A National-Scale Web-Based Repository for Groundwater Models

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A project report submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

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The purpose of this project was to set up an online repository where groundwater models can be stored and downloaded. The models are stored in two formats: native MODFLOW files and MODFLOW files that are georeferenced and compatible with the Groundwater Modeling System (GMS) software. Groundwater models help engineers understand how water and pollution move in the ground, and engineers have built groundwater models for many different aquifers. MODFLOW is the most commonly used groundwater modeling code. Aquaveo’s GMS is a graphical user interface (GUI) that allows users to build and run MODFLOW models. The models are georeferenced in GMS so that they can be displayed on base maps. Using a website that runs on a free, open-source content-management framework called Drupal, a database was created that can potentially store all available GMS and MODFLOW models. The coding for this database was done primarily in PHP. Two different interfaces were built for the database: one for administrative workers working for Aquaveo, and the other for users of the models. The website allows administrative workers to add, edit, or delete models and users to download georeferenced, GMS-ready models, along with the original USGS MODFLOW model data.

Keywords: GMS, PHP, GIS, Drupal, MODFLOW, USGS, Aquaveo, Google APIs, phpMyAdmin, MySQL, ArcMap, georeference, KML, KMZ, shapefile
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1 INTRODUCTION

Groundwater modeling is important in understanding the flow and possible pollution of groundwater aquifers. The Groundwater Modeling System (GMS) software developed by Aquaveo (Owens, Jones, & Holland, 1996) is a popular tool for building and using groundwater models. When users of GMS need to build a groundwater model in a specific region, they often prefer to expand upon a basic model that was previously built by the United States Geological Survey (USGS) for that region. However, importing a basic model into GMS can be challenging for some users. In order for the USGS model to be compatible in a modeling project within GMS, the model must be spatially registered and, in some cases, adjustments need to be made to the input files. The purpose of this project is to provide a system that gives users easier access to the native USGS files as well as GMS-ready, spatially registered input files. This was accomplished by developing a web interface that draws information from a cloud-based model database where users can search for and download model files. The interface includes administrator tools for uploading, editing, and deleting models. It also includes a map-based lookup utility.
2 BACKGROUND

The need for a public database of groundwater modeling data in both USGS and GMS formats was proposed by Aquaveo, LLC in Provo, Utah. The customer support staff deals with users who incorrectly set up their models or do not have the correct data in order to build their models. This database will make it easier to locate preexisting models and allow users to immediately open and start manipulating the model files in GMS.

2.1 Groundwater Modeling

The USGS is an organization that works to provide information on and an understanding of the landscape and natural resources found in the United States, as well as potential natural hazards that threaten the U.S. It “collects, monitors, analyzes, and provides scientific understanding about natural resource conditions, issues, and problems.” One of the resources it monitors is groundwater (U.S. Geological Survey, 2016). Utilizing this information is needed when simulating groundwater flow. The USGS simulates groundwater flow using a program called MODFLOW. Many models of aquifers around the country are built using this format, and it is also a well-known and well-established modeling program (Owens, Jones, & Holland, 1996).

MODFLOW was designed as a standardized way for individuals to run groundwater simulations by inputting the parameters and model geometry into a set of text input files.
However, users of MODFLOW have encountered challenges with the program’s complexity. MODFLOW simulates groundwater in a three-dimensional, finite-difference grid using a groundwater flow equation (Barlow & Harbaugh, 2006), but the output of the program can be difficult to visualize and apply to the actual geographical area. Aquaveo, an engineering software and consulting firm located in Provo, Utah recognized this problem and developed a software solution.

Aquaveo is an environmental engineering computer software modeling company originally founded by members of the Environmental Modeling Research Laboratory at Brigham Young University. Aquaveo creates software that aids in environmental modeling of groundwater, surface water, and watershed drainage. One example of this software is the Groundwater Modeling System (GMS). GMS software is a pre- and “post-processor that can be used for various groundwater numerical modelling operations” (Gogu, Carabin, Hallet, Peters, & Dassargues, 2001). The GMS-compatible MODFLOW models compiled using Aquaveo’s GMS software is the primary focus for the repository developed as a part of this project.

GMS was created to make MODFLOW and other groundwater models easier to construct and visually analyze. One of the functions of GMS is to provide a graphical user interface (GUI) for MODFLOW. This GUI helps prepare model input and generates a visual model output in a manner that aids in the understanding of what has happened with groundwater in the past and what may happen in the future. GMS helps users prepare and run the model and shows the paths of the groundwater or pollution in a simple and intuitive fashion.

A Geographic Information System (GIS) is an application included within GMS that is used to input and manage spatial information. This data normally describes characteristics of geographical locations using points, lines, and polygons (Baker & Case, 24-26). Data that is
useful for groundwater including soil characteristics, hydrologic information, pollution, and location of wells and springs can be stored and referenced within a GIS application (Gogu, Carabin, Hallet, Peters, & Dassargues, 2001). GIS stores information where the model is geographically situated, and allows the user to locate the model spatially using an embedded map.

2.2 Drupal

The web-based model database developed by this research project, was developed using Drupal. Drupal is an open-source web content management system. Drupal’s aim is to allow people who have no web development experience to create a finished website that can be competitive with other websites developed by professionals (Byron, Berry, & De Bondt, 2012).

Aquaveo manages a website called modflow.org, which was created using the Drupal platform. It was decided to make the web-based model database utilizing Drupal, a component of modflow.org. This standardizes the layout of the website, so it is easier for current modflow.org users to access the database.

2.3 Similar Projects

Others have tried to create a method to share models using web interfaces. For example, the Utah Division of Water Rights has an extensive database filled with MODFLOW and GMS files found at www.waterrights.utah.gov/groundwater/gwmodelsview.asp. They provide files that are formatted in the native MODFLOW files and in GMS files for versions 2.1 and 6.0 for many of the groundwater models of Utah. An interactive map is utilized to show where the available groundwater model regions are located, as shown in Figure 2-1. Clicking on a model brings up a box, where the user has the option to Click Here For More Info. This link, also shown in Figure
2-1 leads to the USGS and GMS files available for that area. The objective of this project was to develop a similar system that is focused on the entire US, not just the state of Utah.

Figure 2-1: Groundwater regions available online from the Utah Division of Water Rights

Another organization attempting to share models and data over the web is the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). CUAHSI has developed the Hydrologic Information System (HIS) to enable users of hydrologic data to share
data and models with others (Tarboton, et al., 13-17 July, 2009). The CUAHSI HIS is still in the
development stages. Two parts of HIS are HydroServer and HydroShare. HydroServer is an
online platform that allows users to create a digital version of a groundwater model (along with
other hydrologic models) and store it for others to use (Horsburgh, et al., June 2010). HydroShare is an open-source project where models and data can be uploaded to a public
repository. This creates a community environment where users can find and download data for
their models (Tarboton, et al., 15-19 June, 2014). Hypothetically, HydroShare could store the
same models that are uploaded to modflow.org, but the repository at modflow.org is built for
MODFLOW and GMS users only. Catering more to a single group of users allows a more
extensive repository to be created.

2.4 Project Objectives

The objectives of this project were twofold. The first objective was to create a cloud-
based database that is populated by a user-friendly web interface. Administrators can upload,
edit, and store MODFLOW and GMS-compatible models into the database. Aquaveo’s website
modflow.org was connected to this cloud-based database and set up so that users can find models
associated with a specific aquifer by searching in a list or by using an interactive map. Once
located, a link can be used to download the files.

The second objective of this project was to find and convert USGS MODFLOW models
into a GMS-compatible format so that both formats can be uploaded to the database. Some
models were found in the states of Utah and Arizona by searching on the internet, and many
models in Texas were provided by Aquaveo. Converting the models into a GMS-compatible
format involved georeferencing the USGS MODFLOW model and saving it as a part of a GMS
project file (*.gpr). A shapefile was then extracted from the model and converted into a KML file to provide a polygon of the model’s spatial location on the website map.
3 DEVELOPING THE WEBSITE

As previously stated, the modflow.org website was developed using Drupal. In this section, I will discuss how Drupal was used to set up multiple pages on modflow.org for access to the model database, the organization of the webpages, how the webpages were coded, and the database schema.

3.1 Page Set-up

At the point that this project began, Aquaveo had a website already created in which they wanted to add the repository of groundwater models. The website they manage is modflow.org, and it is run using the Drupal platform. PHP code was used to set up the site in order to enable the admin features of the site to fully access and manage the database. Because Drupal is not inherently dynamic, a line of PHP code within the Drupal manager accesses a separate PHP file to create a dynamic interface compatible with Drupal. As can be seen in Figure 3-1 the line of code inserted is `<?php require_once('filepath/filename.php'); ?>`.

A module called PHP filter allows PHP to run in Drupal. This module allows a line of PHP to be evaluated within Drupal (Clark, 2009). Drupal runs on the concept of modules, and PHP filter is one of many that the developer of the website can choose to turn on or off. In other content management systems, modules may be called plug-ins or extensions (Byron, Berry, & De Bondt, 2012). Once the module PHP filter was enabled, the line of code found in the Body section of Figure 3-1 was written in. In order for that line of code to work, the Text format
needed to be changed from filtered HTML to PHP code. The PHP code option was unavailable until the PHP filter module was enabled.

To finish setting up each page, the tabs found at the bottom of Figure 3-1 were filled out and populated. In the Menu settings tab, each new page that was created was given a different title and description. In the URL path settings tab, each new page was given a URL alias, and at the time this document was written, under the Publishing options, these pages have not yet been published.

Figure 3-1: Drupal interface of modflow.org for the page called Models
3.2 Website Organization

The website is organized based on public and private access to certain pages. Currently, all of the pages that have been created are unpublished and inaccessible on modflow.org, but in the future there will be public pages available so users can download the models within the database. Administrative portions of the website will not be released to the public.

3.2.1 Admin

Administrative privileges will only be available for those that are manipulating models in the database by entering, editing, or deleting models. In the future, anyone at Aquaveo, particularly the customer service staff, will have access to make changes to models in the database. This allows Aquaveo to monitor the models being built, saved, and used often. If a model needs updating, they will have the responsibility to do so. Those administrative pages are called Models Admin, Add Model, Edit Model, and Delete Model.

The Models Admin page is the page that connects all administrative pages. On this page, an administrator can see what models are available, the files associated with each model, and what information has been entered for each model, as is shown in Figure 3-2. The table can be organized in alphabetical order based on any column that has a blue heading. From this page administrative personnel may add, edit, or delete models.
When Add New Model is clicked, a page similar to Figure 3-3 opens, allowing admin-authorized users to enter all pertinent information into the provided textboxes. Files also need to be chosen for the Shapefile, Original File, and GMS File. A detailed explanation of what file formats should be used will be given in the Case Study section of this report. After all fields are filled and all files chosen, the submit button saves all the data entered into the database. A new ID is created automatically and a new row will be added to the Models Admin page. If the Cancel button is clicked, the page reverts to the Models Admin page.
Administrators also have access to edit already available models. Clicking on the edit link for a model will bring up a page similar to the Add Model page. As shown in Figure 3-4, the only difference in appearance between the Edit Model and Add Model options is that in the Edit Model page, all the fields that were previously uploaded are already filled, and its title is Edit Model. Any information that is changed or any new file chosen will update the database and reflect that change on the Models Admin page once the Submit button is clicked. If the Cancel
button is clicked, no changes will be made to the model on the database, and the page will revert back to the *Models Admin* page.

![Edit Model](image)

*Figure 3-4: An example of the Edit Model page where the changed information is saved onto the database*

Lastly, models may need to be deleted. It is anticipated that this function will not be used as often as adding and editing models, but it is still important to have the option to delete a model. When the *delete* link to the left of a model is clicked, a page similar to Figure 3-5 will load. This page confirms that deleting the model is what is really desired. Once the *Submit* button is clicked, the model is deleted from the database and will no longer show up on the *Models*
Admin page. If the Cancel button is clicked, nothing is deleted and the page reverts back to the Models Admin page.

![Delete Model](image)

Figure 3-5: An example of the Delete Model page where a model may be deleted from the database

3.2.2 Public

The public will be given access to the Models page. The Models page is made up of two parts. The first part is an interactive map of all available models depicting the aquifers as polygons. The second part is a list of all available models, which will appear directly under the map. These two options will help the users easily find their desired models whether they only know the name of the aquifer or where it is located.

The interactive map, shown in Figure 3-6, will show all available models as a polygon. After the user clicks on the desired polygon, a pop-up window, also shown in Figure 3-6, allows users to choose a file to download. The pop-up window first states the model’s title, then
provides links to download the Shapefile, the GMS Files, or the USGS Files, and at the bottom shows any notes available for those files. If the user clicked on a polygon by mistake, he can click on the \( x \) in the top right corner to get rid of the pop-up window. The map runs using Google APIs.

Figure 3-6: Interactive map, shows where models are located and allows users to download models
Using the list of aquifers adds another step, but it is a simple step. If the user knows the name of the actual model or aquifer, he can click on the link associated with the model title, as shown in Figure 3-7. The title is a link to another page, called the *Download Model* page. To download the files, the user clicks on the links of the files he desires, i.e. *Shapefile, Original File, or GMS File*. An example of a *Download Model* page is found in Figure 3-8. Anytime he may choose, a user can go back to the *Models* page by pushing the *Cancel* button at the bottom of the *Download Model* page. Pushing *Cancel* will not stop the download from taking place once a link has been clicked.

![Figure 3-7: A partial list of available models, also can be used to download needed files](image)

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3.3 Code

Much of the code for this project was provided by Dr. Norman Jones as an example of how to write code in PHP to do basic administrator management of records in a database. It was slightly altered to get all the pages working. This was done with help from Dr. Jones and Hoang Tran, an employee of Aquaveo. Each page connects to the database when the page is loaded using a file called myconn.php.
3.4 Database

The database management system used in this project is MySQL. MySQL is an open-source relational database management system. The database was created and designed using a utility called phyMyAdmin. PhpMyAdmin was created to administer MySQL databases and is “a web application written in PHP and contain[ing] (like most web applications) XHTML, CSS, and JavaScript client code.” PhpMyAdmin has the ability to create, delete, rename, etc… databases, tables, and data (Delisle, 2009). PhpMyAdmin is essentially a web-based GUI for MySQL. Using phpMyAdmin, administrators can manually change data within the database for this project, but data are created, renamed, and deleted within the database using MySQL functions in PHP code.
4 GETTING MODELS ONLINE

Many groundwater models are not easily or readily accessible. The goal of this project is to resolve this issue. While collecting data at the start of this project, multiple resources were utilized. Aquaveo had copies of models for many aquifers in Texas, so these were used to begin populating the database. Utah has many models saved online at the website mentioned on page 5. These were entered into the database as well.

In order for the models to show up on the map, a KMZ file needed to be created. Using GMS, I used each model’s boundary to create a georeferenced shapefile in the form of a polygon (details on how this was done will be given in the Case Study portion of this report). Opening that shapefile in ArcMap 10.3, I used an ArcToolbox tool called To KML. This converted the chosen shapefile to a KMZ file, which is a compressed version of a KML file (Karatepe, 2012), and it could now be uploaded into the database. Once uploaded it would be seen on the map.

If the KMZ file was uploaded that means that the model was uploaded. However, some models online were impossible to georeference without the proper original documentation. At first, all the information found relating to MODFLOW models and GMS models was put into the database, but over time it became apparent that only models that could be georeferenced should be used to keep the project from becoming too broad; hence, only the completed models have been uploaded to the database.
A few aspects of this project were difficult. I had never written code in PHP so I had to learn many aspects of PHP in order to finish this project. As mentioned before, it was difficult to find models that were properly georeferenced to actually populate the database. Another struggle was getting the interactive map to show the polygons of the aquifer locations.

In some cases, I performed the georeferencing of models myself, which was also difficult. Sometimes the models did not have a shapefile already available, and when this was the case, no projection was recorded for many of these models. This made it so sometimes it was necessary to estimate the boundaries of some models.

After the models were saved and zipped, some of the files were large. No files could be uploaded that were larger than 2,000 kilobytes. Most of zipped files for USGS and GMS were much larger than that.

Each new challenge was researched and I tried to debug problematic code myself. Dr. Jones or Hoang Tran were often called upon for guidance. They both helped out immensely with coding problems and with providing data.
5 CASE STUDY

The following example is a step-by-step instruction guide to receiving a model, georeferencing it, creating a KMZ file, and uploading all files into the database. The format in which this model was received is not the only way models are received. The following is only an example of how I took files in this format and made them ready to be put onto the website. This example deals with many different situations that may arise while preparing files to upload, but I realize it will not cover every nuance. This example can help those preparing files for uploading to understand how I prepared files in the past, and they will continually build on these concepts.

5.1 USGS Native Files

The files saved from the USGS for MODFLOW files can be opened straight into the GMS GUI. Normally, the files will be saved in a folder similar to the one in Figure 5-1. All files within the folder are important to run the model within MODFLOW. In order for this model to be opened in GMS, the name file needs to be located and opened in the GMS GUI.
Figure 5-1: An example of a MODFLOW file

The name file is the file with the extension of *.nam. Figure 5-2 shows the sey_mo.nam file from Figure 5-1 opened using GMS. To open the name file in GMS, the user can open GMS and select File, then Open, and then navigate to the name file, or the name file can be dropped directly in to an open instance of the GMS GUI. When the model has loaded it could look something like Figure 5-2.
When models are developed they are sometimes developed in a certain map projection of the earth. “A map projection is a systematic rendering of locations from the curved Earth surface onto a flat map surface (Bolstad, 2012). In order to georeference a model, the projection the model was built in must be known. Sometimes the source of the model will have a shapefile available which distinguishes the projection and position of a model. This is the case for this example. The shapefile can be added to the GMS GUI in the same ways the MODFLOW model
was. When the shapefile is added, it can look similarly to Figure 5-3. Shapefiles and models do not line up spatially unless prior georeferencing has occurred.

For this example model to be georeferenced, it must be transformed. When models are loaded into GMS without a projection, the origin of the model is set on the axis at 0, 0. GMS has a transform tool that will move the model within the shapefile and ultimately georeference the model. This model was set up to have the origin match with the bottom left corner of the shapefile.
The first step using this method is to find the location of the bottom left corner of the shapefile. To accomplish this a new coverage needs to be created. The user right-clicks the project explorer in a place where nothing is and clicks New, then Coverage. Click the bottom left cell of the shapefile while in the GIS module to select the cell. The shapefile is then right-clicked within the project explorer window. This pulls up a window where the user can click on Convert To, then Feature Object. While under the Map module, the user can now click on the bottom left hand corner of the cell and see the XY coordinates at the top of the GMS window. The user should copy and paste those values into an Excel or Word document to reference later.

The user will then right-click on grid in the project explorer, scroll down to Projection, then find and click on Transform. In the next window the user will click on the Translate toggle and enter the XY coordinates into the correct spaces. Once finished the model will overlap the shapefile and look like Figure 5-4. The model is now georeferenced. The shapefile and new coverage can be deleted from the project explorer. Once saved, this model can be in the folder that will later be zipped to add to the database.
5.3 Creating the KMZ

The shapefile that was previously found and used was rectangular. It was my desire to have the actual shape of the aquifer show on the online map. To do this a KMZ file needed to be created, but first a shapefile of the shape and position of the aquifer must exist.

The georeferenced model is kept open in GMS. The display options are opened for the model. Within the Display Options menu and under the 3D Grid, the user checks the *Cell edges* and checks the *Layer Boarders*. Under the *MODFLOW* sub-window within Display Options
menu, the user clicks on the *Check None* button. Now the outline of the model is the only thing showing in the window, as see in Figure 5-5.

![Figure 5-5: Readying the model outline to be saved as a shapefile in GMS](image)

The next step for this particular example is for the user to right-click anywhere in the project explorer and click *Convert to CAD*. The user then turns off the *3D Grid Data* and the
CAD drawing shows; it should also look similar to Figure 5-5. The user then right-clicks on the CAD file in the project explorer window and goes to **CAD To** then **Feature Objects**. This turns the CAD drawing into a bunch of arcs and points. With the **CAD layers** feature object highlighted, it is time to build polygons. Once the shape is a single polygon, the user right-clicks on the **CAD layers** again and clicks **Export**. It is saved as a shapefile (with the extension *.shp).

In the next window it has three options of boxes to check. The **Polygon File** is the one that is most important for the user to check in order to save as a polygon for the shapefile.

After the shapefile is saved, there is still more to do. Shapefiles are not KMZ files; they need to be converted to KMZ files. The user opens the shapefile in ESRI’s ArcMap. Within ArcMap’s **Toolbox** under **Conversion Tools**, there is a tool called **To KML**. The user clicks on this and chooses **Layer to KML**. Doing so opens the dialogue box found in Figure 5-6. The user fills it out with the shapefile as the layer and chooses where to have to file output. Once the conversion is complete, a KMZ file is ready to upload to the database.
5.4 Uploading to the Database

The USGS original files and GMS files all need to be compressed, or zipped up, in separate folders to upload to the database. Once that is done, the user goes to the Models Admin page in modflow.org and clicks Add New Model. The user fills out the form as it is shown in Figure 5-7, pushes Submit, and the files load. The speed of the upload is dependent on the size of the files being uploaded. Once all the files have loaded, the user can load the Models page and notice, as in Figure 5-8, the files are now all downloadable for users of the website.
Figure 5-7: Example of adding a new model into database
Figure 5-8: Example of the KMZ file shown on the map portion of the Models page
6 CONCLUSION

This project created an online repository of groundwater models for users of the GMS software to quickly and easily access. Using this repository will allow users to search for prebuilt models and use these models for their purposes. Administrators will be able to add more models. The hope for this project is to continue to populate the database with as many models as possible. This can only be achieved with collaborative help. As Aquaveo customer service representatives help others build models, they can ask for the original files and quickly build a base model for many aquifers. They then can populate the database with those base models for others to use.
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