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SMARTControl

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

Deliverable D4.4

Web-based real-time modelling

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

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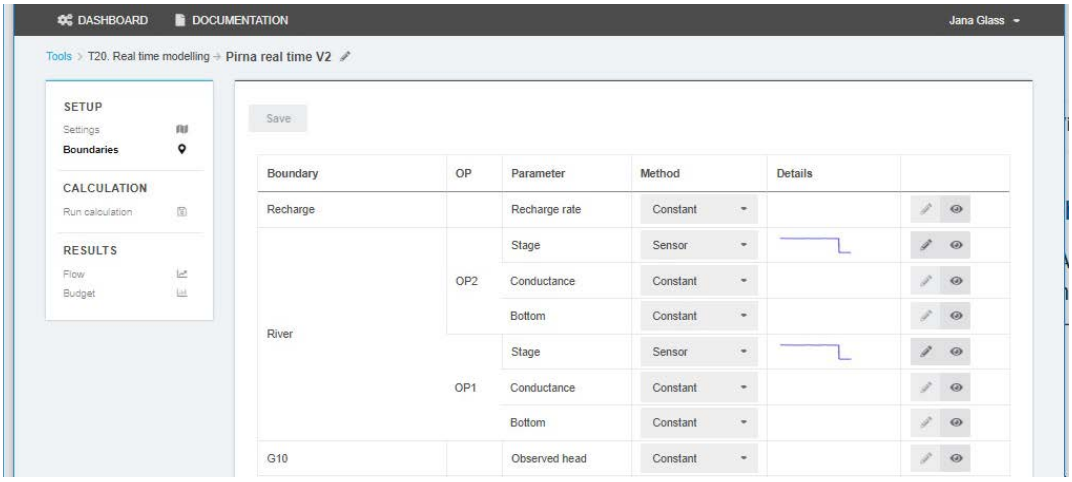

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Web-based real-time modelling

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

Short summary

This report describes the main functionality of the web-based tool “Real time modelling”. 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. Currently, the calculation process must be initiated manually but new data can be automatically imported from the INOWAS tool “Real-time monitoring”.

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ABSTRACT

Numerical groundwater flow models are essential for sustainable groundwater management. So far, groundwater models are mostly set up once and not updated on a regular basis. For this, the web-based real-time modelling tool has been developed on the INOWAS platform to allow the automatic integration of real-time sensor data into the numerical groundwater flow model.
Sensors, that are able to transmit data automatically, can be set up in the real-time monitoring tool (T10 of INOWAS platform). This data can be automatically integrated into the numerical groundwater flow model, once a real-time modelling project has been setup based on an existing calibrated groundwater flow model (T03 of INOWAS platform). At the moment, the model calculation must be initiated by hand to actualize the groundwater flow model with new data.
The developed 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. In that way it facilitates the up-to-date diagnostic of groundwater for regulators, decision-makers, operators and water managers.

CONTENT

Abstract 2
Content 3
Figures 4
1. Introduction 5
1.1 Background 5
1.2 About the SMART-Control project 5
1.3 Simulation tools 5
2 Tool concept and Technical infrastructure 7
2.1 Tool concept 7
2.2 Technical infrastructure 8
3. Tool UTILIZATION 9
3.1 Setup of real-time modelling instance 9
3.2 Definition of boundary conditions and observation heads 10
3.3 Run calculation and visualize results 12
4. Application at Pirna, Germany 14
5.1 Conceptual model 14
5.2 Web-Based model implementation 15
5.3 Definition of new boundaries 16
5.4 Results of the real-time model in Pirna, Germany 17
5. Conclusions and outlook 18

FIGURES

Figure 1. Concept of the real-time modelling tool. ... 7
Figure 2. Technical infrastructure of the INOWAS DSS utilized by the real-time modelling tool. ... 8
Figure 3. Setup of real-time modelling instance. ... 9
Figure 4. Definition of boundary conditions for a real-time model. ... 10
Figure 5. Integration of sensor data into the real-time model from tool T10 Real-time monitoring. ... 11
Figure 6. Boundary view of the real-time model. ... 12
Figure 7. Start the calculation of the real-time model. ... 13
Figure 8. Model area of the Pirna case study site including observation wells (Glass et al., 2021). ... 14
Figure 9. Screenshot of the web-based implementation of the model concept (Glass et al., 2021). ... 15
Figure 10. Screenshot of the simulation results for the time period April 2019- February 2021. Left contour map of groundwater heads in the fourth layer for the last time step including cross sections and right groundwater head over time. ... 16
Figure 11. Definition of boundary conditions for the actualized model at Pirna, Germany. ... 16
Figure 12. Water level over time for layer 4 of the Pirna groundwater flow model showing the time frame of the base model and the actualized model part. X-axis denotes daily stress periods of the model (09.04.2019 – 10.02.2021 for the base model and 11.02.2021 – 01.09.2021 for the actualized model). ... 17
Figure 13. Budget view of the actualized model results. ... 17

TABLES

Table 1. Short description of simulation tools developed in the SMART-Control project ... 5

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.

This report focuses on how real-time monitoring networks can be utilized to update an existing groundwater flow model with continuous, recent data. Numerical models are frequently used to plan, optimize and assess MAR facilities (Ringleb et al., 2016) but optimal use of modelling results is hindered as models are not frequently actualised and compared to present observation data. The innovative model update and simulation module will overcome this issue by integrating real-time observation data into the web-based modelling framework allowing for up-to-date simulations. This can bring a significant contribution to the reduction of risks associated with MAR since it allows the system operators to take very quick decisions.

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):

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.
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 **"T3. Automated groundwater model update and simulations"**. For the description of the other tools see the SMART-Control Deliverables D4.1, D4.2 and D4.3 or the project website: https://www.smart-control.inowas.com where also a detailed documentation of the tools is available.

2 TOOL CONCEPT AND TECHNICAL INFRASTRUCTURE

2.1 TOOL CONCEPT

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 (https://inowas.com/tools/t03-modflow-model-setup-and-editor/), 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 is hereby imported from a sensor defined in the INOWAS tool T10 Real-time monitoring. Alternatively, the values can be also set as constant.

The monitoring system covered by tool T10 integrates real-time 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 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 1). 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.

The online documentation of the tool is available at: https://inowas.com/tools/t20-real-time-modelling/.

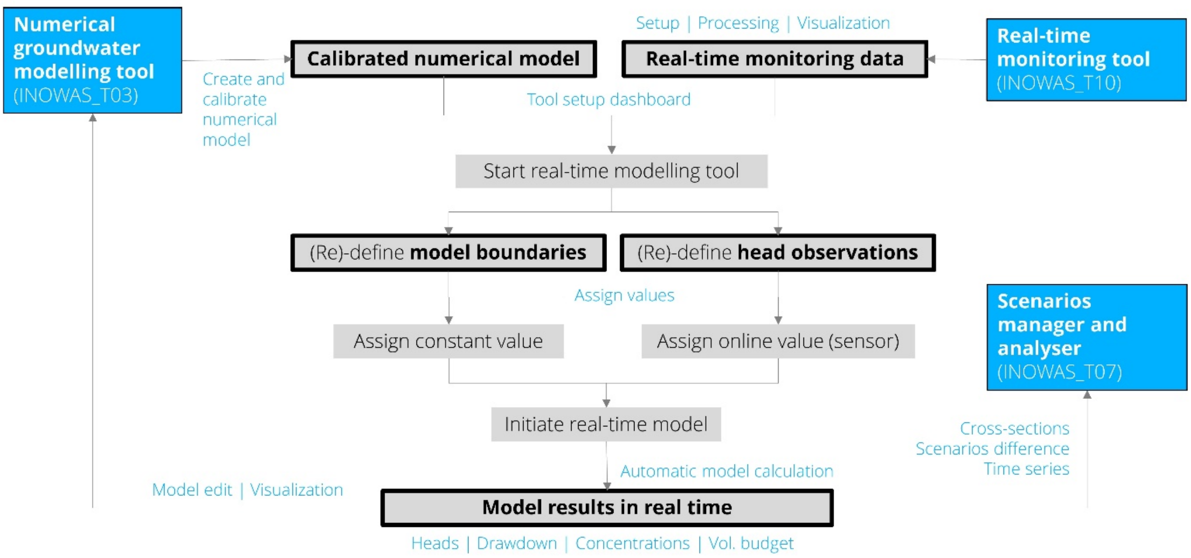

Figure 1. Concept of the real-time modelling tool.

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 2). 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).

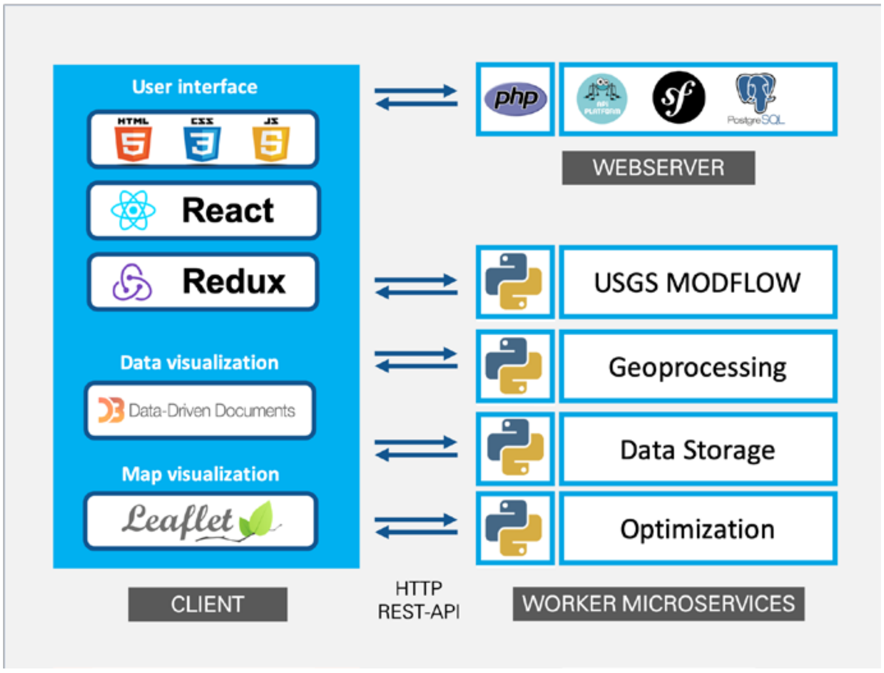

Figure 2. Technical infrastructure of the INOWAS DSS utilized by the real-time modelling tool.

3. TOOL UTILIZATION

3.1 SETUP OF REAL-TIME MODELLING INSTANCE

In the INOWAS dashboard, a new instance under tool “T20 Real-time modelling” can be created. First, the connected model needs to be selected from a list of existing models (Figure 3). A name for the real-time modelling instance can be selected as well as a description. Please be aware that you need to be the model owner in T03 to edit the model in T20. If you are not the model owner yet, go in the dashboard to tool T03 and clone an existing public model.

The new real-time modelling project can be either public (visible for everyone using the platform) or private (only visible for the user that created the instance). As time resolution, only daily time steps are currently supported. The starting date is automatically filled and corresponds to the ending date of the selected groundwater flow model.

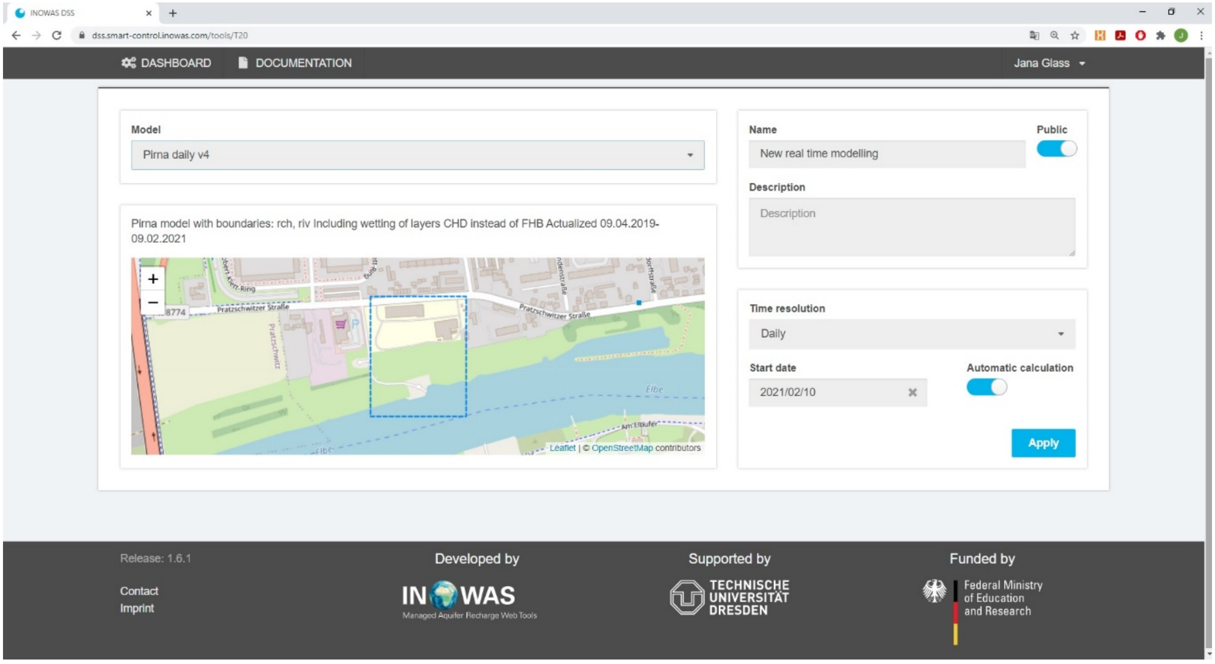

Figure 3. Setup of real-time modelling instance.

3.2 DEFINITION OF BOUNDARY CONDITIONS AND OBSERVATION HEADS

The boundary conditions of the selected numerical groundwater flow model are automatically integrated in the overview table (Figure 4). The boundary parameters for the real-time model can be currently either set to constant, meaning the value of the last stress period of the selected groundwater model is taken for all new stress periods, or with the help of a sensor.

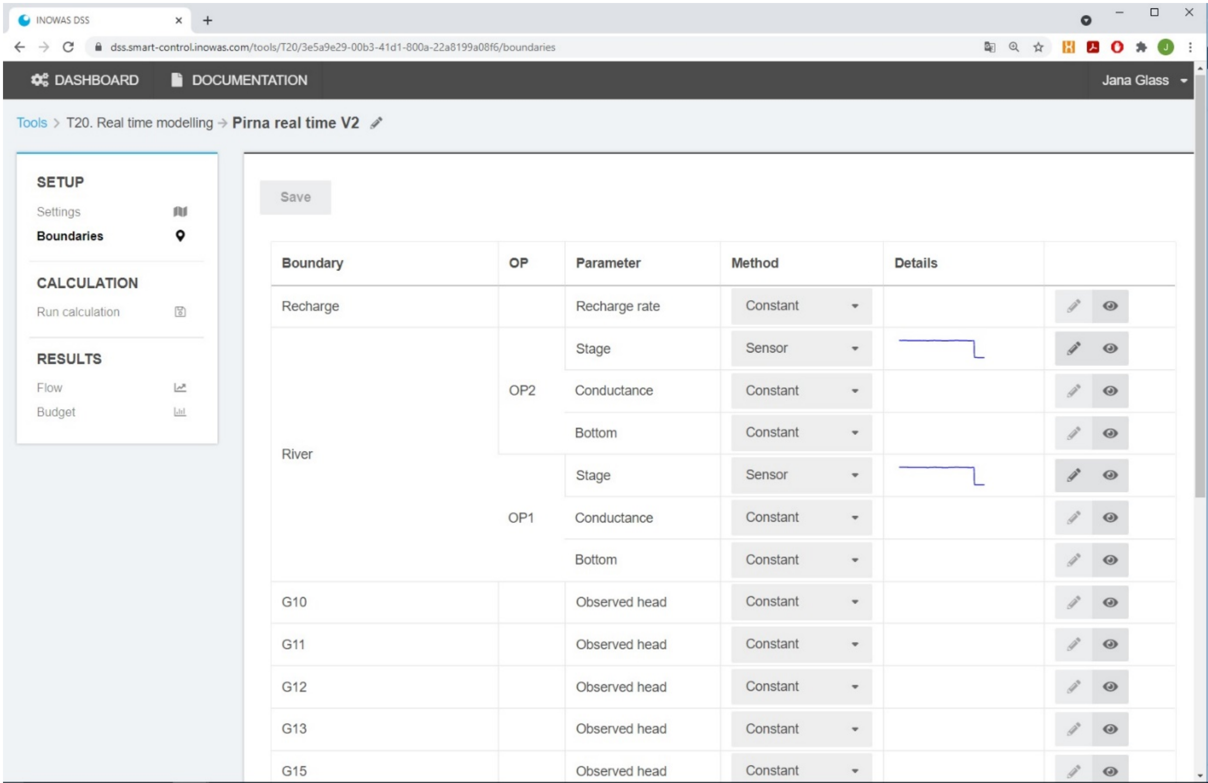

Figure 4. Definition of boundary conditions for a real-time model.

Real-time data can be integrated in the numerical model using the method “sensor”. The sensor, which has to be integrated in tool T10 Real-time monitoring can be selected using the edit button. The T10 instance, the Sensor and the Parameter need to be selected (Figure 5). Be aware that the sensor data needs already to be pre-processed in T10, using the value and time processing features of the tool.

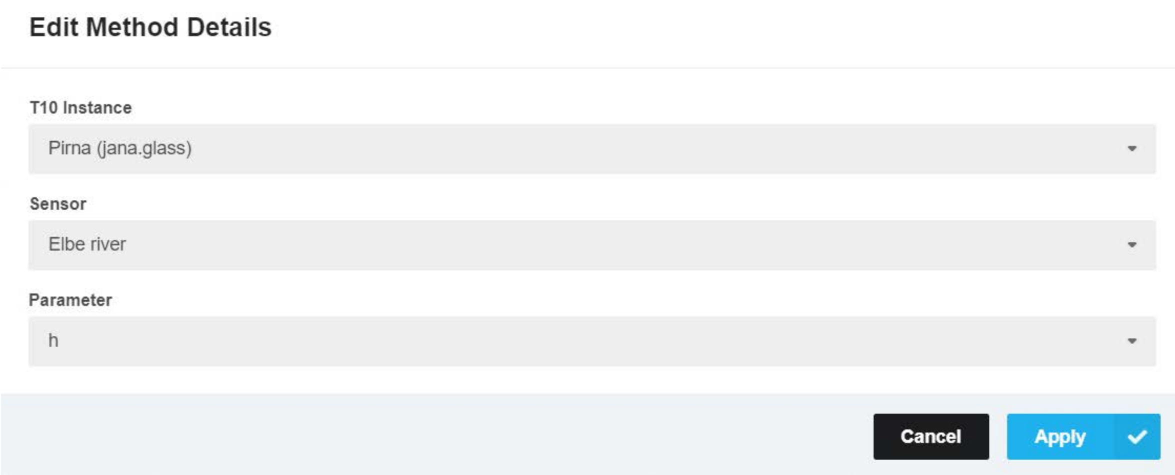

Figure 5. Integration of sensor data into the real-time model from tool T10 Real-time monitoring.

Sensor data can be integrated for each boundary visible in the Boundaries section of T20. To include offline sensor data, the data must be first included in tool T10 as monitoring data and can then, as a second step, be included as a sensor in the real-time model as described previously. In addition, a feature is planned to define boundaries not only constant or by sensors, but also by using a function.

The view option helps the user to evaluate the specific data of a boundary. To open the window, click on the “eye” in the right side of the boundary table. For each time step, the location of the boundary on the map as well as the values for each time step are shown (Figure 6). Be aware that in the view window, data cannot be changed.

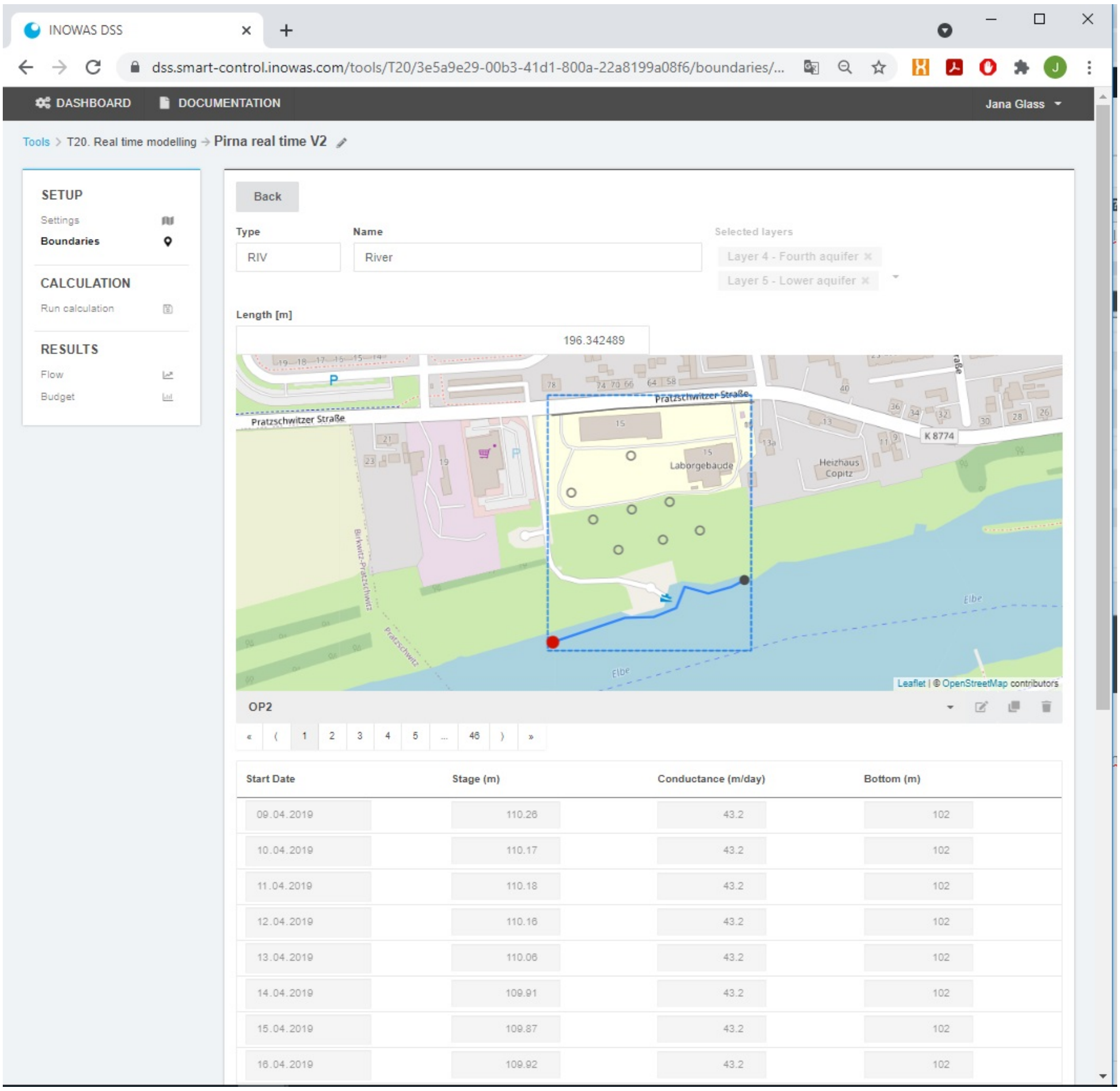

Figure 6. **Boundary view of the real-time model.**

3.3 RUN CALCULATION AND VISUALIZE RESULTS

The run calculation menu has the same structure as in T03.Numerical groundwater modelling and optimization. The calculation can be initiated using the “Calculate” button. Once the calculation has terminated, the calculation logs and model files can be viewed.

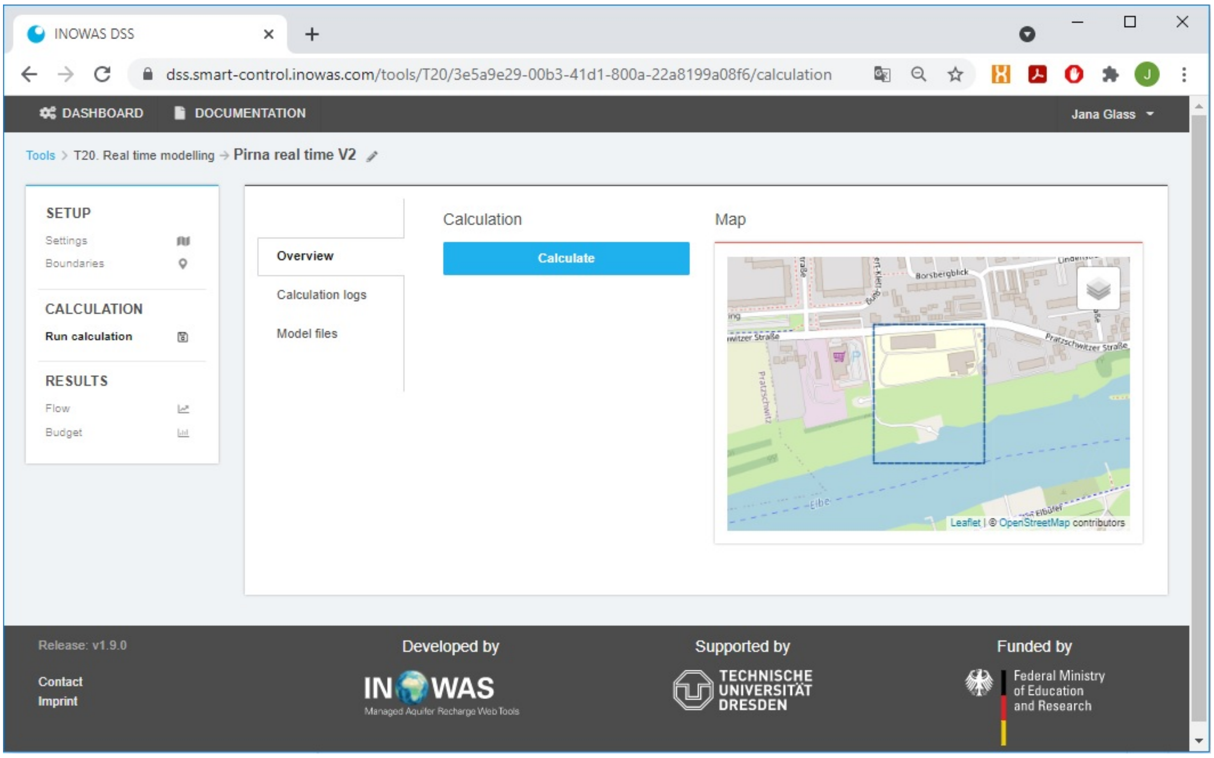

Figure 7. **Start the calculation of the real-time model.**

The results section also includes the same features as in tool T03. 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.

4. APPLICATION AT PIRNA, GERMANY

In SMART-Control project, the tool was validated using a numerical groundwater flow model that covers the test field in Pirna, Germany (Bista, 2015; Li, 2014). First, the numerical model was implemented on the web-based INOWAS platform "as it is" to validate the tool implementation on the platform and exclude implementation mistakes (Glass et al., 2021). After successful web implementation, the model was actualized with recent monitoring data, the nothern boundary was updated and the simulation period was expanded. These steps were followed to prepare the numerical model so that it can be used as a web-based real-time modelling case using real-time monitoring data in the frame of SMART-Control.

5.1 CONCEPTUAL MODEL

The model area is divided into 90 rows and 70 columns. The cells of the model are 2.5 m high and 2.6 m wide. The model consists of 5 layers with varying thickness reaching from the surface to the baserock in a depth of about 15 m below surface. The simulation time starts on the 9th April 2019 and ends on the 10th February 2021. The first stress period is steady state, the other stress periods are transient.

The flow in the model domain is mainly influenced by the Elbe river, specified as the river boundary condition (RIV) at the southern boundary of the model domain (Figure 8). Data for the river stage is derived from a public monitoring station which is located about 500 m upstream of the pilot site considering a gradient of 0.25 m/km. The streambed conductance was assumed constant and estimated to be 43.2 m/d using a riverbed thickness of 1 m and a streambed hydraulic conductivity of 0.864 m/d. The stage of the river for the real-time model is actualized using the public monitoring station, which is connected to the INOWAS platform by a WSV layer.

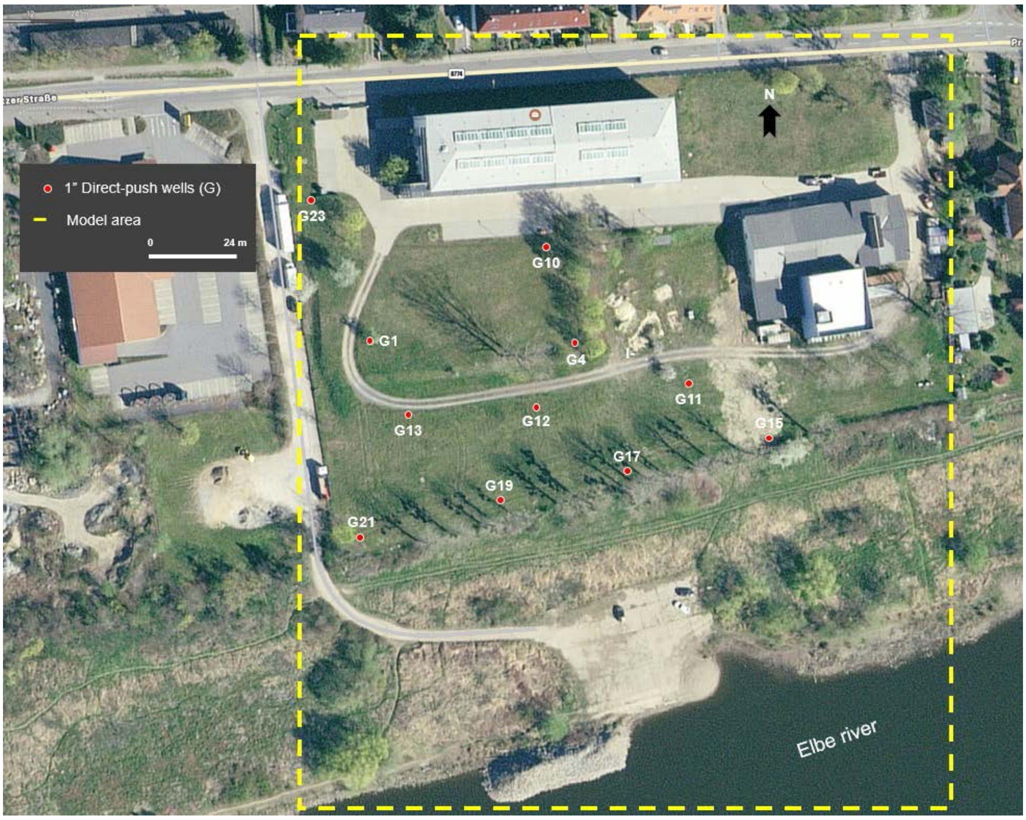

Figure 8. Model area of the Pirna case study site including observation wells (Glass et al., 2021).

The Constant Head boundary condition (CHD) is specified along the northern boundary of the model domain to be able to regard the changing flow direction. The head is specified with the help of the groundwater monitoring well G23. For the real-time model, the head at FI3 is chosen as the northern boundary as G23 is too small for the installation of a real-time sensor.

In addition, recharge (RCH) is applied to the highest active cell at a constant rate of 0.000432 m/d, derived from the precipitation during the study period and a coefficient of 0.2.

5.2 WEB-BASED MODEL IMPLEMENTATION

The numerical groundwater flow model was implemented on the web-based INOWAS platform using Tool T03. Numerical groundwater modelling and optimization (https://inowas.com/tools/t03-modflow-model-setup-and-editor/, Figure 9) by uploading data via GeoJSON, in raster format or as CSV file. In that way, the model domain, layer heights, soil parameters, boundary conditions as well as observation wells were integrated on the platform for the initial time period June 2014-January 2015 (Glass et al., 2021).

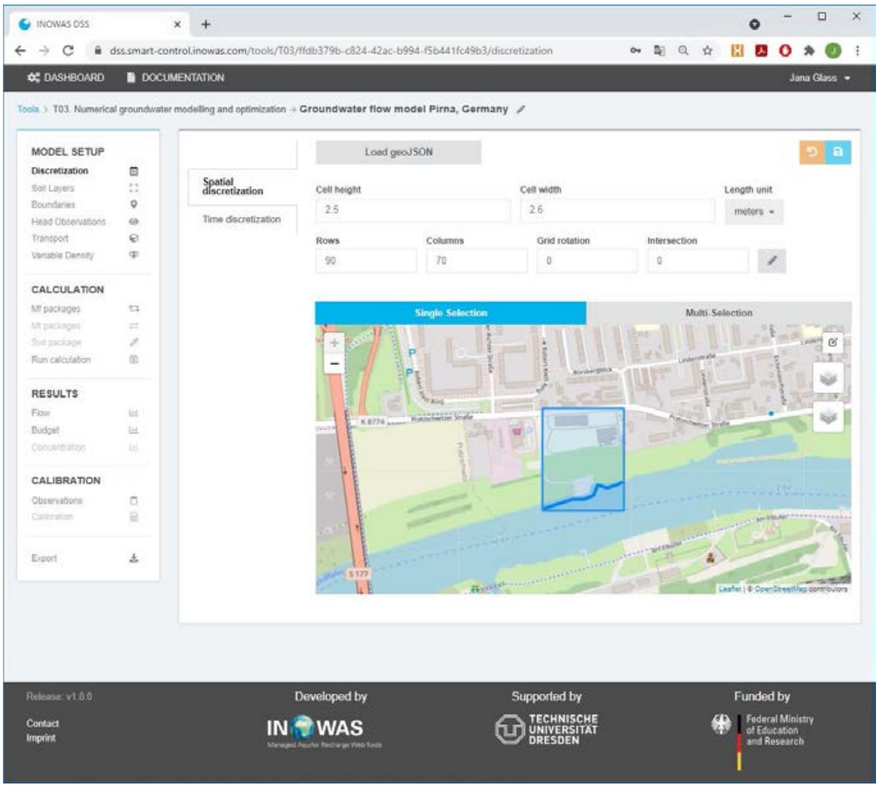

Figure 9. Screenshot of the web-based implementation of the model concept (Glass et al., 2021).

As a next step, the model was updated with available monitoring data for the time period April 2019- February 2021 corresponding to 674 daily time steps. The first stress period is set as steady state, the following time steps as transient.

The model results show that the groundwater levels in the study area are highly influenced by the water level of the closeby Elbe river (Figure 10). During low flow in the Elbe river, water is flowing towards the river. If the Elbe river water level is rising during floods, the groundwater flow direction is reversed and water is flowing from the river into the study area.

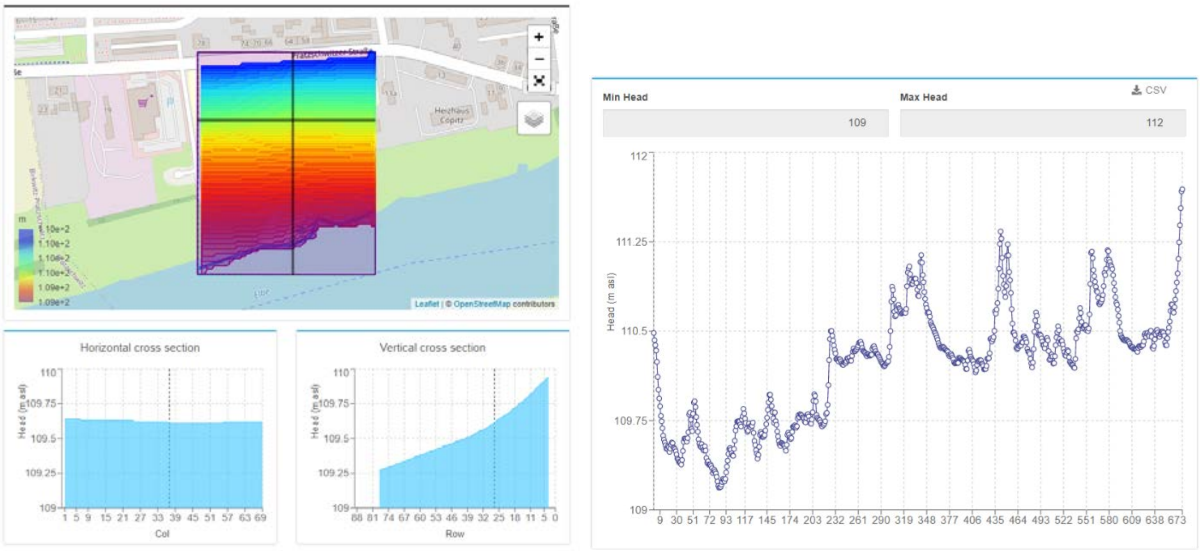

Figure 10. **Screenshot of the simulation results for the time period April 2019- February 2021. Left contour map of groundwater heads in the fourth layer for the last time step including cross sections and right groundwater head over time.**

5.3 DEFINITION OF NEW BOUNDARIES

Time series data which should be used in the real-time modelling instance have to be included in tool T10 Real-time monitoring.
In the Pirna model, automated incorporation of new monitoring data as boundary conditions or observation points was incorporated for (Figure 11):

- River stage, and
- Northern CHD boundary

All other boundaries such as recharge and observation points are kept constant for the purpose of testing the tool. The real-time model instance was tested with data from 11.02.2021 – 01.09.2021.

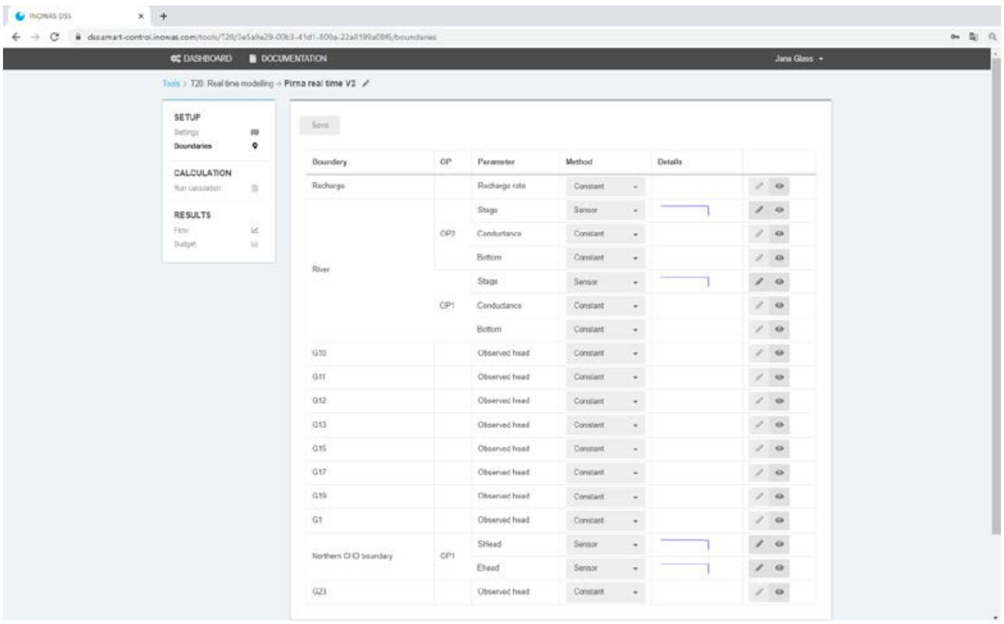

Figure 11. **Definition of boundary conditions for the actualized model at Pirna, Germany.**

5.4 RESULTS OF THE REAL-TIME MODEL IN PIRNA, GERMANY

The calculation of the Pirna model with extended calculation using real-time data was successful. The water level over time is shown in Figure 12 for the base model and the actualized model part.

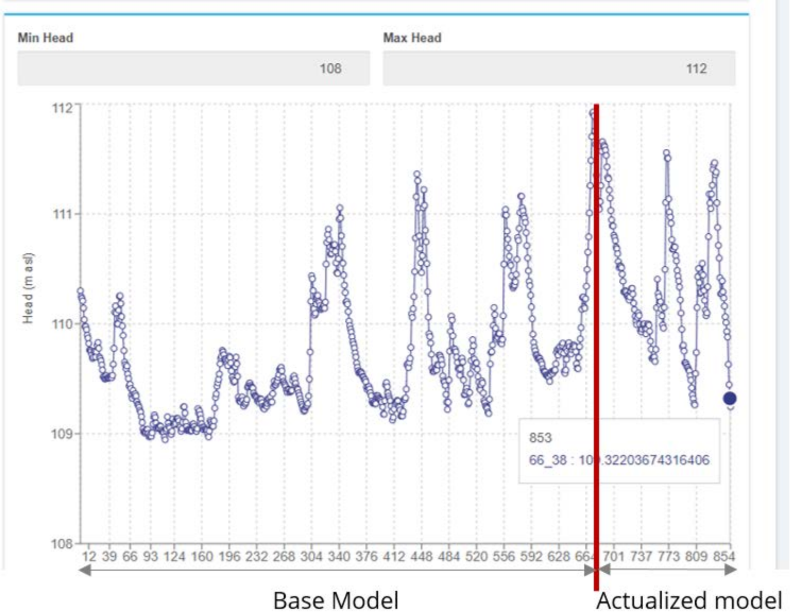

Figure 12. **Water level over time for layer 4 of the Pirna groundwater flow model showing the time frame of the base model and the actualized model part. X-axis denotes daily stress periods of the model (09.04.2019 – 10.02.2021 for the base model and 11.02.2021 – 01.09.2021 for the actualized model).**

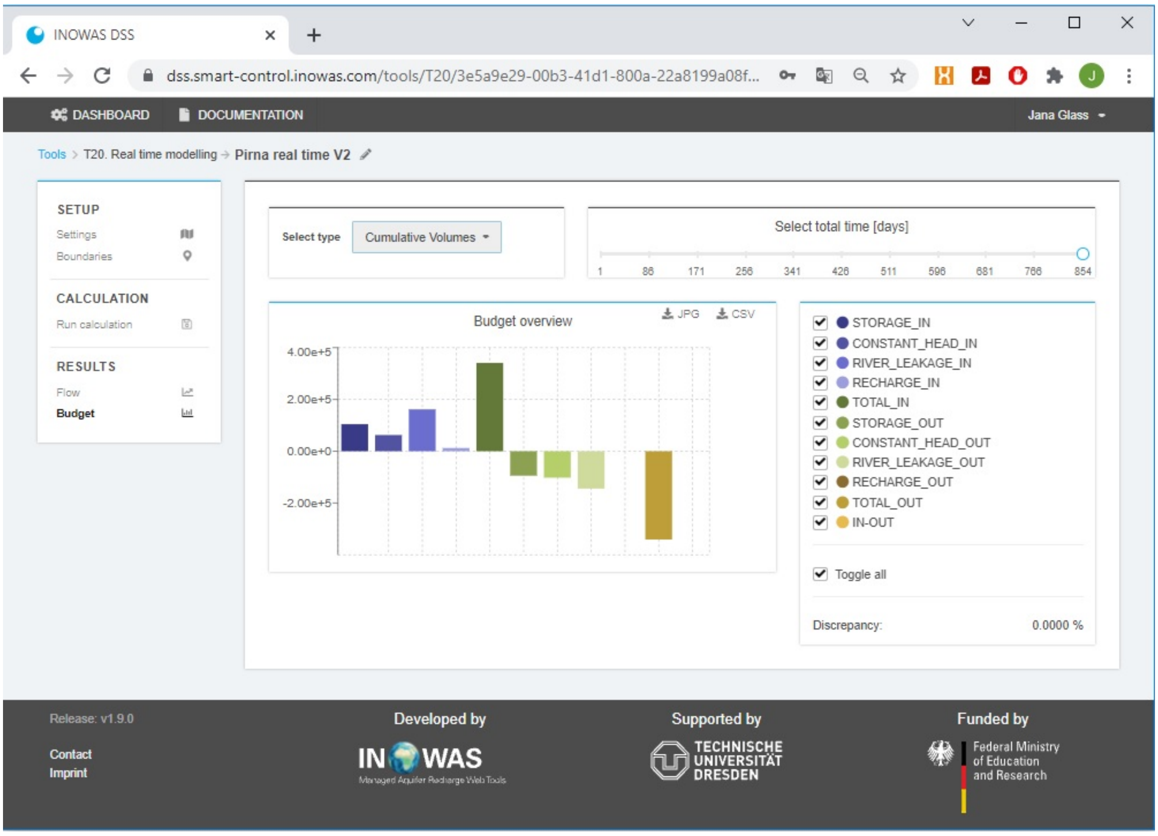

Figure 13. **Budget view of the actualized model results.**

5. CONCLUSIONS AND OUTLOOK

In the frame of SMART-Control, the real-time modelling tool has been developed and successfully tested at the Pirna case study site in Germany. The automated integration of real-time sensor data into the numerical model has been realised. The model is not yet automatically run as the calculation must be initiated in the real-time modelling tool if new model results are needed. But new monitoring data received by the INOWAS platform in tool T10 Real-time monitoring are automatically integrated into the numerical model once the real-time modelling instance has been setup. This is 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.

It is planned to further expand the functionalities of the tool by e.g. adding the possibility to define boundary conditions by functions or an algorithm for extrapolation of the data. It is also antipicated to improve the results visualisation so that those can be more customized by the user and it is clearer which section of the model results belongs to the base model and which section has been newly added. This is also planned for the calibration section if observation data is integrated in the real-time model. Furthermore, an option to save the calculated model as a new base model is planned. In that way, once the model results are checked for corectness and feasibility, the new model can be taken as base model, the added time steps are saved to the model and the model can be further expanded by a new real-time modelling instance.

Despite its (current) basic functionalities, the developed 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.

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