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METHODOLOGY AND PROCESS TO ACCOMPANY

A VIRTUAL GEOTECHNICAL DATABASE

FOR THE ST. LOUIS METROPOLITAN AREA

by

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A THESIS

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Approved by

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ABSTRACT

The St. Louis metropolitan (STL) area, which spans Missouri and Illinois, currently has no overarching organization of geospatial data (geodata). The two states have their own geodata, using their own individual standards. The development of a virtual geotechnical database (VGDB) encompassing the entire STL area on both sides of the Mississippi River is a solution to the data sharing and standardization problem of this area. The VGDB integrates geodata from disparate sources into a geographic information systems (GIS) database accessible via the internet.

The creation of the STL area VGDB consisted of three parts: 1) compiling the geodata; 2) formatting the geodata in GIS and extensible markup language (XML); 3) making the VGDB viewable in an internet browser. Two types of geodata were compiled: subsurface log data such as borehole logs and vector data such as surficial and bedrock geology, seismic hazards, Karst topography, mine locations, and pipelines. The subsurface data was converted into XML format, which output to an aesthetically-pleasing layout for easier analysis. The vector data was imported into a GIS program and converted to a scalable vector graphics (SVG) format. Both the resulting XML and SVG files were spatially linked and viewable in an internet browser. The result was an internet accessible VGDB that integrated geodata from national, state, and local levels, creating an exclusive source for area-wide analysis.

ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1 STATEMENT OF PROBLEM

Many geotechnical databases today are in analog format, existing as reams of paper stored in many file cabinets. This is inconvenient for users because there is no easy way to search for data or reference it geographically. A virtual geotechnical database (VGDB) takes digital data and organizes it into a searchable, geographically-referenced database. Users are able to quickly pinpoint areas of interest and find all associated types of geospatial data, or geodata.

Currently, there is no over-arching organization of geotechnical data in the St. Louis (STL) metropolitan area, which straddles the Missouri-Illinois boundary. Both Missouri and Illinois have state geological surveys that cannot cross over state boundaries with their work. Consequently, those who analyze the area are not getting area-wide depiction of the subsurface. The states employ different systems of storage, database architecture and database management. There is a definite need within both the geo-professional community and government agencies within the STL area to 1) combine relevant geologic and geotechnical data into one database, 2) share up-to-date information, and 3) allow for easy updating.

1.2 PURPOSE AND SCOPE

Industries involved with subsurface information have an acute need for a VGDB. The ultimate goal of this project is to provide geo-professionals with a VGDB covering the STL area that is comprehensive, user-friendly, and accessible with an internet browser. The purpose of this thesis is to outline the steps performed in creating a VGDB of the STL area. It will cover acquiring the geodata from various sources, formatting it, and outputting it to end users. It can be used as a template for other areas needing a VGDB.

J.W. Chung's dissertation (2007) covered the development of geographic information systems (GIS) -based VGDB for the STL area, but this project adds more

layers of geodata, a data dictionary, and ports the VGDB onto the internet using extensible markup language (XML) -based functionality.

1.3 COMPUTING COMPONENTS

1.3.1. Geographic Information Systems. A geographic information system (GIS) is a system used for integrating, analyzing, and displaying spatial data. The Environmental Systems Research Institute's (ESRI) ArcGIS 9.1, which is considered the GIS industry standard, was used to process the geodata. There are two main kinds of geodata: vector and raster (Figure 1.1). Vectors are geometrical shapes called "shapefiles" in ArcGIS. Shapefiles spatially display data from attribute tables; they can be polygons, polylines, or points. Raster data is any kind of digital image and is composed of identically-sized square cells called pixels (ArcGIS, 2008). Examples of raster data are digital elevation models (DEM) and satellite imagery. Both shapefiles and raster data can be added as layers to an ArcGIS map project. The VGDB incorporates many layers of geodata, as discussed in section two of this thesis.
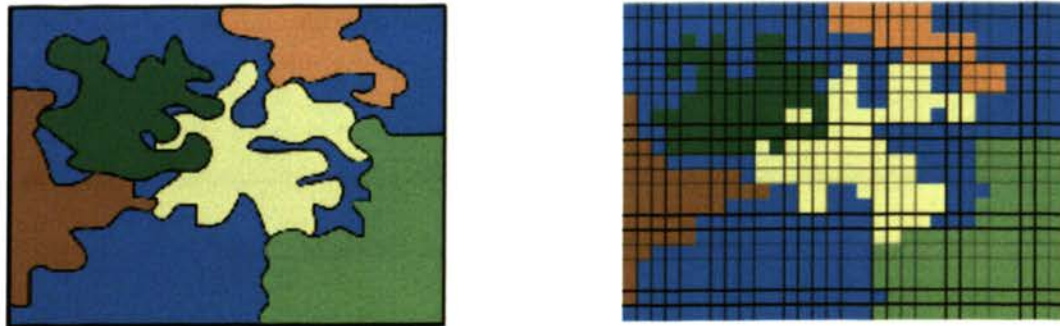
Figure 1.1. An area is depicted as both vector polygons (left) and raster data (right) (ArcGIS, 2008).

1.3.2. eXtensible Markup Language. XML is a language that is hierarchal and self-describing in nature; it contains both data and metadata, or data about data. It describes data using starting and closing tags (Eindhal, 2007). An XML document can be

structured with nested elements, i.e. one element being the "child" of another. Figure 1.2 shows an example of a simple XML document where the element "Missouri" has two children, "Rolla" and "St. James", and both of which have two children each, "Population" and "Zip."

```
<States>

      <State> Missouri </State>

            <City> Rolla </City>

                  <Population> 17985 </Population>

                  <Zip> 65401 </Zip>

            <City> St. James </City>

                  <Population> 4057 </Population>

                  <Zip> 65559 </Zip>

      <State> Minnesota </State>

            <City> Andover </Andover>

                  <Population> 30000 </Population>

                  <Zip> 55304 </Zip>

</States>
```

Figure 1.2. A simple XML document.

The VGDB for this project utilizes the XML-based database architecture developed by the British Association of Geotechnical and Geoenvironmental Specialists and the Consortium of Organizations for Strong Motion Observations Systems (COSMOS) which is being implemented nationwide by the United States Federal Highway Administration (FHWA) (Swift et al., 2004). It was chosen as the standard because it is widely supported in a variety of applications including internet browsers, it

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adheres to a strict schema, and it supports style sheets which can display the data in an attractive manner (Caronna, 2006).

In order to provide the most compatibility and productivity for users, the STL area VGDB utilizes XML to display borehole data in a table format. Other geodata layers do not contain the complexity of the borehole logs, which typically contain many attributes of subsurface data that is often confusing if left on the identify pane of ArcGIS.

1.3.3. Scalable Vector Graphics. The scalable vector graphics (SVG) format uses XML to describe two-dimensional graphics, such as vector shapes, text, and images. It preserves the shape of the vector at any scale, unlike a bitmap image which becomes pixelated when zoomed in (Figure 1.3) (Lilley and Jackson, 2004). SVG has become a popular choice for internet-based mapping because of its ability to quickly render large amounts of data. Most browsers natively support SVG so no additional plug-ins are necessary.

Figure 1.3. The difference in clarity between bitmap and scalable vector images at variable scales (Cheng, 2006).

ArcGIS has limited native SVG export support, so the VGDB was output to the internet in SVG form through an ArcGIS extension called MapViewSVG. This plug-in converts all layers to SVG format, and provides templates for a web interface that includes a legend, scale bar, and toolbar.

1.3.4. Internet Browser. Microsoft's Internet Explorer and Mozilla's Firefox are two main browsers users utilize to access the internet. The browser is the final step in the

VGDB process. Figure 1.4 gives an overview of the overall computing process of the VGDB.
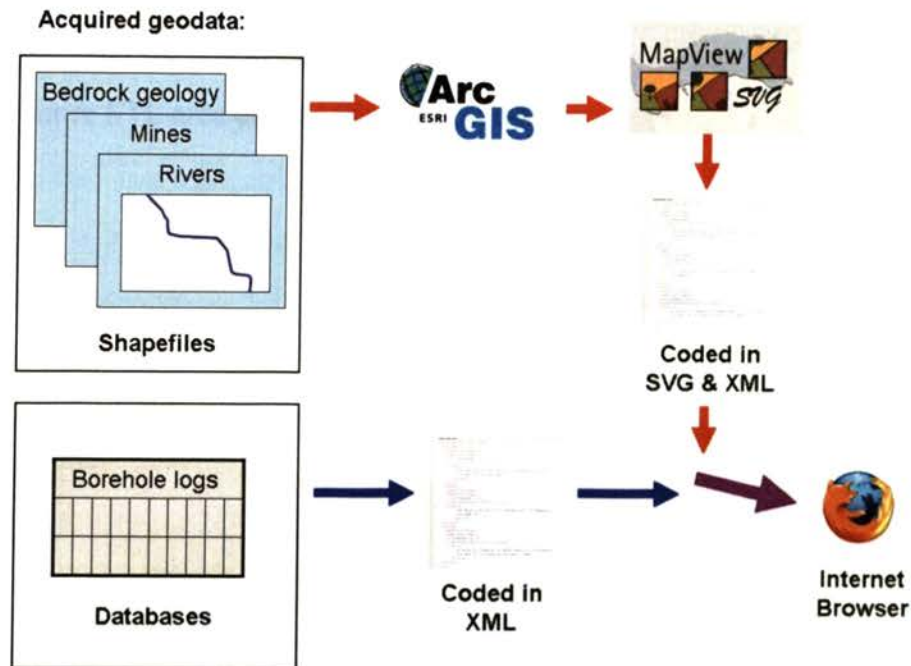
Figure 1.4. Diagram showing the overall VGDB process.

1.4 STUDY AREA

The STL area in this study covers a land area of 4,432 km^2, or 29 quadrangles as seen in Figure 1.5. This bi-state area contains the confluences of the Mississippi River with the Missouri, Illinois, and Meramec Rivers. Alluvial floodplains makeup much of the area on the Illinois side and within St. Charles County on the Missouri side. In the southwestern part of the STL area is the edge of the Ozark Uplands (Lutzen and Rockaway, 1987).

The STL area is the eighteenth largest metropolitan area in the United State. It has a population of roughly 2.8 million and has seen accelerated growth since 2000 (STLRCGA, 2008). This growth creates a greater demand for additional housing and businesses, as well as for improved infrastructure. In such large metropolitan areas,

hazard assessment, engineering design and construction, environmental studies, and risk management industries are in demand.

The southern part of the STL area is about 200 km north of the New Madrid Seismic Zone (NMSZ), which is the Midwest's most active seismic (Chung, 2007). Because of the loose sediments comprising the Mississippi River bed, seismic waves are easily carried from the NMSZ to the STL area; this makes seismic site response analysis across the entire STL area critical (Karadeniz, 2007).
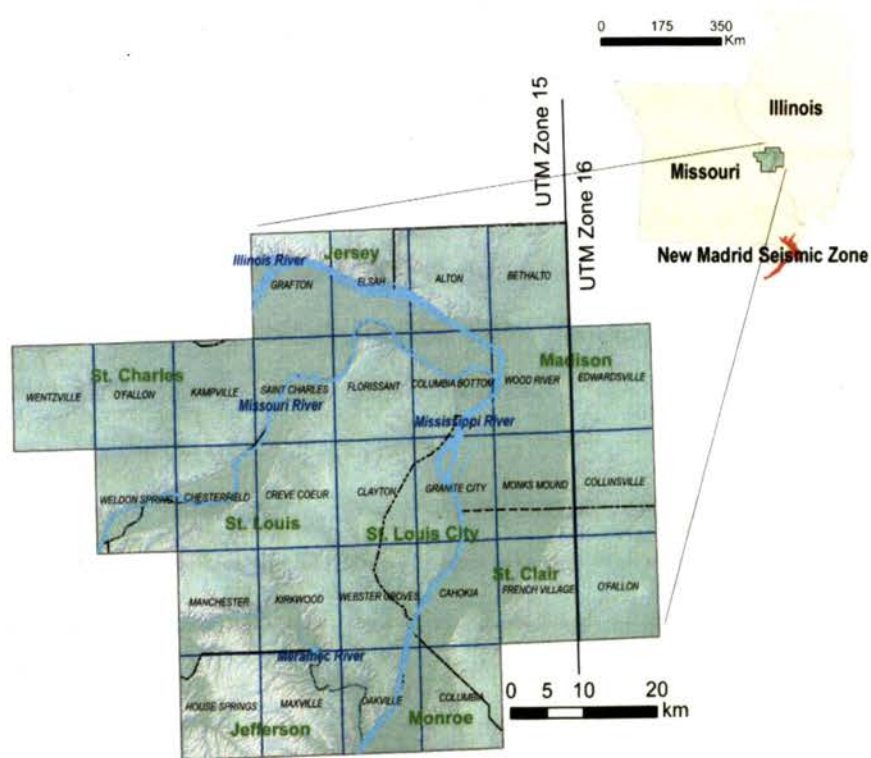
Figure 1.5. The St. Louis Metropolitan Area, 200km north of the New Madrid Seismic Zone (Chung, 2007).

2. ACQUISITION OF GEODATA

2.1 DATA SOURCES

A useful VGDB should include as many different subsets, or layers, of practical geodata in order to be of the most benefit to users. Having too few layers would make the database not useful, while too many layers may make it overwhelming for end users. In this VGDB, many different layers of subsurface data were compiled. But above surface data that may affect geotechnical projects were also added, giving users a comprehensive view of the area. In ArcGIS, any number of layers may be hidden or "turned off" to view an area in greater or lesser complexity.

A list of possible geodata layers and corresponding data sources was created, then the process began to acquire them. For the STL area, data from government agencies at the federal, state, and local levels were used (Table 2.1). Because almost all information collected by these agencies is in the public domain, the use is not restricted (USGS, 2007). Two types of geodata were compiled: subsurface log data such as borehole logs and vector data such as geology and mine locations.

Table 2.1. Data layers and corresponding sources for this VGDB.

	Layer	Source	Feature type
Base	DEM	USGS	Raster
	Roads	USGS	Vector (polylines)
	Boring Logs	MoDOT, ISGS, MEGA	Vector (points)
Geology	Surficial Geology	MEGA, ISGS	Vector (polygons)
	Bedrock Geology	MEGA, ISGS	Vector (polygons)
	Landslides	USGS	Vector (points and polygons)
	Cross-Sections	Karadeniz (2007)	Vector (polylines)
	Soil	USDA	Vector (polygons)
Geo-physical	Seismic Hazards	USGS	Vector (polylines)
	Magnetic Field	USGS	Vector (polylines)
	Karst Topography	USGS, MEGA, ISGS	Vector (polygons)

Table 2.1. Data layers and corresponding sources for this VGDB (cont.).

Water	Groundwater	USGS	Vector (polygons)
	Surface Water	MEGA, ISGS	Vector (polygons and polylines)
	Historic Water Areas	J.W. Chung (personal comm.)	Vector (polygons)
Human Activity	Mines	MEGA, ISGS	Vector (points) Vector (polygons)
	Underground Tanks	MEGA, Ill. EPA	Vector (points)
	Landfills	MEGA, ISGS	Vector (polygons)
	Pipelines	ISGS, St Charles County	Vector (polylines)
	Dams and Power Plants	MEGA, USGS	Vector (points)

2.2 BASE LAYERS

A base layer is a layer that a user can utilize as a reference point. A 10 x 10m digital elevation model (DEM) from the USGS along with a shapefile containing interstates and secondary roads were used for the VGDB. The DEM is the only raster file in the VGDB. An earth-toned gradient was used to shade the DEM, with brown representing the lower elevations and the tan representing higher elevations. The color scheme for the interstates is red, following the ArcGIS default, while the secondary roads are black.

2.3 BOREHOLE LOGS

Locations where boreholes were collected from three different agencies. The Missouri Department of Natural Resources Division of Geology and Land Survey (MoDNR-DGLS) has a database contained in their Missouri Environmental Geology Atlas (MEGA) 2007 CD-ROM. There are 1720 of these in the STL area, and many were from the first half of the twentieth century. Each well log contains at least an identification number, well type, location, elevation, drilling depth, and owner of the

well. Most logs contain at least the first six strata including geologic formation and layer thickness.

Most boreholes from the Missouri Department of Transportation were drilled for bridge and highway construction. MoDNR-DGLS provided the 2,394 boring logs in Microsoft Access 97 format. Universal Tranverse Mercator (UTM) coordinates were an attribute for every log, allowing them to be mapped in ArcGIS. Each well log contains much more geotechnical information such as standard penetration test blow counts, dry unit weight, and sieve analysis.

The Illinois State Geological Survey (ISGS) collected borehole and water well data from the Illinois Department of Mines and Minerals, the Illinois Department of Public Health, county health departments, as well as some engineering borings from the Illinois Department of Transportation (IDOT). ISGS provided the 4,817 boring logs in spreadsheet format.

Borehole distribution and type is shown in Figure 2.1. Illinois has boreholes more widely distributed because of the water well regulations, whereas boreholes on the Missouri side are primarily along major highways.
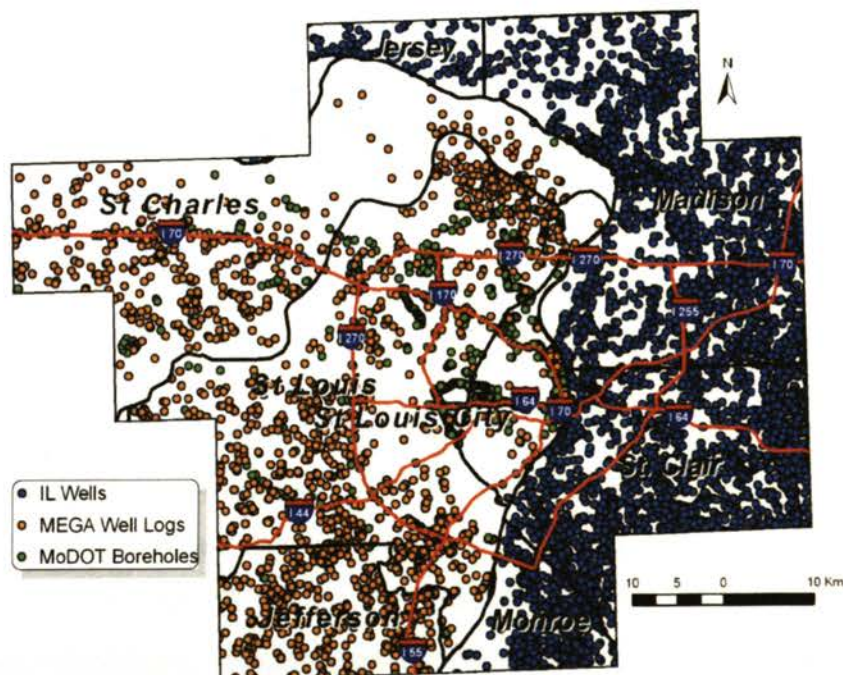
Figure 2.1. Distribution of boreholes locations and corresponding data source.

2.4 GEOLOGY

2.4.1. Surficial Geology. Surficial geological maps on the Missouri side utilized data from the MEGA 2007 CD-ROM produced by MoDNR-DGLS. They compiled the map utilizing a digitized 1983 statewide surficial materials map as a basemap, then filling in with individual maps at a scale of 1:24,000. The stratigraphic units are not named.

On the Illinois side, the United States Geologic Survey (USGS) STATEMAP program funded the ISGS Metro-East mapping project. ISGS mapped surficial materials at a scale of 1:24,000, named stratigraphic units, and deduced depositional environment.

2.4.2. Bedrock. The VGDB incorporated bedrock geology maps from MEGA 2007 at 1:24,000 scale for the Missouri side. On the Illinois side however, the only available bedrock data was a statewide map at a scale of 1:500,000 (Kolata, 2005). Correlating the bedrock geologic maps proves challenging due to the disparity of the map scales.

2.4.3. Landslides. Areas of landslide incidence and susceptibility are mapped from the USGS Landslide Overview Map (Godt, 1997) at a scale of 1:3,750,000. The highest susceptibility areas are mainly along the eastern bank of the Mississippi River. ISGS georeferenced point locations of earth slumps, slumps on bedrock, rock creep, and flows. Larger landslides are depicted as polygons (ISGS, 1995).

2.4.4. Cross-sections. Locations of seven depth-to-bedrock cross-sections for the Granite City, Monks Mound, and Columbia Bottom quadrangles were mapped. Hyperlinks were created in ArcGIS to the cross-section images produced by Karadeniz (2007) (Figure 2.2).

2.5 SOIL

The United States Department of Agriculture (USDA) created a nationwide soil survey. In 2004 they processed data for STL at a 1:12,000 scale, including ESRI ArcGIS shapefiles and Access database files. These detail the soil type, average percentage of slope, and areas of flooding (USDA, 2004). Soil thickness maps from three quadrangles in STL, Granite City, Monks Mound, and Columbia Bottom, were calculated using the

co-kriging method. Soil composition and thickness play a large role in determining the seismic site response (Karadeniz, 2007).
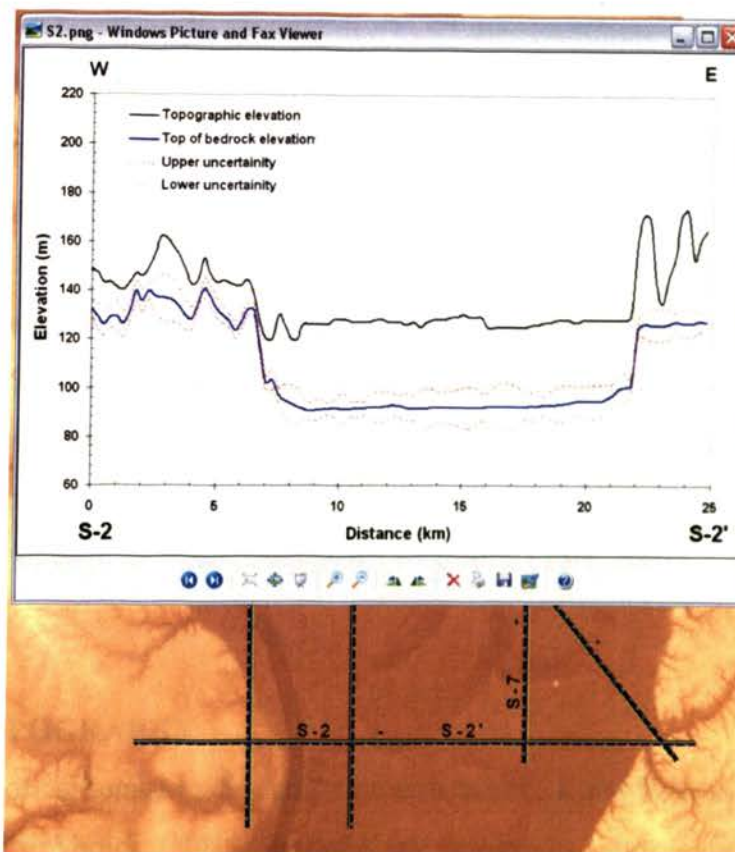
Figure 2.2. A screenshot showing the link between the polyline feature in ArcGIS and the correlating cross-section image.

2.6 GEOPHYSICAL

2.6.1. Seismic Hazards. Predicting site response to earthquakes depends on surficial material depth and composition. It is especially critical in this historically seismic area. Available maps from USGS give peak horizontal acceleration (Rukstales, 2002) and point locations where earthquakes have occurred from 1568-2004 (USGS 2005). There are only four earthquakes locations within the STL area, all of which occurred in the 20th century. While these locations can pinpoint areas of vulnerability, it is more important to consider in the NMSZ. It may be 200 km away, but earthquakes are

able to propagate through the relatively homogenous and rarely fractured bedrock and could have a dramatic effect on the STL area (Karadeniz, 2007).

Therefore peak acceleration (given here in % g with 10% probability of exceedance in 50 years) becomes all the more useful. The problem is that the USGS data is nationwide, and does not take into account local site conditions. D. Karadeniz studied three quadrangles within the STL area that were most urban (2007). Outside of these quadrangles are mostly single- and two-story buildings that would not be as dramatically affected by an earthquake. Data from the three quadrangles was incorporated into the database.

2.6.2. Magnetic Field. Variations in Earth's magnetic field were measured by USGS from 1995-2000. Though the STL area fits within an 86 km by 70 km square, there are still variations in the magnetic field. Parameters measured include direction (declination and inclination) and intensity (horizontal, vertical, and total), as well as the secular variation of each of these components over time (Tarr, 2001).

2.7 KARST TOPOGRAPHY

Solution of carbonate rocks cause this area to have Karst features like fissures, tubes, caves, and sinkholes. USGS mapped Karst features as applied to engineering aspects. It classified the length and vertical extent of fissures, tubes, and caves; bed dip; and rock type. Because this map is nationwide and on a scale of 1:7,500,000 (Tobin and Weary, 2005), it is more accurate to use data in a smaller scale.

On the Missouri side, two layers in MEGA are sinkholes and sinkhole areas. Both map known and probable locations of sinks, and were transferred from 1:24,000 scale USGS topographic maps. The sinkholes layer contains point locations, whereas the sinkhole areas layer contains polylines representing larger areas typically about 200m (MEGA, 2007).

In Illinois, ISGS mapped areas which are believed to contain sinkholes (Weibel and Panno, 1997). While the scale is larger (1:100,000) than Missouri's, it is still more detailed than the USGS map and provides coverage for the east part of the Mississippi.

2.8 WATER

2.8.1. Groundwater. A groundwater map from USGS was added to the VGDB that displays principal aquifers. It is scaled at 1:2,500,000 (USGS, 2003). Though the scale is large, it provides a consistent view across the bi-state area.

2.8.2. Surface Water. Lakes, rivers and streams on the Missouri side was extracted from MEGA, at a scale of 1:24,000 (MEGA, 2007). For the Illinois side, a map showing displaying surface water from ISGS at a scale of 1:100,000. On both sides, lakes and large rivers are polygons, while streams are polylines.

2.8.3. Historic. Old maps of STL from the nineteenth and twentieth centuries were scanned and the locations of major rivers and lakes were mapped (Chung, personal communication). On the Illinois side, historic lake beds are the foundation for major highways, including Interstate-255. Rivers, especially the Mississippi, have changed their course over the past 200 years; this layer displays the history of that movement (Figure 2.3).

2.9 HUMAN ACTIVITY

2.9.1. Mines. Areas containing both active and abandoned mines were added to the VGDB. MEGA provided point data for locations of both active and abandoned mines, along with the material mined. Active mines were displayed with a circle, while abandoned mines were displayed as a circle with an "X" through it. The color of the point varied with the material mined.

On the Illinois side, there are also points representing mine locations, but they are only in western Madison County. Polygons covering the eastern half of the Illinois side represent areas containing coal beds, as well as areas that have been mined. Polygons better than points convey the impact mining has had on the subsurface.

2.9.2. Underground Tanks. MEGA provided locations of both active and abandoned underground tanks. Active tanks are displayed with a neon green circle, while abandoned tanks are navy blue. The state of Illinois' Environmental Protection Agency (EPA) provided data for tanks in Google Earth format (.kmz). These were converted into a shapefile for use in ArcGIS, but no metadata was provided. Only leaking tanks

managed by the Illinois EPA have been mapped (Ill. EPA, 2008). These are represented by a neon green circle also.
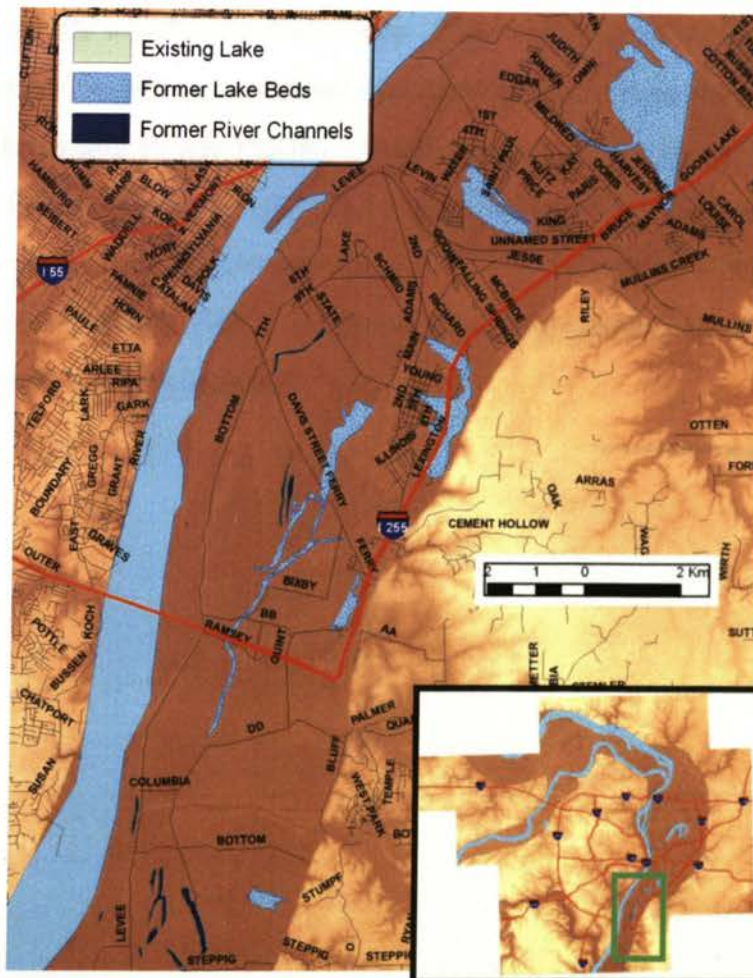
Figure 2.3. An example of development and infrastructure overlapping with historic lake beds and river channels.

2.9.3. Landfills. Geodata for landfill locations were added from the MoDNR website. They were not included with MEGA 2007 because they were produced by the Air and Land Protection Division of MoDNR (MoDNR, 2004). ISGS provided data for the Illinois side, which was originally compiled by the Illinois EPA in 1997 (ISGS, 1997).

2.9.4. Pipelines. The STL area is home to many pipelines bringing fuel supplies from the Gulf of Mexico to the rest of the United States. The National Pipeline Mapping

System locked public access to their maps for national security reasons. Their maps, which are current and nationwide, do not appear in the VGDB, but older maps from ISGS were added to the database. Data displayed includes pipelines that carry crude oil, natural gas and/or refined products (ISGS, 1984). The only county in Missouri that had pipelines mapped and available was St. Charles County. They had a portable document format (PDF) file available, which was imported into ArcGIS and converted to a shapefile.

2.9.5. Dams and Power Plants. Dam data was provided by the USGS and added to the VGDB. Dams are represented with a black chevron; the default within ArcGIS. Power plant locations from MEGA are represented with a lightning bolt icon and labeled with their fuel type (MEGA, 2007). No power plant information from Illinois was included, because it was not available.

3. FORMATTING DATA

3.1 FORMATTING ARCGIS 9.1 SHAPEFILES

3.1.1. File Type. When geodata is compiled from disparate sources, great attention to detail must be used to standardize them. Most data incorporated into the VGDB was acquired already in shapefile format. Some layers from the ISGS were in the ArcInfo interchange (.e00) file format, and the layer from the Illinois EPA was in Google Earth format (.kmz). ArcGIS imported the interchange files seamlessly, but the Google Earth files required a free translator plug-in.

3.1.2. Geographic Coordinate Systems and Projections. Geographic coordinate systems use three coordinates to specify locations on the earth. Most data layers used the NAD 1983 datum, which fits North America reasonably well. The "Projection Wizard" function within ArcGIS' ArcToolbox was used to transpose layers that did not conform to the NAD 1983. Zones 15N and 16N in the UTM coordinate system were used. Zone 15 covers the Missouri side and most of the Illinois, with zone 16 covering the easternmost portion of Illinois (Figure 1.5).

3.1.3. Attribute Tables. The attribute table for many layers contained fields with only one letter or a number. In order to find out what the letter or number represented, one must open the metadata file bundled with the layer, or find the metadata online. The longer field names extracted from the metadata, along with the attribute table data, were imported into Microsoft Excel. The coherent table was then exported into ArcGIS. For example, instead of the label for a feature reading "34", after the transformation it read "sand."

When geodata from nation- or state-wide sources were imported, extraneous data points from outside the STL area came with it. While these points were not visible because they are outside the 29-quadrangle area, they still were a part of the layer and taking up memory. To slim down the VGDB and create a faster export, these extra data points were deleted via the attribute table. Within ArcGIS, first the "Select by Location" function was used to select all data points within the STL area for a given layer. The selection was then switched to include all data points *outside* the STL area using the

"Switch selection" command within the attribute table. The extra data points were then deleted, making for a more streamlined VGDB.

3.2 FORMATTING XML

3.2.1. Conversion. The VGDB has three sources of borehole data with differing formats. Borehole data from MoDOT were in Microsoft Access format, well log data from both MoDNR-DGLS and ISGS were in Microsoft Excel spreadsheet format. In their current form, these data are difficult to read. Figure 3.1 shows the spreadsheet obtained from the ISGS. Users must scroll left and right to obtain data about well logs, and it is inconvenient to use.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	api	latitude	longitude	UTM 15_N83_X	UTM15_N83_Y	lamx	lamy	td	sect	twp	tdir	rng	rdir	nsf	nsdir
2	121192772200	38.990684	90.05987	754640	4319861	2841726	2173419	28	12	6 N		9 W		2000 N	
3	121192700200	38.887035	90.168782	745563	4308057	2810661	2136084	63	13	5 N		10 W		0	
4	121192772300	38.990684	90.05987	754640	4319861	2841726	2173419	19	12	6 N		9 W		2000 N	
5	121192700100	38.887035	90.168782	745563	4308057	2810661	2136084	69	13	5 N		10 W		0	
6	121192772100	38.990684	90.05987	754640	4319861	2841726	2173419	27	12	6 N		9 W		2000 N	
7	121192772400	38.990684	90.05987	754640	4319861	2841726	2173419	35	12	6 N		9 W		2000 N	
8	121192653700	38.79997	90.034284	757546	4298764	2848553	2104296	56	18	4 N		8 W		1400 S	
9	121192653400	38.79997	90.034284	757546	4298764	2848553	2104296	56	18	4 N		8 W		1400 S	
10	121192653500	38.79997	90.034284	757546	4298764	2848553	2104296	56	18	4 N		8 W		1400 S	
11	121192822600	38.779319	90.003328	760310	4296559	2857286	2096766	40	20	4 N		8 W		1800 S	
12	121332238500	38.385297	90.256454	739623	4252136	2784328	1954548	28	6	2 S		10 W		0	
13	121332238600	38.385297	90.256454	739623	4252136	2784328	1954548	26	6	2 S		10 W		0	
14	121192808700	38.831107	89.996329	239894	4302307	2859373	2115513	80	4	4 N		8 W		0	
15	121192808600	38.831107	89.996329	239894	4302307	2859373	2115513	35	4	4 N		8 W		0	
16	121192808800	38.831107	89.996329	239894	4302307	2859373	2115513	40	4	4 N		8 W		0	
17	121632861600	38.623844	90.171873	746198	4278836	2809081	2040761	130	14	2 N		10 W		0	
18	121190221300	38.721131	90.155587	747281	4289678	2813963	2075965	66	12	3 N		10 W		1100 S	
19	121192647300	38.721131	90.155587	747281	4289678	2813963	2075965	61	12	3 N		10 W		1100 S	
20	121192647200	38.721131	90.155587	747281	4289678	2813963	2075965	66	12	3 N		10 W		1100 S	
21	121192647500	38.721131	90.155587	747281	4289678	2813963	2075965	66	12	3 N		10 W		1100 S	
22	121632871500	38.612713	90.167898	746582	4277611	2810181	2036721	120	23	2 N		10 W		0	
23	121632871300	38.612713	90.167898	746582	4277611	2810181	2036721	131	23	2 N		10 W		0	
24	121632869900	38.609094	90.172519	746192	4277197	2808858	2035420	71	23	2 N		10 W		0	
25	121632872400	38.605429	90.167946	746603	4276803	2810148	2034083	120	23	2 N		10 W		0	
26	121192668400	38.762041	90.150287	747601	4294233	2815573	2090772	51	25	4 N		10 W		0 N	
27	121630290100	38.618868	90.069488	755131	4278564	2838163	2038760	72	14	2 N		9 W		0	
28	121632871600	38.612713	90.167898	746582	4277611	2810181	2036721	118	23	2 N		10 W		0	
29	121632903700	38.575023	90.111199	751652	4273582	2826203	2022956	100	32	2 N		9 W		0	
30	121632884900	38.5778	90.11232	751545	4273887	2825891	2023964	100	32	2 N		9 W		0	
31	121632871800	38.612713	90.167898	746582	4277611	2810181	2036721	136	23	2 N		10 W		0	
32	121632895000	38.5778	90.11232	751545	4273887	2825891	2023964	100	32	2 N		9 W		0	
33	121632833800	38.509428	90.204787	743719	4266049	2799407	1999390	72	28	1 N		10 W		0	
34	121632833900	38.509428	90.204787	743719	4266049	2799407	1999390	72	28	1 N		10 W		0	

Figure 3.1. A screenshot of the current state of borehole information from ISGS.

Access and Microsoft Excel translated the data into raw XML code (Figure 3.2). The translation did not preserve the correct data format. Some modification of XML tags, which are elements describing the data, was performed.

```
                    <row>
                        <ID>000121</ID>
        ┌──────────┐   <WELL_TYPE>Private well</WELL_TYPE>        ┌──────────┐
        │ Tags     │   <OWNER>BOEHLE, WELL #1</OWNER>            │ The      │
        │ describe │   <DRLDATE>1904/12/00</DRLDATE>            │          │
        │          │   <DRILLDEPTH>650</DRILLDEPTH>             │ slash    │
        │ the data │   <DEPTHTOBED>60</DEPTHTOBED>              │          │
        │ type     │   <ELEVATION>470</ELEVATION>               │ closes   │
        │          │   <LAYER>                                  │          │
        └──────────┘       <TOP>0000</TOP>                      │ the tag  │
                           <BASE>0025</BASE>                    └──────────┘
                           <NAME>NO SAMPLES [] </NAME>
                    </LAYER>
                    <LAYER>
                           <TOP>0025</TOP>
                           <BASE>0025</BASE>
        ┌──────────┐       <NAME>RESIDUUM TOP SOIL [SAND; CLAY; ] </NAME>
        │ Data is  │   </LAYER>
        │ stored   │   <LAYER>
        │          │       <TOP>0060</TOP>
        │ between  │       <BASE>0600</BASE>
        │ tags     │       <NAME>RESIDUUM TOP SOIL [SAND; CLAY; ] </NAME>
        └──────────┘   </LAYER>
                    <LAYER>
                           <TOP>0060</TOP>
                           <BASE>0280</BASE>
                           <NAME>MERAMECIAN SERIES [] </NAME>
                    </LAYER>
                    <LAYER>
                           <TOP>0060</TOP>
                           <BASE>0200</BASE>
                           <NAME>SALEM FORMATION [LS; CH; DOLO] </NAME>
                    </LAYER>
                    <LAYER>
                           <TOP>0200</TOP>
                           <BASE>0280</BASE>
                           <NAME>WARSAW FORMATION [LS; SH; ] </NAME>
                    </LAYER>
                    <LAYER>
                           <TOP>0280</TOP>
                           <BASE>0565</BASE>
                           <NAME>OSAGEAN SERIES [] </NAME>
                    </LAYER>
                    </row>
```
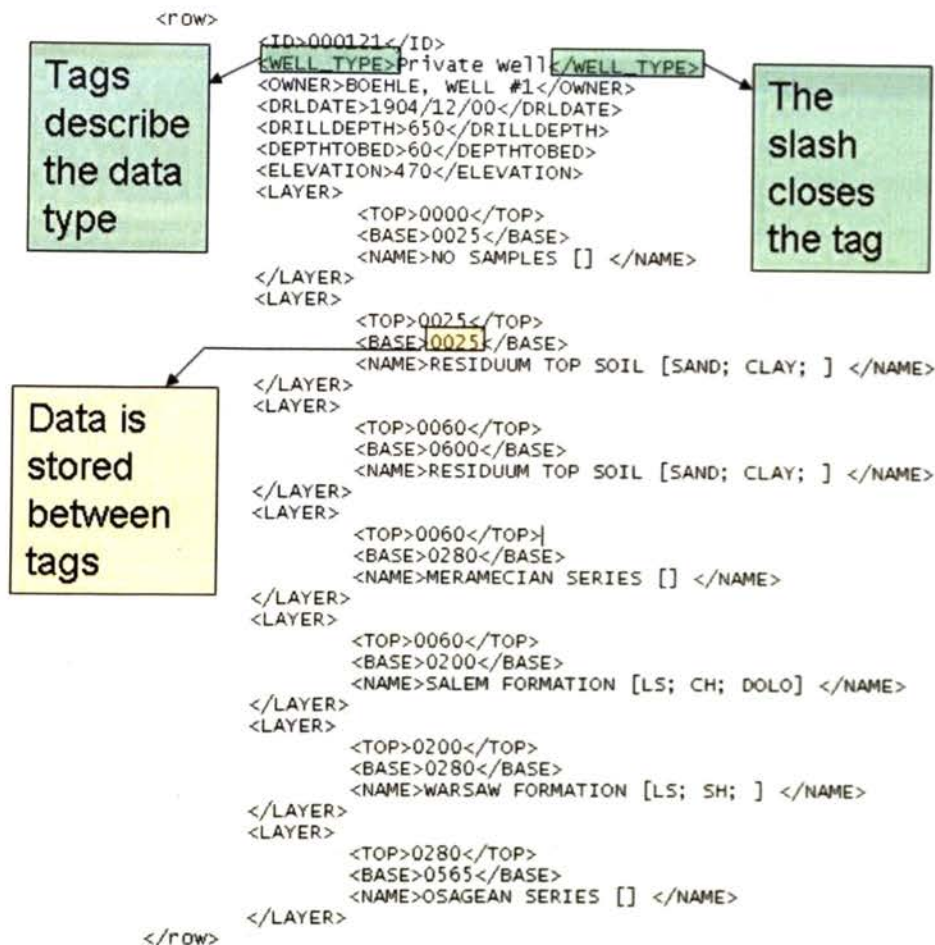
Figure 3.2. An example of raw XML code displaying data for one well log.

Having the data encoded in XML is only part of the formatting process. The XML document contains raw code and must be associated with two other XML documents: a schema which structures the XML code, and a stylesheet which formats the data in an easy to read layout (Figure 3.3).

3.2.2. Schema. An XML schema (a .xsd file) defines the structure of an XML document. As seen in Figure 3.4, the "ID" element is the "parent" for all the other fields, making all the other fields "children." The elements "TOP", "BASE", and "NAME" are all children of "LAYER." Additionally, each element is associated with a data type classification, i.e. "string" if that data field contains text or "integer" if it contains numbers.
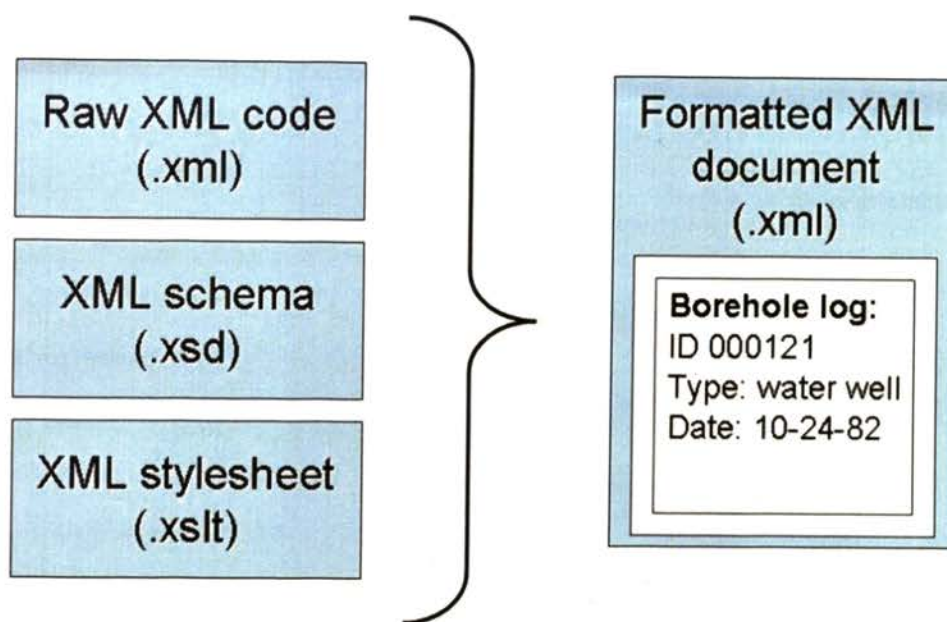
Figure 3.3. In order for an XML document to display correctly, three separate XML documents must be associated with each other.

Schemata for data from all three sources were created. Because they all contain different information, the schemata had to be customized for each. The schema for MoDNR-DGLS (Figure 3.4) contained only 12 elements, while the schema for MoDOT was most complex because there were over 30 elements to be structured.

3.2.3. Stylesheet. An XML stylesheet (an .xslt file) processes the raw XML code into the schema and transforms it into a readable format. It utilizes XML and HTML code to render page format including styled text, images, and tables. The resulting XML file is readable in internet browsers (Figure 3.5).

Because the boreholes data contain different elements, different stylesheets had to be created using the structure of the schemata. The primary objective when formatting the stylesheets was making the various elements easy to find for end users. In Figure 3.4, the well log identification number is at the top in a larger font and in bold. Strata names and corresponding top and base depths were listed in table format on the left side. The top of the right side contained information such as the well type, total depth, and elevation. Below that information was the drill date, owner of the well, and source of the borehole data.
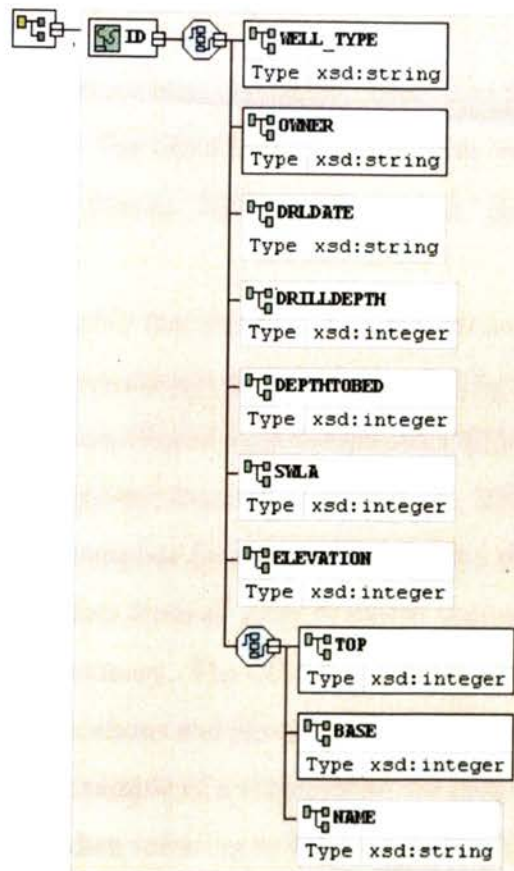
Figure 3.4. The tree structure view of the XML schema for well logs from MoDNR-DGLS.

Figure 3.5. A window in Internet Explorer displays the final XML output for one of the well logs.

3.3 DATA DICTIONARY

Because the VGDB incorporates subsurface data from three different sources, terms have to be standardized. The identification of borehole logs was dissimilar for all three sources. It was "api" for Illinois "ID" for MEGA, and "BH_ID" for MoDOT (Table 3.1).

A data dictionary is a table that standardizes these terms. They are clearly defined so there is no confusion. A geotechnical database compiled by the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) developed a data dictionary based on needs of geo-professionals (Swift et al., 2004). The VGDB for the STL area used the COSMOS template for developing the data dictionary.

Terms from borehole data from all three borehole sources (MoDOT, MEGA, and ISGS) comprised this data dictionary. The database and spreadsheets were gone through meticulously to extract specifications and parameters for geotechnical data, such as the standard penetration test. An example of a table within the data dictionary is below in Table 3.1. The code is used when referring to the term within XML. The full data dictionary is listed in Appendix B.

3.4 METADATA

Metadata, or data about data, almost always accompanies geodata. It includes information like the source individual or organization, map scale, geographic coordinate system, method of acquiring the data, and citation information. It is included as a separate file from the geodata, usually as a plain text (.txt) or raw XML file (.xml). The quality of the metadata is dependent on the source of the data. Sometimes metadata does not even exist, in which case it must be created.

Because this project is ultimately being produced for a national agency, metadata must be formatted to meet the Content Standard for Digital Geospatial Metadata, from the Federal Geographic Data Committee (FGDC) (FGDC, 2007). Most metadata from the USGS, MEGA, and ISGS already followed this standard. The metadata attached to the VGDB layers was checked to ensure compliance. Created layers, such as the cross-

section layer, had no associated metadata. It was created in ArcCatalog, which includes an existing stylesheet titled "FGDC."

Table 3.1. Table representing the different data associated with each borehole source.

MoDOT	MEGA	ISGS
Struc_Id	ID	api
BH_Id	WELL_TYPE	UTM 15_N83_X
FHoleElev	OWNER	UTM15_N83_Y
FDepth	DRLDATE	elev
FSampEl	DRILLDEPTH	elevref
Blows_2	DEPTHTOBED	cdate
Blows_3	SWLA	st
Nm	ELEVATION	fname
Em	TOP	fnum
Ne_N60	BASE	cname
PP	NAME	permitnum
Torvane	UNIT_1	permitdate
Qu_psf	TOP	project
c_psf	BASE	bridge
phi_angle	NAME	route
Cc	UNIT_2	station
Cv_e	TOP	offset
P1_e	BASE	surface_water_elev
Pc_e	NAME	gwater_compl
P2_e		gwater_final
e0		gwater_time
ec		metric
e2		
LL		
PI		
ASTM_class		
Wn_percent		
EDryWt		
DryWtMeth		
Comment		
Xutm_point		
Yutm_point		

Table 3.2. A portion of the data dictionary

Name	Code	Definition
Name	ID	A common name for the hole. This name does not need to be unique within the naming system.
Type	Well_Type	The primary or current type of sampling station/hole. This is used to supply more specificity to the Site Type. Value should be one of the following:
Date	Date	The ending date of the collection activity for this hole.
Owner	Owner	Owner of the installed well.
Elevation	Elev	Elevation of the hole at the depth datum. Elevations are positive upward, measured from the elevation datum.
Location X	Xutm_point	The first coordinate for the location of the location reference point. In the US, this would be the Easting.
Location Y	Yutm_point	The second coordinate for the location of the location reference point. In the US, this would be the Northing.

4. DATA OUTPUT

4.1 HYPERLINKING DATA

4.1.1. Portable Document Format Files. An engineering properties report included in the Microsoft Access soil database from the USDA was outputted as a portable document format (PDF), as seen in Figure 4.1. The PDF file format was chosen because of its ubiquity on the internet and ability to preserve text format across any platform.

Engineering Properties

St Clair County, Illinois

[Absence of an entry indicates that the data were not estimated]

Map symbol and soil name	Depth	USDA texture	Classification		Fragments		Percent passing sieve number--				Liquid limit	Plasticity index
			Unified	AASHTO	>10 Inches	3-10 Inches	4	10	40	200		
	In				Pct	Pct					Pct	
79B												
Menfro	0-10	Silt loam	CL	A-6	0	0	100	100	95-100	90-100	29-43	12-18
	10-62	Silty clay loam, silt loam	CL	A-6, A-7	0	0	100	100	95-100	95-100	34-47	16-25
	62-80	Silty clay loam, silt loam	CL, CL-ML	A-4, A-6	0	0	100	100	95-100	90-100	25-40	9-21
79C2												
Menfro	0-7	Silt loam	CL	A-6	0	0	100	100	95-100	90-100	28-41	12-19
	7-56	Silty clay loam, silt loam	CL	A-6, A-7	0	0	100	100	95-100	95-100	34-47	16-25
	56-80	Silty clay loam, silt loam	CL, CL-ML	A-4, A-6	0	0	100	100	95-100	90-100	25-40	9-21
79C3												
Menfro	0-5	Silty clay loam	CL	A-6	0	0	100	100	95-100	90-100	35-45	15-25
	5-50	Silty clay loam, silt loam	CL	A-6, A-7	0	0	100	100	95-100	95-100	35-45	15-25
	50-80	Silty clay loam, silt loam	CL, CL-ML	A-4, A-6	0	0	100	100	95-100	90-100	25-40	5-20
79D2												
Menfro	0-7	Silt loam	CL	A-6	0	0	100	100	95-100	90-100	30-35	10-15
	7-56	Silty clay loam, silt loam	CL	A-6, A-7	0	0	100	100	95-100	95-100	35-45	15-25
	56-80	Silty clay loam, silt loam	CL, CL-ML	A-4, A-6	0	0	100	100	95-100	90-100	25-40	10-20

USDA **Natural Resources Conservation Service**   Survey Area Version: 2
Survey Area Version Date: 08/01/2006   Page 1

Figure 4.1. This PDF shows a typical engineering report from the USDA. Four different slopes are represented on the left.

The PDF file was automated to have a file name corresponding to the USDA map unit and county name. For example, a soil with the map unit name "79B" in St. Clair

County would have a corresponding file name of "79Bc.pdf", with the "c" representing St. Clair County. This was done because many of the map units had different properties in different counties. In ArcGIS, another field was created in the attributes table for the soil layer. This field was populated with hyperlinks to the corresponding engineering report. Because the soil layer contained over 10,000 records in each county and the attribute table within ArcGIS is cumbersome to work with, the attribute table data was processed in Microsoft Excel and exported back to ArcGIS. The hyperlink is then active within the entire polygon of that map unit.

Though the engineering properties report contains subsurface material data along with corresponding depth similar to the borehole information, no specific borehole location is listed. While the soil regions are generally relatively small (most are about 1000 - 1500 m^2 in area), they are too large to consider the subsurface data exact across the entire area.

4.1.2. Images. The cross-section layer was augmented by having images hyperlinked to its data points in ArcGIS (Figure 2.2). The hyperlinks were preserved when outputting the VGDB to the internet. A link to a separate SVG file that included satellite imagery from the USDA was made. Because of its size and detail, this layer slowed down the entire VGDB, so it was not included.

4.2 MAP IN SVG FORMAT

There are several software options for the output of maps to the internet, including ESRI ArcIMS, Google Earth, and SVG format. For this VGDB, SVG format was chosen because of its ability to quickly render large amounts of data, versatility across browsers, and preservability of appearance at any scale. Because ArcGIS 9.1 has limited SVG export capabilities, MapViewSVG, an ArcGIS extension was installed. MapViewSVG includes layout templates for placement of the toolbar, legend, scale, and overview map. The MapViewSVG toolbar contains zoom functions, pan, zoom to extent, measure, and coordinate read-out tools.

Once all VGDB layers were properly formatted using the methods in section three, they were selected for output. The MapViewSVG extension exported them to a

folder "mapview" located in the same file structure as the ArcGIS file. Certain settings were entered, including the final size of the map window, which was set at 600 pixels. Certain layers were chosen to have their attribute tables viewable. The resulting SVG file was tested in an internet browser.

4.3 VIEWING IN A BROWSER

The resulting SVG map (Figure 4.2) can be viewed in most standard browsers, including Mozilla Firefox 1.5, Opera 9, and Apple Safari 3.1 for Windows and Macintosh, which all have native SVG support. To view SVG files in Microsoft Internet Explorer, the free Adobe SVGViewer plug-in must be downloaded. In all browsers, the layout appears the same.
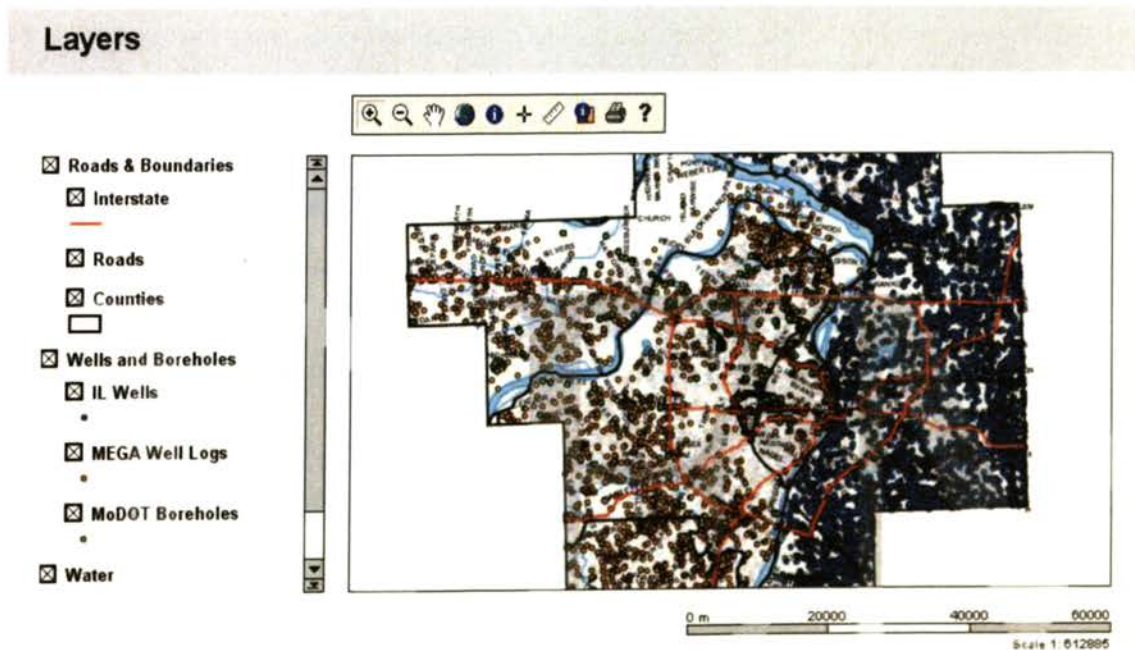
Figure 4.2. A screenshot of the resulting map within a browser showing just the boreholes layer.

MapViewSVG also includes a query builder. Users can construct query expressions within layers. For example within the "Mines" layer, a user may want to see

where all of the limestone mines are within the STL area. The user could then enter [material = limestone], and then either press the "Select and Zoom" button or the "Select" button. All data points matching the query would be highlighted. The query builder can also produce advanced Boolean searches. Using these searches, one would be able to find all past-producing limestone mines in St. Charles County.

5. CONCLUSIONS AND FUTURE WORK

This thesis provided insight into the process and methodology of creating a VGDB for the St. Louis metropolitan area that spans two states, Missouri and Illinois. It involved obtaining and configuring many layers of geodata from a variety of different sources. It also involved acquiring and formatting raw databases and spreadsheets of borehole information into XML documents. Once formatted, the data were converted to a format that is viewable on the internet; the XML documents were linked to schema and stylesheets, while the vector data were converted to the SVG format. The result was a comprehensive and unique source for geospatial analysis of the STL area.

There is a wide range of applications for the VGDB, and many industries will benefit from the availability of area-wide subsurface information. The proximity of the STL area to the New Madrid Seismic Zone makes it a crucial area for seismic site response. The area's continuing growth will also necessitate land use planning so areas with potential geologic hazards can be properly analyzed. Individuals involved with environmental planning and remediation need subsurface and above surface information to estimate current or future issues.

The goal of this thesis was accomplished; a VGDB of the STL area viewable in an internet browser was created. However, the next step is clearly to make it accessible to geo-professionals. A server dedicated to hosting the files would need to be implemented, and an interface requiring a login and password would likely need to be integrated so users could add their data to the VGDB. The entry parameters for this entered data would need to be strict so no misinformation was present. The entries would be linked to the user, so if another user had questions about the entry, he or she could contact the user who entered it. It would also be beneficial to create SVG images of borehole layers, making them dynamic. More borehole data that include accurate stratigraphy would be needed in order to do this.

The STL VGDB can be used as a template for other areas wishing to create a VGDB. However, generating a VGDB depends largely on the source geodata; the geodata provided by the federal, state, and local agencies needs to be accurate, relevant,

and up-to-date. In areas where there is a lack of government funding for mapping geodata, data from private companies or other entities can be used.

From taking raw data, compiling it from different sources, formatting it, and outputting it, the creation of the VGDB has involved many steps. Overall, it will ease the inconvenience and hassle of referencing different sources at different locations for separate geodata. Individuals needing to perform area-wide analysis of the STL area will find that the VGDB is extremely helpful.

APPENDIX A.

EXAMPLES OF XML CODES USED

```xml
<?xml version="1.0"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
    <xsd:element name="root">
        <xsd:complexType>
            <xsd:sequence>
                <xsd:element name="Struct_ID" maxOccurs="unbounded">
                    <xsd:complexType>
                        <xsd:sequence>
                            <xsd:element name="ID" maxOccurs="unbounded">
                                <xsd:complexType>
                                    <xsd:sequence>
                                        <xsd:element name="Elevation" type="xsd:decimal"/>
                                        <xsd:element name="Sample">
                                            <xsd:complexType>
                                                <xsd:sequence>
                                                    <xsd:element name="SPT_Data">
                                                        <xsd:complexType>
                                                            <xsd:sequence>
                                                                <xsd:element name="Blows_2" type="xsd:integer"/>
                                                                <xsd:element name="Blows_3" type="xsd:integer"/>
                                                                <xsd:element name="Nm" type="xsd:integer" minOccurs="1"/>
                                                                <xsd:element name="Em" type="xsd:integer"/>
                                                                <xsd:element name="Ne_N60" type="xsd:integer"/>
                                                            </xsd:sequence>
                                                        </xsd:complexType>
                                                    </xsd:element>
                                                    <xsd:element name="Other_tests">
                                                        <xsd:complexType>
                                                            <xsd:sequence>
                                                                <xsd:element name="PP" type="xsd:integer"/>
                                                                <xsd:element name="Torvane" type="xsd:decimal"/>
                                                                <xsd:element name="Qu_psf" type="xsd:integer"/>
                                                                <xsd:element name="c_psf" type="xsd:integer"/>
                                                                <xsd:element name="phi_angle" type="xsd:integer"/>
                                                            </xsd:sequence>
                                                        </xsd:complexType>
                                                    </xsd:element>
                                                    <xsd:element name="Atterberg">
                                                        <xsd:complexType>
                                                            <xsd:sequence>
                                                                <xsd:element name="LL" type="xsd:integer"/>
                                                                <xsd:element name="PI" type="xsd:integer"/>
                                                                <xsd:element name="ASTM" type="xsd:string"/>
                                                                <xsd:element name="Water_percent" type="xsd:decimal"/>
                                                                <xsd:element name="Dry_Wt" type="xsd:decimal"/>
                                                            </xsd:sequence>
                                                        </xsd:complexType>
                                                    </xsd:element>
                                                    <xsd:element name="Sample_Elev" type="xsd:decimal"/>
                                                    <xsd:element name="Depth" type="xsd:decimal"/>
                                                </xsd:sequence>
                                            </xsd:complexType>
                                        </xsd:element>
                                        <xsd:element name="Comment" type="xsd:string"/>
                                        <xsd:element name="Date" type="xsd:date"/>
                                    </xsd:sequence>
```

```
                            <xsd:attribute name="BH"/>
                        </xsd:complexType>
                    </xsd:element>
                    <xsd:element name="Coords">
                        <xsd:complexType>
                            <xsd:sequence>
                                <xsd:element name="Xutm_point" type="xsd:integer"/>
                                <xsd:element name="Yutm_point" type="xsd:integer" minOccurs="1"/>
                            </xsd:sequence>
                        </xsd:complexType>
                    </xsd:element>
                </xsd:sequence>
                <xsd:attribute name="SH"/>
            </xsd:complexType>
        </xsd:element>
    </xsd:sequence>
    </xsd:complexType>
</xsd:element>
</xsd:schema>


<?xml version="1.0"?>
<root xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="file:///d:/XML/New%20Folder/modot.xsd">
    <!--Element Struct_ID, maxOccurs=unbounded-->
    <Struct_ID SH="IS170_A3001S">
        <!--Attribute SH is optional-->
        <!--Element ID, maxOccurs=unbounded-->
        <ID BH="IS170_A3001S486+6296L">
            <!--Attribute BH is optional-->
            <Elevation>581.51</Elevation>
            <Sample>
                <SPT_Data>
                    <Blows_2>22</Blows_2>
                    <Blows_3>26</Blows_3>
                    <Nm>48</Nm>
                    <Em>60</Em>
                    <Ne_N60>48</Ne_N60>
                </SPT_Data>
                <Other_tests>
                    <PP>7</PP>
                    <Torvane>0</Torvane>
                    <Qu_psf>0</Qu_psf>
                    <c_psf>0</c_psf>
                    <phi_angle>0</phi_angle>
                </Other_tests>
                <Atterberg>
                    <LL>0</LL>
                    <PI>0</PI>
                    <ASTM>string</ASTM>
                    <Water_percent>0</Water_percent>
                    <Dry_Wt>0</Dry_Wt>
                </Atterberg>
                <Sample_Elev>551.51</Sample_Elev>
                <Depth>30</Depth>
            </Sample>
```

```
            <Comment>-</Comment>
            <Date>2006-03-03</Date>
        </ID>
        <ID BH="STL_MSD-88158_1__61017-N1">
            <!--Attribute BH is optional-->
            <Elevation>419.88</Elevation>
            <Sample>
                <SPT_Data>
                    <Blows_2>2</Blows_2>
                    <Blows_3>3</Blows_3>
                    <Nm>5</Nm>
                    <Em>60</Em>
                    <Ne_N60>5</Ne_N60>
                </SPT_Data>
                <Other_tests>
                    <PP>0</PP>
                    <Torvane>0</Torvane>
                    <Qu_psf>0</Qu_psf>
                    <c_psf>0</c_psf>
                    <phi_angle>0</phi_angle>
                </Other_tests>
                <Atterberg>
                    <LL>37</LL>
                    <PI>18</PI>
                    <ASTM>CL</ASTM>
                    <Water_percent>22.90</Water_percent>
                    <Dry_Wt>22.9</Dry_Wt>
                </Atterberg>
                <Sample_Elev>406.38</Sample_Elev>
                <Depth>13.5</Depth>
            </Sample>
            <Comment>string</Comment>
            <Date>2006-03-03</Date>
        </ID>
        <Coords>
            <Xutm_point>743975</Xutm_point>
            <Yutm_point>4285180</Yutm_point>
        </Coords>
    </Struct_ID>
</root>
```

APPENDIX B.

DATA DICTIONARY

Borehole Attributes

Name	Code	Definition
Name	ID	A common name for the hole. This name does not need to be unique within the naming system.
Structure	Struct_ID	A MoDOT unique number comprised of the abbreviation for type of highway and the route number followed by an underscore, then the design number and lane direction. This number will be automatically perpetuated through all records pertaining to this structure.
Type	Well_Type	The primary or current type of sampling station/hole. This is used to supply more specificity to the Site Type. Value should be one of the following: {see Hole Type sheet}.
Date	Date	The ending date of the collection activity for this hole.
Owner	Owner	Owner of the installed well.
Elevation	Elev	Elevation of the hole at the depth datum. Elevations are positive upward, measured from the elevation datum.
Location X	Xutm_point	The first coordinate for the location of the location reference point. In the US, this would be the Easting.
Location Y	Yutm_point	The second coordinate for the location of the location reference point. In the US, this would be the Northing.
Bottomhole depth	DrlDepth	The measured depth of the hole at its deepest point. The depth is measured from the depth datum, and is positive downward, as measured along the hole alignment. The value may also be qualified by who measured the depth {loggers, drillers}.
Depth to bedrock	DepBedrock	The measured depth to bedrock of this hole.
Type of bedrock material	TBedRckMtl	The bedrock geologic unit at the location of this hole.
Depth to water	SWLA	The measured depth to groundwater of this hole.
Layer Top	Top	The measured depth to the top of the layer. The depth is measured from the depth datum of the hole, and is positive downward, as measured along the hole alignment. The value may also be qualified by who measured the depth {loggers, drillers}.

Layer Base	Base	The measured depth to the lowermost boundary of the layer. The depth is measured from the depth datum of the hole, and is positive downward, as measured along the hole alignment. The value may also be qualified by who measured the depth {loggers, drillers}.
Classification	Name	The value used as a primary description for the layer. This is intended to be an element of the classification system.
Comments	Comments	A text descriptor providing information relevant to the layer interval.
Blows First	Blows_1	The number of blows required to drive the split-spoon sampler for the first 6 inch (150 mm) increment. This first increment is considered the seating drive. Penetration is stopped and often noted as "refusal" if the number of blows reaches 50 for any of the 6 inch (150 mm) increment or if there is no observed advance during the application of 10 successive blows or if the total number of blows have reached 100.
Blows Second	Blows_2	The number of blows required to drive the split-spoon sampler for the second 6 inch (150 mm) increment. Penetration is stopped and often noted as "refusal" if the number of blows reaches 50 for any of the 6 inch (150 mm) increment or if there is no observed advance during the application of 10 successive blows or if the total number of blows have reached 100.
Blows Third	Blows_3	The number of blows required to drive the split-spoon sampler for the third 6 inch (150 mm) increment. Penetration is stopped and often noted as "refusal" if the number of blows reaches 50 for any of the 6 inch (150 mm) increment or if there is no observed advance during the application of 10 successive blows or if the total number of blows have reached 100.
N Value	Nm	The uncorrected SPT N-Value is defined as the sum of second and third increments (from 6 to 18 inches - 150 to 450 mm). Deviation from this definition occurs if penetration is stopped due to any of the 6 inch (150 mm) increment reaching 50 blows or if there is no observed advance during the application of 10 successive blows or the

		total number of blows have reached 100. Such deviations should be reported as number of blows for each complete 6 inch increment or number of blows for each partial increment. Partial increments should be reported to the nearest inch (25 mm).
Measured Energy	Em	The measured energy ratio expressed as a percentage.
PP	PP	The measured results from a pocket penetrometer test of unconfined compressive strength of sediments.
Torvane	Torvane	The measured results from a Torvane test of approximate shear strength
Liquid Limit	LL	The water content of a soil at the arbitrary boundary between the semi-liquid and plastic states, generally expressed in percent.
Plastic Limit	PL	The water content of a soil at the arbitrary boundary between the plastic and semi-solid states, generally expressed in percent.
Natural Water Content	Wn_percent	The water content of a soil in it's natural in situ moisture condition, generally expressed in percent.
Sample Elevation	Sample_Elev	The measured depth associated with the sample tested.

	75_mesh	
	50_mesh	
	37point5_mesh	
	25_mesh	
	19_mesh	
	9point5_mesh	
	4point75_mesh	
	2point36_mesh	
Percent Passing	2_mesh	The percentage of soil passing or finer by weight or mass for each sieve or size of soil particle.
	1point18_mesh	
	point60_mesh	
	point425_mesh	
	point30_mesh	
	point15_mesh	
	point075_mesh	
	point02_mesh	
	point002_mesh	
	point001_mesh	
Percent Fines	minus200-0poin	The percentage of fines by weight passing the No. 200 sieve (finer than 0.075 mm).

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VITA

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