

Risks for Drinking Water Source Areas: Surface and Hydrogeologic Displays

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Abstract

The U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water (OGWDW) has implemented a secure Web-based facility called the Drinking Water Mapping Application (DWMA). The application's main purpose is to allow users to select information related to specific source waters associated with public water supply systems and to provide ways to display maps or other data products with related information to these source waters. Examples of enhancements to the DWMA that facilitate developing data tables and geographic information systems (GIS) maps of potential contaminant risks within source water areas (SWAs) will be presented. For source waters involving groundwater wellheads and for areas around Underground Injection Control (UIC) wells, refinements to the system will be explored that allow hydrogeologic cross-section displays.

1.0 Introduction

EPA's OGWDW DWMA is a Web-based geospatial application that enables queries of the Safe Drinking Water Information System (SDWIS/FED), as well as the identification of potential contaminant risks to surface water and groundwater used for public drinking water supplies. The primary goal of the DWMA is to provide a secure application that EPA staff can easily use to obtain reports and maps that help manage programs under the Safe Drinking Water Act (SDWA). The core data sources, Web interface, functionality, and system architecture of the DWMA are described in an earlier paper entitled *EPA Drinking Water Mapping Application: Client Focus and Architecture Design*, which was presented at the 23rd Annual ESRI International User Conference and is available online at <http://gis.esri.com/library/userconf/proc03/abstracts/a0149.pdf>.

This paper will describe the evolving process being used to build, update, and expand the underlying DWMA geodatabase, including the use of database-level services provided by other ongoing project work.

2.0 Georeferencing to the National Hydrography Dataset (NHD)

The DWMA uses the U.S. Geological Survey's (USGS) National Hydrography Dataset (NHD) to represent surface waters. In order to analyze potential upstream and downstream effects, it is necessary to georeference¹ relevant data sets to this NHD framework. These relevant data sets include locations, such as drinking water intakes, facility pipe discharges, and combined sewer

¹ Georeferencing is an approach to geocoding locational information by reference to existing GIS data layers. Point georeferencing to the NHD involves the application of ESRI dynamic segmentation techniques to define a table with point-event instructions relative to linear features in the NHD.

overflows, located throughout the entire United States. Figure 1 shows both the original locations (as red crosses) and the stream network locations georeferenced to NHD (as blue triangles) for several drinking water intakes from SDWIS/FED.

Because there are over 8,000 drinking water intake locations associated with public water systems in SDWIS/FED, over 100,000 known facility pipe discharge locations in the Permit Compliance System (PCS), and over 9,000 combined sewer overflow locations in the United States, this georeferencing process had to be automated. Under another EPA project², a database level service for georeferencing single points to NHD was created using Oracle Spatial. This simple “snap to the closest point on the closest NHD stream” georeferencing service was extended to perform batch georeferencing for any number of points and was used to georeference all of the point locations described above to NHD. There are immediate plans to turn the current batch georeferencing database service into a true Web service to open up this type of processing to any interested consumer of Web services.

An important note about this type of “blind” batch georeferencing is that the georeferenced location is only as good as the accuracy of the input data sets. NHD is currently only available nationally at a scale of 1:100,000. As a result, some tributaries are missing and snapping to the closest point on the closest NHD stream may not be the optimal result. Likewise, data errors in the point source data being georeferenced will result in sub-optimal results. Because of these potential errors, the georeferenced locations of drinking water intakes are currently undergoing extensive automated and manual reviews. Once these improved data are available, they will be incorporated into the DWMA.

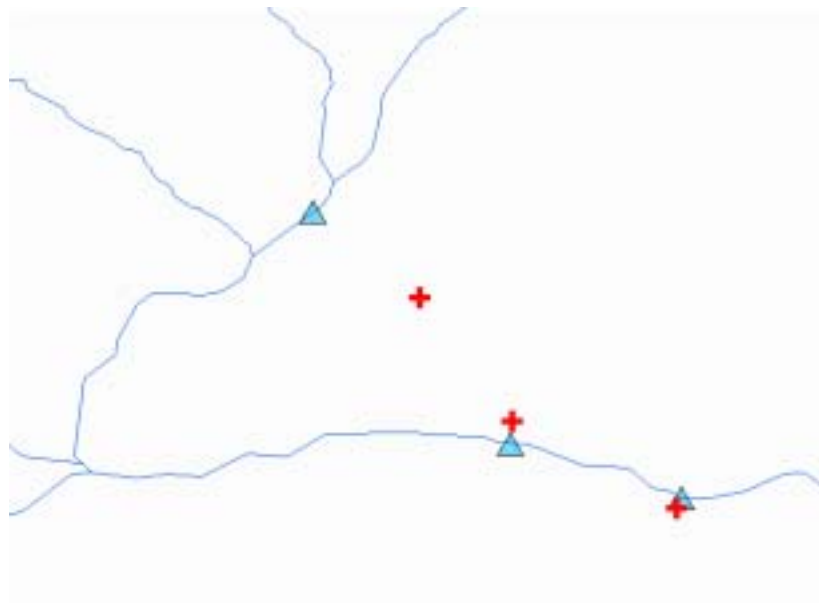


Figure 1. Georeferenced Drinking Water Intakes

² Rineer, J. (presenter-RTI), A.M. Miller, J. Sinnott, and M. Plastino. 2003. *Developing and Integrating Web Services for Georeferencing to the NHD*. Presented at the 23rd Annual ESRI International User Conference, San Diego, CA.

3.0 Building Analytical Source Water Areas (SWAs)

Source Water Areas (SWAs) are the land areas that can contribute water and pollutants to the water supply for surface water intakes, or groundwater wells that supply drinking water (paraphrased from <http://www.epa.gov/safewater/protect/assessment.html>). EPA is in the process of collecting state-supplied SWAs for public water supplies, but these SWAs were only available for a small number of states during the time this work was being conducted. To complete this task, it was necessary to build and use analytical SWAs. When state-supplied SWAs become widely available, they will probably be used in conjunction with the analytically defined areas, as both of these types of SWAs may be of value for different types of analyses.

Because there are more than 8,000 surface water intakes associated with public water systems in the United States, the process of building analytical surface SWAs had to be automated. The first step in building these SWAs was to build upstream drainage networks for each drinking water intake. To build the upstream drainage network, an upstream distance had to be chosen. Fifteen miles upstream was chosen as a rough approximation of the distance water would travel in a single day. A recursive upstream search algorithm was encoded in a procedure to collect the upstream drains (i.e., a small stream segment) within 15 miles upstream. This procedure was exercised for each of the 8,000+ surface water intakes. Figure 2 shows the derived upstream network (shown in red) for a single drinking water intake (shown as a blue triangle).

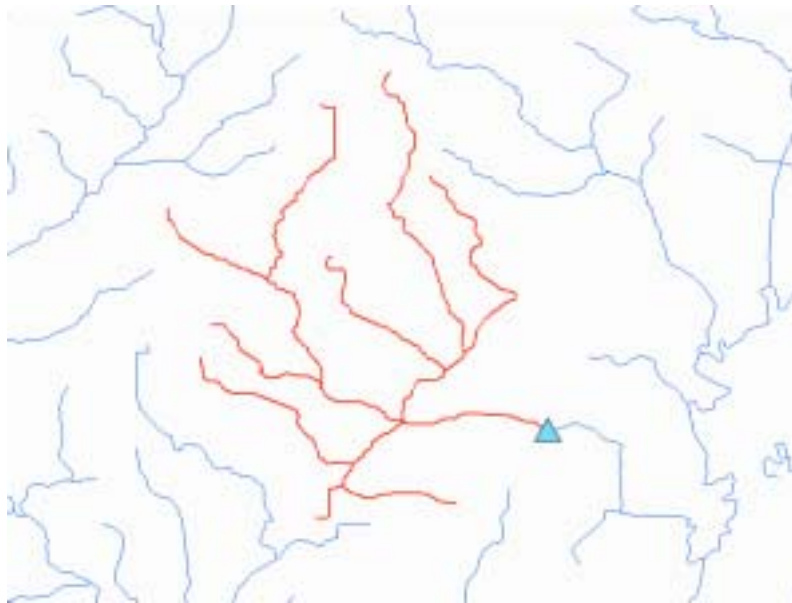


Figure 2. Example Drinking Water Intake Upstream Network

A number of “value added attributes” are currently being computed for each drain within NHD. One of these attributes is the average stream flow. When these data are available, they could be used to improve the rough approximation of “15 miles upstream equals 1 day of travel.” The distance upstream from each drinking water intake could be tailored to the average stream flow associated with the intake location. A national navigation database level service is also in progress and is dependent on the completion of the value-added attributes. Once this navigation service is available, the DWMA will make use of its improved algorithm via this shared service environment.

The next step for building surface SWAs was to create the watershed for the upstream drainage network. There is also work in progress to define a national set of “drain catchments” based on Thiessen³ polygons and other methodologies. Once these data are available, drain catchments for the upstream network of drains for a particular drinking water intake could be unioned to create the watershed for this intake. Because these drain catchments were not available at the time this task was being performed, analytical watersheds were built using a “convex hull” approach. A convex hull is defined by the set of points that is the smallest convex set that includes all of the drains that comprise the upstream network. Figure 3 shows an analytical surface SWA polygon (shown in green) defined by the convex hull that surrounds the derived upstream network (shown in red).



Figure 3. Drinking Water Intake Analytical Watershed

Where state-defined SWAs are available, they can be compared with the analytical SWAs, as seen in Figure 4 where the state-defined SWA is shown in purple. In addition to the 8,000+ surface water intakes associated with public water systems in the United States, there are almost 200,000 wells. Analytical wellhead SWAs were created for each of these wells by generating simple buffers of 2 miles around each wellhead.

³ Thiessen polygons can be used to describe the area of influence of a point in a set of points. If you take a set of points and connect each point to its nearest neighbor, you have what's called a triangulated irregular network (TIN). If you bisect each connecting line segment perpendicularly and create closed polygons with the perpendicular bisectors, the result will be a set of Thiessen polygons. The area contained in each polygon is closer to the point the polygon is based on than any other point in the dataset. A division of space into polygons of this nature is also known as a Voronoi Tessellation.



Figure 4. Analytical SWA vs. State Defined SWA

4.0 Relating SWAs to Risks, Vulnerabilities, and Other Factors

After building the analytical SWAs, national scale spatial analyses will be performed to relate these SWAs to a number of potential risks, vulnerability indicators, and other relevant factors. SWAs will be related to traditional point risk sources, including

- Superfund sites
- Point source water discharges
- Waste sites
- Class I Underground Injection Control (UIC) wells.

Figure 5 shows the result of a query to locate any wellhead SWAs (shown as a dark green circle) containing Superfund sites (shown as an orange square) in a specific region of the United States.

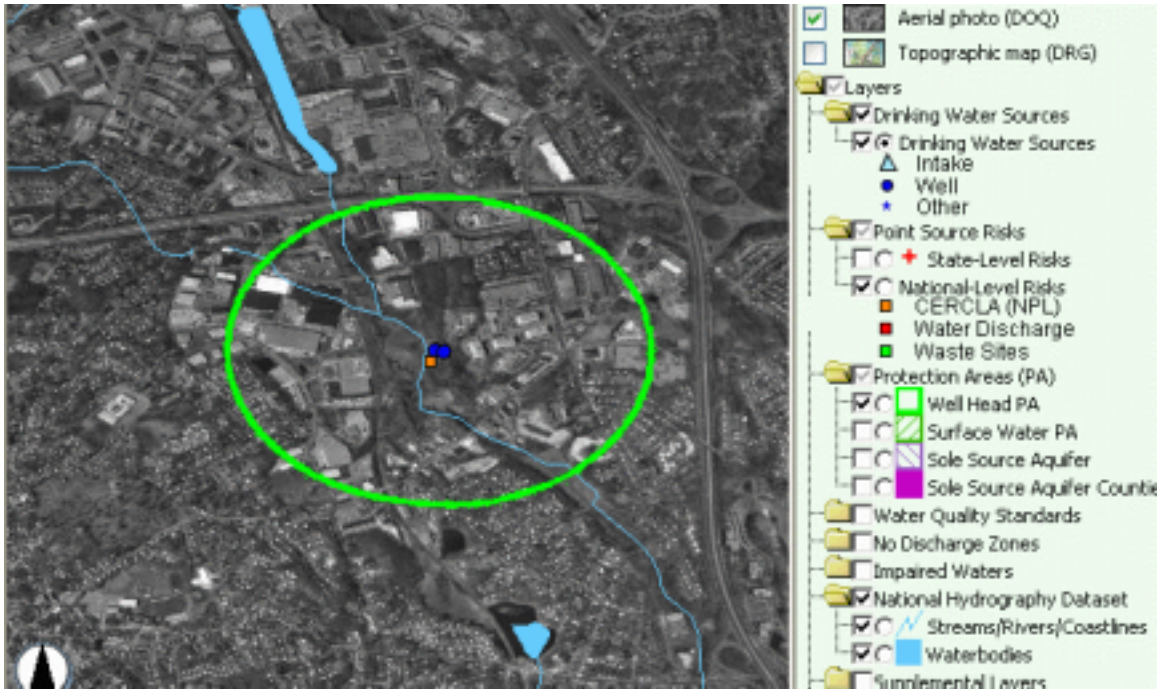


Figure 5. Potential Risk within a Wellhead SWA

Vulnerabilities were explored by relating SWAs to a number of risk factors, such as

- Percent impervious cover
- Presence of sole source aquifers
- Presence of karst geology
- Type of surficial geology
- Degree to which the area relied on septic systems for domestic waste disposal.

The percent of impervious cover for the conterminous United States (shown in Figure 6) can be obtained from an analysis based on the National Land Cover Data (NLCD). Percent impervious cover estimates based on Year 2000 U.S. Census Bureau Tract polygons will be used to identify SWAs with a level of impervious cover that can indicate serious disruptions in hydrologic patterns involving runoff or groundwater recharge. Landscape areas with levels of impervious covers (e.g., roads, parking lots, and roofs) over a threshold of 10 percent may show increases in wet weather runoff and reductions in normal infiltration rates into soils and aquifers. Changes in the hydrography patterns may also be related to increased pollutant risk for both surface and groundwater supplies.

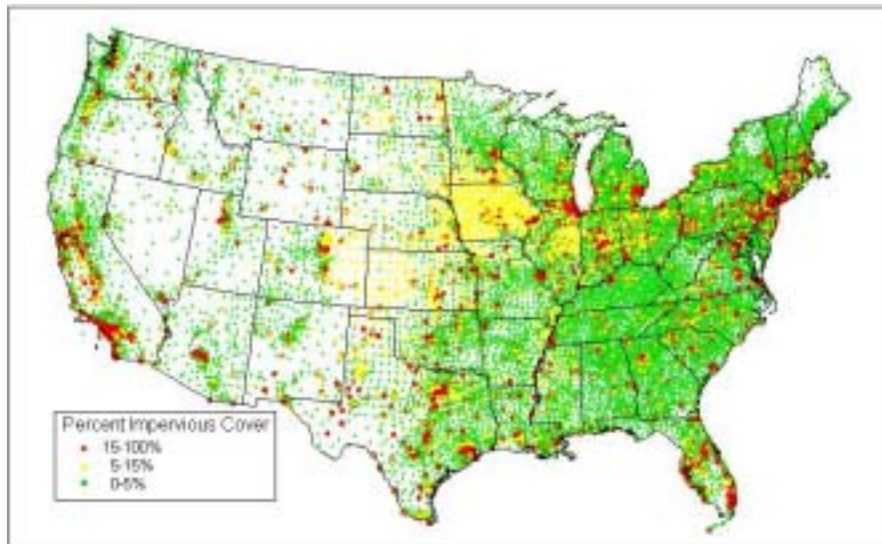


Figure 6. Impervious Cover in the Conterminous United States

Sole source aquifer, karst, and surficial geology layers will be used to assign related vulnerability attributes to SWAs. Sole source aquifer designations are one tool used to protect drinking water supplies in areas with few or no alternative sources to the ground water resource, and where, if contamination occurred, using an alternative source would be extremely expensive. The designation (authorized by the SDWA) protects an area's groundwater resource by requiring EPA review of any proposed projects that are receiving federal financial assistance within the designated area.

The karst layer shows areas with predominant subsurface karst lithology. This layer was obtained from the USGS and is considered draft. The surficial geology of the conterminous United States was generated from a USGS 1:7,500,000-scale map of surficial geology, published as part of the USGS National Atlas map series.

The 1990 Decennial Census of Population and Housing contains information on housing units, including types of wastewater disposal methods (e.g., onsite septic systems) and the sources of drinking water (e.g., domestic drilled or dug wells). Many people in small communities, in rural areas, or in some urban suburbs do not have access to public sewers or to treated drinking water from public water systems. The 1990 U.S. Census Bureau information provided data on the degree to which public infrastructure services are present (or lacking) for spatial units smaller than counties. Areas with a high reliance on septic systems for domestic waste disposal may also rely on UIC Class V wells to handle wastes from industries or commercial establishments (e.g., car repair shops). These areas, some of which are shown in Figure 7, may be used as indicators of vulnerability for the contamination of drinking water sources.

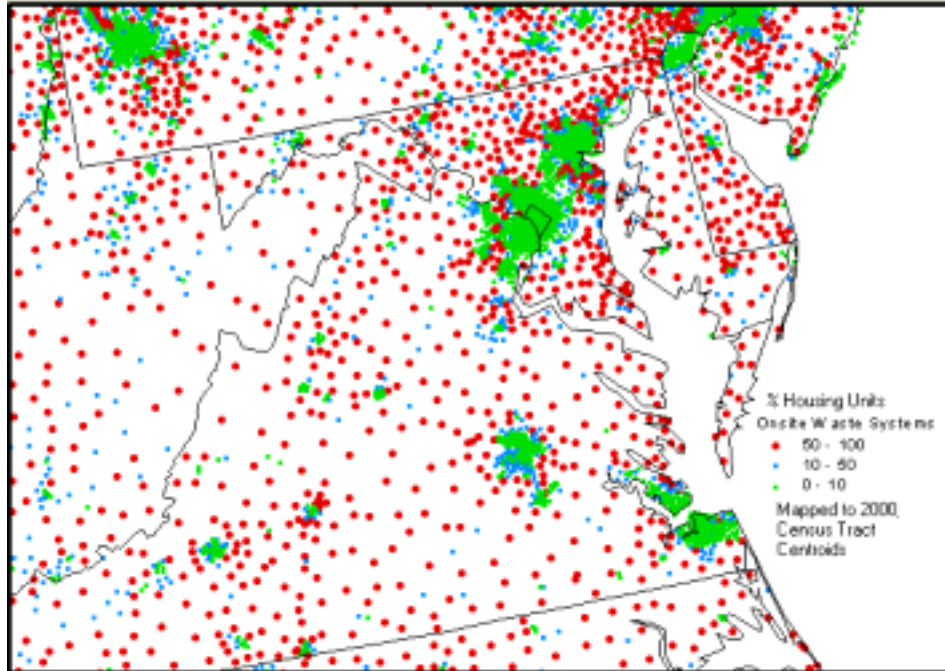


Figure 7. Percent of Housing Units with Onsite Waste Systems

Finally, environmental justice issues will be explored by relating SWAs to areas with

- Low income
- Native American populations
- Vulnerable population segments.

Figure 8 shows data related to household income, which were also obtained from U.S. Census Bureau data.

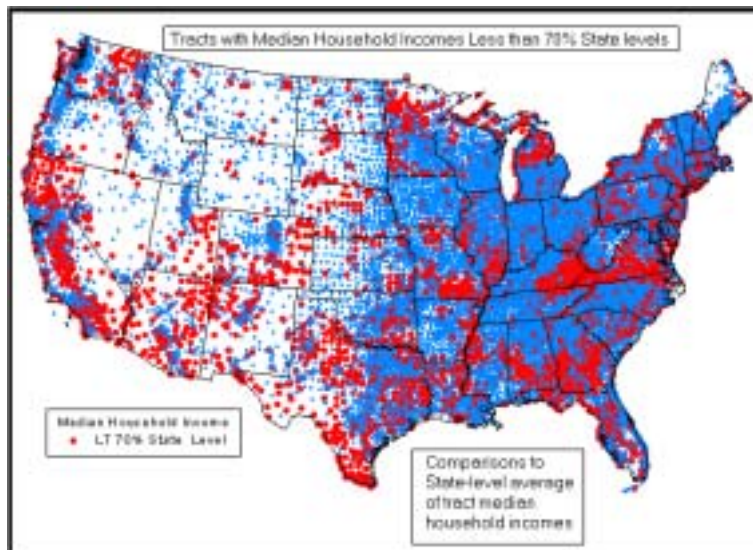


Figure 8. Household Income Distribution

Once the risks, vulnerability indicators, and other relevant factors described above have been spatially related to SWAs, a query interface will allow users to create maps and reports describing SWAs with any combination of these factors. An example of the organization of such an interface is shown in Figure 9.



Figure 9. SWA Query Interface

5.0 Wellhead Visualization Tool

The Wellhead Visualization Tool released with DWMA v1.04 allowed the end user to generate a basic well profile for a single Class I UIC well. This tool is being enhanced to show the relative locations and depths of all drinking water wells within a radius of up to 2.5 miles from a user-selected UIC well. The new composite well will profile will include generalized geologic and well information to add perspective to the tool and increase its usefulness as a conceptual regional model.

A number of types of information will be used to attribute UIC well locations and generalized drinking water well information, including

- Elevation of the ground surface
- Chronostratigraphic (System) layers obtained from generalized maps
- Saline groundwater depths
- Depth ranges for drinking water wells.

By simply locating and clicking on a UIC well in the main DWMA map, a user will be able to generate a composite well profile, as shown in Figure 10.

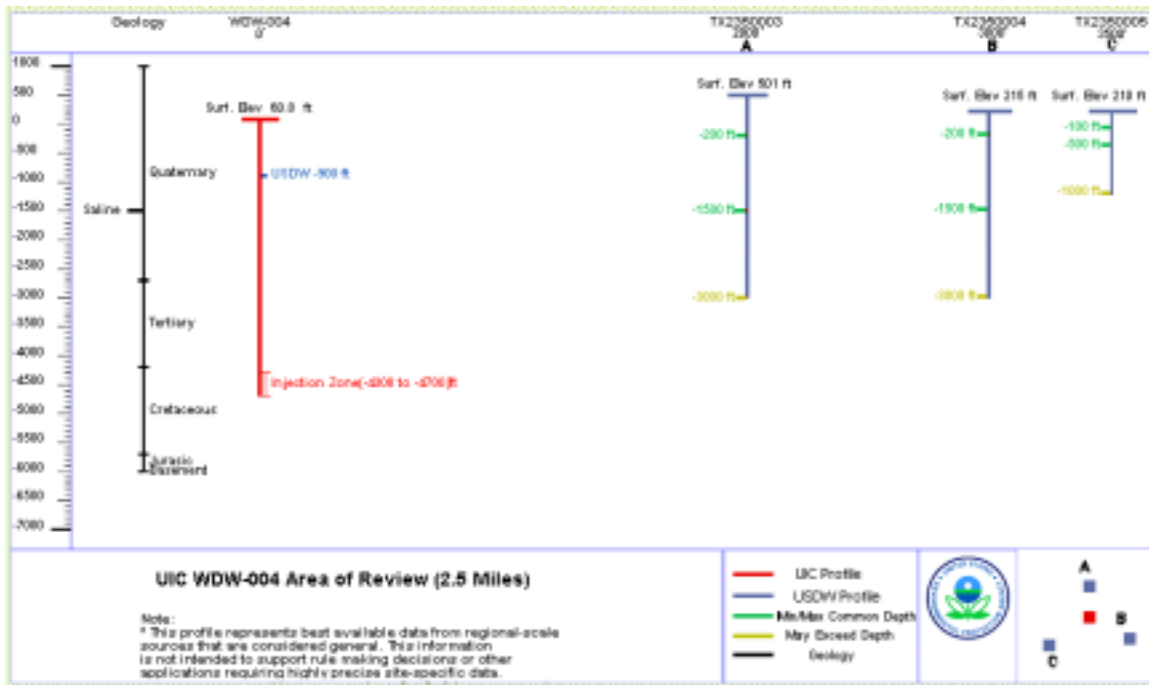


Figure 10. Composite Well Profile

The horizontal position of drinking water wells will be displayed relative to the UIC well and will also be vertically scaled. A geologic cross-section bar to the left of the UIC well position in the view will display generalized information that is specific to the UIC well location. Vertical bars will be used to represent well positions, with the top of the bar positioned relative to surface elevation. USGS-generalized depths for drinking water wells will be displayed using markers along the vertical bars. The well identification code will be displayed at the top of the view immediately over the well position, along with a numerical distance from the UIC well. Both vertical and horizontal scaling will be applied to the WVT window, and the current user interface will be enhanced to allow manipulation of the view scale and the page size. Aspects of the WVT window will also be summarized in tabular form. The current user interface will be enhanced to allow users to either generate the visualization shown in Figure 10 (see above) or to generate a companion tabular report, as shown in Figure 11.

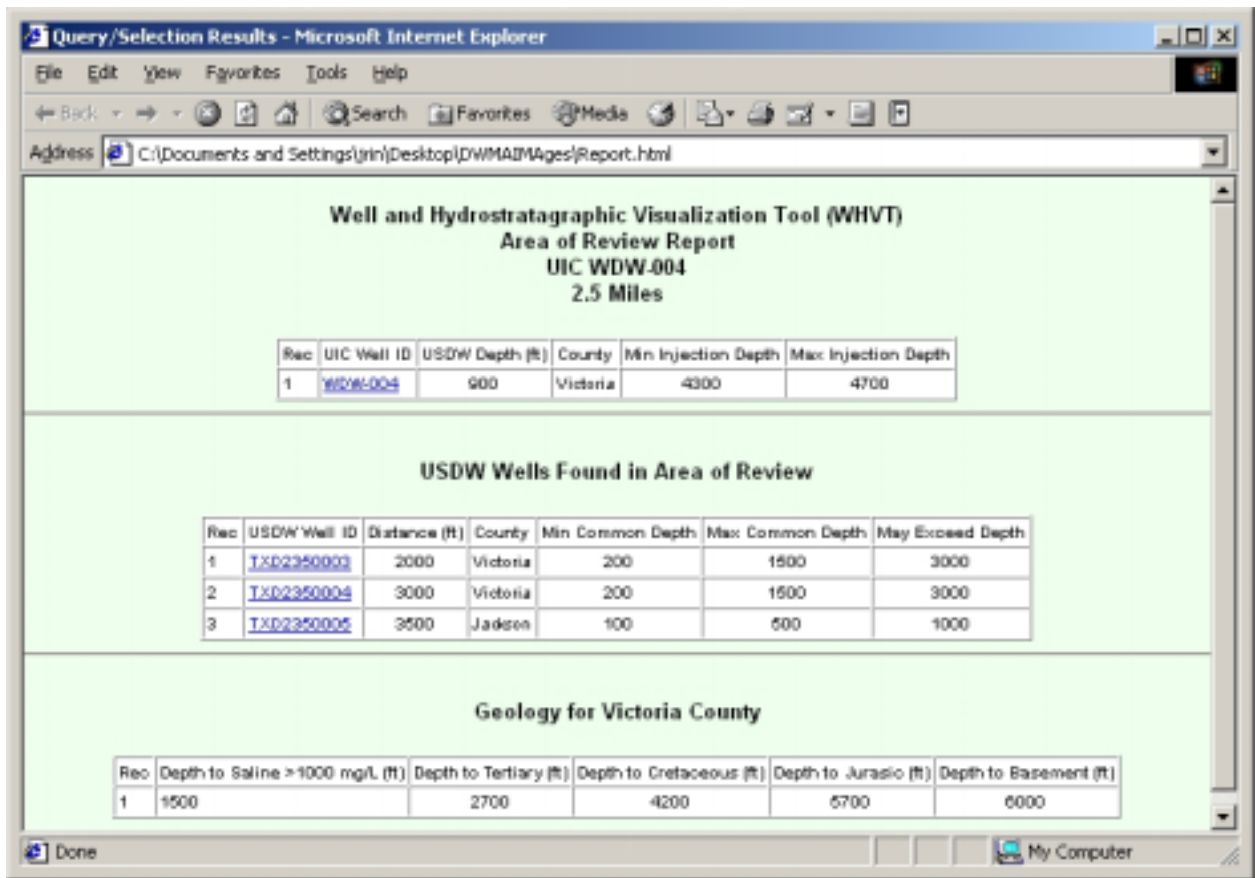


Figure 11. Well Area Report

6.0 Conclusions

Trying to build a national-scale application to assist in the identification of potential contaminant risks to surface water and groundwater used for public drinking water supplies can be challenging. Creating analytically based SWAs, spatially relating them to potential risks, and assigning vulnerability and other attributes to the SWAs makes it possible to start looking at potential problem areas at a national scale. As more detailed local data and relevant data processing services become available, the SWAs can be integrated into the DWMA database and application to improve the accuracy of the results and the ease of conducting these analyses.

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