

Using Rapid Prototyping to Model Groundwater Data

Mara Bechwar
Computer Science and Software Engineering
University of Wisconsin – Platteville
One University Plaza
Platteville, Wisconsin 53818

Rapid Prototyping Center
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee, Wisconsin 53202

Faculty Advisor: Michael McGeen

Abstract

This research involved using geographical data in various formats to create three-dimensional models using rapid prototyping, also known as solid freeform fabrication. Specifically, this research investigated the addition of a representation of the water table to three-dimensional terrain models. In its typical form, information on groundwater and the water table can be hard to understand. The major purpose of this research was the development of a method to produce educational three-dimensional models. These models can help to make citizens aware of the location and workings of groundwater. In turn, the method used in this research can also be extended in order to model things like groundwater clarity or the contamination of groundwater in an area. The results of this project could prove especially useful to conservation efforts, particularly those concerned with maintaining or improving the level and quality of groundwater, as any models produced using this method should be useful as educational tools to illustrate the target of conservation efforts. Models produced based on this research are suitable for display and interaction with the public, for example at a museum, nature center or government building.

Keywords: Terrain Modeling, Groundwater, Rapid Prototyping

1. Introduction

Information dealing with groundwater and the water table can often be hard to understand because of the manner of its presentation. This research attempts to establish a method by which data on groundwater and the water table can be presented to and understood by the typical citizen. Specifically, models can be produced using rapid prototyping (RP) which incorporate both data on elevation of the land surface of a certain area and data on the groundwater residing beneath that particular area.

1.1. previous research

Researchers have already determined ways both to model terrain data using rapid prototyping and to model groundwater data. Laura D. Jacobs,¹ Josh Mueller,² and Matthew Ollayos³ have each completed research enabling rapid prototyping of elevation data. Allison Block has developed a method to rapid prototype sub-aqueous terrain data.⁴ Beverly L. Herzog, David R. Larson, Curtis C. Abert, Steven D. Wilson, and George S. Roadcap have presented a method to combine surface elevation data with data on an aquifer beneath that surface and produce a model.⁵ This research draws on selected aspects of these attempts in order to determine a method by which to produce an RP model of both surface terrain data and groundwater data beneath the surface.

1.2. models

A major purpose of this research is to make the information in question comprehensible to the general public. The creation of a physical, three-dimensional model to present the information is a key step toward helping the average person grasp the concept of groundwater. Models have proven very useful as teaching tools, both in general and with specific application to the modeling of aquifers. Tim Herman, Jennifer Morris, Shannon Colton, Ann Batiza, Michael Patrick, Margaret Franzen, and David S. Goodsell, using physical models showing protein structure and function, contend that “models function as ‘thinking tools’ that stimulate discussion because the model itself provides spatial insights that stimulate questions and because participants can clearly articulate their questions in reference to the model.”⁶ Beverly L. Herzog, et al. produced a three-dimensional model of the Sankoty-Mahomet Aquifer in central Illinois that “was a powerful visual aid for showing the local, nontechnical audience.”⁷ For this reason, it is believed that interaction with a physical model will greatly aid the viewer in learning about groundwater and the water table.

It is hoped that any knowledge gleaned by the viewer of these models will in turn be put to use in conservation efforts in some capacity. As associate director for Water Resources of the U.S. Geological Survey Robert M. Hirsch wrote, “scientific understanding is critical to the formulation of balanced decisions about the management of land and water resources.”⁸ As municipal awareness grows and groundwater conservation efforts become more prominent, the avenue for education using three-dimensional models becomes more evident. In fact, the Waukesha Water Utility in Waukesha, Wisconsin lists public education programs, particularly for school children, as the number one activity in its timeline for implementing a water conservation and protection plan.⁹

1.3. groundwater, aquifers, and the water table

Groundwater is water that resides beneath the earth’s surface, stored between rock particles (Figure 1). An estimated 21% of total water use in the United States comes from groundwater withdrawal.¹⁰ It is used for drinking water, irrigation, and industry, and it replenishes surface water like streams.

An aquifer is a geologic unit of groundwater with a supply sufficient enough to yield significant quantities to wells. Groundwater is sometimes concentrated in multiple aquifers, above but separated from one another, which increases the complexity of a model.

The water table is the surface of the water in an unconfined aquifer, “unconfined” meaning that there is no impermeable rock between the aquifer and the surface of the land (Figure 1).

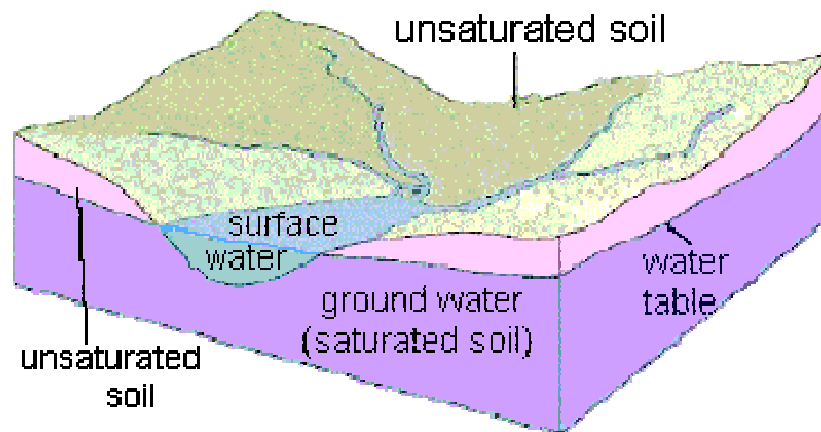


Figure 1. An unconfined aquifer.¹¹

1.4. environmental concerns

Poor management of groundwater resources can have a variety of negative effects on the environment in which we live. The two most major concerns are land subsidence and groundwater contamination.

1.4.1. land subsidence

Land subsidence is the sinking of the surface of the land. It can be attributed to several processes, the most common of which is the removal of groundwater. If more groundwater is removed than will be replaced by natural recharge from precipitation, issues with the land are likely to result. Soil that was once saturated with groundwater compacts as it dries out, without the water to fill its pores. The surface of the land sinks as the water table beneath it drops. Subsidence has been most severe in drier areas like the southwestern United States, but it has occurred all over the country. In some places, the surface has sunk nearly 30 feet, as shown by the marker in Figure 2. In other areas, massive sinkholes have appeared rapidly (in a matter of hours) as the soil dries (Figure 3).



Figure 2. San Joaquin Valley, California. The surface of the land here has subsided nearly 30 feet in a 52-year period due to the removal of groundwater.¹²



Figure 3. Winter Park, Florida. A number of massive sinkholes appeared here within a matter of hours.¹³

1.4.2. groundwater contamination

Because groundwater is frequently used for drinking, any contamination present arouses major concern. Excessive removal of groundwater is one practice that can lead to groundwater contamination. As the water table drops and once-saturated soil dries out, fissuring can occur on the earth's surface. Fissures will naturally enlarge over time due to erosion, and will capture surface runoff, along with which will be carried sediment and debris.¹⁴ This mixture flowing into a fissure can lead to contamination of groundwater, which lies open in the fissure. The more groundwater removed, the more contaminated the groundwater can become.

1.5. rapid prototyping

Rapid prototyping, also known as solid freeform fabrication, is an additive process that uses three-dimensional computer data to produce physical objects. The object is built one thin layer at a time, using a two-dimensional slice from the three-dimensional model to guide the placement of material. That material can be resin, powder, plastic, wax, paper, or plaster, depending on the particular machine used. In this investigation, the RP machine used was the stereolithography apparatus (SLA), which builds using various types of resin.

2. Objective

The objective of this research was to combine data on the surface of the land with subsurface data from beneath it, and convert it to a format that could be used to produce models on rapid prototyping machines. In this case, data on the water table for a selected area was to be chosen and combined with corresponding surface data.

3. Data

Data for both the land's surface and subsurface were required for this research.

3.1. surface data

Data on the surface of the land for a given area are relatively easy to find on the Internet. They come in many different formats from a number of different websites. For this research, a Digital Elevation Model (DEM) of Waukesha County, Wisconsin was obtained from Geo Community at <http://www.geocomm.com>. A DEM consists of a series of points, with three coordinates representing the east/west location, the north/south location, and the elevation corresponding to the pair. It is not, however, formatted as a readable file of text.

3.2. subsurface data

Information on groundwater is typically obtained through a lengthy process of interpretation of records on wells and boreholes, drillers' logs, test borings, installation of new wells, water samples, and seismic tests. For the purpose of this research, data on the water table was obtained from hydrogeologist Daniel Feinstein. The information has previously been used in an aquifer simulation for the Southeastern Wisconsin Regional Planning Commission.¹⁵ It comprises a seven-county area of southeastern Wisconsin together with portions of some adjacent counties. It is in the form of a multi-line text document with one point on each line. Each point consists of three coordinates, the first denoting the east/west location, the second the north/south location, and the third the elevation of the water table above sea level corresponding to the pair.

4. Methodology

A series of data conversions and alterations was required in order to produce a file that could be used by a rapid prototyping machine to build a final model.

4.1. AutoCAD Map 3D

The first program used in the process of this research was AutoCAD Map 3D, a geographical information systems tool from Autodesk, Inc. AutoCAD Map 3D has the capability to import surface data as a DEM and export it in Drawing Interchange Format (DXF) as a specially formatted series of (X, Y, Z) points.

4.2. DXF converter

For the next step of this research, a piece of software was written in Visual Basic. This software served two purposes: to convert the text data on the water table to DXF format and to exaggerate the elevation of a file already in DXF format. Once in DXF format, the water table was viewable with other software which would otherwise not have been able to open the file.

It was necessary to multiply the Z-coordinates of both the land and the water table to accentuate variations in elevation within each surface. Without exaggerated elevation a model would have little illustrative value, as a specific place (for instance, the viewer's hometown, or the downtown area of a city) would be difficult to locate. A multiplication by three was selected for use on the land's surface. A multiplication by 20 was selected for use on the water table, because the variations in height were more subtle. The advantage of exaggerating a landform can be understood through comparison of Figures 4 and 5.

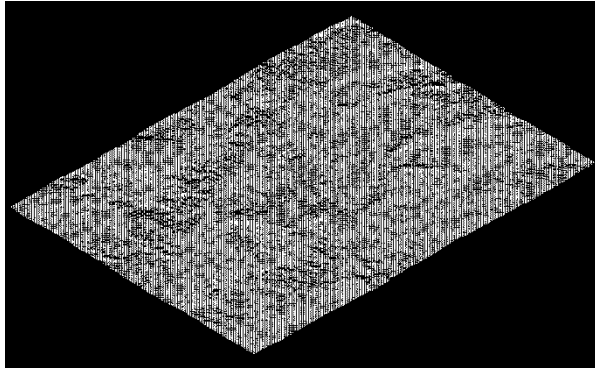


Figure 4. Waukesha County, original elevation.

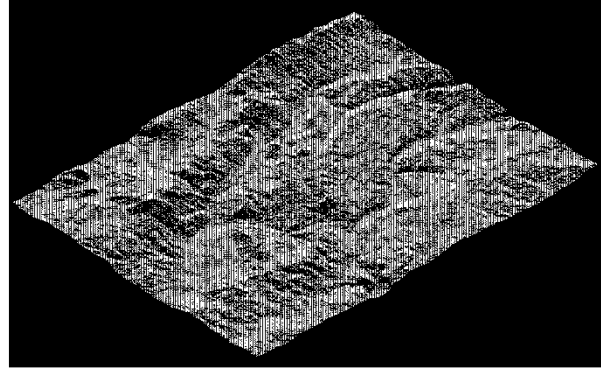


Figure 5. Waukesha County, elevation exaggerated by a factor of three.

4.3. AutoCAD

In order for a rapid prototyping machine to produce a physical model, the data it uses must be in the form of a solid. Stereolithography (STL) is a commonly-used file format for this purpose. For this research, the DXF files created by the DXF conversion software were opened in AutoCAD. The drape function of AutoCAD was then employed to solidify the spaces between the points in those files, resulting in the creation of solids for both the surface and the groundwater. Those solids were then exported in STL format.

AutoCAD was also employed to create positional cues to be added to the surface of the model. A grid of township borders, major highways, and lakes was created to correspond to the surface of Waukesha County (Figure 6). It is expected that local viewers of the model will find it more appealing if they can pinpoint places with which they are familiar.

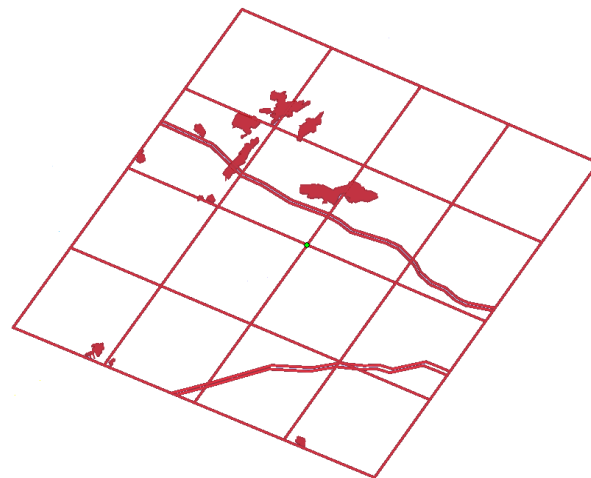


Figure 6. The reference grid of townships, major highways, and lakes in Waukesha County.

4.4. Magics

At this point, the data for the model consisted of three separate STL files (the surface, the water table, and the reference grid). In order to be built using rapid prototyping, the three had to be combined into one. The files were sent to the Milwaukee School of Engineering Rapid Prototyping Center, where they were opened in Materialise Magics, lined up, and saved as one STL file (Figure 7). The model was then ready to be built.

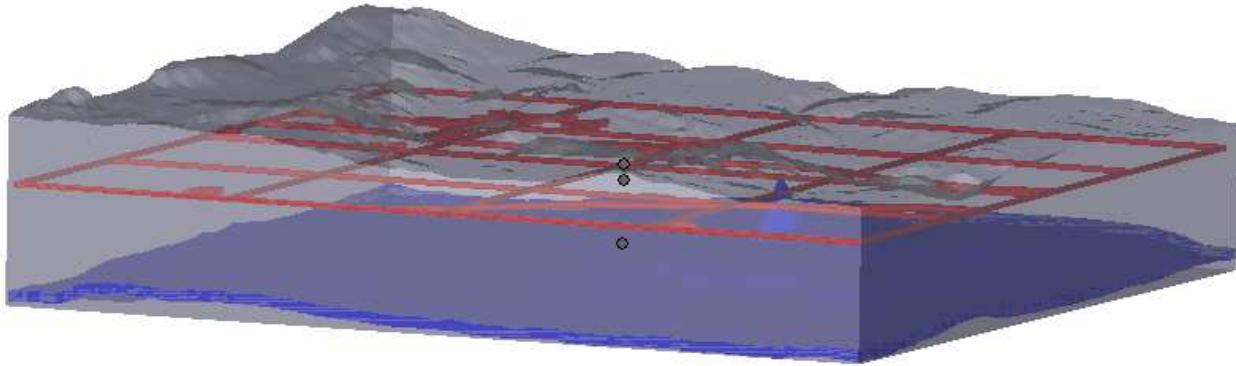


Figure 7. The STL file used as the final build for the model.

5. Conclusions

A physical three-dimensional model combining surface terrain and groundwater data was created using rapid prototyping. This model represents the relationship between terrain and groundwater, and as such is valuable as an educational tool.

6. Recommendations

This research can be continued in a number of directions. Because subsurface data in the form of the water table has now been successfully modeled, representation of other types of subsurface data can now be explored. Some possibilities include representation of bedrock, faults, aquifer depth, groundwater clarity, and locations of groundwater contamination.

In the interest of making an instructional model, a somewhat atypical type of resin was used in the production of the model. This project employed a medical modeling gel usually used in rapid prototyping of organic models. This particular material is clear when sintered once with the machine's laser, and turns pink when sintered a second time. In this investigation, the water table and reference grid were double-burned, while the rest of the model was burned only once, so that the groundwater and grid would be visible through the rest of the model from any direction. It is not recommended that any future research continue use of the medical modeling resin. Any part built with this material come out of the stereolithography apparatus badly warped, leaving the model's base bowed and unable to lay flat. In addition, the clear resin was not sufficiently clear to see the subsurface data from any part of the model except for the outer edges. Production using a different resin or on a rapid prototyping machine other than the SLA is strongly suggested.

7. Acknowledgments

This project was funded by the National Science Foundation (NSF) and the Milwaukee School of Engineering (MSOE) Rapid Prototyping Center (RPC). Special thanks to Professor Michael McGeen (advisor), Daniel Feinstein at the United States Geological Survey for providing the water table data, Ann Bloor, Betty Albrecht, and all of the MSOE and RPC staff who supported this project.

This material is based upon work supported by the National Science Foundation under Grant No. EEC-0648845. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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