

Model as a Service (MaaS): middle and high school students learn about groundwater using MODFLOW

Summary

Jointly with the Office of Mathematics, Science, and Technology Education (MSTE) at University of Illinois at Urbana-Champaign, we develop a web application of MODFLOW to simulate the impacts of groundwater withdrawal on the water table and streamflow. Hypothetical scenarios are used to illustrate water conflicts between urban and farming use. Through the interactive web interface on the client side, students can set up pumping wells, invoke the execution of the MODFLOW model on the server side with various pumping rates via the network, and view the impacts with the web browser. As a result, we expect students to learn basic concepts of groundwater and the dynamic interactions between stream and aquifer through the web application.

Instruction

In order to support MODFLOW as a Service, a web-application of the groundwater model is developed as follows:

Step I: Develop a groundwater model with MODFLOW

MODFLOW is free, open-source software to develop (3D) finite-difference groundwater models. MODFLOW uses the modular structure framework which facilitates the integration of independent packages and enhances its original scope. These packages include, but not limited to, discretization package (*.dis), basic package(*.bas), flow package(*.bcf), well package(*.wel), ... Each package simulates specific aspects of a groundwater-flow system with a set of format-specific parameters. One of the main challenges of groundwater modeling with MODFLOW lies in setting up the parameters of the selected packages correctly. Even a simple groundwater model involves dozens of parameters, and thus a user friendly interface is in demand to select the packages and set up the parameters. In this project, we choose MODFLOW-2005 and the student version of Groundwater Vistas 6.0 is used to prepare model inputs for the groundwater modeling under three scenarios.

- **Model Geometry and Settings**
 - One-layer unconfined aquifer
 - Size: 50×50 grids
 - Grid: $200\text{m} \times 200\text{m}$
 - Thickness: 100m
 - Boundary conditions: constant head boundaries on the north and south side; impervious boundaries on the east and west side.
 - Simulation period: five years
 - Stress period: one month

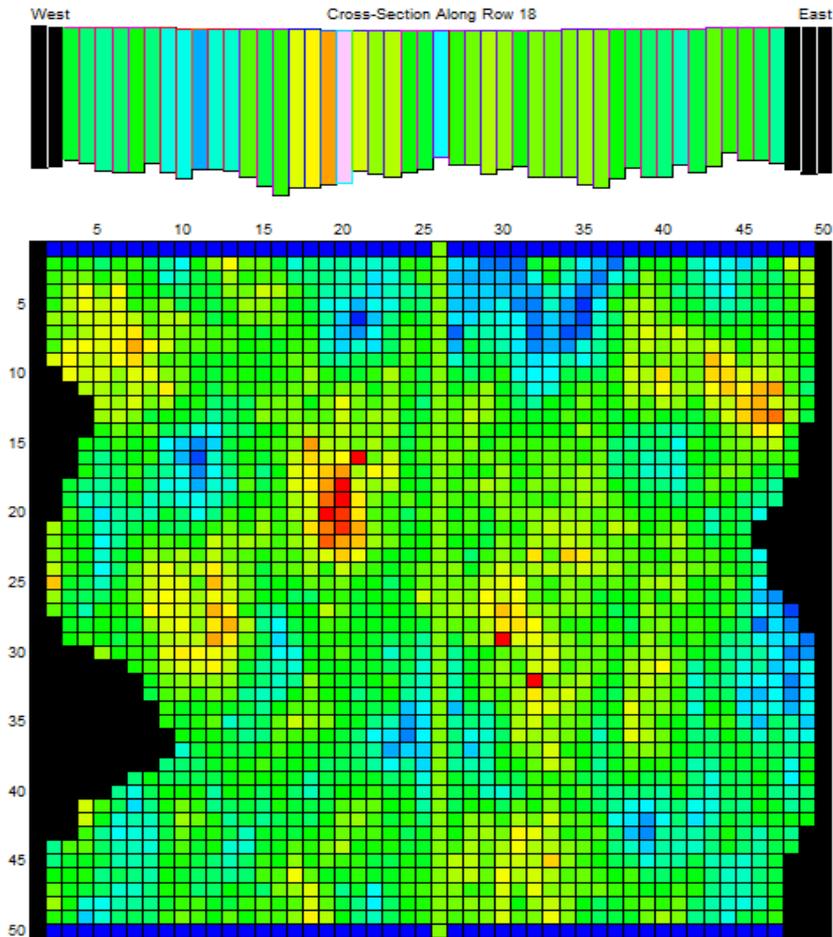


Figure 1. Top: cross-section of the groundwater model along row 18; bottom: plain view of the groundwater model with B.C.s and hydraulic conductivity color coded

We build a groundwater model with MODFLOW-2005 to simulate the impacts of groundwater withdrawal on the aquifer under three scenarios (see below). The impacts examined include 1) change of the water table at a specific location over time; 2) change of the water table profile across an entire row or column; 3) change of the size of wetland; 4) water exchange between stream and aquifer; 5) change of stream outflow. Please refer to Fig. 2 for more details.

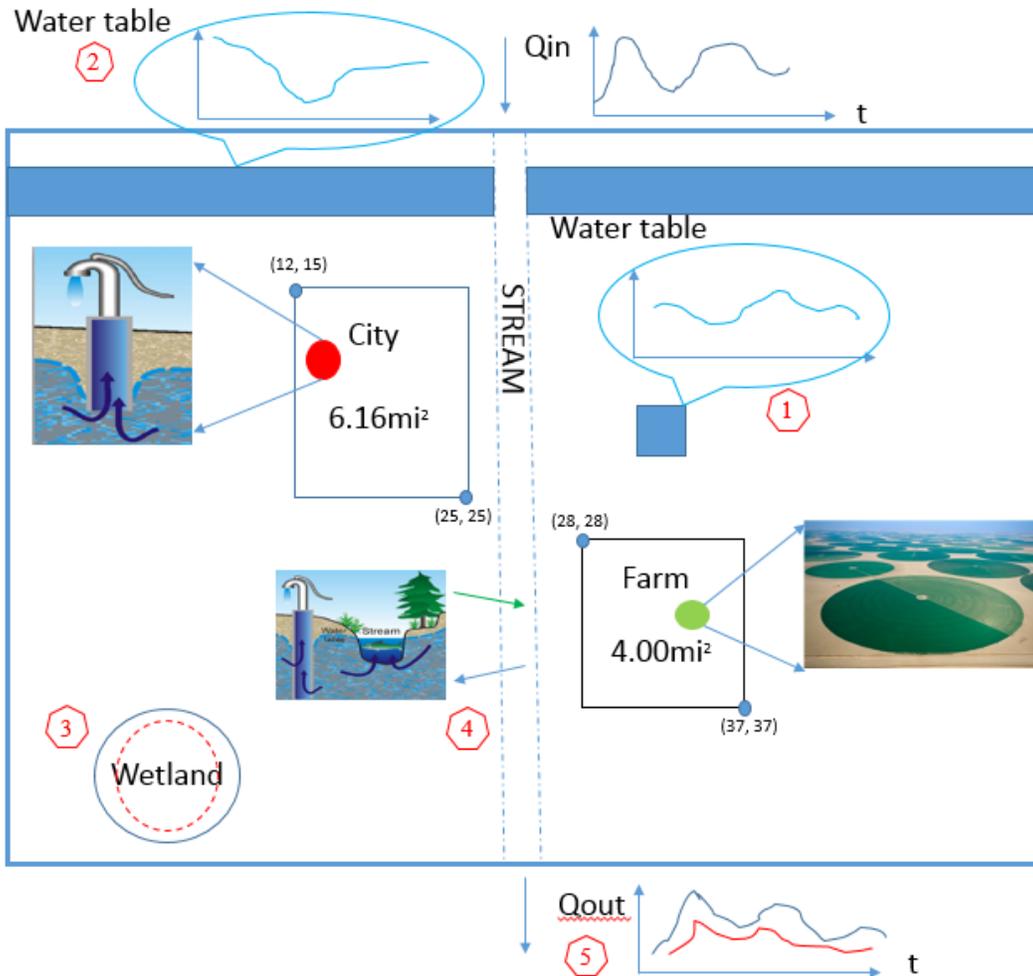


Figure 2. Interaction of the groundwater model with different systems including stream, city, farm and wetland.

- Scenarios
 - Non-development
 - Stream: defined by the column 26 in Fig. 1 and Streamflow-Routing Package (SRP) is used to simulate stream in the model, flowing from north to south with monthly varying inflow. Aquifer and stream are interconnected.
 - Wetland: defined by the area where the depth to the groundwater level is less than 0.2m
 - Recharge: ≈ 0.25 mm per day
 - Pumping only in the city
 - City area: denoted by a rectangle in Fig.2
 - Pumping wells: three wells in city area with constant pumping rate: $-10,000$ m^3/d
 - Recharge: ≈ 0.0625 mm per day
 - Pumping both in the city and farm
 - Farm area: denoted by a rectangle in Fig. 2

- Pumping wells: three wells in city area with constant pumping rate: -10,000 m³/d; two wells in farm area with monthly varying pumping rate as follows:

Month	May	Jun	Jul	Aug	Sep	Oct
Pumping rate (m ³ /d)	-203.2	-4836.2	-8717.3	-6238.3	-1930.4	-772.2

They pump for the first three years and then shut down the wells.

- Recharge: 20% of the pumping rate in the farm area.

Then, we prepare the groundwater model inputs using Groundwater Vistas 6.0 based on the descriptions of the three scenarios.

Step 2: Running groundwater model as a web application

- Choose the Server: Windows Server or Linux Server

MODFLOW is available both for Windows and Unix/Linux. The selection of the server depends on the version of MODFLOW used for a specific project. To save the efforts to compile MODFLOW on the Linux machine, in our project we use the Windows version which contains a compiled executable. Thus, we choose a Windows server accordingly.

- Upload the groundwater model to the server

The Windows server is set up and configured by Engineering IT Shared Services provided by University of Illinois at Urbana-Champaign. We then upload the MODFLOW-2005 executable file (.exe) and model inputs for different scenarios to the Windows server. Note that the groundwater model input and output for different scenarios are saved into different folders on the server. The folder name depends on the scenario ID and user ID. For each scenario, we will need a copy of MODFLOW executable (.exe file) in the corresponding folder. In our case, although it is not necessary, we still change the name of input files we need to modify (e.g., .hds and .nam) in each folder based on the scenario ID and user ID.

- Design the web interface

The web interface is used by users on the client side to send the request to run the groundwater model hosted on the server side. Besides Javascript, the visualization of model results makes heavy use of HTML 5 canvas element.

- Communication between the client and the server

- Users can set up pumping wells and rates in the city or/and farm area. The well information are then posted to the server through AJAX (asynchronous JavaScript and XML) call as shown in Fig. 3. To be more specific, when different users make an AJAX call from the client (Step 1) to send the well data (Step 2) and invoke the

groundwater model on the server, a specific user ID and scenario ID will be assigned to different users, and a new folder will be created on the server based on the user ID and the scenario ID. A copy of the groundwater executable and the corresponding model input files will be prepared and saved into this folder (Step 3) using the script written in PHP, which is a standard server-side scripting language. The PHP script is also used to call the execution of the groundwater model on the server side (Step 4). After the execution of the groundwater model is complete, the results are saved to the same folder (Step 5) and the program returns back to the PHP function call (Step 6).

- The model results including water table (.hds) and list (.lst) files are formatted into binary data type (Step 7) and sent back to the client side (Step 8). The results are then displayed on the browser (Step 9) as shown in Fig.3.

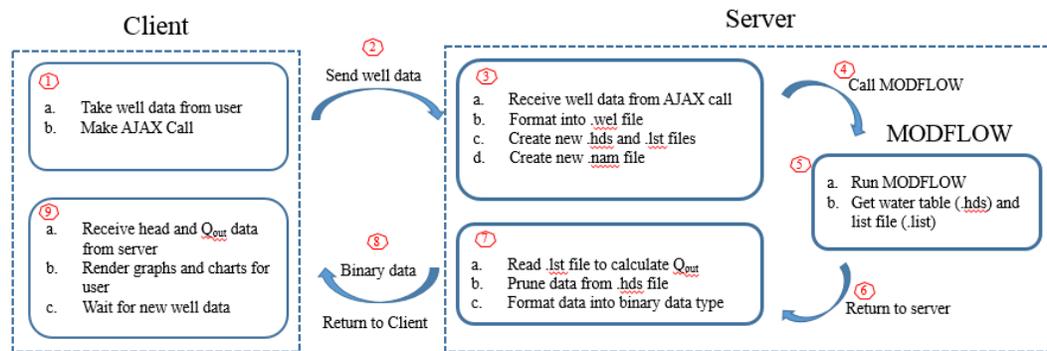


Figure 3. Communication between the client and the server

Once Step I and II are complete, we can then explore the web application of the groundwater model with MODFLOW as shown by Fig. 4.

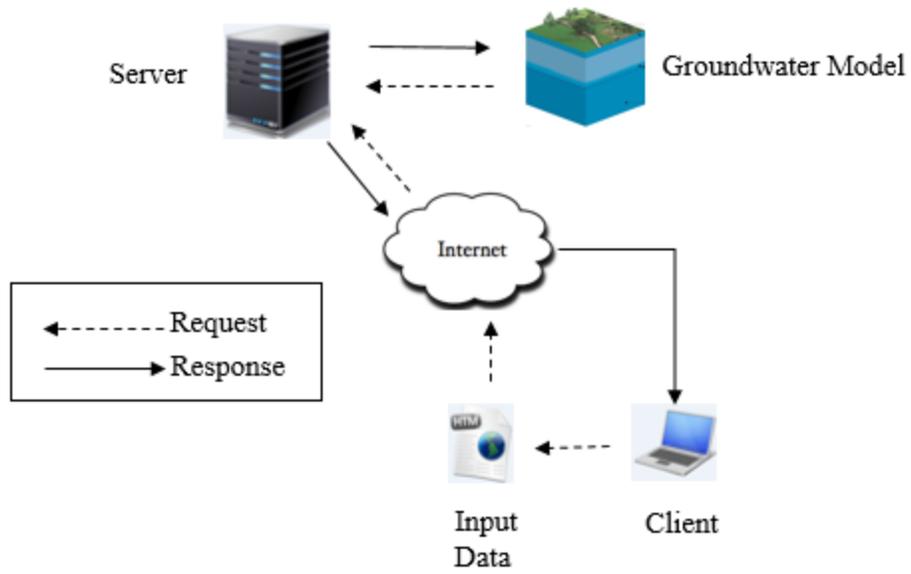


Figure 4. The architecture of the web application of the groundwater model. The groundwater model is hosted on the server. The interactions between the server and the groundwater model are implemented through PHP script.