ground water

Software Spotlight/ Motomu Ibaraki, Software Editor

uWATER-PA: Ubiquitous WebGIS Analysis Toolkit for Extensive Resources—Pumping Assessment

reviewed by J. Fernando Rios[1], Ming Ye[2], and Liying Wang[3]

Introduction

According to the National Research Council (2010), a significant challenge in the GISciences is the creation and development of tools that enable the results of scientific modeling to be easily understood. For science-informed decision making as well as for the purposes of informing and engaging ordinary citizens in discussions regarding geographical technologies, the National Research Council (2010) argues that it is indispensible to develop tools that can easily present scientific modeling results and translate scientific understanding into the process of decision making. Yang and Lin (2011) at the Illinois State Water Survey (ISWS) address this challenge in the context of assessing the effect of pumping on changes of groundwater levels (i.e., drawdown) of a confined aquifer by making freely available the GIS-based software uWATER-PA to calculate drawdown based on the Theis equation (Theis 1935). The model was developed using the Microsoft Visual Basic 2008 programming language and implemented as an extension (add-in) to ArcGIS Explorer Desktop (AGX), a free GIS by ESRI Inc. Compared to ESRI's flagship product ArcGIS, AGX has a simplified user interface (UI) and reduced functionality.

The uWATER-PA software is built on top of the uWATER framework previously developed by the ISWS (Yang and Lin 2010). The purpose of the uWATER framework is to extend AGX by enabling the execution of both spatial and attribute query functions, which are common in a more advanced GIS (e.g., ArcGIS), but are absent from AGX. This framework enables uWATER-PA to determine existing wells that will be affected by a new pumping well at a specified location. The scientific model behind uWATER-PA is the Theis equation,

$$s(r,t) = \frac{Q}{4\pi T} W(u),\ u = \frac{r^2 S}{4Tt}, \tag{1}$$

which calculates the drawdown s [L] at a distance r [L] from a well with a constant pumping rate Q [L^3/T] for a given duration t [T] in a 2D, confined aquifer of infinite extent with homogeneous transmissivity T [L^2/T] and storativity S [—]. The well function $W(u)$ is an integral function and is calculated by uWATER-PA via an approximation that does not require numerical integration. While these simplifications make uWATER-PA computationally efficient and easy to use, the limitations imposed by simplifying the system in this way limit uWATER-PA to being primarily used as a preliminary assessment tool. Simulation results generated by uWATER-PA are readily interpreted; they are reported as the "impact ratio," the ratio of the additional drawdown in a given cell to the maximum additional drawdown (i.e., the drawdown of the cell containing the test well). The impact ratios are presented as both a map of drawdown distribution and a color-coded map showing which existing wells are affected by a new pumping well at a specified location with the colors representing the degree of impact.

How We Tested

Testing was performed using uWATER-PA version 1.0 downloaded from http://isws.illinois.edu/gws/sware/uwaterpa/ and AGX (build 1700) downloaded from http://www.esri.com/software/arcgis/explorer/download.html. The download size for uWATER was approximately 3.5 MB and the download size for AGX was about

[1]Corresponding author: Department of Geography, State University of New York at Buffalo, Buffalo, NY 14260; jfernand@buffalo.edu

[2]Department of Scientific Computing, Florida State University, Tallahassee, FL 32306; mye@fsu.edu

[3]Department of Scientific Computing, Florida State University, Tallahassee, FL 32306; lwang3@fsu.edu

doi: 10.1111/j.1745-6584.2011.00872.x

100 MB. The test environment consisted of a laptop computer having an Intel Core i7 processor and 2 GB of RAM. The operating system used was Microsoft Windows 7 Enterprise 64-bit edition with service pack 1. The testing environment included additional software which met or exceeded uWATER-PA's requirements: Microsoft's .NET Framework 3.5.1, Microsoft XML Core Services (MSXML) 4.0 service pack 2, and Internet Explorer 9. Note that there are two versions of AGX available for download; one requires administrative permissions to install and the other does not. The former version must be used if ArcGIS is installed on the test system. Because ArcGIS 10.0 was present on the test system, the first mentioned version of AGX was used; the installation of AGX proceeded smoothly.

The uWATER-PA download package was unzipped to a folder on the local hard disk. The contents of the zip package consisted of the installation file (with extension .ncfg), the user's manual (also available as a separate download from the uWATER-PA Web site), and the test data. The source code for uWATER-PA was not provided. Installation consisted of double-clicking the uWATER-PA.ncfg file from the download package which resulted in the launching of AGX and the automatic addition of a new tab to the AGX interface labeled "uWATER." The tab contained two items: the original uWATER and uWATER-PA.

Testing of uWATER-PA was done using the example data, provided in the download package, which consisted of a site in the southeastern part of McHenry County, Illinois, USA located approximately 50 km northwest of Chicago. McHenry County is a rapidly growing county the water supplies of which are derived exclusively from groundwater (McHenry County 2006; Yang and Lin 2011). The example data included the locations of several wells in the test site where a hypothetical assessment was conducted and the only other required input data were maps of aquifer transmissivity (T) and storativity (S), also provided in the example data set. The hypothetical assessment corresponded to the deep bedrock aquifer known as the Ancell Unit, the top of which is located approximately 400 to 600 ft below the land surface (Yang and Lin 2011).

Several test runs were conducted. The first run consisted of following the step-by-step tutorial contained in the user's manual. Another run tested the functionality that enables the use of the actual pumping rate and duration (as opposed to the maximal rate and duration used in the tutorial). A subsequent run tested the functionality to show the drawdown distribution for the entire map (as opposed to the 8 mile radius of the tutorial). Subsequent runs tested some of the additional options present in the software. The testing results are briefly discussed in the next section.

What We Found

The software was first tested by following the tutorial presented in the user's manual. For this run, a test well was placed at an arbitrary location in the domain. The simulation was run using a distance of interest of 8 miles, a maximal pumping rate of 200,000 gal/d and a maximum pumping duration of 365 d. The calculation was run with the checkbox labeled "Show the drawdown distribution (more time needed)" checked and by clicking the "Compute Impact with Maximal Pumping" button. The calculation proceeded to run, with progress indicated by a progress bar. The run was problem free and produced the output shown in Figure 1. Execution time was approximately 1 min and the total time was approximately 5 min to set up the model for the run (e.g., loading input data and setting model parameters) and prepare the output as shown in Figure 1. The figure shows that with a distance of interest of 8 miles and the pumping parameters mentioned above, the majority of the wells in the test data lie within or outside the Low Impact Ratio zone marked in green. A run that tested the calculation using the actual pumping rate of 100,000 gal/d and duration of 30 d using the same maximal rate and duration as the first run is shown in Figure 2. Comparing Figures 1 and 2, the resulting smaller zone of high impact in Figure 2 is, qualitatively speaking, the expected result. The run that tested the functionality to compute the drawdown distribution for the entire aquifer also completed correctly, taking approximately 25 min. The parameters used in this test were the same as those used for the first run except with the option to calculate the impact for the entire aquifer enabled. The resulting drawdown distribution was the same as the first run, as expected, except that the entire aquifer had now been calculated.

Although the runs based on the tutorial completed successfully, there were a few issues encountered. An issue that initially hampered usability regarding the UI was the following: on the test system, visual styles (also known as Windows Themes, a system setting) had been previously disabled in order to reduce general system resource consumption and increase responsiveness for other applications. This had an adverse effect on the usability of the software since with visual styles disabled, uWATER-PA's buttons and other controls did not render correctly (text on some controls was absent), essentially rendering the software unusable. To ensure correct functioning, it was necessary to re-enable visual styles. On the Windows 7 test system, this was done via right-clicking "Computer" located in the "Start Menu" and selecting "Properties" and subsequently "Advanced System Settings." In the dialog that appeared, the "Advanced" tab was selected and the "Settings" button for "Performance" was clicked. In the resulting dialog in the "Visual Effects" tab, the box labeled "Use visual styles on windows and buttons" was checked. Another concern regarding the UI, was that the size of uWATER-PA's interface may be too large to adequately be used on laptop-sized screens (especially when docked to the AGX interface, the recommended method of using uWATER-PA), which normally have a lower resolution than the 1680×1050 recommended in the manual. Apart from these UI issues, we encountered two

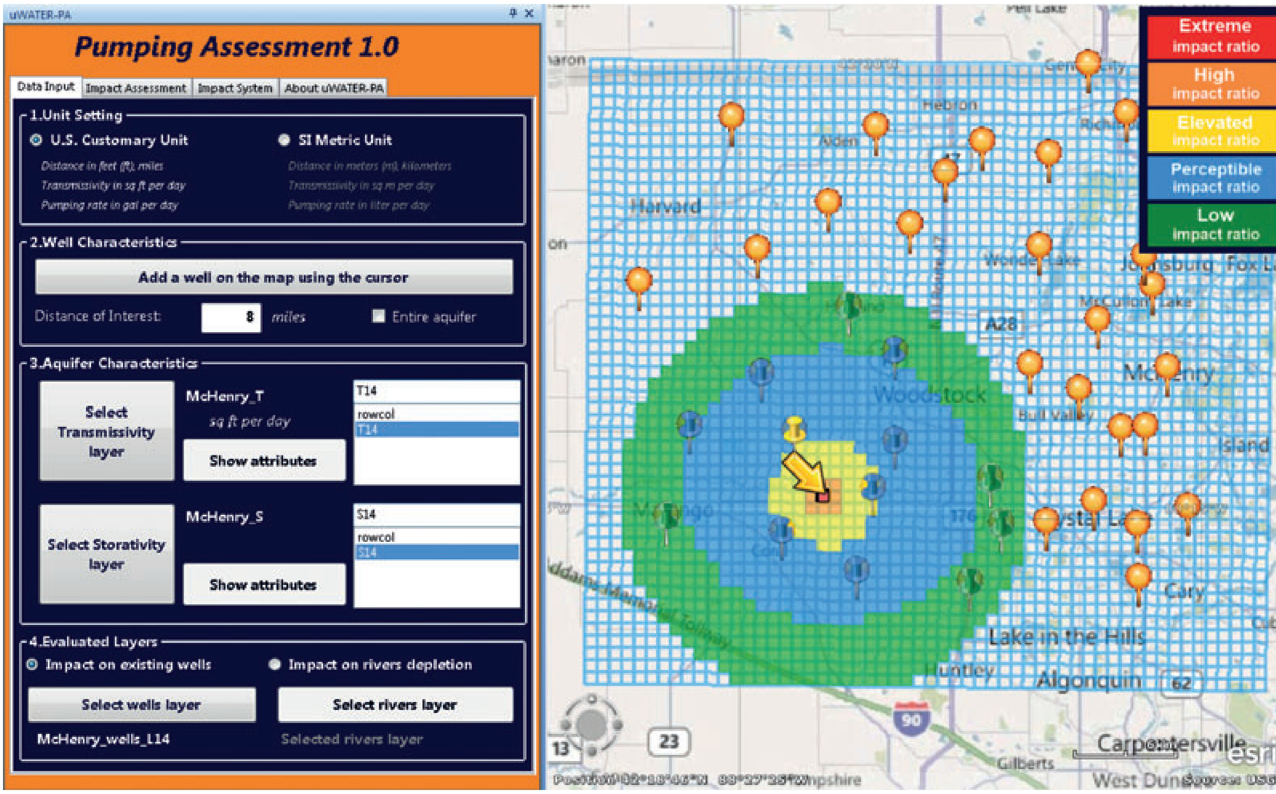

Figure 1. Drawdown distribution of a hypothetical test well, the location of which is indicated by the arrow. The maximal pumping rate and duration are 200,000 gal/d and 365 d, respectively. The pushpins indicate the locations of other wells. The globe-like pushpins represent wells that are outside the distance of interest. The colored cells correspond to the impact ratio in each modeling cell (see the legend modified from "Impact System" tab).

other issues, which we think are worth reporting in the review:

- The uWATER-PA.ncfg file must be executed every time it is desired to use uWATER-PA. In other words, after closing AGX with the uWATER tab present and re-opening AGX by any other method other than executing uWATER-PA.ncfg (e.g., by running the AGX executable directly or double-clicking a saved map from Windows Explorer) caused the uWATER tab to disappear. After corresponding with the uWATER-PA developers and consulting the AGX documentation, this appears to be the default behavior for application configuration (.ncfg) files. Fortunately, for those expecting the uWATER-PA toolbar to be persistent (analogous to a toolbar in Microsoft Word for example) the default behavior can be overridden. In our tests, by following the instructions in the AGX documentation (ESRI 2011) and then using the AGX Application Configuration Manager to modify the .ncfg file and changing the "Use your own map" setting so that maps saved to disk (.nmf) files opened correctly when being double-clicked, the uWATER-PA toolbar was made persistent.
- When creating a new model run, the run must be completed within the same AGX session, an inherent limitation of AGX. That is, if one loads the model input data and selects a well location to evaluate the impact, then saves the map and exits AGX, upon re-opening the saved map and selecting the appropriate input data and setting the simulation parameters, uWATER-PA does not execute (the button to execute using the maximal pumping rate is greyed out and clicking the button to use the actual pumping rate, which is not greyed out, causes AGX to crash).

The uWATER-PA manual contains a brief description of the purpose of the software development, Theis equation, and procedure of using the software. A few suggestions are given below for improving the manual. For users who are more interested in technical aspects of the software, it may be useful to include Yang and Lin (2011) in the download package or the software Web site. Although there is no on-line help, the developers were easily reached via E-mails. They provided rapid responses to questions, and several bugs that caused the software to crash were fixed during the review, which led to an updated version of the software.

What We Liked

The fact that uWATER-PA is released completely free of charge and relies on a GIS that is available completely free of charge from a reputable vendor makes it a very attractive option for conducting preliminary pumping assessment. To our knowledge, uWATER-PA is the only software of this kind in the groundwater

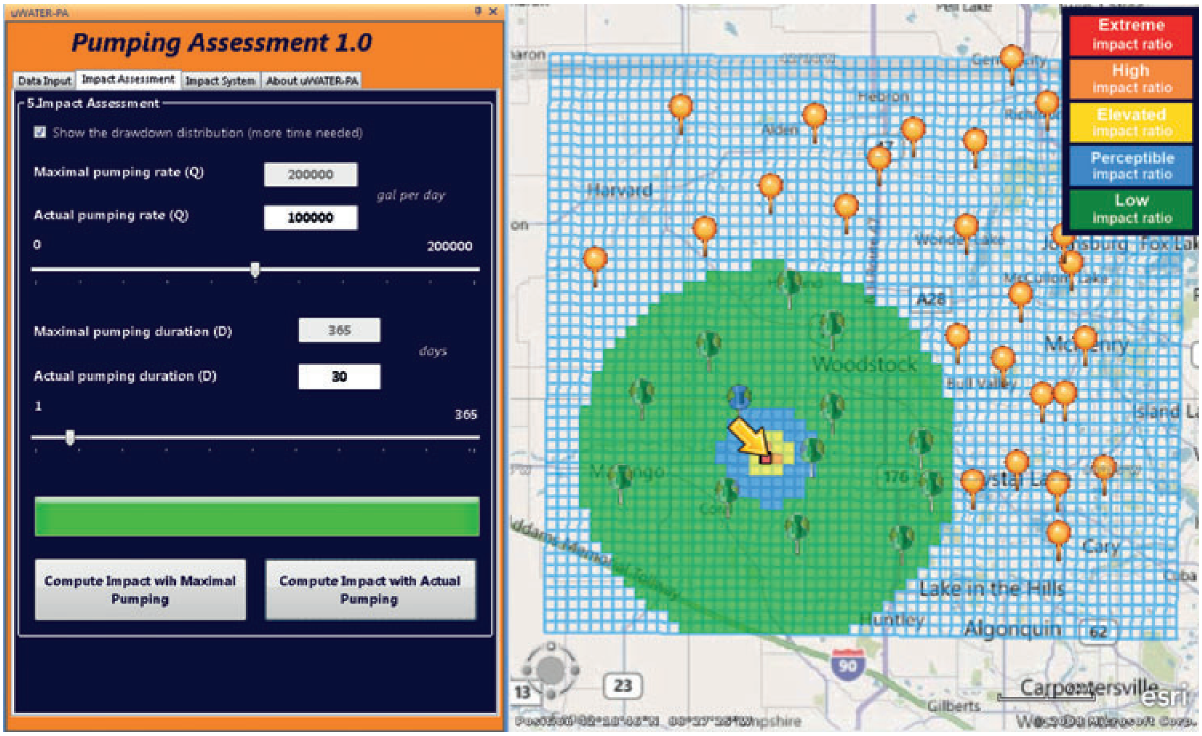

Figure 2. Drawdown distribution of a well located at the location indicated by the arrow. This run is the same as the one in Figure 1 except that the actual pumping rate (100,000 gal/d) and duration (30 d), instead of the maximal rate and duration, are used.

community, and this software design philosophy should receive more attention. Essentially, the only barrier of entry for evaluating the software is the small time commitment required to download the software and to read the manual and work through the example. We believe that this low barrier of entry will encourage less technically proficient decision makers and interested citizens to at least evaluate the software.

Ease of use of the program is very good. There are few buttons and settings that can be adjusted which streamlines the general usability of the software. Due to the few parameters available, skimming the manual and working through the example provides sufficient knowledge to understand what uWATER-PA is capable of. In addition, the mathematical model based on which the software is developed is simple enough that ordinary citizens should be able to interpret the modeling results by understanding diagram of the Theis equation in the manual. The color coding adapted from the Homeland Security Advisory System makes the impact analysis intuitive to ordinary citizens and decision makers.

The developers' responses to questions and comments were prompt and courteous. Comments and questions resulting from our tests resulted in an updated version of the software and associated documentation that addressed some of the questions we had.

What We Did Not Like

For a smoother use of WATER-PA, certain additional robustness is required in the uWATER-PA code to ensure that it fails gracefully in the case of unexpected user input or a workflow that differs from the tutorial data. This can be done by displaying a warning box or otherwise notifying the user of the proper procedure, or by disallowing the action completely. Additionally, it may be necessary to address the UI issues described previously. One final suggestion to the improvement of the UI is the addition of an abort functionality to stop the current run since currently there is no way to do so.

Regarding the provided documentation, it was found that there were several omissions and areas which required clarification. After corresponding with the developers, these clarifications were made and will be included in a revised version of the manual. For example, one of these omissions was the "Evaluate rivers depletion" option in the uWATER-PA Data Input tab. This function was not documented anywhere in the user's manual, even though it is prominently featured in the interface alongside the documented feature to evaluate the impact on existing wells (the "Evaluate rivers depletion" feature seems to correspond to the stream flow capability mentioned in Yang and Lin (2011) as a future improvement). Another important aspect we feel should be discussed in the documentation is that of the creation of the input transmissivity and storativity grids. Although the example data set contains the required T and S data sets, no instruction is provided in the user's manual on how to create these data sets. According to the manual, T and S must be grid-based shapefiles. Because uWATER-PA's target audience is of a non-technical background (e.g., policy makers or ordinary citizens), it would be worthwhile to document the requirements for these files and to have a detailed instruction on their creation.

Given the potential usefulness of the software in performing preliminary pumping assessments, it would be advantageous to have a version that runs within the full ArcGIS suite. This would readily enable more sophisticated users to perform more advanced analyses of the results. For instance, it would be useful to simultaneously display the impact radius of several wells at different locations or the same well with different pumping rates. Another type of analysis would be the calculation of difference maps which can be used to quantitatively compare the results of different modeling runs. As it stands, the output of uWATER-PA cannot be exported to a more common spatial format such as a shapefile or a raster file to enable such analyses. After corresponding with the developers, it seems the issue of exporting data is complicated by the fact that the AGX libraries are not capable of exporting to other formats. Since the function to export with AGX is intentionally restricted by ESRI, a future improvement depends on a future version of AGX. A possible alternative is that the developers could integrate a third-party library to enable such exports without licensing issues.

Overall

The uWATER-PA code provides an easy to use and interpret GIS-based software of the impact of drawdown from a pumping well on nearby wells based on the Theis (1935) solution of a 2D, confined aquifer. Because uWATER-PA and ArcGIS Desktop are both free of charge, it dramatically reduces the entry barrier for its adoption and use by decision makers and interested citizens. Apart from some issues with usability regarding the UI and application robustness, uWATER-PA appears to have the potential to be a genuinely useful management tool that allows for the easy calculation, interpretation, and visualization of the impacts of drawdown from a pumping well on other neighboring wells and the entire aquifer.

How to Obtain the Software

The uWATER-PA software, example data and user's manual is available as a free download from http://isws.illinois.edu/gws/sware/uwaterpa/ and ArcGIS Explorer Desktop may be downloaded from http://www.esri.com/software/arcgis/explorer/download.html.

References

ESRI. 2011. ArcGIS Explorer help. http://webhelp.esri.com/arcgisexplorer/1700/en/index.html#appconfig_set.htm (accessed August 2011).

McHenry County. 2006. County of McHenry, Illinois Groundwater Resources ManagementPlan. http://www.co.mchenry.il.us/departments/waterresources/Pages/ManagementPlan.aspx (accessed August 2011).

National Research Council. 2010. *Understanding the Changing Planet Strategic Directions for the Geographical Sciences.* Washington, DC: National Academies Press.

Theis, C.V. 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Transactions of the American Geophysical Union* 2: 519–524.

Yang, Y.-C.E., and Y.-F.F. Lin. 2011. A new GIScience application for visualized natural resources management and decision support. *Transactions in GIS* 15: 109–124. DOI:10.1111/j.1467-9671.2011.01267.x.

Yang, Y.-C.E., and Y.-F. Lin. 2010. Making the results of analysis accessible: ArcGIS Explorer plug-in aids natural resources management. *ArcUser* 14, no. 1: 22–25. http://www.esri.com/news/arcuser/0111/uwater.html (accessed August 2011).