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# *Designing an Open Source Web Application for Visualizing Aquifers*

PENNSTATE



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596 B Report

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## Abstract

Open source web mapping has created opportunities for the development of powerful geospatial tools that are freely available across the web for hydrogeologic subsurface mapping. This project focuses on the design of an open source aquifer web mapping application using leaflet.js that generates user-customized aquifer structure data in a graphical format. The resulting custom data can be utilized in groundwater drilling, well servicing, hydrogeology, oil and gas exploration, and groundwater resource management. The project is designed for the Central Texas Groundwater Conservation District, located in Burnet County, Texas, for the purpose of aquifer visualization, groundwater management, and a general educational tool. The design incorporates the popular open source software structures of PostGIS, Geoserver, and Leaflet to achieve a responsive web map that can function within a web browser on multiple devices. Existing data of a three-dimensional aquifer model is used to create raster images and grid cell shapefiles of the top and bottom of each layer throughout the cross section. The results of this project include a web map with a few simple and powerful tools. The application can generate a stratigraphic column by clicking on the desired location on the map or use geolocation data to view the hydrogeology or subsurface layering of that area.

## Introduction

The Central Texas Groundwater Conservation District (CTGCD) is one of 99 groundwater districts in the state of Texas designated with the authority to manage groundwater resources. The state of Texas' preferred method of groundwater management is through the local groundwater districts (Brock, 2003). The CTGCD's mission statement is to "protect and enhance the groundwater resources of Burnet County while protecting groundwater users and maintaining the economic vitality of the communities it serves, by adopting and enforcing rules consistent with State law" (CTGCD, 2012). It is the duties of the CTGCD to use its rules to manage in a prudent and cost effective manner through conservation, education, management, and permitting (CTGCD District Rules 2012).

Many groundwater districts in Texas operate on funding from ad valorem property taxes collected within each district. The use of public funds entails prudent and transparent spending while maximizing the return so that management goals are being met. Managing groundwater can be a challenging endeavor due to the fact that much of what is underground is invisible from the surface, which makes data collection expensive, and it is very difficult even for a specialist to manage what you cannot see (Wijnen, 2014). There has been a strong drive to advance the collection of groundwater data in Texas from the local levels of groundwater districts, such as the CTGCD, to the state level at the Texas Water Development Board (TWDB), and up to the national level from agencies such as the U. S. Geological Survey (USGS). The CTGCD recognizes the challenges associated with managing a large number of different aquifers, with significant variations within aquifers, which can provide for unique and complicating issues (CTGCD District Rules, 2014). Through the work of the CTGCD and other entities, there have been new groundwater data collected within the past 10 years that have allowed for more accurate mapping of the aquifers in the area.

Subsurface aquifer data are not only important for groundwater management, but also important from an educational perspective. The CTGCD was created by the Texas 79<sup>th</sup> Legislature with a directive for

conservation and education of the resource (CTGCD District Rules, 2012). Being a public entity, funded by the tax payers, it is an obligation of the CTGCD to perform community outreach by educating the public about their groundwater resources and to share data that are being collected. Stakeholders, such as well owners, have a high interest in knowing information about where their water is coming from or how deep they will have to drill to encounter an aquifer. Stakeholders that are involved in the drilling, completing and pump installation of wells are dependent on the depth information for their work. Other stakeholders such as policy makers, rule makers, and groundwater managers are reliant on the basic aquifer data so that they can make informed decisions that are based on science.

## Proposed Project

Currently there is no simple method to identify depths and location data for multiple aquifers for a given location, without expert analysis. Data containing the various depths of aquifers and their thicknesses are needed to drill or service groundwater wells. Two dimensional maps are readily available to represent the coverage area of a specific aquifer, however when multiple aquifers overly each other, it can be difficult to interpret the sequential layering. Furthermore visualizing underground aquifers is difficult for non-experts who do not have access to sophisticated software or the knowledge needed to interpret data.

This project designs an open source web-based mapping application that will generate user customized aquifer data in a graphical format. The web application is produced for the intended use of the CTGCD and will therefore have an initial project boundary of Burnet County, Texas (Figure 1) with the intent and wherewithal for further expansion. The web mapping application will be hosted on the CTGCD's existing website at [www.centralexasgcd.org](http://www.centralexasgcd.org). The project objectives include:

- 1) Utilizing open source software to create a responsive web map design that functions within a browser on any device.
- 2) Creating custom stratigraphic column and cross sectional graphs generated from grid cell elevation values representing the various aquifer layers.
- 3) Developing a simple, powerful, and user friendly interface/experience for a wide number of public users.
- 4) Employing a design that follows Open Geospatial Consortium (OGC) standards, can be easily duplicated, and is scalable for additional data and features.

# Project Area

## Central Texas Groundwater Conservation District

- Burnet County
  - pop 50,000
  - 1,021 sq. miles
- 6 aquifers -> sub-aquifers



Figure 1: A map and description of the initial project area within the Central Texas Groundwater Conservation District boundary coextensive with Burnet County.

## Related Work

There has been an increase in the number of web maps that are available for geology in recent years. In June 2015 the USGS released the Texas Geology Web Map Viewer (<http://txpub.usgs.gov/dss/texasgeology/>), an interactive web-based tool allowing a wide audience of users to display multiple geologic layers and identify detailed geologic descriptions (LaVista, 2015). The map is focused on the geology located on the Earth's surface but not necessarily representative of the subsurface geology. The geologic data is contained in a vector format and maintains several different attributes including rock name, group, and description (Figure 2). Similar interactive web maps have been made available to the public that also include surface geology features including several different maps from the Minnesota Geological Survey (<http://www.mngs.umn.edu/service.htm>).

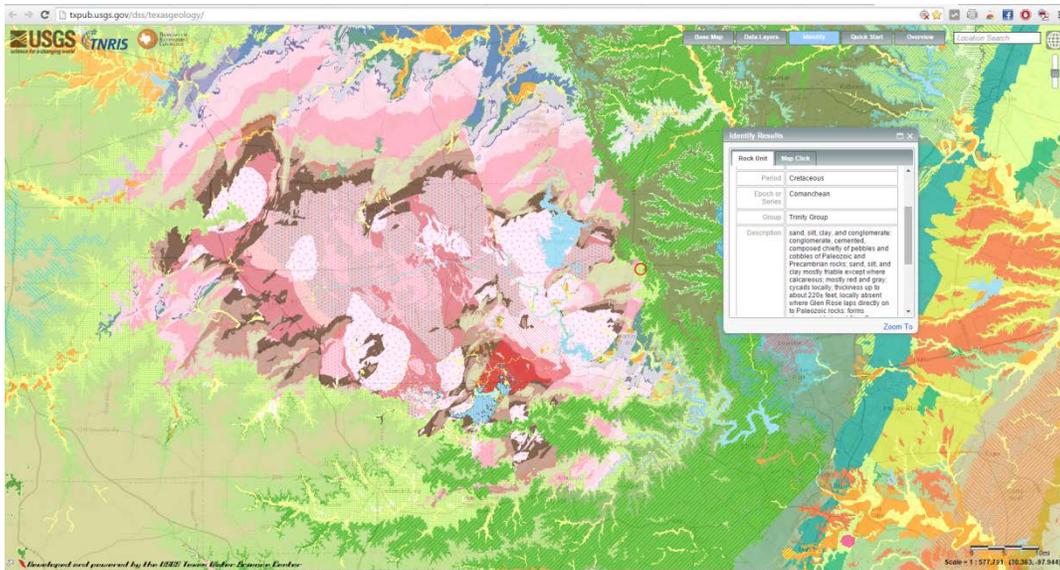


Figure 2: A screenshot of the Texas Geology Web Map Viewer. A popup window is generated from the identify tool, displaying several different geologic attributes.

For subsurface geologic or aquifer information there appears to be less interactive mapping applications available. The Minnesota Geological Survey has a web map that displays the depth to and elevations of bedrock for the entire state of Minnesota ([http://mgsweb2.mngs.umn.edu/MGSBdrkTopo\\_Qthck/](http://mgsweb2.mngs.umn.edu/MGSBdrkTopo_Qthck/)). The data for the depth to/elevation of bedrock are displayed in a raster format that contains cell values that correlate to the z-values of the bedrock. There is interactive zooming, panning, location search, measuring, and identifying tools available. The identify tool allows the user to get the values of either depth or elevation of the bedrock, depending on the layer selected, in a popup box. A similar web map was created for the High Plains Aquifer System by Intera Incorporated (<http://hpsagam.intera.com/>) that can toggle multiple aquifer surfaces on or off. The aquifer surfaces are in raster format and contain elevation values for the bottom of the aquifer. An identify tool is also available for determining the elevation values at the desired location on the map (Figure 3).

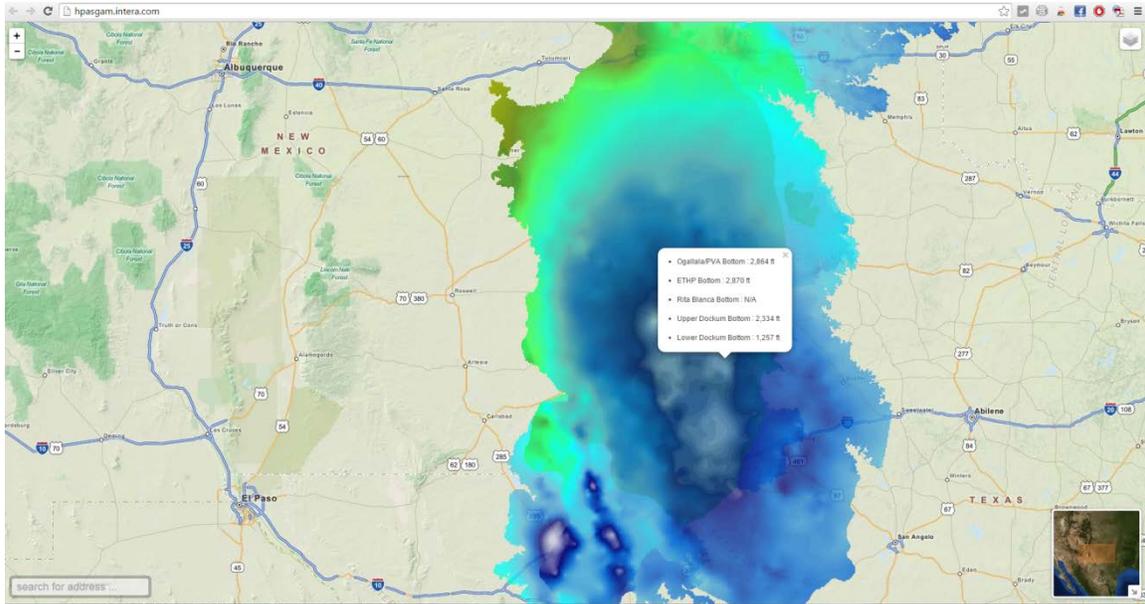


Figure 3: A screenshot of the High Plains Aquifer System interactive map. The aquifer raster layers are shown with a popup box generated using the identify tool, displaying elevation values of each layer.

A popular type of mapping application that is available on mobile phones uses the internal global positioning system (GPS) functionality on the device to track a running, hiking, or biking trail. While this type of application is intended for a different use, the methods behind the application are similar to this proposed project. Mapmyride (<http://www.mapmyride.com/>) is an iPhone application that records a user's biking trail on a map interface, then calculates and displays an elevation profile graph (Figure 4) and statistics to the user (Elliot, 2011). The method used to display the elevation profile graph is similar to creating a cross section of an aquifer. The difference is that the Mapmyride application uses only the surface elevation values along the polyline to generate a graph, whereas this project will use many more subsurface layers to display multiple aquifers.

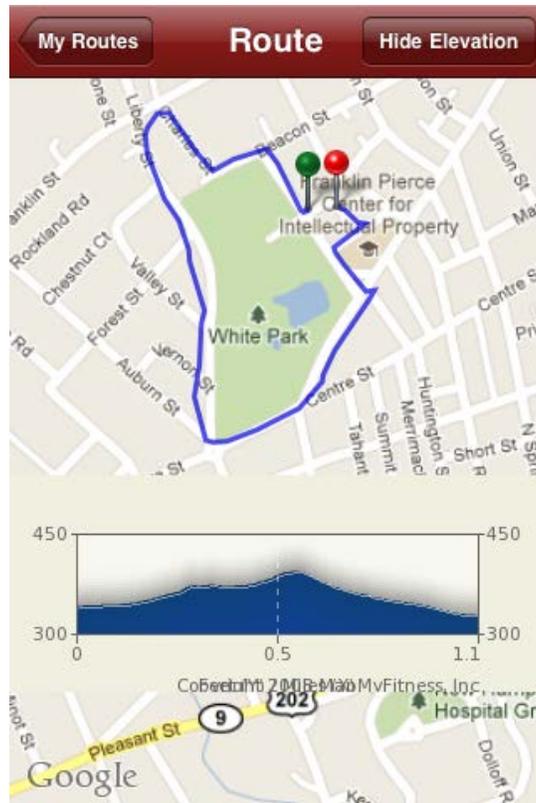


Figure 4: A screenshot of the Mapmyride iPhone application showing the biking route and elevation profile generated along the polyline.

Perhaps an existing web application that is most closely related to this project is the cross section tool from the Hanford Site, part of the U.S. Department of Energy (USDOE) nuclear weapons complex ([http://higrv.hanford.gov/Hanford\\_Reports/Cross\\_Section\\_Tool/](http://higrv.hanford.gov/Hanford_Reports/Cross_Section_Tool/)). This tool is a web-based application that allows the user to draw custom polylines on a map, thus generating a cross section of the aquifers in a separate popup window. The cross section graph includes different aquifer layers, water level information, and water well information, including their depths (Figure 5).

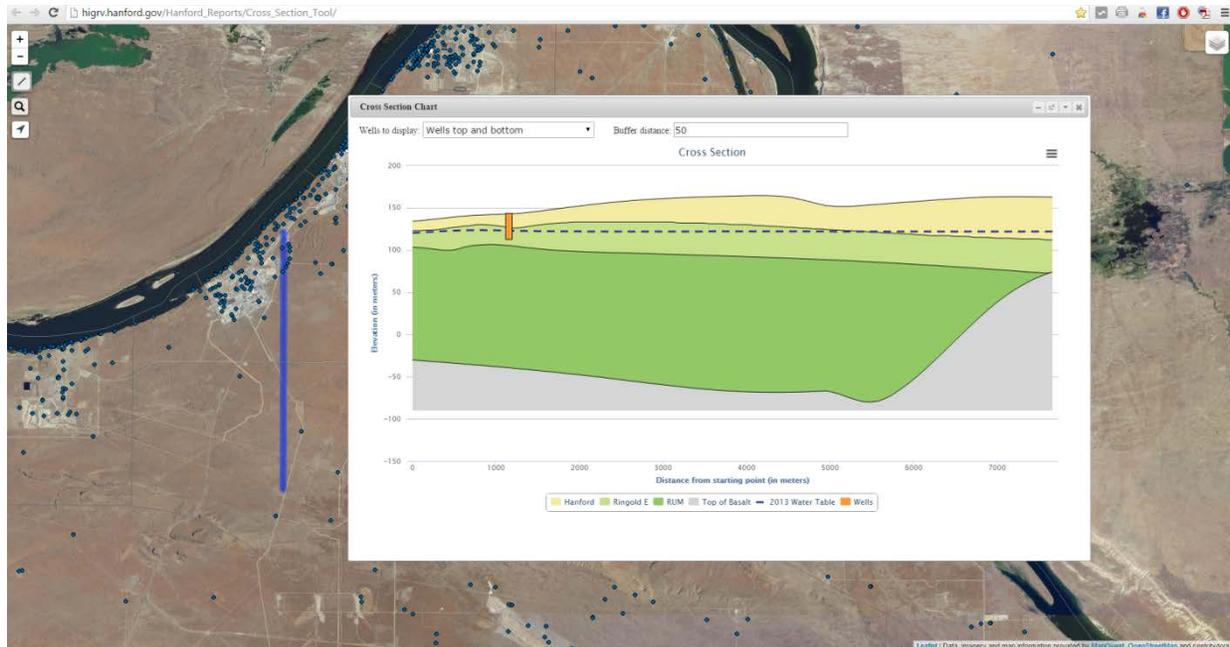


Figure 5: A screenshot of the Hanford Site cross section tool. A polyline (blue north-south oriented line) is drawn on the map and the resulting cross section of the aquifer layers is drawn in the popup window.

## Web maps

Today the primary source for maps and the dissemination of spatial information through dynamic user interaction is through Internet applications (Peterson, 2008). The availability of web maps offers the user a convenient avenue to access data from a variety of sources from desktop, mobile devices, or tablets. According to research done at the University of Wisconsin-Madison (Roth, 2014) there has been tremendous growth in the web technologies available for web cartography, in fact so much growth so quickly that it can become overwhelming for GIS professionals to keep pace.

In early Internet maps and even some that are still in operation today, the use of browser plugins, for instance Java applets, Flex, Microsoft Silverlight, and Adobe Flash, were very popular due to several advantages such as consistency across browsers, compactness of file formats, and simple development with a single scripting language (Roth, 2014). Today there are many free and open source options that do not require the use of plugins or externally downloaded software, and operate fully within a browser. In fact many of the most popular open source solutions also abide by the Open Geospatial Consortium (OGC) standards which has the goal to “advance the development and use of international standards and supporting services that promote geospatial interoperability” (OGC, 2015).

## Web Application Design

The design of the web application is a critical component for a successful Internet GIS map, because it sets the frame in which the user interacts, views the information, and analyzes the results of any processes (Hoover et al., 2014). The front-end design for this project must incorporate a simple and elegant user

interface that allows the user to interact with GIS data and toolsets. The audience of this web application is a very broad range of individuals and businesses, as it is geared toward the public at large. The design will incorporate as few moving parts as is necessary to obtain the desired results. The web map will have a full screen frame that is responsive to the size of the users screen. This will allow the application to be used on a number of different devices including, desktops, tablets, and phones.

The framework for this web map application will incorporate three specific parts: 1) a spatial database to store data and allow new data to be incorporated with ease, 2) a spatial data publisher to act as a server that will send data over the web so it can be mapped, and 3) a web mapping library to display the data and functions of the map itself. This framework is illustrated in Figure 6, and a description of each is provided in the following subsections.



Figure 6: The framework for the web map application encompasses PostGIS as a database, Geoserver as a web server, and Leaflet mapping library.

### *Spatial Database*

The back-end of a web map is supported by a database of some form. GIS data, being spatially driven, are best supported with a spatial database such as PostgreSQL/PostGIS, which can store both vector and raster spatial data and attributes (Peterson, 2012). PostGIS, a spatial extension of PostgreSQL database is open source software that provides extensive implementation of OGC standards (Swain, 2015). The web application for this project will be retrieving raster data and various shapefiles that contain spatial and attribute properties. The PostGIS database was chosen for this project because it is well known for its vast support of an array of raster and vector formats and it also supports spatial indexing schemes for fast retrieval (Swain, 2015).

### *Spatial Data Publisher*

The spatial data that are stored in the database are not easily transferred over the Internet to web mapping software libraries. A geospatial data server will present the spatial database in a more web friendly format (Swain, 2015). Many proprietary software packages are commercially available from well-known GIS providers, including Intergraph GeoMedia, Esri, and ERDAS, that will provide web services for web maps. However, there are also many free and open source software platforms that support OGC standards for Web Mapping Services, such as Geoserver, which runs on the very popular Java based platform (Peterson, 2012).

Geoserver was chosen for this project as the spatial data publisher due in part to its graphical web administration tool (Swain, 2015), which allows for easier configuration, its compliance with OGC standards using open source software, and its active support from a large and robust community of users (Peterson, 2012). Geoserver can easily handle the most common spatial databases, like the PostGIS database that will be used in this project, as well as standard Esri shapefiles and raster formats (Peterson, 2012).

## *Mapping Library*

Mapping libraries bring to life the finished product that the end user will see on their device and have the ability to interact with the data that are coming from the database and publisher. The mapping library consumes data from the web services that are published by Geoserver and are then rendered so that they can be displayed in maps within browsers or plugins (Swain, 2015). Today there are many options both commercially (Google Maps, and MSN Bing Maps) and open sources (OpenLayers and Leaflet) that are Javascript-based client side libraries that can create interactive maps within the browser, not needing any plugins (Peterson, 2012).

The mapping library chosen for this project is Leaflet, an open source software mapping library. Leaflet is a JavaScript library that offers a vast amount of mapping features that works well on desktop and mobile platforms, and is lightweight, simple, and uses understandable coding (Leaflet, 2015). Leaflet uses an HTML5 and CSS user interface that is responsive in design, meaning the same coding can be used to generate maps adjusted accordingly to fit on desktops as well as smaller screens on phones (Dimitrijevic, 2014). Leaflet also boasts a large number of JavaScript plugins that can be simply integrated into the mapping code to provide geoprocessing tools, address search, base tiles, and many other features. The open source community following for Leaflet is also quite extensive and provides for active support from other users on GitHub (<https://github.com/>), an open source coding repository.

## **Project Data**

The data for this project are from two Texas Water Development Board groundwater availability models for the Northern Trinity and Woodbine Aquifer (2014) and the Llano Uplift Aquifer (2016). These groundwater models are in USGS MODFLOW format and will be converted to shapefile grid cells containing elevation attributes, and raster images for each modeling layer. The raster images will contain the elevation values for the bottom of the associated layer. The resolution for both datasets is  $\frac{1}{4} \times \frac{1}{4}$  mile grid cells. The surface will be represented by a digital elevation model of the same resolution as the aquifer modeling layers.

## **Project Methodology**

The shapefile grid cells contain the elevation values for each aquifer layer within each grid. For a given point, each cell contains the z (elevation) value that corresponds to the bottom of each layer; therefore, combining all the layer values together will create a stratigraphic column of the subsurface layers (Figure 7).

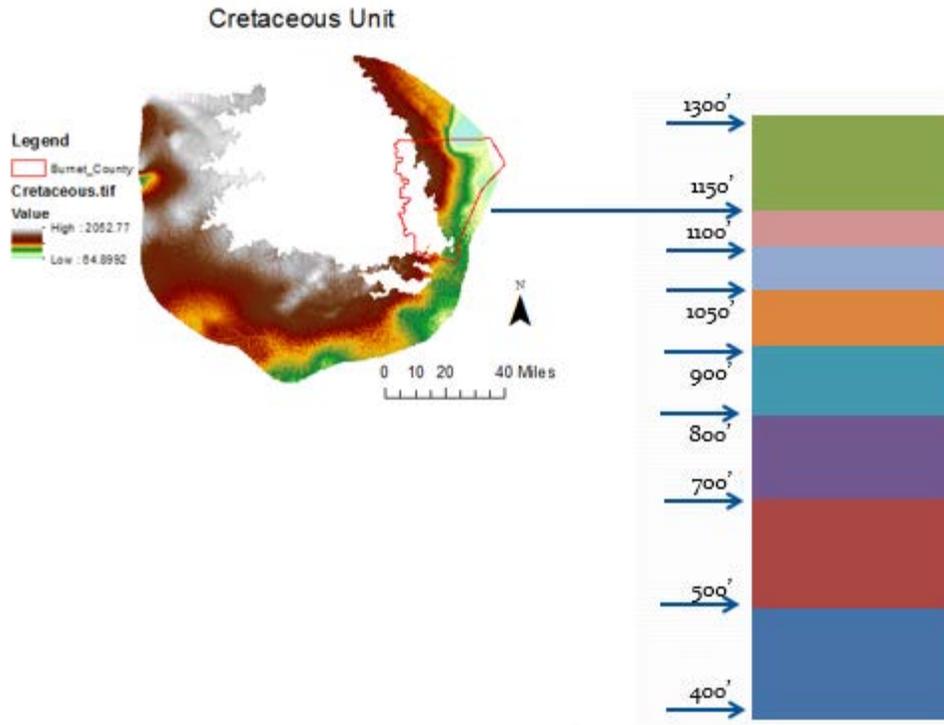


Figure 7: An example of the methodology to building a stratigraphic column. The elevation values for the bottom of each aquifer layer are used to create a sequential vertical column where the bottom of a layer also corresponds to the top of the overlying layer.

The web application will have two tools available to generate a custom aquifer graphic. A stratigraphic column graphic can be developed with a click of a particular location within the project boundary. The user can utilize the address geocoding search tool, location services tool, or simply zoom and pan across the map to the desired area. A polyline tool will be used to draw a custom polyline within the project boundary and a popup box will appear with a cross section graph along the length of the polyline. To form this cross section graph, the elevation values contained in the shapefile grid cells will be collected across the length of the polyline, and plotted on a graph. The graph will have a vertical axis containing the elevation values and a horizontal axis with distance along the cross-sectional line.

## Application Build and Results

The application build begins by installing and connecting the three applications previously discussed in the project framework. PostgreSQL/PostGIS was installed and an object-relational database was optimized for this specific project. Both raster and vector shapefiles containing aquifer data were uploaded to the PostGIS database.

For running and testing web-based applications an Apache Tomcat servlet container is used. The installation configuration, security settings, performance, and tuning of Geoserver and Apache Tomcat for this project were based on Iacovella and Youngblood (2013).

Leaflet initializes in the HTML code file for the web map application. A link to hosted copies of Leaflet CSS and Javascript files must be included within the head section of the HTML document along with any additional files for plugins and tile services. Functions and services can be called within the body of the HTML file that correspond to the previously mentioned CSS and Javascript files, which greatly reduces the amount of code needed.

## Importing Data

With data stored within a PostGIS database, Geoserver offers a very convenient option to connect straight to the database. In addition to connecting directly to the PostGIS database, other data can be directly uploaded to Geoserver itself. Once the data are within the Geoserver environment, there are different services, primarily Web Map Server (WMS) and Web Feature Server (WFS), that allow you to share the data across the web. WMS is a popular service of Geoserver and allows a client to request maps as images in such formats as png, jpeg, or geotiff (Iacovella and Youngblood, 2013). For this project, raster images of elevations for each aquifer are served by Geoserver as geotiff images and displayed in Leaflet as image tile layers. By default, all of the geotiff images are turned off, but individual layer images can be toggled on within the layer control tab. The WFS service can provide the client with the raw data from Geoserver in several different output formats including shapefile, JSON, and CSV (Iacovella and Youngblood, 2013). A grid cell shapefile with attributes containing the elevation values of each aquifer layer is served by Geoserver to leaflet using the WFS service. Since Leaflet offers several built-in functions for GeoJSON file format, this is format used for the output from Geoserver.

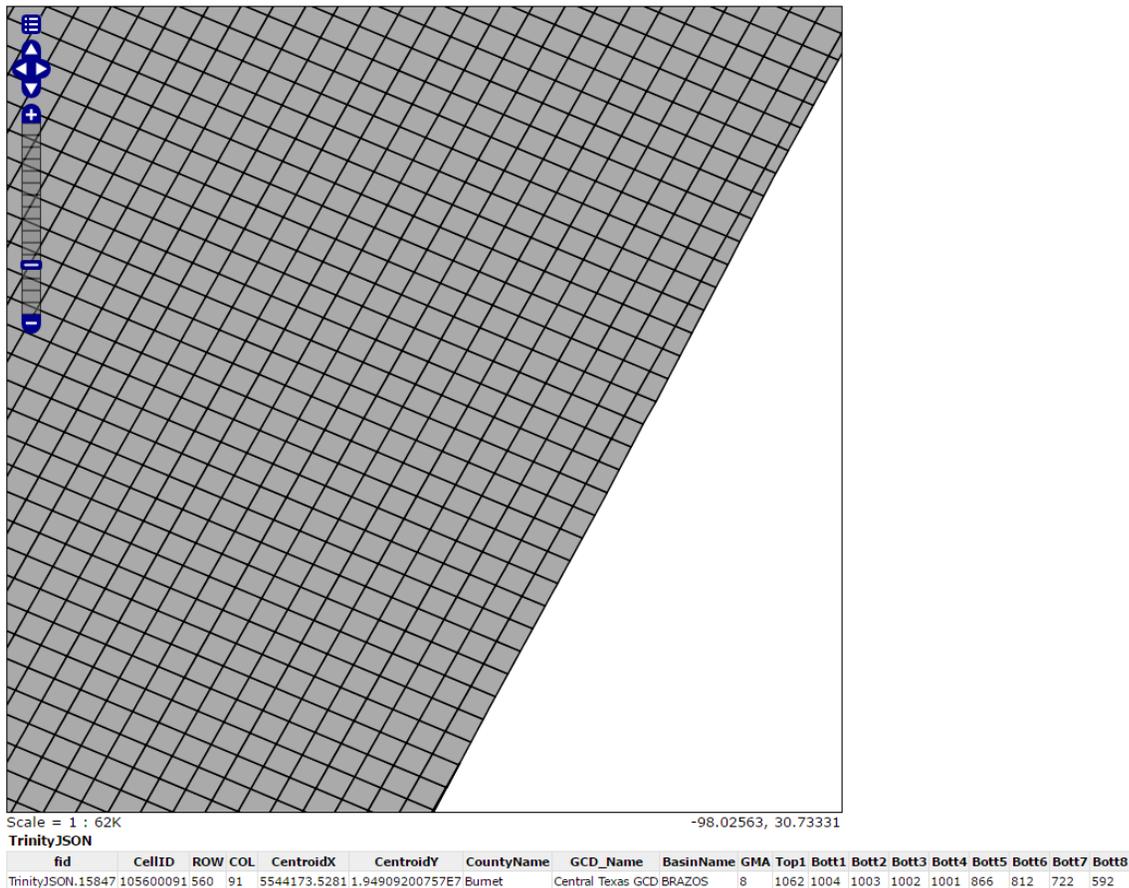


Figure 8: An example of the Geoserver GeoJSON output of a grid cell Shapefile (polygon vector shapefile that mimics a grid). Each cell contains attribute information of the elevations of each aquifer layer.

## *Default Map Base*

For web map applications many tools and features are a part of the default map and are always in view, such as base tile layers, zoom and pan tools, address search, geolocation and draw tools for this application. The base map for the web application uses the MapBox tiles (<https://www.mapbox.com/>) that are free to use for non-commercial purposes. MapBox offers several visually appealing and functional tiles such as streets, satellite, terrain, and high contrast maps. The base map for this project is the basic street map by default, with layer options to change to the others mentioned. A geocoding service is a basic but important feature for this map application. Geocoding service allows the user to search for a specific address or place and then zoom to that location. The Esri geocoding service plugin for Leaflet was chosen because it offers an autofill feature that tries to predict as you type, saving time and providing for a more accurate results. A geolocation service plugin was also added to the map that shows the location of the user based on their IP address or GPS location. The feature can be used on desktops/laptops and mobile devices. The draw plugin tool for Leaflet using the draw polyline feature was added to the default map.

## *Stratigraphic Column*

The web application initially loads while automatically adding the GeoJSON grid cell data to the map. The GeoJSON is shaded slightly to show the extent of the data. Leaflet contains a function called 'onEachFeature' which, upon a click of the GeoJSON, a popup box can be bound to each feature and properties of each feature can be extracted (Crickard, 2014). Each grid cell contains the elevation of each aquifer layer, which can be extracted and then further action can be done with those values. In this project a chart will be created using the elevation values. For this project Highcharts, a JavaScript based graphing library, was used to create the stratigraphic column. The basic area chart can be configured to display multiple aquifer layers with the y-axis being elevation above mean sea level in feet. A stratigraphic column is representative of aquifer units at a point location, which would mean the x-axis is not relevant. However, there is not a suitable option for a chart with no x-axis, therefore to create the stratigraphic column using the basic area Highchart a minimum of two x values had to be used. In this case both values are duplicates of each other and the chart is only showing the elevation values for a single point. Highcharts has a tooltip option, which allows the user to hover the mouse over the chart and the exact values for each layer will be displayed. There is also a threshold option to establish a minimum y-axis value, which is set to the last layers' elevation value. Otherwise the default is zero.

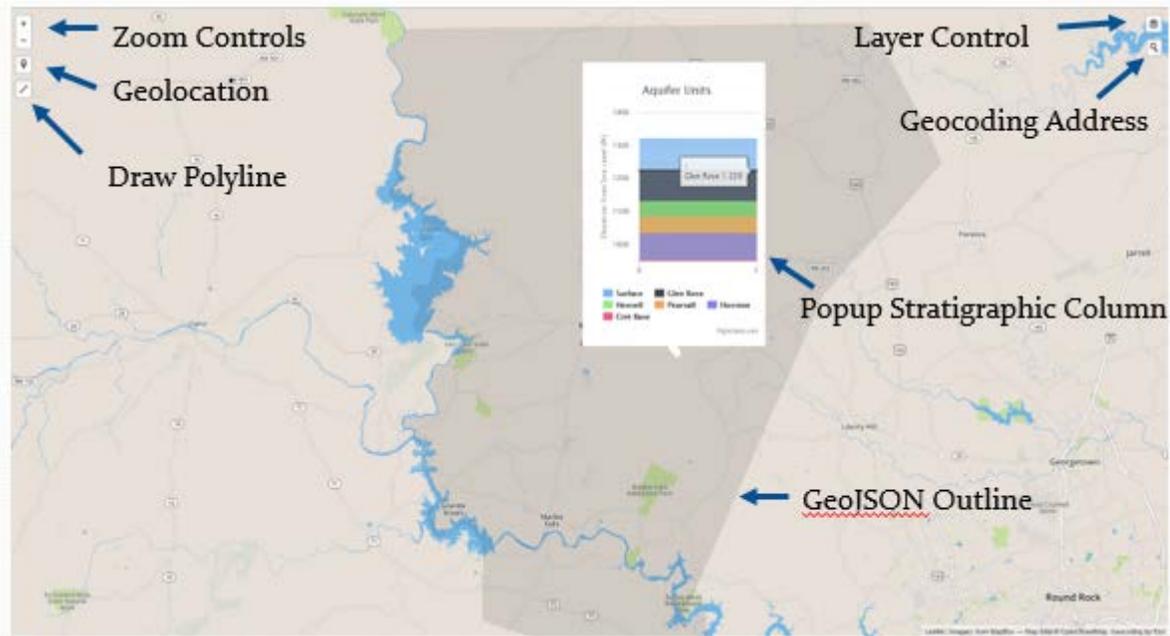


Figure 9: A screenshot of the web application showing the stratigraphic column popup box resulting from a user click.

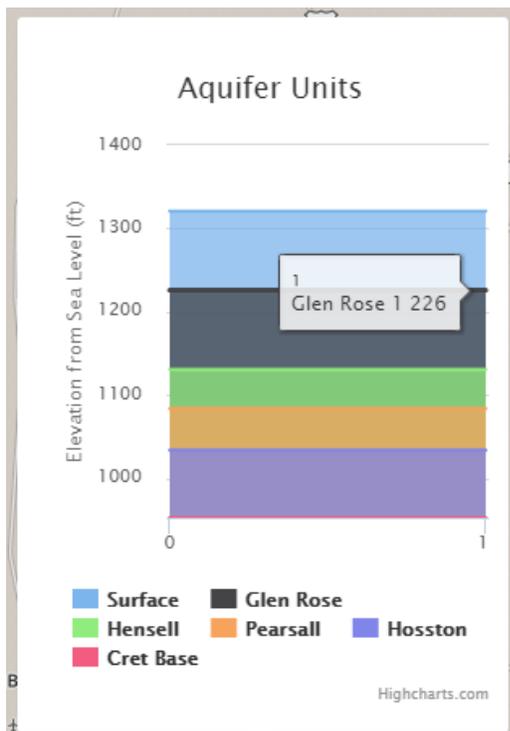


Figure 10: A close-up view of the resulting stratigraphic column using the basic area Highchart.

*Cross Section* The cross section is similar to the stratigraphic column but instead the x-axis is the distance along a drawn line. The draw plugin for Leaflet has a polyline option, that allows the user to draw a custom polyline. There are several options for the plugin such as not allowing the polyline to cross itself

which may result in an error. The imperial units can also be able to show the distance of the line as the user draws it. The cross section method gathers the elevation data in relation to the distance along the drawn line. A Leaflet plugin called L.GeometryUtil has a function to return the coordinate of the point located on a line at the specified ratio of the line length. This functionality allows the polyline to be segmented in proportional increments to create a proportional cross section. For instance, if a line were drawn eight miles long and the L.GeometryUtil function had its ratio set at 1/8 the line length, then every mile across the polyline the data could be extracted from the GeoJSON grid cell at each mile coordinate (Figure 11).

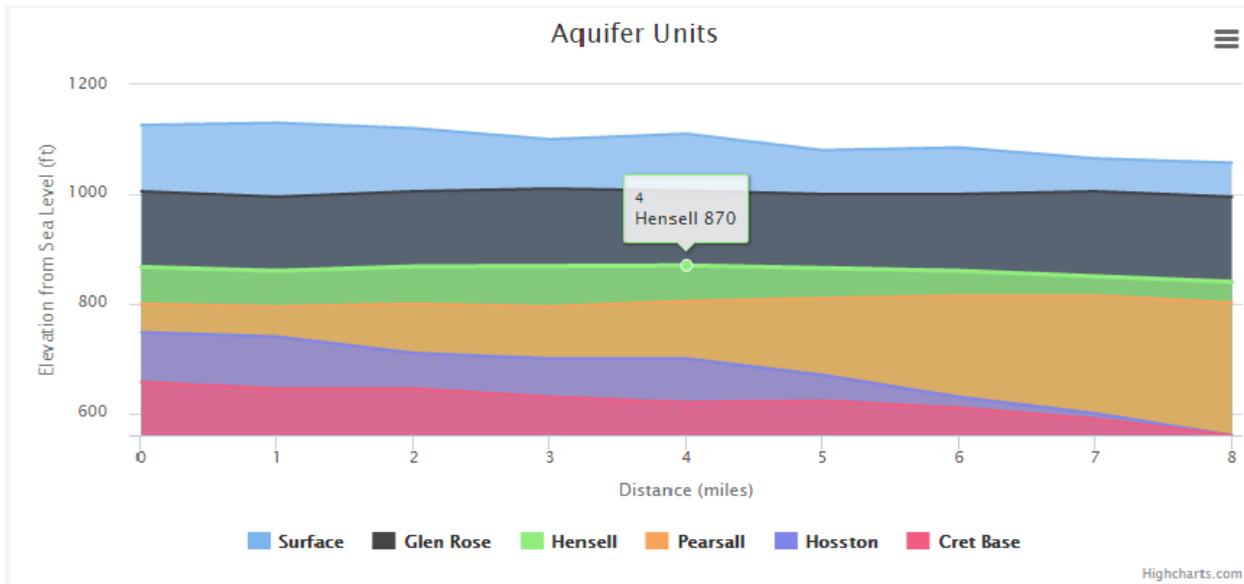


Figure 11: A cross section drawn from a polyline that is eight miles long. The Highchart basic area graph was used to create the cross section and the threshold (y-axis minimum) was set at the minimum value of the deepest aquifer layer.

## Discussion

The challenge of offering a web mapping application for a large public stakeholder was a key element of this project as the functionality and experience needed to be user friendly, but still provide enough substantive value. Leaflet and Highchart both offer a simple user interface and provide visually appealing maps and graphs. Sizing of the graphics and fonts was a challenge to make legible in a variety of different formats.

Coding of the web map application was simplified by using the Leaflet JavaScript base mapping platform. Much of the coding is already designed with the Leaflet core functions and the various plugins that have been developed, thus reducing the lines of code a developer needs for map creation. Nonetheless the coding for this project still provided a challenge for a non-coding professional.

A working prototype of this web application was created for this project and tested over a local host server. A screenshot of the working prototype can be seen in Figure 9, using the stratigraphic column popup. The future work needed for the completion of this web application is for further refinement of

JavaScript code of the polyline cross section tool utilizing the L.GeometryUtil plugin so that it is functional with any polyline drawn within the project boundary. Additional code refinement and beta testing will need to be done before the project is ready to become live.

## Summary

Obtaining specific aquifer data relating to the spatial extent and elevation of numerous overlapping aquifers has traditionally been available only through a professional. One of the goals of this project was to design a web map application that would allow the public to have free and simple access to this important aquifer data. Through the design framework of PostGIS, Geoserver, and Leaflet software, the web map application delivers this aquifer data within a browser on any device using custom tools and functions to deliver the user area specific information.

Opportunity for this web mapping application to go live online is strong for the CTGCD and the ability to integrate additional data and features such as water level information, wells, and water quality data make this a great starting platform. With the design framework of the open source software the opportunity to add additional features would be simple and very cost effective. The project area can also grow to a much larger scale and the application can be utilized in other areas that have aquifer layer data. The functionality of this web application is not only tied to aquifer data, but can be employed in other fields that use elevation profiles and can also be used for comparison and analysis of digital elevation models.

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