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Web-based tool compilation of analytical equations for groundwater management applications

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ABSTRACT

The INOWAS platform provides a compilation of free web-based tools for groundwater management. All tools are running on a web server and can be accessed via standard web browsers. The implemented analytical equations enable the assessment of saltwater intrusion induced by pumping or sea level rise, the calculation of travel time through unconfined aquifers and the evaluation of pumping-induced river drawdown. The groundwater mounding calculator can be used to estimate the rise of groundwater levels underneath infiltration basins. To determine the contaminant concentration downgradient of a constant source, an analytical tool solving the advection-dispersion equation can be utilized. All tools are incorporated into a decision support environment. The user is provided with detailed online support that contains the theoretical background of the tools, possible applications and examples.

Software availability

The INOWAS platform is accessible via web-browser under https://inowas.hydro.tu-dresden.de/ (free user registration required).

1. Introduction

Groundwater is an important water supply resource in many regions that needs to be managed sustainably while meeting societal demands. This is especially true with regard to the increasing pressure on groundwater caused by climate change, urbanization and population growth.

Flexible methods and tools are needed to assess quantitative and qualitative aspects of groundwater management. Besides numerical models, empirical and analytical equations are frequently used to depict the underlying hydrogeological processes (e.g. Callander et al., 2011; Carleton, 2010; Halford and Kuniansky, 2002). To facilitate the use of these equations and to speed-up the calculation, various spreadsheets have been developed by researchers, environmental service operators or governmental agencies. These assess a wide range of groundwater-related problems: from basic hydrogeological investigations such as the estimation of hydraulic conductivity from grain size analysis (Devlin, 2015) or the analysis of pumping and slug test data (Halford and Kuniansky, 2002) to more complex tools for the estimation of hydraulic gradients and flow velocities using groundwater head data (Beljin et al., 2014; Devlin, 2003) and transient or time-dependent groundwater modeling (Karahan and Ayvaz, 2005a, 2005b). Spreadsheets are also used for specific problems such as the calculation of groundwater mounding underneath an infiltration basin (Carleton, 2010) and the characterization of seawater intrusion in coastal aquifers (Callander et al., 2011).

Despite their simplicity and high compatibility with personal computers (they mostly run under different versions of Microsoft Excel), spreadsheets for groundwater management have all the typical limitations of desktop-based software including e.g. system dependence, manual updating and software installation. Few attempts have been made to overcome this by developing web-based tools. Recent advances in computational speed as well as improved computational networks and internet accessibility have also facilitated this development. In contrast to desktop computing that uses existing computer programs and spreadsheets, web-tools hold the advantage of increased software availability, device and location independence, easy maintenance, platform and hardware independence as well as resource pooling. One key disadvantage is the dependence on an internet connection.

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One such example is STRMDEPL08[1], a web-based version of a spreadsheet developed by the United States Geological Survey (USGS) that uses various analytical solutions to calculate the streamflow depletion caused by nearby pumping wells (Reeves, 2008). The USGS web-tool requires the input of various hydrogeological and operational parameters and provides a table of the streamflow depletion over time. The Environmental Software Online Company[2] also provides various online calculators as preliminary screening tools. The implemented tools include groundwater mounding calculations, a one-dimensional transport model based on the advection-dispersion equation and hydraulic conductivity estimation from grain size analysis or slug tests. Valocchi and Werth, 2004 developed a web-based interactive simulator for groundwater pollutant fate and transport for the application in introductory student courses. The influence of variable contaminant inputs and groundwater age distributions on contaminant trends in wells or other groundwater discharges can be estimated using another USGS web-tool called GAMACTT[3] (Böhlke et al., 2014). The tool is only designed for educational uses as the aquifer model and the calculations are highly simplified.

These web-based tools represent an important step forward from classical desktop-based spreadsheets and can be applied for educational purposes or as screening tools for various groundwater problems. However, their principle is quasi-identical, implying manual input of various parameters for the spreadsheet-based calculation of an output value. A major drawback of the available web-based tools is that values cannot be stored and the later continuation of calculations is not possible.

The INOWAS platform presented in this paper closes this gap by combining the graphical representation of results commonly found in spreadsheets with the features and functionality of cloud-based computing.

2. INOWAS platform

The INOWAS platform is a free web-service aimed to solve groundwater-related issues. The particularities of the platform include account-based simulations with the possibility to save the workflow at any time for later continuation. The pooling of tools and open-access availability aims to enhance usability of already existing applications. The design of the tools is very intuitive with modern, standardized graphical user interfaces (GUI).

The platform is freely accessible under the following link: https://inowas.hydro.tu-dresden.de/. User registration is required to access the full functionality of the INOWAS platform.

2.1. Architecture

The technical infrastructure is based on two components (Fig. 1): the CLIENT representing the terminal for the user with internet access via a web browser and the SERVER that consists of a standard Linux Server hosted by the Centre for Information Services and High Performance Computing (ZIH) of Technische Universität Dresden, Germany. The reactive web-based user interface is based on the latest version of ReactJs[4] and Redux[5], two JavaScript libraries. The communication to the server through HTTP commands and REST-API is only initiated if the user saves or opens existing tool instances. Implemented third-party libraries such as D3.js[6] help to calculate the analytical equations and visualize their results.

2.2. Features

The core of the platform is the personal dashboard (Fig. 2) with an overview of available tools and projects. After selecting a tool from the left menu, the user has several options: a) start a new project with the selected tool, b) open a previously saved project and continue working on it or c) import (duplicate) a project and use it as basis for a new project. For each tool run, the system offers two types of confidentiality: projects can be either saved as *private* (available only to project owner) or *public* (any registered user can access and utilize the data). In this way, the user can control the access to the tool run and it is guaranteed that sensible or restricted data is protected. This advanced dashboard is one of the key features of the INOWAS platform, which is not available in any previously developed web-tool.

Furthermore, a documentation containing the theoretical background including restrictions and equations, a description of the default example and references is available for each tool from a link in the navigation bar.

2.3. Graphical user interface

The web-based GUI of each tool is comprised of several components: a) tool sketch (conceptual model used as basis for the tool), b) graph displaying the results and the calculated parameter(s), c) data input panel with sliders for easy parameter input, and d) message box with additional information, settings, warning messages, or results analysis (Fig. 3). For each tool, a default example is displayed upon creation of a new project (which can be reset through a button). A simplified submenu allows to rename and save the actual project. This standardized GUI makes it is easy for the user to get familiar and apply new tools.

3. INOWAS analytical tools

The INOWAS platform was developed aiming to solve groundwater related issues with a particular focus on the planning, management and optimization of managed aquifer recharge (MAR) applications. Nevertheless, the platform is not only restricted to MAR and it can be applied to solve a wide range of groundwater problems.

The implemented tools cover a variety of issues that can be evaluated using analytical equations (Table 1). The implemented tools were chosen as they were already partly implemented in other spreadsheets or web interfaces and fit the general purpose of the INOWAS platform.

The documentation pages of the INOWAS platform[7] or the provided supplementary material give a detailed description of the theoretical background of the implemented tools.

3.1. Groundwater mounding

MAR, defined as the intentional recharge of water for later recovery or environmental benefits, is a valuable tool for the sustainable management of groundwater (Dillon, 2005). The impact of water recharge on the groundwater is an important aspect that needs to be evaluated before a new MAR scheme can be implemented. For surface infiltration systems, the analytical Hantush equation (Hantush, 1967) can be used to calculate the groundwater mounding underneath an infiltration basin depending on the recharge rate and duration of recharge, the infiltration basin size, and aquifer parameters such as the initial groundwater level, the specific yield and the hydraulic conductivity.

[1] https://mi.water.usgs.gov/software/groundwater/CalculateWell/index.html, 19.06.2018.
[2] http://www.groundwatersoftware.com/calculator.htm, 19.06.2018.
[3] https://ca.water.usgs.gov/projects/gamactt/, 19.06.2018.
[4] https://reactjs.org/, 19.06.2018.
[5] https://redux.js.org/#license, 19.06.2018.
[6] https://d3js.org/, 19.06.2018.
[7] https://inowas.hydro.tu-dresden.de/.