State of Ohio
Environmental Protection Agency

Division of Drinking and Ground Waters

2006 305(b) Report Ohio's Ground Water Quality

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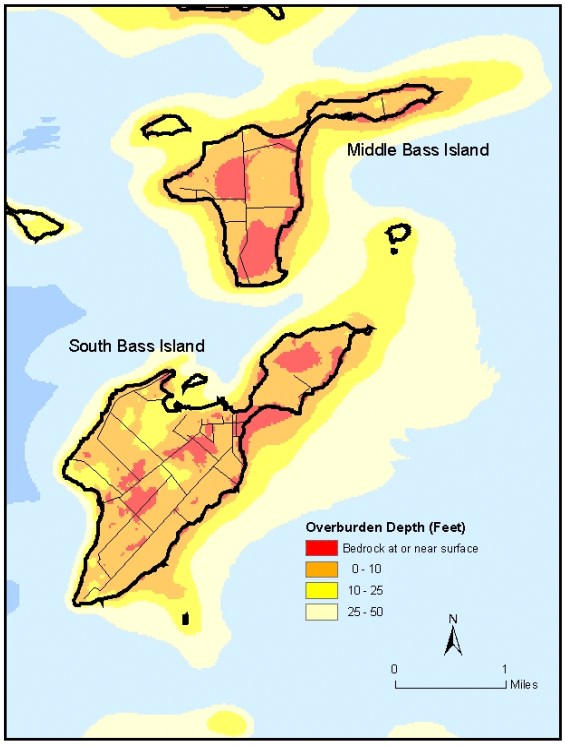

Bob Taft, Governor
Joe Koncelik, Director

2006 305(b) Report

Ohio's Ground Water Quality

Prepared by Ohio Environmental Protection Agency
Division of Drinking and Ground Waters

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June 2006

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Cover Illustration: Depth to bedrock on Middle and South Bass Islands with hottest colors indicating bedrock at or near the surface. The thin glacial till overlying the fractured and dissolved bedrock on these islands indicates areas of sensitive aquifers. See the section on Sensitive Aquifers - Relationships to Highly Susceptible PWSs for additional explanation on South Bass Island.

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EXECUTIVE SUMMARY

2006 305(b) Report - Ohio's Ground Water Quality

Ground Water Characterization Program
Ground water quality monitoring and data analysis programs for the state of Ohio are summarized in the 2006 305(b) report as required in section 106(e) of the Clean Water Act. Programs to monitor, evaluate, and protect ground water resources in Ohio are carried out by various state, federal and local agencies. Ohio Environmental Protection Agency (Ohio EPA) is the designated agency for monitoring and evaluating ground water quality conditions and assessing ground water contamination problems for the state of Ohio. Within Ohio EPA, the Division of Drinking and Ground Waters (DDAGW) carries out these functions, and coordinates various ground water monitoring efforts with other state programs through the Ohio Water Resources Council and the State Coordinating Committee on Ground Water. The 2006 305(b) Ground Water Report provides DDAGW the opportunity to enhance characterization of state-wide ground water quality through updated analysis and improved presentation, as well as meeting the 305(b) reporting requirements.

Two main sources of information are used to characterize Ohio's ground water quality in the 2006 305(b) Report. The Ambient Ground Water Monitoring Program (AGWMP) is the DDAGW program created to monitor "raw" (untreated) ground water. This program's goal is the collection, maintenance, and analysis of ground water quality data to measure changes in the water quality of the State's major aquifer systems. The second source of information is the public water system (PWS) compliance data, which is compiled from information on treated (processed) ground water. These two data sources compliment one another and provide water quality data from most of the state.

Ground Water Quality by Aquifer Type
The geologic settings and distribution of Ohio's three major aquifer types, sand and gravel, sandstone, and carbonate, are described. The sand and gravel aquifers, which are superimposed on the bedrock of the state, comprise Ohio's most productive and sensitive aquifers. These buried valley aquifers are composed of bands of permeable, unconsolidated sand and gravel (20 to 200 + feet thick) filling old river valleys which were cut by glacial meltwater and preglacial streams. The sandstone aquifer system is present throughout the eastern portion of Ohio. These aquifers are characterized by gently dipping strata of sandstone, shales, and other units which yield moderate to high volumes of water, although in the southeast the yields may drop to low production levels due to the presence of interbedded shales, coals, and clays. The carbonate bedrock aquifer system is found in the western half of the state. These carbonates can be thick (up to 600 feet), and may yield over 500 gallons of water per minute in fractured zones with solution channels.

Water quality data for the three main aquifer types are presented in this report. Ground water quality across the state is generally of high quality as documented by AGWMP data, although the AGWMP includes mostly high production, deeper public water system wells. Table 3 of this report presents summary statistics for the inorganic parameters grouped by major aquifer types. This table establishes typical chemical concentrations based on over 30 years of sampling and illustrates major element

variation as a function of aquifer type. This information is useful for evaluating ground water quality impacts; for example it illustrates that the total dissolved solid concentration of sand and gravel aquifers is intermediate between that of the limestone and sandstone aquifers. Figure 1, a plot of sulfate concentration against hardness, represents another illustration of the intermediate nature of the water quality of the sand and gravel aquifers. Although there is some scatter, the sand stone aquifers (red squares) are generally low in sulfate and hardness compared to the carbonate aquifers (green circles). Water composition from the sand and gravel aquifers (blue triangles) is intermediate between the sandstone and carbonate concentrations for sulfate and hardness. The carbonate aquifers exhibit some elevated concentrations of sulfate and particularly hardness (data points to the upper right of Figure 1) in wells associated with the Salina Formation which includes marine evaporites. The association of higher hardness and sulfate in the sand and gravel aquifer compared to the sandstone aquifer is attributed to the rock composition of the aquifers. The sand and gravel aquifers include carbonate rock debris eroded and deposited by glacial processes, and consequently, its water quality gains a carbonate character related to the amount and type of carbonate debris included. The lower hardness and sulfate of the sandstone aquifers is attributed to the higher silica sand and lower carbonate rock content of the sandstone aquifers.

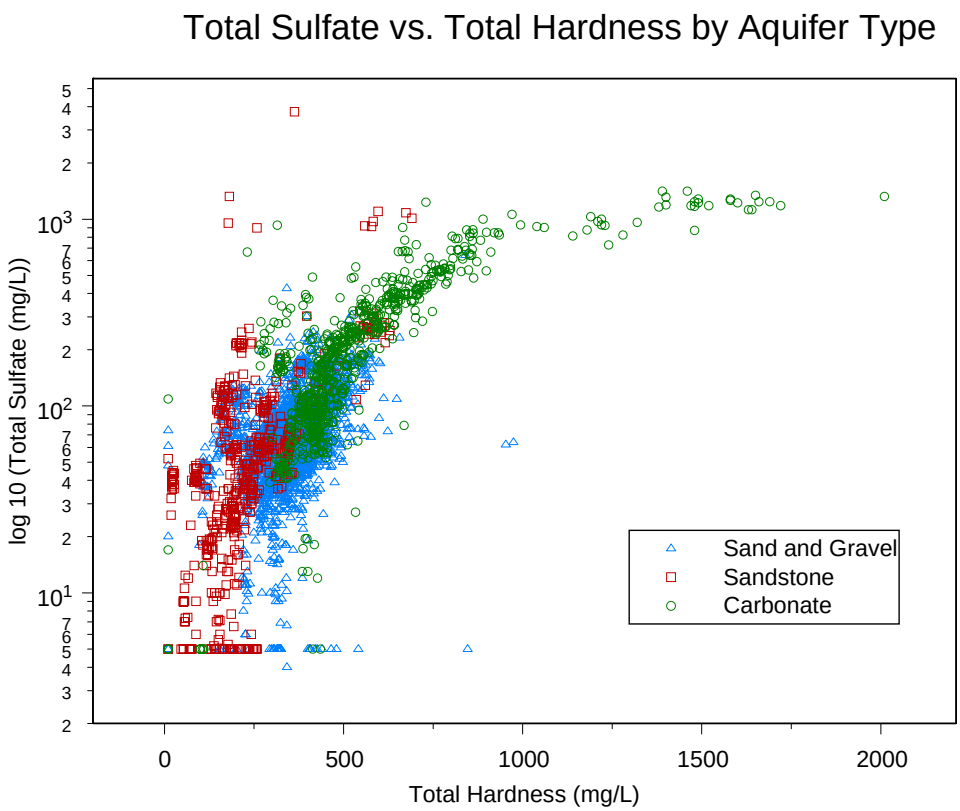

Figure 1. Sulfate versus total dissolved solids by aquifer type.

Data in Table 4 of the report illustrates the changes in the water chemistry associated with changes in oxidation state. Generally, ground water becomes more reduced with increased depth below the water table (farther removed from oxygen bearing atmosphere). Only AGWMP data from wells with mean nitrate concentrations greater than 2.0 mg/L, known to be in an oxidized (oxygen bearing) condition, were included in Table 4 of the report. This subset of data illustrates that oxidizing conditions impose predicable changes to oxidization-reduction sensitive parameters, such as As, Fe, Mn, and NO_3. Comparison of the Table 4 (oxidized conditions) parameter means with Table 3 (all data - generally more reduced) illustrates the lower concentrations of arsenic, iron, and manganese associated with oxidized water compared to higher concentration of these elements in more reduced water (deeper ground water, isolated from the atmosphere). Thus, oxidation state geochemistry is one of the major factors that control arsenic concentration in PWS wells and helps explain the presence of dissolved iron in deeper wells.

Sensitive Aquifers - Relationship to Highly Susceptible PWSs

We have continued to work to identify sensitive aquifers in Ohio utilizing concepts of vertical recharge pathways and ground water quality data. The sensitive aquifers section uses locations of public water systems (PWSs) determined to be highly susceptible based on water quality data in the Source Water Assessment and Protection program's susceptibility analysis to refine sensitive aquifer identification. PWS locations were associated with ODNR's Glacial Aquifer Map attributes. The number of PWSs with ground water quality impacts were compared to the total number of PWSs associated with specific geologic settings and lithologies to identify characteristics of PWSs with water quality impacts. This effort illustrates that ground water quality impacts are more strongly correlated with glacial lithology than geologic setting. This is logical, since it is the unconsolidated lithology that controls the rate of vertical recharge through glacial overburden. These results confirm that the shallow sand and gravel aquifers are the most sensitive aquifers in Ohio, followed by areas of thin till directly overlying bedrock aquifers. Our recent analysis indicates the importance of distinguishing coarser sand and gravels from finer sands to define the most sensitive aquifers. Consequently we are distinguishing between the coarse grained and fined grained sands in the sensitive aquifer mapping effort. The fact that empirical ground water quality data correlates with aquifer map data, simplified for a statewide map, raises our confidence in the validity of this approach for identifying sensitive aquifers.

The 2004 South Bass Island investigation of an infectious disease outbreak illustrates the aquifer sensitivity of areas where thin till overlies bedrock aquifers. The geology and hydrology of South Bass Island is described and the ground water sample results of the investigation are summarized. Results of samples collected from public water systems during Ohio EPA's investigation confirm there is substantial microbiological contamination of ground water across South Bass Island. The Ohio Department of Health came to the same conclusion for the private wells on South Bass Island. These results have resulted in extensive efforts to ensure public water systems on the Island are providing safe drinking water and to educate South Bass Island residents about the vulnerability and health threats of private wells.

Organic Contaminants in Ohio's Ground Water

PWS compliance data and Ambient Ground Water Monitoring program (AGWMP) data were used to identify VOC impacts and to further delineate sensitive aquifers in Ohio. A PWS was considered impacted by VOC contamination if at least two detections of the same or related compound were recorded. Analysis revealed that the percentage of VOC impacted PWSs in sensitive aquifers is greater than the percentage of VOC impacted PWSs in non sensitive settings (10% versus 4% for PWSs; 16% versus 3% for the AGWMP wells). Generally, VOC contamination is associated with areas of higher

population density. Within drinking water source protection areas, VOCs are 1.5 to 2 times more likely to impact wells associated with areas that contain higher percentages of urban land use (such as commercial, industrial, transportation). The vast majority of VOCs found in Ohio's ground water are solvents (PWSs 87%; AGWMP 78%) and hydrocarbons (PWSs 4%; AGWMP 12%). Only 15% of the PWSs with VOC detections also exhibit elevated nitrate concentrations, indicating nitrate concentration is not a good predictor of VOC impact. This poor correlation is partly related to the geochemically reduced nature of the deep ground water (nitrate degraded to N_2) associated with VOC contamination as well as the differences in distribution of point (VOC) and non-point (nitrate) sources of potential contaminants. Figure 2 illustrates the association of VOC impacts within the buried valley (areas of high population density) and some nitrate detections in the uplands within agricultural areas (low population density).

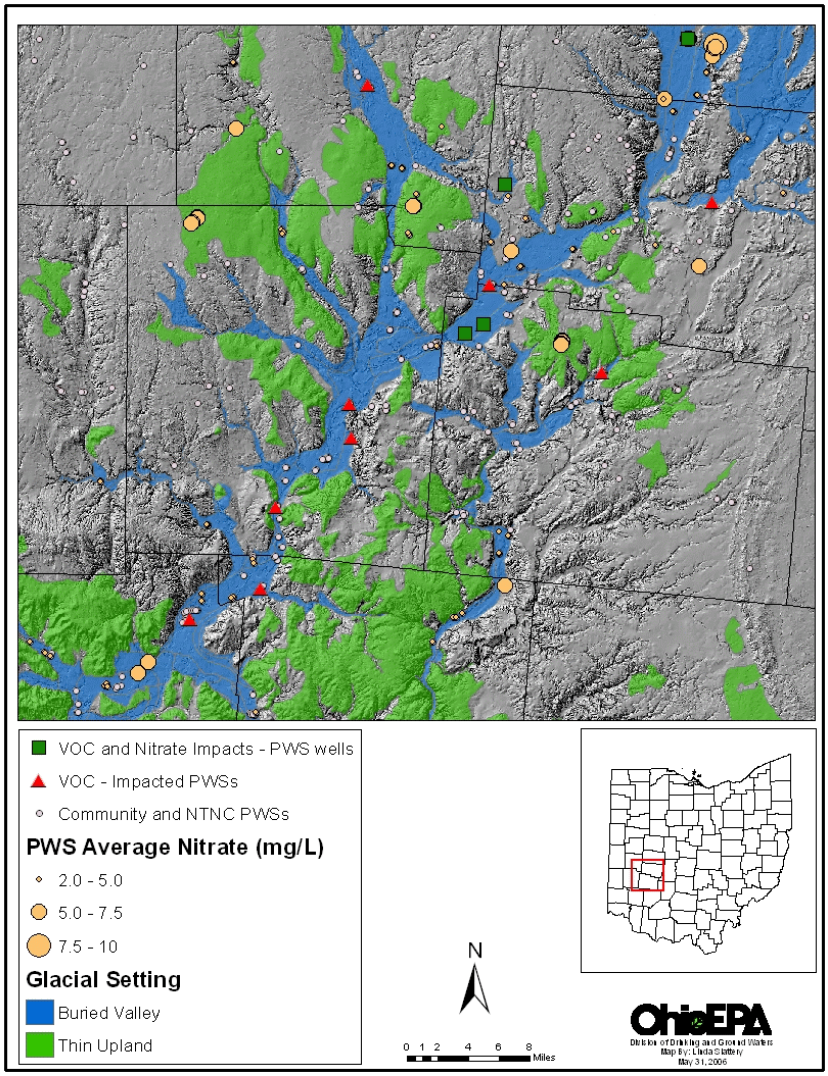

Figure 5. Distribution of VOC and nitrate impacts in a portion of the Great Miami River basin.

C-8 Impacts to Ground Water Quality in SE Ohio

C-8 (ammonium perfluorooctanoate) released from Dupont's Washington Works fluoropolymer manufacturing facility in West Virginia has resulted in widespread dispersal of C-8 into public and private water supplies in Washington, Athens and Meigs Counties in Southeast Ohio. Ground water data, along with surface water and soil sampling results and computer models of air and ground water transport, have led to a better understanding of the possible transportation pathways for migration of C-8 from the facility. Transportation of C-8 through the air and subsequent leaching through soil is believed to be the primary pathway for C-8 to migrate from the facility to ground water in adjacent areas of Ohio. A secondary transportation pathway for C-8 is via discharge to the Ohio River and subsequent infiltration of river water to the alluvial aquifer due to recharge induced by pumping at downstream public water supplies. Continued sampling of environmental media is necessary to provide a better understanding of the fate, transport and human exposures of C-8 from fluoropolymer manufacturing. Specifically, continued ground water monitoring is necessary to evaluate long term trends of C-8 concentrations in ground water and determine how ground water concentrations will decrease in response to reduced air and surface water emission.

Conclusions and Future Focus

Ground water quality staff continue to work to increase the quality of the AGWMP data, to incorporate improvements in the data management tools and to improve our data analysis with expanding use of geographic information systems tools, as illustrated in the sections of this report. This progress allows the utilization of ground water quality data and data analysis tools to support DDAGW programs, including:

- Increasing our understanding of the ground water resources of Ohio;
- Cataloging and evaluating ground water resources impacted from land use activities;
- Continuing to refine criteria to identify sensitive aquifers at statewide and local scales;
- Supporting effective implementation of new SDWA rules;
- Continuing to collect data to identify long term trends at AGWMP sites; and
- Making water quality data readily available and understandable to the public.

A priority activity with significant implication for the 305(b) report is the effort to compile all sites in Ohio with documented releases of contaminants to ground water. A Ground Water Impacts database was developed in 2005 to capture summary data for facilities or areas with documented ground water quality impacts. General information about the facility is collected, along with specific information about the plume and its source. This database will be used as the focus for discussing ground water quality impacts for the 2008 305(b) Ground Water Quality Chapter for Ohio. In addition, efforts to identify areas of anthropogenetic impacts to water quality will help refine criteria for identifying sensitive aquifers.

The Ground Water Rule, expected to be finalized in 2006, will require development of a Hydrogeologic Sensitivity Assessment to identify PWSs susceptible to fecal contamination. Identification of sensitive aquifers is a valuable start for this effort and leads to understanding areas where recharge to ground water is rapid. These areas are characterized by dynamic changes in ground water quality which can be related to recharge and surface water processes. The different behavior of particulates, such as pathogens, and dissolved material, such as nitrate, in sensitive aquifers are factors that need to be evaluated for the Ground Water Rule Hydrogeologic Sensitivity Assessment. The cause and effect relationships that are being documented in areas with septic system discharge impacting ground water quality in site specific studies should be helpful in developing the Ground Water Rule Hydrogeologic Sensitivity Assessment.

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INTRODUCTION

Ground water is a vital resource in Ohio. Approximately 1,000 of Ohio's 1,300 community water systems utilize ground water, including three of Ohio's largest cities (Dayton, Canton, and Springfield). The cities of Columbus and Cincinnati use ground water to meet part of their daily water needs. More than 99 percent of the 4,100 non-community public water systems, (schools, small industries or businesses, service stations, golf courses, etc.) use ground water. In addition, approximately one million rural homes use ground water. Four-and-a-half million Ohio residents, approximately 40 percent of the state's population, depend upon wells for drinking water. Ground water is critical in meeting the demands of industry, agriculture, commercial establishments, and households. Total ground water pumped in Ohio for all uses is estimated at one billion gallons per day (ODNR, personal communication).

The Ohio Environmental Protection Agency (Ohio EPA) is the designated state ground water quality management agency for preventing and addressing ground water quality problems. To help meet this responsibility, Ohio EPA characterizes ambient ground water quality conditions; identifies ground water contamination; determines cause and effect relationships; and recommends strategies for preventing contamination. The Division of Drinking and Ground Waters (DDAGW) has the lead role for these activities within Ohio EPA. In addition, DDAGW coordinates ground water monitoring efforts with other state programs.

The 2006 305(b) Ohio's Ground Water Quality Report summarizes DDAGW's efforts to characterize the quality of Ohio's ground water. These efforts focus on maintaining data collection programs, continuing to improve our capabilities for manipulating the available data, and for incorporating geographical information systems (GIS) and other graphic tools to improve the analysis of data and the presentation of the analytical results. The primary focus of recent activities has been to refine the presentation of ambient water quality for Ohio aquifers, to identify natural geochemical variation within state aquifers, to document ground water quality impacts, and to illuminate the identification of sensitive aquifers. The goal is to utilize water quality data to help identify areas where ground water quality has been affected by human activities in order to understand land use impacts. Using this water quality data to help prioritize ground water protection efforts, as well as making these data available to the public are continuing efforts.

This report is organized to provide a summary of state ground water programs followed by a description of the DDAGW's programs, including the development of a ground water impacts database. Once populated, the Ground Water Impacts database will allow geographic analysis of documented ground water impacts and promote understanding of the relationship between potential contaminant sources and ground water impacts. A description of the ground water quality of the major aquifer types in Ohio is then provided followed by an evaluation of the identified sensitive aquifers using public water system locations with documented water quality impacts as defined by the Source Water Protection Program. Finally, analysis of VOC detections in the Ambient Ground Water Monitoring Program (AGWMP) data and the public water system compliance data is provided. These efforts are consistent with the guidance provided for ground water within the Integrated Report Guidance for 305(b) Reports.

OHIO GROUND WATER PROGRAMS

On July 1, 2001, Governor Bob Taft established a permanent Ohio Water Resources Council (OWRC) with the mission: To guide the development and implementation of a dynamic process to advance the management of Ohio's water resources. The State Agency Coordination Group, with representatives from the state agencies dealing with water issues, was also established to serve as a technical resource for the OWRC. The 10 year vision currently focuses on the following issues:

- Data and Information - encourage collection of long-term water resources data, cultivate effective management of the data, and promote easy access to data and information.
- Education and Outreach - coordination of water resources education efforts have been identified as a critical issue to promote the importance of water resources and to protect the sustainability of Ohio's water resources.
- Watershed Management - alignment of state water resource programs by watershed, along with partnering between all levels of water management players have been identified as an effective approach to promote protection of water resources.
- Water Quality - collaborative approaches for land management activities need to be promoted to maximize water quality benefits from protection and restoration activities for surface and ground water.
- Water Quantity - managing Ohio's water resources for sustained use requires improving water quantity data and characterization as well as strengthening co-operation between water management programs to prepare for future water quantity conflicts.
- Infrastructure - promote adequate planning, financing, education, and management coordination for wastewater, storm water, and combined sewer overflows to ensure clean, safe water for Ohio's citizens, businesses and industries with proper infrastructure and application of best management and water conservation practices.
- Water Hazards - encourage effective hazard management by assisting OEMA and other agencies with implementation of preparedness, response, recovery and mitigation for water related hazards.

OWRC workgroups are promoting integration of programs and activities to understand and to protect Ohio's resources. Ensuring sustainable use of Ohio's water resources requires a focus on the strategic needs identified in the OWRC's 10 year visions. More information about the 10 year vision and OWRC sponsored workgroups is listed on the OWRC web site: http://www.dnr.ohio.gov/owrc

The State Coordinating Committee Ground Water (SCCGW) was created in 1992 by the directors of the state agencies with ground water responsibilities. The purpose of the SCCGW is to promote and guide the implementation of a coordinated, comprehensive, and effective ground water protection and management program for Ohio. Overlapping membership of the SCCGW and the OWRC's State Agency Coordination Group helps to promote coordination of water management issues. As OWRC workgroups are organized to address water quality and quantity objectives, the SCCGW members will play significant roles in these workgroups to promote ground water protection and to emphasize the importance of surface water and ground water interaction. More information is available on the SCCGW Web site: http://www.epa.state.oh.us/ddagw/SCCGW/index.htm

Programs to monitor, evaluate, and protect ground water resources in Ohio are administered by various federal, state and local agencies. Ground water related activities at the state level are conducted by Ohio EPA, the Public Utilities Commission, and the Ohio Departments of Agriculture, Commerce (Division of

State Fire Marshal), Health, Natural Resources, and Transportation. The United States Geological Survey (USGS), Ohio Water Science Center, contributes to these efforts with water resource research. Figure 1 identifies the agencies with ground water quality monitoring responsibilities in Ohio. Short descriptions of these ground water monitoring programs are provided in the following paragraphs. Additional information is available from the agencies in charge of specific monitoring programs. Web site addresses are provided in the summaries for ground water protection programs.

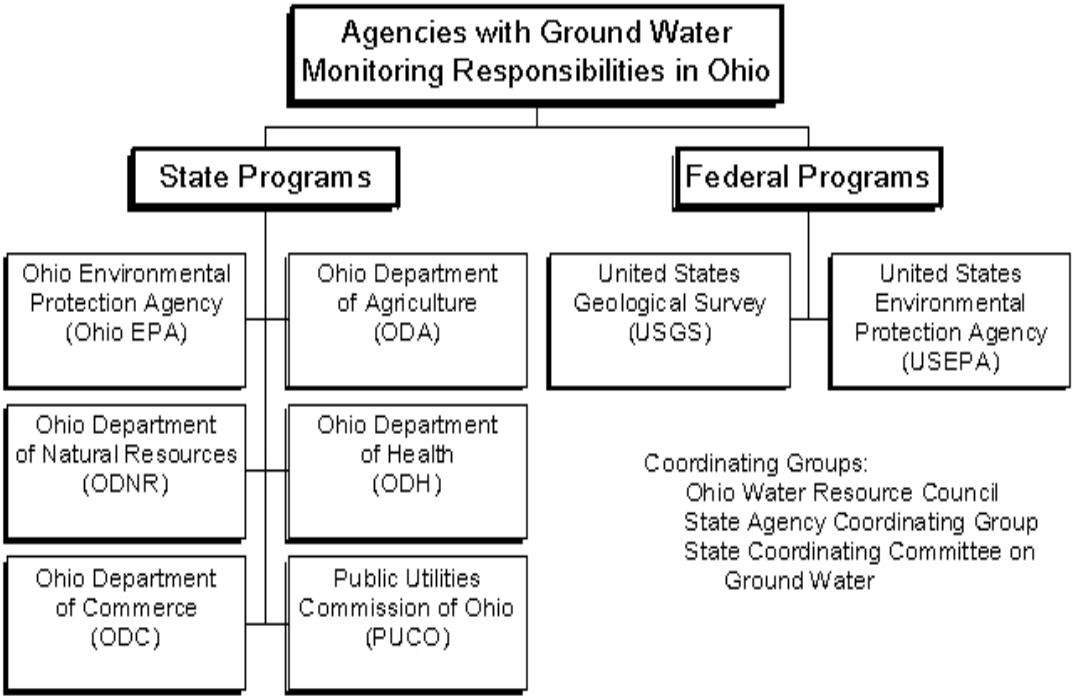


Figure 1. Agencies with ground water monitoring responsibilities in Ohio.

Ohio EPA's ground water related activities include ground water quality monitoring and assessment, as well as evaluation, prevention, and remediation of ground water pollution from existing and proposed treatment, storage and disposal sites. Ohio EPA's Division of Drinking and Ground Waters (DDAGW), functions as a technical support unit for other Ohio EPA programs by providing technical expertise on local hydrogeology and ground water quality. Specific activities of the ground water staff include: waste disposal treatment and storage site investigations; ground water complaint response; review of hydrogeologic models and site feasibility reports to ensure adequate ground water protection; and surveillance at waste disposal sites. The division also maintains a statewide ground water quality monitoring program; oversees activities associated with underground injection wells (Class I, IV, and V); carries out the state public water system supervision program; and has implemented Ohio's Source Water Protection Program (SWAP). Legal authority to support Ohio EPA ground water functions is included in Sections 6109, 6111, 3734, and 3745, of the Ohio Revised Code (ORC). Other divisions and units within Ohio EPA also have major ground water

responsibilities, including the Divisions of Solid and Infectious Waste Management, Hazardous Waste Management, Emergency and Remedial Response, and the Division of Surface Water. Additional information is available at: http://www.epa.state.oh.us/ddagw/

The **Ohio Department of Natural Resources** (ODNR), **Division of Water** is responsible for the quantitative evaluation of ground water resources. Specific functions include: ground water mapping, administering Ohio's well log and drilling report laws, conducting special hydrogeologic investigations, operating an observation well network, conducting water quantity assessments, and providing technical assistance to municipalities, industries, and the general public regarding local geology, well drilling, and water development. Statutory authority for these activities is contained in Sections 1521 and 1523 of the ORC. The Division of Water is also compiling existing hydrogeologic data from their files to generate potentiometric surface maps, and continues to produce Ground Water Pollution Potential Maps (DRASTIC criterion) for Ohio counties (ODNR, 1985). The Division of Water has recently developed an on line filing procedure for water well logs and will be redesigning the on line well log search process. The Division of Water has improved the dissemination of ground water data by serving all of the Ground Water Resources Maps, Ground Water Pollution Potential Maps, the State Aquifer Maps and the completed Potentiometric Surface maps on their website as readable maps and reports or as downloads. Additional information on these programs and the maps are available on the Division of Water Web site at: http://www.dnr.state.oh.us/water/

The **ODNR Division of Mineral Resources Management**, acting under authority of Sections 1509, 1513, and 1514, of the ORC, administers rules and regulations to manage waste and prevent pollution from activities associated with oil and gas exploration and production. Major functions that directly relate to ground water protection include regulating well drilling, enforcing well casing and abandonment standards, and regulating storage and disposal practices for associated brine and waste fluids. The division administers the state's underground injection control programs for mineral extraction wells, enhanced oil recovery operations, and brine disposal (Class II and III injection wells). Additionally, the division issues permits and oversees coal and industrial mineral mining activities. Coal permits are issued subject to conditions that establish ground water quality and static water level monitoring requirements, and isolation of acid forming spoil to ensure protection of ground and surface water resources. The division requires industrial mineral mine operators to model ground water impacts associated with planned de-watering activities to determine the anticipated impact on mined aquifers. The division has authority to require operators to replace water supplies that are damaged by mining or oil and gas activities. The division also funds and oversees plugging of orphaned oil and gas wells and restores abandoned mine lands to restore ground and surface water resources. More information about these programs is available at: http://www.dnr.state.oh.us/mineral/index.html

Other divisions within ODNR also have ground water related responsibilities. The **Division of Soil and Water Conservation** (Section 1511, ORC) is responsible for developing and administering programs which abate water pollution associated with soil erosion and animal waste handling activities from nonpoint sources. The division also acts as a liaison with the 88 soil and water conservation districts in Ohio whose programs also abate nonpoint sources and reduce threats to ground water. In addition, this division jointly oversees, with the Ohio EPA Division of Surface Water, a comprehensive watershed planning program. These watershed plans frequently include measures to protect drinking and ground waters and are integrated with source water assessments. These programs are summarized on their web site at: http://www.dnr.state.oh.us/soilandwater/

The **Division of Geological Survey** collects, interprets, and disseminates information on Ohio's bedrock and glacial geology. Ongoing programs for geologic mapping, geophysical testing, and test drilling provide a better understanding of the geologic framework of Ohio aquifers. The Division of Geological Survey has produced reconnaissance 3-dimensional, surficial-geology maps for Ohio at 1:100,000 scale for 41% of Ohio. These maps show the extent, vertical succession and thickness of mappable geologic materials from the surface down to and including the top of bedrock. The Division of Geological Survey is also working with the Central Great Lakes Mapping Coalition to develop detailed 3-D models and maps of selected topographic quadrangles in Ohio. More information on division programs is available on their web site at: http://www.dnr.state.oh.us/geosurvey/

The **Ohio Department of Health** (ODH) is responsible for programs to regulate the siting, design, operation, and maintenance of private, residential water supply systems and sewage disposal systems which may have direct impact upon local ground water quality and drinking water safety. ODH has adopted rules governing specific well construction practices and a well permit system, effective January 1, 2000 (Chapter 3701-28, OAC). These rules are administered in cooperation with local health departments. Local health departments and ODH investigate complaints of private wells that are suspected of being contaminated. ODH programs are mandated by Section 3701of the ORC, and include a registration program for private water system contractors. ODH continues to investigate the distribution of arsenic in private wells in various counties. Increased awareness of arsenic in ground water has raised concerns about private wells in areas where compliance sampling for public water systems has identified high arsenic values. Samples collected were analyzed for arsenic, total iron, phosphorous, nitrate, and total coliform. The studies found that most of the wells with arsenic detections were completed in buried valley aquifers or in the sandstone formation immediately underlying the buried valley deposits. These studies have also confirmed that the presence of arsenic can be a very localized phenomenon. More information is available on these programs at: http://www.odh.ohio.gov/odhprograms/eh/water/water1.aspx

In the **Ohio Department of Commerce**, Division of State Fire Marshal, the Bureau of Underground Storage Tank Regulations (BUSTR) is responsible for the registration of underground storage tanks (UST) for petroleum products and the implementation of rules for underground tank installation, testing, and abandonment. BUSTR staff investigate and direct UST removal and associated ground water cleanup activities in conjunction with local fire departments. These programs are summarized on their web site at:http://www.com.state.oh.us/sfm/bust/

The **Ohio Department of Agriculture** (ODA), through the Pesticide & Fertilizer Regulation Section, administers programs regulating the storage, distribution and use of pesticides and fertilizers in Ohio. This program works closely with both Ohio State University Extension and the Pesticide Education Program to coordinate applicator training and re-certification programs. ODA was the lead agency for developing the state's Pesticide Management Plan (PMP) to protect Ohio's ground waters from pesticide contamination (ODA, 1998). After receiving verbal concurrence for Ohio's PMP in 1999, written approval was received in August 2000 after the directors of ODH, ODNR, and Ohio EPA signed a cooperative commitment to implement the Pesticide Management Plan for the State of Ohio. As outlined in Ohio's PMP, ODA's Pesticide & Fertilizer Regulation Section is responsible for coordinating an annual ground water sampling program. The state plan ranked areas of the state for vulnerability to ground water contamination based on soil type, geology, and land use and is used each year in planning the ground water sampling program. Historically these sampling efforts have been focused in areas of heavy row crop agriculture production and in areas in close proximity to large-scale pesticide distribution facilities. Future sampling is planned in areas of intense greenhouse crop and nursery stock production. Collected samples are analyzed for a broad array of pesticide parent compounds and metabolites. When pesticides are found in ground water resources, ODA works with the identified sources to implement best management practices to prevent further contamination. More information on the pesticide and fertilizer programs is available online at: http://www.ohioagriculture.gov/pesticides/

In addition to the pesticide programs, various ODA divisions sample ground water for pathogens in wells that produce water used in food processing. In July 2002, primary regulatory authority for approval of confined animal feeding operations (CAFOs) moved from the Ohio EPA Division of Surface Water to the ODA Livestock Environmental Permitting Program. The Ohio EPA Division of Surface Water retains responsibility for issuing discharge permits for these facilities.

The **United States Geological Survey, Ohio Water Science Center** collects, analyzes, and interprets ground-water data in order to further knowledge of the State's ground-water resources. Relevant research includes describing and evaluating water resources, mapping water levels, estimating ground-water discharge from regional aquifers, modeling ground-water flow at various scales, and collecting and interpreting water-quality data. Funding for this research includes cooperative matching of Federal funds with State and/or local-agency funds.

Relevant ongoing national programs that include Ohio are the National Water Quality Assessment Program (NAWQA) and the Ground-Water Availability of Selected Principal Aquifers - Great Lakes Basin Pilot. The USGS also has produced summary reports on national trends of water quality. The USGS Ohio Water Science Center has information on projects, programs, and publications, as well as online data, at: http://oh.water.usgs.gov/

U.S. EPA collects ground water monitoring data at hazardous waste sites for which they oversee cleanup or which are permitted by U.S. EPA. Federal legislation overseen by U.S. EPA drives much of the ground water monitoring and analysis completed in the state, such as the requirement for the 305(b) Report. The U.S. EPA office of Water web page is: http://www.epa.gov/ebtpages/water.html

OHIO EPA GROUND WATER QUALITY CHARACTERIZATION PROGRAM

DDAGW is responsible for characterizing Ohio's ground water quality. Ground water quality monitoring information is collected through the new well approval process for public water supply wells, compliance sampling for public drinking water systems, sampling of the Ambient Ground Water Program wells, and special studies. The division also receives or has access to water quality data collected from permitted solid waste sites, RCRA-regulated hazardous waste sites, and Ohio EPA Division of Emergency and Remedial Response (DERR) sites. Progress continues to be made to utilize these data to characterize Ohio's water quality. The goal is to employ water quality data to identify ambient water quality information for the main aquifer types, and to characterize the natural geochemical variation within aquifer types on a regional and temporal basis. These data can then be used to identify areas of impacted ground water within Ohio. Once identified, areas of ground water impact can be investigated and analyzed to identify possible causes. This process will improve our understanding and delineation of sensitive aquifers which will in turn allow Ohio EPA to focus protection strategies in priority areas. Figure 2 illustrates the hierarchy of DDAGW programs that collect ground water quality monitoring data.

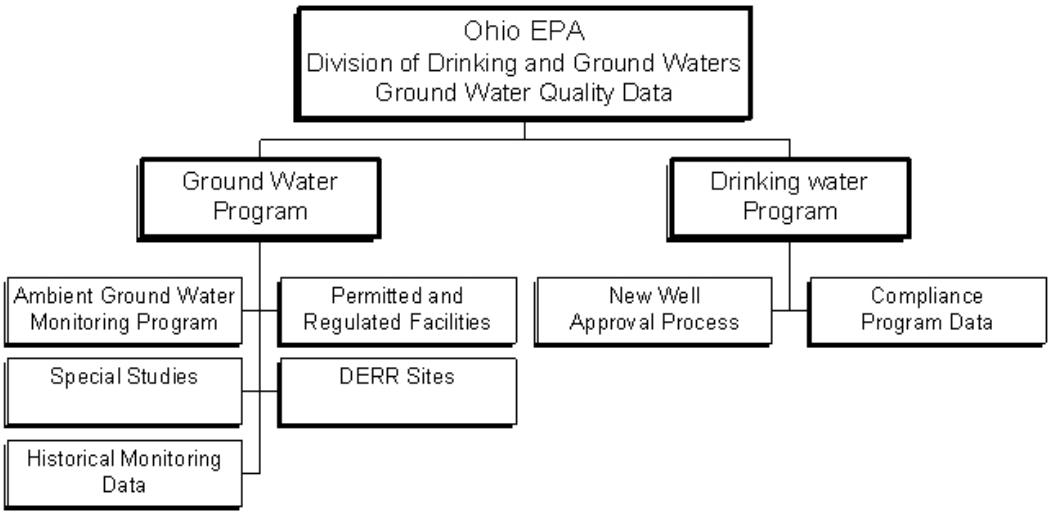


Figure 2. DDAGW programs that collect ground water quality data.

The water quality analysis presented in this report utilizes Ambient Ground Water Monitoring Program (AGWMP) data and, to a lesser extent, public water system (PWS) compliance data. The AGWMP was specifically designed for broad-based water quality analyses of Ohio's major aquifers and consequently, collects raw (untreated) water quality data. In contrast, PWS compliance data is generally treated or distribution water quality data. The PWS compliance data is collected to ensure that PWSs are meeting water quality standards, and consequently is more restrictive in parameter selection. Nevertheless, the wide geographic distribution of PWSs makes these data useful for statewide studies. Because of the importance of the AGWMP and PWS compliance data to the water quality analysis presented in this report, these data are described in separate sections below.

DDAGW completes special ground water studies that focus on nonpoint sources such as arsenic, radon, pesticides, pathogens, or nitrates, which provide additional sources of data for water quality characterization. The water quality data for these studies will be entered into STORET for future access and analysis. Finally, the required raw water analysis for a new PWS well includes an extensive suite of parameters, and provides data that can be used to help characterize Ohio's water quality.

The monitoring data received from permitted/regulated facilities and DERR sites are another source of ground water quality information. Most of these data are submitted in formats dictated by the regulatory program, and the effort to organize this information into a water quality database for statewide analysis has not been initiated. A database has been developed to capture summary data for waste management units (treatment, storage, disposal), RCRA, VAP, and other sites where impacts to ground water quality are documented. This database, referred to as the Ground Water Impacts database, was developed as a survey tool and consequently the level of detail captured is limited. The database is intended for statewide analysis of ground water quality, and every site is associated with a latitude and longitude for geographic analysis.

Another DDAGW ground water quality monitoring data source is the Historical Monitoring Data, which will contribute to the water quality characterization effort in specific areas where historic data is available. DDAGW staff have evaluated and organized paper files containing old ground water sample data, collected primarily between 1973 and 1985. These files include data collected during complaint investigations, litigation sampling, and pollution source investigation sampling. Data with accurate location and basic geologic information were selected and added to county files. Currently the data are only available in counties files with map locations, thus, it is relatively easy to identify historic data that may be useful for site specific analysis.

Other Ohio EPA divisions have data relevant to ground water quality. The **Division of Surface Water** (DSW) has extensive surface water sampling data that will be important for evaluating ground water-surface water (GW-SW) interactions. In addition, their nonpoint source programs collect data that are relevant to potential ground water impacts through GW-SW interactions. DDAGW has collaborated with DSW on development of a Public Water System Beneficial Use Assessment Methodology which is included in DSWs 2006 Integrated Water Quality Report (Ohio EPA, 2006). Assessment of the PWS beneficial use will be based on comparison of chemical data to established Clean Water Act water quality criteria. A pilot project in the Sandusky River watershed is being completed in order to evaluate the proposed methodology.

Ambient Water Quality Data

As part of the effort to characterize general water quality conditions in Ohio, DDAGW maintains the Ambient Ground Water Monitoring Program (AGWMP). Data collection activities occur at the district offices, and compilation, database design, and data analysis are completed primarily in the Central Office. This program to sample raw water was originally established in 1973 to measure seasonal and annual changes in water quality in the state's major aquifers. The network consisted of approximately 45 wells in 1973. The program expanded to 60 wells in the mid 1970s, but sampling of these wells decreased steadily to the mid 1980s. In 1986, the AGWMP was re-energized with 150 samples collected from about 100 active wells. To provide better representation of the primary aquifers in Ohio, a number of wells were added to the network in the mid 1990s.

The program currently includes 204 active wells at approximately 199 sites. There are also 149 inactive wells, wells that are no longer sampled. The 94 standby wells, associated with specific active wells, are sampled if the active well is down for repairs. The distribution of AGWMP wells across Ohio, broken out by aquifer type, is illustrated in Figure 3. Of the total sites, roughly 83 percent are public water systems; the rest (17 percent) are industrial sites, commercial enterprises, or private residences. Raw water samples are analyzed for inorganics every 6 or 18 months depending on the total number of samples that have been collected, and the stability of the geochemistry of major elements at the site. Table 1 lists the inorganic parameters for which AGWMP samples are analyzed. Samples are analyzed for volatile organic compounds once every 18 months. District staff have identified some AGWMP wells as vulnerable to VOC contamination based on VOC releases near the wells; these wells are analyzed for VOCs every six months to help monitor for potential contamination. Starting in the mid 1990s, pesticides and semi-volatile organic compounds (SVOC) samples were collected every 18 months. These analyses were discontinued in 1999 because so few compounds were detected, making it difficult to justify the added expense.

Locational and lithologic information have been updated for all of the ambient wells in the process of entering AGWMP data into STORET. Of the active wells, 64 percent (130) produce from unconsolidated sand and gravel aquifers, 20 percent (41) from carbonate bedrock aquifers, and 16 percent (33) from sandstone bedrock aquifers. The unconsolidated wells are predominantly sand and gravel wells, but four of the well logs identify the screened zone as gravel and two well logs identify the screened zone as sand. In general terms, we refer to all the unconsolidated wells as sand and gravel aquifers. The sandstone wells produce from Pennsylvanian and Mississippian sandstones in the eastern half of Ohio. Of the sandstone wells, eleven are identified as sandstone/shale wells and three wells are identified as shale. This distinction is based on the well logs, but bedrock wells are generally open bore holes below the casing, so some water contribution from the stratigraphic section below the casing is expected. From this perspective, all the sandstone wells could be called sandstone/shale wells. The carbonate wells are located in the west half of Ohio. Most of the carbonate wells are producing from Silurian dolomites, but wells in the Devonian or Devonian and Silurian limestones account for ten of the carbonate wells. These aquifers are discussed in more detail in the "Ground Water Quality By Aquifer Types" section.

The primary objective of the AGWMP is to collect raw water quality data to characterize the general ground water quality across the state in order to evaluate the quality of the source water used by ground water based the public water systems. The AGWMP wells accomplish this goal, but this is not to say that no AGWMP wells are impacted by land use activity. The impacts documented, however, are generally limited. One of the limitations of the AGWMP wells it that they are generally characteristic of higher production and deeper wells used by larger PWSs. This subset of wells are not characteristic of shallow, lower production wells typical of residential wells, which are more likely to be impacted by land use activity. Consequently, the limited impact to ground water quality in the AGWMP wells may provide a false security for ground water impacts in the shallower aquifers. Other limitations include the numberand variety of sampling personnel and the somewhat irregular sampling frequencies. On the other hand, sampling follows standard protocol and a single laboratory is used for all AGWMP chemical measurements statewide, providing strong analytical consistency. Overall, the data set quality is quite high and the geochemical variability between the aquifer types is easily discerned, as illustrated in the Ohio Water Quality Characterization Section of this report.

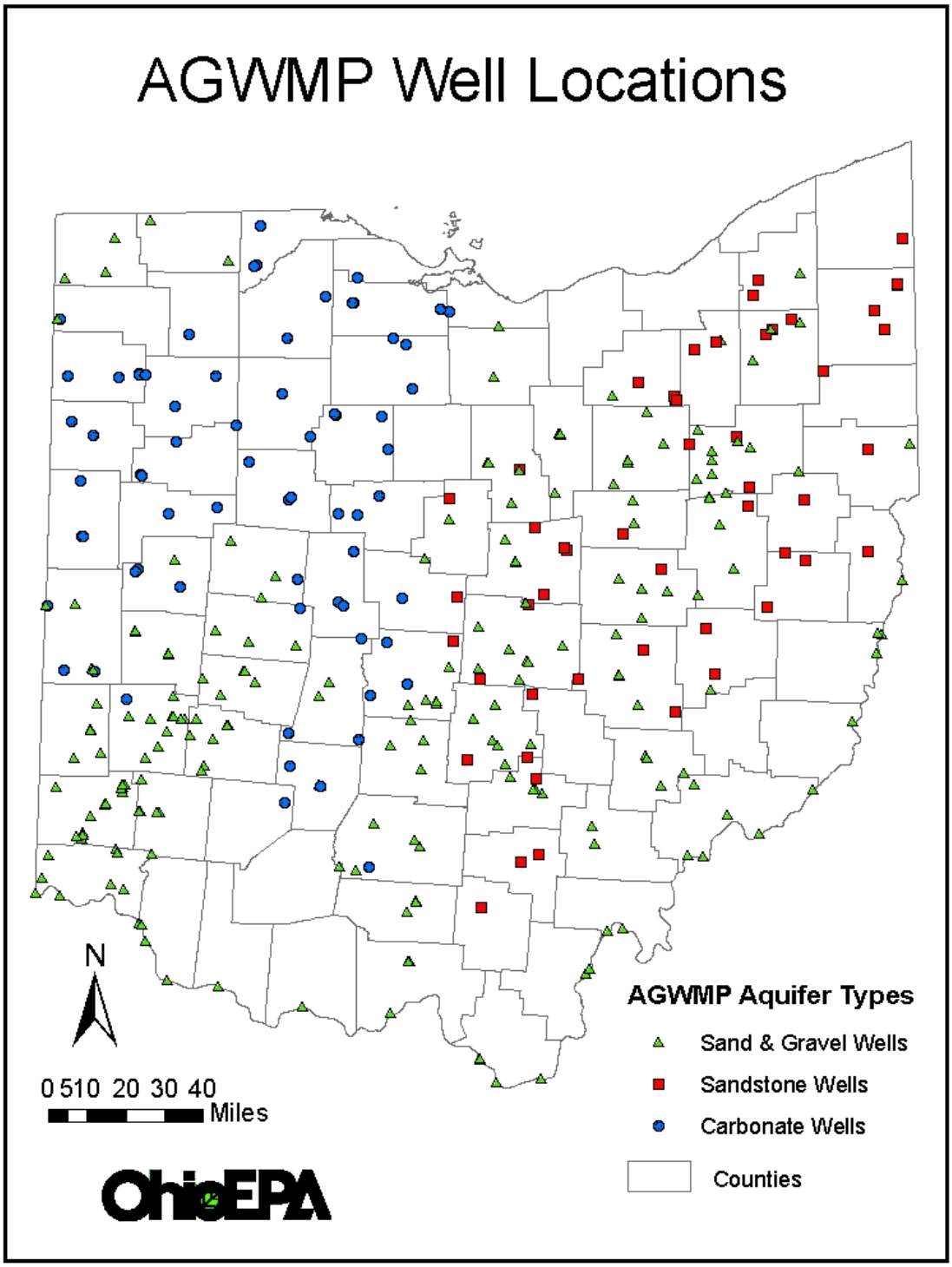


Figure 3. AGWMP well locations and aquifer type.

Table 1 - AGWMP Inorganic Chemical Parameters

PARAMETER	CURRENT REPORTING LIMIT	MCL/SMCL
Major Constituents	**mg/L**	**mg/L**
Alkalinity, Total as $CaCO_3$	5	
Calcium (Ca)	2	
Chloride (Cl)	5	SMCL 250
Hardness as $CaCO_3$	10	
Magnesium (Mg)	1	
Potassium (K)	2	
Sodium (Na)	5	
Sulfate (SO_4)	5	SMCL 250
Total Dissolved Solids (TDS)	10	SMCL 500
Trace Constituents	**µg/L**	**ug/L**
Aluminum (Al)	200	SMCL 50-200
Arsenic (As)	2	MCL 10
Barium (Ba)	15	MCL 2000
Cadmium (Cd)	0.2	MCL 5
Chromium (Cr)	30	MCL 100
Copper (Cu)	10	
Fluoride (F)	0.10 mg/L	MCL 4000; SMCL
Iron (Fe)	50	SMCL 300
Lead (Pb)	2	
Manganese (Mn)	10	SMCL 50
Nickel (Ni)	40	MCL 100
Selenium (Se)	2	MCL 50
Strontium (Sr)	30	
Tritium (^3H)	0.8 T.U.	
Zinc (Zn)	10	SMCL 5000
Nutrients	**mg/L**	**mg/L**
Ammonia (NH_3)	0.05	
Chemical Oxygen Demand	10	
Nitrate/Nitrite (as N)	0.10	MCL 10
Phosphorus (P)	0.05	
Total Kjeldahl Nitrogen (as N)	0.2	
Total Organic Carbon (TOC)	2	
Field Analysis	**Relative Accuracy**	
pH	± 0.01 S.U.	SMCL 7.0 - 10.5
Specific Conductance	± 1 %	
Temperature	± 0.1 °C	
Oxidation Reduction Potential	± 1 mV	
Total Dissolved Solids (TDS)	± 1 %	

Since the completion of the 2002 305(b) Report, the AGWMP staff have continued to work to increase the utility of the AGWMP water quality data, to develop procedures for capturing ground water data collected for special studies, to maintain standard procedures for data collection and management, and to identify ways to make ground water quality data more accessible to the public. A primary focus over the past several years has been establishing STORET as the primary database for AGWMP data. These efforts maintain our high confidence in the AGWMP data and hopefully, increase data availability. The following AGWMP data management and analysis procedures have been completed:

- Established STORET as the primary database for AGWMP data;
- Developed an Oracle module (SEAGATE) to store Ambient header data and interface with STORET;
- Uploaded all AGWMP data into the National STORET data warehouse;
- Developed STORET reporting capabilities for retrieving data;
- Instituted QA/QC procedures for new data into the End-of-Round Quality Assurance Report;
- Revised Operating Procedures Document (OPD) to include electronic upload and QA/QC of data into STORET;
- Reviewed water quality data to shift some wells to less frequent sampling, reducing sampling time by 16 days/year and analytical costs by $ 18,000 /year;
- Incorporated data from inactive wells into water quality analyses;
- Purchased new field meters capable of testing for oxidation-reduction potential (ORP) and total dissolved solids (TDS);
- Developed a database to track facilities in Ohio with documented impacts to ground water;
- Outlined a watershed-based approach to present local ground water quality in a user-friendly format;
- Developed a plan for conducting ground water quality special studies and uploading the data into STORET;
- Began analysis of AGWMP and PWS volatile organic compound (VOC) detections.

With these efforts to increase the value and utility of the AGWMP water quality data, it continues to be the best untreated water quality data that DDAGW has to characterize statewide ground waters. Consequently, we have used these data extensively to update the characterization of water quality for the three major aquifer types in Ohio. These data are used in conjunction with the PWS compliance data to evaluate the distribution of VOC detections and to continue our efforts to identify sensitive aquifers in Ohio. Other efforts, such as the development of the Ground Water Impacts database, are attempts to use other ground water quality data to help identify impacts to Ohio's aquifers. The expertise of the GIS staff and the continued development of expertise with data analysis programs are critical parts of the effort to examine, to utilize, and to present these data in effective ways.

Public Water System Compliance Data

In the early 1940s, the Ohio Department of Health (ODH) began evaluating the water quality of public water supplies. With the formation of Ohio EPA in 1972, these duties were transferred to Ohio EPA. Samples of both raw and finished water from community water suppliers were collected and analyzed through the mid-1970s. The analyses provided a record of public water supply quality to ensure that violations of recommended health (primary) or aesthetic (secondary) standards in drinking water were identified and corrected. Between 1950 and 1977, over 15,000 raw water chemical analyses of the state's public ground water supplies were obtained. Since around 1977, only finished (treated) water has been tested by the public water systems on a regular basis, and analyses are limited to primary (health related)

drinking water parameters. In proposed/new public water system wells, however, raw water is required to be tested for all primary and secondary parameters for well approval. The PWSs collect and submit these samples to certified labs for analysis and the results are sent to the Ohio EPA for review.

Even though public drinking water compliance sampling targets only treated water, the wide distribution and large number of public water systems make these data useful in characterizing and in identifying trends in Ohio's ground water quality. The data from treated water (compliance sampling), as well data from the untreated (raw) water from public water supplies, are hereafter collectively referred to as public water system (PWS) data. In the case of nitrate, we make the assumption that most PWSs do not have treatment processes that significantly reduce nitrate concentration in the sampled water. Other parameters, however, may be reduced in the treatment process. For example, if a PWS is removing iron, and arsenic is present as well, the arsenic concentration will be reduced with iron removal.

Treated water from Ohio's public water systems is currently being monitored for compliance purposes on a continuing basis in accordance with the Federal Safe Drinking Water Laws and Chapter 6109 of the Ohio Revised Code. Sampling is based on three-year cycles, but sampling schedules for each contaminant group are different. Individual sampling schedules are produced for each public water supplier by DDAGW based on past sampling results and various waiver programs. Guidelines for public drinking water monitoring for ground water based systems are provided in Table 2.

Table 2
Drinking Water Monitoring Requirements for Public Water Supply Wells

Contaminant Group	Community PWS	Non-Transient, Non-Community PWS	Transient Non-Community PWS
Radiological [a]	✘		
Trihalomethanes	✘	✘ [i]	
Asbestos [b]	✘	✘	
Inorganic Constituents [c]	✘	✘	
Synthetic Organic Compounds (SOCs) [d]	✘	✘	
Volatile Organic Compounds (VOCs) [e]	✘	✘	
Lead and Copper [f]	✘	✘	
Microbiological [g]	✘	✘	✘
Nitrate and Nitrite [h]	✘	✘	✘

[a] Must monitor for gross alpha radioactivity once every three years. New community systems must complete four consecutive quarterly samples the first year of operation.
[b] Asbestos concentration must be analyzed once every nine years.
[c] Required to sample for 12 inorganic constituents once every 3 years.
[d] All ground water systems are required to sample for alachlor, atrazine, and simazine once every 3 years. Systems with detections are required to monitor these compounds on a quarterly schedule until they are reliably and consistently below the maximum contaminant level (MCL). Systems that had one or more nitrate detections above 2.0 mg/L are required to monitor the other 15 SOCs once every 3 years.
[e] Required to sample for 21 compounds. Initially, samples are required on a quarterly basis for one year, then a public water system can reduce sampling frequency to once a year. After three years of annual samples without VOC detections, sampling frequency can be reduced to once every three years.
[f] Action levels, not MCLs
[g] All ground water-based public water systems are required to monitor for total coliform at least once every quarter. A community system must sample for total coliform at least once per month. If any sample is positive for total coliform then the sample must be analyzed for fecal coliform or E.Coli.
[h] All ground water-based public water systems are required to monitor for nitrate at least once per year. Nitrite is required once every 9 years. If the nitrate exceeds 50 percent of the MCL (i.e., 5 mg/L), or if nitrite exceeds 50 percent of the MCL (i.e., 0.5 mg/L), quarterly samples are required until the system is reliably and consistently below the MCL. Ground water systems designated as under the direct influence of surface water are required to sample for nitrate monthly.
[i] Trihalomethanes are required at NCNT PWSs if the system disinfects.

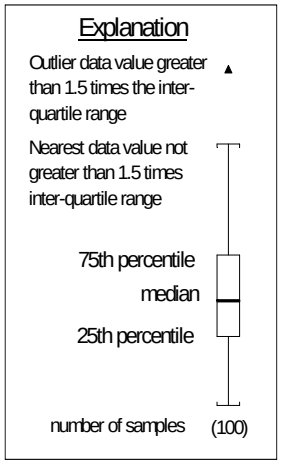
GROUND WATER QUALITY BY AQUIFER TYPE

Introduction

The overall ground water quality within the State of Ohio is described here using the Ambient Ground Water Monitoring Program database, consisting of approximately 5,400 water quality samples distributed across 353 active and inactive sites. Figure 3 illustrates the distribution of AGWMP wells across Ohio by aquifer type. The major aquifers in Ohio include unconsolidated sand and gravel units deposited on top of the consolidated bedrock units consisting of sandstone bedrock in the eastern half, and carbonate bedrock in the western half of Ohio. The majority of the wells used in this characterization are public water supply production wells, usually developed within higher yielding zones with good water quality. This effort to characterize the ground water supports the goals of the AGWMP - to collect, analyze, and describe the source (ambient) ground water quality used by public water systems across the state.

AGWMP data are presented by aquifer type since water-rock interaction imparts distinct geochemical signatures, which are reflected in the ground water quality data. Several factors contribute to the chemical makeup of ground water; the most significant are the composition of the recharge (percolation) water, the soil and vadose zone composition, the composition and porosity of the aquifer solids, and the residence time of the ground water. These factors vary widely across the three main aquifers in Ohio, but some broad observations are possible. In general, the initial composition of percolation water across the state is similar. Long-term average precipitation for Ohio is 38 inches per year while ground water recharge rate estimates range from 3 inches to 16 inches per year, with a median of 6 inches per year (Dumochelle and Schiefer, 2002). Composition and solubility of soil and vadose materials, however, is variable across the state, leading to recharge waters with dissimilar initial compositions. Thus, the thick glacial tills (clayey soils) found across much of north, central, and west Ohio affect the initial percolation water quality differently than the thin loess soils of southeast Ohio. The permeability of these thick glacial soils tends to increase the residency time, however, agriculture tile drains in these glacial soils can short circuit flow paths to surface water and can influences the volume of recharge reaching the aquifer.

Increased residence time in an aquifer typically leads to higher salinity and greater mineralization of the water, depending on the solubility of the aquifer minerals present. The unconsolidated sand and gravel units, for example, commonly have short residence times, leading to lower salinity in these waters. These younger waters are generally shallower, and are more likely to be affected by contamination from surface land use activities. Older, deeper waters, such as in the carbonate aquifers of northwestern Ohio, may follow much longer flow paths, allowing the water ample time to establish a geochemical equilibrium with the rock system. Figure 4 is a box plot indicating the distribution of well depths by aquifer type for the AGWMP wells. The median depth of the carbonate aquifers (~220 feet) is greater than the median depth of the sandstone aquifers (~180 feet). The median depth for the sand and gravel aquifers (80 to 90 feet) is significantly shallower. The median depth of the carbonate and sandstone well depths is roughly twice the depth of the sand and gravel wells.



Box and Whisker Plots

Box and Whisker Plots are an efficient method to visualize how individual points are distributed in data sets. The "box" itself outlines the range of half the data (25th to 75th percentiles). The median, or 50th percentile, is shown by the bar inside the box. Two whiskers (vertical lines extending from the box) indicate the distance to the highest and lowest data points which are not outliers. Outliers are indicated by points above or below the whiskers. If the median is located midway between top and bottom of the box, the data are normally distributed.

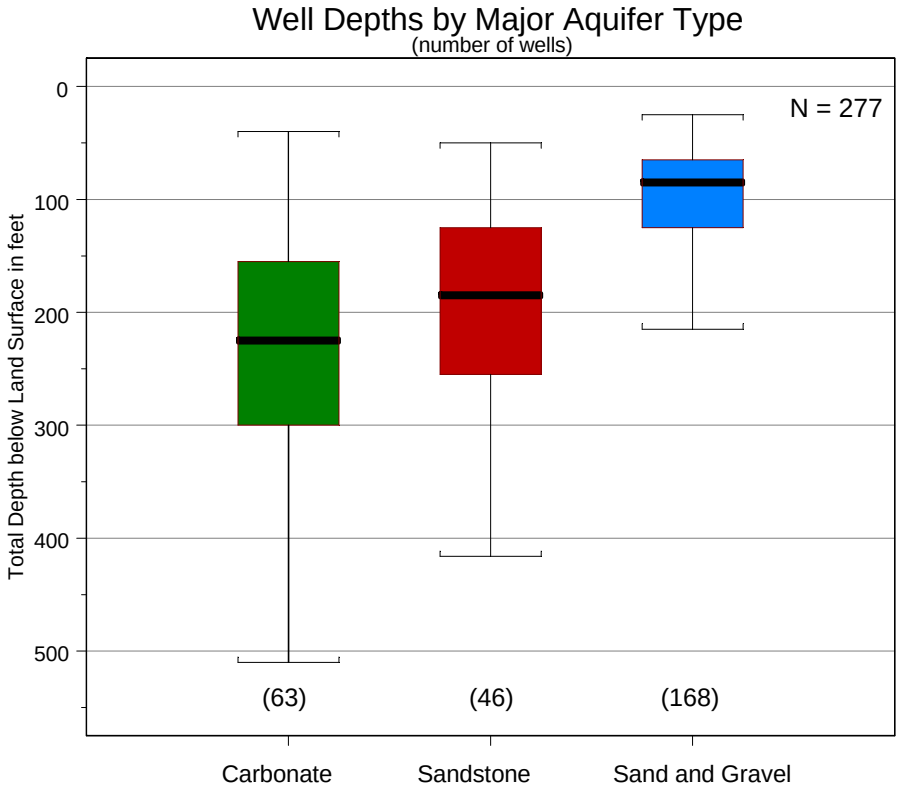


Figure 4. Box plot of active AGWMP well depths by aquifer type.

Inorganic Parameter Mean Values

Ambient Ground Water Quality data summarizes the geochemistry by aquifer. This table provides the arithmetic mean, median, minimum value, maximum value, standard deviation, total number of samples, number of samples below the reporting limit, and the percent censored for inorganic and field parameters in each aquifer type as of July, 2005. The reporting limit was used for the non detect value in calculating means. The "percent censored" column records the percent of analyses measured below the current reporting limit (rounded to the nearest percent). The presence of a less than sign (<) in the minimum value field (column 5) indicates the minimum value is the reporting limit. The minimum value may not always coincide with the current reporting limit (Table 1) due to multiple reporting limits resulting from changes in analytical methods or errors in data transcription. The estimates of the number and percentages of censored data (columns 8 and 9) may also be influenced by changes in the reporting limits.

The data summarized in Table 3 represents the accumulation of over 141,000 raw, inorganic ground-water data results gathered at more than 350 sites across Ohio from over 35 years of ground water sampling. Consistency in sampling protocol, analytical procedures and stability of site histories over time combine to lend a unique significance to the AGWMP database. A significant consequence of the long history of the AGWMP is the ability to evaluate ground water quality trends at individual wells over periods of time. Thus, Table 3 is the best summary available for the general water quality of Ohio's major aquifers, the source water for Ohio's public drinking water systems using ground water. However, it should be noted that some wells in the Ambient network have been impacted by anthropogenic sources, such as nitrates or VOCs.

The Ambient Water Quality Table is organized into four categories, identified in the first column:

- **Field Parameters** – measured in field, such as pH and water temperature;
- **Major Constituents** – such as calcium or sulfate, concentrations in the range of mg/L (ppm);
- **Trace Constituents** – such as arsenic or cadmium, concentrations in range of ug/L (ppb); and
- **Nutrients** – components required by organic systems for growth, concentrations in mg/L (ppm).

To illustrate the utility of the Ambient Water Quality Table, a simple example is provided. To find which major aquifer has the most manganese, find the Manganese row in Column 1 (under Trace Constituents), and read off the mean values for each aquifer type from column three. In this case, we see that the sand and gravel aquifer has the greatest mean manganese concentration (226.4 ug/L), while the carbonate system has the lowest, 30.0 ug/L. Suppose now you were interested in looking up the probabilities of encountering a manganese detection in each of the three aquifer types. To do this, follow the manganese row across to the last column, Percent Censored. Here we find that within the sand and gravel units, only fourteen out of every 100 water samples is recorded below the reporting limit, so we would expect to find a manganese detection with an 86 percent probability. In the case of the carbonate bedrock system in Ohio, we find the percent censored for manganese is 31, indicating that a 69 percent chance exists that a water sample from this aquifer type will yield a detection for manganese. It should be noted that these censored values are not probabilities in the stricter sense of a probability distribution, but rather are observed percentages. They are useful values for estimating expected levels of non-detects, based on the long-term sampling history of AGWMP wells.

Table 3 - Ambient Ground Water Quality
Ambient Network Data Summary by Major Aquifer as of July 2005.

FIELD PARAMETERS				‡ *				* §	§
Parameter and Units	**Major Aquifer**	**Mean Value**	**Median Value**	**Minimum Value**	**Maximum Value**	**Standard Deviation**	**Number of Samples**	**Number Below Rep. Limit**	**Percent Censored**
Oxidation-Reduction Potential (ORP) mV	Sand and Gravel	50.55	36	-163.0	534.0	122.1	75	na	na
	Sandstone	148.21	74.0	-137.0	600.0	228.8	22	na	na
	Carbonate	-33.19	-23.0	-264.0	162.0	107.5	27	na	na
pH, Field S.U.	Sand and Gravel	7.32	7.33	5.6	8.9	0.3	2775	na	na
	Sandstone	7.26	7.3	5.2	8.7	0.5	596	na	na
	Carbonate	7.25	7.2	5.6	9.3	0.4	984	na	na
Specific Conductivity µmhos/cm	Sand and Gravel	646	625	50	2300	191	2941	na	na
	Sandstone	628	505	105	7900	491	643	na	na
	Carbonate	889	824	270	2900	322	993	na	na
Total Dissolved Solids, Field mg/L	Sand and Gravel	531	506	310	1202	141	68	na	na
	Sandstone	547	381	230	2075	415	21	na	na
	Carbonate	769	676	495	1549	258	23	na	na
Water Temperature Degrees C	Sand and Gravel	13.8	13.5	5.1	31.9	2.5	2644	na	na
	Sandstone	13.1	12.8	7.0	57.3	2.9	533	na	na
	Carbonate	13.5	13.1	6.9	25.0	1.9	932	na	na
MAJOR CONSTITUENTS									
Parameter and Units	**Major Aquifer**	**Mean Value**	**Median Value**	**Minimum Value**	**Maximum Value**	**Standard Deviation**	**Number of Samples**	**Number Below Rep. Limit**	**Percent Censored**
Alkalinity, Total as $CaCO_3$ mg/L	Sand and Gravel	262	269	< 5.0	1500	73.6	3439	6	0
	Sandstone	216	196	< 5.0	1500	112.9	715	4	1
	Carbonate	294	302	5	642	67.6	1033	5	0
Calcium, Total mg/L	Sand and Gravel	95.5	94	< 2	640	32.5	3533	4	0
	Sandstone	60.3	54	< 2	184	36.3	741	5	1
	Carbonate	133.0	117	2	613	68.6	1049	5	0

Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Censored
Chloride mg/L	Sand and Gravel	39.4	29.8	< 2.0	420	36.8	3498	101	3
	Sandstone	39.4	22.0	< 1.0	530	50.1	733	65	9
	Carbonate	28.4	14.4	< 2.0	449	45.2	1014	103	10
Hardness, Total as $CaCO_3$ mg/L	Sand and Gravel	355	360	< 10	974	86.2	2503	5	0
	Sandstone	227	202	< 10	691	130.9	557	4	1
	Carbonate	540	469	< 10	2010	249.0	779	6	1
Magnesium, Total mg/L	Sand and Gravel	28.8	29	< 1	135	10.3	3536	9	0
	Sandstone	19.4	16	< 1	76	13.8	742	5	1
	Carbonate	50.8	45	< 1	134	19.7	1051	6	1
Potassium, Total mg/L	Sand and Gravel	2.4	2.0	< 1	56.0	1.6	3089	419	14
	Sandstone	3.6	2.0	< 0.5	610.0	23.5	689	178	26
	Carbonate	3.0	3.0	1.1	14.0	1.3	938	14	1
Sodium, Total mg/L	Sand and Gravel	26.0	21	< 2	773	24.2	3529	71	2
	Sandstone	59.7	26	< 5	774	86.1	742	33	4
	Carbonate	36.8	28	< 5	472	32.2	1052	12	1
Sulfate mg/L	Sand and Gravel	81.0	68.0	< 5	1975	82.1	3497	36	1
	Sandstone	89.4	43.5	< 5	3750	198.7	737	56	8
	Carbonate	284.7	199.0	< 5	3150	267.4	1047	12	1
Total Dissolved Solids mg/L	Sand and Gravel	468	450	< 10	3050	163.6	3379	0	0
	Sandstone	425	338	< 10	2480	306.8	704	0	0
	Carbonate	771	678	< 10	2360	341.5	980	0	0
TRACE CONSTITUENTS									
Parameter and Units	**Major Aquifer**	**Mean Value**	**Median Value**	**Minimum Value**	**Maximum Value**	**Standard Deviation**	**Number of Samples**	**Number Below Rep. Limit**	**Percent Censored**
Aluminum ug/L	Sand and Gravel	203.4	200.0	84.0	2880	88.2	2085	2078	100
	Sandstone	200.1	200.0	< 200.0	234	1.6	584	582	100
	Carbonate	205.2	200.0	< 200.0	1810	73.1	669	662	99
Arsenic, Total ug/L	Sand and Gravel	5.79	2.0	< 2.0	102	8.8	3085	1596	52
	Sandstone	3.13	2.0	< 2.0	78	4.8	671	505	75
	Carbonate	4.01	2.0	< 2.0	30	4.2	969	580	60

Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Censored
Barium ug/L	Sand and Gravel	176.9	127.0	<15.0	2160	202.7	3039	129	4
	Sandstone	153.5	65.0	<15.0	2080	312.5	652	61	9
	Carbonate	71.4	40.0	<7.0	863	82.1	978	120	12
Cadmium, Total ug/L	Sand and Gravel	0.45	0.2	< 0.2	5.0	12.19	2504	2465	98
	Sandstone	0.24	0.2	< 0.2	18.8	0.73	666	653	98
	Carbonate	0.21	0.2	< 0.2	5.0	0.17	930	913	98
Chromium, Total ug/L	Sand and Gravel	30.0	30.0	< 0.2	110	2.18	2670	2650	99
	Sandstone	29.9	30.0	< 10.0	30	1.47	688	684	99
	Carbonate	29.9	30.0	< 10.0	90	2.77	962	947	98
Copper, Total ug/L	Sand and Gravel	12.37	10.0	< 2.0	405	16.99	2247	1935	86
	Sandstone	12.10	10.0	< 2.0	168	11.23	635	513	81
	Carbonate	15.20	10.0	< 2.0	387	29.16	709	523	74
Fluoride mg/L	Sand and Gravel	0.41	0.3	< 0.1	2.7	0.39	2016	403	20
	Sandstone	0.31	0.3	< 0.1	2.1	0.20	562	104	19
	Carbonate	1.38	1.4	< 0.1	3.2	0.57	685	13	2
Iron, Total ug/L	Sand and Gravel	1424.3	880.0	20.0	70000	2467.0	3479	614	18
	Sandstone	1617.8	437.0	< 50.0	36500	12716.8	731	134	18
	Carbonate	1230.8	710.0	< 40.0	96700	3427.8	1042	117	11
Lead, Total ug/L	Sand and Gravel	4.36	2.0	< 1.0	785	38.04	3086	2749	89
	Sandstone	2.43	2.0	< 2.0	40	2.45	681	609	89
	Carbonate	2.90	2.0	< 2.0	167	7.01	910	781	86
Manganese, Total ug/L	Sand and Gravel	226.4	117.0	<10.0	10880	486.6	3221	449	14
	Sandstone	205.8	84.5	<10.0	1910	316.2	699	108	15
	Carbonate	30.0	17.0	<10.0	300	30.8	959	296	31
Nickel, Total ug/L	Sand and Gravel	40.1	40.0	< 1.0	269	5.3	2173	2161	99
	Sandstone	41.1	40.0	<20.0	144	8.9	611	595	97
	Carbonate	40.2	40.0	< 20.0	97	3.0	711	707	99
Selenium, Total ug/L	Sand and Gravel	2.02	2.0	< 2.0	7	0.20	2310	2233	97
	Sandstone	2.00	2.0	< 2.0	3	0.04	643	638	99
	Carbonate	2.05	2.0	< 2.0	7	0.38	706	676	96
Strontium, Total ug/L	Sand and Gravel	1904.7	396.0	< 30.0	30800	4114.3	2164	8	0
	Sandstone	530.0	360.0	< 30.0	7480	690.0	597	5	1
	Carbonate	17870.7	16000.0	< 30.0	66200	12381.1	715	7	1

Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Censored
Tritium T.U.	Sand and Gravel	9.6	10.1	< 0.8	42	5.5	106	8	8
	Sandstone	8.4	8.5	< 0.8	22	6.0	28	7	25
	Carbonate	3.9	1.3	< 0.8	13	4.0	40	16	40
Zinc, Total ug/L	Sand and Gravel	34.2	10.0	< 6.0	6300	207.6	2291	1502	66
	Sandstone	31.4	12.0	< 10.0	1600	76.5	636	288	45
	Carbonate	63.8	11.0	< 10.0	2420	194.3	711	325	46
NUTRIENTS									
Parameter and Units	**Major Aquifer**	**Mean Value**	**Median Value**	**Minimum Value**	**Maximum Value**	**Standard Deviation**	**Number of Samples**	**Number Below Rep. Limit**	**Percent Censored**
Ammonia-N mg/L	Sand and Gravel	0.26	0.08	< 0.01	42.0	0.87	3415	1296	38
	Sandstone	0.87	0.18	< 0.05	2.6	11.27	721	204	28
	Carbonate	0.39	0.34	< 0.05	5.1	0.39	1028	118	11
Chemical Oxygen Demand mg/L	Sand and Gravel	11.3	10.0	< 10.0	572	12.9	3320	2876	87
	Sandstone	10.9	10.0	< 4.0	227	9.1	708	632	89
	Carbonate	12.1	10.0	< 4.0	371	13.9	1034	833	81
NO2+NO3 as N mg/L	Sand and Gravel	0.87	0.10	< 0.10	11.1	11.6	3467	1875	54
	Sandstone	0.37	0.10	< 0.10	19.1	1.1	739	532	72
	Carbonate	0.79	0.10	< 0.10	15.1	20.1	1037	896	86
Phosphorus, Total mg/L	Sand and Gravel	0.10	0.05	< 0.01	17.3	0.55	2692	2017	75
	Sandstone	0.10	0.05	< 0.01	4.4	0.28	599	363	61
	Carbonate	0.07	0.05	< 0.01	2.0	0.15	825	605	73
Total Kjeldahl N mg/L	Sand and Gravel	0.38	0.24	< 0.2	3.6	0.40	1274	546	43
	Sandstone	0.72	0.33	< 0.2	2.8	3.66	384	124	32
	Carbonate	0.55	0.46	0.1	5.3	0.49	459	78	17
Total Organic Carbon mg/L	Sand and Gravel	3.0	2.0	< 0.5	75	3.9	2438	1966	81
	Sandstone	2.6	2.0	< 1.0	57	3.0	634	539	85
	Carbonate	2.8	2.0	< 1.0	73	4.4	763	614	80

‡ records with '<' represent reporting limit

* Current reporting limits are listed in Table 1; generally, the minimum values are current or historical reporting limits.

§ na denotes not applicable

Use of Primary and Secondary MCLs

Maximum Contaminant Level (MCL) are regulatory standards for permissible concentrations of parameters in drinking water delivered to the public. Secondary Maximum Contaminants (SMCL) are advisory limits which are applied strictly to treated water at public water systems for aesthetic water quality issues, such as taste and odor. Since AGWMP data are obtained entirely from raw (untreated) ground water, which is unregulated, any exceedence of an MCL or SMCL by an AGWMP data point has no legal or regulatory consequence for a PWS. However, since MCLs and SMCLs are widely known, they represent a practical benchmark for discussion purposes. The MCLs and SMCLs are included in Table 1.

Eight of the primary parameters for which drinking water standards (MCLs) exist are monitored in raw water through the AGWMP. The MCLs for these parameters are: arsenic (50 ug/L, lowered to 10 ug/L effective January 2006), barium (2 mg/L), cadmium (5 ug/L), chromium (100 ug/L), fluoride (4 mg/L), nickel (0.1 mg/L), nitrate-nitrite as N (10 mg/L), and selenium (50 ug/L). Additionally, action levels (not MCLs) for both lead (0.015 mg/L) and copper (1.3 mg/L) are monitored by the drinking water program.

As indicated by the Ambient Ground Water Quality Table, no chemical parameters exceed a MCL based on averages by aquifer type. Mean arsenic concentrations for all three aquifer systems were well below both the old MCL of 50 ug/L and the new MCL of 10 ug/L (sand and gravel = 5.79 ug/L, sandstone = 3.13 ug/L, carbonate = 4.01 ug/L). Only a single (sand and gravel) well recorded a mean arsenic concentration above 50 mg/L. The new arsenic MCL (10 ug/L), effective 1/1/2006, raises concerns for those public water systems close to and above the new standard, or those that exhibit a wide range of values. A summary of the arsenic geochemistry and distribution in Ohio was provided in the 2002 305(b) Report (http://www.epa.state.oh.us/ddagw/pdu/gw_305b.html). Mean concentrations for barium, cadmium, chromium, fluoride, nickel, nitrate-nitrite, and selenium were also below the associated MCLs for these parameters within all three aquifer systems. Individual station means indicate no primary MCL exceedences for barium, cadmium, chromium, fluoride, and selenium.

In addition to the eight primary drinking water standards, nine parameters with established SMCLs are monitored by the AGWMP. Elevated levels of these parameters are associated with aesthetic degradation of water quality. The SMCL parameters monitored in this program are: aluminum (0.05 - 0.2 mg/L), chloride (250 mg/L), fluoride (2.0 mg/L), iron (0.3 mg/L), manganese (0.05 mg/L), pH (7-10.5 SU), sulfate (250 mg/L), total dissolved solids (TDS, 500 mg/L), and zinc (5 mg/L). Since these parameters are more closely related to general ground water quality, they will be discussed in the aquifer type sections below.

Nitrate as Proxy for Redox State

The oxidation-reduction (redox) sensitivity of ground water chemistry can be observed by the influence these changes have on the redox sensitive parameters. Redox sensitive parameters exist as redox "couples", or paired species, whose concentrations reflect their reaction to changes in existing oxidation-reduction (and sometimes pH) conditions. The main effect of a redox reaction is to change the valence of the element in question, thus transforming it into its "pair". These transformations are sometimes slow, and may require a catalyst such as microbial mediation to facilitate or complete the process. Common ground water parameters with redox pairs are nitrate [NO_3/N_2], arsenic [As(III)/As(V)], iron [Fe(II), Fe(III)], and manganese [Mn(II), Mn(III), Mn(IV)]. In general, a high ground water redox potential equates to well-aerated environmental conditions and a low redox potential reflects reduced or anaerobic conditions. Consider also that these two redox extremes exists as a continuum, and not as a sharp ground water facies boundary. In an oxidized ground water environment, as it changes to fully reducing conditions, generally has a transitional zone which grades to mildly oxidizing and then mildly reducing conditions.

As ground water conditions change from oxidized to reduced conditions, sequential and predictable changes in redox sensitive parameters are observed. These changes are controlled by energy requirements needed to modify the compound or elements' valence. For common ground water redox pairs, the oxidation of organic matter occurs concurrent with sequential reduction of the following parameters: 1) dissolved oxygen (O_2); 2) nitrate; 3) manganese oxides; 4) iron oxides; 5) sulfate; and finally 6) methane (rare in near-surface ground water). Because the ordering of these transformations is well established, we can apply this sequence to observed data, and make predictions and estimates for parallel changes in other parameters.

Within the AGWMP, we use nitrate (NO_3 as N) as a "proxy" (an indirect indicator) for redox state since the behavior of nitrate is fairly consistent under given redox conditions. As a proxy for redox conditions, elevated values of nitrate (NO_3 as N) indicate the dominance of oxidizing conditions within the formation at the time of sampling. Nitrate is quite stable in these aerobic ground waters, as evidenced by the fact that it is a persistent contaminant under near surface conditions. In contrast, nitrate is inherently unstable under reducing conditions, in which denitrification reactions ultimately reduce the nitrate nitrogen to N_2 gas.

Nitrate ground water concentrations greater that 2.0 mg/L are interpreted as clear evidence of impact from surface land use activities, and are associated with well-aerated environmental conditions. The criterion of 2.0 mg/L is based on USGS reports citing nitrate background levels in Ohio as being less than 2.0 mg/L, and is used in the Source Water Assessment and Protection Program (SWAP) Susceptibility Analysis. In order to illustrate this point using AGWMP data, a subset of data representing nitrate impacted sites (mean nitrate > 2.0 mg/L) which likely represent oxidized ground water, was extracted into Table 4. This table is constructed to parallel Table 3, and shows the mean, median, minimum, maximum, and other data for this oxidized subset of ground water. The goal of this subset is to highlight the sensitivity of selected parameters to changes in redox conditions within the given aquifer system. The expectation for this table is that differences between oxidized and reduced conditions will be most obvious in arsenic, iron, manganese, and nitrate concentrations. The association of As and Fe with the parent iron hydroxide compounds, which are are insoluble under oxidizing conditions, defines the geochemical control. The solubility of major elements (Ca, Mg, Cl, Na, etc.) tend to be insensitive to redox changes.

Ground water data for which the mean nitrate concentration exceeds 2.0 mg/L are presented in Table 4, and thus represent data from oxidized environments. We can now compare the data in Table 4 to those in Table 3 to observe geochemical changes which represent different underlying redox conditions. Lower mean and median values for ammonia are expected in Table 4 compared to Table 3 since ammonia is a more reduced form of nitrogen. The arsenic, iron, and manganese means and medians of Table 4 are significantly lower than those in Table 3, also as expected. Arsenic is at or very close to its reporting limit in the oxidizing conditions represented in Table 4. Iron and manganese values are also greatly lowered in Table 4 as compared to Table 3, in spite of their more erratic geochemical behavior. In contrast, the solubility of the major elements appear insensitive to redox changes, for example hardness and TDS display little change in mean or median values between the tables.

Table 4 records ground water samples from predominantly sand and gravel aquifers; that is, these are the geologic settings most likely to be impacted by dissolved constituents with a surface water souce, such as nitrate. Of the 29 wells in Table 4 which show elevated nitrate impact, 24 (82%) are sand and gravel sites, three (10%) are sandstone sites, and two (7%) are wells penetrating carbonate aquifers. These proportions are close those for the whole Ambient network, whether impacted or not (66%, 15%, and 16% for sand and gravel, sandstone, and carbonate settings, respectively). But the percentage of sand and gravel wells with

elevated nitrates is clearly higher than those in bedrock. This suggests that based on the nitrate evidence, the sand and gravel settings are more likely to be impacted by dissolved surface water contaminants than are bedrock settings. The following chapter on sensitive aquifers develops this relationship in greater detail.

That we can observe such differences in geochemistry is quite remarkable, considering that these data are collected as independent samples. Consequently, the concentrations of selected parameters in a well can be used effectively to infer geochemical redox conditions in individual wells.

Table 4
AGWMP Data Summary of Selected Parameters Under Oxidized Conditions
Data from wells with elevated nitrate (>2.0 mg/L) only. §

Parameter and Units	Major Aquifer	Mean Value	Median Value	Min. Value	Max. Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Censored
Ammonia mg/L	Sand and Gravel	0.064	<0.050	<0.050	0.310	0.053	405	357	88
	Sandstone	0.050	<0.050	<0.050	0.051	0.001	21	19	91
	Carbonate	0.054	0.054	<0.050	0.058	0.005	8	7	88
Arsenic, Total ug/L	Sand and Gravel	2.1	<2.0	<2.0	6.0	0.45	398	389	98
	Sandstone	<2.0	<2.0	<2.0	<2.0	0.00	19	19	100
	Carbonate	<2.0	<2.0	<2.0	<2.0	0.00	8	8	100
Hardness mg/L	Sand and Gravel	351	352	10.0	846	77.90	352	1	0
	Sandstone	227	198	174	214	12.00	19	0	0
	Carbonate	439	438	411	469	32.60	4	0	0
Iron, Total ug/L	Sand and Gravel	245	50.0	30.0	29700	1528.0	419	261	62
	Sandstone	346	82.0	50.0	330	85.6	20	6	30
	Carbonate	113	54.5	50.0	500	161.0	8	4	50
Manganese, Total ug/L	Sand and Gravel	85.4	42.0	<10.0	1970	146.0	393	172	44
	Sandstone	80.6	<10.0	<10.0	220	47.9	21	13	62
	Carbonate	16.1	<10.0	<10.0	44.1	14.0	6	4	67
NO2+NO3 as N mg/L	Sand and Gravel	3.35	2.74	<0.01	11.1	1.64	410	14	4
	Sandstone	5.65	3.80	2.18	11.4	1.91	21	0	0
	Carbonate	5.34	4.03	0.84	15.1	4.33	8	0	0
Total Dissolved Solids mg/L	Sand and Gravel	438	426	154	1110	3.4	420	0	0
	Sandstone	442	294	252	780	18.9	21	0	0
	Carbonate	574	544	515	674	78.5	6	0	0

§ 29 wells total: 24 sand and gravel, 3 sandstone, 2 carbonate

General Water Types

Based on major ion composition, the three general water types encountered in Ohio's major aquifers are a calcium-bicarbonate type in the sand and gravel aquifers, a calcium-sodium-bicarbonate type in the sandstone aquifers, and a calcium-bicarbonate-sulfate type in the carbonate aquifers. This information is displayed graphically in Figure 5, in which the mean major ion composition of the three aquifer systems are subdivided and compared. While all three water types are based on the calcium-bicarbonate model, the

sandstone aquifer waters exhibit the highest percentage of sodium and chloride. The carbonate ground waters have the highest bicarbonate, calcium, magnesium, and sulfate ion concentrations. Also notable is the fact that the carbonate waters have the highest mean ionic strength of the three aquifer types which correlates with the longer residence time within the carbonate system , the higher solubility of carbonate rocks, and the presence of evaporates. The lower total dissolved solids (TDS) of the sandstone aquifers is attributed to the higher silica sand and lower carbonate rock content in the sandstones. These same data are presented on a Piper diagram in Figure 6. The Piper diagram provides a summary of cation data (left triangle), anion data (right triangle) and composite data (center diamond) to visually distinguish waters of different chemistries and origin.

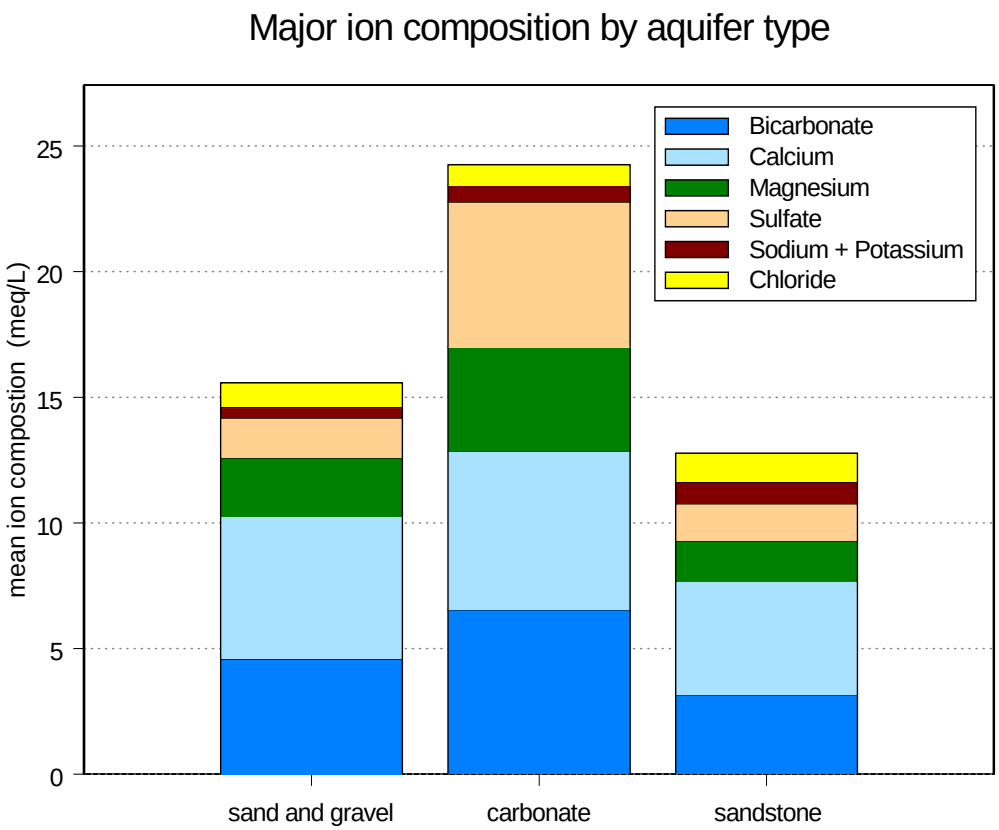


Figure 5. Mean major ion composition of the three aquifer systems.

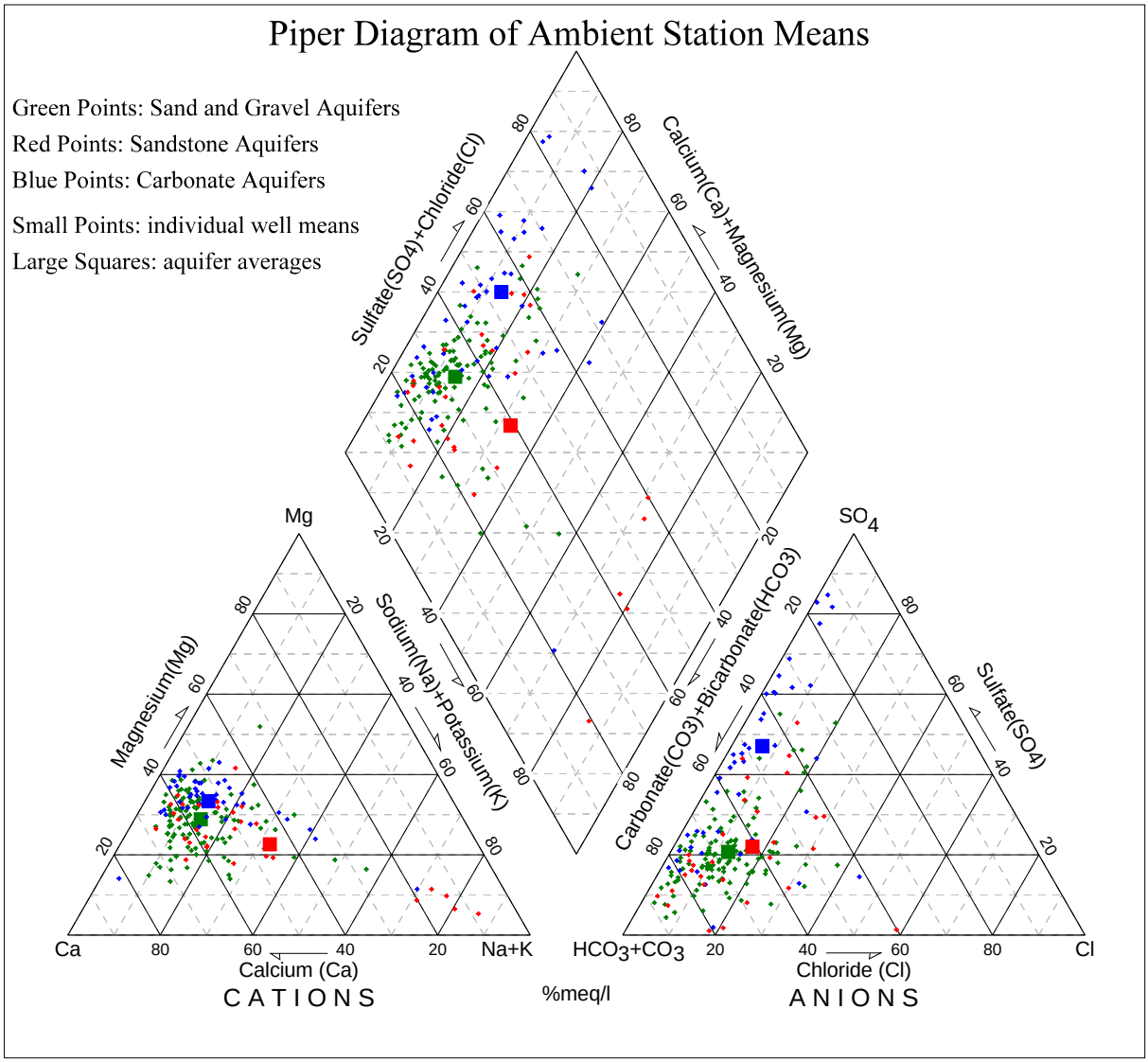


Figure 6. Piper diagram of individual data points and aquifer means for AGWMP wells.

The carbonate ground waters in Figure 6 (blue points) trend toward a more sulfate-rich composition (upper apex of lower right triangle), reflecting the dissolution of celestite ($SrSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$) associated with marine evaporates in the Salina Formation and deposition from hydrothermal fluids. These waters display a wide range of alkalinity concentrations. The overlap between the carbonate and sand and gravel aquifer water chemistries (green points) is due to the fact that much of the aquifer material in the unconsolidated (sand and gravel) units is actually eroded from carbonate bedrock. The sandstone water chemistry (red points) reveals a higher mean sodium, potassium, and chloride content than the other two systems, indicating a probable natural source for these ions, apparently from dissolution of simple salts or matrix cements.

Major Aquifer Types

Ohio has abundant surface and ground water resources. Average rainfall ranges between 30 to 44 inches a year (increasing from northwest to southeast), which drives healthy stream flows, except in prolonged periods of drought. Infiltration of a small portion of this rainfall recharges (3-10 inches) the states aquifers and keeps the streams flowing between rains. Ohio's aquifers can be divided into three major types of productive aquifers which are present throughout most of the state. Nevertheless, there are significant areas of the state where local aquifers exhibit limited ground water production potential. The three major, productive aquifers are illustrated in Figure 7. The sand and gravel valley aquifers (in blue) are distributed through the state. The valleys these sands fill are cut into sandstone and shale in the eastern half of the state (in tan) and into carbonate aquifers (in greens) in the western half of the state. The sandstone and carbonate aquifers generally provide sufficient production for water well except where dominated by shale, as in southwest Ohio.

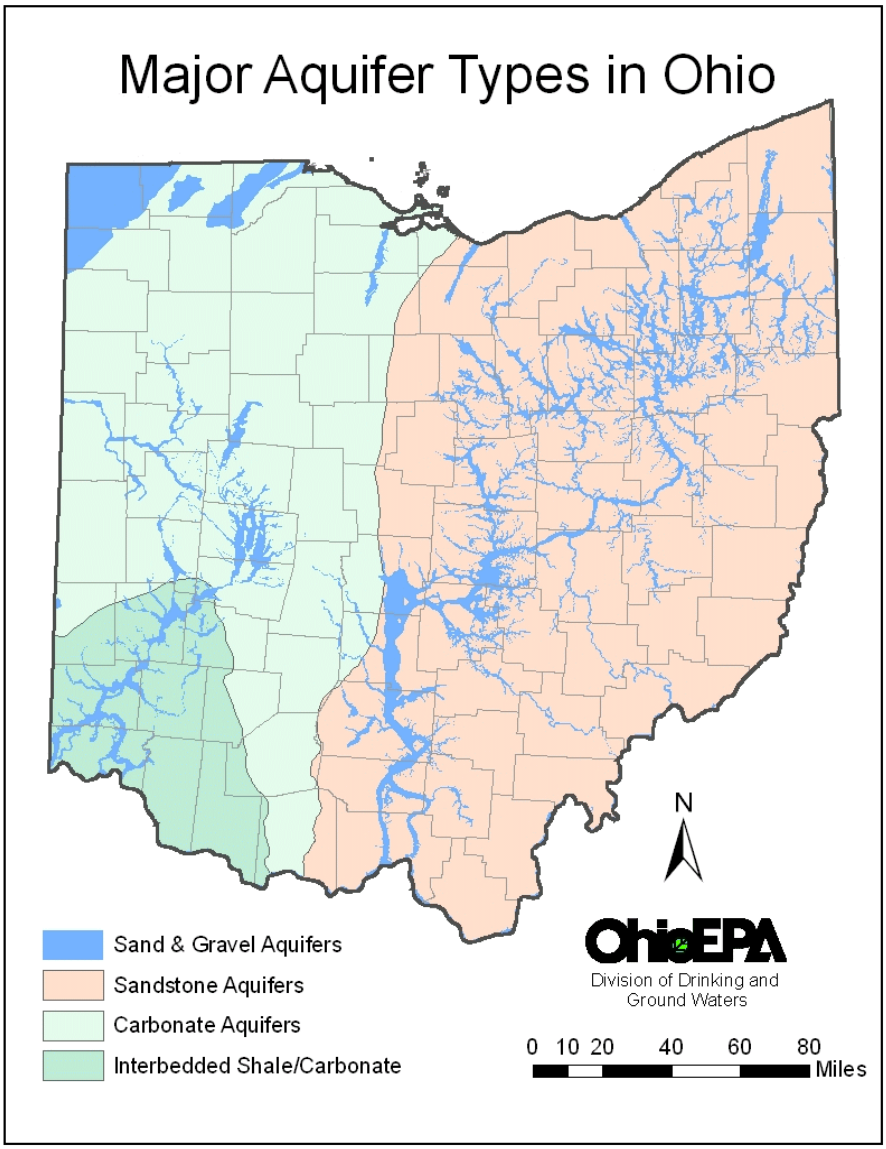


Figure 7. Aquifer Types in Ohio, modified from ODNR Aquifer Map (ODNR, 2000)

The following sections discuss the geologic setting of each major aquifer type, the water quality exhibited by each type, and the relationships between the major aquifer types, utilizing the data summarized in the Ambient Ground Water Table, Table 3. Several of the graphic relationships presented here are repeated from previous 305(b) reports because they clearly present distinctions between water quality of the major aquifers. The reader is referred to previous reports for additional graphic representations of aquifer water quality relationships. Water quality for the major aquifers is discussed in stratigraphic order starting with the youngest aquifers.

Sand and Gravel Aquifers - Ground Water Quality

The unconsolidated sand and gravel units, typically associated with buried valley aquifer systems are Ohio's most productive water bearing formations or aquifers. These valleys were cut into the bedrock by pre-glacial and glacial streams and subsequently the valleys were filled with deposits of sand, gravel, and till by alluvial and glacial processes as the glaciers advanced and receded. Buried valley aquifers are found beneath and adjacent to the Ohio River, its major tributaries, and other pre-glacial stream channels such as the Teays River. The distribution of these Quaternary sand and gravel units is presented in a generalized manner as thin bands of blue in Figure 7, from the ODNR Glacial Aquifer Maps (ODNR, 2000). The Glacial Aquifer Maps provide details on the distribution of sand and gravel deposited by glacial and alluvial processes. Although generally referred to as buried valley aquifers, this is not an accurate description of all the sand and gravel deposits that provide water to Ohio wells. For instance, in the northwest corner of the state, the triangular area of sand and gravel units (Figure 7) includes sheets of outwash or sand and gravel deposits that occur between sheets of glacial till. Present day stream processes deposit alluvial sand and gravel deposits that also serve as aquifers. Other hydrogeologic settings included in the sand and gravel aquifers are the outwash/kame and beach ridge deposits, including the Oak Opening Sands (patches of sand and gravel in northwest Ohio, Figure 7).

Water production from the coarser grained and thicker sand and gravel deposits ranges from 500 to 1,000 gallons per minute. Lower yields from sand and gravel aquifers are more common. The production rate depends on the type, distribution, permeability, and thickness of permeable glacial/alluvial deposits as well as on well construction parameters, such as well diameter and length of well screen.

The AGWMP database for the unconsolidated sand and gravel aquifers consists of about 3,500 inorganic ground water samples from 217 sites. This water chemistry is summarized in Table 3. The ground water from the sand and gravel aquifers is characterized by relatively low TDS, zinc, fluoride, and sulfate. These aquifers are geochemically related to the carbonate bedrock aquifers since the clastic material making up the buried valleys can be dominated by carbonate rock debris transported by glacial meltwater. This similarity is reflected in their ground water chemistries; for example, the sand and gravel aquifer waters plot closely to the carbonate waters on the cation triangle (lower left triangle) of Figure 6. In the anion triangle of Figure 6, however, the carbonates are heavily influenced by the high sulfate concentrations. In Figure 8 the distribution of the total dissolved solids data (all data points, not just the means) is illustrated in a box plot for each of the aquifer types. The TDS concentrations of the sand and gravel aquifers (median 450 mg/L) are intermediate between the carbonate (median 678 mg/L) and sandstone (median 338 mg/L) aquifers. This relationship is illustrated in the median values in Figure 8 as well as the mean values for TDS in the Ambient Ground Water Quality Table (Table 3).

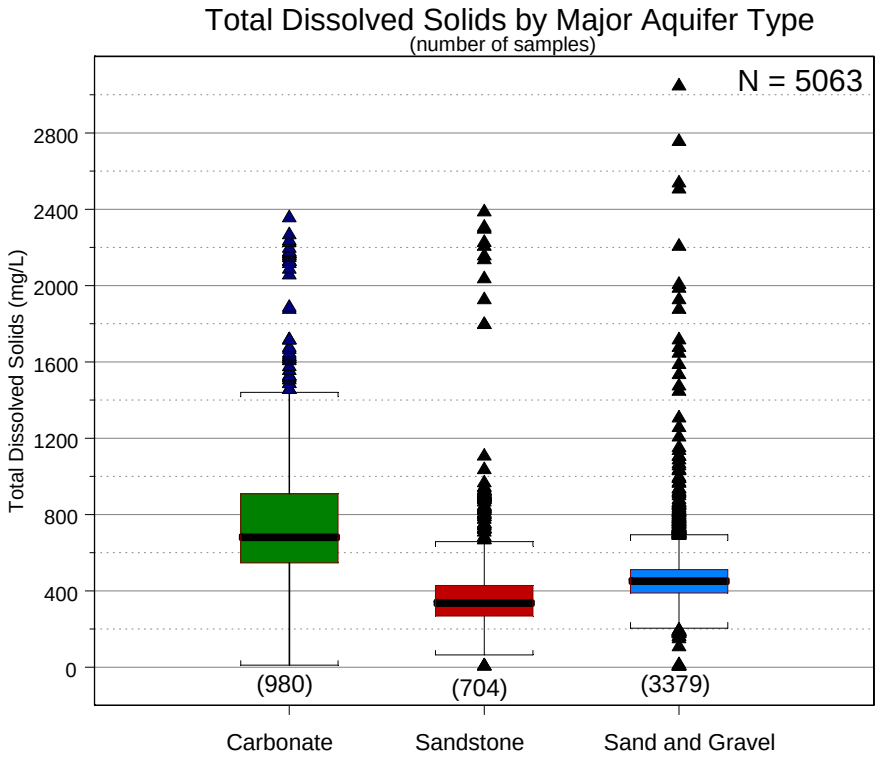


Figure 8. Box plot of total dissolved solids for AGWMP data.

Other parameters for which the sand and gravel water quality concentrations exhibit intermediate values between the carbonate and sandstone aquifer waters include alkalinity, calcium, magnesium, hardness, fluoride, and strontium. This is a consequence of the glacial origins of the sand and gravel aquifers. Glacial erosion, transport, and deposition produces mixtures of local bedrock with rocks transported from greater distances, so the material that filled the glacial valleys generally includes a mixture of rock types, including carbonate and sandstone bedrock debris from Ohio, as well as debris transported from areas of the Canadian shield. Consequently, water quality characteristics of water produced from these aquifers of mixed rock lithologies exhibit intermediate characteristics.

Sandstone Bedrock Aquifers - Ground Water Quality

In the eastern half of Ohio, where buried valley aquifers are not present, Mississippian and Pennsylvanian sandstone units are the dominant bedrock aquifers (Figure 7). Upper Paleozoic siltstone, sandstone, and conglomerate formations (Mississippian to Permian age) in eastern Ohio occur as numerous layers of siltstone and sandstone of variable thickness and areal extent separated by layers of shale and minor amounts of limestone, clay and coal. The sandstone units generally dip a few degrees to the southeast. Some of the thicker sandstones and conglomerates are capable of yielding 50 to 100 gallons per minute to individual wells, but 25 gallons a minute is generally a good yield for the sandstone aquifers. The more productive stratigraphic units include:

- Pennsylvanian Sharon through Massillon Formations, and the Homewood Sandstone within the Pottsville and Allegheny Groups - These sandstones were deposited on the stable coastal plain under conditions of rising sea level. These aquifers are most commonly used in the northern areas of Eastern Ohio. To the southeast, farther into the Appalachian Basin, these units are generally too saline for drinking water production.
- Mississippian Berea Sandstone, Cuyahoga Group, Logan and Blackhand Formations - These siltstones and sandstones with minor conglomerate were sorted and deposited in deltaic complexes from material eroded from the Acadian Mountains (Late Devonian uplift) to the east. These units extend to the SE, farther into the Appalachian Basin, but the water quality becomes too saline for drinking water use.

In southeastern Ohio, Upper Pennsylvanian and Permian stratigraphic section includes low yielding aquifers. The bedrock consists of varied sequences of thin bedded shales, limestones, sandstones, clays, and coals of the Pennsylvania Allegheny, Pottsville, Conemaugh and Monongahela Groups and the Permian Dunkard Group. Yields below 5 gallons per minute is common in these areas (ODNR, 2002) .
The Ambient Ground Water Quality database for this aquifer contains about 740 samples from 55 sites, whose mean water chemistries are presented in Table 3. These waters are characterized by low bicarbonate alkalinity. A significant trend for some sandstone waters is increasing chloride and sodium composition shown in Figure 6 (Piper Diagram). This suggests that these waters may have long residence times, and/or may represent mixing with saline sodium-chloride type water from bedrock shales or with deeper formation waters. The distribution of sodium data is illustrated in box plots for each of the aquifer types in Figure 9 (log scale for vertical axis). The elevated sodium in the sandstone aquifers is clearly illustrated. Although the median sodium value for the sandstone and carbonate aquifers are similar (26-28 mg/L), the mean value for the sandstones is 59.7 mg/L versus 36.8 mg/L for the carbonates. This higher sandstone mean is explained by numerous elevated values in the more strongly asymmetric sodium distribution for the sandstone aquifers. Most of the higher sodium concentrations are associated with deeper wells, supporting the postulated influence of deeper formation waters or longer residence time.

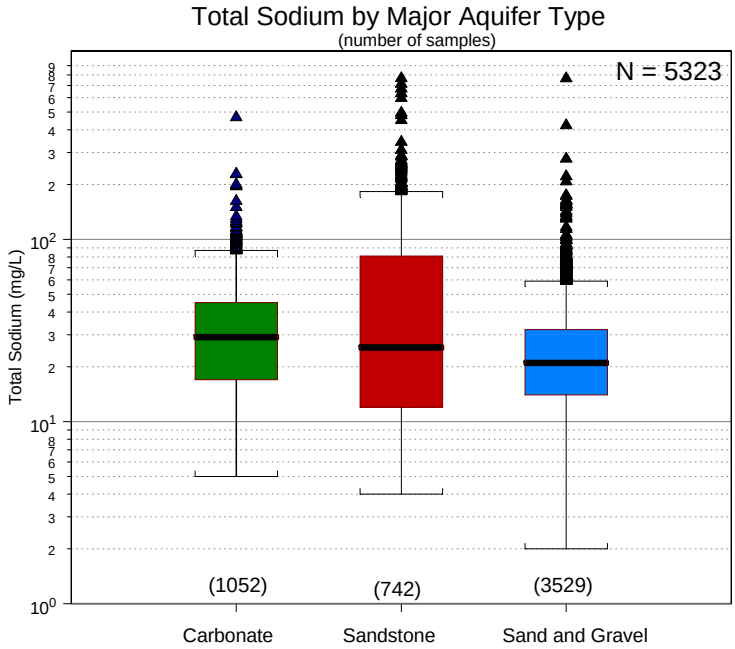


Figure 9. Box plot of sodium for AGWMP data.

Carbonate Bedrock Aquifer - Ground Water Quality

Ohio's third major aquifer type is carbonate bedrock, the dominant aquifer in the western part of the state (Figure 7). Middle Devonian and Silurian limestones and dolomites reach a total thickness of 300 to 600 feet, and are capable of yielding from 100 to over 500 gallons of water per minute. Higher production units are associated with fractures and dissolution features that increase the permeability of the carbonate bedrock. The high production aquifers are fractured or karst Silurian Lockport/sub-Lockport Dolomite, the Salina Group, consisting of the Tymochtee and Greenfield Dolomites, and the Undifferentiated Salina Dolomite. The Devonian Delaware and Columbus Limestone, exposed along the eastern edge of the Silurian Dolomites, and equivalent Devonian units in the northwest corner of Ohio (Traverse Group, Dundee Limestone, and Detroit River Group) are also productive carbonate aquifers. These carbonates were generally deposited in warm, shallow seas with limited input of sediment from continental sources.

The southwestern portion of the state is underlain by interbedded lower Ordovician carbonates and shales. These units (undivided Ordovician) are dominated by shale (Figure 7) and consequently, well yields are generally less than 10 gallons per minute, and in many areas are less than one gallon per minute. In southwest Ohio, public water systems depend on the buried valley aquifers as the main ground water source. The low yielding aquifers are only practical for low volume water users, and consequently, this aquifer is not discussed further in this report. Another area with low yields is the Devonian shales that overlie the Columbus and Delaware Limestone aquifers. The narrow north-south trending area of the **Devonian Shales** in central Ohio curves eastward along the Lake Erie shoreline. These shales are also poor aquifers yielding less than 5 gallons per minute and hydrogen sulfide tends to be present causing water quality problems.

The Ambient Ground Water Quality database for the carbonate system consists of about 1050 samples from 68 sites. Most ground water in the carbonate bedrock is of the calcium-bicarbonate-sulfate type, as depicted in the Piper diagram (Figure 6), and is slightly alkaline in pH. This aquifer type exhibits the greatest mean concentrations for calcium, magnesium, sulfate, TDS, alkalinity, strontium, hardness, and conductivity of the three aquifer types. Mean hardness (540 mg/L) is at levels which typically require treatment to remove calcium and magnesium in the finished water. The mean concentrations of TDS (771 mg/L), iron (1230 ug/L), and sulfate (285 mg/L) are all above their respective SMCLs (500 mg/L, 0.3mg/L, and 250 mg/L). About 40 percent of the individual samples from carbonate aquifers exceed the SMCL for sulfate (250 mg/L). Mean fluoride is highest in the carbonate system (1.38 mg/L) and is probably controlled by the dissolution of fluorine bearing minerals such as apatite and fluorite. Generally, the high solubility of calcite and dolomite in the carbonate bedrock results in routine ground water quality that exceeds secondary drinking water standards.

The elevated concentrations in the carbonate system relative to the other major aquifers are related to longer residence times within the system, and the relatively high solubilities of minerals in the carbonate bedrock. Figure 10 illustrates the relationship between sulfate and hardness (sum of the ions Ca and Mg) by aquifer type for about 3,800 samples. The higher concentrations of hardness and sulfate in the carbonate aquifers, clearly illustrated in Figure 10, are associated with wells in Silurian Salina Formation which includes soluble marine evaporates (anhydrite, $CaSO_4$, and Gypsum, $CaSO_4 \cdot H_2O$). The intermediate water quality chemistry of the sand and gravel aquifer (between the sandstone and carbonate aquifer values) is also exhibited in Figure 10. The cluster of 9 to 10 elevated sulfate values for the sandstone aquifer (1,000 mg/L range) are from a well completed in an area that was reclaimed surface mining for coal and are clearly anomalous for sandstone aquifers.

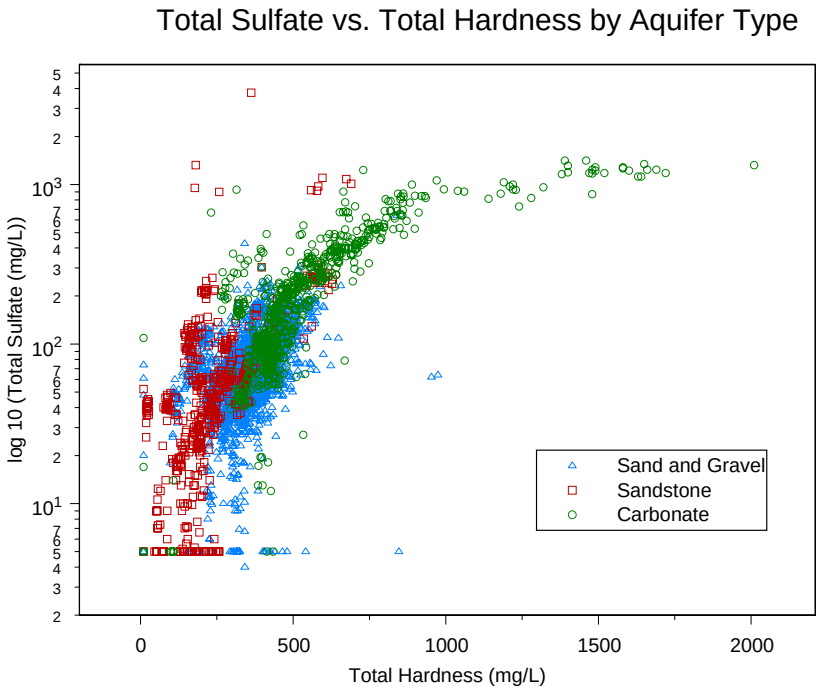


Figure 10. Hardness vs. Sulfate for AGWMP data.

The geographic distribution of mean total dissolved solids (TDS) for AGWMP wells is presented in Figure 11 with the major aquifers as the base map. TDS is one of the better single parameters to illustrate distinct water quality differences between bedrock aquifers in Ohio. The elevated TDS values associated with the carbonate aquifers in the western half of Ohio compared to lower TDS concentrations in the eastern sandstone aquifers is evident in Figure 11. The TDS concentrations in the sand and gravel aquifers generally appear similar to the sandstone aquifers. The box plots of TDS (Figure 8) illustrates that the median TDS concentration in the sand and gravel aquifers is a bit higher than the median TDS in sandstone aquifers (450 vs. 338 mg/L), but generally TDS exhibits similar concentrations in the sand and gravel and sandstone aquifers (Table 3). The highest TDS values are located in the northern area of the carbonate aquifers, on the east and west flanks of the Findlay Arch, where wells penetrate the Salina Formation and their associated marine evaporates.

The TDS relationships to well depth and aquifer type are illustrated in Figure 12. All of the AGWMP TDS data are plotted. Horizontal data clusters (most obvious in areas of low data density) represent the range of TDS concentrations at individual wells. Figure 12 demonstrates the generally high TDS concentrations for the carbonate aquifers. In contrast, the sand and gravel aquifers generally exhibit significantly lower TDS values. The sandstone aquifers include several AGWMP wells with elevated TDS. The group of data points with the highest TSD values for a sandstone aquifer are from a well located in an area that has been reclaimed after surface coal mining, which exhibits significantly anomalous TDS, sulfate, and sodium. Overall, TDS concentrations in the sandstone aquifers are the lowest of the three major aquifer types. The shallower depths and intermediate TDS values of the sand and gravel aquifers are obvious in Figure 12.

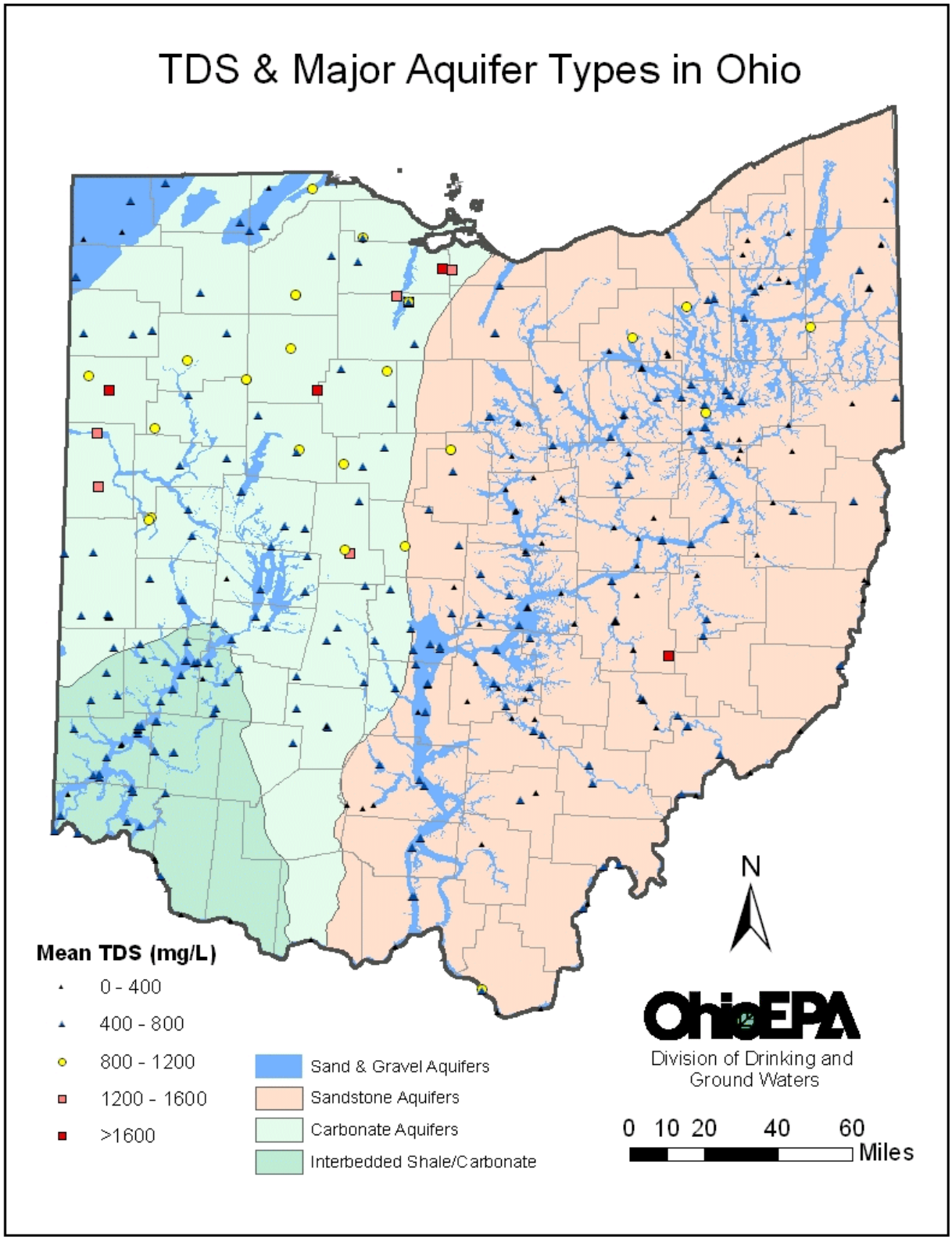


Figure 11. Geographic distribution of the mean TDS vales for AGWMP wells.

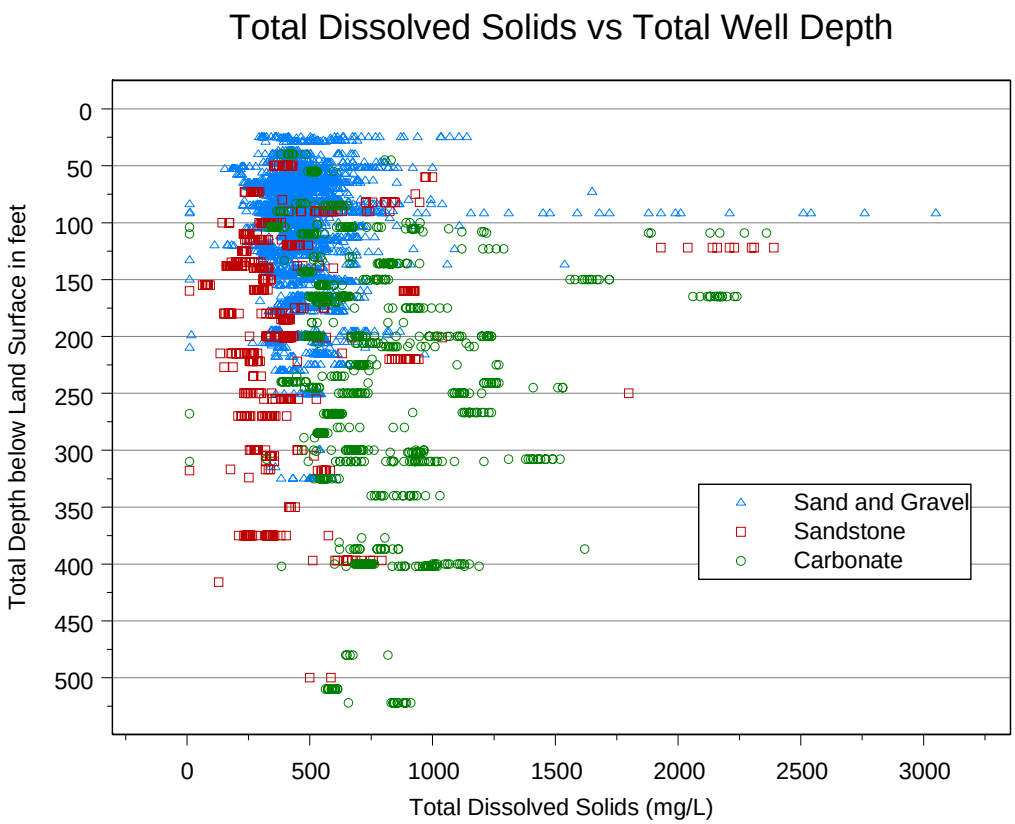


Figure 12. AGWMP TDS data relative to well depth and aquifer type.

These relationships are consistent with residence time and geology of the major aquifers. It is common for longer flow paths to correlate with a chemical evolution toward higher concentrations of total dissolved solids, and the greater depth of the carbonate wells correlates well with the longer flow paths/residence time. In addition, silica sand present in the sandstones is significantly less soluble than the calcite and dolomite in the carbonate aquifers, so calcium and magnesium concentrations would be expected to be relatively high in a carbonate aquifer. The presence of soluble evaporates (mostly gypsum) in the Salina Dolomite also contributes to the elevated sulfate concentrations in Upper Silurian carbonate aquifers. The sand and gravel aquifers are composed largely of glacial debris from eroded local bedrock with contributions from bedrock encountered up stream/up ice as far north as the Canadian shield. The geochemistry of water from the sand and gravel aquifers reflects the mixed lithology of the glacial debris. Consequently, the sand and gravel water quality tends to be intermediate between the sandstone and carbonate aquifers due to the mixed lithologies that include significant proportions of the local sandstone or carbonate bedrock as well as other lithologies.

Regional Water Quality Analysis - Buried Valley Aquifers

The AGWMP data for the major aquifers documents distinct differences between the three major aquifer types due to aquifer rock composition as discussed in the previous sections. Since sand and gravel aquifers include variable amounts of local bedrock debris, it is expected that the ground water quality of sand and gravel aquifers dominated by carbonate bedrock debris will be distinct from sand and gravel aquifers dominated by sandstone bedrock debris. Figure 13 illustrates the locations of three subsets of AGWMP wells associated with buried valley aquifers and their relationship to the bedrock aquifers. The buried valley systems, the Great Miami, Scioto, and Muskingum, from west to east, are expected to include mostly carbonate bedrock debris in the west with an increasing proportion of sandstone bedrock debris to the east. These buried valley aquifers will also include some glacial erratic material transported from the Canadian shield. Differences in buried valley bedrock debris should be reflected in regional ground water quality associated with buried valley systems. Variability in ground water quality may be associated with other factors as well, such as increased contamination loading down gradient, variation of road salt applications, or changes in water quality with longer residence times down gradient.

To test the hypothesis of ground water quality differences from west to east buried valleys, ground water quality in buried valley aquifers were evaluated by comparing means of selected ground water quality parameters for the AGWMP wells in the Great Miami, the Scioto, and the Muskingum buried valleys. Information on the wells used in this study is shown in Table 5. Generally, wells are deepest and exhibit more variability in well depth and casing length in the Great Miami River aquifer, followed by the Scioto River and Muskingum River aquifers.

Table 5

Information on Wells Used in the Water Quality Analysis of the

	Great Miami River	Scioto River	Muskingum River
Number of Wells	18	12	14
Well Depth (ft) - Average	142	87	62
Well Depth (ft) - Std. Dev.	57	34	12
Casing Depth (ft) - Average	83	54	44
Casing Depth (ft) - Std. Dev.	38	19	15

Great Miami, Scioto, and Muskingum Buried Valley Aquifers.

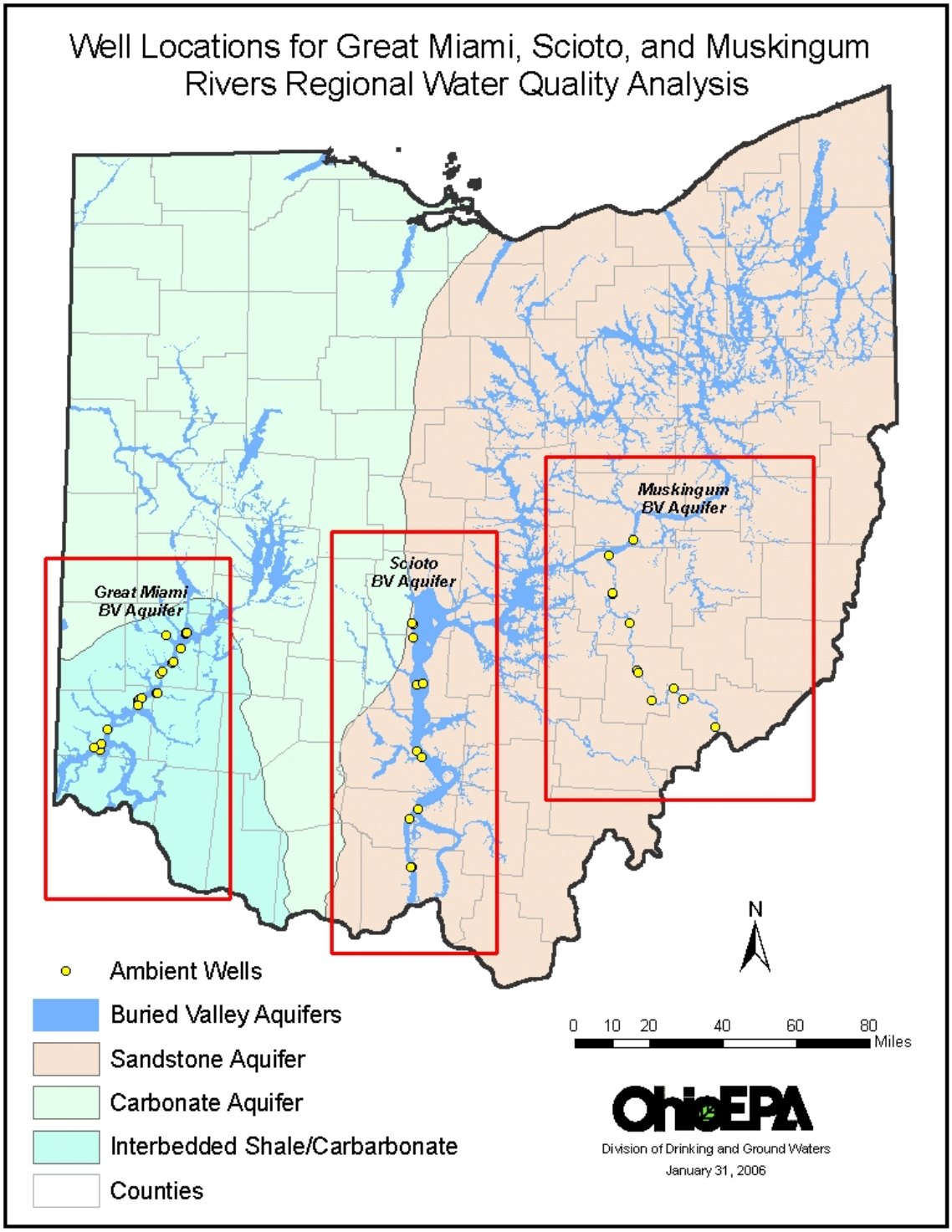


Figure 13. Locations of AGWMP wells used in the regional water quality analysis.

Means of ground water quality parameters from these buried valley aquifers, with variable mixtures of bedrock debris from west to east are presented in Table 6. The statewide means for the ground water quality parameters in sand and gravel aquifers (from Table 3) is included for comparison. The sand and gravel water quality means for individual buried valleys can also be compared to the major aquifer means presented in Table 3 to appraise similarities of ground water quality associated with sandstone and carbonate bedrock aquifers.

Table 6

Regional Ground Water Quality - Means of Selected Parameters for Buried Valleys Subgroups

All units mg/L	Alk	Ca	Mg	TDS	Sr	Cl	SO_4	Fl	Mn
Great Miami Buried Valley (22)	272	92	33	492	1.14	59	70	0.44	204
Scioto Buried Valley (14)	285	103	32	483	1.16	36	80	0.37	302
Muskingum Buried Valley (15)	212	96	21	463	0.26	55	91	0.25	526
Statewide Sand & Gravel Aquifers (217)	262	96	29	468	1.9	39	81	0.41	226

Number of sites in ( )

Several of the major parameters in Table 6 exhibit only limited differences between the buried valley aquifers from the west, believed to be dominated by carbonate rich debris, to the east, dominated by sandstone rich debris. Calcium is variable but the buried valley means cluster around the statewide sand and gravel mean of 95.5 mg/L (Tables 3 and 6) and do not appear to be strongly influenced by a significant decrease of carbonate debris from the western buried valleys to the eastern buried valley. This is also true for sulfate (sand and gravel mean of 81 mg/L) and TDS (sand and gravel mean of 468 mg/L). The lower alkalinity in the Muskingum buried valley (212 mg/L) appears to reflect influence of the sandstone bedrock (state mean of 216 mg/L) as compared to carbonate bedrock(state mean of 294 mg/L) which is similar to the Great Miami and Scioto buried valley values for alkalinity (272 and 285 mg/L respectively, Table 3).

Magnesium, strontium, and fluoride exhibit distinctly lower values in the Muskingum buried valley compared to the Great Miami or Scioto buried valleys. The statewide carbonate aquifers means for magnesium (50.8 mg/L), strontium (1.8 mg/L), and fluoride (1.38 mg/L) are significantly higher than the statewide means for the sand and gravel aquifers (Mg, 29 mg/L; Sr, 1.9 mg/L; and Fl_2, 0.41 mg/l respectively) or sandstone aquifers (Mg, 19.4 mg/L; Sr, 0.53 mg/L; and Fl_2, 0.31 mg/l respectively from Table 3). Consequently, the association of higher concentrations of magnesium, strontium, and fluoride in Table 6 associated with the Great Miami River and the Scioto River ground water quality as compared to the Muskingum River ground water quality, support the expected regional water quality trends predicted for buried valleys with high concentrations of carbonate debris. The fact that the Great Miami and Scioto buried valleys ground water quality demonstrate similar concentrations of magnesium, strontium, and fluoride suggests that they have similar carbonate concentrations in the aquifer material. Thus, the Scioto

buried valley aquifer does not appear to represent a geochemically intermediate buried valley aquifer relative to the Great Miami and Muskingum. The low concentrations of Mg, Sr, and Fl_2 in the ground water quality data of the Muskingum buried valley is consistent with a buried valley dominated with sandstone debris as suggested in Figure 13.

Another way to evaluate these buried valley data is to consider ground water quality variability down gradient. Since these buried valleys run generally in a north-south direction, plotting well data by latitude provides a proxy for down gradient positions in individual buried valleys. In Figure 14, well means for magnesium from these three buried valley aquifers are plotted against latitude, representing a flow direction from the top of the graph towards the bottom of the graph. The magnesium in the Muskingum buried valley ground water is low. In contrast, the magnesium in the Great Miami and Scioto buried valleys ground water is elevated by comparison and appears to decrease down valley. Robust regression lines are included in Figure 14 to document the trends. The reduced Mg concentrations in the ground water by latitude are interpreted to result from the presence of dolomite bedrock in the buried valley debris and the dilution of the dolomite by Ordovician shales in the Great Miami and Devonian and Mississippian shales and sandstones in the Scioto buried valley. The trends are subtle but the robust regression document the trends.

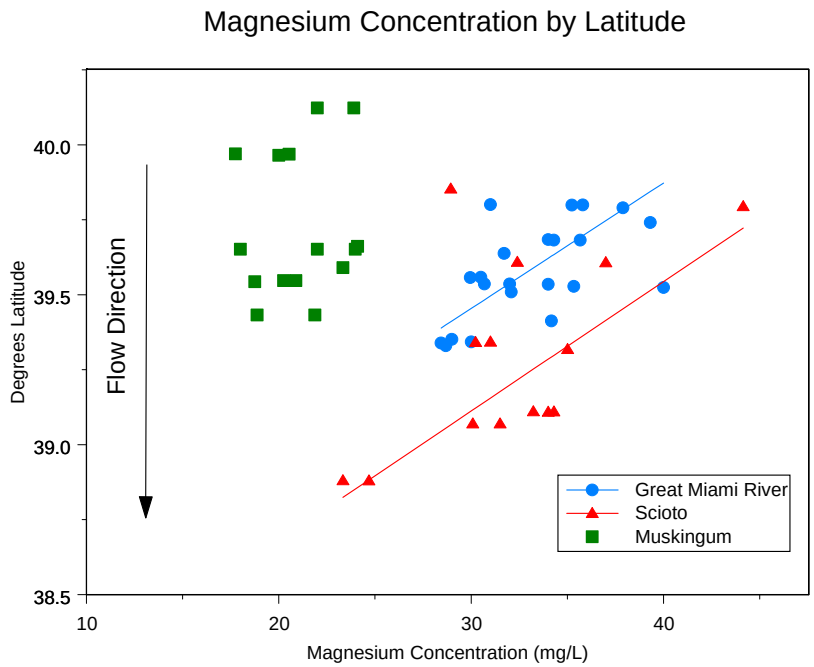


Figure 14. Magnesium Concentrations against latitude for buried valleys.

Strontium exhibits a distinct association with calcium due to the similarity of strontium and calcium chemistry, resulting in Sr replacing Ca in the calcium carbonate. The relationships between concentrations of mean strontium and latitude are presented in Figure 15, which exhibits similar relationships as shown for magnesium in Figure 14. Figure 15 illustrates that strontium concentrations in the ground water in the Great Miami and Scioto buried valleys are elevated in comparison to the Muskingum ground water as

indicated in Table 6. In addition, Figure 15 illustrates that the more northerly (up graident, higher latitude) locations in the Great Miami and Scioto buried valleys generally exhibit the higher concentrations of strontium. This variation with latitude contrasts with the Muskingum data which exhibits little to no variation down gradient as represented by latitude. In Ohio the areas of elevated strontium are associated

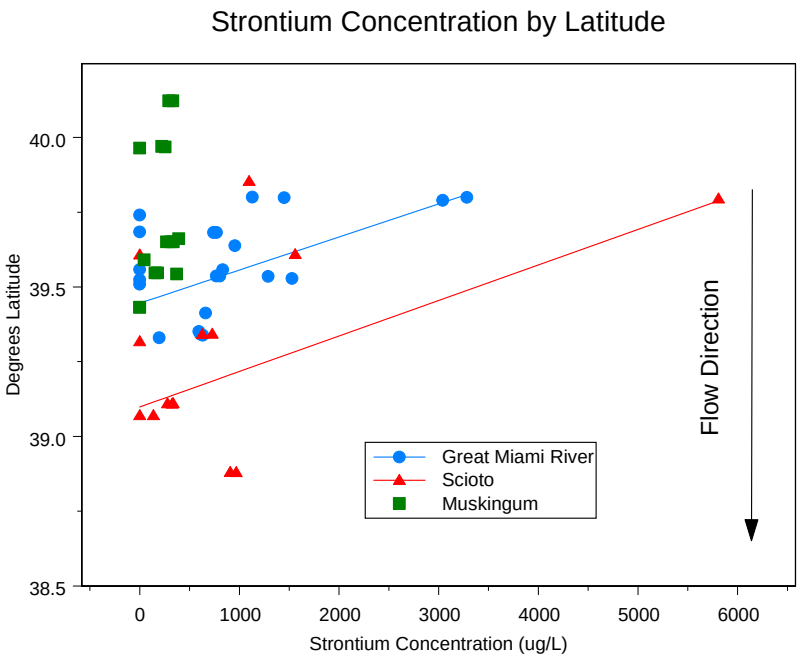


Figure 15. Strontium versus Latitude for buried valley aquifers.

with marine evaporates in the upper Silurian bedrock in northwest Ohio. The headwaters of the Great Miami and Scioto Rivers reach into the area of these elevated strontium bedrock, providing a source of the bedrock debris with elevated strontium. The decrease in strontium concentrations in ground water down gradient is attributed to increased contributions of bedrock debris with low strontium concentrations, similar to the explanation provided for the decreasing Mg concentrations down gradient for the Great Miami and Scioto buried valleys.

This preliminary analysis documents that the AGWMP ground water quality data can be used to illustrate regional water quality variation within the major buried valley aquifers. The variation within the buried valley aquifers described above is more subtle than expected, but the analysis can be useful to identify trends within the buried valley aquifers. The number of data points are limited and the variables are numerous so careful analysis is needed to document variations and relate changes to physical factors. This effort is continuing and results will be included in future 305(b) reports on ground water quality.

Low Aquifer Yields

The ODNR aquifer maps provide data on aquifer yields. Figures 16 and 17, with similar images available on ODNR's Web page, exhibit the yields of the unconsolidated aquifers and uppermost bedrock aquifers in Ohio, respectfully. These maps illustrate that although Ohio is a water rich state with significant rainfall and recharge, several areas of the state have limited ground water resources. Additional information is available at: http://www.dnr.state.oh.us/water/maptechs/

The high yields of the buried valley aquifers, emphasized in the sand and gravel geochemistry discussion, are obvious in the unconsolidated aquifers map (Figure 16) and constitute a tremendous water resource. The area of high yield in the northwest corner of Ohio is associated with sheets of coarse grained outwash material (sand and gravel) contained in ground and end moraine deposits. In some areas, wells into these aquifers exhibit artesian pressure and even produce flowing wells. Southeast Ohio is unglaciated so there are no glacial aquifers in the upland areas. The streams that transported glacial meltwater and deposited glacial outwash represent glacial aquifers with generally high yields. These aquifers generally associated with major streams and rivers, including the Ohio River, are particularly important due to low yield potential of the bedrock aquifers in southeastern and southwestern Ohio.

Figure 17 summarizes the aquifer yields in the upper bedrock aquifers in Ohio. Due to the layer cake stacking of stratigraphic units, many productive aquifers exist below the upper bedrock aquifers that are represented in Figure 17. These deeper aquifers may be utilized by drilling through the upper bedrock units to reach more productive, deeper aquifers. Water quality issues, however, can limit the use of water produced from deeper aquifers when they become too saline for drinking water use. Figure 17 illustrates that low yield or saline bedrock aquifers dominant the southeastern and southern parts of the state and occur along a north-south band in the middle of the state.

In southeastern Ohio, Upper Pennsylvanian and Permian stratigraphic sections includes low yielding aquifers. The bedrock consists of varied sequences of thin bedded shales, limestones, sandstones, clays, and coals of the Permian Dunkard Group and the Pennsylvania Allegheny, Pottsville, Conemaugh and Monongahela Groups. Yields below 5 gallons per minute are common in these areas. In southeastern Ohio, lower stratigraphic units which are productive aquifers to the north or east are no longer useful aquifers because the water quality is too saline to be used for drinking water.

The narrow north-south trending area of the Devonian Shales in central Ohio that curves eastward along the Lake Erie shoreline are also areas of low bedrock yields. These shales are poor aquifers; they typically yield less than 5 gallons per minute and frequently contain hydrogen sulfide. The Columbus and Delaware Limestone aquifers underlie the Devonian shales from central Ohio north to lake Erie, and can provide ground water in these area. If the shale thickness overlying the Devonian Columbus and Delaware Limestone exceeds 100 feet, the aquifer is generally not viable due to poor water quality.

The southwestern portion of the state is underlain by lower Ordovician carbonates and shales. These interbedded shale and carbonate units (undivided Ordovician) are dominated by shale (Figure 7) and consequently, well yields are generally less than 5 gallons per minute. In southwest Ohio, public water systems depend on the buried valley aquifers as the main ground water source. The interbedded shale and carbonate aquifer with low yields are only practical for low volume water users, and no AGWMP wells are located in these low yield aquifers. Consequently, this aquifer is not discussed in any detail in this report.

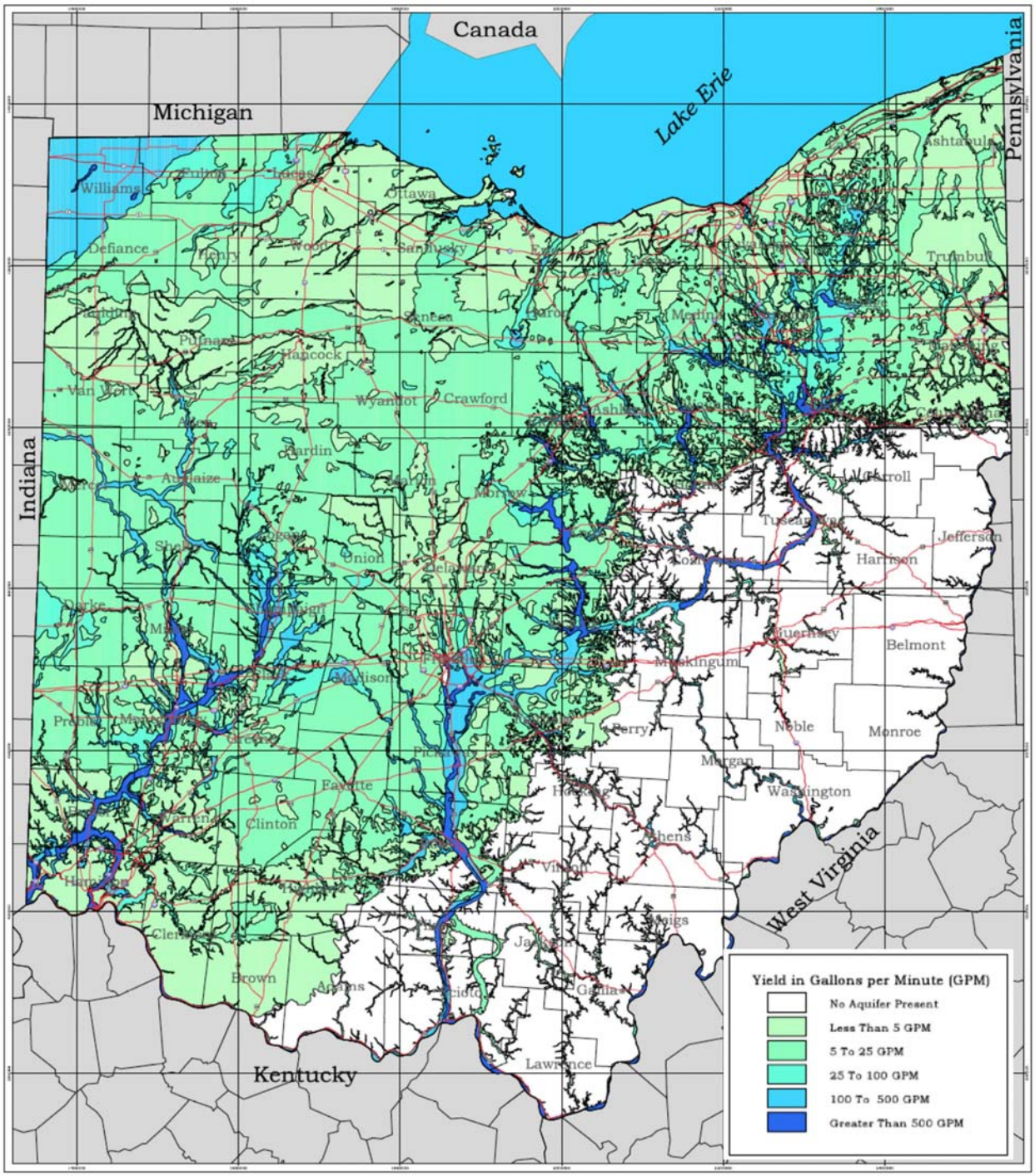


Figure 16. Glacial Aquifer Yields (from ODNR).

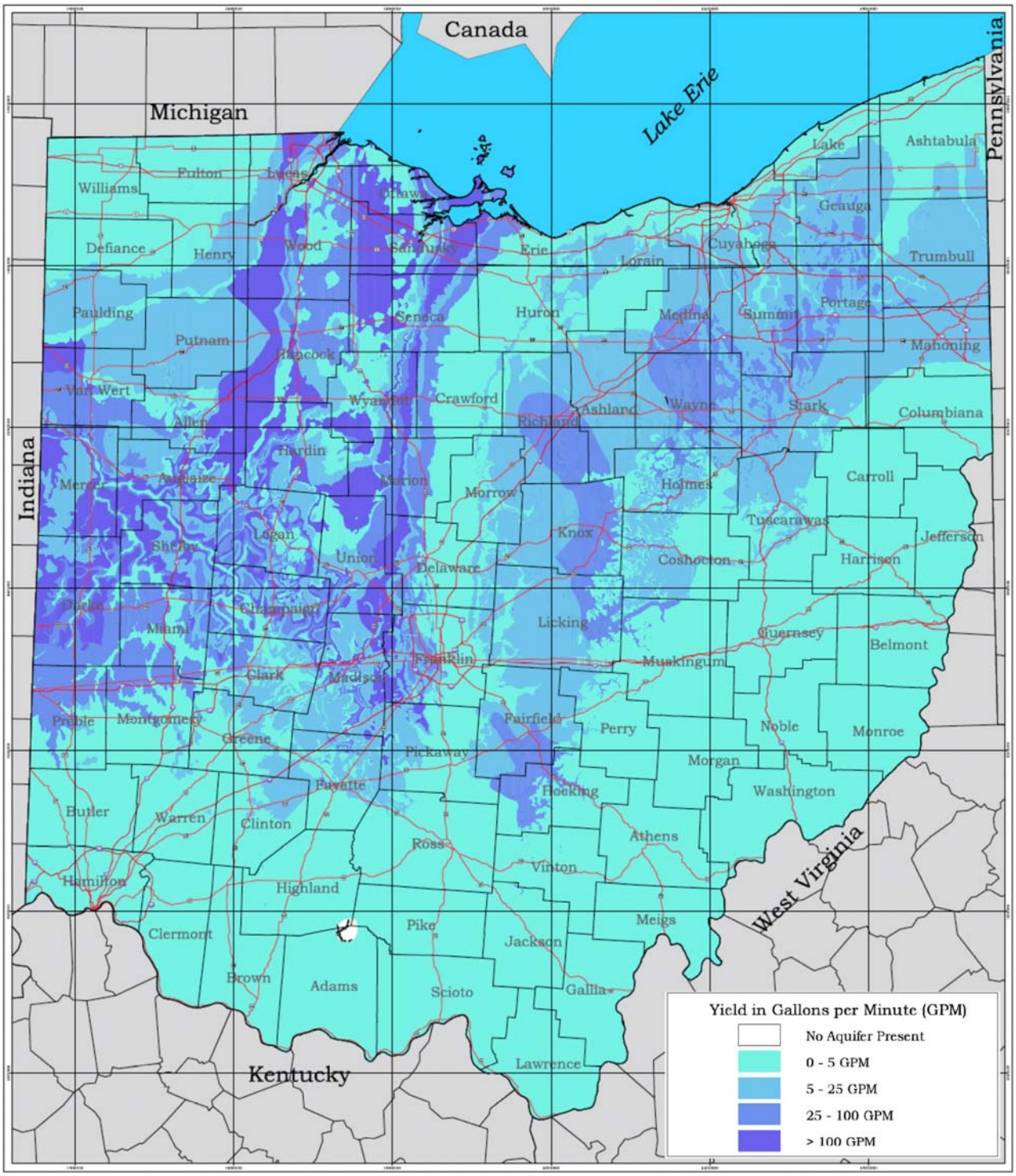


Figure 17. Bedrock Aquifer Yields (from ODNR).

SENSITIVE AQUIFERS - RELATIONSHIP TO HIGHLY SUSCEPTIBLE PWSs

Overview

A broad understanding of ground water recharge pathways and water quality data were used to identify sensitive aquifers, those aquifers most likely to be impacted by land use activities. The concept that shorter or rapid recharge pathways increase the sensitivity of local aquifers is generally accepted and is used for evaluating aquifer vulnerability. Applying this concept to Ohio aquifers demonstrates that the most sensitive aquifers are the sand and gravels in the glacial deposits, including the buried valley aquifers, valley fill, alluvial settings, beach ridge deposits, and outwash/kame deposits. A second group of sensitive aquifers are shallow bedrock aquifers, especially fractured or karst bedrock, that underlie thin glacial drift, tills or thin lacustrine deposits. Concentrations of nitrate in public water system (PWS) water quality compliance monitoring data have been used for the analysis to identify sensitive aquifers.

Highly Susceptible PWSs

The 1996 Amendments to the Safe Drinking Water Act established a program for all states to assess the drinking water source for all public water systems. Ohio's Source Water Assessment and Protection (SWAP) Program is designed to help public water systems protect their sources of drinking water from becoming contaminated. The assessment has three steps: identify the drinking water source protection area, based on the area that supplies water to the wells (delineation); identify the potential contaminant sources in the area (inventory); and evaluate the likelihood that the drinking water source could become contaminated (susceptibility analysis). The susceptibility analysis utilizes concepts similar to those used to identify sensitive aquifers, with a focus on recharge pathways. In addition to geologic considerations, some PWSs will be considered susceptible due to poor well construction that may allow rapid flow of surface water into a well. The presence of numerous potential contaminant sources in the drinking water source water protection area can increase the likelihood of ground water contamination as well. The geologic controls of contaminant transport lead to the expectation that highly susceptible PWSs are likely to be associated with aquifers identified as sensitive. This association can be used to document the validity of sensitive aquifers. Care must be taken, however, not to apply circular reasoning to confirm the validity of the sensitive aquifers using the highly susceptible PWSs, since similar reasoning is applied to determine both.

As outlined in the SWAP Susceptibility Analysis Process Manual (Ohio EPA, 2003), a PWS is considered "highly susceptible" if it has been impacted by anthropogenic contaminants, regardless of the geologic setting. Water quality impacts are defined as nitrate concentrations greater than 2.0 mg/L or confirmed detections of organic parameters. The SWAP staff reviewed more than 60,000 compliance samples including over 1,100,000 results to identify the subset of high susceptible PWSs based on water quality impacts. This subset of 561 PWSs, out of a total of 5151 ground water sourced PWS, can be used as an independent data set to evaluate the determination of sensitive aquifers in Ohio. Figure 18 shows the locations of 561 PWSs with documented water quality impacts (highly susceptible in SWAP terminology) in relationship to the sensitive aquifers. The visual association of the PWSs with water quality impacts to sensitive aquifers is most obvious along buried valleys.

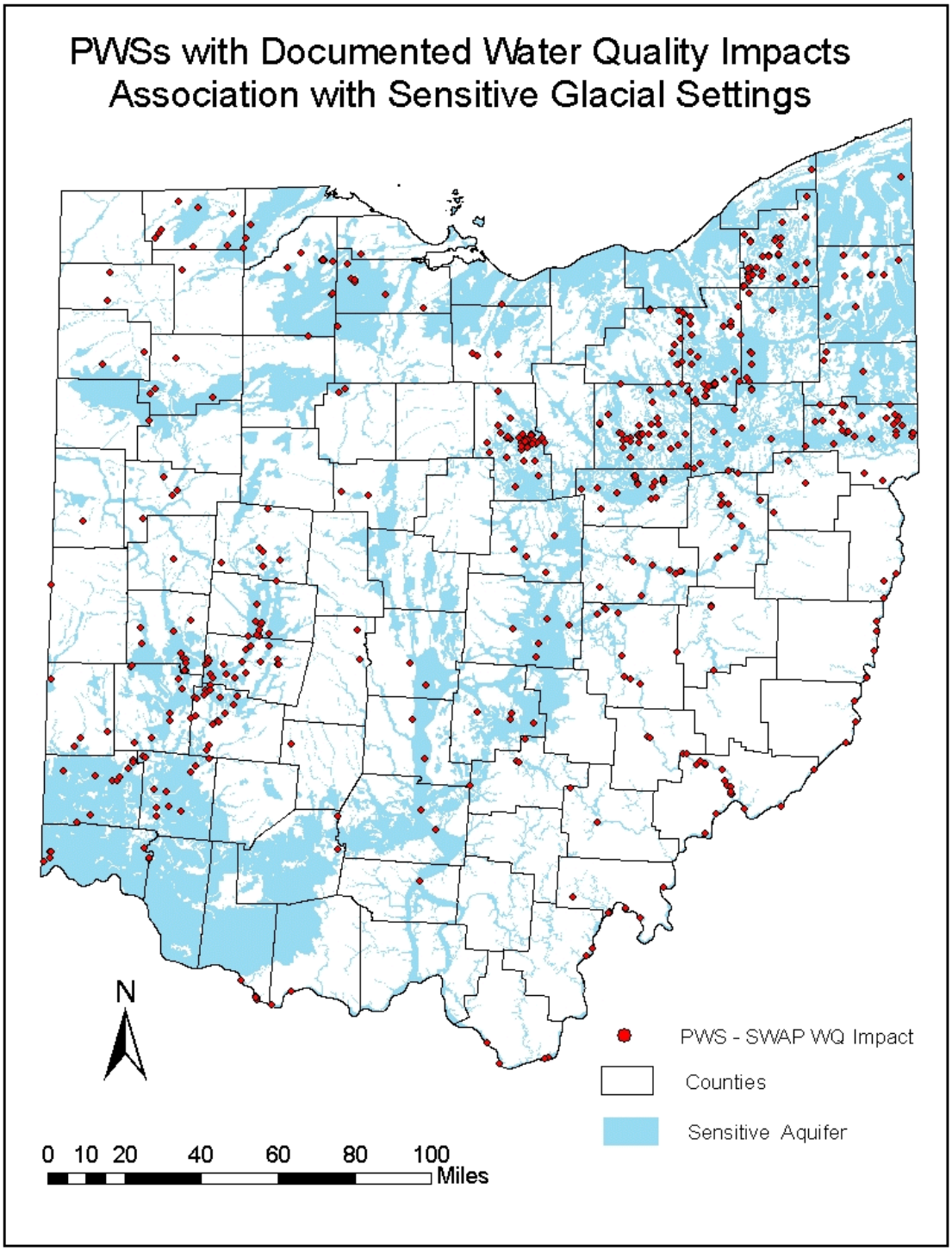


Figure 18. PWSs with documented water quality impacts in relation to sensitive glacial settings.

Association of High Susceptibility PWSs with Sensitive Aquifers
The following analysis utilized the ODNR Glacial Aquifer maps to determine if the locations of highly susceptible PWSs, based on water quality, are associated with sensitive aquifers. To accomplish this, the 561 highly susceptible PWSs with water quality impacts were associated by location to the attributes of the ODNR Glacial Aquifer maps. These attributes, including geologic setting, thickness, and lithology, were used to count the number of highly susceptible PWSs that occur in different geologic settings or the number associated with different lithologies. These counts were compared to counts of all ground water based PWSs associated with the same groupings of geologic settings or lithologies in order to normalize the results for accurate comparisons.

Extracting Glacial Aquifer Map attributes based on PWS locations has several limitations that need to be identified in order to understand the results presented in the following tables. The thickness of the glacial drift at a given PWS location is not the well depth or average well depth of the PWS wells, but rather it is a rough estimate of the glacial drift thickness. The PWS wells may be producing water from the glacial drift or the well may be cased through the drift and producing water from a bedrock aquifer. If the glacial thickness is thin, it is reasonable to deduce that the well is a bedrock well. In thicker glacial drift, it is not possible to know if the well is producing water from the glacial aquifers or bedrock aquifers without additional information, such as a well log. If the PWS wells are located in thick glacial drift in geologic settings that are considered sensitive (buried valley, beach ridge, outwash/kame) it is likely that the well is producing from glacial aquifers, however, the well depth does not have to approach glacial drift thickness. For example, the well may be 45 feet deep in an area of drift that is greater than 100 feet thick. These data limitations need to be considered when reviewing the data presented in Tables 7 and 8. Overall, there appears to be a strong association between PWSs with impacted GW quality and aquifers independently identified as sensitive.

Geologic Setting Associations
As noted previously, geologic settings with rapid recharge are identified as sensitive aquifers and include the follows geologic settings in the ODNR Glacial Aquifer Map:

- Sand and Gravel Aquifers:
  - Buried Valley
  - Alluvial
  - Valley Fill
  - Outwash/Kame
  - Beach Ridge

- Bedrock Aquifers Below Thin Uplands and Lacustrine Deposits:
  - Thin Uplands
  - Lactustrine

In contrast, areas of thick till generally reduce or slow recharge through moraine deposits and include the following geologic settings in the ODNR Glacial Aquifer Map:

- Moraine Deposits:
  - Ground Moraine
  - End Moraine
  - Complex

These geologic settings are associated with different glacial drift thicknesses across the state. It is generally assumed that greater glacial thicknesses provide the aquifers more protection. The result of longer recharge pathways and increased recharge travel time to the aquifer reduces the overall sensitivity of the aquifer. The ODNR aquifer maps grouped glacial drift into three categories: thin (<25 feet), moderate (25-100 feet), and thick (>100 feet). This thickness describes either the thickness of the glacial drift including the aquifer, or the thickness of glacial drift overlying a fractured bedrock aquifer. Each of the hydrogeologic settings were separated into these thickness groups to evaluate if impacts were influenced by the glacial overburden thickness. Even though these groupings are coarse, differences between geologic settings and thickness group are discernible in Figure 7 and 8.

In order to evaluate the association of ground water quality impact and sensitive geologic settings, the number of PWSs with impacted ground water in these geologic settings were compared to the total number of PWSs within each geologic setting, for each thickness, to produce percentages of impacted PWSs for sensitive aquifers. Table 7 outlines the percentage of impacted PWSs associated with groups of specific geologic settings by increasing thickness of glacial drift. Overall the highest percentages of PWSs with impacted source water are associated with the sand and gravel aquifers. The major aquifer groups associated with geologic settings are discussed individually below.

Sand and Gravel Settings - The percentage of PWSs with documented water quality impacts is higher for the geologic settings dominated by sand and gravel deposits (buried valley; alluvial; valley fill; outwash/kame; and beach ridge). The percentage of impacted systems decreases with increasing glacial drift thickness from 25.6 % for thin glacial drift, 18.9 % for intermediate glacial drift and 14.4 % for glacial drift of more than 100 feet thick. This trend supports the concept of increased protection as the recharge pathways lengthen. Based on the statutory requirement of 25 feet of casing for PWS wells, wells associated with the 0-25 foot group of sand and gravels generally represent wells drilled through the glacial sand and gravel into bedrock.

Bedrock Aquifers Below Thin Uplands and Lacustrine Deposits - PWSs in bedrock aquifers below thin upland or lacustrine deposits (< 25 and 25-100 feet thick) exhibit ground water quality impacts in 14.7 to 10.0 % of the PWSs. These percentages suggest that the thin till and lacustrine material provides a bit more protection from land use activity generating dissolved contaminants than does sand and gravel. The low yield from till and lacustrine deposits requires most of these wells to be bedrock production wells. The 28.6 % of PWSs that showed ground water impacts in the greater than 100 foot group is based on relatively few wells and appears anomalous. Two of the eight wells in lacustrine settings with glacial drift more than 100 feet thick include sensitive buried valley or beach ridge geologic settings within the one year time-of- travel in the Drinking Water Source Protection Areas, which provide rapid recharge pathways. The other six wells are deep wells (>120 feet) and are presumed to be geologically confined based on available well logs. This is an unlikely set of wells to exhibit elevated nitrate (nitrate concentrations > 2.0 mg/L typically occur in Ohio wells with depths less than 75 feet). Three of these four wells were drilled in the 1950's. One explanation is that corrosion of the casing may allow cascading of shallow, nitrogen rich ground water into the well. Several of these wells are within a couple of miles of each other and exhibit similar nitrogen time series patterns that suggest a regional rather than a local control. These relationships may indicate that the nitrogen concentrations are geochemically reduced in these wells when the surface water table is low, restricting the influx of oxygenated shallow ground water into the well casings and thus reducing nitrogen input. This example illustrates some of the difficulties of interpreting site specific information of the data in Table 7.

Table 7
Documented Water Quality Impacts at PWSs - Associations
Between Impacts and Hydrogeologic Setting* of Glacial Units

Thickness of Glacial Unit (Feet)	Number of PWSs in Glacial Unit with Impacts	Total Number of GW Based PWSs in Glacial Unit	Percentage of Impacted PWSs
Sand and Gravel Aquifer Settings (Aquifer Map settings - Buried Valley, Alluvial, Valley Fill, Outwash/Kame, Beach Ridge)			
0-25	10	39	**25.6 %**
25-100	92	487	**18.9 %**
>100	153	1066	**14.4 %**
Bedrock Aquifers Below Thin Uplands and Lacustrine Deposits (Aquifer Map settings - Thin Uplands and Lacustrine)			
0-25	133	904	**14.7 %**
25-100	103	1032	**10.0 %**
>100	8	28	**28.6 %**
Moraine Deposits (Aquifer Map Settings - Ground Moraine, End Moraine, Complex)			
0-25	0	0	**0.0 %**
25-100	27	704	**3.8 %**
>100	13	559	**2.3 %**
Unglaciated Areas (No glacial units on Aquifer Map)			
0	22	332	**6.6%**

* Hydrogeologic settings are from ODNR Aquifer Map

Moraine Deposits - Protection of ground water resources provided by thick till cover is demonstrated in the moraine deposits category of Table 7, where the percentage of impacted PWSs does not exceed 4 %.

In the geologic setting breakout, the thin tills are grouped with the thin upland and lacustrine settings which indicate 14.7% of PWSs in these settings exhibit water quality impacts. The thicker tills, however, are associated with relatively few impacted PWSs, indicated by the 3.8 % and 2.3 % for the 25-100 feet and >100 feet thickness groups of till geologic settings respectively. These low percentages suggest the thick till provides significantly more protection than the sand and gravel or thin tills. The role that fractures and micropores play in controlling recharge to aquifers through tills is a current topic of discussion in Ohio as elsewhere (Weatherington-Rice and Christy, 2000; Weatherington-Rice and Christy, 2006). Fractures and micropores certainly play an important role in the movement of recharge through thin tills, as indicated in the high percentage (14.7 %) of impacted PWSs associated with thin upland and lacustrine settings. The critical question is the vertical extent of fractures and what volume of fluid is transported to depth. Fractures and micropores appear to be significantly less important in recharge transport in thick tills as documented by the much lower percentages (3.8 % and 2.3 %) of impacted PWSs associated with thicker moraine deposits in Table 7. This is believed to be the result of the limited vertical extent of fractures in till, typically limited to upper 20-25 feet (Scott Brockman, personal communication).

Unglaciated Areas - The last category in Table 7 includes the PWSs located in the unglaciated areas of Ohio, primarily the southeastern uplands. These areas include weathered bedrock (colluvium) overlying late Paleozoic sandstones and shales with some overlying local loess deposits. In most cases wells will produce water from the bedrock aquifers, however, yields are generally low and relatively few PWS use these aquifers. Consequently, we have limited data for the unglaciated areas, but the available data indicates that the colluvium is better than sand and gravel and thin till, but not as good as thicker tills at protecting wells from land use impacts. From Table 7, PWSs in unglaciated areas are shown to be impacted 6.6 % of the time, a value that is intermediate between sands and gravel and thicker tills. The lower density of population and consequently the reduced number of potential pollution sources in southeastern Ohio may contribute to this low percentage.

Lithologic Associations

The lithologic associations of impacted PWS source water are presented in Table 8 using the same format as the geologic settings in Table 7. The lithologic attributes describe the primary materials within mapped polygons in the ODNR Aquifer Maps, and were divided into three groups:

- Sand and Gravel Lithologies: Includes coarse to fine sand and gravels with minor fine grained material, including thin lenses of alluvium, lacustrine or till.
- Fine Grained Lithologies: Predominantly fine grained geologic materials with minor sand and gravel lenses. Alluvium, slack water, till, and colluvium deposits are included in this group.
- Till Lithologies: Predominantly tills with little evidence of sand and gravel lenses. In thin tills, wells generally penetrate the till into bedrock aquifers. In thicker tills, limited production may be associated with sand and gravel lenses, but larger production wells will be drilled to bedrock aquifers.

Table 8 presents the percentage of impacted PWSs associated with these lithologic groups, ordered by increasing thickness of glacial drift. Over all, the coarser lithologies would be expected to allow more rapid recharge, and consequently be associated with higher percentages of impacted PWSs and this is exactly what Table 8 exhibits. The percentage of PWSs with documented water quality impacts is

Table 8
Documented Water Quality Impacts at PWSs - Associations
Between Impacts and Lithology* of Glacial Units

Thickness of Glacial Unit (Feet)	Number of PWSs in Glacial Unit with Impacts	Total Number of GW Based PWSs in Glacial Unit	Percentage of Impacted PWSs
Sand and Gravel Lithologies (including: sand and gravel, minor fines, confined, thin till included within or over unit)			
0-25	6	9	**66.7 %**
25-100	50	133	**37.6 %**
>100	113	495	**22.8 %**
Fine Grained Lithologies (including: fine grained sediments undifferentiated, fines with minor sand and gravel lenses)			
0-25	4	36	**11.1 %**
25-100	44	405	**10.9 %**
>100	37	464	**8.0 %**
Till Lithologies (including: till, till with sand and gravel lenses)			
0-25	133	898	**14.8 %**
25-100	128	1682	**7.6 %**
>100	24	697	**3.4 %**
Unglaciated Areas (areas with no glacial units on ODNR Aquifer Map)			
0	22	332	**6.6 %**

* Lithology divisions are from ODNR Aquifer Map

highest for the sand and gravel lithologies and lowest for the till materials. This is similar to the results presented in Table 7 for geologic settings, but the percentages associated with the lithologic divisions indicate the recharge processes are more dependent on the lithologic material present than the geologic setting. The major lithologic groups are discussed individually below.

Sand and Gravel Lithologies - For these lithologies, the low number of wells in the <25 feet thickness results from the fact that PWS wells are required to have 25 feet of casing installed. Thus the few wells in this thickness grouping are either old wells with short casing lengths or bedrock wells cased through the thin glacial sand and gravel. With 66.7 % of these wells being associated with water quality impacts, it appears that these wells are likely to be highly susceptible, but the percentage is based on a very low number of wells to be given too much significance. With greater thicknesses of sand and gravel, the percentage of impacted PWSs decreases to 37.6 % and 22.8 % for the 25-100 feet and >100 feet groupings respectively. These wells probably do not penetrate the entire glacial thickness, but it appears that the thicker section of sand and gravel provides more filtration and increased travel time, as one would expect. Almost all of the areas of sand and gravel lithologies in Table 8 are included within the geologic settings that are considered most sensitive in Table 7. The sensitive geologic settings, however, also include fine grained lithologies and even some till lithologies. The increased correlation between coarser sand and gravel lithologies and PWSs with water quality impacts reported in Table 8, significantly above the sand and gravel aquifers based on geologic settings in Table 7, supports the importance of identifying coarser sand and gravel lithologies for better identification of sensitive aquifers. This is entirely consistent with the sensitivity of aquifers being controlled by recharge rate and rapid transport of surface contaminants to aquifers. It also suggests that the sand and gravel portions of the buried valley aquifers need to be identified as more sensitive than finer grained portions.

Fine Grained Lithologies - The fine grained portions of the glacial lithologies in the ODNR Aquifer Maps are predominantly undifferentiated fine grained sediments and deposits with minor sand and gravel lenses. Approximately 8.0 % to 11.1 % of the PWSs associated with these fine grained lithologies exhibit water quality impacts in Table 8, significantly less than coarse sand and gravel deposits (22.8 % to 66.7 %). The percentage decreases with increasing glacial drift thickness, but not significantly, which may result from the variability of well depths independent of the glacial deposit thickness.

Till Lithologies - The till lithology results in Table 8 document a significant difference between impacted PWSs in thin tills and the thicker tills. Limited protection is provided by thin glacial drift overlying bedrock aquifers, as evidenced by the 14.8 % of impacted PWSs associated with thin tills (< 25 feet). Wells producing from fractured bedrock just below thin glacial cover will be the most vulnerable and probably account for the bulk of the PWSs with water quality impacts. The percentage of water quality impacts associated with thicker tills drops dramatically for thicker tills: 7.6 % for tills in the 25-100 feet group and 3.4 % for tills greater than 100 feet group.

Unglaciated Areas - The unglaciated areas include the same subset of wells presented in Table 7. As stated earlier, the limited data restricts broad conclusions, but the low percentage of impacted PWSs suggests that colluvium provides some protection for these wells from land use activities. The lower density of population and consequently the reduced number of potential pollution sources in southeast Ohio may also contribute to this low percentage.

This analysis documents the importance of distinguishing the coarser lithologies in the buried valleys, alluvial, valley fill, outwash/kame, and beach ridge deposits as being more sensitive than the finer grained

deposits in these same settings. Figure 19 illustrates the association of the PWSs with water quality impacts along a section of the Great Miami buried valley aquifer in southwest Ohio. This figure illustrates the relationship between the high concentrations of water quality impacts and sections of the buried valley identified as sand and gravel. Water quality impacts are also associated with the finer grained buried valley deposits and the thin tills in the uplands, but with lower frequency as documented in Tables 7 and 8.

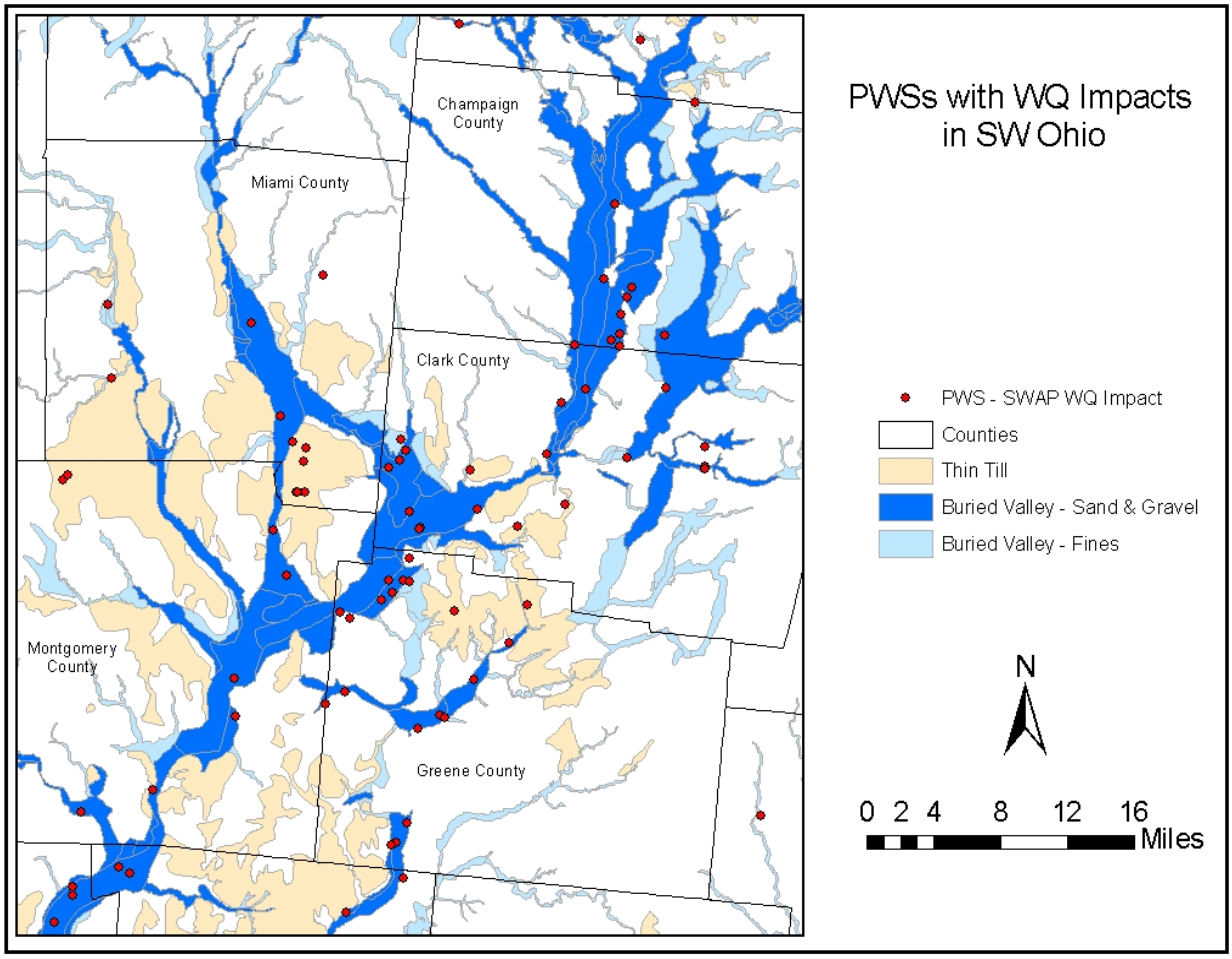


Figure 19. Association of PWSs with water quality impacts to sensitive aquifers and lithologic divisions in the buried valley aquifers in SW Ohio.

Highlighting Sand and Gravel Aquifers

The glacial aquifer map divisions are general groupings that were selected to represent glacial material on a state scale based on geologic and well log data. Analysis using empirical water quality data (nitrate in PWSs) exhibit significant correlations with the identified sensitive geologic settings and lithologies. The stronger association of impacted PWSs with coarser and more permeable sand and gravel lithologies supports the role recharge plays in making aquifers sensitive, and suggests the sand and gravel units need to be highlighted in the identification of Ohio's sensitive aquifers.

Figure 20 illustrates the distribution of sensitive glacial geologic settings across Ohio utilizing attributes identified in ODNR's Aquifer Maps (ODNR, 2000). This figure represents the combined analysis of sensitive aquifers and water quality impacts based on nitrate and VOC concentrations, and SWAP susceptibility. In the glacial settings where sand and gravel deposits are common, the lithology is broken into fine and coarse grained units. The analysis presented above documents that the coarser grained units are more sensitive. The classification processes used in developing the glacial aquifer maps required a great deal of simplification and consequently these generalizations need to be considered in any application of Figure 20. Nevertheless, the correlation of the empirical PWS water quality data to the lithologic and geologic setting descriptors supports the simplifications made in developing the ODNR Glacial Aquifer map and the validity of using recharge in determining sensitive aquifers.

The goal of identifying sensitive aquifers is to help set priorities for protecting the state's ground water resources. Statewide, aquifers that have more than 25 feet of till or fine grained glacial deposits overlying the well production zone are less likely to exhibit water quality impacts than sand and gravel aquifers. If till overlying a bedrock production aquifer is less than 25 feet thick, the bedrock aquifer is likely to exhibit water quality impacts but not as likely as the sand and gravel aquifers. The data in Tables 7 and 8 and Figure 19 illustrates the high geologic sensitivity of Ohio's productive sand and gravel aquifers, in particular the areas of coarser sand and gravels. These conclusions are not unexpected and they support the generally accepted views of hydrogeologists familiar with the fate and transport of contaminants within sensitive aquifers in Ohio. These empirical data provide significant support for opinions based on professional experience, and consequently, they increase our confidence in applying the identified sensitive aquifer settings to protecting Ohio's ground water resources.

Thin Till Over Bedrock Aquifers

Several situations in areas of thin glacial till (< 10 feet) over bedrock have been identified recently which emphasize the sensitivity of this geological setting. The close placement of septic systems to residential or public wells can result in public health issues if the septic effluent moves rapidly through the thin till along macro pores, fractures, or other available pathways to fractured bedrock aquifers. It appears that microbiological contamination is more likely in these situations than in sensitive unconsolidated sands due to the limited filtration capacity of macro pores and fractures in till and bedrock. Invariably, ground water microbiological contamination increases proportionally to increasing population concentration in areas of paired septic/well systems. The 2004 South Bass Island investigation is presented as a timely example of this situation.

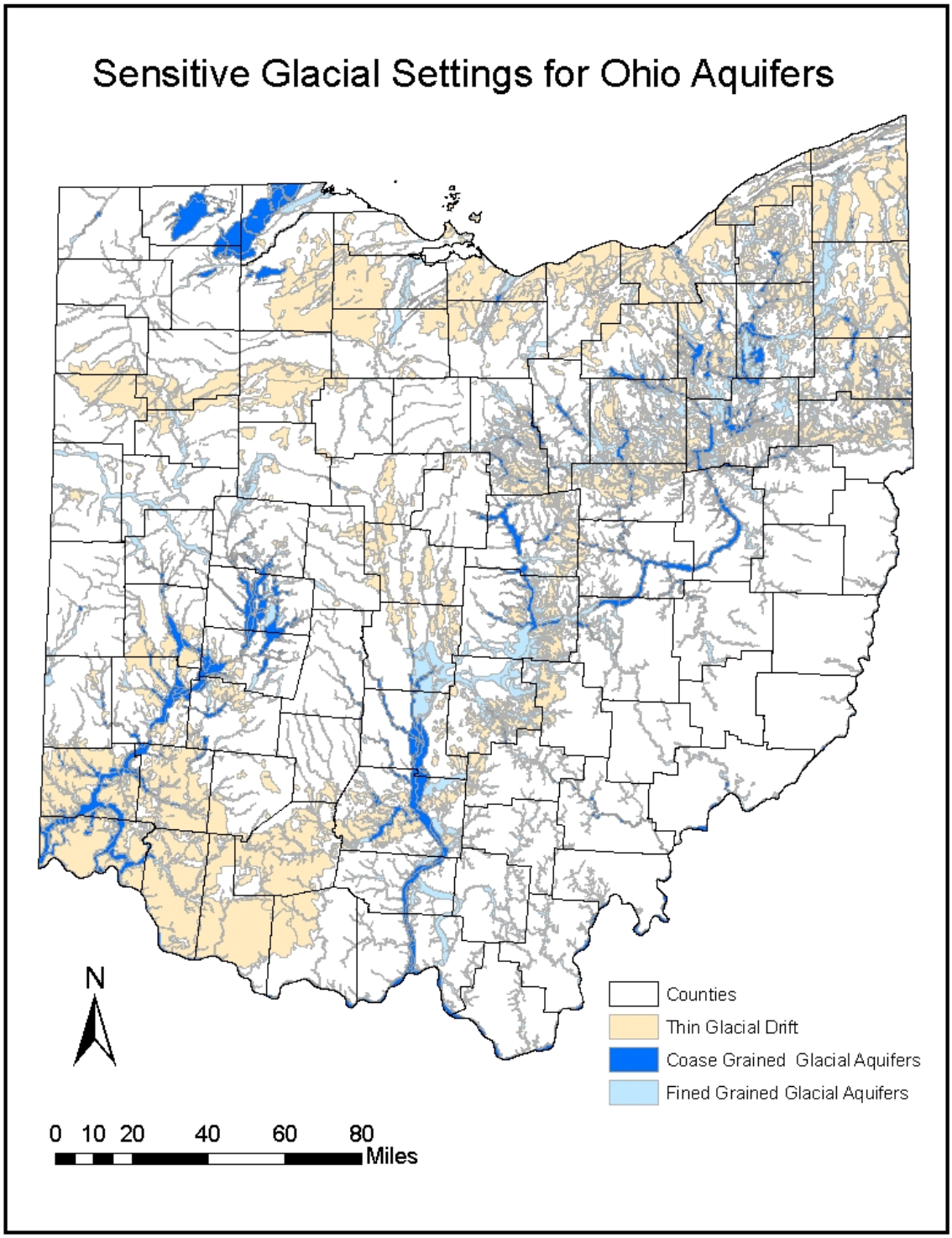


Figure 20. Statewide distribution of sensitive glacial aquifers.

South Bass Island Investigation

The investigation of a 2004 infectious disease outbreak on South Bass Island, in Lake Erie just north of Sandusky Bay, and the resulting determination that there is substantial microbiological contamination of ground water across the island provides an example of a sensitive aquifer setting as a result of areas of thin glacial drift and high population density. Figure 21 illustrates the depth to bedrock on South Bass and Middle Bass Islands. The thickness of glacial drift is generally less than 10 feet throughout the islands, with exposed bedrock in many places. The Ottawa County Soil Survey (USDA,1985) indicates that areas of South Bass and Middle Bass Islands have severe limitations for septic systems due to the shallow depth to bedrock and the presence of large stones. The insights gained from the detailed investigations on South Bass Island can be applied in other areas of the state where thin glacial overburden covers fractured bedrock.

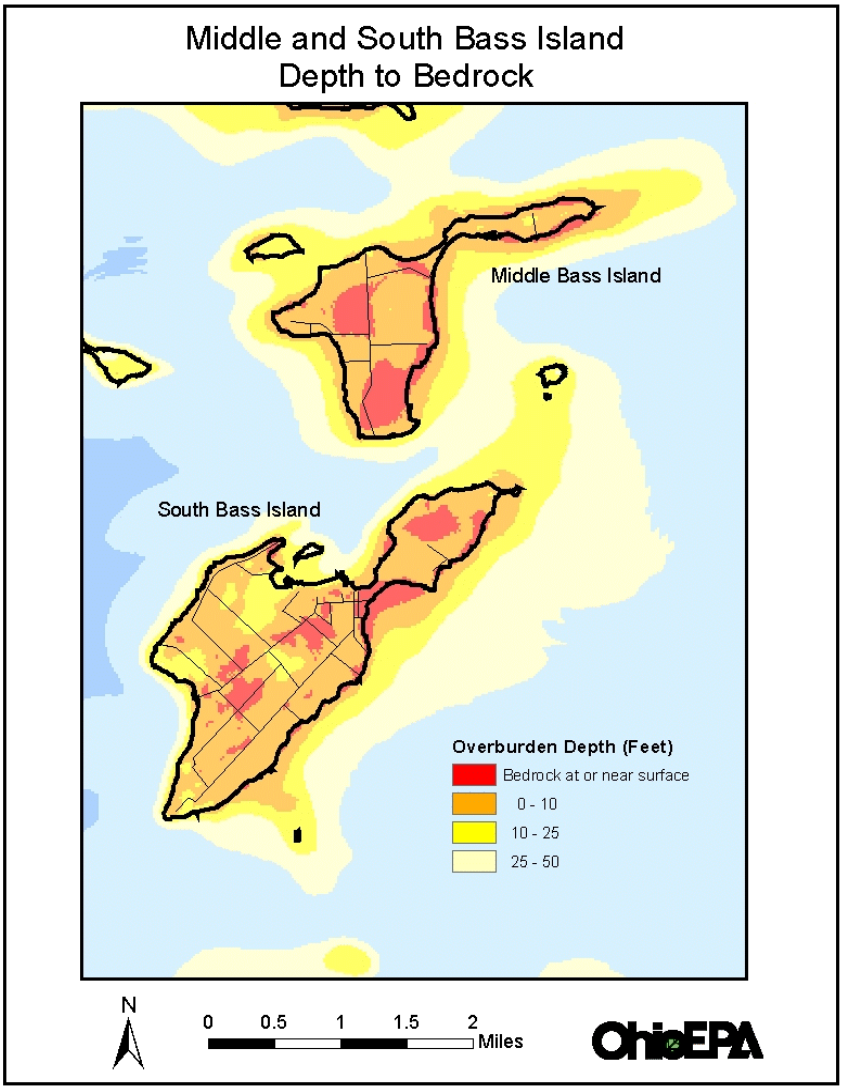


Figure 21. Depth to bedrock on Middle and South Bass Islands

The South Bass Island investigation is an example of interagency participation to address a significant health issue. From July 23 to September 12, 2004, 1,450 cases of gastrointestinal illness in residents and visitors to South Bass Island were identified. The Ohio Department of Health (ODH) was the lead agency for the South Bass Island investigation that was initiated after the Ottawa County Health department notified the Ohio Department of Health of an increase of gastrointestinal illnesses on South Bass Island. Partners in the investigation included: the Ottawa County Health Department, the Centers for Disease Control and Prevention (CDC), the Ohio EPA, the Ohio Department of Agriculture, and the Ohio Department of Natural Resources. The investigation identified widespread ground water contamination as the most likely source of the gastrointestinal illnesses. The investigation included study of ill persons who fit the case definition; extensive testing of water systems on the island; a study of the aquifer on the island; a review of past hydrological studies of the island; and a case-control study comparing sick persons with their well traveling companions. The ODH Web page at:

http://www.odh.state.oh.us/alerts/southbassisland/southbassinvestigationPR.aspx

has a link to the ODH Director's Preliminary Report on the Gastrointestinal Illness on South Bass Island, Lake Erie, August 2004. This Web page includes links to the ODH Report appendices, which include reports from other agencies that participated in the investigation. The reader is referred to these reports for the details on the South Bass Island investigation. A brief summary of the geology, hydrogeology, and a selected summary of the microbiologic ground water quality sampling that was completed for this investigation is provided below to illustrate the potential for water quality impacts associated with areas of thin glacial till. The data presented has been pulled primarily form the Ohio Department of Health and the Ohio EPA summary reports presented as appendices to the ODH Director's Preliminary Report. The reader is referred to these reports for a comprehensive understanding of the results of this investigation.

Geology and Hydrogeology of South Bass Island

South Bass Island soils are dominantly the Castalia-Milton association composed of well drained soils of dominantly loamy and clayey material over dolomitic limestone according to the General Soil Map of Ottawa County. These soils are poorly suited for septic system absorption because they are thin and they are highly permeable. In many areas of South Bass Island, these soils contain abundant stones from the shallow bedrock. The glacial drift is thin, generally 10 feet or less, throughout South Bass Island as illustrated in Figure 22.

The thin till overlying South Bass Island requires wells to utilize bedrock aquifers as a water source. The bedrock exposed at the surface of South Bass Island is the Bass Island Dolomite. Sinkholes, closed depressions, rectilinear fractures, and caves are present on the surface. These features document the presence of karst which is known for rapid migration of surface water and associated contaminants to the water table. The Bass Island Dolomite karst aquifer is the upper aquifer and ranges from 30 to 65 feet thick across the island. The lower aquifer is the Salina Group which lies directly below the Bass Island Dolomite. The Salina Group is over 200 feet thick in this area. The contact between these bedrock units is below the surface of Lake Erie. Well logs document the presence of fractures and voids at depth, confirming the vertical extent of karst solution features.

Ground water on South Bass Island is recharged by precipitation and infiltration. Ground water flow is generally towards the lake. The karst geometry and close proximity to Lake Erie suggests that ground water flow and recharge is influenced by lake levels. The shallow glacial drift, fractured bedrock and karst features are consistent with rapid infiltration with limited filtration. These are the classic characteristics of a sensitive aquifer setting, as confirmed by the 2004 South Bass Island Investigation.

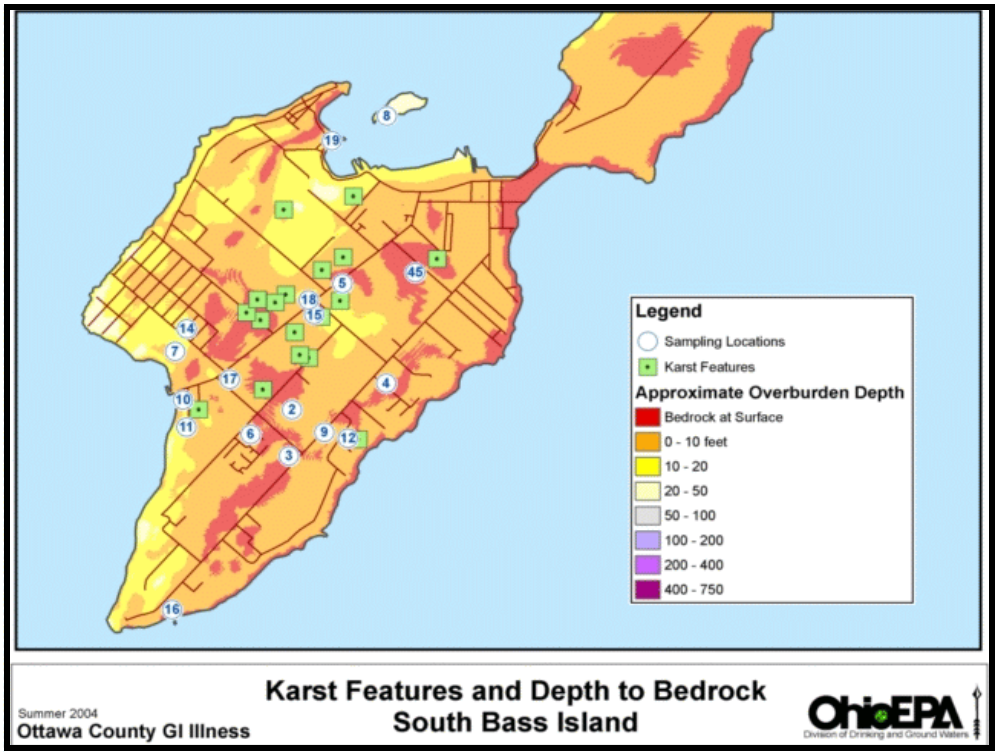


Figure 22. Drift thickness and karst features on South Bass Island.

In total, the karst geologic setting with thin glacial drift on South Bass Island is sensitive and is not well suited for filtering septic waste. Ground water at 25 feet in this hydrogeologic setting has had very little opportunity for natural filtration, and due to the rapid movement and recharge through the fractured rock to the ground water, very little time for natural die-off of bacteria, viruses, and parasites, or attenuation of chemical contaminants. Data suggests that both aquifers are hydraulically connected to Lake Erie, therefore, lake water quality may also have an influence on ground water quality.

Ground Water Quality Data

As part of the investigation, ODH developed a sampling plan for the private wells on South Bass Island to identify baseline ground water quality for the island. Ohio EPA developed a sampling plan to evaluate the water quality associated with the PWSs. The data presented here is the result of Ohio EPA's investigation of PWSs, however, conclusions for the private wells are similar to that for the PWSs. Investigation of waste water treatment and disposal systems was also undertaken to evaluate potential sources, but the results of this part of the investigation are not summarized here beyond the conclusion that partially treated waste water appears to be reaching the ground water resources, as expected considering the sensitive geologic setting.

On August 13, 2004, Ohio EPA Division of Drinking and Ground Waters (DDAGW) and Division of Surface Water (DSW) staff, at the request of the Ottawa County Health Department, visited possible transient non-community public water systems. On August 23, 2004, Ohio EPA sent three teams to South

Bass Island to initiate a three-pronged investigation of all public water systems on the Island including all wells and plumbing to ensure compliance with rules regarding well construction, isolation, treatment, cross-connection and backflow prevention. This work continued for several weeks.

The first Ohio EPA team conducted an extensive evaluation of the Village of Put-In-Bay public water system including a review of operational and water sampling records. Potential cross-connections associated with auxiliary wells were also investigated. The second team conducted inspections and collected samples from known transient non-community water systems on the Island, and also investigated businesses that had package wastewater treatment plants. The third team investigated other commercial establishments outside of the Village of Put-In-Bay with their own wells to determine if they were an unidentified public water system and to determine what type of wastewater system was utilized. All total coliform bacteria samples were collected using Ohio EPA protocol for collecting bacteriological samples and analyzed at a laboratory certified for conducting analyses of public drinking water.

Village of Put-In-Bay

Ohio EPA staff investigated the existence of auxiliary wells on properties connected to the public water system to ensure compliance with Ohio EPA's cross-connection and backflow prevention regulations. A large number of businesses on the Island utilize auxiliary wells for geothermal cooling, flushing toilets and outdoor cleaning. If an auxiliary well was identified during a property investigation, efforts were made to collect raw water samples from the auxiliary well and from a tap within the premises connected to the Village of Put-In-Bay water system. All samples were analyzed for total coliform bacteria and, if positive, further tested for *Escherichia coli (E. coli*). Twenty-two (22) samples also were analyzed for *Campylobacter*.

In total, Ohio EPA staff collected thirty-eight (38) samples from twenty (20) businesses connected to the Village of Put-In-Bay water system that also have auxiliary wells. Twenty-four (24) of these samples from eighteen (18) businesses were collected from the auxiliary wells themselves. Eleven (11) of the auxiliary wells tested positive for total coliform and four (4) tested positive for *E. coli*.

The remaining fourteen (14) samples were collected from taps connected to the Village water supply at ten (10) businesses that also have auxiliary wells. While four (4) locations served by the Village's public water system were discovered to have physical cross-connections with plumbing connected to auxiliary wells, none of the samples collected from the Village system at these or any of the other businesses with auxiliary wells tested positive for bacteriological contamination.

Transient Non-community Public Water Systems

On August 23, 2004, Ohio EPA initiated an investigation to collect water samples from all transient non-community public water systems located on South Bass Island. Efforts were made to collect both raw (untreated) and treated water samples that were analyzed for total coliform and *E. coli* bacteria. Raw water samples and some treated water samples were analyzed for *Campylobacter*. Most of this sampling was completed by August 30, 2004.

Total coliform, fecal coliform and *E. coli* bacteria are a very specific family of indicator organisms that are susceptible to inactivation/removal with disinfection. Ohio EPA wanted to get raw water samples and actual distribution samples from the water systems to see if there was any microbiological contamination. There is a common local practice of shock-chlorinating wells at regular intervals (e.g. monthly). Also, many systems have chlorination treatment systems with unknown maintenance records and reliability. In many instances, investigators had difficulty collecting raw water samples due to the lack of raw water taps and the common practice by businesses of shock-chlorinating their wells. There was a possibility that source water contamination was being masked by the various chlorination activities.

Ohio EPA staff also conducted a detailed reconnaissance of South Bass Island for other potential facilities meeting the definition of a public water system but not identified in Ohio EPA records. A total of seven (7) businesses were determined to be public water systems that were not in Ohio EPA records.

Sampling for Additional Pathogens and Indicator Organisms

On August 30 and 31, 2004, representatives from the Center for Disease Control (CDC) conducted sampling at public water systems and private water wells where initial sampling by Ohio EPA or ODH had *E. coli* positive results and at the Village of Put-In-Bay. Samples collected from these wells were analyzed for: *E. coli*, fecal coliform, *Campylobacter*, Somatic coliphage, F-specific coliphage, *C. perfringens*, *Salmonella*, *Cryptosporidium*, *Giardia*, *Norovirus*, *Adenovirus* and *Enterovirus*. Several of these organisms were analyzed using multiple laboratory techniques.

Beginning on September 15, 2004, Ohio EPA in cooperation with Michigan State University (MSU) initiated an investigation of all other public water systems not sampled by the CDC. MSU analyzed samples for: total coliform, *E-coli*, *Campylobacter*, Somatic coliphage, F-specific coliphage, *C. perfrigens*, *Cryptosporidium*, *Giardia*, *Salmonella*, *Norovirus* and Enterococci. Additionally, portions of the water samples collected were provided to laboratories at the CDC in Atlanta to be analyzed for: *Campylobacter*, *Giardia* and *Cryptosporidium* DNA. Sampling was completed September 21, 2004.

In total, 112 samples were collected from transient noncommunity public water systems.

- Of the eighteen (18) transient non-community water systems sampled, all had at least one positive detection of an indicator organism in samples collected from their well(s). Sixteen (16) have had positive detections for organisms other than total coliform bacteria.
- Among the sixteen (16) systems that tested positive for indicators other than total coliform bacteria, *E. coli* and *Campylobacter*-like DNA are the most frequently detected organisms.
    - Twelve (12) tested positive for *E. coli*;
    - Twelve (12) tested positive for *Campylobacter*-like DNA (further speciation yielded four (4) *Campylobacter jejuni*, one (1) *Campylobacter upsaliensis* and *Arcobacter butzleri*, six (6) *Arcobacter butzleri*, and one (1) *Acinetobacter rhizosphearae*);
    - Seven (7) tested positive for Enterococci;
    - Six (6) tested positive for Somatic coliphages;
    - Four (4) tested positive for fecal coliforms, *Salmonella* DNA and/or *Cryptosporidium* DNA;
    - Three (3) tested positive F-specific coliphages;
    - Two (2) tested positive for *Campylobacter*-like culture (further speciation yielded one (1) *Campylobacter jejuni* and one (1) *Arcobacter butzleri*);
    - One (1) system tested positive for *C. perfrigens*, *Giardia* cysts, *Adenovirus* and/or *Enterovirus.*

The location and results of the sampling for total coliform, fecal coliform and *E. coli* for transient non-community public water systems (TNC PWSs) are presented in Figure 23. The frequent positive results for *E. coli* and fecal coliform and other microbiological parameter detections confirm the widespread microbiological contamination of ground water across South Bass Island.

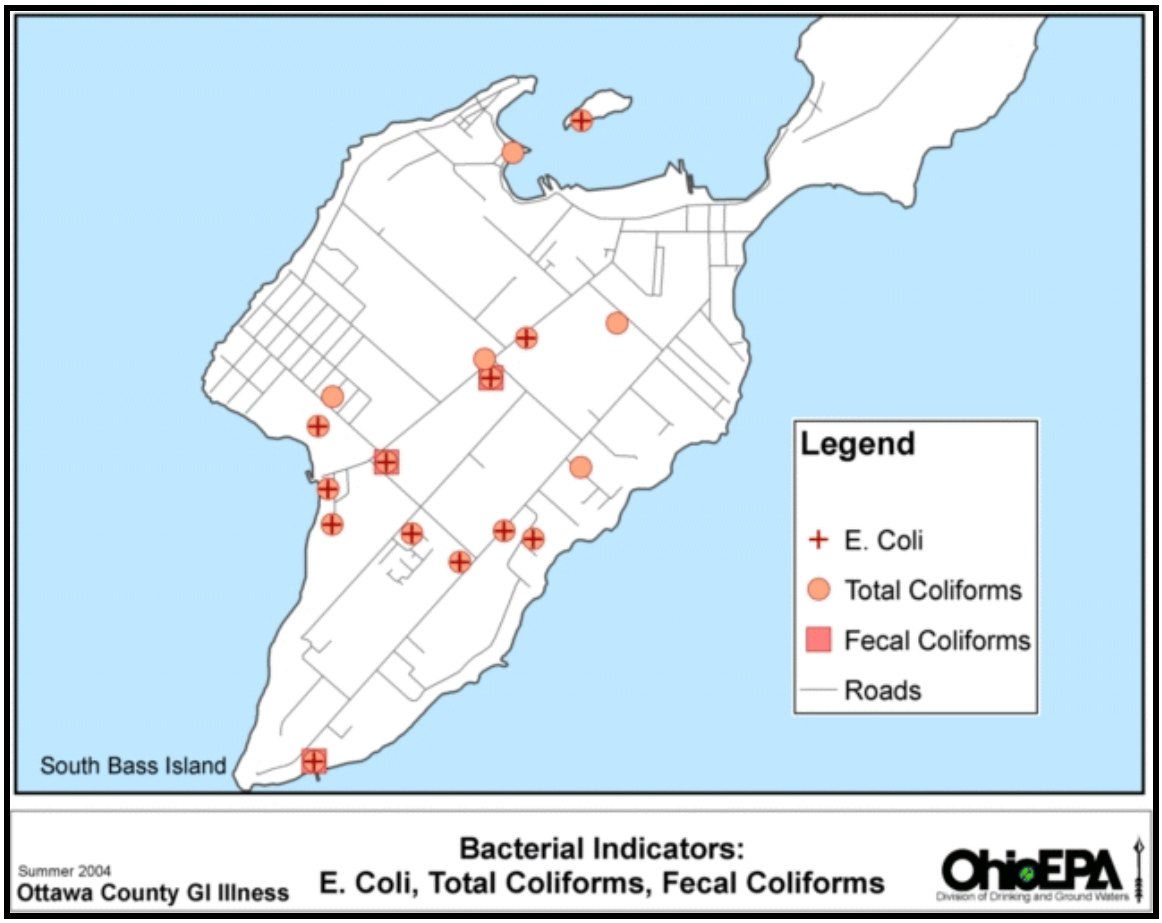


Figure 23. Microbiologic sample results for TNC PWSs on South Bass Island.

South Bass Island Conclusions

Results of samples collected from public water systems during Ohio EPA's investigation confirm there is substantial microbiological contamination of ground water across South Bass Island. The Ohio Department of Health came to the same conclusion for the private wells on South Bass Island. The conclusion was expected considering the sensitive aquifer setting and the large, seasonal population pressure. Other areas in Ohio have similar hydrogeologic setting and are probably also sensitive to ground water contamination. There is a priority to identify these areas to help protect public health.

These results have resulted in extensive efforts to ensure public water systems on the Island are providing safe drinking water. The Village of Put-in-Bay is implementing measures to ensure their public water system is not compromised by connections with contaminated auxiliary wells. Transient noncommunity public water systems are adding treatment or finding an alternative sources of water. Ohio EPA believes a community public water system and centralized sewer system for the entire Island are the most reliable solutions to ensure public health protection and to address environmental impacts documented by the 2004 South Bass Island Investigation. Ohio EPA will continue to assist business owners and local officials in identifying long-term solutions to ensure the provision of adequate supplies of safe drinking water to individuals living on and visiting the Island. Ohio Department of Health and the Ottawa County Health Department are working with residents to provide safe drinking water for private homes. The reader is referred to the Ohio Department of Health web page and the Gastrointestinal Illness on South Bass Island Report appendices for details on the investigation, enforcement actions, and ongoing ground water protection activities that focus on the public and private water systems on South Bass Island.

ORGANIC CONTAMINANTS IN OHIO'S GROUND WATER

Introduction

The primary objective of the Ambient Ground Water Monitoring Program (AGWMP) is to collect raw water quality data to characterize the ambient ground water quality across the state, the source water for ground water based Public Water Systems (PWSs) in Ohio. Ground water in some PWS and ambient wells exhibit impact of VOC contamination at low concentrations. The distribution of VOC detections and the parameters detected within PWSs are useful indicators of ground water quality. In this section, the PWS compliance data and the AGWMP data are used to identify VOC impacts to characterize Ohio's ground water quality and to further delineate and evaluate sensitive aquifers.

Data Sources

The PWS compliance data and the AGWMP data are used to identify ground water systems in Ohio that have been impacted by VOCs. These two data sets are described in detail in the Ohio Ground Water Characterization Program description starting on page 9 of this document. Table 9 provides a comparison of the VOC data in these two data sets.

Table 9

Comparison of Public Water System data and Ambient Ground Water Monitoring data sets.

	Public Water Systems	**Ambient Stations**[1]
PWSs Sampling for VOCs[2]	~2,000	~200
Date range[3]	1991 to present	1985 to present
Treated/Untreated	Mostly treated water	All untreated water
Number of results	~380,000	~84,000
Number of detections	~7200	~260
Detection Percentage	1.9%	0.3%
Sampling frequency	Monthly to every 3 years	Every six to 18 months

[1] 83 % of the Ambient stations are also public water systems.

[2] For Public Water Systems, only Community and Non-Transient, Noncommunity systems are routinely sampled for regulated VOCs. Ambient stations are sampled for 61 VOCs (20 regulated) using EPA method 624.

[3] Pre-1991 data was screened from the PWS data set to maximize data quality.

Data Filter

There is a risk that a false positive VOC result may identify a PWS as impacted when it is not. Criterion for identifying impacted PWSs or wells are needed to ensure our confidence in identification of impacted PWSs. The *State of Ohio Source Water Assessment and Protection (SWAP) Program Ground Water Susceptibility Analysis Process Manual* (2003) states that a public water system will be considered susceptible to contamination if the data indicates at least two confirmed results of the same or related compound. The detections do not have to be consecutive. This established approach is understood to be conservative and was used as the basis for determining VOC impacts. Additionally, the following guidelines were also applied:

- Trihalomethanes (chloroform, bromoform, bromdichloromethane, dibromochloromethane) were removed in the public water system compliance data because they are byproducts of the disinfection process. They were kept in the Ambient data set because the AGWMP samples untreated water, where they can be an important water quality indicator.
- Common plasticizers, rubberizers, and lab contaminants were ignored in both data sets. These include:
    - di(2-ethyhexyl) phthalate
    - bis(2-ethyhexy) phthalate
    - di(2-ethyhexyl) adipate
    - dichloromethane

For the public water systems, Ohio EPA staff geologists completing the drinking water source assessment reports reviewed each system's water quality data to determine if it met the criteria of a VOC impact. This information was tracked in a source water assessment database (SWAPTrack), which was used as a filter to establish public water systems which had VOC impacts.

The Ambient data set of VOC detections is fairly small (0.3 %). This data set was evaluated manually using the same criteria as for the PWS data, except that the trihalomethanes (THMs) were not removed because the water sampled was untreated. Detections of THMs in untreated water could be an indication of treated water recharging the aquifer from residential or commercial irrigation (e.g. lawns, golf courses). Other possibilities are that the presence of THMs in raw water samples indicates that the sampled well was disinfected recently or natural production of chloroform in soils (Ivahnenoko and Barbash, 2004).

State-Wide Analysis

The public water systems and the Ambient stations that exhibited VOC impacts using the previously mentioned data filter were plotted on a state-wide map in relation to aquifers that are considered sensitive to anthropogenic influences (Figure 24). Sensitive aquifer settings are susceptible to contamination because these settings lack a protective geologic layer or barrier between the ground surface and the aquifer. Sensitive aquifer settings include buried valleys, beach ridges, outwash deposits, valley fill, alluvial deposits, thin uplands, and thin lacustrine deposits (thin = < 25 feet) as presented in the ODNR State Aquifer Maps (ODNR, 2000). Although there appears to be a correlation between the VOC impacted sites and sensitive aquifers, the state scale in Figure 24 is too small to evaluate the correlation with accuracy.

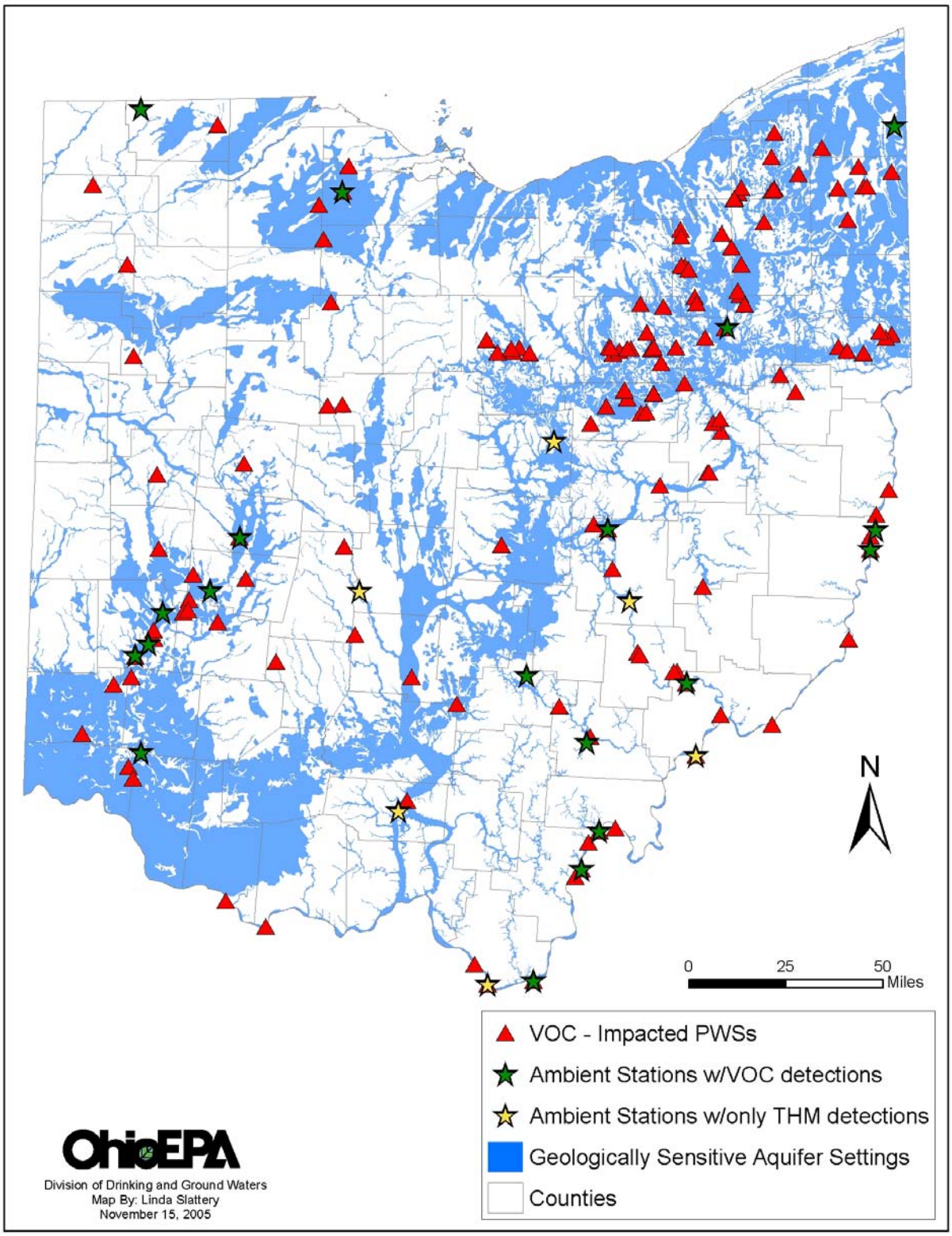


Figure 24. Public water systems and Ambient ground water monitoring wells impacted by VOCs.

Correlations between VOC impacts and sensitive aquifers were established by comparing the percentage of impacted sites within sensitive settings to the percentage within non-sensitive settings:

1,949 active Community and NTNC PWSs

1,057 sites are located within sensitive aquifer settings;
of these1,057 sites, 109 exhibit VOC impacts **(10 %)**
842 sites are located outside of sensitive aquifer settings;
of these 842 sites, 35 exhibit VOC impacts **(4 %)**

204 active AGWMP wells

146 sites are located within sensitive aquifer settings;
of these 146 sites, 23 exhibit VOC impacts **(16 %)**
58 sites are located outside of sensitive aquifer settings;
of these 58 sites, 2 exhibit VOC impacts **(3 %)**

This analysis reveals that the percentage of VOC impacted sites within sensitive aquifer settings is greater, 10 % and 16 % respectively for PWS and AGWMP wells, than those of impacted sites located in non-sensitive aquifer settings, 4 % and 3 %, respectively. The majority of the public water systems (56%) and the Ambient wells (72%) fall within sensitive aquifer settings. PWSs in sensitive aquifers are 2-5 times more likely to be impacted by VOC contamination than those in non-sensitive aquifer settings.

Figure 25 illustrates VOC impacted systems in a portion of the Great Miami Buried Valley aquifer system in southwestern Ohio. This figure is based on a digital elevation model in which the topography is represented in shaded relief and the sensitive aquifers are represented by the blue and green overlays. Note that all of the VOC-impacted sites are within the buried valleys, blue overlay. The PWSs located above the valleys in the green overlay occur in the areas of thin till overlying carbonate bedrock. Unlike nitrates, VOCs are generally not detected in these sensitive, thin uplands. This may result from the limited number of VOC sources present in the upland areas.

Thirty-five (35) public water systems that had VOC impacts did not fall within a sensitive aquifer setting. Upon closer examination, many of these systems had wells near sensitive aquifers. Approximately 30% of these public water systems have their drinking water source protection (SWAP) area overlapping a sensitive aquifer setting. Thus, at these sites it is possible that recharge travels vertically through sensitive geologic settings, then horizontally towards pumping wells once it reaches the production aquifers. Other possible reasons for VOCs impacting wells in non-sensitive settings include:

- Mapping discepancies: Aquifer setting, as indicated by ODNR mapping, may indicate a non-sensitive setting, but actual well logs may contradict this larger scale mapping. For example, the Village of Fayette is indicated on ODNR aquifer maps as situated in a complex till setting while actual PWS well logs describe continuous sand and gravel throughout the boring.

- Well construction: Well construction was not reviewed in this study, but isolated cases of poor well construction or deteriorated casing can easily account for some of the VOC impacts.

- Long term VOC source: The presence of a persistent VOC source allows VOCs to be transported with local recharge over time, and may eventually be transported through the local hydrogeologic barriers to contaminate local aquifers.

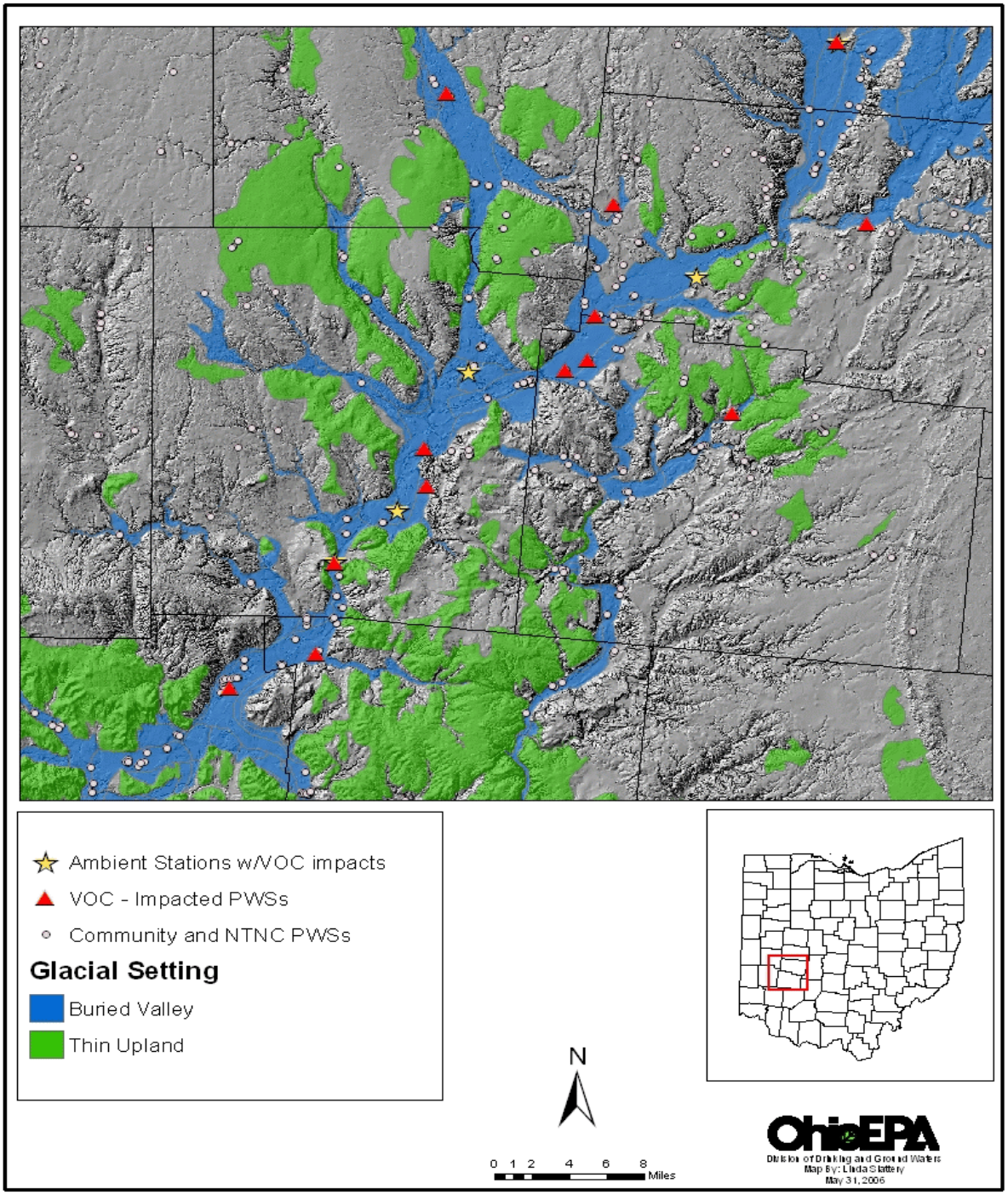


Figure 25. Area in southwestern Ohio showing locations of VOC-impacted systems and stations, along with all active public water systems, in relation to sensitive aquifer settings.

Population Density

Data obtained from the 2000 US Census survey shows that Ohio's high population centers are located mainly in the sensitive aquifer settings (Figure 26). It makes sense that cities would prosper at these locations since water for drinking and industry is plentiful. Since the VOC sources predominantly overlie sensitive aquifers, it is not surprising that the majority of VOC impacts occur in areas of high population densities.

However, the positive correlation between VOC impacts in drinking water and high population density is generally valid only in those areas where ground water is the major drinking water source. For example, Figures 24 illustrates that the Cleveland and Toledo metropolitan areas contain very few VOC impacted PWSs. This apparent contradiction has to do with the fact that these cities (and most others along Lake Erie) extract their drinking water from Lake Erie, not ground water resources. This report reviews VOC impacts in ground water based PWSs and is not a comprehensive analysis of all potential VOC impacts in the state.

Land Use

VOCs are produced and used primarily in urban land use settings (such as commercial, industrial, transportation, and residential). Therefore, it is expected that wells in these urban land use settings will be more prone to VOC contamination. To assess this expectation, land uses within drinking water source protection (SWAP) areas located in sensitive aquifer settings were evaluated (Table 10).

Table 10

Percent Land Use† in Drinking Water Source Protection Areas located in Sensitive Aquifer Settings

	Commercial Industrial Transportation	**Residential**	**Agricultural**
PWSs with No VOC Impacts	4	12	61
PWSs with VOC Impacts	10	19	49

† *Land use data obtained from the 1994 USGS National Land Cover Dataset (Vogelmann, et al., 2001).*

For drinking water areas with VOC impacts (red row), the area of the commercial, industrial and transportation land use class was 2 to 2.5 times that of the non-VOC impacted drinking water areas (blue row). This finding is significant in two ways: first, it demonstrates the potential burden this land use class places on ground water quality. This result supports previous studies which conclude that commercial/industrial/transportation land uses are most likely to contaminate ground water with volatile organic compounds. The effect of this land use class area is evident even though the total area of commercial, industrial and transportation land use is not great (<11 %). This indicates that a large concentration of sources is not required to contaminate an aquifer. Secondly, it indicates that the PWS data, which are collected for the express purpose of regulating compliance at PWSs, can be used to reveal the effectiveness of other program elements such as the drinking water source protection areas and land

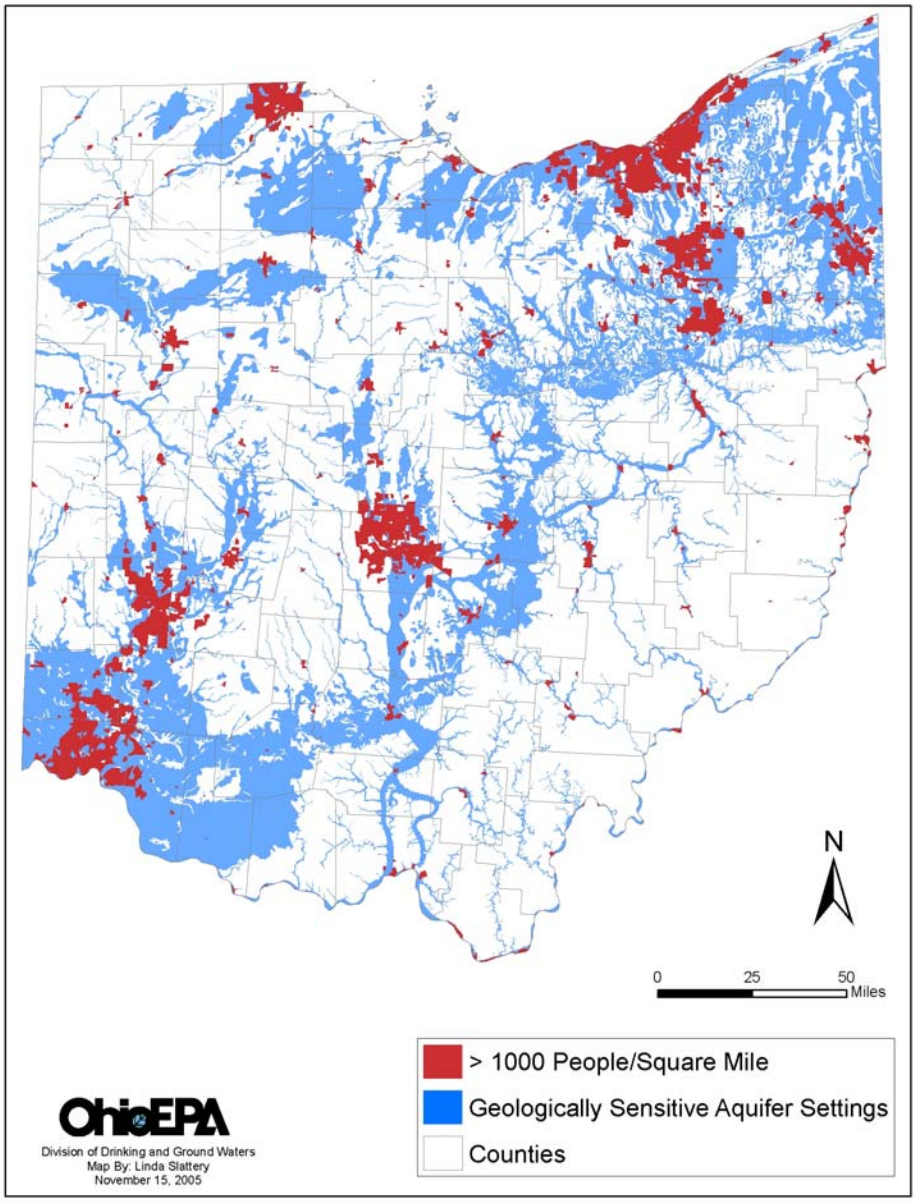


Figure 26. Population density and distribution of sensitive aquifers.

use class determinations. These data provide at the very least a conservative portrayal of ground water contamination for the state of Ohio, despite the fact that the data were not generated with this purpose in mind.

The residential land use also increases (by about half) between the impacted and non-impacted areas. This is probably because people tend to live close to commercial activities. Agricultural land use decreases approximately 10-20% in the impacted areas. PWSs located in areas of high agricultural uses would be more likely to have nitrate impacts than VOC impacts.

Relationship Between VOCs and Nitrate

Ohio is an extremely rich agricultural state, with widespread nitrogen sources. Ohio is also an industrial state, with thousands of potential source locations for VOC releases to the environment. This study has revealed that ground water, when vulnerable to point source organic contamination, is not automatically at risk for non-point source contaminants such as nitrates. The behavior and interaction of these two contaminants is complex. Numerous man-made and natural factors compound even the most simplified explanation for the presence or absence of either contaminant type in a given setting. In this study, we have used empirical observations, along with their spatial relations to geologic setting, aquifer type, and well attributes, to reveal broad relations between the presence of VOCs and nitrates, and the geologic framework in which they are found.

Of the 144 PWSs that have VOC impacts, only 22 (15 %) also had nitrate impacts. A nitrate impact is defined as two or more nitrate detections at 2.0 mg/L or greater. In Figures 27 and 28, the red triangles are the PWSs with VOC impacts, the tan circles are the PWSs with nitrate impacts, and the green squares are the PWSs that have both VOC and nitrate impacts. The impacted source water generally exhibit a close association with the sensitive aquifers, but the red triangles (VOC impact) and tan circles (nitrate impact) are more numerous than the green squares (VOC and nitrate impacts). Clearly, nitrate is not a good indicator for VOC contamination. The previous population and land use discussions suggest that the general distribution of point sources for VOC contamination and non-point sources for nitrate contamination help to explain this poor relationship. VOC contamination is more likely in the developed areas and nitrate contamination more likely in agricultural areas and areas with a high density of septic systems. In Figure 28, the nitrate contamination present in the areas of thin upland till (green overlay), where agriculture activities dominant the land use activities, supports the land use or source control of the VOC- nitrate association.

The lack of correlation between nitrate and VOC contamination in ground water is influenced by external factors, such as the presence of a micorobial community able to thrive on the additional VOC as a food source. Past studies done by Ohio EPA (Ohio EPA, 2002) indicate that nitrate is typically not found at depths greater than 70-75 feet in Ohio. This apparent extinction depth is thought to be related to a more (geochemically) reduced environment, in which the presence of nitrate (NO_3) is limited by denitrification. In wells with VOC impacts, the average casing length is 18 feet greater and the average well depth is 50 feet deeper, than in wells with nitrate impacts only (Table 11). The presence of VOCs provides an excellent food (electron and carbon) source, and subsequent bacterial activity consumes the available oxygen, thus lowering its redox potential. This process is a significant contributor to the reduced nature of VOC impacted ground water as the consumption of oxygen and other electron donors drives the denitrification process, eliminating the presence of nitrate.

Table 11

Well Construction Data for Wells with VOC Impacts, and both VOC and Nitrate Impacts.

	Average Casing Length (ft)	**Average Total Well Depth (ft)**
Nitrate and VOC impacts	51	86
VOC impacts only	69	139

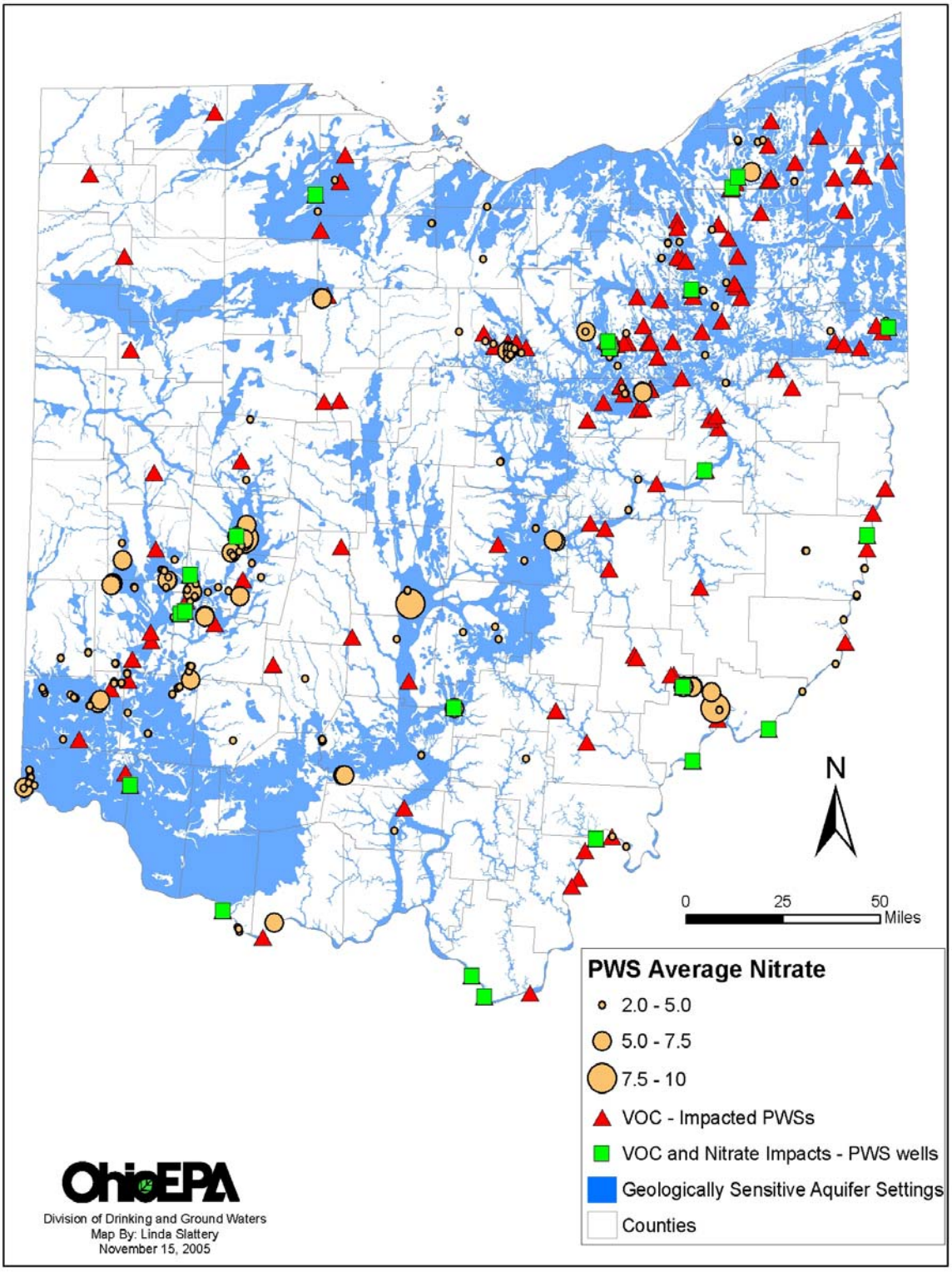


Figure 27. Mean Nitrate and VOC and Nitrate impacts in PWSs.

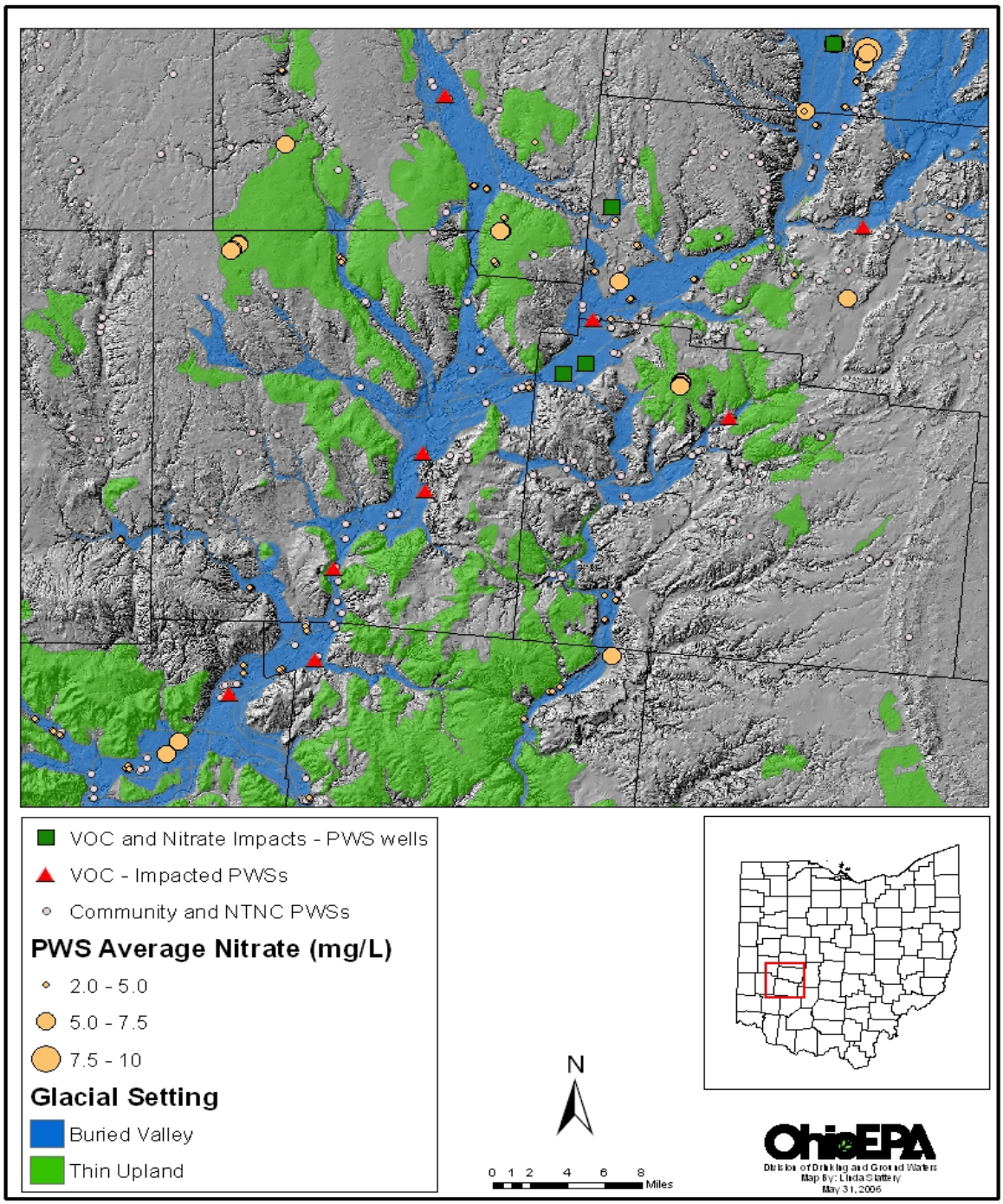


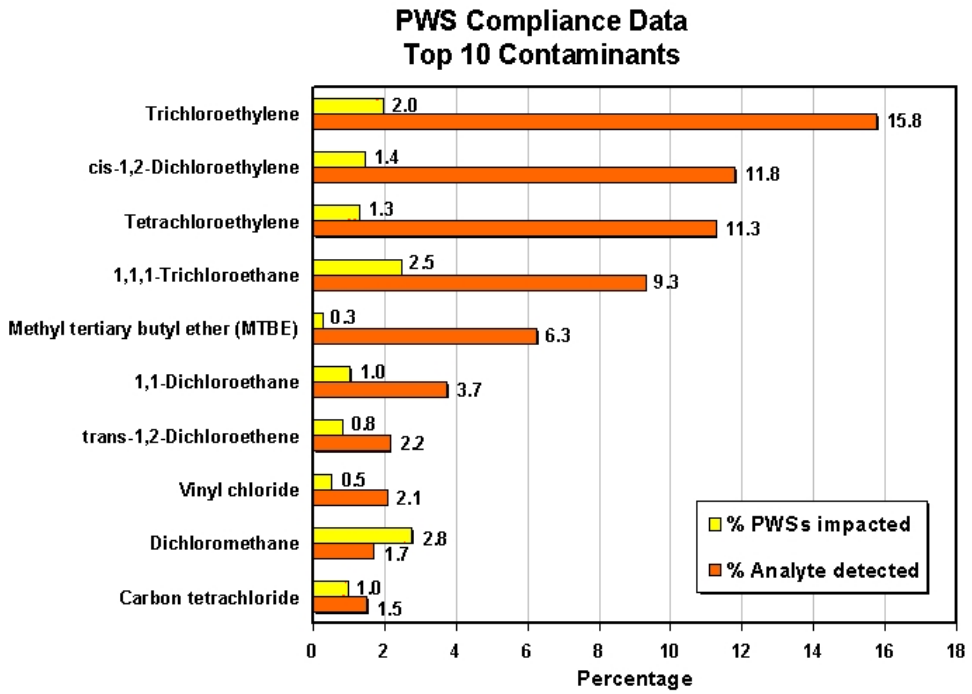
Figure 28. Portion of GMR with mean nitrate, VOC, and nitrate impacted PWSs.

Most Frequent VOC Contaminants

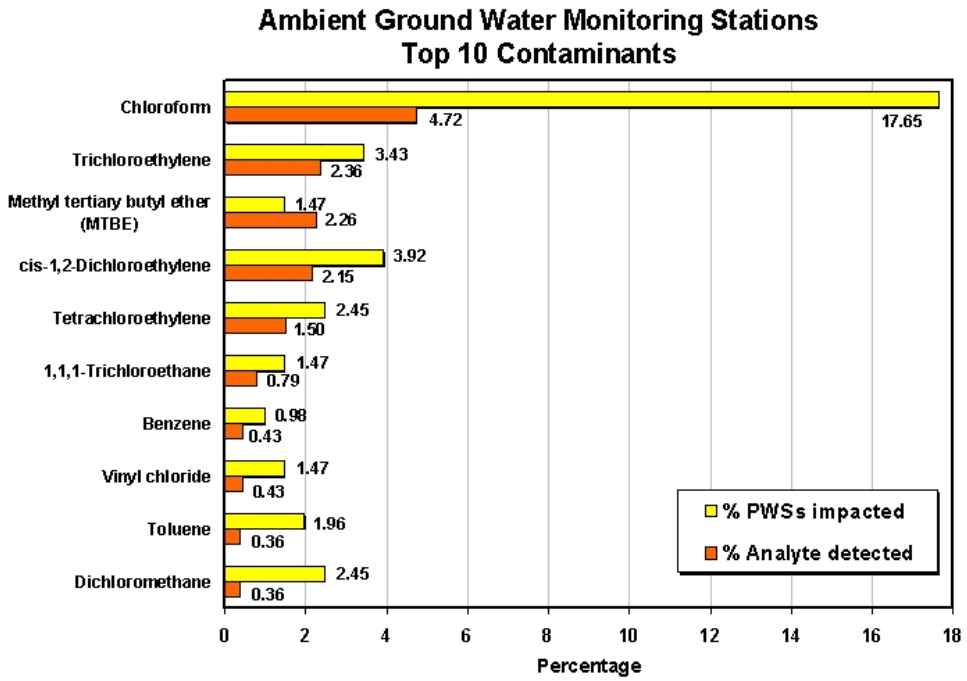
Figures 29A and 29B show the detection frequencies of the ten most common VOCs detected in the PWSs and the Ambient stations, respectively. Although data from PWSs represent treated water and data from ambient sites reflect untreated water, the observed results are similar. The vast majority of VOCs found in Ohio's ground water are solvents (PWS: 87%; Ambient: 73%). Solvents have a wide variety of uses, such as for house hold cleaners, chemical processing, paint stripping, dry cleaning, metal cleaning, and specialty adhesives applications. In contrast, hydrocarbons were detected infrequently (PWS: 4%; Ambient: 12%).

The PWS VOC sample detection rate far exceeds the percent of systems impacted. This is reversed for the Ambient data, where the rate of detection is far less than the percent of systems impacted. This difference results from the sampling structure of the PWS compliance data. If a PWS gets a significant VOC detect, the sampling frequency is immediately increased to help define the magnitude of the problem and to ensure the protection of public health. Thus, more samples will be collected at PWSs with VOC detections as reflected in Figure 29A. The Ambient Ground Water Monitoring Program does not automatically increase the sampling frequency as result of detections since it is not a regulatory program.

Chloroform is frequently detected in the Ambient data (Figure 29B). Chloroform forms when water containing organic matter is oxidized for disinfection. Chloroform was filtered out of the PWS data set for this analysis because the PWS data represents treated water, which includes disinfection by- products. The presence of chloroform in the untreated Ambient water may provide insight into the movement of organics during recharge of aquifers. The positive chloroform results may be attributed to treated water recharging the aquifer through the watering of lawns, leaking storm drain or sewer infrastructure, the disposal of treated wastewater, or from natural production of chloroform in soils. It is also possible that the Ambient station owners (most of which are PWSs) shock chlorinated their wells shortly before sampling, either by coincidence or upon notification that Ohio EPA would be collecting an Ambient sample. The sampling protocol now includes requesting information from the operator when they last disinfected the well.



29 A



29 B

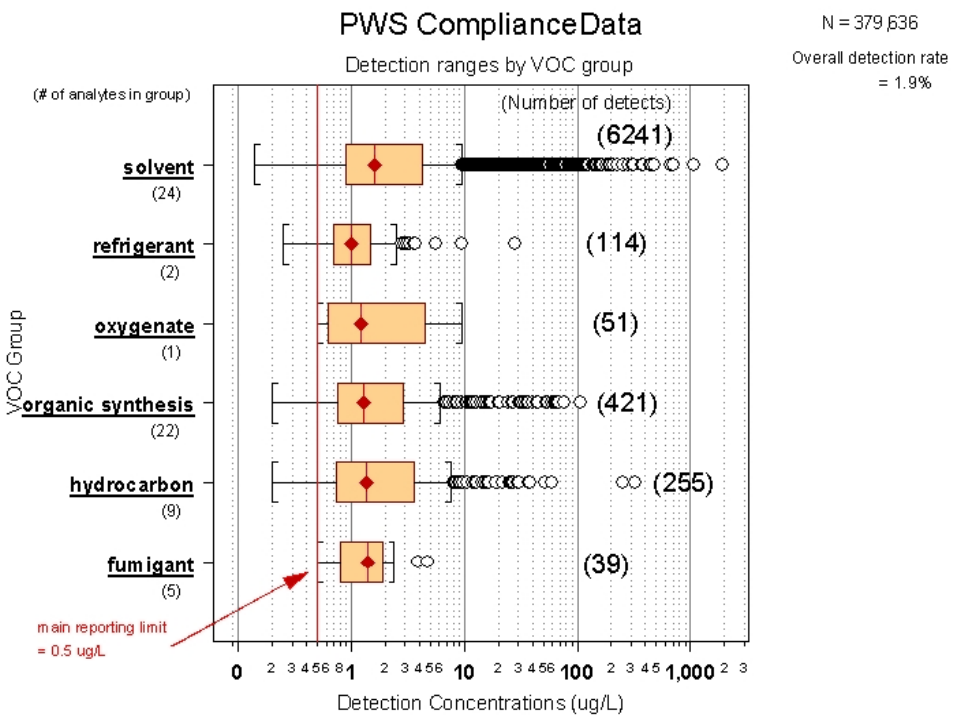
Figure 29. Ten most common detected VOCs found in the public water systems using ground water (29A) and the Ambient ground water monitoring stations (29B).

Figures 30A and 30B display "box and whisker" plot distributions of VOC detections for PWSs and for AGWMP wells respectively. VOC analytes are bundled into groups based on their most significant industrial usage. Figure 30A represents PWS compliance data from the early 1990's to the present, and comprises a database with a total of 379,636 records of VOC determinations. Of this total, about 7,200 records record VOC detections (1.9% detection rate) after excluding THM detections. The number of analytes bundled into each VOC group is indicated below that VOC group name and the number of detections comprising each box plot is indicated in parentheses to the right of each box plot. Outliers are indicated by open circles, and the median is shown with a red diamond. Please note that the horizontal scales are logarithmic and different for Figures 30A and 30B. These figures document the dominance of detections within the solvent group. The group with the next highest number of detections (both figures) is the organic synthesis group, followed by the hydrocarbon group.

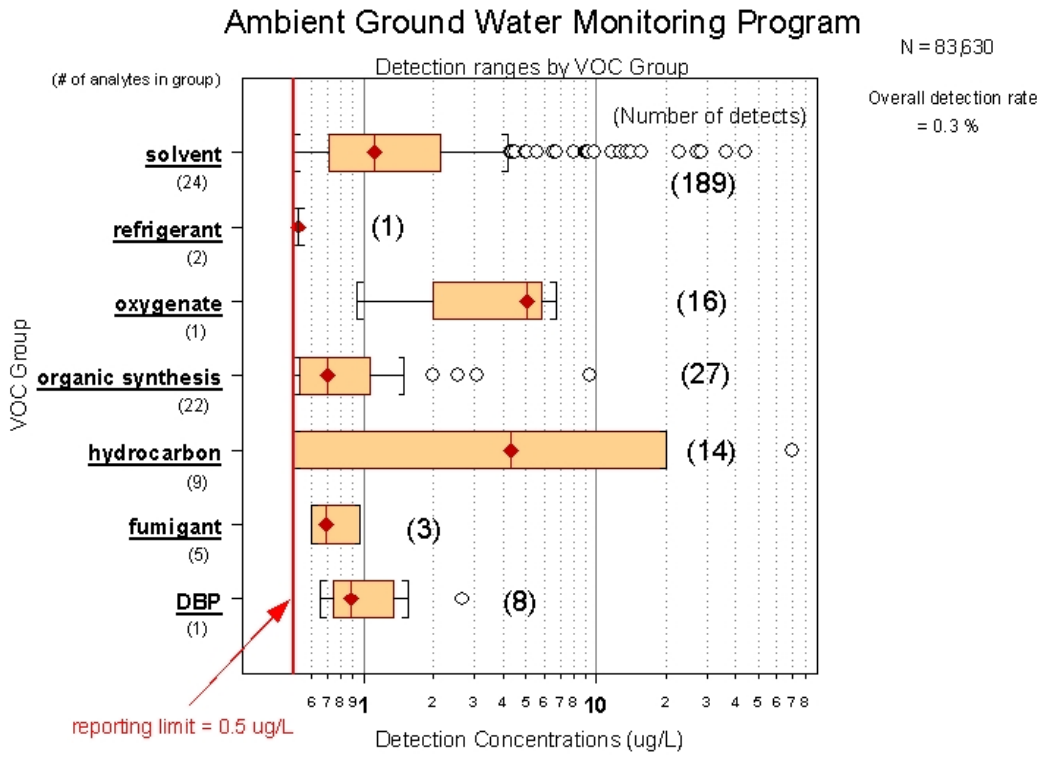
Figure 30A (PWS compliance data) illustrates that the 75th percentile (the rightmost "side" of the box) for each parameter is below the common maximum contaminant level (MCL = 5.0 ug/L, vinyl chloride has the lowest MCL of 2.0 ug/L) for a standard VOC scan. MCL exceedance determinations are not possible from these data since they 1) derive from mixed PWS sites; 2) are not individual parameters (as MCL determinations require) and 3) reflect individual results, not yearly averages (as MCL determinations require).

When VOCs are detected at a PWS, sampling frequencies may be increased to provide accurate determinations of potential MCL exceedances for individual PWSs to protect public health.
The high number of sample data observed for the solvents or other parameter groups results from these increased sampling requirements. Some PWSs provide treatment for removing VOCs.. Since the compliance data is for finished or treated water, the elevated levels of VOC comtamination requiring removal may not be represented in the compliance data.

Comparing Figures 30A and 30B, the only parameter groups for which the boxplot's 75th percentile in 30B exceed the 75th percentile of Figure 30A are the oxygenate and hydrocarbon groups. Although hydrocarbons are used extensively in Ohio, they volatilize quickly, are rapidly consumed by bacteria, and exhibit immiscibility or low solubility, which helps to explain their relatively low detection percentages (PWS: 4%; Ambient: 12%). The general treatment processes at the public water systems tends to further volatilize hydrocarbons, which helps explain why they are detected in the raw Ambient water samples three times more often than in PWSs, in spite of the sampling bias towards impacted systems in the PWS data. The range of hydrocarbon concentrations detected in PWSs is tight compared to the Ambient system; the 25th to 75th percentile concentrations range from 0.7 to 1.4 ug/L (PWS), compared 0.5 to 20 ug/L (Ambient). The oxygenate MTBE is one parameter for which the AGWMP collected extra samples to help determine the significance of contamination at a couple of sites. MTBE is discussed in more detail in the next section.



30 A



30 B

Figure 30. Box plots showing the range of detections by contaminant group for the public water systems using ground water (26A) and the Ambient ground water monitoring stations (26B).

MTBE

Methyl *tert*-butyl ether (MTBE) is an oxygenate that has been added to gasoline since the early 1990's. Although MTBE is not added to gasoline in Ohio, it is added in surrounding states. Ohio EPA initially analyzed public water system distribution water for MTBE in February, 2000. The Ambient wells were first analyzed for MTBE in the Fall 2000 sampling round. Table 12 lists the two Ambient stations and the six public water systems that have detected MTBE in treated or untreated ground water samples.

Table 12

Detections of MTBE in Ground Water Samples from Ambient Wells and PWSs[1]

	Site	County	Number of Detections	Range of Detections (ug/L)
Ambient Station Samples	Village of Dresden (well 1)	Muskingum	11	1.49 - 6.73
	Village of Proctorville (well 1)	Lawrence	2	0.94 - 1.46
Public Water System Compliance Samples	Bell Stores South Citgo	Wayne	1	0.7
	Village of Coal Grove	Lawrence	1	0.8
	Village of Dresden	Muskingum	24	0.63 - 9.51
	Village of McConnellsville	Morgan	10	0.5 - 1.0
	Village of Proctorville	Lawrence	1	1.8
	Rubber Associates	Summit	1	1.3

[1] Ground water from Ambient stations is raw water from a single well, whereas ground water from PWSs may be treated and/or blended with ground water from several wells. All detections are from wells located in southeastern Ohio, with the exception of *Bell Stores South Citgo* and *Rubber Associates*.

The Village of Dresden in Muskingum County has had the most frequent detections and highest concentrations of MTBE in both the Ambient and PWS wells. Additional samples were collected at Dresden by the AGWMP to help determine the significance of the MTBE detections. Figure 31 shows a 5-year time-series plot of MTBE detections at the Village of Dresden. Since this Ambient station was sampled at regular intervals (every six months), the plotted compliance data was selected based on the sampling date that was close to the Ambient sampling date. The compliance samples from treated water are on average 20 % to 25 % lower in concentration than the untreated Ambient samples, with both sets following the same general trend. The Village of Dresden has several wells and the diversion of the Ambient data and the PWS data in 2002 (Figure 31) suggests that the PWS was producing water from a well or mix of wells producing dilution of the MTBE contamination. Dresden also has low-level detections of 1,1,1-trichloroethane (< 1 μg/L), which is a petroleum derivative.

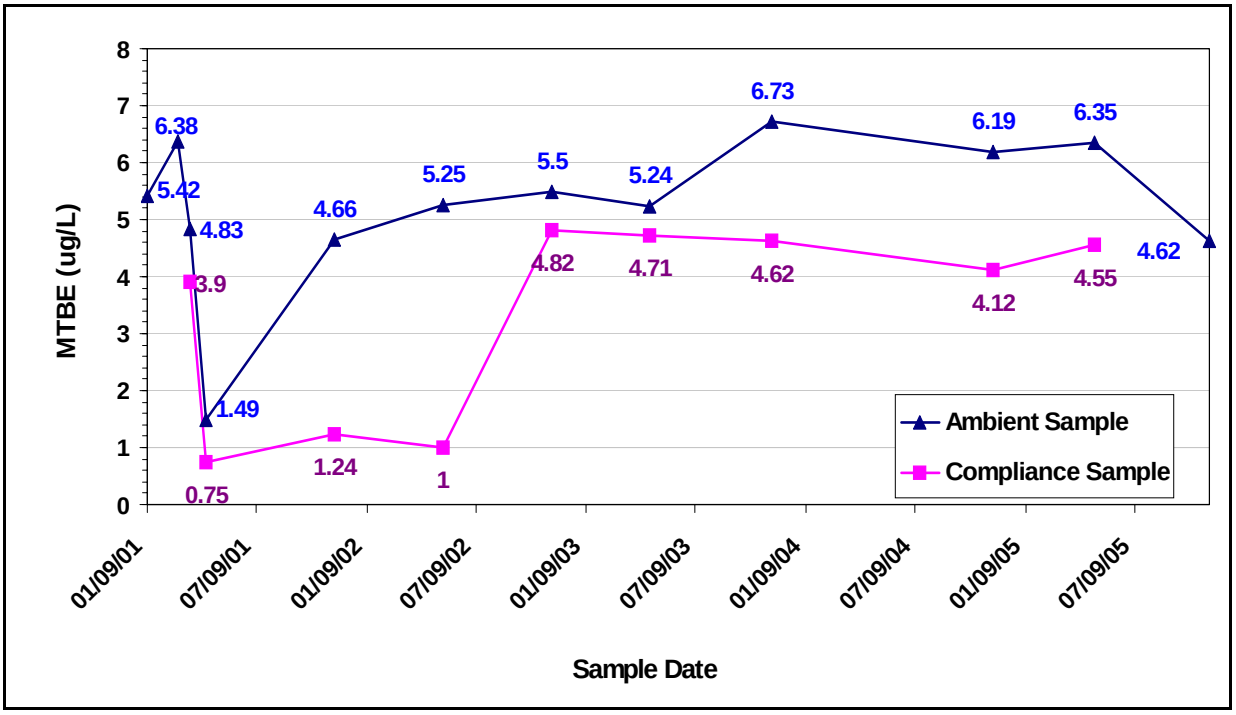


Figure 31. MTBE detections at the Village of Dresden.

Summary

Volatile organic compounds have been regularly monitored in treated water from Ohio's Public Water Systems (PWS) since the promulgation of the National Primary Drinking Water Regulations Phase II rule in January, 1991. Review of this data set includes analysis of some 50,000 VOC samples from approximately 1,900 PWSs. Untreated ground water in Ohio has been monitored since the mid 1980s through the Ambient Ground Water Monitoring Program (Ambient) and currently comprises approximately 1,300 VOC analyses from 228 sites. Approximately 85% of the Ambient stations are PWSs, with the remaining sites being industrial or residential wells. A reporting level of 0.5 ug/L has been in consistent use since the early 1990s across both programs. The VOC data sets have been pre-screened to ensure that only certified detections (not transient or false positives) are used in this analysis. This data filtering is consistent with criteria set forth by Ohio EPA Source Water Assessment Program's Susceptibility Analysis. Less than 8% of the PWSs and approximately 12% of the Ambient stations have confirmed VOC impacts to ground water.

The majority of PWS and Ambient wells are located within geologically-sensitive aquifer settings such as sand and gravel aquifers and thin glacial drift over bedrock aquifers. Wells located in sensitive aquifers are 2.5 to 5 times more likely to be impacted by VOCs than those located in more protected aquifers. VOCs are 1.5 to 2 times more likely to impact wells located within areas that contain higher percentages of urban land use (such as commercial, industrial, transportation) within drinking water source protection

areas. Data obtained from the 2000 U.S. census overlain on ODNR Aquifer Maps indicates that high population centers are mainly located in sensitive aquifers. Consequently, it is not surprising that the withdrawal of drinking water in or near population centers, associated with urban land use leads to increased likelihood ofVOC impacts at these PWSs.

Solvent and petroleum compounds were the most frequently detected VOCs in the PWS data set. Chloroform was the most frequently detected compound in the Ambient data set (~20% of the sites), followed by solvents and petroleum compounds. The source for chloroform in untreated water is most probably from recharge of treated water or well disinfection, but chloroform can be generated naturally in soils. Almost 90% of these AGWMP sites with detectable chloroform are located within a sensitive aquifer setting.

Nitrate concentration is not a good predictor of VOC impacts. Only 15% of the PWSs with VOC detections also exhibit elevated nitrate. This poor correlation is partly related to the geochemically reduced nature of the deep ground water associated with VOC contamination as well as the differences in distribution of point (VOC) and non-point (nitrate) sources of potential contaminants.

This broad based, statewide analysis can be enhanced with analyses of the site specific details of the impacted and non-impacted PWSs and Ambient stations. This includes correlating VOC impacts with well depths, casing lengths, till thickness, types of treatment (for PWSs), pumping rates, and well integrity. In addition, associating potential contaminant source data collected for Drinking Water Source Assessments for the public water systems with distance to PWS wells and VOC impacts may identify relationships between types, frequency, or numbers of potential VOC sources within the drinking water source protection areas. Site-specific investigations are necessary to determine the nature of contaminant pathways to ground water and may point to common relationships that will be useful to direct effective ground water protection efforts.

C-8 IMPACTS TO GROUND WATER QUALITY IN SOUTHEAST OHIO

Introduction

A man-made chemical known as ammonium perfluorooctanoate, or C-8, has been widely detected in ground water in the vicinity of DuPont's Washington Works fluoropolymer manufacturing facility located near Parkersburg, West Virginia. C-8, released from this facility, has been found in five Ohio public water supplies that use ground water along the Ohio River causing C-8 exposure through drinking water to more than 37,000 people. It is also known that C-8 has impacted nearly 100 private drinking water wells in the vicinity of Little Hocking, Ohio which is located across the Ohio River from DuPont. Although C-8 is an unregulated chemical and it's health effects on humans are not fully known, these exposures are receiving considerable attention from the U.S. EPA. Site specific investigations are underway near Little Hocking to evaluate the fate and transport of C-8 from the source area and determine the extent and concentration in affected environmental media. In addition, the settlement of a class action lawsuit requires treatment of contaminated drinking water and a study to evaluate potential health impacts to thousands of citizens.

The objective of this section of the 2006 305b Report - Ohio's Ground Water Quality is to describe C-8 and its unique properties, summarize the known impacts to ground water quality in southeast Ohio, and explain the transportation pathways from the source area in West Virginia. The data and modeling results presented in this report have been generated by DuPont and provided to Ohio EPA.

What is C-8?

Ammonium perfluorooctanoate, which is also known as APFO or C-8, is the most commonly used salt of perfluorooctanoic acid (PFOA). The term C-8, which refers to the number of carbon atoms in the molecular structure, is commonly used to refer to both APFO or PFOA. C-8 is a surfactant that is used to make fluoropolymers such as Teflon® which is manufactured by DuPont. Fluoropolymers are high performance plastics that have valuable fire resistance and oil, stain and water repellency properties. Common uses of fluoropolymers include wire and cable insulation, protective finishes on carpet and clothing and the non-stick surface on cookware. Although C-8 is used to make fluoropolymers, it is largely removed during the last steps of polymer production and is not believed to be in final products such as cookware (www.pfoa-facts.com).

C-8 is a water soluble, man-made chemical that does not occur naturally in the environment. However, C-8 is known to persist in the environment (i.e., it does not breakdown easily) and it has even been detected in remote areas of the earth, such as the arctic. Potentially significant sources of C-8 are released to the air, soil and water from fluorochemical manufacturing facilities. In addition, some evidence suggest that other related chemicals, called telomers, may degrade into C-8 over time and may be released to the environment. C-8 has been found in blood of the general U.S. population. However, the routes of human exposure and possible health effects to them are not completely understood. Long term efforts are underway by the U.S. EPA to strengthen the risk assessment of C-8, to evaluate the fate and transport of C-8, and to determine what additional actions, if any, would be appropriate to protect human health (USEPA, PFOA web site).

Impacts to Public Water Supplies in Southeast Ohio

C-8 has been detected in five public water supplies which draw water from the Ohio River Buried Valley Aquifer in Washington and Meigs Counties (Figure 32). This aquifer consists of alluvial sand and gravel deposits generally 40 to 60 feet thick that are overlain with variable thicknesses of silt and clay alluvium.

Public water supply wells in the Ohio River Buried Valley Aquifer may obtain yields greater than 500 gpm. Figure 33 illustrates the locations of the five well fields that are impacted by C-8. These systems with their corresponding distance in river miles from the C-8 source area include: The City of Belpre (4.6 miles upstream), Little Hocking Water Association (0.5 miles upstream), Tuppers Plains/Chester Water District (14.2 miles downstream), and the Villages of Syracuse and Pomeroy (both located 56.9 miles downstream). The Village of Racine, which is located 51.2 miles downstream has not detected C-8 in its water supply wells.

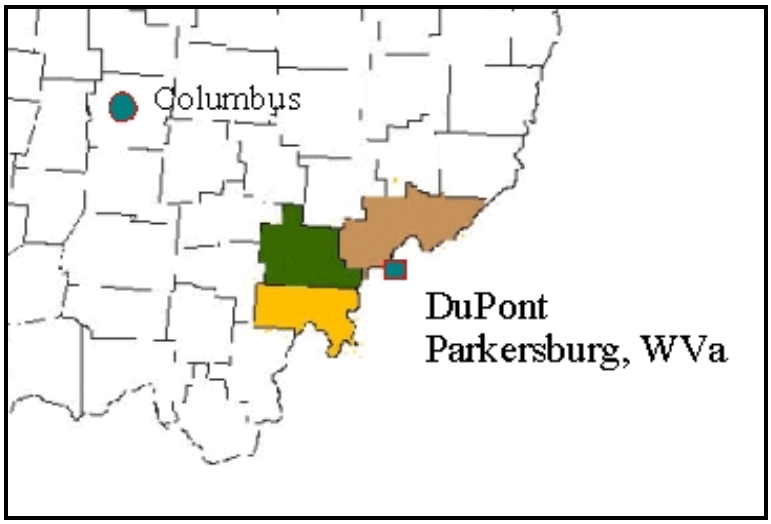


Figure 32. Location of Washington, Athens and Meigs Counties in Southeast Ohio.

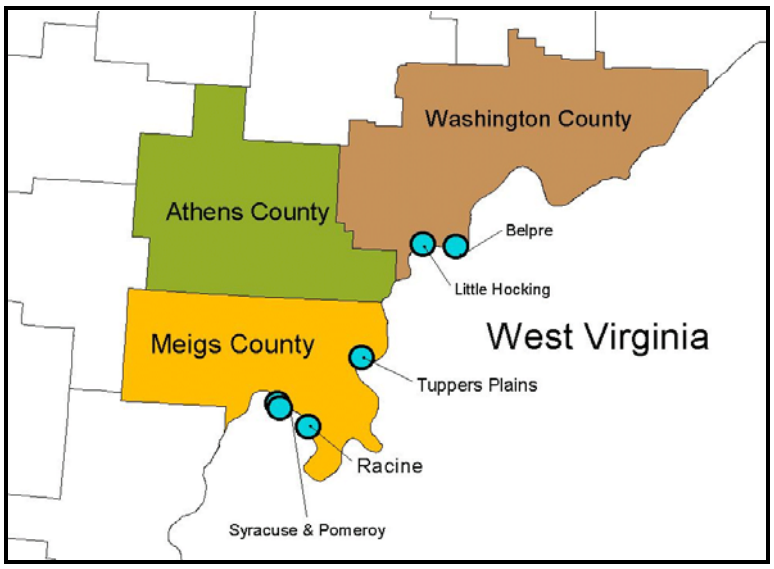


Figure 33. Community PWS wellfields impacted by C-8.

The C-8 data for these five public water supplies are presented in Table 13. C-8 has been detected at less than 1 µg/L in all wells with the exception of the wells operated by the Little Hocking Water Association (LHWA). The LHWA well field is located directly across the Ohio River from the source area in West Virginia, and has the highest concentrations of C-8 - ranging from a low of 0.42 ug/L in well 3 to a high of 18.6 ug/L in well 5. The locations of LHWA wells and detected concentrations ranges of C-8 are shown in Figure 34.

Table 13
C-8 Analytical Results from PWSs ***

C-8 results in ug/L

Sample Date	Post-Treatment	Pre-Treatment	Well #1	Well #2	Well #3	Well #4	Well #5	Well #6
City of Belpre				Population = 7,400				
February-02	0.0818		0.0995	NQ		0.101	0.107	
March-02	0.113		0.13	NQ	0.141	0.133	0.103	
April-02	0.12				0.12	0.114	0.111	
March-05	0.223		0.205	0.235	0.227	0.248		
Little Hocking Water Association				Population = 11,953				
December-01			1.82	3.72	0.844		7.66	
January-02	1.69		1.72	2.97	0.744		6.22	
February-02			2.37	2.07	0.42		5.69	
March-02	2.62		2.99	3.31	0.827		6.57	
April-02	1.93		2.02	3.4	0.783		6.11	
August-02			3.65	4.26	0.952		8.09	
October-02	4.29		3.41	3.98	0.495		8.58	
February-03	2.33		3.38	3.62	0.733		7.16	
May-03	2.54		3.34	4.31	0.921		6.92	
August-03	3.73		3.6	4.39	1.22		8.97	
December-03	1.5		1.68	2.64	0.772		4.67	
February-04	4.33		5.39	5.48	1.87		10.1	
May-04	3.64		4.38	5.07	2.16		8.64	
September-04	5.39		7.53	6.84	2.92		13.4	
November-04	7.2		9.03	9.89	3.9		18.6	
January-05	3.57		4.39	4.78	1.78		9.03	
May-05	5.64		5.88	7.28	2.59		15	
July-05	3.5		4.63	5.74	1.82		11.1	

Sample Date	Post-Treatment	Pre-Treatment	Well #1	Well #2	Well #3	Well #4	Well #5	Well #6
Tuppers Plains/Chester Water District				Population = 14,945				
February-02	0.361	0.372	0.726	0.417	NQ	0.0734	0.201	0.649
March-02	0.358	0.347	0.705	0.327	NQ	0.07	0.201	0.634
April-02	0.363		0.702	0.371				0.62
July-02	0.246	0.24	0.588	0.235	ND	0.052	0.216	0.62
October-02	0.268	0.226	0.486	0.255	ND	0.076	0.229	0.433
February-03	0.291	0.285	0.532	0.356	NQ	0.05	0.297	0.542
May-03	0.287	0.288	0.541	0.35	ND	0.078		0.542
August-03	0.183	0.18	0.364	0.211	ND	0.05	0.205	0.364
September-04	0.229		0.373	0.287	ND	0.05	0.277	0.343
July-05	0.111	0.113	0.186	0.116	NQ*	0.092	0.132	0.167
Village of Syracuse				Population = 879				
March-02	NQ		0.208	NQ				
April-02	ND		ND	0.491				
September-04	ND		NQ	ND				
Village of Pomeroy				Population = 2,9000				
March-02	0.066			0.069		0.085		
April-02	0.063		ND	ND		0.071		
September-04	0.106		ND	0.705		NQ		

*** In Table 13, ND is a value less than 0.01 µg/L and NQ is a result between ND and 0.05 µg/L with the following exception. The NQ obtained from Tuppers Plains/Chester Water District's Well #3 in July, 2005 (noted by "*") represents a value less than 0.007 µg/L utilizing newer laboratory techniques.

Since C-8 has been found in the LHWA wells (Figure 34) at an order of magnitude greater than any other public water supply well in Ohio (or West Virginia), the C-8 investigations have focused on this area. In August 2002, a field investigation was completed by DuPont at the request of Ohio EPA to evaluate the extent and concentration of C-8 in soil and ground water in the LHWA well field. Ground water samples collected during this investigation using a Geoprobe® and temporary wells ranged from non-detect (<0.01 µg/L) to 78.0 µg/L. In general, the highest concentrations of C-8 in ground water were detected in the silty sand alluvium above the sand and gravel aquifer. With respect to soil, the C-8 concentrations measured in two borings ranged from ND (<2 µg/kg) to 170 µg/kg in one soil boring and from ND to 110 µg/kg in another boring. At each location, the highest concentration C-8 in soil was found in the sample collected at the ground surface. In general, the concentration of C-8 in soil decreased with depth. However, at one boring, 18 µg/kg of C-8 was detected in soil at 21 feet below ground surface.

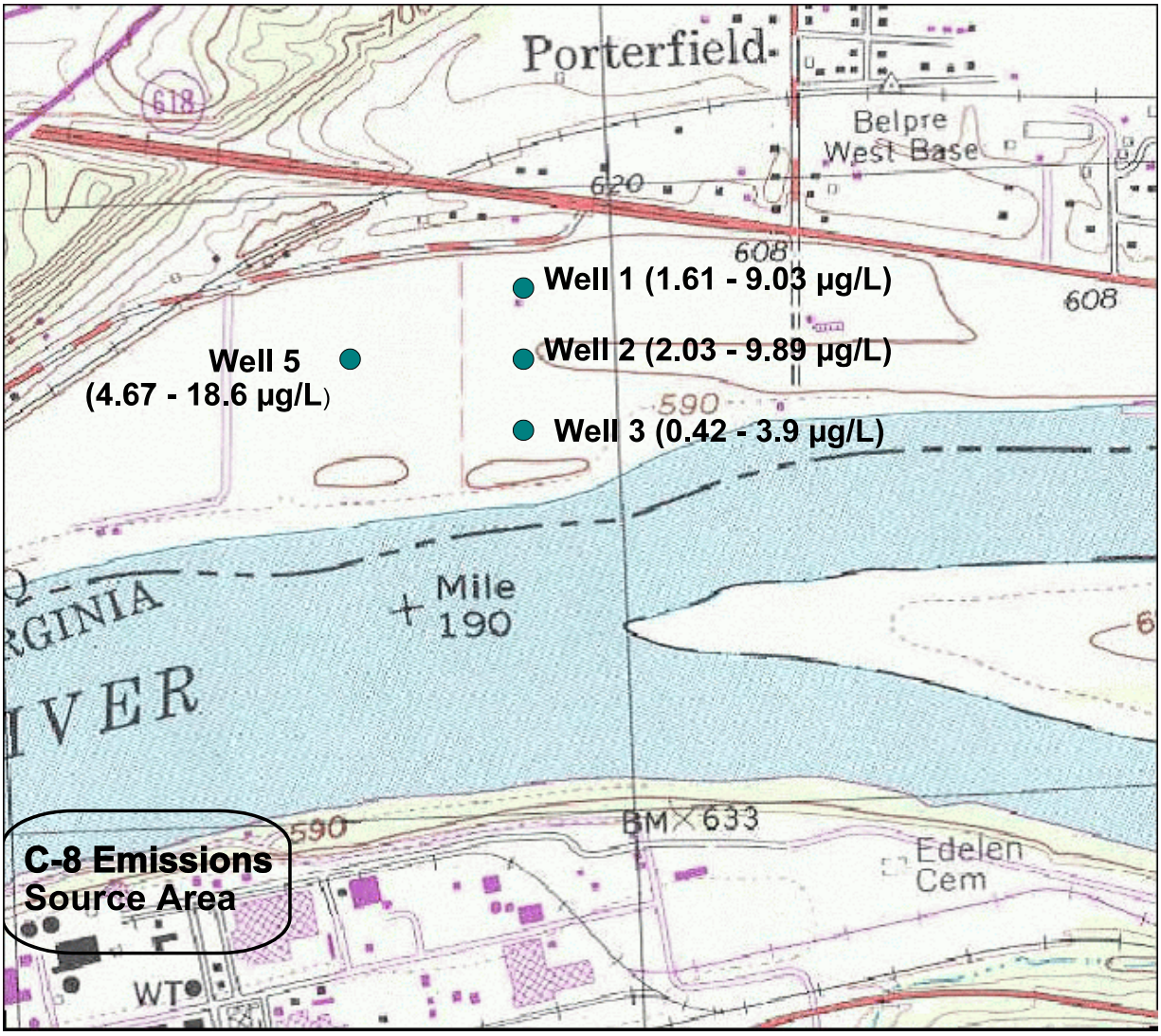


Figure 34. Location of LHWA drinking water wells and C-8 concentrations.

Private Water Supply Impacts

Between March 20, 2002 and September 30, 2002, nearly 900 homes were surveyed and a total of 134samples were collected from private water sources in Ohio within a two mile radius of the DuPont Washington Works facility in West Virginia (Figure 35). Most of this area is comprised of uplands consisting of alternating layers of sandstone and shale of the Permian Age Dunkard Group. The remainder of the area is comprised of sand and gravel alluvial terrace deposits located in the Ohio River valley.

Samples were collected from drinking water wells, non-drinking water wells, springs and cisterns. C-8 was detected (>0.01 µg/L) in 115 of the 134 samples that were collected. Non-drinking water wells,

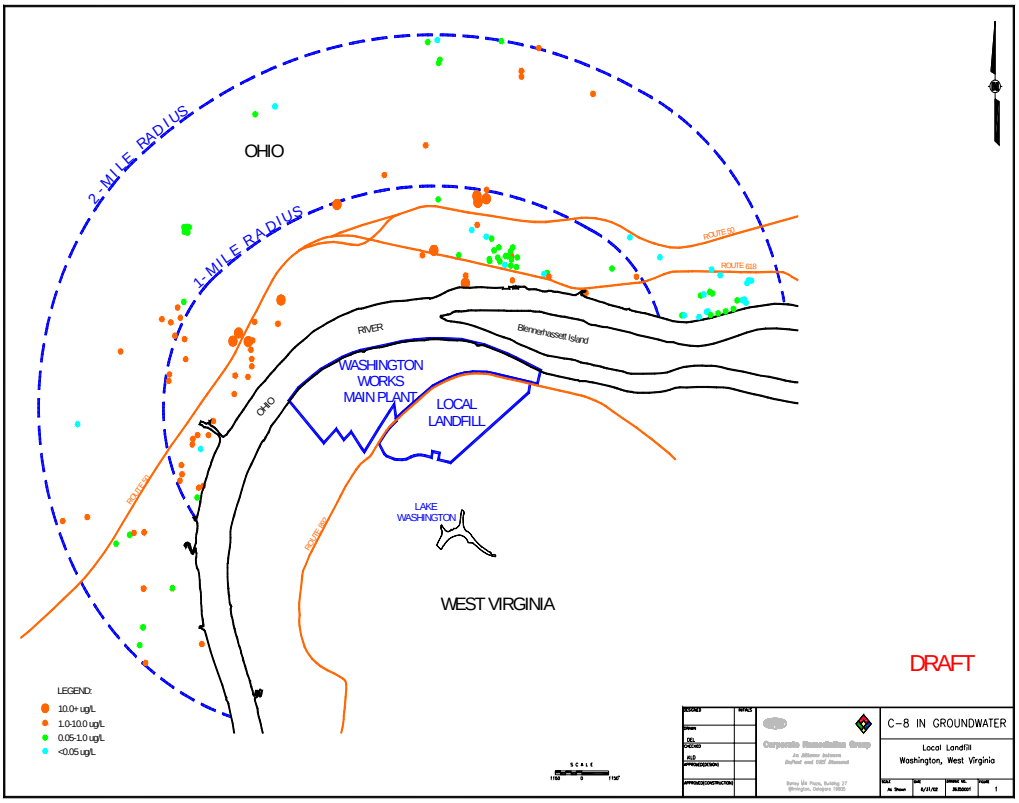


Figure 35. Ohio 2-mile radius residential water C-8 sampling results (Source: DuPont Corporate Remediation Group, May 31, 2002).

springs and cisterns accounted for over half of the water systems where C-8 was found. Notably, cisterns and springs accounted for some of the higher concentrations of C-8 detected, including 23.6 µg/L found in a spring used for watering livestock. This spring originates from a sandstone outcrop in an upland bluff overlooking the Ohio River Valley.

Within the 2 mile radius study area, approximately 68 drinking water wells were sampled, half of which are located in the bedrock upland area. These results are plotted in Figure 35. Fifty-two of the 68 drinking water wells had detections of C-8. It is interesting to note that all of the drinking water wells in the upland bedrock had detections of C-8, while just over half of the wells in the sand and gravel alluvial aquifer in the river valley detected C-8. Quantifiable (> 0.05 µg/L) concentrations of C-8 in drinking water wells ranged from a low of 0.059 µg/L to a high of 23 µg/L. The average concentration of C-8 in drinking water wells is 1.5 µg/L.

To evaluate trends in private water supplies in Ohio, the Ohio EPA along with DuPont selected eleven locations within the 2 mile radius for ongoing quarterly sampling. Three of these 11 private water systems are drinking water wells that have an average concentration of C-8 over 8 µg/L. Sample results showing the trend in C-8 concentration over time for the drinking water well with the highest levels is depicted in Figure 36. This well is located approximately one half mile east of DuPont and is drilled into bedrock. Note that in late November 2004 the concentration of C-8 peaked in this well, and in several other wells that are sampled quarterly. The November sampling event followed heavy rains in the region in September and mid November 2004. The increased precipitation may have flushed C-8 from soil

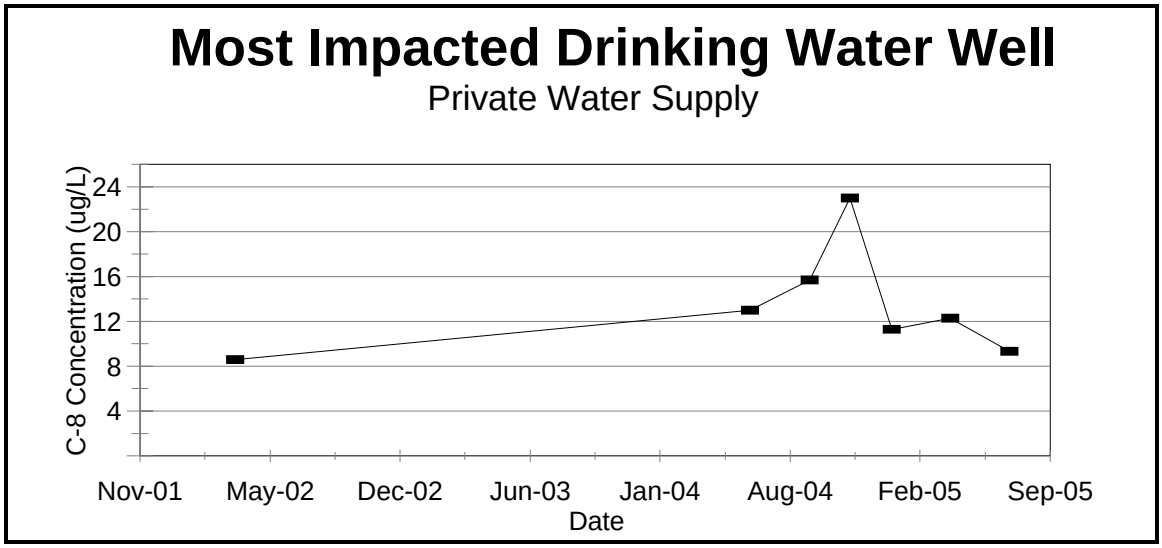


Figure 36. Private drinking water well with highest know concentration of C-8.

through the vadose zone and increased the concentration in ground water.

In addition to the samples collected within the two mile radius study area, approximately 70 private drinking water wells in Ohio were sampled for C-8 in 2004 and 2005. Most of these wells are located in the upland bedrock areas of Washington, Athens and Meigs Counties. C-8 was detected in approximately 40 of these drinking water wells. In the vicinity of Little Hocking, it is important to note that there is a widespread distribution of C-8 impacted wells. Three wells with concentrations of C-8 above 0.2 ug/l are located approximately 7, 8 and 12 miles east, northeast and north of the DuPont facility, respectively.

Transport Pathways for C-8

Ground water sampling data has shown that the DuPont fluoropolymer industrial facility in West Virginia has caused widespread dispersal of C-8 into public and private water supplies in Washington, Athens, and Meigs Counties in Ohio. These data, along with air transport modeling conducted by Dupont staff, have led to a better understanding of the possible transportation pathways for the migration of C-8 from the facility. Figure 37 conceptually identifies the two primary pathways: air emissions and aqueous discharges to the Ohio River. Ground water modeling conducted by DuPont's consultants indicates that on-site C-8 releases to ground water are contained by pumping and do not migrate beneath the Ohio River to the LHWA well field.

Air Emissions

Transportation of C-8 in both vapor and particulate phases through the air and subsequent leaching through soil is believed to be the primary pathway for C-8 to migrate from the facility to ground water in adjacent areas of Ohio. The ability for C-8 to be transported through the air and reach soil is supported by air transportation modeling. In the year 2000, DuPont estimates that approximately 31,000 lbs of C-8 was released to the air from the Washington Works facility. Using the 2000 emissions data, the model predicted that the annual average vapor concentration in Ohio near the facility was a maximum of 0.8 $\mu g/m^3$ (Figure 38). Again, using the model to predict the vapor and particulate concentrations released from the source area, DuPont estimated that in the year 2000 about 46.5 lbs of C-8 was deposited

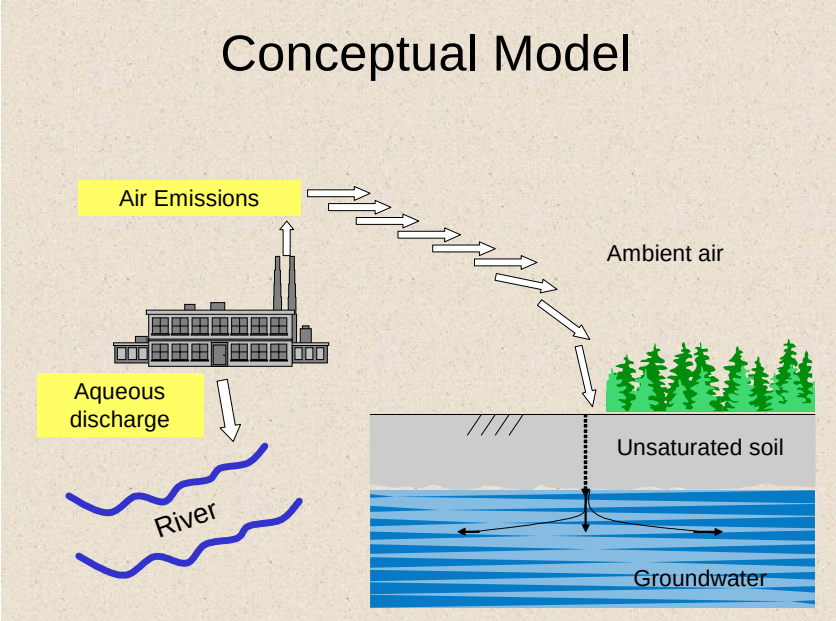


Figure 37. Conceptual model of C-8 migration. (Source: C. Barton, DuPont, Fluoropolymer Manufacturing Group presentation on August 21, 2003).

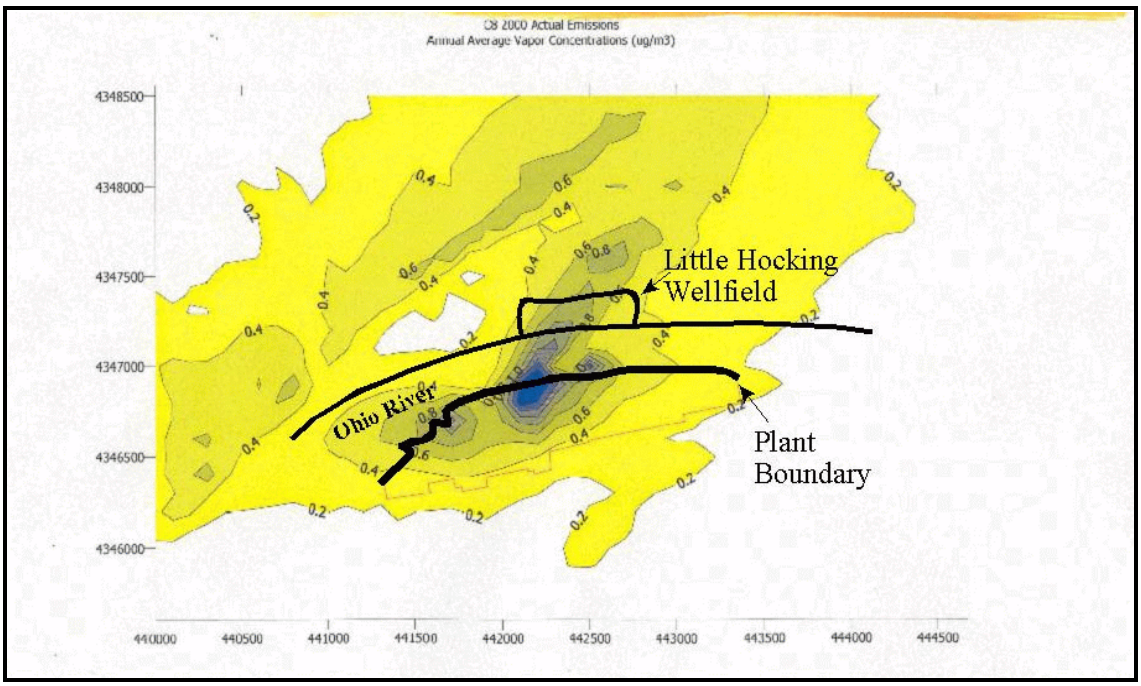


Figure 38. Annual average vapor concentration of C-8 from air modeling. (Modified by Ohio EPA, orginal source: Debbie Mulrooney, DuPont Engineering Technology, WVDAQ Presentation, April 24, 2002)

in a 2.5 km^2 area which includes the LHWA well field. Thus, it is likely that C-8 released since the 1950's has migrated through air and been deposited in soils at the LHWA well field and surrounding area. Recent installation of air pollution control equipment has significantly reduced C-8 discharges to the atmosphere from the Washington Works facility.

The focused field investigation in the LHWA well field in 2002 supports the air pathway hypothesis based on the presence of higher concentrations of C-8 in surface soils, with a general decrease in C-8 concentration with depth. In addition, private wells in upland areas and cisterns which receive only rainwater were found to contain C-8. The only viable pathway for C-8 to reach these water supplies is by air transport.

Considering the air transportation modeling and the widespread impacts to ground water, the pathway for C-8 to migrate from the facility to drinking water supplies is as follows: C-8 from the facility is transported through the air and is deposited on surface soils (or other surfaces), possibly miles from the source area. Because C-8 is water soluble, infiltration of precipitation transports it downward through the soil and unsaturated zone to ground water. Ground water containing C-8 then moves to discharge areas, such as springs, streams and rivers, or is pumped from the ground through drinking water wells. Figure 39 presents the trend analysis of LHWA wells which shows that concentrations peaked in November of 2004 in LHWA wells. This increase in C-8 concentration was observed in many private wells in the area as well. These increases in 2004 occurred in spite of the fact that the DuPont facility has reduced C-8 air emissions systematically since 2000. The late November sampling event that captured the elevated C-8 concentrations followed heavy rains in September and mid November 2004, indicating that C-8 was flushed from shallow soil through the vadose zone and increased C-8 levels in ground water. Continued

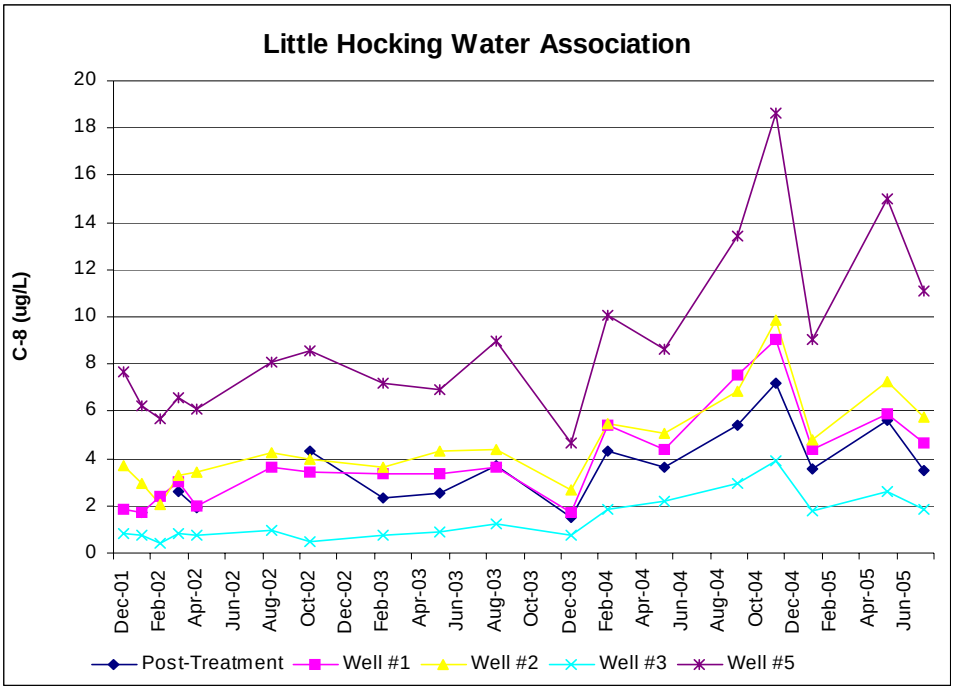


Figure 39. Time series of C-8 concentration in wells and treated water at LHWA.

ground water monitoring is necessary to determine how long it will take for concentrations of C-8 in the Little Hocking area to decrease in response to reduced air emissions.

Discharge to the Ohio River

A secondary transportation pathway for C-8 is via discharge to the Ohio River and subsequent infiltration of river water to the alluvial aquifer due to recharge induced by pumping or losing stream processes. Discharge of C-8 in an aqueous solution has occurred and continues to occur from wastewater outfalls at the facility. In 1999, it is estimated that 56,000 lbs of C-8 was discharged directly to the Ohio River, although recent installation of a carbon filtration treatment system for wastewater has reduced discharges significantly. In order to determine the concentration of C-8 in the river, 46 river water samples were collected in the year 2002 upstream, downstream and near the facility. Of the 34 samples collected upstream of the facility and along the facility reach, C-8 was non-detect (< 0.01 µg/L) in 31 of 34 samples (three were NQ < 0.05 µg/L). However, downstream of the facility, C-8 was consistently found ranging from 0.0949 to 1.09 µg/L. The highest concentration was detected at a location in the middle of the river approximately 3 miles downstream. At locations 10 and 18 miles downstream, the C-8 concentration ranged from 0.236 µg/L to 0.292 µg/L.

At approximately 14 miles downstream of the facility, the Tuppers Plains/Chester Water District well field draws ground water from the alluvial sand and gravel aquifer. Wells 1 and 6, which are located closest to the Ohio River have higher concentrations of C-8 as compared to wells 3 and 4, which are located further from the river (Table 13). This indicates that the source of C-8 to these wells is from the Ohio River water recharging the alluvial aquifer. Figure 40 illustrates the trend analysis of Tuppers Plains/Chester Water District which clearly shows that C-8 discharge reductions undertaken at the facility between 2001 and 2005, are reflected in the C-8 levels in the PWS water wells at Tuppers Plains/Chester Water District.

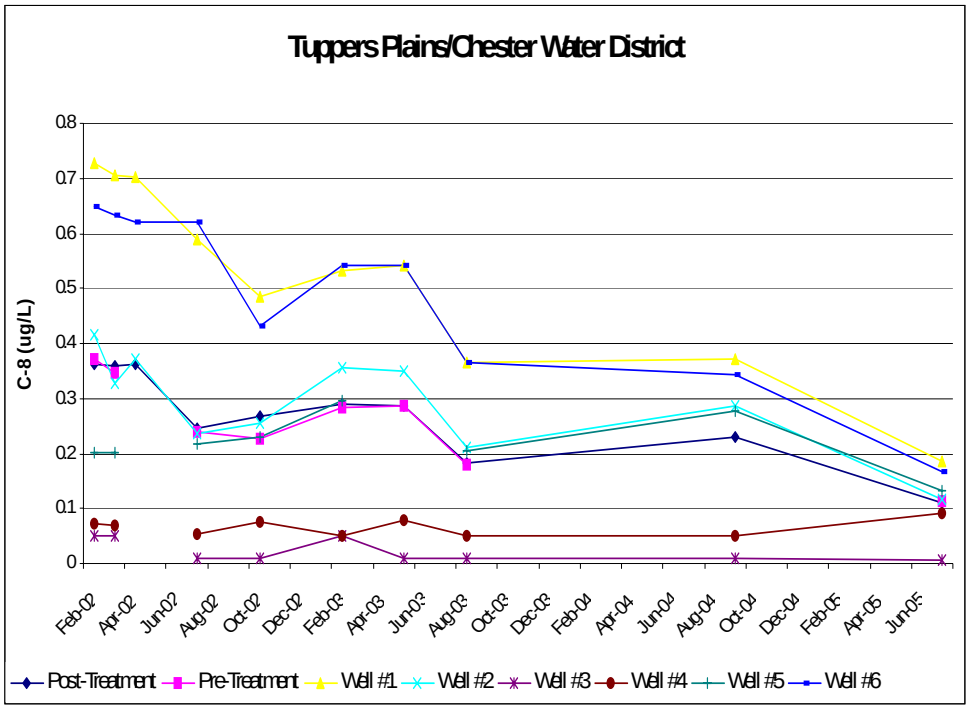


Figure 40. C- 8 time series illustrating the decrease in C-8 in Tuppers Plains/ Chester Water District wells.

Conclusions

Ground water sampling data have shown that emissions from Dupont's Washington works fluoropolymer manufacturing facility in West Virginia have caused widespread dispersal of C-8 into public and private water supplies in Washington, Athens and Meigs Counties in Southeast Ohio, causing C-8 exposure through drinking water to more than 37,000 people. These ground water data, along with surface water and soil sampling results and computer models of air and ground water transport, have led to a better understanding of the possible transportation pathways for migration of C-8 from the facility. Transportation of C-8 through the air and subsequent leaching through soil is believed to be the primary pathway for C-8 to migrate from the facility to ground water in adjacent areas of Ohio. A secondary transportation pathway for C-8 is via discharge to the Ohio River and subsequent infiltration of river water to the alluvial aquifer due to recharge induced by pumping at downstream public water supplies. Continued sampling of environmental media is necessary to provide a better understanding of the fate, transport and human exposures of C-8 from fluoropolymer manufacturing. Specifically, continued ground water monitoring is necessary to evaluate long term trends of C-8 concentrations in ground water and determine how ground water concentrations will decrease in response to reduced air and surface water emission.

CONCLUSIONS AND FUTURE FOCUS

The water quality characterization and analysis presented in this report illustrates the ongoing progress that Ohio EPA, Division of Drinking and Ground Waters, has made since the last ground water chapter of the 305(b) Report. The major accomplishment has been to establish STORET as our primary database for ground water quality data for the AGWMP and for special studies completed by the division. We continue to work to increase the quality of the AGWMP data, to incorporate improvements in the data management tools and to improve our data analysis with expanding use of GIS tools, as illustrated in the sections of this report. This progress allows the utilization of ground water quality data and data analysis tools to support DDAGW programs, including:

- Increasing our understanding of the ground water resources of Ohio;
- Cataloging and evaluating ground water resources impacted from land use activities;
- Continuing to refine criteria to identify sensitive aquifers at statewide and local scales;
- Supporting effective implementation of new SDWA rules; and
- Making water quality data readily available and understandable to the public.

The Ambient Network Data Summary (Table 3) provides an updated summary of ambient ground water quality in Ohio that can be used to help identify ground water that exhibits impact from human activity or reveals significant natural variability. The influence of ground water oxidation-reduction state on ground water quality is illustrated for parameters whose solubilities are sensitive to oxidation-reduction changes. The 2006 305(b) Report presents all the inorganic AGWMP data in Appendix I as box plots for each parameter listed in Table 3, in order to illustrate the distribution of individual data points. AGWMP data collection efforts will continue to provide data to document long term trends at active AGWMP sites, producing valuable data for evaluating environmental trends. Special studies will focus on identifying and evaluating areas of ground water impact and attempt to determine causes of contamination.

Compiling all sites in Ohio with documented releases of contaminants to ground water from regulated sites and nonpoint sources is another priority activity. Efforts to identify areas of anthropogenetic impacts to water quality will help refine criteria for identifying sensitive aquifers. Lessons learned at specific sites of ground water contamination can be extrapolated to similar geologic settings across the state. A Ground Water Impacts database was developed in 2005 to capture summary data for facilities or areas with documented ground water quality impacts. General information about the facility is collected, along with specific information about the plume and its source. Multiple plumes and/or multiple sources at a facility can each be tracked in the database. Information collected includes: depth to ground water; thickness and lithology of the aquifer(s); approximate dimensions of plume(s) along with its geographic location; types of remediation occurring; and a list of contaminants in each of the aquifer zones with current and historical maximum result. Figure 41 is an example of the information captured in the Ground Water Impacts database.

The GW Impacts design incorporated comments from DDAGW staff from all five district offices as well as other Ohio EPA divisions in an attempt to maximize the usefulness of the database so the database will be populated and updated. The Ground Water Impacts database requires latitude and longitude so the summary data can be analyzed with GIS tools and be represented geographically as overlays to aquifer, geologic, and cultural maps. Currently, over 50 records have been added to the database. DDAGW has a

goal of adding 150 facilities each quarter over the next four quarters. Once the database is sufficiently populated, at the end of 2006, the data will be analyzed. Analysis of this data base will be a central component of the Ohio's Ground Water Quality 2008 305(b) Report.]

Facility Information

Facility Name: OWENS CORNING FIBERGLASS CORP. City: NEWARK District: CDO
Physical Address: MANNING STREET Township: NEWARK CoreplaceID:
County: LICKING FacilityID: 45-01-01

Source Unit Information

Source Unit Type: LANDFILL - INDUSTRIAL WASTE PrimaryLandUse: COMM / INDUST / TRANS YearOpen/Permitted: E+03 Operational Type: ACTIVE
Source Unit Name: Status: CORRECTIVE ACTIONS/MEASURES YearClosed: Responsible Prog: DSIWM
Liner System: PARTIALLY LINED LinerThickness: COMP W/ 5' CLAY

Hydrogeologic Information

Zone	Lithology	Name	Avg. Depth To GW	Max Zone Thickness	Utility
1	SAND	0-10' SAND & SANDY CLA		0-10 ft	ISOLATION MATERIAL
2	SAND/GRAVEL	LOWER WATER BEARING	31-40 ft	21-30 ft	UPPERMOST AQUIFER
3	SAND/GRAVEL	LOWER WATER BEARING	41-50 ft	31-40 ft	UPPERMOST AQUIFER

Source of Ground Water Impact

Source Plume #	Length	Width	Thickness	Impacted MWs	Impacts to DW Wells	Primary Remediation / Secondary Remediation	Latitude (dec.deg) / Longitude (dec.deg)	Lat/Long Location / Lat/Long Source	Off Property Migration / PlumeTruncation
1				☐	NONE	LANDFILL CAP ENHANCEMENTS	40.077222 / 82.398333		NO

Ground Water Contamination

Zone	Plume	Contaminant	Current_Results	Units	Date	Historical_Max	Historical_Units	Historical_Date	Upgradient
2		Nitrogen Ammonia	38	mg/L	4/1/2005	38	mg/L	4/1/2005	☐
2		Antimony, total	60	ug/L	4/1/2005	75	ug/L	10/20/2004	☐
2		Boron, total	29	mg/L	4/1/2005	29	mg/L	4/1/2005	☐
2		Chemical Oxygen Dem	29	mg/L	4/1/2005	29	mg/L	4/1/2005	☐
2		Sodium, total	472	mg/L	4/1/2005	472	mg/L	4/1/2005	☐
3		Nitrogen Ammonia	23	mg/L	10/20/2005				☐
3		Boron, total	24	mg/L	10/20/2005				☐
3		Vinyl chloride	0	ug/L	10/20/2005	2.5	ug/L	10/15/2002	☐
3		Chemical Oxygen Dem	20	mg/L	10/20/2005				☐
3		Sodium, total	302	mg/L	10/20/2005				☐

Comments
"0" FOR VINYL CHLORIDE IS ACTUALLY ND AT <1 UG/L
This summary is based on samples reviewed from (dates) 1/1/1995 To 10/20/2005
Staff Name STEVE CHURCHILL Last Updated Date: 6/5/2006

Figure 41. Ground Water Impacts Data Entry Screen.

The identification of impacted ground water and understanding of sensitive aquifers can be used to set broad priorities for ground water protection efforts and/or compliance activities. SWAP assessment processes provided electronic access to site-specific and regional data useful for analyzing impacted water quality data, including source location information, hydrogeologic setting information, well construction data, and aquifer hydrologic parameters. This information increases the opportunity to establish associations between geologic parameters or land use data with water quality data. Land use/land cover analysis can be enhanced with these improved data to help identify or confirm cause and effect relationships between potential sources of contamination and the resulting ground water contamination in public water systems or at other locations.

Once areas of impact are identified and probable causes confirmed, they can be targeted as priority areas for implementation of best management practices to protect the ground water through 319 grant funds. Our ability to focus protection efforts on sensitive aquifers or public water systems with the greatest

potential for impact becomes critical in order to maximize the effectiveness of ground water protection efforts. The option or requirement to target implementation to areas of vulnerable public water systems, for instance, the effort to focus on UIC Class 5 Wells in Drinking Water Source Protections Areas, illustrates the advantages of the approach.

The Ground Water Rule, expected to be finalized in 2006, will require development of a Hydrogeologic Sensitivity Assessment to identify PWSs susceptible to fecal contamination. Identification of sensitive aquifers is a valuable start for this effort. The different behavior of particulates, such as pathogens, and dissolved material, such as nitrate, in sensitive aquifers is one of the factors that needs to be evaluated for the Ground Water Rule Hydrogeologic Sensitivity Assessment. The cause and effect relationships that are being documented in areas with septic system discharge impacting ground water quality in site specific studies should be helpful in developing the Ground Water Rule Hydrogeologic Sensitivity Assessment. The results of PWS bacterial sampling also needs to be integrated with efforts to identify aquifers sensitive to pathogens. Once in place, the Ground Water Rule compliance monitoring will provide valuable data for refining the criteria for identifying sensitive aquifers.

Another benefit of identifying sensitive aquifers is that these are the aquifers where the recharge to ground water is more rapid and consequently the ground water quality is more dynamic with variation related to surface water processes. We plan to identify several areas with rapid recharge and initiate a short term sampling program to monitor temporal geochemical variation associated with seasonal ground water levels. This effort will lead directly to a better understanding of the local ground water-surface water interaction, and to a larger understanding of the nature of the sensitivity of shallow water resources in Ohio. The intent is to include a sensitive SWAP area in the short-term sampling program, and to investigate how some new environmental tracers, such as the nitrogen and oxygen isotopes, may allow tracing nitrate impact to specific contaminant sources. This sampling will be integrated with a plan to collect shallow ground water quality data in order to increase the representation of shallow ground water quality data in our ground water quality databases. As stated previously, the AGWMP data is dominated by ground water quality data from deeper, high volume aquifers, so including shallower more vulnerable sites in our ground water quality data collection effort is critical to characterizing all of Ohio's ground water.

Another important goal is to make the ground water quality data accessible to the public in simple, understandable formats. The documentation of local variation in the major aquifers as presented for the Great Miami, Scioto, and Muskingum Rivers in this report illustrates the potential for identifying regional or local variation in the major aquifers in Ohio. A template for presenting ground water quality data on a watershed basis is under development. The associated report would describe glacial and bedrock aquifers and provide summary ground water quality data for local aquifers. These watershed based reports will be designed to be useful to local water users, such as homeowners with questions about local water quality.

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