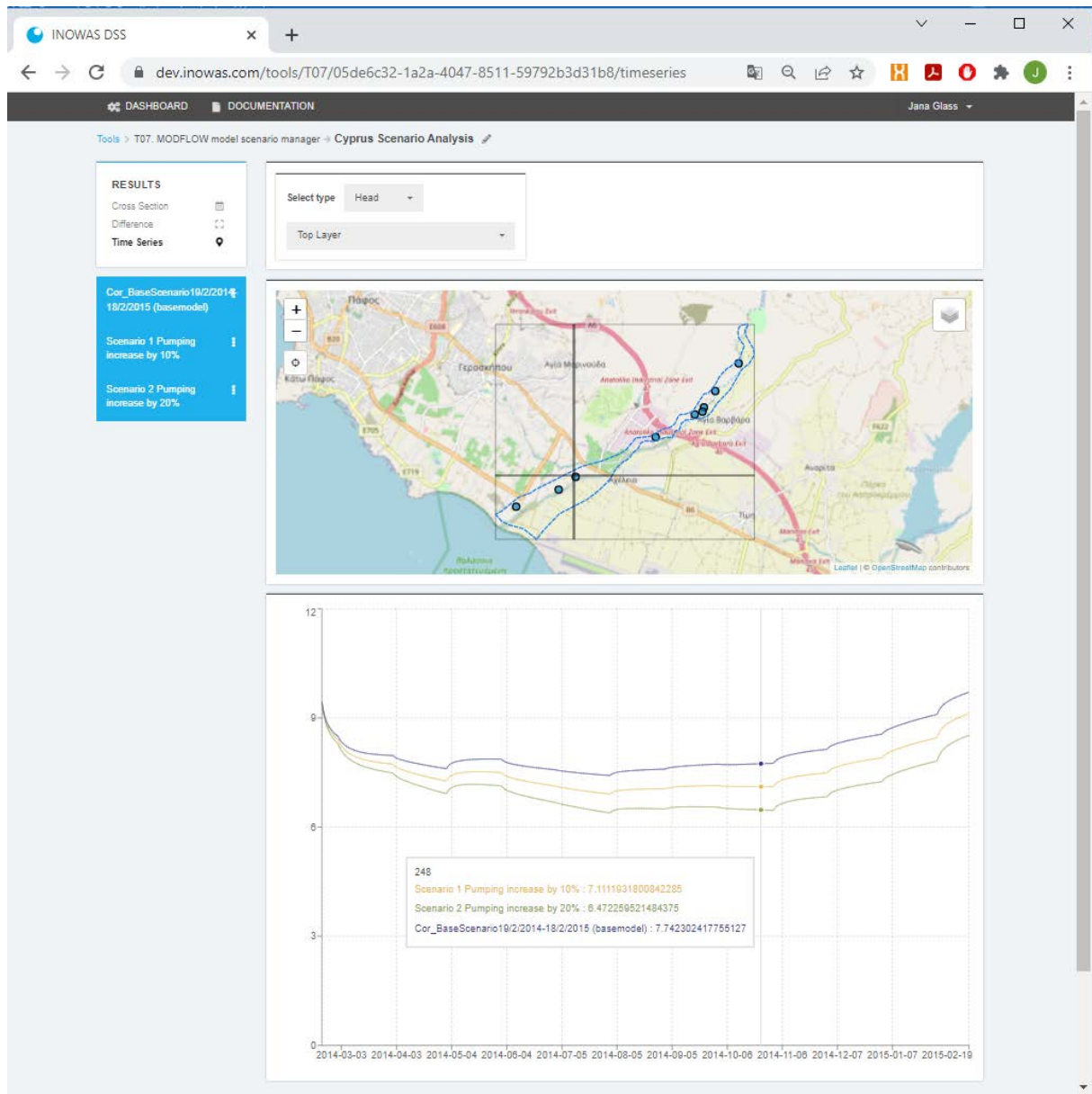
4. CONCLUSIONS AND OUTLOOK

This report describes the successful implementation of a web interface for scenario management and analysis of numerical groundwater flow (and transport) models on the INOWAS platform. 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 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. 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 scenario management tool offers the unique possibility to compare two or more model runs with each other. For this, distinct results visualization options including the cross section view, the difference view and the time series view have been developed. Multiple scenarios can be evaluated in one project, where the visualization of model results can be turned on and off for each of the model runs. In that way, the occurring changes between the scenarios can be easily visualized.

The web-interface provides new possibilities for easy transfer of modelling results to local stakeholders and decision-makers, independent of location and software. 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. The presented tools were specifically developed to solve MAR-related issues but can also be used to solve other, general groundwater-related questions.

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