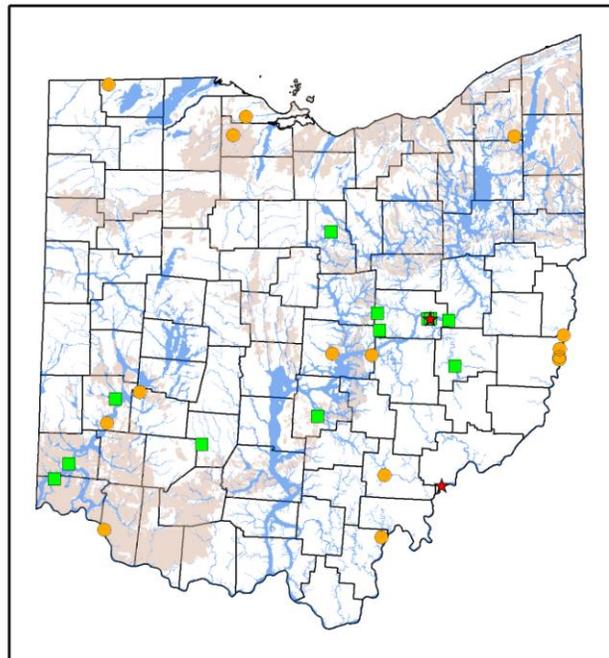




State of Ohio
Environmental Protection Agency

Division of Drinking and Ground Waters

2008 305(b) Report Ohio's Ground Water Quality



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Ted Strickland, Governor
Chris Korleski, Director

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Cover Illustration: Map of Ohio that indicates the locations where contamination from waste management activities has affected the ground water quality in drinking water well. These locations overlay the distribution of sensitive aquifers. See the section on Ground Water Quality Impacts database for additional explanation.

EXECUTIVE SUMMARY

2008 305(b) Report - Ohio's Ground Water Quality

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 2006 305(b) Ground Water Report. The major accomplishment has been finishing development of the Ground Water Quality Impacts database and initiating data analysis of these data. We continue to work to increase the quality of the Ambient Ground Water Quality Monitoring Program (AGWQMP) data, to incorporate improvements in data management tools, and to improve our data analysis with expanding use of GIS and data graphing tools. These efforts, in conjunction with special studies focused on site-specific ground water contamination, direct the use of ground water quality data and data analysis to support DDAGW programs and long-term goals, 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.

Ground water quality monitoring and data analysis programs for the state of Ohio are summarized in the first section of the 2008 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 implemented 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 within the agency and with other state programs through the Ohio Water Resources Council and the State Coordinating Committee on Ground Water.

Two primary sources of information are used to characterize Ohio's ground water quality in this Report. The AGWQMP is the DDAGW program created to monitor "raw" (untreated) ground water. This program's goal is the collection, maintenance, and analysis of raw ground water quality data to measure changes in the water quality of the State's major aquifer systems. The second major source of information is the information captured in the Ground Water Quality Impacts database as discussed in the third section of the report. Finally, Ohio EPA's public water system compliance monitoring data compiled from information on treated (processed) ground water is used to help characterize Ohio's ground water quality.

The second section of this report discusses the characterization of ground water quality in Ohio with a focus on relating ground water quality to the major aquifers. The AGWQMP data summary tables (Tables 4, 5, and Appendix B) and various figures provide updated summaries 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. It is important to remember that the AGWQMP data used to generate these tables do not represent pristine aquifer settings, but include wells with ground water impacts as documented by the presence of sites with volatile organic compound detections and elevated nitrate. The influence of ground

water oxidation-reduction state on ground water quality is illustrated in Table 5 for parameters whose solubility is sensitive to oxidation-reduction changes. The 2008 305(b) Report presents means and medians for each parameter by major aquifer types in Table 4. All the inorganic AGWQMP data is presented in Appendix A as box plots for each parameter, grouped by aquifer type, in order to visually illustrate differences between major aquifer ground water chemistry and to exhibit the distribution of individual data points. AGWQMP data collection efforts will continue to provide data to document long-term trends at active AGWQMP sites, producing valuable data for evaluating environmental trends. Special ground water quality studies will continue to focus on identifying and evaluating areas of ground water quality impacts, attempt to associate it to the source(s) of contamination and expand our knowledge of recharge pathways and sensitive aquifers in Ohio.

Results of organic samples included in the AGWQMP database are summarized in Appendix B. The data documents limited detection of organic compounds in AGWQMP wells and that detections generally occur at low concentrations. This is not to say that there are no detections. The AGWQMP wells are not pristine, but fortunately, the frequency of detections is limited. The rate of detections may be artificially increased due to the six month sampling frequency for wells known to be close to contamination plumes or with a history of low concentrations of organic contaminants. Organics samples are normally collected on an eighteen-month interval.

The compounds most frequently detected in the AGWQMP sampling are consistent with organic compound detections from drinking water compliance data. The detection rates of these most commonly detected parameters range from 0.2 % for toluene, to 4.5 % chloroform. The overall detection percentage, across all organic sample types is 0.28 %. These numbers are quite low and illustrate the broadly protected nature of ground water resources used by public water systems to point source contaminants. In addition, both the overall detection rate of 0.28%, and the highest individual component detection rate (4.5 % chloroform) are low compared to national statistics of volatile organic detections across multiple aquifers of the United States. The compounds most frequently detected are chlorinated solvents and petroleum byproducts like toluene and benzene. Chloroform is the parameter most commonly detected in the AGWQMP wells. This may be associated with back flow of treated water or disinfection of wells, but recharge of treated water or natural sources of chloroform are also possible explanations.

The Ground Water Quality Impacts Database includes sites with documented releases of contaminants to ground water from regulated sites. The development and implementation of this database and analysis of Ground Water Quality Impacts data are major achievements since the 2006 305(b) Report. Database entry is not complete so the analysis presented in Section 3 of the report is preliminary, however it does illustrate the type of analyses that are useful in evaluating the distribution and sources of ground water contamination. The conclusion that impacts to ground water quality are not preferentially associated with the sensitive aquifers is interesting and suggests that the site-specific ground water monitoring programs, associated with regulated entities, evaluate mostly localized ground water quality impacts than does a regional analysis based on water quality data obtained from public water system wells. This independence of sensitive aquifers was also suggested in analysis of VOC detections in AGWQMP data and in PWS compliance data as reported in the Organic Contaminant in Ohio Ground Water section presented in the 2006 305(b) Report. The implication is if a long-term source of contamination is present, pathways to ground water will be available for contaminant transport. It is likely, however, that the volume of contaminant transported in the non-sensitive settings will be less than the contaminant volumes transported in sensitive settings. Additional analysis will explore the relationships between sensitive aquifers and the evidence for the

volume of contaminant reaching the ground water using plume size, contaminant concentrations, or depth of water quality impacts.

Identification of ground water quality impacts and understanding of sensitive aquifers can be used to set broad priorities for ground water protection efforts or compliance monitoring activities. The increased use of 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 should enhance the opportunity to establish associations between geologic parameters and/or land use data with water quality data.

Continued identification of regional areas of ground water quality impacts with linkages to probable causes will aid in targeting priority areas for implementation of best management practices to protect the Ohio's ground water resources. Our ability to focus protection efforts on sensitive aquifers or public water system well fields with the greatest potential for ground water quality impacts are critical 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 section on the ground water - surface water interactions briefly summarizes special study activities focused on sensitive aquifers where local ground water recharge pathways directly influenced ground water quality. These studies expand our knowledge of surface water - ground water interaction. Water program structures, generally focused on ground water or surface water as the priority, inhibit integration of ground water - surface water interactions. The OWRC Workgroup on Water Resource Monitoring is organizing a workgroup to evaluate the state ground water monitoring programs. The proposed focus of this group is to assess Ohio's ground water monitoring networks for evaluating ground water sustainability. The scale and approach for this workgroup has not been determined, but sustainability is an effective way to force integration of ground water programs and ground water - surface water interactions. Reducing recharge, storage or discharge over the long run generates sustainability issues for both ground water and surface water.

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LIST OF ACRONYMS

AGWQMP	Ambient Ground Water Quality Monitoring Program
BNA	Base Neutral and Acid Extractables
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
DBP	Disinfection By-Product
DCE	Dichloroethylene
DSW	Division Of Surface Water
DDAGW	Division of Drinking and Ground Waters
GW-SW	Ground Water - Surface Water
MCL	Maximum Contaminant Level
MTBE	Methyl Tert-Butyl Ether
PCE	Tetrachloroethylene
PWS	Public Water System
ODNR	Ohio Department of Natural Resources
OEMA	Ohio Emergency Management Agency
OWRC	Ohio Water Resource Council
SCCGW	State Coordinating Committee on Ground Water
SMCL	Secondary Maximum Contaminant Level
SWAP	Source Water Assessment Program
TCE	Trichloroethylene
TDS	Total Dissolved Solids
VC	Vinyl Chloride
VOC	Volatile Organic Compounds

2008 305(b) Report Ohio's Ground Water Quality

INTRODUCTION

Ground water is a vital resource in Ohio. Approximately 1,000 of Ohio's 1,250 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 3,900 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. Roughly, 40 percent of Ohio's population, four-and-a-half million residents, depends 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 2008 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 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 the major state aquifers, to document ground water quality impacts, and to identify sensitive aquifers. The goal is to identify areas where ground water quality is affected by human activities in order to understand land use impacts, to help prioritize ground water protection efforts and provide public access to these data are continuing efforts.

This report is organized to provide updated ground water information requested in the 2008 Integrated Report Guidance, including a summary of:

- State ground water monitoring and protection programs;
- Ground water quality;
- Ground water contamination sources; and
- Ground water-surface water (GW-SW) interactions.

The summary of state ground water programs and the description of the ground water quality of the major aquifer types in Ohio are very similar to the 2006 305(b) Report, with the incorporation of recent data and program updates. The discussion on sources of ground water contamination

utilizes the Ground Water Impacts Database, which was developed to allow geographic analysis of documented ground water quality impacts and to promote understanding of the relationship between the potential contaminant sources and ground water quality impacts. The distribution of ground water quality impacts and the general characteristics of the sources of contamination are presented. Finally, ground water – surface water interaction is discussed in the context of identifying sensitive aquifers.

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 and four year action plan 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 - coordinate water resources education efforts to promote the importance of water resources and to protect the sustainability of Ohio's water resources.
- Watershed Management - align state water resource programs by watershed, and encourage partnerships between all levels of water management players to promote protection of water resources.
- Water Quality - promote collaborative approaches for land management activities to maximize water quality benefits from protection and restoration activities for surface and ground water.
- Water Quantity - manage Ohio's water resources for sustained use by improving water quantity data and characterization as well as strengthening cooperation among water management programs to prepare for future water quantity conflicts.
- Infrastructure - endorse 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 - support 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 water 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 on the 10-year vision and sponsored workgroups is listed on the OWRC web site:

<http://www.dnr.ohio.gov/owrc>

The **State Coordinating Committee on 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. The SCCGW is a Subcommittee of the Ohio Water Resource Council and helps to promote coordination of water management issues. As OWRC workgroups are organized to address water quality and quantity objectives,

the SCCGW members play significant roles in these workgroups to promote ground water protection and to emphasize the importance of surface water and ground water interaction. The SCCGW used the OWRC four year action plan to outline SCCGW priorities. Details on the SCCGW priority actions for data and information, education and outreach, watershed management, water quality, water quantity, water resource infrastructure, and water related natural hazards are provided on the SCCGW Web site at:

<http://www.epa.state.oh.us/ddagw/SCCGW/>

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.

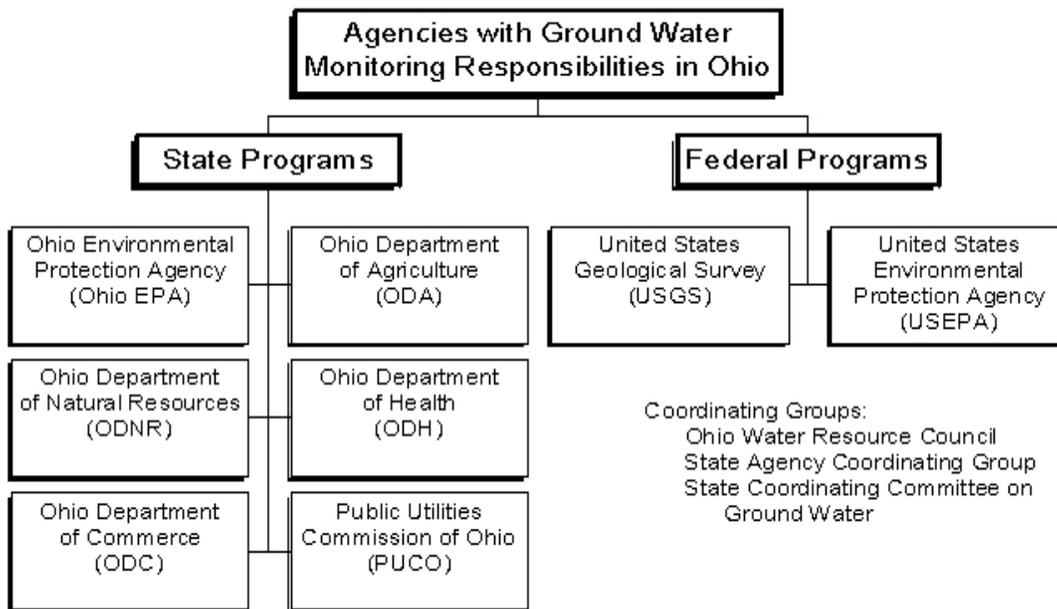


Figure 1. Agencies with ground water monitoring responsibilities in Ohio



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 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 implements 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/>



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 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 developed an on-line filing procedure for water well logs and has updated 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. A new product is the Water Withdrawal Atlas by Drainage Basin and County, which show water withdrawals from Ohio counties and basins in 2005 as well as withdrawal trends from 1991 to 2005. 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 development and restoration of mineral and fossil fuel extraction sites. Its programs address the environmental and safety aspects of coal and mineral mining and oil and gas extraction. 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/default/tabid/10352/Default.aspx>

Other divisions within ODNR also have ground water related responsibilities. The mission of the **Division of Soil and Water Conservation** is to "provide leadership and services that enable Ohioans to conserve, protect, and enhance soil, water, and land resources." 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 administers the Ohio Watershed Program with the Ohio EPA Division of Surface Water and OSU Extension. Specifically, Division of Soil and Water Conservation administers the Ohio Watershed Coordinator Grant Program, which provides funding for local sponsors to hire watershed professionals who facilitate development and implementation of Watershed Action Plans (WAP). The division also leads the WAP state endorsement process with which a number of funding incentives are associated. Watershed Action Plans frequently include measures to protect drinking water and ground water resources and can be integrated with source water assessment and protection plans. 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. An example of a new map product is the 2006 Bedrock Geologic Map of Ohio. The Division of Geological Survey continues to produce reconnaissance 3-dimensional, surficial-geology maps for Ohio at 1:100,000 scale. These maps show the extent, vertical succession and thickness of mapable 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 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 3701 of the ORC, and include a registration program for private water system contractors.

In 2005-2006 ODH worked to draft and pass statewide household sewage treatment rules and small flow sewage treatment plants, OAC Chapter 3701-26. These sewage treatment rules were adopted by the Public Health Council and became effective on Jan. 1, 2007. The new rules were rescinded as required by Amended Substitute House Bill 119 and the bill includes interim sewage rules which are effective from July 2, 2007 to July 1, 2009 (identical to 1977 home sewage treatment systems rules). In compliance with Amended Substitute HB 119, the director of health adopted statewide interim sewage rules effective July 2, 2007. The Public Health Council, at its July 25, 2007 meeting, adopted these rules as minimum standards through July 1, 2009. The bill set up the Home Sewage and Small Flow Onsite System Sewage Treatment System Study Commission whose directive is to recommend efficient and effective ways to treat sewage to ensure protection of public health with consideration of economic impacts. More information is available on these programs at:

<http://www.odh.ohio.gov/odhprograms/eh/sewage/sewage1.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 investigates and directs UST removal and associated ground water cleanup activities in conjunction with local fire departments. The BUSTR Online Office allows internet users to submit requests to the State Fire Marshal for additional information and publications. In addition, UST owners can complete and submit registration and permit applications and process fee payments online. 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), with written approval received in August 2000. As outlined in Ohio's PMP, ODA's Pesticide & Fertilizer Regulation Section is responsible for coordinating an annual ground water sampling program. The state pesticide plan ranked areas of the state for vulnerability to ground water contamination based on soil type, geology, and land use. This information was used in planning the ground water sampling program. Historically these samples were located in close proximity to large-scale pesticide distribution facilities and then

collected at dairies located in areas of extensive row crop agriculture. More recent sampling focused on areas of intense greenhouse crop and nursery stock production and last year samples were collected close to railroad grades. Samples are analyzed for a broad array of pesticide parent compounds. The focus of the 2008 sampling is under discussion with the intent to identify areas of sensitive aquifers with row crops with samples collected from private wells in the area. 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 on line 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. The primary regulatory authority for approval of confined animal feeding operations (CAFOs) lies in the ODA Livestock Environmental Permitting Program (LEPP). The Ohio EPA, Division of Surface Water has the 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 advance 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 assessment of ground water quality in the regional glacial aquifer. The NAWQA Program provides an understanding of water-quality conditions and how those conditions may vary locally, regionally, and nationally; whether conditions are getting better or worse over time; and how natural features and human activities affect those conditions. The USGS and NAWQA projects produce summary reports that describe trends in water quality in Ohio related to trends observed in watersheds throughout the nation. 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 Office of Ground Water and Drinking Water (OGWDW)** protects public health by ensuring safe drinking water and protecting ground water. OGWDW, along with EPA's ten regional drinking water programs, oversees implementation of the Safe Drinking Water Act, which is the national law safeguarding tap water in America. The U.S. EPA Office of Water web page address is <http://www.epa.gov/safewater/>.

OHIO EPA GROUND WATER QUALITY CHARACTERIZATION PROGRAM

The Division of Drinking and Ground Waters (DDAGW) is responsible for characterizing Ohio's ground water quality. Ground water quality data 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 Quality Monitoring 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 major 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 help 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 in turn will 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.

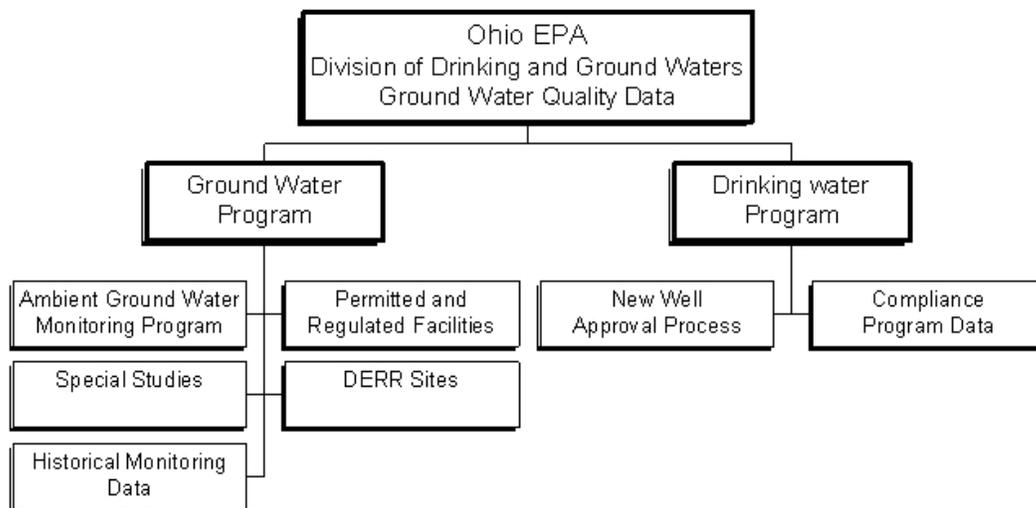


Figure 2. DDAGW programs that collect ground water quality data.

The water quality data and analysis presented in this report utilizes Ambient Ground Water Quality Monitoring Program (AGWQMP) data and, to a lesser extent, public water system (PWS) compliance data. The AGWQMP was specifically designed for broad-based water quality analyses of Ohio's major aquifers and collects raw (untreated) water quality data. In contrast, PWS compliance data is 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, especially for parameters that are not influenced by standard drinking water treatment techniques. Because of the importance of the AGWQMP 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 ground 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 each regulatory program, which uses the data to evaluate compliance, corrective action or remediation. The effort to organize all this information into a single 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, and disposal) and other sites where a confirmed contaminant release has affected ground water quality. 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 documented releases to ground water, and every site is associated with a latitude and longitude for geographic analysis. The third section of this report utilizes the Ground Water Impacts Database to characterize the distribution of ground water impacts and the general characteristics of the sources of contamination affecting ground water quality in Ohio.

Another DDAGW ground water quality data source is the Historical Monitoring Data. These data may contribute to the water quality characterization effort in specific areas where historic data is available. DDAGW staff evaluated and organized paper files containing old ground water sample data collected 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 included in county files. Currently the historic 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, but these data are not readily available for GIS analysis as are analytical results stored in digital formats.

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 interactions. In addition, the Nonpoint Source Pollution Program collects data that are relevant for evaluating sources of potential pollution that may affect ground water quality.

Ambient Water Quality Data

As part of the effort to characterize general water quality conditions in Ohio, DDAGW maintains the Ambient Ground Water Quality Monitoring Program (AGWQMP). Data collection activities occur at the district offices, and, database design, data entry, and data analysis are completed primarily in the Central Office. The program was originally established in 1973 to measure seasonal and annual ground water quality changes 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 AGWQMP 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 199 active wells at 190 sites. In addition, there are 164 inactive wells that are no longer sampled. Standby wells, associated with specific active wells, are sampled if the active well is down for maintenance or repairs. The distribution of AGWQMP wells across Ohio, broken out by lithology/aquifer type, is illustrated in Figure 3. Of the total sites, roughly 80 percent are public water systems 20 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 AGWQMP samples are analyzed.

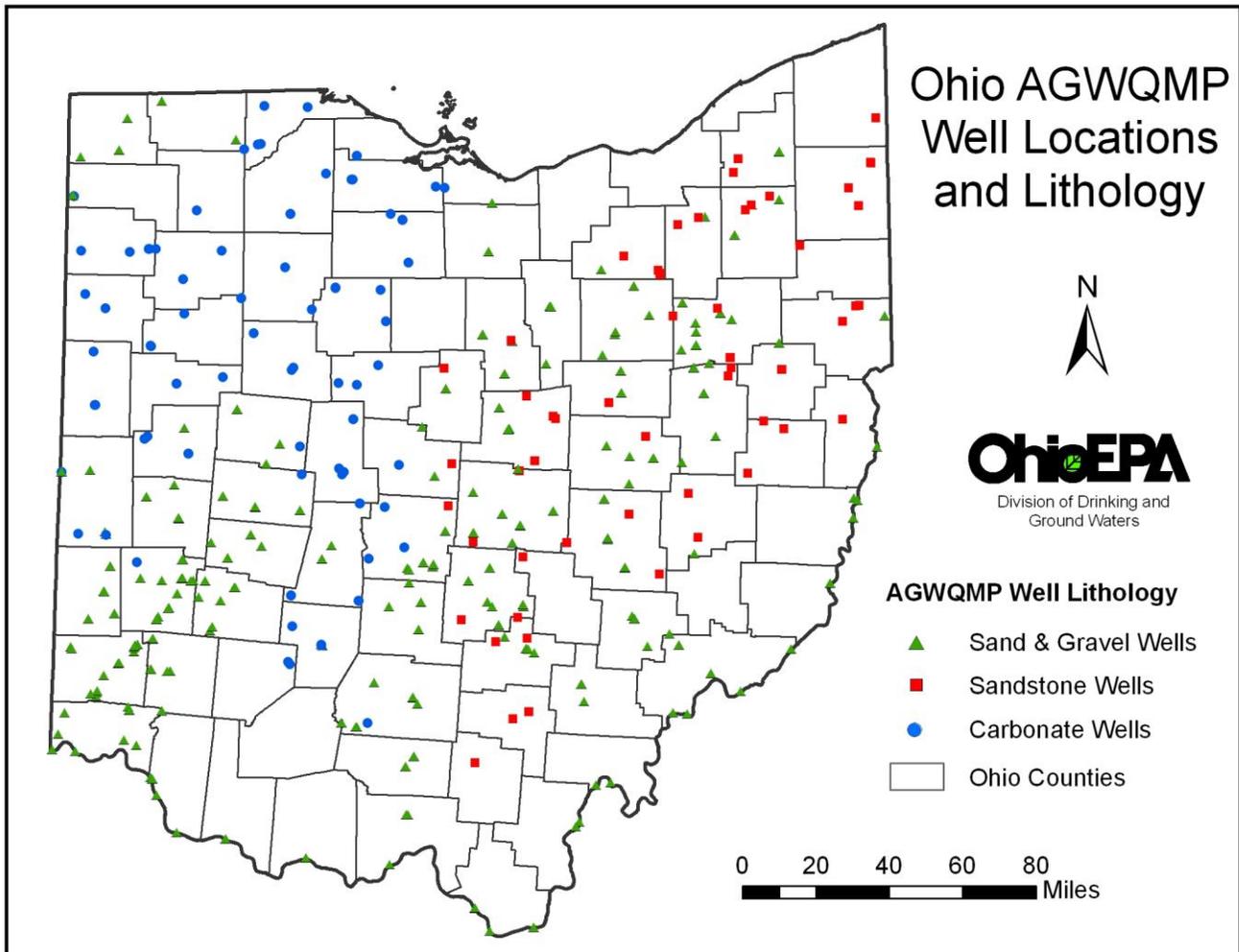


Figure 3. AGWQMP well locations and aquifer lithology.

Table 1 - AGWQMP 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	µg/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 3000
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 (³ H)	0.8 T.U.	
Zinc (Zn)	10	SMCL 5000
Nutrients	mg/L	mg/L
Ammonia (NH ₃)	0.05	
Chemical Oxygen Demand (COD)	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 (µmhos/cm)	± 1 %	
Temperature	± 0.1 EC	
Oxidation Reduction Potential (ORP)	± 1 mV	
Total Dissolved Solids (TDS)	± 1 %	

Samples are collected and analyzed for volatile organic compounds once every 18 months. District staff have identified some AGWQMP 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 contamination impacts. 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. A subset of 28 AGWQMP wells, considered vulnerable based on elevated nitrate concentrations, were analyzed for herbicides between fall 2006 and fall 2007 with no detections besides lab contaminants. The parameters currently analyzed in the volatile organic, herbicide, and semi-volatiles are listed in Table 2. Generally, the detection limit for the organic parameters is 0.5 µg/L.

Locational and lithologic information were updated for all of the ambient wells in the process of entering AGWQMP data into STORET in 2005. Of the active wells, 63 percent (126) produce water from unconsolidated sand and gravel aquifers, 22 percent (43) from carbonate bedrock aquifers, and 15 percent (30) 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, 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. Bedrock wells are generally open boreholes below the casing, so some water contribution from the entire stratigraphic section below the casing is possible and 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 Type" section.

Since completing the implementation of STORET as the primary AGWQMP database, efforts moved to using the database and working to increase the utility of the STORET to the Ground water Program staff. A major accomplishment was the development of reports to query data from STORET using various selection criteria in late 2006. Additional efforts have focused on developing procedures for capturing ground water data collected for special studies, maintaining standard procedures for data collection and management of the new database, and identifying ways to make ground water quality data more accessible to the public. These efforts maintain our high confidence in the AGWQMP data and hopefully, increase data utility and availability. The AGWQMP data continues to be the best untreated ground water quality data that DDAGW has to characterize ground water resources statewide.

A primary focus over the past two years has been work on special studies, including:

- An unsafe water supply investigation in Wooster Township in Wayne County in a setting of thin till overlying a fractured sandstone aquifer;
- A study on the ground water quality impacts of partially treated wastewater infiltration to a buried valley aquifer in northeastern Butler County; and
- Evaluation of the source of microbiologic detections in PWS compliance samples in an area of a confined, glacial aquifer.

Table 2 - Compounds Included in VOC, Herbicide, and BNA Analysis

VOLATILE ORGANIC COMPOUNDS		METHOD 524.2	
Benzene	4-Chlorotoluene	1,3-Dichloropropane	1,1,2,2-Tetrachloroethane
Bromobenzene	Dibromochloromethane	2,2-Dichloropropane	Tetrachloroethene
Bromochloromethane	1,2-Dibromo-3-Chloropropane	1,1-Dichloropropene	Toluene
Bromodichloromethane	1,2-Dibromoethane	cis-1,3-Dichloropropene	1,2,3-Trichlorobenzene
Bromoform	Dibromomethane	trans-1,3-Dichloropropene	1,2,4-Trichlorobenzene
Bromomethane	1,2-Dichlorobenzene	Ethylbenzene	1,1,1-Trichloroethane
n-Butylbenzene	1,3-Dichlorobenzene	Hexachlorobutadiene	1,1,2-Trichloroethane
sec-Butylbenzene	1,4-Dichlorobenzene	Isopropylbenzene	Trichloroethene
tert-Butylbenzene	Dichlorodifluoromethane	4-Isopropyltoluene	Trichlorofluoromethane
Carbon tetrachloride	1,1-Dichloroethane	Methylene chloride	1,2,3-Trichloropropane
Chlorobenzene	1,2-Dichloroethane	Methyl-tert-butyl ether	1,2,4-Trimethylbenzene
Chloroethane	1,1-Dichloroethene	Naphthalene	1,3,5-Trimethylbenzene
Chloroform	cis-1,2-Dichloroethene	n-Propylbenzene	Vinyl Chloride
Chloromethane	trans-1,2-Dichloroethene	Styrene (Ethenylbenzene)	o-Xylene
2-Chlorotoluene	1,2-Dichloropropane	1,1,1,2-Tetrachloroethane	m-Xylene &/or p-Xylene
SEMIVOLATILES/HERBICIDES		METHOD 525.2	
Acetochlor	Benzo[a]pyrene	Butachlor	Metribuzin
Alachlor	bis(2-Ethylhexyl)adipate	Cyanazine	Propachlor
Atrazine	bis(2-Ethylhexyl)phthalate	Metolachlor	Simazine
SEMIVOLATILES/BNA (Base Neutral and Acid extractable)		METHOD 625	
Acenaphthalene	4-Bromophenylphenylether	2,4-Dinitrophenol	Naphthalene
Acenaphthene	4-Chloro-3-methylphenol	2,4-Dinitrotoluene	Nitrobenzene
Anthracene	2-Chloronaphthalene	2,6-Dinitrotoluene	2-Nitrophenol
Benzo[a]anthracene	2-Chlorophenol	Fluoranthene	4-Nitrophenol
Benzo[a]pyrene	4-Chlorophenylphenylether	Fluorene	n-Nitrosodiphenylamine
Benzo[b]fluoranthene	Chrysene	Hexachlorobenzene	n-Nitroso-di-n-propylamine
Benzo[g,h,i]perylene	Di-n-butylphthalate	Hexachlorobutadiene	Pentachlorophenol
Benzo[k]fluoranthene	Di-n-octylphthalate	Hexachlorocyclopentadiene	Phenanthrene
Benzylbutylphthalate	Dibenzo[a,h]anthracene	Hexachloroethane	Phenol
Bis(2-chloroethoxy)methane	2,4-Dichlorophenol	Indeno[1,2,3-cd]pyrene	Pyrene
Bis(2-chloroethyl)ether	Diethylphthalate	Isophorone	1,2,4-Trichlorobenzene
Bis(2-chloroisopropyl)ether	Dimethylphthalate	2-Methyl-4,6-dinitrophenol	2,4,6-Trichlorophenol

These studies have all contributed specific site specific information that has been particularly useful for evaluating sensitive aquifers and helping to determine and document differences in aquifers sensitive to dissolved components and particulates (such as pathogens). These data are being incorporated into Ohio's approach to implementing the Ground Water Rule. Other efforts, such as the development of the Ground Water Impacts database, are attempts to use other ground water quality data to help identify anthropogenic effects on 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, utilize, analyze, and present these data in effective ways.

Ambient Ground Water Quality Versus Pristine Ground Water Quality

A definition of ambient is "in the surrounding area" and the Ambient Ground Water Quality data is ground water quality data in the area surrounding the sampled well. Ambient Ground Water Quality data is not intended to be pristine ground water quality data. The primary objective of the AGWQMP 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 public water systems. The AGWQMP wells accomplish this goal, but this is not to say that no AGWQMP wells are impacted by land use activity. Ground water quality impacts are documented in several AGWQMP wells, however, these impacts are generally limited. A common example of an impacted AGWQMP well is the presence of elevated nitrate. The influence of elevated nitrate associated with local land use on several water quality parameters is illustrated in Table 5 in the Ground Water Quality by Aquifer Type section. In some cases, if an AGWQMP well becomes significantly impacted, for example a significant spike of potassium associated with fertilizer back flow into a well, the well will be removed from the AGWQMP and the anomalous data excluded from analysis. Other wells that exhibit limited impact continue to be sampled as ambient wells because the water quality is considered typical of the ambient conditions of the ground water in the area that is being used as source water for a public water system.

One of the limitations of the AGWQMP wells is that they are generally characteristic of higher production and deeper wells used by larger PWSs. This subset of wells does not characterize the water quality of shallow aquifers that are utilized by low production wells typical of residential wells. Shallow aquifers that are sensitive and associated with numerous potential contaminant sources are more likely to be impacted by local land use activity than deeper aquifers. Consequently, the limited impact to ground water quality observed in the AGWQMP wells may provide a false security for ground water impacts in shallower aquifers. Because of this limitation, the AGWQMP wells may not be an appropriate subset of wells to be used as background water quality for comparison with shallow aquifers. Other limitations include the number and 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 AGWQMP chemical measurements statewide, providing strong analytical consistency. Overall, the quality of the AGWQMP data set is high and the geochemical variability between the aquifer types is easily discerned, as illustrated in the Ground Water Quality by Aquifer Type Section of this report. Nevertheless, the AGWQMP data does not reflect pristine ground water and use of the AGWQMP data for background water quality comparisons must be carefully evaluated and qualified. Because of the variability inherent in ground water data, caution must be taken in extrapolating well specific sample results beyond the collection area or associating specific data from one aquifer type to different aquifer types.

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. For new public water system wells, however, raw water is required to be tested for primary and secondary parameters for well approval. The PWS personnel 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 as 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 generally be reduced to some extent with the 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 3.

Table 3			
Drinking Water Monitoring Requirements for Public Water Supply Wells			
Contaminant Group	Community PWS	Non-Transient, Non-Community PWS	Transient Non-Community PWS
Radiological ^a	X		
Trihalomethanes/Haloacetic Acids	X	X ⁱ	
Asbestos ^b	X	X	
Inorganic Constituents ^c	X	X	
Synthetic Organic Compounds (SOCs) ^d	X	X	
Volatile Organic Compounds (VOCs) ^e	X	X	
Lead and Copper ^f	X	X	
Microbiological ^g	X	X	X
Nitrate and Nitrite ^h	X	X	X

^a Must monitor for gross alpha radioactivity and radium 228 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 if PWS has asbestos-cement distribution pipe .

^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 have a five year mean nitrate value above 2.0 mg/L are required to monitor the other 15 SOC's 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 and haloacetic acids are required at NCNT PWSs if the system disinfects.

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 (3-16 inches) recharges 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 4. 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 wells except where dominated by shale, as in southwest and southeast Ohio.

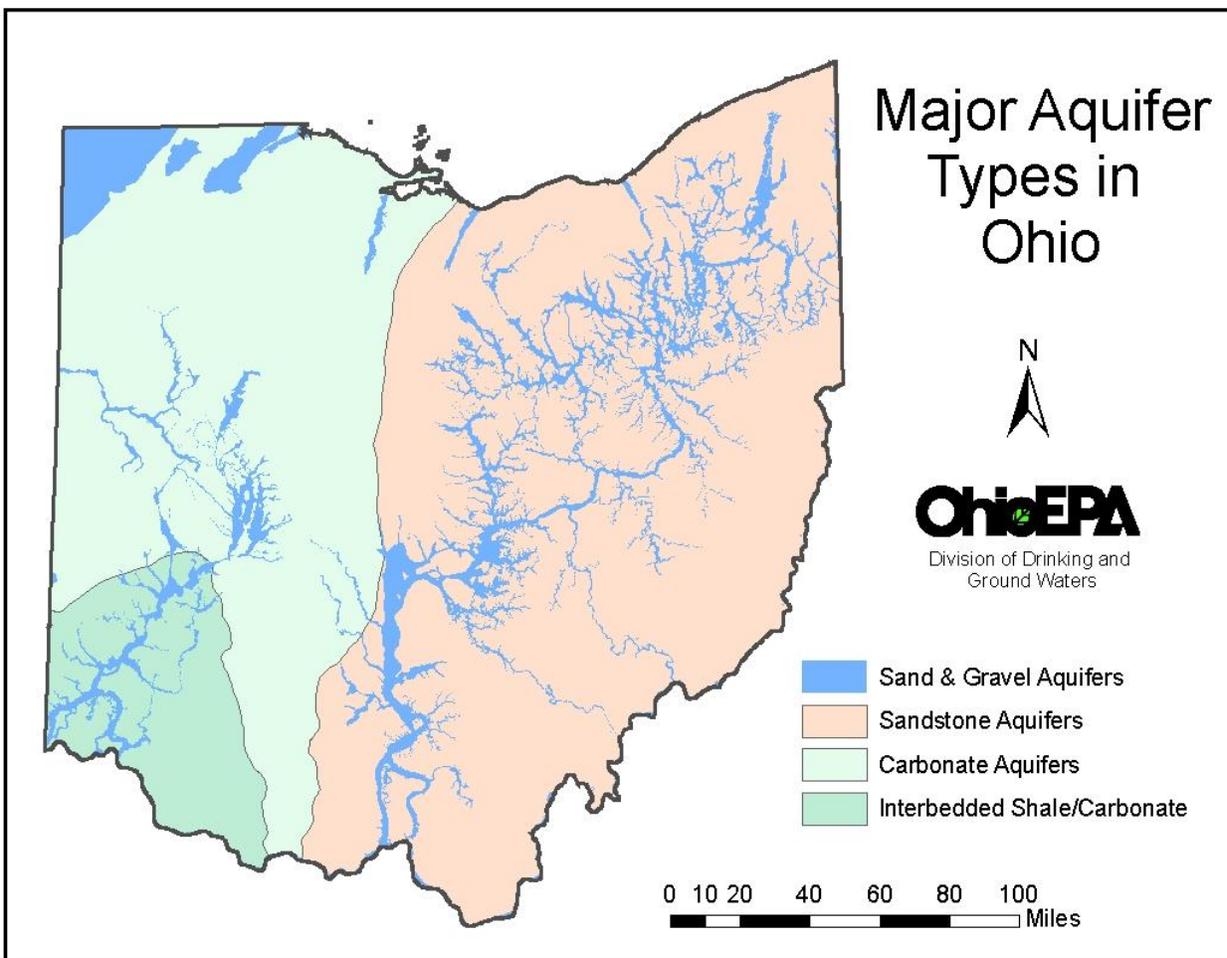


Figure 4. Aquifer Types in Ohio, modified from ODNR Aquifer Map (ODNR, 2000).

Sand and Gravel Aquifers

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 other glacial drift 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 4, 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 in Ohio. 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 geologic settings included in the sand and gravel aquifers are the outwash/kame and beach ridge deposits, including the Oak Opening Sands (large patches of sand and gravel in northwest Ohio, Figure 4).

Water production from the coarser grained and thicker sand and gravel deposits ranges up to 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.

Sandstone Aquifers

In the eastern half of Ohio, Mississippian and Pennsylvanian sandstone units are the dominant bedrock aquifers (Figure 4). 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, 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 a 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 sections include low yielding aquifers. The bedrock consists of varied sequences of thin-bedded shales, limestones, sandstones, clays, and coals of the Pennsylvania, Conemaugh and Monongahela Groups and the Permian Dunkard Group. Yields below 5 gallons per minute are common in these areas (ODNR, 2002).

Carbonate Aquifers

Ohio's third major aquifer type is carbonate bedrock, the dominant aquifer in the western part of the state (Figure 4). Middle Devonian and Silurian limestone and dolomite 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, in order of deposition, are fractured or karst Silurian sub-Lockport/ Lockport Dolomite and equivalent units, 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 (Ten Mile Creek Dolomite, Silica formation, Dundee Limestone, and Detroit River Group) are productive carbonate aquifers. These carbonates were generally deposited in warm, shallow seas with limited input of sediment from continental sources. If the Devonian limestone is overlain by 100 feet or more of Devonian shale, the ground water quality in the aquifer is poor and generally cannot be considered a viable aquifer.

The southwestern portion of the state is underlain by inter-bedded lower Ordovician carbonates and shales. These undivided Ordovician units are dominated by shale (Figure 4) and consequently, well yields are generally less than 10 gallons per minute, and in many areas is 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 region of Devonian shale that overlies the Columbus and Delaware Limestone aquifers. The narrow north-south trending area of the **Devonian Shale** in central Ohio curves eastward along the Lake Erie shoreline. These shale bedrock units are also poor aquifers yielding less than 5 gallons per minute and hydrogen sulfide tends to be present causing water quality problems.

GROUND WATER QUALITY BY AQUIFER TYPE

Introduction

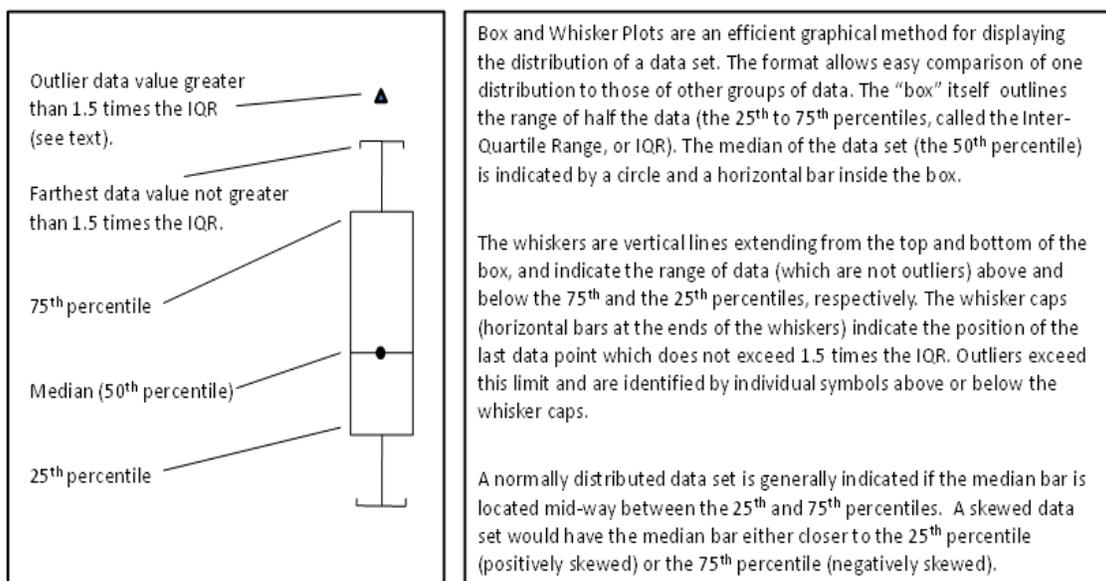
The overall ground water quality within the State of Ohio is described here using the Ambient Ground Water Quality Monitoring Program (AGWQMP) database, consisting of approximately 6,000 inorganic and 2,000 organic water quality samples distributed across 337 active and inactive wells. Figure 3 illustrates the distribution of AGWQMP wells across Ohio by aquifer type. As described above, 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 AGWQMP - to collect, analyze, and describe the source (ambient) ground water quality used by public water systems across the state.

AGWQMP data are presented by aquifer type since water-rock interaction along flow paths 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 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, are variable across the state, leading to recharge waters with variable initial compositions. The thick glacial tills (clayey soils) found across much of north, central, and west Ohio affect the initial percolation water quality differently than the weathered colluvium with variable amounts of loess in southeast Ohio. The permeability of the heavy glacial soils tends to increase the residency time, however, agriculture tile drains in many of these glacial soils can short circuit flow paths to surface water and thus, reduce the volume of recharge reaching local aquifers.

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 land use activities. Older, deeper waters, such as found 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 5 is a box plot indicating the distribution of well depths by aquifer type for the AGWQMP wells. The median well depth in the carbonate aquifers (~225 feet) is slightly greater than the median well depth in the sandstone aquifers (~220 feet). The median well depth for the sand and gravel aquifers (~ 90 feet) is less than one-half the depth of the carbonate or sandstone aquifers suggesting shorter resident times for sand and gravel aquifers compared to bedrock aquifers.

Box and Whisker Plot Explanation



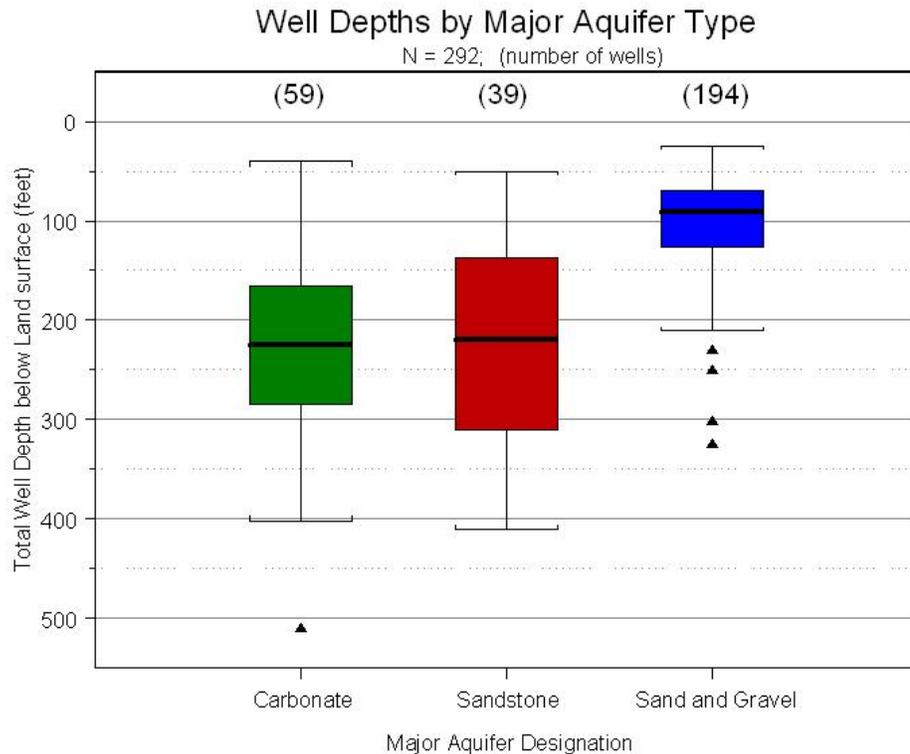


Figure 5. Box plot of active AGWQMP well depths by aquifer type.

Inorganic Parameter Mean Values

Ambient ground water quality data presented in Table 4 summarizes the geochemistry by major aquifer type. This table provides the arithmetic mean, median, minimum value, value of the 95TH percentile, standard deviation, total number of samples, number of samples below the reporting limit, and the percent non-detect for inorganic and field parameters in each aquifer type as of December 2007. The reporting limit was used for the non-detect values in calculating means. The “non-detect” 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. The estimates of the number and percentages of non-detect data (columns 8 and 9) may also be influenced by changes in the reporting limits.

The data summarized in Table 4 represents the accumulation of over 164,000 raw, inorganic ground-water data results gathered at 337 wells across Ohio from 35 years of ground water sampling. Consistent sampling protocol, analytical procedures, and long site histories lend a unique significance to the AGWQMP data. A significant result of the long history of the AGWQMP sampling is the ability to evaluate ground water quality trends at individual wells over periods of time. Table 4 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. It should be noted, however, that some wells in the AGWQMP network have been influenced by

anthropogenic sources, such as nitrates or VOCs. Thus, the water quality presented is not pristine, but rather is typical of the ground water quality of aquifers utilized for source water by the PWSs.

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

- **Field Parameters** – measured in the 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 $\mu\text{g/L}$ (ppb); and
- **Nutrients** – components required by organic systems for growth, concentrations in mg/L (ppm).

To illustrate the utility of the Ambient Ground 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 (225 $\mu\text{g/L}$), while the carbonate system has the lowest (30.3 $\mu\text{g/L}$). Suppose now you were interested in looking up the probabilities of encountering manganese detections in each of the three types of aquifers. To do this, follow the manganese row across to the last column, Percent Non-detect. 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 concentration above the detection limit 86 percent of the time. In the case of the carbonate bedrock system in Ohio, we find the percent non-detect (or percent censored) for manganese is 32 percent, indicating that a 68 percent chance exists that a water sample from this aquifer type will yield a detection for manganese. It should be noted that these non-detect 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 AGWQMP wells.

Use of Primary and Secondary MCLs

Maximum Contaminant Levels (MCLs) are regulatory standards for permissible concentrations of parameters in drinking water delivered to the public. Secondary Maximum Contaminant Levels (SMCLs) are advisory limits applied strictly to treated water at public water systems for aesthetic water quality issues, such as taste and odor. Since AGWQMP data are obtained entirely from raw (untreated) ground water, which is unregulated, any exceedence of an MCL or SMCL by an AGWQMP 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. 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 AGWQMP. The MCLs for these parameters are arsenic (10 $\mu\text{g/L}$), barium (2 mg/L), cadmium (5 $\mu\text{g/L}$), chromium (100 $\mu\text{g/L}$), fluoride (4 mg/L), nickel (0.1 mg/L), nitrate-nitrite as N (10 mg/L) and selenium (50 $\mu\text{g/L}$). 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 (Table 4), no chemical parameters exceed a MCL based on averages by aquifer type. Mean arsenic concentrations for all three aquifer systems are well below the arsenic MCL of 10 $\mu\text{g/L}$ (sand and gravel = 5.69 $\mu\text{g/L}$,

sandstone = 3.06 µg/L, carbonate = 4.04 µg/L). Only a single (sand and gravel) well recorded a mean arsenic concentration above the old MCL of 50 mg/L, with a value of 75.6 µg/L. However, 34 active AGWQMP wells have raw water mean values of arsenic that exceed the new arsenic MCL of 10 µg/L. If these wells are PWS wells, treatment may be required to bring the Arsenic concentrations below the MCL in the distributed water. 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 AGWQMP. 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 ground water quality sections below.

Table 4 – Ambient Ground Water Quality Data
Ambient Ground Water Quality Monitoring Data Summary by Major Aquifer as of December 2007

FIELD PARAMETERS									
Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value *	95th Percentile	Standard Deviation	Number of Samples	Number § Below Rep. Limit	Percent § Non-detect
Oxidation-Reduction Potential (ORP) mV	Sand and Gravel	39.1	17.0	-531	255	133	442	NA	NA
	Sandstone	52.4	16.5	-530	530	195	124	NA	NA
	Carbonate	-36.6	-37.0	-295	179	131	136	NA	NA
pH, Field S.U.	Sand and Gravel	7.31	7.32	5.60	7.82	0.34	3042	NA	NA
	Sandstone	7.26	7.27	5.15	7.95	0.46	664	NA	NA
	Carbonate	7.24	7.22	5.61	7.84	0.36	1076	NA	NA
Specific Conductivity µmohms/cm	Sand and Gravel	662	650	50	1005	202	3217	NA	NA
	Sandstone	649	520	86	1340	499	711	NA	NA
	Carbonate	911	848	270	1559	336	1052	NA	NA
Total Dissolved Solids, Field mg/L	Sand and Gravel	543	513	59.0	862	177	406	NA	NA
	Sandstone	515	405	57.3	970	365	122	NA	NA
	Carbonate	789	739	254	1490	306	125	NA	NA
Water Temperature Degrees C	Sand and Gravel	13.8	13.4	5.1	18.1	2.49	3046	NA	NA
	Sandstone	13.0	12.7	7.0	16.2	2.04	635	NA	NA
	Carbonate	13.5	13.1	6.9	16.7	1.91	1045	NA	NA
MAJOR COMPONENTS									
Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	95th Percentile	Standard Deviation	Number of Samples	Number ¶ Below Rep. Limit	Percent Non-detect
Alkalinity, Total as CaCO ₃ mg/L	Sand and Gravel	260	267	<5.0	353	73.1	3839	10	0
	Sandstone	216	196	<5.0	415	113	815	3	0
	Carbonate	291	300	<5.0	376	68.9	1149	6	1
Calcium, Total mg/L	Sand and Gravel	95.5	94.8	<2.0	138	31.7	3936	3	0
	Sandstone	60.1	55.0	<1.0	141	35.5	841	5	1
	Carbonate	132	116	<2.0	209	66.7	1163	6	1

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Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	95 th Percentile	Standard Deviation	Number of Samples	Number ≠ Below Rep. Limit	Percent Non-detect
Chloride mg/L	Sand and Gravel	40.1	30.0	<2.0	111	36.7	3898	117	3
	Sandstone	40.7	22.8	<1.0	147	51.7	833	75	9
	Carbonate	31.1	15.0	<2.0	102	54.9	1130	114	10
Hardness, Total as CaCO ₃ mg/L	Sand and Gravel	355	358	<10.0	488	86.0	2910	5	0
	Sandstone	228	202	<10.0	565	130	656	3	0
	Carbonate	537	464	<10.0	898	243	893	7	1
Magnesium, Total mg/L	Sand and Gravel	28.7	29.0	<1.0	42.0	10.2	3936	7	0
	Sandstone	19.1	16.0	<1.0	53.0	13.4	842	6	1
	Carbonate	50.7	45.0	<1.0	92.0	19.6	1165	7	1
Potassium, Total mg/L	Sand and Gravel	2.45	2.0	<0.7	4.0	1.57	3490	482	14
	Sandstone	2.56	2.0	<0.6	5.0	1.14	788	196	25
	Carbonate	3.02	3.0	<1.1	6.0	1.31	1052	27	3
Sodium, Total mg/L	Sand and Gravel	26.1	21.0	<2.0	63.0	23.8	3929	82	2
	Sandstone	63.4	27.0	<4.0	223	91.7	842	38	5
	Carbonate	37.5	29.0	<5.0	93.5	33.9	1166	13	1
Sulfate mg/L	Sand and Gravel	80.1	67.1	<4.0	163	78.8	3897	38	1
	Sandstone	84.3	43.0	<5.0	268	148	837	73	9
	Carbonate	279	199	<5.0	810	249	1163	13	1
Total Dissolved Solids mg/L	Sand and Gravel	466	450	<5.0	680	164	3948	29	1
	Sandstone	429	336	<8.0	920	318	846	9	1
	Carbonate	743	664	<10	1421	412	1170	55	5
TRACE CONSTITUENTS									
Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	95 th Percentile	Standard Deviation	Number of Samples	Number ≠ Below Rep. Limit	Percent Non-detect
Aluminum µg/L	Sand and Gravel	203	<200	<84.0	<200	80.9	2490	2482	100
	Sandstone	200	<200	<200	<200	1.5	683	681	100
	Carbonate	204	<200	<200	<200	67.6	783	776	99
Arsenic, Total µg/L	Sand and Gravel	5.69	<2.0	<2.0	17.6	8.58	3484	1801	52
	Sandstone	3.06	<2.0	<2.0	7.70	4.60	771	586	76
	Carbonate	4.04	<2.0	<2.0	15.8	4.27	1083	648	60
Barium µg/L	Sand and Gravel	173	125	<15.0	476	196	3439	129	4
	Sandstone	162	65	<15.0	675	326	752	78	10
	Carbonate	73.9	40	<7.0	230	84.0	1092	131	12

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Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	95 th Percentile	Standard Deviation	Number of Samples	Number ≠ Below Rep. Limit	Percent Non-detect
Cadmium, Total µg/L	Sand and Gravel	0.21	<0.2	<0.2	<0.2	0.10	2906	2865	99
	Sandstone	0.23	<0.2	<0.2	<0.2	0.68	766	753	98
	Carbonate	0.21	<0.2	<0.2	<0.2	0.16	1044	1025	98
Chromium, Total µg/L	Sand and Gravel	30.0	<30	<10	<30	2.1	3072	3052	99
	Sandstone	29.9	<30	<10	<30	1.4	788	784	99
	Carbonate	29.9	<30	<10	<30	2.6	1076	1061	99
Copper µg/L	Sand and Gravel	12.5	<10	<2.0	20.0	16.6	2650	2271	86
	Sandstone	13.7	<10	<2.0	30.3	19.4	735	585	80
	Carbonate	16.9	<10	<2.0	35.9	40.3	823	602	73
Fluoride mg/L	Sand and Gravel	0.40	0.26	<0.04	1.30	0.39	2423	553	23
	Sandstone	0.31	0.26	<0.10	0.66	0.20	661	133	20
	Carbonate	1.39	1.38	<0.10	2.33	0.59	801	16	2
Iron, Total µg/L	Sand and Gravel	1392	831	<20	4201	2384	3879	699	18
	Sandstone	1589	440	<50	9194	3517	832	149	18
	Carbonate	1213	708	<40	3234	3279	1157	136	12
Lead, Total µg/L	Sand and Gravel	3.69	<2.0	<1.0	4.58	23.7	3485	3116	89
	Sandstone	2.78	<2.0	<2.0	4.70	6.70	781	697	89
	Carbonate	2.94	<2.0	<2.0	5.47	6.86	1024	869	85
Manganese, Total µg/L	Sand and Gravel	225	119	<8.0	670	465	3621	503	14
	Sandstone	202	86	<9.0	826	314	799	115	14
	Carbonate	30.3	17	<10	100	32.1	1073	341	32
Nickel, Total µg/L	Sand and Gravel	40.1	<40	<1.0	<40	4.87	2579	2567	100
	Sandstone	40.9	<40	<23	<40	8.15	709	694	98
	Carbonate	40.2	<40	<40	<40	2.78	825	821	100
Selenium, Total µg/L	Sand and Gravel	2.02	<2.00	<2.00	<2.00	0.19	2711	2625	97
	Sandstone	2.00	<2.00	<2.00	<2.00	0.05	743	737	99
	Carbonate	2.05	<2.00	<2.00	<2.00	0.40	820	789	96
Strontium, Total µg/L	Sand and Gravel	1878	387	<30	10960	4163	2569	8	0
	Sandstone	549	371	<30	1335	722	696	10	1
	Carbonate	17910	15800	<30	39260	12930	829	8	1
Tritium T.U.	Sand and Gravel	9.64	10.05	<0.08	15.23	5.46	106	8	8
	Sandstone	8.37	8.50	<0.08	18.69	6.01	28	7	25
	Carbonate	3.81	3.81	<0.08	11.79	4.09	38	16	42

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Zinc, Total µg/L	Sand and Gravel	32.7	<10	<6.0	56.0	202	2694	1788	66
	Sandstone	31.3	11	2.73	97.0	73.3	736	342	46
	Carbonate	62.7	11	<10	224	188	825	372	45
NUTRIENTS									
Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	95 th Percentile	Standard Deviation	Number of Samples	Number † Below Rep. Limit	Percent Non-detect
Ammonia mg/L	Sand and Gravel	0.24	0.08	<0.01	0.79	0.48	3816	1462	38
	Sandstone	0.37	0.18	<0.04	1.29	0.46	820	224	27
	Carbonate	0.38	0.33	<0.05	0.91	0.40	1142	130	11
Chemical Oxygen Demand mg/L	Sand and Gravel	11.3	<10	<0.5	14.0	12.6	3716	3220	87
	Sandstone	10.9	<10	<4.0	12.0	8.97	804	726	90
	Carbonate	12.2	<10	<5.0	20.7	13.9	1148	922	80
Nitrite & Nitrate NO ₂ +NO ₃ as N mg/L	Sand and Gravel	0.75	<0.10	<0.10	3.47	1.26	3801	2061	54
	Sandstone	0.36	<0.10	<0.10	1.86	0.85	833	599	72
	Carbonate	0.19	<0.10	<0.10	0.31	0.67	1149	984	86
Phosphorus mg/L	Sand and Gravel	0.10	<0.05	<0.01	0.14	0.52	3094	2273	73
	Sandstone	0.10	<0.05	<0.01	0.28	0.24	696	396	57
	Carbonate	0.07	<0.05	<0.01	0.13	0.14	938	680	72
Total Kjeldahl N mg/L	Sand and Gravel	0.38	0.24	<0.08	0.89	0.37	1682	706	42
	Sandstone	0.53	0.31	<0.20	1.92	0.51	485	166	34
	Carbonate	0.55	0.45	<0.12	1.22	0.49	576	102	18
Total Organic Carbon mg/L	Sand and Gravel	2.84	<2.0	<0.5	6.5	3.66	2846	2367	83
	Sandstone	2.51	<2.0	<0.5	5.0	2.81	733	635	87
	Carbonate	2.78	<2.0	<1.0	5.0	4.46	877	718	82

* Records with '<' represent reporting limit

§ NA denotes not applicable

£ Generally minimum values are current or historical reporting limits, historic reporting limits can be lower than current reporting limits.

† Current reporting limits are listed in Table 1.

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 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” with a different charge. 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 [$\text{Mn(II), Mn(III), Mn(IV)}$]. In general, a high ground water redox potential equates to oxidized or well-aerated (aerobic) environmental conditions and a low redox potential reflects reduced or anaerobic conditions. Consider also that these two redox extremes exist 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 pairs, the oxidation of organic matter occurs concurrently with sequential reduction of parameters in the following order: 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 ground water quality data, and make predictions and estimates for parallel changes in other parameters.

Within the AGWQMP, we use nitrate (NO_3 as N) as a “proxy” (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 indicate the dominance of oxidizing conditions within the formation water at the time of sampling. Nitrate is quite stable in 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 than 2.0 mg/L are interpreted as evidence of influence from 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 AGWQMP data, a subset of nitrate impacted wells (samples with nitrate > 2.0 mg/L) which represent oxidized ground water, were extracted to generate Table 5. This table generally has the same structure as Table 4, and shows the mean, median, minimum, maximum (rather than 95th percentile), etc., for the oxidized subset of ground water data. The goal of presenting this subset of data is to highlight the sensitivity of the selected parameters to changes in redox conditions within aquifers. Differences between Tables 4 and 5 reflect differences between reduced and oxidized conditions. The differences are most obvious in arsenic, iron, manganese, and nitrate concentrations. The association of As and Fe with iron hydroxide compounds, which are insoluble under oxidizing

conditions and soluble in reducing conditions, defines the geochemical control. The solubility of major elements (for example Ca, Mg, Cl, Na, etc.) tend to be insensitive to redox changes.

Ground water quality data compiled for 69 wells with nitrate concentration that exceed 2.0 mg/L are presented in Table 5, and thus represent data from oxidized environments. Comparing the data in Table 5 to those in Table 4 illustrates geochemical changes that represent different underlying redox conditions. Lower mean and median values for ammonia are expected in Table 5 compared to Table 4 since ammonia is a more reduced form of nitrogen. The low arsenic, iron, and manganese means and medians in Table 5 are also expected since Table 5 represents oxidized conditions where these elements exhibit low solubility. Arsenic is at or very close to its reporting limit in the oxidizing conditions represented in Table 5. Iron and manganese exhibit erratic behavior, but they are greatly lowered in Table 5 as compared to Table 4 due to their lower solubility in oxidized conditions. In contrast, the solubility of the major elements appears insensitive to redox changes, for example, hardness and TDS display little change in mean or median values between the tables. Consequently, the concentrations of selected parameters in a well can be used effectively to infer geochemical redox conditions in individual wells.

Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
Ammonia mg/L	Sand and Gravel	0.059	<0.050	<0.050	0.40	0.038	548	476	87
	Sandstone	0.051	<0.050	<0.050	0.068	0.003	36	32	91
	Carbonate	0.056	0.050	<0.050	0.10	0.014	13	12	89
Arsenic, Total µg/L	Sand and Gravel	2.1	<2.0	<2.0	17.0	1.08	547	536	98
	Sandstone	<2.0	<2.0	<2.0	<2.0	0.00	36	36	100
	Carbonate	<2.0	<2.0	<2.0	<2.0	0.00	12	12	100
Hardness mg/L	Sand and Gravel	340	349	<10.0	648	73.5	548	1	0
	Sandstone	223	203	174	347	48.4	36	0	0
	Carbonate	433	420	408	469	25.4	13	0	0
Iron, Total µg/L	Sand and Gravel	315	<50.0	<20.0	29700	1636.0	544	326	60
	Sandstone	124	57.0	<50.0	599	129	34	11	31
	Carbonate	133	59	<50.0	500	129.7	13	7	52
Manganese, Total µg/L	Sand and Gravel	111.8	13.0	<10.0	1970	201	548	241	44
	Sandstone	25.4	<10.0	<10.0	230	49	36	22	62
	Carbonate	14.7	<10.0	<10.0	44.1	10.7	13	9	67
Nitrite & Nitrate NO ₂ +NO ₃ as N mg/L	Sand and Gravel	3.37	2.92	2.01	12.3	1.38	548	22	4
	Sandstone	3.48	3.08	2.01	11.4	1.91	35	0	0
	Carbonate	5.59	5.2	2.90	15.1	3.09	12	0	0
Total Dissolved Solids mg/L	Sand and Gravel	431	422	<10	1110	105	537	0	0
	Sandstone	322	294	252	780	94	31	0	0
	Carbonate	429	520	<10	674	244	11	0	0

** for comparison with summary results in Table 4;

§ 69 wells total: 62 sand and gravel, 5 sandstone, 2 carbonate.

Table 5 contains ground water samples from geologic settings most likely to be oxidized and influenced by dissolved constituents associated with surface land use, such as nitrate. Of the 69 wells in Table 5 which include samples with elevated nitrate concentrations, 62 (90%) are sand and gravel sites, 5 (7%) are sandstone sites, and 2 (3%) are wells utilizing carbonate aquifers. The higher percentage of sand and gravel wells with elevated nitrates suggests the sand and gravel settings are more likely to be impacted by dissolved surface water contaminants than the bedrock settings. This is consistent with documentation of sensitive aquifers in Ohio. The lower number of sandstone and carbonate wells included in Table 5 allows local variability associated with aquifer lithology or residence time to influence the results and provide greater variability between Tables 4 and 5 for parameters not sensitive to redox conditions (hardness and TDS).

General Ground 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 6, in which the mean major ion compositions of the three principal aquifer systems are presented in bar graphs. While all three water types are based on the calcium-bicarbonate model, the sandstone aquifer waters exhibit the highest percentage of sodium and potassium. 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 higher total dissolved solids (TDS); longer residence time within the carbonate system; the higher solubility of carbonate rocks; and the presence of evaporates. The lower TDS of the sandstone aquifers is attributed to the higher silica sand (low solubility) and lower carbonate rock content in the sandstones. These same data are presented on a Piper diagram in Figure 7. 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.

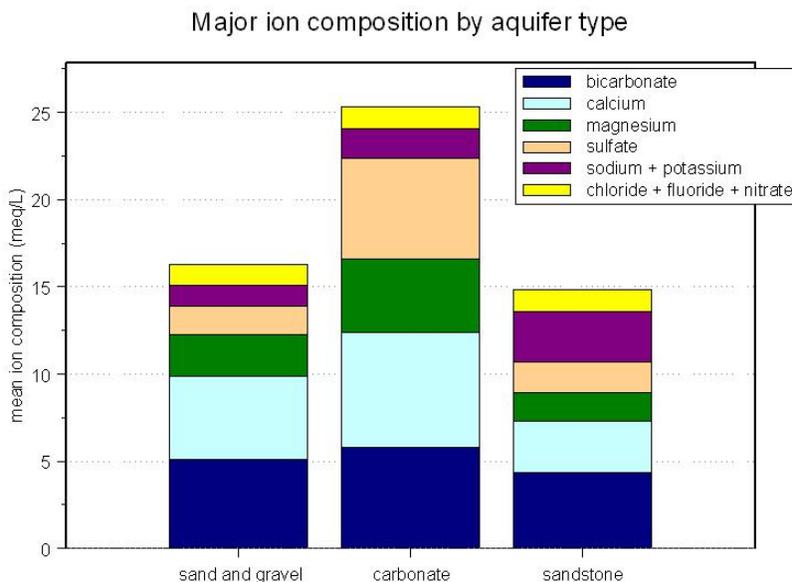


Figure 6. Mean major ion composition of the three aquifer systems.

The carbonate ground waters in Figure 7 (blue points) trend toward a more sulfate-rich composition (upper apex of lower right triangle), reflecting the dissolution of celestite (SrSO_4) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) 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 because 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.

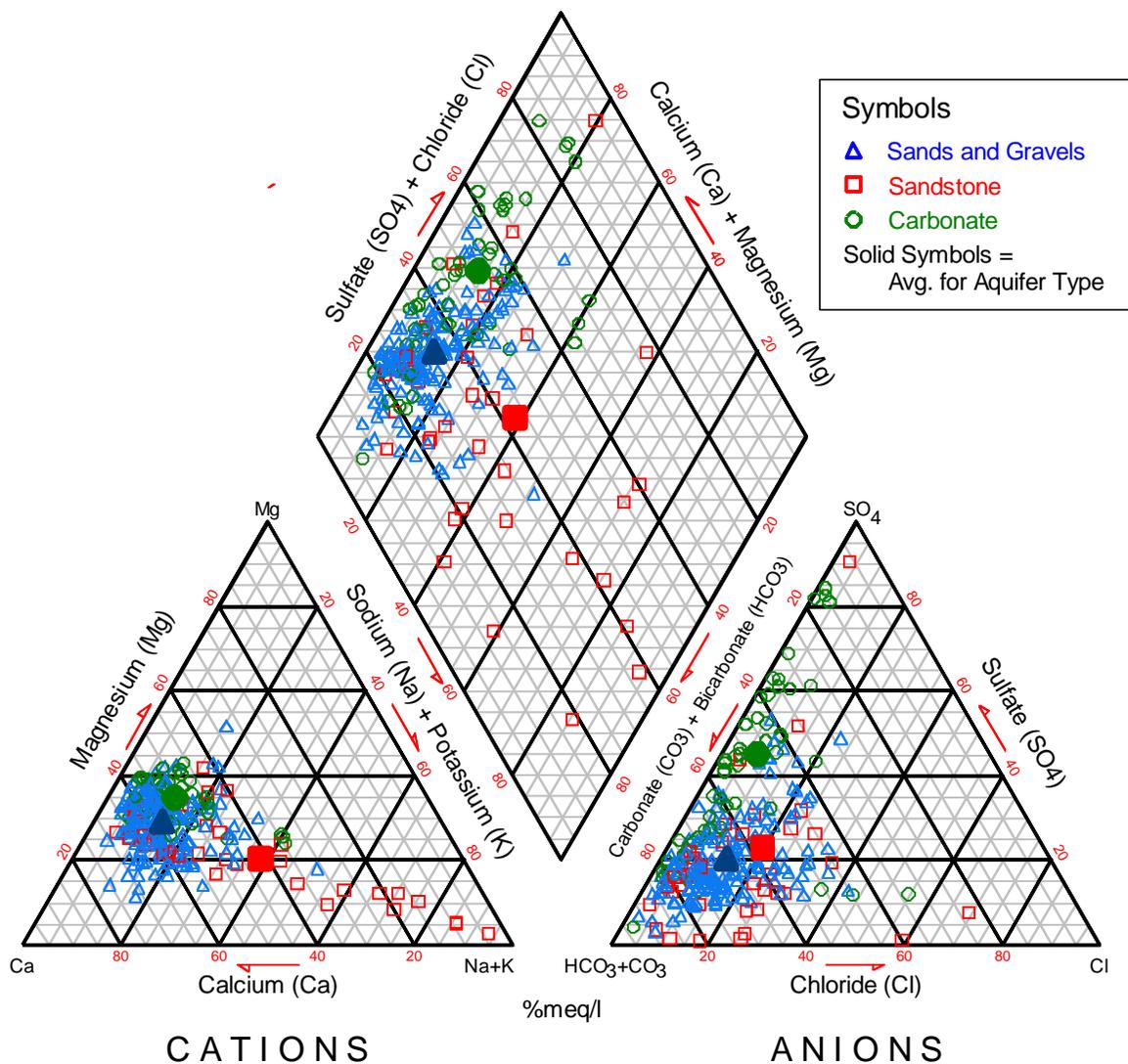


Figure 7. Piper diagram of well means and aquifer means for AGWQMP wells.

The following sections discuss the ground water quality exhibited in each of the major aquifer types, and the relationships between the major aquifer types, utilizing the data summarized in the Ambient Ground Water Table, Table 4. Several of the graphic relationships presented here are repeated from previous 305(b) reports because they present clear distinctions between ground water quality in the major aquifers. Previous reports contain 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 AGWQMP database for the unconsolidated sand and gravel aquifers contains about 3,900 inorganic ground water samples from 222 wells. This water chemistry is summarized in Table 4. 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 (green square) plot close to the carbonate waters (blue square) on the cation triangle (lower left triangle) of Figure 7. In the anion triangle of Figure 7, however, the carbonates are heavily influenced by the high sulfate concentrations. In Figure 8, the total dissolved solids data are presented in a box plot for each of the major aquifer types. The TDS concentrations of the sand and gravel aquifers (median 450 mg/L) is intermediate between the carbonate (median 664 mg/L) and sandstone (median 336 mg/L) aquifers. This relationship is illustrated in the median values and in the outlier points as illustrated Figure 8 as well as the mean values for TDS in Table 4.

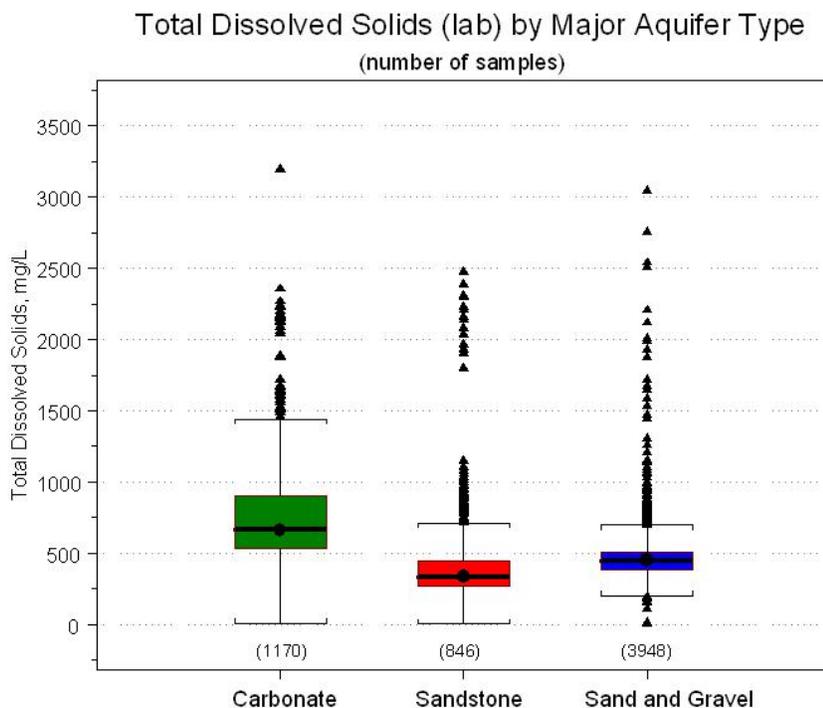


Figure 8. Box plot of total dissolved solids for AGWQMP data.

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 produced 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

The AGWQMP database for sandstone aquifers contains about 850 samples from 56 wells, whose mean water chemistries are presented in Table 4. These waters are characterized by low bicarbonate alkalinity. A significant trend for some sandstone waters is increasing chloride and sodium composition shown in the Piper Diagram (Figure 7). 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 (27-29 mg/L), the mean value for the sandstones is 63.4 mg/L versus 37.5 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.

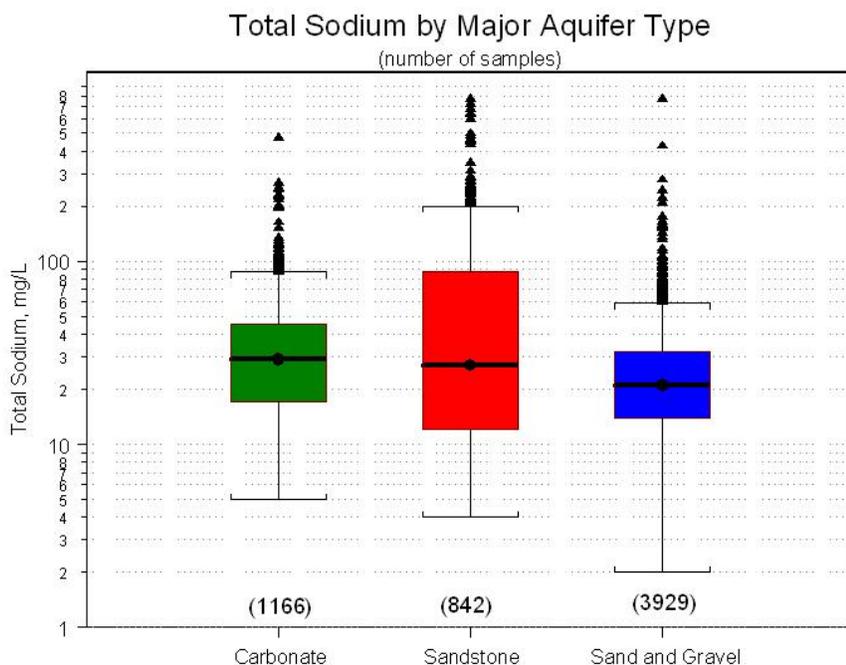


Figure 9. Box plot of sodium for AGWQMP data.

Carbonate Bedrock Aquifer - Ground Water Quality

The AGWQMP database for the carbonate system consists of about 1150 samples from 70 wells. Most ground water in the carbonate bedrock is of the calcium-bicarbonate-sulfate type, as depicted in the Piper diagram (Figure 7), 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 major aquifer types. Mean hardness (537 mg/L) is at a level that typically requires treatment to remove calcium and magnesium in the finished water. The mean concentrations of TDS (743 mg/L), iron (1213 µg/L), and sulfate (279 mg/L) are all above their respective SMCLs (500 mg/L, 0.3 mg/L, and 250 mg/L, respectively). 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 (1.39 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 and the reduced nature of the deeper production zones results in routine ground water quality that exceeds secondary drinking water standards.

The elevated concentrations in the carbonate aquifers relative to the other major aquifers are related to longer residence times within the system, and the relatively high solubility of carbonate minerals in the limestone - dolomite bedrock. Figure 10 illustrates the relationship between sulfate and hardness (sum of the ions Ca and Mg) by aquifer type for about 4,400 samples

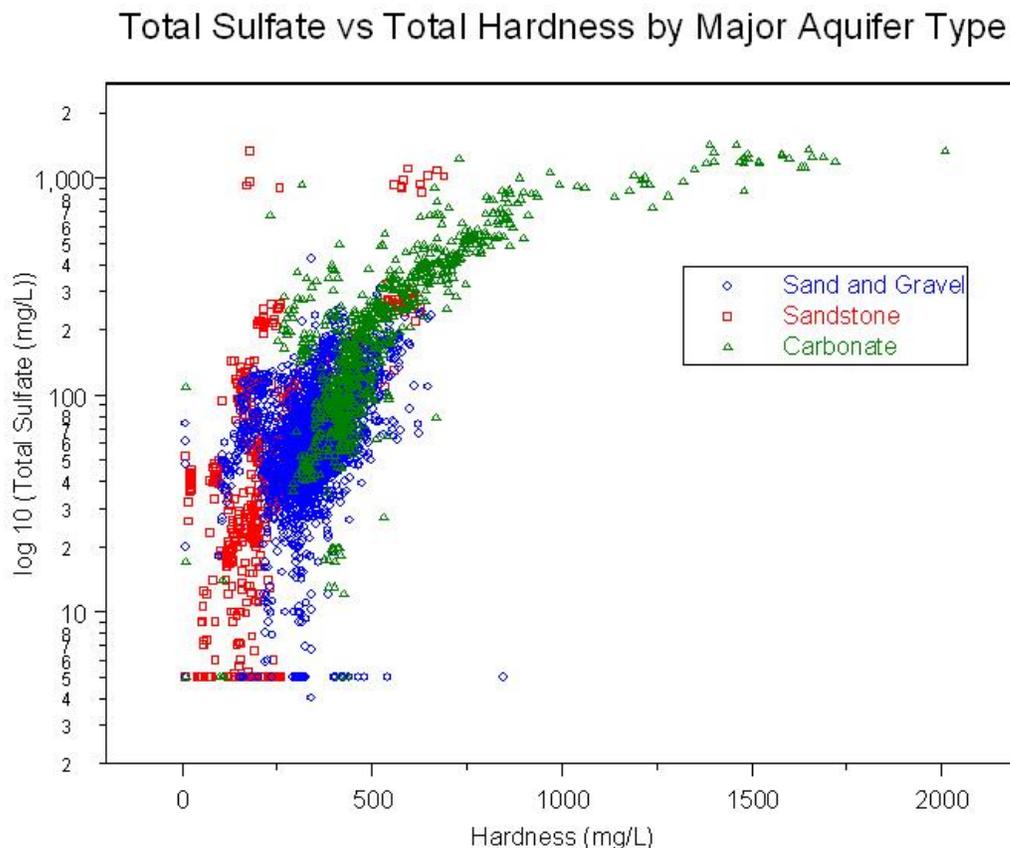


Figure 10. Hardness vs. Sulfate for AGWQMP data. The higher concentrations of hardness and

sulfate in the carbonate aquifers, clearly illustrated in Figure 10, are associated with wells in Silurian Salina Group which includes soluble marine evaporates (anhydrite, CaSO_4 , and gypsum, $\text{CaSO}_4 \cdot \text{H}_2\text{O}$). The intermediate water quality chemistry of the sand and gravel aquifer (between the sandstone and carbonate aquifer values) is also exhibited. The cluster of over 10 elevated sulfate values for the sandstone aquifer (about 1,000 mg/L sulfate with hardness range between 200-700mg/L) are from The Wilds well completed in an area that was reclaimed after surface mining for coal. These values are clearly anomalous for sandstone aquifers

The geographic distribution of mean total dissolved solids (TDS) for AGWQMP 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. 336 mg/L), but generally TDS exhibits similar concentrations in the sand and gravel and sandstone aquifers (Table 4). The Wilds well in Muskingum County, in an area reclaimed from coal mining, is the anomalous well in the sandstones. The areas of 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 Group with associated marine evaporates, including anhydrite and gypsum.

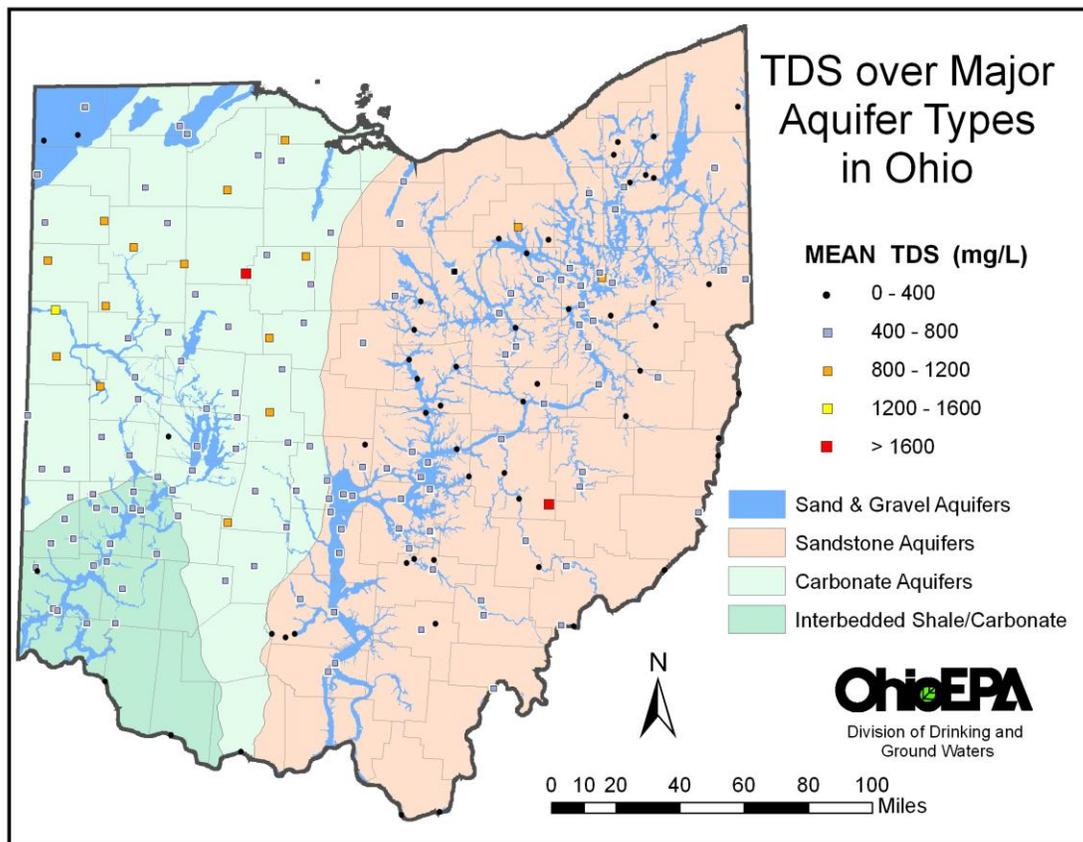


Figure 11. Geographic distribution of the mean TDS values for AGWQMP wells.

The TDS relationships to well depth and aquifer type are illustrated in Figure 12. The 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 (green symbols). The highest levels of TDS in carbonate aquifers are associated with evaporates in the Silurian Salina Formation. In contrast, the sand and gravel aquifers (blue triangles) generally exhibit significantly lower TDS values than the carbonate aquifers. The sandstone aquifers (red squares) exhibit the lowest TDS concentrations. The sandstone aquifers include several AGWQMP wells with elevated TDS. The group of data points with the highest TSD values for a sandstone aquifer (~2000 mg/L) is from a well located in an area that has been reclaimed after surface coal mining. The Wilds well 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 also obvious in Figure 12. One sand and gravel well exhibits a wide range of anomalous TDS concentrations (up to 3000 mg/L). This well is the CSOE Conesville well that was dropped from active sampling in 1989 due to impacts from a fly ash waste landfill.

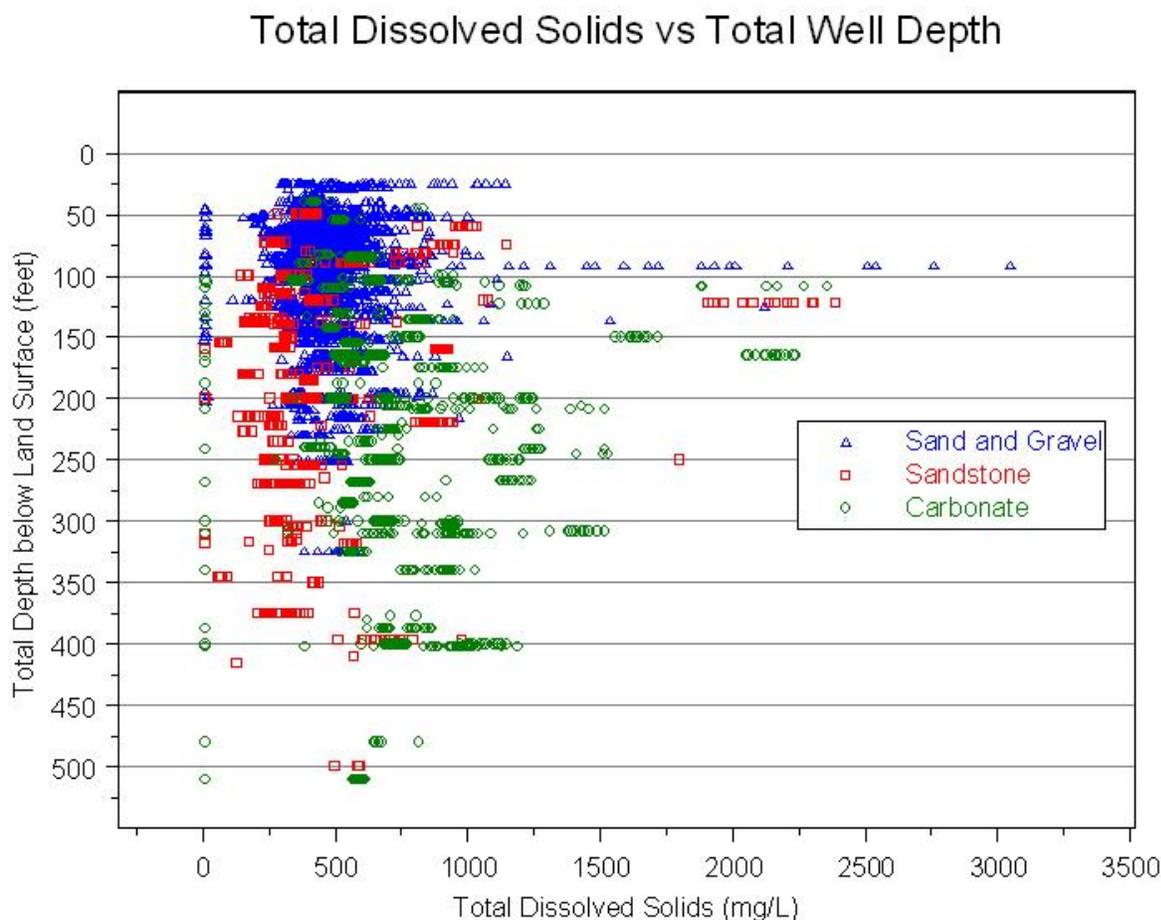


Figure 12. AGWQMP TDS data relative to well depth and aquifer type

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 carbonate aquifers. The presence of soluble evaporates (gypsum and anhydrite) in the Salina Group contributes significantly to the elevated sulfate concentrations in Upper Silurian carbonate aquifers. The sand and gravel aquifers are composed of a large percentage 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.

AGWQMP Organic Samples

The primary objective of the Ambient Ground Water Quality Monitoring Program (AGWQMP) is to collect raw water-quality data to characterize current ground water quality conditions across the state. Analysis of ground water samples from all AGWQMP systems reveals that low-level contamination of organic parameters is confirmed in a small number of AGWQMP wells. Eleven AGWQMP wells are sampled for organics (USEPA method 524.2) every six months because either 1) the wells occur near known ground water plumes, or 2) the systems have a history of low concentrations of organic contaminants. Most AGWQMP wells are sampled for organics every eighteen months.

The AGWQCP database includes one organic sample dating back to 1984 with four additional organic samples collected in 1989. Regular collection of organic samples was initiated in the early 1990s, rising to over 100 organic samples collected in 1995, and a similar sampling effort continuing to the present. Volatile organic compound (VOC) and semivolatile (BNA) samples were collected and analyzed in the mid to late 1990's. BNA samples were discontinued in July 1999 due to the limited number of detections and to reduce analytical costs. VOC sampling at active AGWQMP wells continues on an 18-month sampling schedule. Herbicide analyses (semi-volatiles/herbicides) were collected between May 1996 and January 1999, and this sampling too was discontinued due to lack of detections. More recently, a vulnerable set of the AGWQMP wells was identified (elevated nitrate) for additional herbicide sampling in the fall 2006, spring 2007 and fall 2007 sampling rounds.

The 2006 305(b) Report Ohio's Ground Water Quality included a section that analyzed the distribution of VOC detections in PWS compliance data and AGWQMP wells across Ohio. The reader is referred to this report for a discussion on the distribution of VOC in the major aquifers. The analysis of the AGWQMP organic results for this report confirms the identification of the most commonly detected VOCs (PWS compliance and AGWQMP data) as presented in the 2006 305(b) Report. A discussion of the organic parameters with the most frequent detections is included in the next section.

The AGWQMP organic data is organized around the following three sample templates:

- **BNAs**.....50 parameters analyzed by USEPA Method 625
- **Herbicides**...12 parameters analyzed by USEPA Method 525.2, and
- **VOCs** 61 parameters analyzed by USEPA Method 524.2

The parameters reported in current VOC, herbicide, and BNA sample analysis are listed in

Table 2. Some tentatively identified compounds (TICs) have been entered into the AGWQMP data base if the value reported is greater than 10 times the reporting limit (0.5 µg/L). A sample result is declared a "TIC" when, although a clear signal of a compound is determined, the actual substance is declared tentative because the position of the signal can only be related to the nearest internal standard. There is a high confidence that a compound exists if the TIC reports a value 10 times the reporting limit, but the exact identification remains tentative.

A summary of the organic data in the AGWMP is provided in Appendix B. The data represents the accumulation of over 164,000 raw, organic ground-water data results gathered at 279 wells across Ohio. The high percentage of non-detects means the presentation of these data is primarily a list of non-detect values and counts of total number samples analyzed for a parameter. For all three organic sampling templates in AGWQMP sampling, twenty-six organic compounds have been detected only once and forty-five compounds have never been detected a single time. Appendix B presents the number of samples, minimum value, arithmetic mean, maximum value, date range of samples, and percent non-detect for the listed parameters. The current reporting limit for most organic samples is 0.5 µg/L and was used to calculate mean concentrations for non-detect values. Any well with confirmed organic chemical detections clearly indicates influence by anthropogenic sources; however, the low level of organic detections documents the high quality of the source water in Ohio. The water quality presented is not pristine, but rather is typical of the ground water quality of aquifers utilized for source water for Ohio PWSs.

Two groups of contaminants that are commonly detected need to be addressed as their detection may not represent water quality impacts from land use or point sources. The first is a set of common contaminants such as plasticizers and rubberizers from plastic well casing or lab sources. Generally, little significance is placed on low level detections of the parameters as follows:

- di(2-ethyhexyl) phthalate
- bis(2-ethyhexy) phthalate
- di(2-ethyhexyl) adipate
- dichloromethane

The second group is the trihalomethanes, which are disinfection byproducts (DPB) of disinfection processes using chlorine and include the following:

- chloroform
- bromoform
- bromodichloromethane
- dibromochloromethane

These compounds are more difficult to dismiss in the AGWQMP raw water samples. It is possible that the presence of these disinfection by products (DBP) results from disinfection of the well prior to Ohio EPA staff sampling (generally not reported to AGWQMP staff), or backflow of treated water to the wellhead sample tap. Another possibility is that PWS distributed water is used to water lawns has recharged the local aquifer. A final possibility is that chloroform may be produced by natural processes. Consequently, the detection of disinfection byproducts needs to be given special consideration in AGWQMP data because the interpretation may not be straight forward, and may not relate to anthropogenic impact.

Organic Parameters with Frequent Detections

Ten organic parameters dominate the list of chemicals with the highest rate of detections. These parameters, their detected concentrations, and their detection rates are presented in

Figure 13. On the right hand side of Figure 13 the number of detections for each parameter, followed by its rate of detection as a percentage of the total number of samples taken and analyzed are listed.

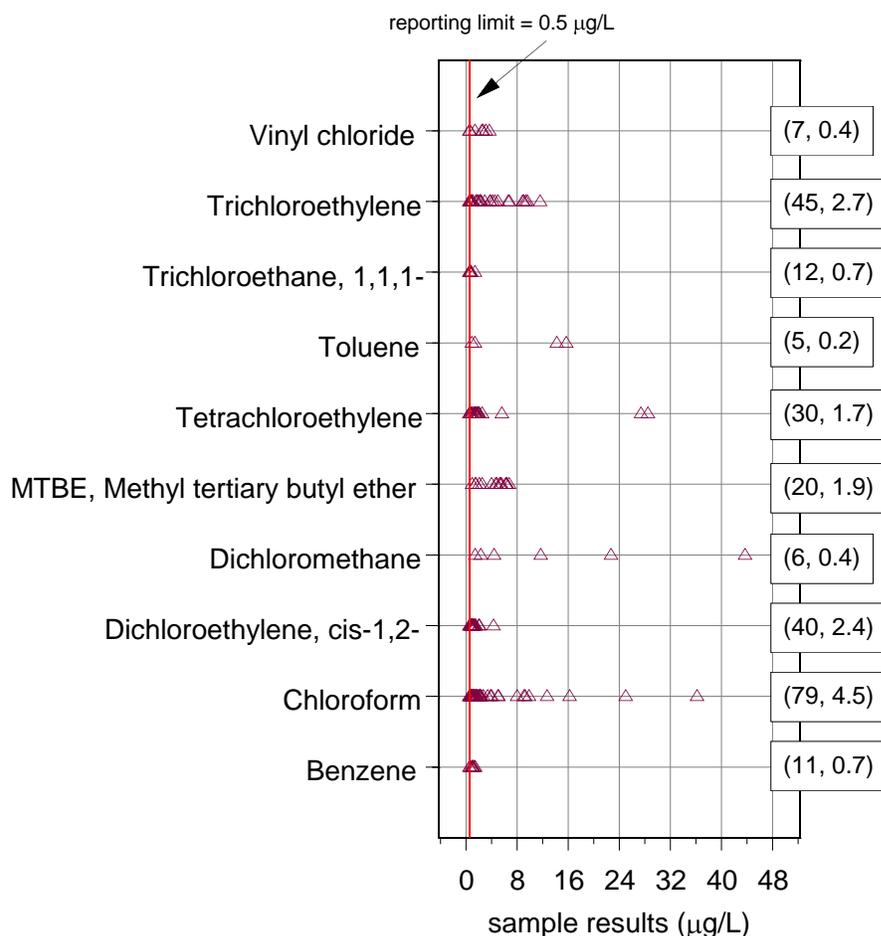


Figure 13. Distribution of most frequently detected organic parameters. Boxes on the right side of the figure include the number of detections followed by the detection rate percentage.

The detection rates of these most common parameters range from 0.2 % for the petroleum BTEX component toluene, to 4.5 % for the DBP chloroform. The overall detection percentage, across all organic sample types (VOC, BNA, and pesticides) is 0.28 %. These numbers are quite low and illustrate the broadly protected nature of PWS ground waters to point source contaminants. In addition, both the overall detection rate of 0.28%, and the highest individual component detection rate (4.5 % for the DBP chloroform) are low compared to national statistics of VOC detections across multiple aquifers of the United States (Zogorski et al., 2006). In addition, a number of these contaminants are found at only one or two systems, a further indication of the localized nature of a point-source impact.

Chloroform was the most commonly detected compound, found in 42 of the 194 wells; see the discussion in the previous section for more on this compound. Methyl *tert*-butyl ether (MTBE) was detected in 20 samples at three sites, although one site accounted for 17 of the detections. The highest MTBE concentration at this site was 6.7 µg/L, and the average MTBE value was 4.7 µg/L. The highest concentration of any of the common organic contaminants is 43.7 µg/L for dichloromethane (Figure 13); it was found in only six samples at five different sites. This compound is a colorless organic liquid with a sweet, chloroform-like odor. The greatest use of dichloromethane is as a paint remover, while other uses include: solvent and cleaning agent in a variety of industries, a fumigant for strawberries and grains.

The most common chemical group represented in Figure 13 is the chlorinated solvents. These include vinyl chloride (VC), trichloroethylene (TCE), 1,1,1- trichloroethane (1,1,1- TCA), tetrachloroethylene (PCE), and cis-1,2- dichloroethylene. This group of contaminants was developed over the last century as cheaper and more practical alternative to petroleum solvents. PCE and TCE have been in industrial use over 60 years as solvents. TCE is widely used in the dry cleaning industry. PCE and TCE can both undergo dechlorination (loss of a chlorine) leading to the daughter products 1,1-DCE, cis- and trans-1,2-dichloroethylene, which finally degrades into vinyl chloride. The detection rates for these compounds range from 0.4% (vinyl chloride) to 2.4 % (cis-1,2-dichloroethene). As a group, their concentrations in Ambient ground water is quite low, mostly well below 10 µg/L, with the highest result being about 28 µg/L for a PCE sample. The usage of multiple solvents or the degradation of one solvent to another can explain the occurrence of mixtures of these compounds found in some AGWQMP wells. Passive mitigation of ground waters contaminated with chlorinated solvents using a variety of aerobic, anaerobic, and microbial dechlorination schemes is commonly referred to as natural attenuation.

Toluene is found in substances commonly used in PWS distribution facilities such as paints (used on floors, water lines, etc), machine oils and greases (possibly associated with the rehabilitation, rebuild, or replacement of pumps, valves, line joints, etc). Toluene is also found in de-rusting sprays.

The majority of detections in the AGWQMP organics database (65%) occurred within unconsolidated aquifers across the state (unconsolidated wells make up 66% of the total). Detections within the carbonate terrain of Ohio (19%) was the next most detected grouping (carbonate wells comprise 20% of the total). Positive organic results within the sandstone aquifers of the state made up 16% of the database, while these wells account for 13% of the total number of wells. Detections of VOCs and other organic compounds correlate roughly with the depth of sampling. This is consistent with the idea of preferred pathways transporting point-source contaminants to the ground water table surface. However, this correlation is not perfect, suggesting that deeper aquifers may be vulnerable to preferred pathways as well, such as the case of fractured bedrock carrying high volumes of recharge to depth, or where a well construction problem provides a direct conduit to a deeper formation.

Generally, the detections of these frequent contaminants correlate geographically with population centers, but also geochemically with redox condition of the aquifer system. In addition, the usage and transportation of VOCs and organic compounds are generally centered in urban areas. Major sources of VOCs to ground and surface water include plants, factories, machine and engine shops; other likely urban-related sources include open dumps, landfills, and storm water runoff from paved areas.

DOCUMENTING ANTHROPOGENIC INFLUENCES ON GROUND WATER QUALITY IN OHIO

Introduction

The Ground Water Quality (GWQ) Impacts Database was developed to provide a centralized location to identify areas where specific anthropogenic activities are affecting ground water quality. Compiling locations in Ohio with documented releases of contaminants to ground water from regulated sites and other point sources is a high priority activity for Ohio EPA. Efforts to identify areas of anthropogenic influences on ground water quality will help refine criteria for identifying sensitive aquifers and prioritize ground water protection efforts. Lessons learned at specific sites of ground water contamination can be extrapolated to similar geologic settings across the state. Land use/land cover analysis can be enhanced with these data to help identify cause and effect relationships between potential sources of contamination and the resulting ground water contamination in public water systems or at other locations.

For the purpose of this database, an "impact" is defined broadly as a negative influence on ground water quality resulting from a facility's management or disposal practices, spills or other releases. Inclusion in the GWQ Impacts database does not imply any judgment regarding the severity of the impact and no standard language has been developed to indicate the degree or severity of ground water impact. Absence from the database does not imply that a facility is not affecting local ground water quality.

Purpose of the GWQ Impacts Database

The purpose of the Ground Water Quality Impacts database is to provide a tool to summarize general aspects of facilities across Ohio where contaminant releases have affected ground water resources. This is the first step in identifying areas of potential threats to public health, and is one of DDAGWs top priorities. Analysis of these data will help identify areas with a high number of facilities affecting ground water quality.

The analysis presented in this chapter represents a broad overview of the data currently in the Ground Water Quality Impacts database.

History of Tracking Impacted Ground Water Quality

Ground water data from impacted sites was collected in 1988 and recompiled in 1994 for Ohio's Non-Point Source (NPS) Assessment; however, these data were not stored in any electronic database. The GWQ Impacts Database was developed in 2005 as a survey tool; consequently, the level of detail captured is limited and is not intended for detailed analysis of individual sites. In most cases, data fields have been standardized to promote uniformity for effective data analysis.

The database was developed with significant input from ground water staff in an attempt to ensure the database is useful for recording general hydrogeologic information about facilities Ohio EPA-DDAGW staff are routinely reviewing or are have regulated monitoring programs. The GWQ Impacts database provides data entry screens for ease of managing and updating data, and incorporates location data (latitude and longitude) to allow map generation and spatial analysis of areas with documented ground water quality impacts. A *Ground Water Quality Impacts Users Manual (Ohio EPA, 2008)* was developed to promote uniform data entry and consistence use of common terms.

The initial effort to populate the GWQ Impacts Database began in late 2005 and focused on sites that have confirmed releases to ground water quality. The facilities are under the jurisdiction of the Divisions of Solid and Infectious Waste Management, Surface Water, and Emergency and Remedial Response (includes the Voluntary Action Program). Ground water quality data from hazardous waste facilities were electronically added to the GWQ Impacts Database in 2006.

The database is designed around individual waste management/treatment units or other facilities that have documented contamination of ground water. The database has sections for Facility Information, Source Unit Information, Hydrogeologic Information, Source of Ground Water Quality Impact, Ground Water Contamination and Comments. The ability to identify multiple ground water zones and multiple sources of impact and associate contaminants with individual ground water zones and/or individual plumes provide the flexibility to describe sites with more complicated monitoring programs. An example of the data entry screen is shown in Figure 14.

Ground Water Application - [Facility]

File Edit Insert Records Window Help Adobe PDF Type a question for help

Use the following dropdown boxes to search for specific records

Facility: _____ City: _____ County: _____ Responsible Program: _____

Ground Water Impacts Tracking System
This form is specifically for facilities that have confirmed ground water contamination

Facility Information

Facility Name: SENECA EAST RECYCLING AND DISPOSAL City: REPUBLIC District: NwDO
 Physical Address: 2780 COUNTY ROAD 43 Township: SCIPIO CoreplaceID: _____
 County: SENECA FacilityID: 74-00-01

Source Unit Information

Source Unit Type: LANDFILL - MSW PrimaryLandUse: _____ YearOpen/Permitted: 1969 Operational Type: CLOSED
 Source Unit Name: _____ Status: CORRECTIVE ACTIONS/MEASURED YearClosed: 1993 Responsible Prog: DSIWM
 Liner System: NO LINER LinerThickness: _____

Hydrogeologic Information

Zone	Lithology	Name/Description	Avg. Depth To GW	Max. Zone Thickness	GW Zone Description
1	CLAY/TILL	TILL		0-10 ft	ISOLATION MATERIAL
2	SAND/GRAVEL	S&G SEAMS IN TILL		11-20 ft	SIG. ZONE OF SATURATION

Record: 1 of 3

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	501-100	1001-1	51-75 ft	<input type="checkbox"/>	NONE	LEACHATE COLLECTION	GAS EXTRACTION	41.166666 83.05		NO

Record: 1 of 1

Ground Water Contamination

Zone	Plume	Contaminant	Current Results	Units	Date	Historical_Max	Historical_Units	Historical_Date	Upgradient
3	1	Barium, total	7.3	mg/L	1/11/2006	7.53	mg/L	9/12/1995	<input type="checkbox"/>
3	1	Potassium, total	48.0	mg/L	1/11/2006	61.8	mg/L	5/20/1999	<input type="checkbox"/>

Record: 1 of 7

Comments
 LAST REGULAR SAMPLING EVENT OCTOBER 2005, WITH RESAMPLING CONDUCTED JANUARY 2006.

This summary is based on samples reviewed from (dates) 4/2/1991 To 1/11/2006

Record: 3 of 482

Start Main Switchboard Facility

Figure 14. Data entry screen for the Ground Water Quality Impacts Database.

Data Analysis

The purpose of the Ground Water Quality Impacts database is to provide a tool to summarize general aspects of sites where contaminant releases have affected ground water resources. The level of detail captured for each facility is limited and is not intended for detailed analysis of individual sites. As of January 31, 2008, 496 records were included in the Ground Water Quality Impacts database. Of these, 69 facilities did not have documented ground water quality impacts. These facilities were screened from the database before analysis occurred. Of the 427 records that indicated impacts to ground water quality, 12 were from facilities that have multiple source units affecting ground water quality. This translates into 415 facilities with documented ground water quality impacts.

Statewide analyses were performed to characterize general aspects of the sites in the Ground Water Quality Impacts database, such as the primary regulatory program overseeing the facility, the local geology at these sites, the most common sources of contamination, types of contaminants, and potential effect on drinking water sources.

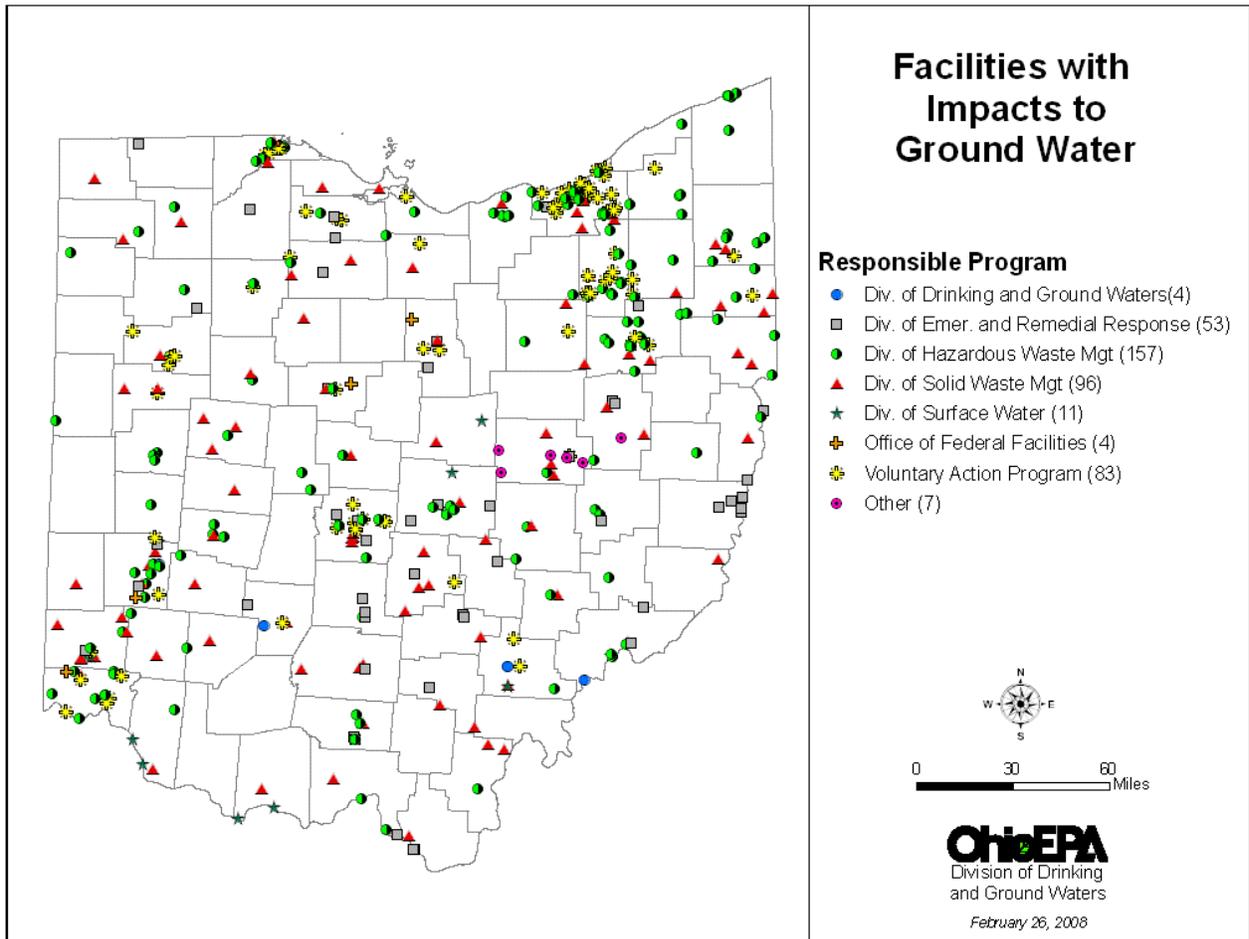


Figure 15. Distribution of Facilities by Responsible Program.

Responsible Programs/Divisions

The initial population of the GWQ Impacts Database consisted primarily of those facilities that are under the jurisdiction of Ohio EPA. These include landfills and hazardous waste facilities, facilities that entered the Voluntary Action Program (VAP), facilities regulated by the Clean Water Act (e.g. surface impoundments), and facilities that are unregulated (i.e., facility closed before regulations were adopted). Figure 15 shows a statewide distribution of facilities with documented ground water quality impacts currently in the database listed by the responsible programs or divisions.

The vast majority of facilities fall under the jurisdiction of the Ohio EPAs Divisions of Hazardous Waste Management (RCRA facilities) and Solid and Infectious Waste Management (landfills). Initially, the focus was on these two programs. Since the database is still being populated with facilities from other programs, the relative percentage of system types will change.

Source of the Ground Water Quality Impact

The GWQ Impacts database provides 21 choices for the source unit of the ground water quality impact (e.g. "UST"). If a facility has more than one source unit with a contaminant release to ground water, then each source unit is entered as a separate record for that facility. The ability to identify multiple ground water zones, multiple sources of impact and associate contaminants with individual ground water zones and/or individual plumes provide the flexibility to describe sites that are more complicated. Most facilities in the database, however, are relatively simple with a single source and single plume.

Figure 16 shows the statewide distribution of the types of sources that are affecting ground water quality. Landfills (hazardous waste, residual waste, municipal solid waste, construction and demolition debris, industrial waste, and unregulated) represent the greatest number of facilities (133 facilities – 32%), followed by Site Wide (multiple management issues and/or sources) and Other (both 47 facilities – 11% each), and Surface Impoundments (45 facilities – 11%).

- **Landfills:** Landfills represent a considerably higher percentage of facilities in the GWQ Impacts database because all types of landfills are lumped together. Figure 17 shows the breakdown by landfill type. This shows that the majority of landfills that are affecting ground water quality are Municipal Solid Waste landfills (68 facilities – 51%). Figure 18 shows that the majority of landfills that are affecting ground water quality are older and have no liner or are partially lined. This indicates that the presence of liners do impede the flow of contaminants to the ground water. Figure 19 shows that most of the landfills affecting ground water quality are closed. If the landfill was not lined or management practices at the landfill were historically poor, contaminants would have had plenty of time to infiltrate through the soil and vadose zone, consequently affecting the quality of the local ground water resources.

At this point, we do not have sufficient facility design information or hydrogeologic data to compare the landfills that are affecting ground water quality to those that are not. This would require additional data collection that exceeds the initial focus of the GWQ impacts database.

- **Hazardous Waste Facilities:** "Site wide" is the second most common source type identified in the database. Site wide refers to facilities with multiple source units that are affecting local ground water quality. In these cases, it may be difficult to determine the specific originating source type unit due to mixing of contaminant plumes.

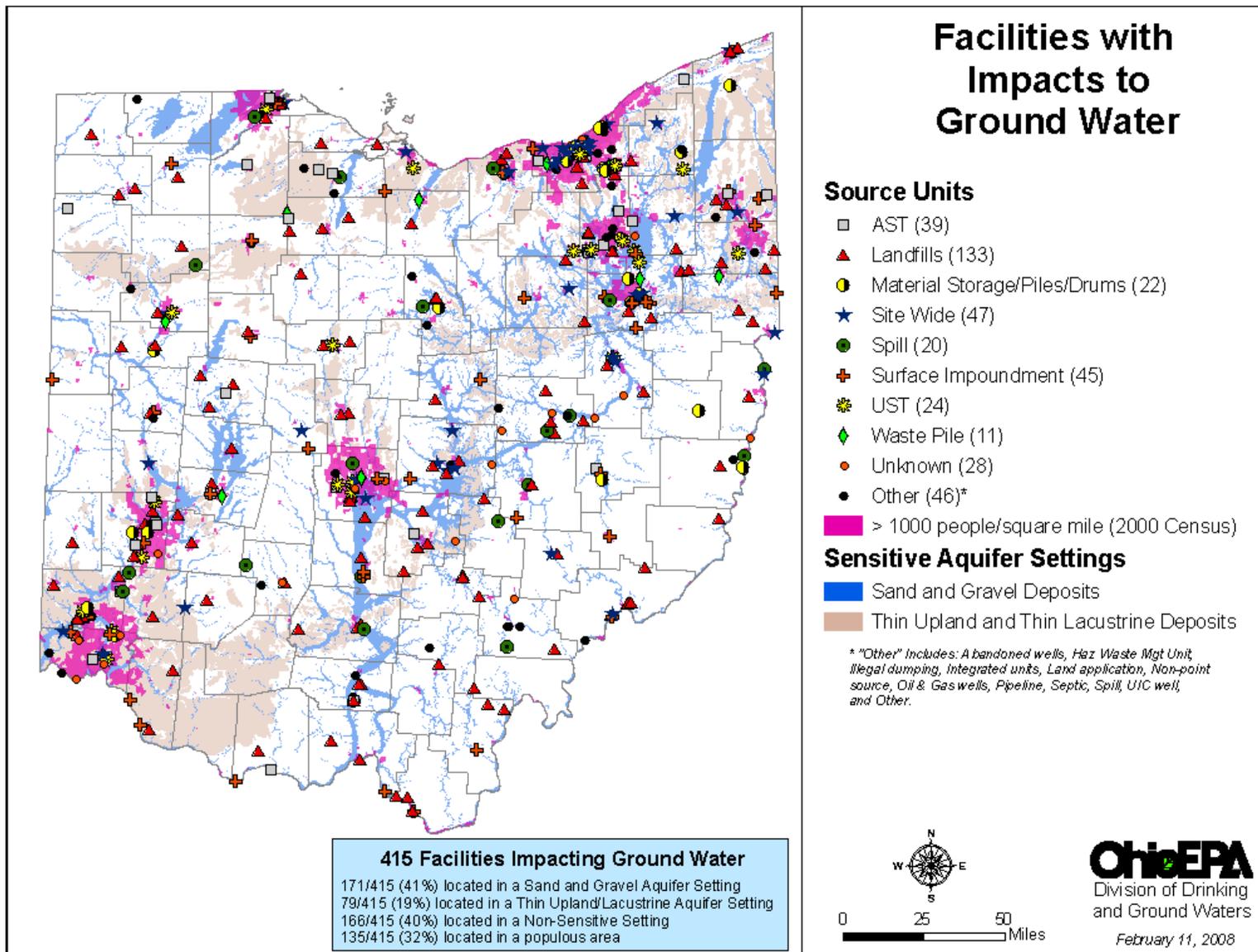


Figure 16. Statewide distribution of the source type affecting ground water quality

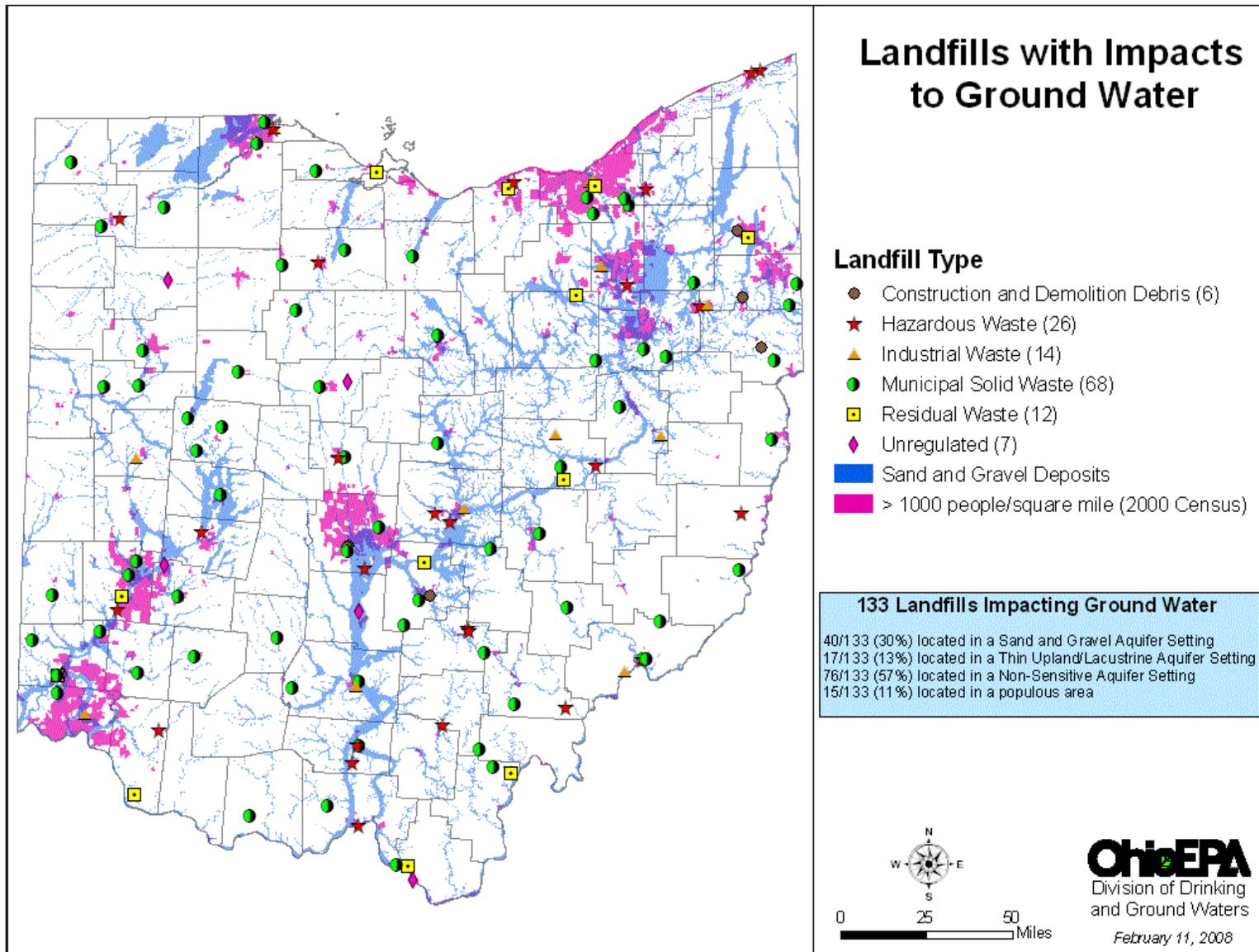


Figure 17. Statewide distribution of landfill types affecting ground water quality

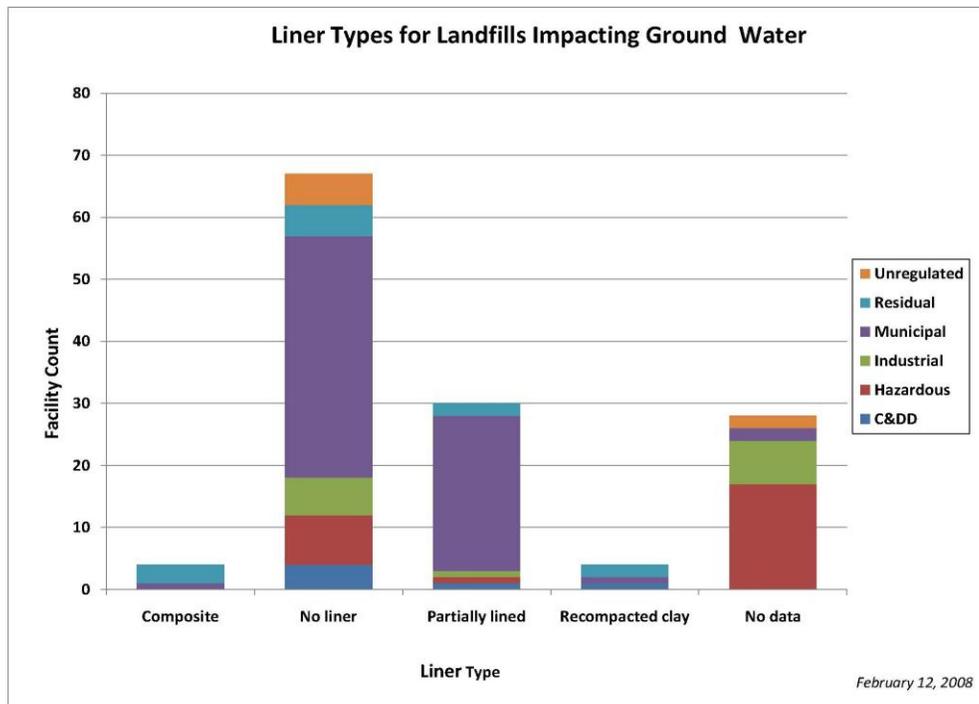


Figure 18. Distribution of liner type for landfills affecting ground water quality.

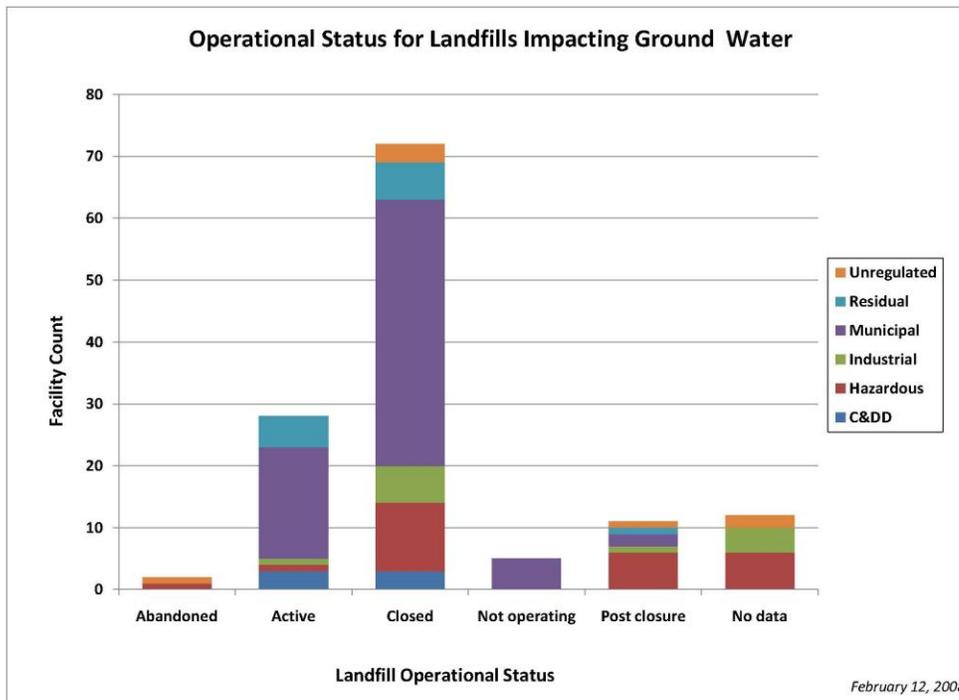


Figure 19. Distribution of the operational status for landfills affecting ground water quality.

Almost all of the facilities that have “site wide” listed as their source of contamination are hazardous waste (RCRA) facilities.

Aquifer Type and Lithology

The 2006 Ground Water Section of the 305b report included a section on Sensitive Aquifers in Ohio that was updated and presented as a standalone document, Identifying Sensitive Aquifers in Ohio (Ohio EPA 2007). Aquifer sensitivity was evaluated for geologic settings and lithologic attributes of glacial drift in order to determine correlations between aquifers, drift thickness, and ground water quality impacts. The geologic settings identified as sensitive include the sand and gravel aquifers (buried valley, alluvial, valley fill, outwash/kames, and beach ridge) and bedrock aquifers below thin glacial drift (thin tills and lacustrine deposits less than 25 feet thick) as described in the ODNR Glacial Aquifer Map (2000). Overall, the coarser lithologies or fractured bedrock material are expected to allow more rapid recharge and consequently, be associated with more sensitive aquifers. In contrast, geologic settings with areas of thicker glacial till generally retard recharge and contaminant transport through moraine deposits, thereby reducing the sensitivity of aquifers within or below the glacial till deposits.

Aquifer sensitivity is more of a concern when evaluating ground water quality impacts from non-point sources, such as agriculture. Although contaminants can travel faster in sensitive settings, ground water quality impacts from point sources (such as industrial facilities or landfills) have occurred in various types of aquifer settings or lithologies. The presence of contaminants leaking from and leaching into local aquifers over a significant amount of time may be due to poor management or historical facility design practices. It typically will take longer for a contaminant release to migrate to an aquifer in a non-sensitive setting, but given enough time, ground water quality impacts may occur.

Figure 16 shows the source units for each facility affecting ground water quality. Sixty percent (60%) of the facilities are located in a sensitive aquifer setting (sand and gravel, and thin uplands/lacustrine settings), whereas forty percent are located in a non-sensitive setting. The larger percentage of facilities with ground water quality impacts in the sensitive settings is mostly likely associated with faster ground water flow rates or recharge travel times. However, forty percent of the facilities are affecting ground water quality in the non-sensitive settings, which is significant.

Table 6 is a comparison between the geologic setting and the depth to the impacted ground water zone (from the GWQ Impacts database). The geologic setting was taken from Glacial and Bedrock Geology Maps (ODNR, 2000) at the location (latitude and longitude) indicated in the GWQ Impacts database. Since the location could either be the centroid of the plume, the source unit of the ground water quality impact, or the facility, Table 6 does not represent an exact set of data. For example, the facility or facility source unit may be physically located in a non-sensitive setting, but the aquifer in the nearby sensitive setting is what is actually impacted. However, a comparison between the ODNR geologic setting and the aquifer type in the GWQ Impacts database indicates that, in most cases, they were the same.

Table 6. Comparison between the Geologic Setting (ODNR Glacial and Bedrock Geology Maps, 2000) and the depth to the impacted ground water zone (Ground Water Quality Impacts Database).

ODNR Glacial Geology Setting	Depth to Impacted Ground Water Zone								Total Known Depths	Total Unknown Depths	TOTAL
	0-10 ft	11-20 ft	21-30 ft	31-40 ft	41-50 ft	51-75 ft	76-100 ft	> 100 ft			
SENSITIVE SETTINGS											
Alluvial	6 (40%)	4 (27%)	2 (13%)	2 (13%)	1 (7%)	0	0	0	15	8	23
Buried Valley	20 (27%)	32 (43%)	11 (15%)	6 (8%)	2 (3%)	1 (1%)	2 (3%)	0	74	33	107
Lacustrine (< 25 ft)	11 (84%)	1 (8%)	0	0	0	1 (8%)	0	0	13	8	21
Outwash/Kame	0	1 (100%)	0	0	0	0	0	0	1	0	1
Thin Upland (< 25 ft)	18 (48%)	7 (19%)	8 (22%)	1 (3%)	0	2 (5%)	1 (3%)	0	37	12	49
Bedrock (no glacial aquifer present)	4 (10%)	10 (26%)	5 (13%)	4 (10%)	3 (8%)	6 (15%)	4 (10%)	3 (8%)	39	9	48
TOTAL (sensitive settings)	59 (33%)	55 (31%)	26 (14%)	13 (7%)	6 (3%)	10 (6%)	7 (4%)	3 (2%)	179	70	249
NONSENSITIVE SETTINGS											
Complex	2 (29%)	3 (43%)	0	0	1 (14%)	1 (14%)	0	0	7	4	11
End Moraine	3 (50%)	2 (33%)	0	1 (17%)	0	0	0	0	6	5	11
Ground Moraine	7 (32%)	9 (41%)	2 (9%)	2 (9%)	2 (9%)	0	0	0	22	4	26
Lacustrine (> 25 ft)	8 (62%)	2 (15%)	3 (23%)	0	0	0	0	0	13	10	23
Thin Upland (> 25 ft)	3 (27%)	2 (18%)	1 (9%)	2 (18%)	1 (9%)	2 (18%)	0	0	11	18	29
Valley Fill	2 (14%)	1 (7%)	6 (43%)	4 (29%)	1 (7%)	0	0	0	14	1	15
TOTAL (nonsensitive)	25 (34%)	19 (26%)	12 (17%)	9 (12%)	5 (7%)	3 (4%)	0	0	73	42	115
TOTAL (all settings)	84 (33%)	74 (29%)	38 (15%)	22 (9%)	11 (4%)	13 (5%)	7 (3%)	3 (1%)	252	112	364

Total numbers reflect multiple ground water zones per facility that have been impacted; only used those facilities that have current results. Numbers in parenthesis are percentages of the total facilities with known depths

Table 6 shows that the majority of the ground water quality impacts identified occur between 0-20 feet below ground surface, regardless of the sensitivity of the setting (sensitive settings = 64%, nonsensitive settings = 60%). However, for the 252 facilities in the GWQ Impacts database with current ground water quality results and known contaminant depths, 179 (71%) are in sensitive settings. One main difference between the sensitive and nonsensitive settings is the affected zone in the aquifer tends to be deeper in sensitive settings. The deepest zone of ground water quality impact in the nonsensitive setting is between 51-75 feet, whereas ten facilities have ground water quality impacts occurring below 76 feet in the sensitive settings.

It is interesting to note that the current water well construction standards require a minimum of 25 feet of well casing for private and public wells. This depth requirement provides some protection from the shallow zones of contamination documented at the sites in the GWQ Impacts database. Additional detailed analysis is needed to evaluate when ground water contamination associated with shallow limited saturated zones are affecting the ground water quality within an aquifer likely to be used as a public or private water source.

Table 7 compares the lithology of the sensitive glacial settings (from ODNR Glacial and Bedrock Geology Maps, 2000) to the depth of impacted ground water quality (from the GWQ Impacts database). There were slightly more ground water quality impacts identified in coarse-grained materials than fine-grained (39% versus 35%), but this difference is not very significant. The significant difference between the two is that the contamination tends to move deeper in the coarse-grained materials. From 0-20 feet, 76% of the fine-grained zones have ground water quality impacts, as opposed to 53% of the coarse-grained. Between 21-40 feet the opposite occurred, with only 18% of the fine-grained material having ground water quality impacts compared to 39% of the coarse-grained material. The thin till over bedrock settings were somewhere in between. Over 90% of the ground water quality impacts occurred in both the fine- and coarse-grained sands and gravels within the upper 40 feet of the identified ground water zone. The coarse-grained materials allowed the contamination to travel deeper into the aquifer, whereas the fine-grained materials tend to impede contaminant migration.

Table 7. Comparison between glacial lithology and the depth to the impacted ground water zone.

ODNR Glacial Lithology	Depth to Impacted Ground Water Zone - SENSITIVE SETTINGS ONLY								Total Known Depths	Total Unknown Depths	TOTAL
	0-10 ft	11-20 ft	21-30 ft	31-40 ft	41-50 ft	51-75 ft	76-100 ft	> 100 ft			
Coarse-grained Sands and Gravels	9 (16%)	21 (37%)	13 (23%)	9 (16%)	2 (4%)	1 (2%)	1 (2%)	0	56	24	80
Fine-grained Sands and Gravels	21 (42%)	17 (34%)	6 (12%)	3 (6%)	2 (4%)	0	1 (2%)	0	50	19	69
Thin till (< 25 ft) over Bedrock	18 (48%)	7 (19%)	8 (22%)	1 (3%)	0	2 (5%)	1 (3%)	0	37	12	49
TOTAL	48 (34%)	45 (31%)	27 (19%)	13 (9%)	4 (3%)	3 (2%)	3 (2%)	0	143	55	198

Total numbers reflect multiple ground water zones per facility that have been impacted; only used those facilities that have current results.

Numbers in parenthesis are percentages of the total facilities with known depths

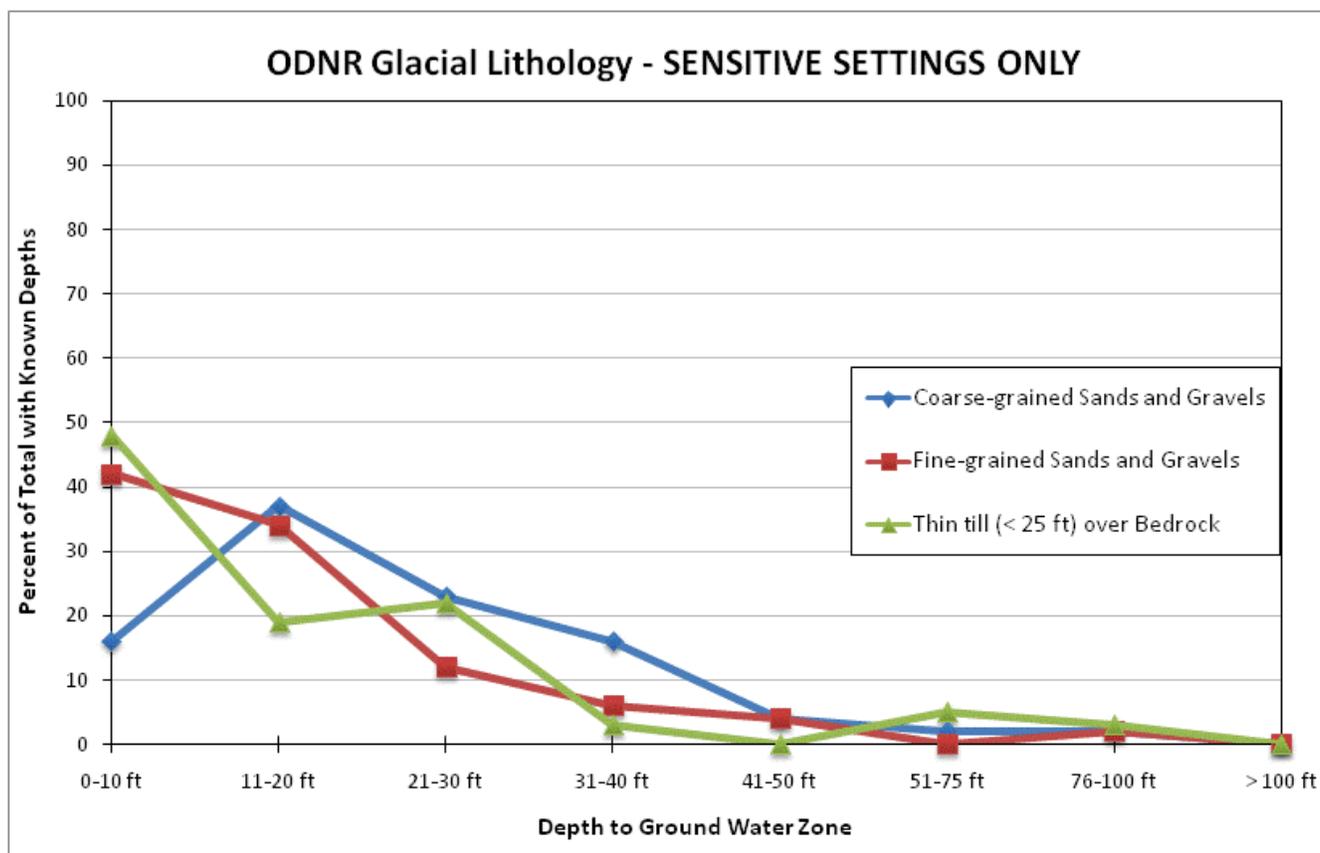


Figure 20. Graph of depth to impacted ground water for facilities in sensitive glacial settings.

Figure 20 indicates that fine-grained materials show a much higher percentage of ground water quality impacts than the coarse-grained materials in the 0-10 foot range. This is reversed from 11-20 feet and deeper, suggesting that contaminant transport is impeded in fine-grained materials compared to coarse-grained materials. These preliminary results need additional evaluation but appear to be consistent the permeability of the materials.

In general, the GWQ Impacts database only contains facilities that are known to be affecting local ground water quality. Therefore, this does not allow for the comparison between facilities/facilities that are affecting ground water quality to those that are not. Because we have locational data for all of the hazardous waste facilities – including those that are not impacting ground water quality – we were able to perform some limited analysis. Figure 21 shows the universe of hazardous waste facilities in Ohio with ground water monitoring. Half of the total number of hazardous waste facilities are affecting ground water quality in the vicinity of the facility. Comparisons between the hazardous facilities affecting ground water quality and those that are not do not show any significant difference between the geologic setting at the facility. Sixty-five percent (65%) of the hazardous waste facilities are located in a geologically-sensitive setting. Of these, 46% are affecting ground water quality and 54% are not.

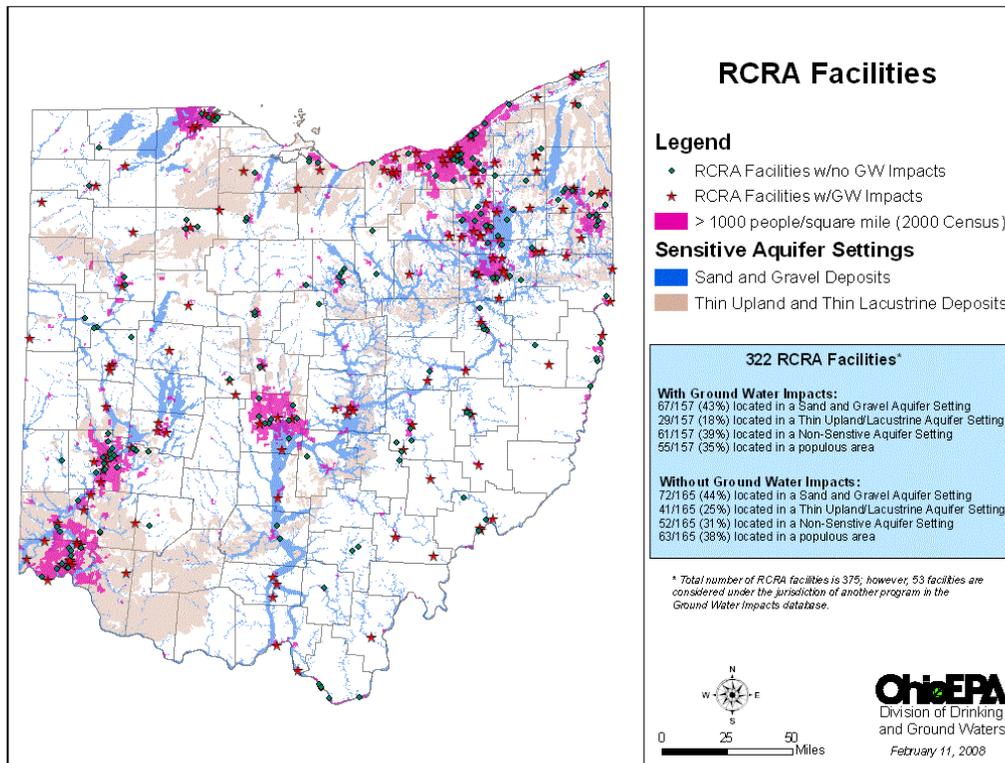


Figure 21. Statewide distribution of RCRA facilities in Ohio.

Most Common Contaminants

Contaminants associated with a ground water quality impact are entered into the database. Current results are entered as well as the historical maximum concentrations, if available. Of the 415 facilities in the GWQ Impacts database, 319 have current results and 120 have historical results. Table 8 lists the ten most commonly occurring contaminants from the current results, along with the most common sources that are contributing to that contaminant. Table 9 is the same information but using the historical maximum results. The results from both sets of data are very similar. Volatile organic compounds (in particular, solvents) are more frequently detected in the ground water than any other type of contaminant, with the most common sources being aboveground storage tanks, municipal solid waste landfills, and facilities with site-wide source units. This makes sense because most of the facilities identified in the database are industrial or manufacturing in nature, with the exception of some landfill types. Solvents are commonly used in their manufacturing processes. Metals (arsenic, lead and chromium) are also commonly detected in the ground water affected by these facilities. The metals could either be coming from management practices at a facility source unit, leachate from a landfill, or a result of pH changes in the water because of the other activities occurring at the facilities. Without the complete water chemistry of the plume, specifically the oxidation-reduction potential, it is unknown if the elevated arsenic is naturally occurring or related to an anthropogenic source.

Table 8. Top ten contaminants detected in ground water for current results

Contaminant	Type	Count (# of facilities)	Most Common Source Unit (# of facilities)	Second Most Common Source Unit (# of facilities)	Most Common Depths (# of facilities)
Trichloroethene	VOC	99	AST (18)	Site Wide (14)	0-10 ft (32); 11-20 ft (28)
Vinyl Chloride	VOC	73	Landfill-MSW (14)	AST, Site Wide (13)	0-10 ft (28); 11-20 ft (17)
cis-1,2-Dichloroethene	VOC	71	Landfill-MSW (16)	AST (12)	0-10 ft (25); 11-20 ft (16)
Benzene	VOC	66	Site Wide (16)	Surface Impoundment (11)	0-10 ft (28) 11-20 ft (17)
Tetrachloroethene	VOC	58	Site Wide (11)	AST (9)	0-10 ft (19); 11-20 ft (14)
1,1,1-Trichloroethane	VOC	51	AST (10)	Landfill-Haz Waste; Material Storage/Piles/Drums; Site Wide; Surface Impoundment (7)	0-10 ft (12); 11-20 ft (12)
1,1-Dichloroethene	VOC	50	AST (9)	Landfill-Haz Waste; Material Storage/Piles/Drums; Surface Impoundment; Unknown (6)	0-10 ft (15); 11-20 ft (11)
Arsenic, total	Metal	42	Landfill-MSW (17)	Site Wide (13)	0-10 ft (14); 11-20 ft (11)
Xylenes, total	VOC	39	Surface Impoundment (8)	AST, UST, Site Wide (6)	0-10 ft (16); 11-20 ft (7)
1,1-Dichloroethane	VOC	38	Landfill-MSW (12)	AST, Site Wide (7)	0-10 ft (13); 11-20 ft (13)

Table 9. Top ten contaminants detected in ground water, historic* maximum results.

Contaminant	Type	Count (# of facilities)	Most Common Source Unit (# of facilities)	Second Most Common Source Unit (# of facilities)	Most Common Depths (# of facilities)
Trichloroethene	VOC	77	AST (12)	Unknown (11)	0-10 ft (33); 11-20 ft (25)
cis-1,2-Dichloroethene	VOC	58	Landfill-MSW (12)	AST; Unknown (11)	0-10 ft (23); 11-20 ft (15)
Vinyl Chloride	VOC	50	Landfill-MSW (12)	AST (10)	0-10 ft (22); 11-20 ft (16)
Tetrachloroethene	VOC	45	Other (9)	Unknown (9)	0-10 ft (17) 11-20 ft (13)
Benzene	VOC	38	Site Wide (7)	AST (6)	0-10 ft (21); 11-20 ft (11)
1,1-Dichloroethene	VOC	37	AST (7)	Other (5)	0-10 ft (14); 11-20 ft (10)
1,1,1-Trichloroethane	VOC	35	AST (8)	Surface Impoundment; UST (5)	0-10 ft (12); 11-20 ft (10)
Lead, total	Metal	35	Site Wide (10)	Surface Impoundment (6)	0-10 ft (20); 11-20 ft (7)
Arsenic, total	Metal	32	Landfill-MSW (11)	Site Wide (9)	0-10 ft (18); 11-20 ft (7)
Chromium, total	Metal	31	Site Wide (10)	Surface Impoundment; Unknown (5)	0-10 ft (14); 11-20 ft (6)

* 120 facilities have historic maximum results in the GWQ Impacts Database.

Ground Water Quality Impacts Associated with Drinking Water Sources

Facilities known to be affecting the ground water quality of a drinking water well are identified in the GWQ Impacts database. The drinking water well can be either public or private. Of the 30 facilities in the GWQ Impacts database that are known to be affecting a drinking water well, 67% are located in a sensitive aquifer (Figure 22).

Ohio's Source Water Assessment and Protection (SWAP) Program identified an area of ground water contribution surrounding each well or wellfield at the more than 5,000 Public Water Systems (PWSs) in Ohio. This area is referred to as the Drinking Water Source Protection Area (DWSPA). Of the 415 facilities in the GWQ Impacts database, 45 (approximately 11%) are located in a Drinking Water Source Protection Area.

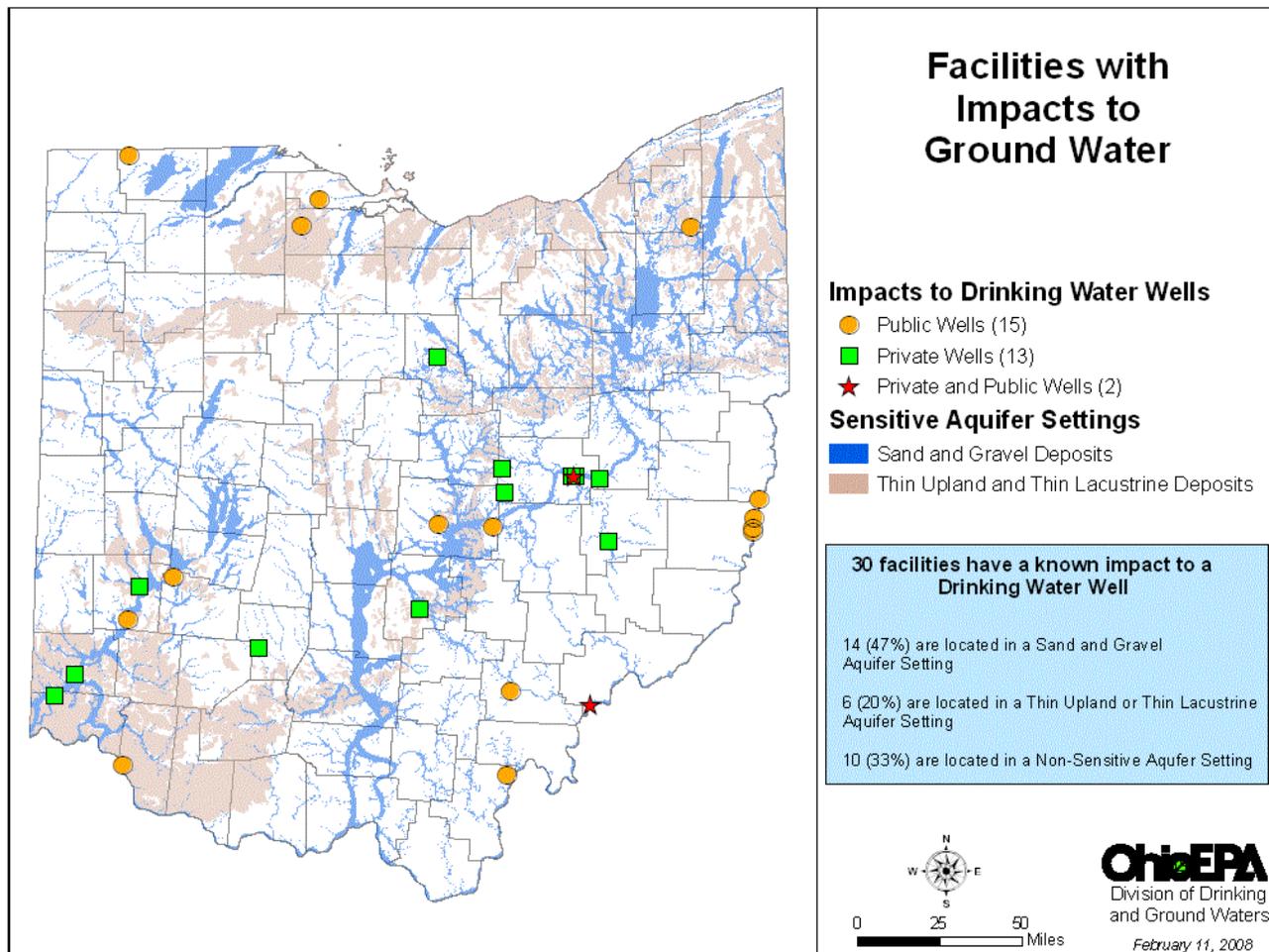


Figure 22. Statewide distribution of facilities known to be impacting a drinking water well.

Preliminary Conclusions

The purpose of the Ground Water Quality Impacts database is to provide a tool to summarize general aspects of facilities across Ohio where contaminant releases have affected ground water resources. The database currently contains 415 facilities with known impacts to ground water quality. Landfills (hazardous waste, residual waste, municipal solid waste, construction and demolition debris, industrial waste, and unregulated) represent the largest number of facilities (133 facilities – 32%) identified in the database, followed by “Site wide” (multiple source units) and Other (both 47 facilities – 11%), and Surface Impoundments (45 facilities – 11%).

Locations of the facilities with documented ground water quality impacts do not exhibit strong correlation to aquifers identified as sensitive using the statewide methodology discussed in the 2006 305(b) report. The delineation of sensitive aquifers relied on evidence of non-point source ground water quality impacts in public water system wells that are typically greater than 25 feet deep. The impacted ground water zones at the facilities are relatively shallow (77 % are less than 30 feet deep) and may not provide a good comparison group for the deeper public water system wells. Although contaminants can travel faster in sensitive settings, ground water quality impacts from point sources (such as industrial facilities or landfills) appear to occur in any type of aquifer setting or lithology. The presence of contaminants leaking from and leaching into local aquifers over a significant amount of time may be due to poor management or historical facility design practices. Comparisons between hazardous waste facilities affecting ground water quality and those that are not, do not show significant difference between the

geologic settings at the facilities. Sixty-five percent (65%) of the hazardous waste facilities are located in a geologically-sensitive setting. Of these, 46% are affecting ground water quality and 54% are not. It may take longer to migrate to an aquifer in a non-sensitive setting, but given enough time, a ground water quality impact may still occur. If management practices are the same, then it is reasonable to expect ground water quality impacts to be identified more frequently in areas of sensitive aquifers.

Volatile organic compounds (in particular, solvents) were the most frequently identified type of contaminant. Metals (arsenic, lead and chromium) were also commonly associated with facilities affecting ground water quality. The presence of these type of contaminants is expected due to the industrial or manufacturing nature of the facilities. The most common type of source units are above ground storage tanks, municipal solid waste landfills, and site wide.

Of the 30 facilities that are known to be affecting the ground water quality of a drinking water well, 67% are located in sensitive aquifers.

Future GWQ Impacts Analysis

The process of populating and updating the Ground Water Quality Impacts database will continue after review of annual compliance ground water monitoring results. In addition, there are several other data sets which may be incorporated in the analysis of ground water quality impacts, for example the Bureau of Underground Storage Tanks (BUSTR) data on leaking underground storage tanks (USTs), compliance data on VOC contamination associated with public water systems (PWS), and possibly Class 5 injection wells (UICs). Figure 23 illustrates the wide spread distribution of the BUSTR Sites (red triangles) and VOC impacted public water systems (blue circles) in relationship to the 415 sites with ground water impacts currently in the GWQ Impacts database (green squares).

The distribution of facilities affecting ground water quality does not correlate very well with the location of sensitive aquifers. The contamination tends to be driven by the type, design and management of the source unit and apparently, contaminant migration pathways exist in most hydrogeologic settings. This observation appears incompatible with the concept of sensitive aquifers based on relative recharge rates. It is possible that the ground water quality impacts identified in facility specific ground water monitoring programs measure a different scale of ground water quality contamination than those ground water quality impacts documented in deeper aquifers used for sources of drinking water.

Evaluating data to determine the volume of contamination released may provide insight into the role of geology and sensitivity aquifers in understanding contamination transport from point sources. Additional analysis to evaluate when ground water contamination is associated with shallow, limited saturated zones and when the contamination occurs more widely within an aquifer may provide a better correlation with sensitive aquifers. There is no doubt that the permeability of the various geologic settings is different, with the more sensitive aquifers associated with more rapid recharge. Indicators of transport volume, such as plume dimensions or contaminant concentrations could be used as factors for analysis.

Another factor that needs to be considered is the depth of the ground water quality impacts. The preliminary results indicate that the ground water impacts are restricted to shallower levels in non-sensitive geologic settings than in sensitive settings. Evaluating the details of this relationship could help identify favorable characteristics restricting vertical transport of contamination. This information may be useful for refining criteria for defining sensitive aquifers or for identifying favorable site characteristics for waste disposal facilities.

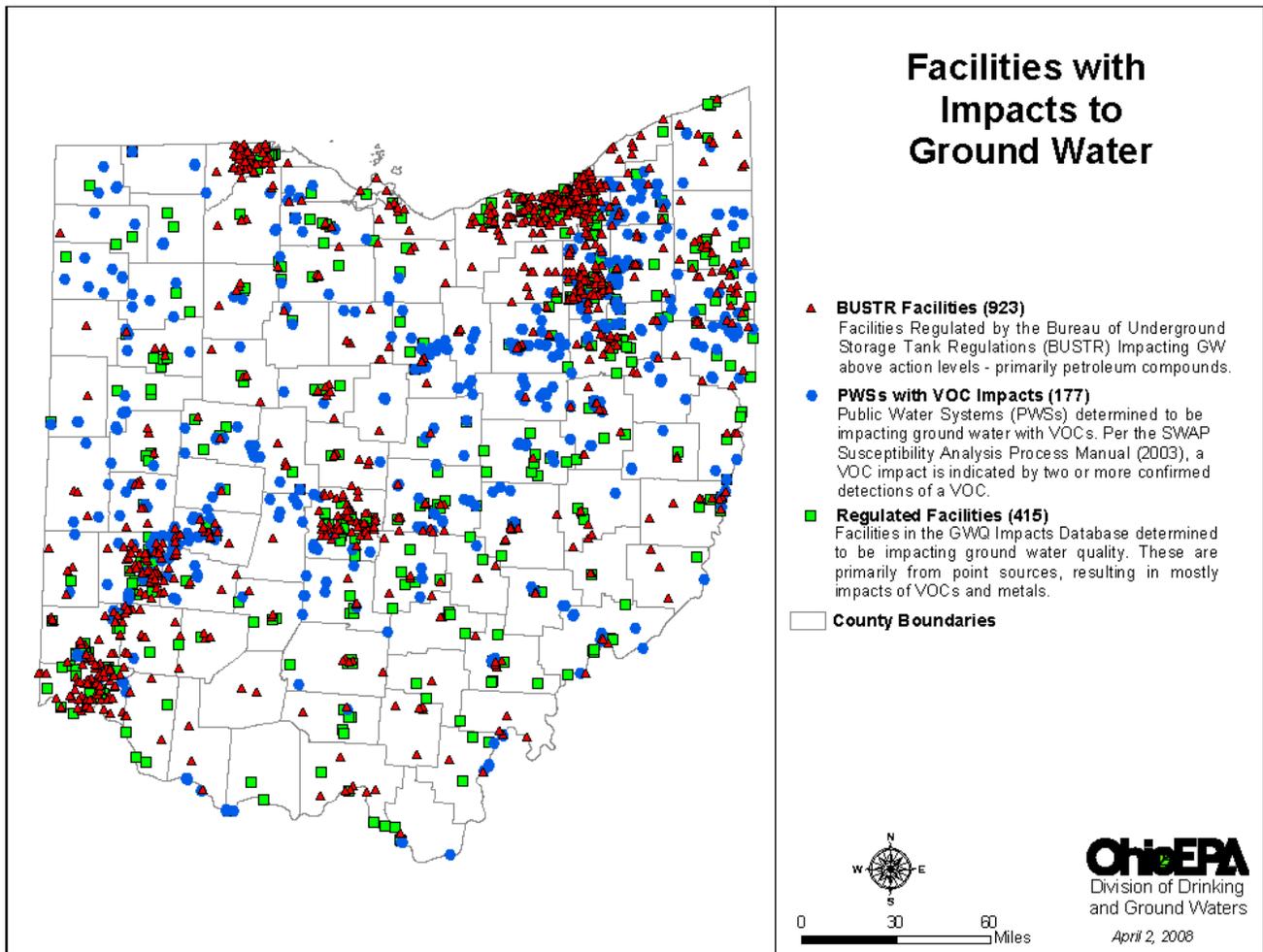


Figure 23. Additional data sets for analysis of documented ground water impacts.

GROUND WATER – SURFACE WATER INTERACTION

Aquifer sensitive to anthropogenic contamination tend to be located in areas that have higher ground water to surface water interaction associated with recent recharge or infiltration of surface waters. To identify sensitive aquifers on a statewide basis in Ohio, a conceptual model of short or rapid recharge pathways increase aquifer sensitivity was evaluated using ground water quality data. This analysis compared locations of public water systems with detections of dissolved contaminants, nitrate and volatile organics with glacial aquifer attributes from the Ohio Department of Natural Resources Glacial Aquifer Map. The results of this analysis suggest that the sand and gravel aquifers in Ohio are the most sensitive aquifers. Shallow bedrock aquifers, particularly fractured or karst bedrock aquifers that underlie thin glacial drift (tills or lacustrine deposits) comprise a second group of sensitive aquifers. This second group aquifers are more sensitive to particulate transport, such as pathogenic organisms and turbidity, as compared to sand and gravel aquifers with more effective natural filtration. Ground water quality data, compiled by the Ohio EPA's Source Water Assessment and Protection Program, were used to confirm the sensitivity of these aquifers. The sensitivity of shallow aquifers in unglaciated areas of Ohio was not included in this analysis. This approach for identifying sensitive aquifers in Ohio was summarized in the 2006 305(b) Report and presented at the 2006 Digital Mapping Techniques Workshop in Columbus Ohio. The complete analysis is detailed in [Identifying Sensitive Aquifers in Ohio, Ohio EPA, May 2007](#), available on the Ohio EPA web site.

Over the past 2 years, several ground water investigations have provided some additional information on recharge pathways in specific geologic settings. This information is useful for evaluating hydrogeologic settings where recharge pathways are more prone to contribute to ground water contamination. These efforts provided site-specific information concerning natural or induced recharge associated with anthropogenic activities. Brief summaries of these special investigations are presented below, with links to the reports if available online.

Wooster Township, Wayne County

An unsafe water supply investigation in Wooster Township, Wayne County Ohio was conducted between April and June 2006 at the request of the Wayne County Health Department. The goal was to determine whether local ground water supplying private water systems was affected by household sewage treatment system effluent within the subdivision or from other potential contaminant sources. The local aquifer is fractured sandstone below thin glacial till cover. The geochemical and isotopic data confirmed local ground water mixing, in varying proportions, with diluted effluent from the household sewage treatment systems. The interpretation of the additional analytical results provide several lines of evidence which indicate that sewage effluent is a major source of nitrate and pathogen contamination of the local ground water within the sensitive fractured bedrock aquifer. The study emphasizes the critical roles that thin glacial cover and fracture flow in bedrock can play in local contamination of ground water. The final report, [Report of Findings, Unsafe Water Supply Investigation, Wooster Township, Wayne County](#) is available on the Ohio EPA web site.

Clark County - Mad River

An investigation of the sources of nitrate and pathogens in the area of the Echo Hills subdivision was conducted in 2005-2006 at the request of the Mad River Township trustees. The subdivision is located in an upland area south of the Mad River and is characterized by thin glacial till which overlies weathered and fractured Silurian limestone and dolomite bedrock aquifers, a karst setting. In this area, the Lockport (shallow) and Sublockport (deeper) aquifers are separated by a thin layer of shale. Based on observations and data analysis of this study

and previous studies it was concluded that water supplies developed in this karst setting are vulnerable to contamination from surface water and anthropogenic sources. This is especially true after periods of heavy rain or snowmelt and the associated recharge. Interestingly, the recharge pathways are both vertical and horizontal on the south side of the Mad River. The vertical recharge pathways dominate the shallower Lockport aquifer. Along the Mad River and its tributaries, outcrops of the Sublockport limestone and dolomite provide open fractures for recharge of the deeper aquifer through horizontal flow paths, especially when streams and rivers are at or near flood stage. Recognizing areas where horizontal recharge is an important recharge process is a critical element of identifying sensitive aquifers.

Ohio EPA conducted a second investigation in early 2007 in Mad River Township to better characterize the geologic setting and determine shallow ground water flow rates using dye tracers. Field investigations identified approximately 30 sinkholes, two disappearing streams, exposed bedrock, and numerous springs along the escarpment. The disappearing streams are obvious evidence of significant interaction between surface and ground water in the region. Two fluorescein dye traces were conducted. The first trace yielded an average flow rate of 28,800 feet/day along a major solution/fracture line and the second trace yielded an average flow rate of 3,100 feet/day for shallow ground water flow and detected at multiple locations. The first trace was conducted during a rain event in a well-developed sinkhole and the second trace was conducted during a dry period in a smaller less-developed sinkhole. Dye was detected in both springs and private wells, demonstrating the connectivity of sinkholes to the upper aquifer. In a down-hole video of one of the wells that tested positive for dye, obvious fractures were evident at a depth of approximately 30 feet. Isopods and what appear to be salamander larvae were also observed in the well, and may indicate a connection with a nearby spring. More information is available in the report *Mad River Township, Clark County Karst Investigation, Ohio EPA, 2008*.

Karst areas in Mad River Township and other regions of Ohio are known to be sensitive due to bedrock dissolution along fractures that increases ground water flow rates. Enlarged fractures increase the potential for rapid infiltration of surface water while reducing natural filtration processes. If sufficient thicknesses of glacial till overlie the karst bedrock, the bedrock aquifers may not be sensitive to surface contamination because the till limits the rate of recharge of surface water. The episodic nature of large or unusual rainfall events, however, may generate sufficient recharge or flooding to transport contaminants to wells that are normally safe. These recharge pulses are generally associated with increased turbidity in drinking water. This episodic nature of contamination is particularly difficult to document and makes the partially protected karst setting a difficult one to identify and manage.

Buckeye Lake – Licking County

Some of the public water systems around Buckeye Lake have had chronic total coliform detections. An investigation was initiated to evaluate whether the detections could be naturally occurring in the local aquifer or possibly due to sampling, treatment or distribution issues. The local aquifer is a buried valley sand and gravel aquifer, which is confined, based on local well log information and static water levels. The water from this aquifer exhibits reduced water chemistry with elevated iron and some arsenic. It is unlikely for land use activities to affect the ground water quality in aquifer setting that is covered by 50 to 100 feet of glacial clay. Wells are generally cased through this clay layer.

Ohio EPA sample results produced few positive total coliform samples resulting in the conclusion that sampling error, poor sampling technique or poor sample taps, are the most likely explanations for the chronic total coliform detections. This study confirms the protection that

thick clay provides for a buried aquifer, although abandoned wells and/or poorly constructed wells can provide pathways for recharge to the aquifer. Since the aquifer in the Buckeye Lake area is confined and overpressured, some hydrostatic head is required to drive recharge into the aquifer and it is possible that this occurs locally. The report, [Investigation of Bacteria in Public Water System Compliance Monitoring Samples - Village of Buckeye Lake, Licking County, Ohio](#) is available on the Ohio EPA web site.

Catalina Mobile Home Park, Butler County

Partially treated wastewater is directed to four unlined infiltration lagoons excavated into the Great Miami River buried valley aquifer at the Catalina Mobile Home Park (MHP) in northeast Butler County. The purpose of this study was to determine the magnitude of ground water quality impacts in the area downgradient of the infiltration lagoons. The wastewater plume is clearly delineated by chloride and TDS concentrations. Ground water quality impacts associated with the wastewater infiltration plume were identified, but inorganic MCLs are not exceeded (nitrate average less than 5 mg/L) and in general, the counts for pathogen indicators are low. While infiltration processes are significantly reducing the pathogen concentrations, the uncertainty in the microbiologic sampling results makes it difficult to state categorically that the water would be safe for human consumption. These results suggest that the processes of chemical transformation, predation, and filtration associated with treatment plant aeration, lagoon processes, infiltration through the bottom of the lagoons, flow through the vadose zone, and transport within the sand and gravel aquifer provide a significant amount of treatment. Since the samples were collected in the lagoons and in ground water at the downgradient property boundary and beyond, we have little information to identify which of these zones provide the most effective treatment for individual parameters. Overall, ground water quality impacts are significantly lower than expected for this treatment system. The findings from this study will be utilized to evaluate the need to regulate similar wastewater treatment systems and to assess the need for statewide ground water quality standards. The complete report, [Ground Water Quality Impacts of Infiltration of Partially Treated Wastewater at Catalina MHP, Butler Co., Ohio](#), is available on Ohio EPA Division of Drinking and Ground Waters web site.

Future Special Studies

Opportunities for completing additional special studies will continue to arise. The recent investigations enhance our understanding of ground water recharge pathways and this information will provide insight on identification of sensitive aquifers, ground water recharge, and ground water - surface water interaction. For example, Ohio EPA may complete a dye trace investigation in Northwest Ohio to better characterize the ground water flow rates and the level of karst development in that region.

Another approach to encourage exploration of ground water - surface water interaction is the question of the sustainability of ground water use. National efforts are beginning to focus on the sustainability of ground water resources and the need to develop monitoring information for a national inventory of water resources, including quantity and quality of surface water and ground water. The Ohio Water Resource Council, through the Workgroup for Water Resource Monitoring (WWRM) is organizing a committee to identify the critical information for evaluating ground water sustainability and to determine if the existing ground water monitoring programs are collecting these critical data. The national efforts of the Federal Advisory Committee on Water Information and its Subcommittee on Ground Water will provide a framework for the WWRM committee efforts. Discussion of ground water sustainability with a focus on recharge, storage, and discharge is an excellent way to highlight the ground water - surface water interaction, which should encourage cooperation between state agencies responsible for water resources.

CONCLUSIONS AND FUTURE FOCUS

The ground 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 2006 305(b) Ground Water Report. The major accomplishment has been finishing development of the Ground Water Quality Impacts database and initiating data analysis of these data. We continue to work to increase the quality of the Ambient Ground Water Quality Monitoring Program data, to incorporate improvements in data management tools, and to improve our data analysis with expanding use of GIS and data graphing tools. These efforts, in conjunction with investigations focused on site-specific ground water contamination, direct the use of ground water quality data and data analysis to support DDAGW programs and long-term goals, 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 ambient ground water quality data readily available to the public.

The AGWQMP data summary tables (Tables 4, and Appendix B) and various figures provide updated summaries of ambient ground water quality in Ohio is used to evaluate long-term trends and help identify ground water that may be affected by anthropogenic activity or reveals significant natural variability. It is important to remember that the data used to generate these tables do not represent only pristine aquifer settings, but include wells with ground water impacts as documented by the presence VOC detections and elevated nitrate concentrations. The influence of ground water oxidation-reduction state on ground water quality is illustrated in Table 5 for parameters whose solubility is sensitive to changes in oxidation-reduction conditions. All AGWQMP inorganic data in Appendix A as box plots for each parameter listed in Table 4 by aquifer type, in order to illustrate differences between major aquifer ground water chemistry and to exhibit the distribution of individual data points. AGWQMP data collection efforts will continue to provide data to document long-term trends at active AGWQMP sites, producing valuable data for evaluating environmental trends. Localized or site-specific investigations will continue to focus on identifying and evaluating areas of ground water quality affected by anthropogenic activities and increase our understanding of ground water recharge pathways and sensitive aquifers.

A summary of the AGWQMP organic sampling results are presented in Appendix B. Limited detections of organic compounds occur in samples collected from the wells and detections generally occur at low concentrations. The rate of detections may be artificially increased due to the six month sampling frequency for wells known to be close to contamination plumes or with a history of low concentrations of organic contaminants. Additional monitoring is conducted to provide information for PWS wells that may be affected by anthropogenic contamination. Organics samples are normally collected on an eighteen-month interval.

The compounds most frequently detected in the AGWQMP sampling are consistent with organic detections from drinking water compliance data. The detection rates of the most commonly detected parameters range from 0.2 % for the petroleum BTEX component toluene, to 4.5 % for the DBP chloroform. The overall detection percentage, across all organic sample types (VOC, BNA, and pesticides) is 0.28 %. These numbers are quite low and illustrate the broadly

protected nature of PWS ground waters to point source contaminants. In addition, both the overall detection rate of 0.28%, and the highest individual component detection rate (4.5 % for the DBP chloroform) are low compared to national statistics of VOC detections across multiple aquifers of the United States. The compounds most frequently detected are chlorinated solvents and petroleum byproducts like toluene and benzene. Chloroform, the most commonly detected organic parameter, may be associated with back flow of treated water or disinfection of wells, but recharge of treated water or natural sources of chloroform are also possible explanations.

The Ground Water Quality Impacts Database houses facility, hydrogeologic and chemical summary information for sites or facilities with documented releases of contaminants to ground water. Data entry is not complete so the analysis presented is preliminary, but Section 3 of the 2008 305(b) report illustrates the type of analyses that can be completed using the information collected and stored in the database. The conclusion that impacts to ground water are not preferentially associated with the sensitive aquifers is interesting and suggests that the site-specific monitoring associated with these sites or facilities measure a local scale of ground water quality impact than a statewide analysis based on ground water quality obtained from public water systems. This independence of sensitive aquifers was also suggested in analysis of VOC detections in AGWQMP data and in PWS compliance monitoring data as reported in the Organic Contaminant in Ohio Ground Water section presented in the 2006 305(b) Report. This suggests if a long-term source of contamination is present, pathways to ground water will be available for contaminant transport. It is probable, however, that the volume of contaminant transported in the non-sensitive settings will be less than the contaminant volumes transported in sensitive settings. Additional analysis needs to be completed to explore relationships between sensitive aquifers and the evidence for the volume of contaminant reaching the ground water using plume size, contaminant concentrations, or depth of water quality impacts.

Identification of site/facility specific locations with ground water quality impacts in sensitive aquifers can be used to set broad priorities for ground water protection efforts or regulatory permitting or compliance requirements. The information in the Ground Water Quality Impacts database can be integrated with geographic analysis tools to analyze ground water quality data, including source location information, hydrogeologic setting information, well construction data, and aquifer hydrologic parameters which should enhance the opportunity to establish associations between geologic parameters and/or land use data with water quality data.

Once areas of significant ground water quality impacts 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 Clean Water Act Section 319 funds or other funding sources. Our ability to focus protection efforts on sensitive aquifers or public water systems with the greatest potential for water quality impacts is critical in order to maximize effectiveness of ground water protection efforts in Ohio.

The section on the ground water - surface water interactions briefly summarizes activities focused on sensitive aquifers and recharge pathways since these issues directly influence ground water quality. Water program structures, generally focused on ground water or surface water as the priority, inhibit integration of ground water - surface water interactions. The OWRC Workgroup on Water Resource Monitoring is organizing a workgroup to evaluate the state ground water monitoring programs. The proposed focus of this group is to assess Ohio's ground water monitoring networks for evaluating ground water sustainability. The scale and approach for this workgroup has not been determined, but sustainability is an effective way to force integration of ground water programs and ground water - surface water interactions.

Reducing recharge, storage or discharge over the long run generates sustainability issues for both ground water and surface water.

Projects in Planning Stages

Sensitive aquifers occur in areas 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. A critical project for ground water - surface water interactions is studying the influence of recharge on water ground water quality in a sensitive aquifer. DDAGW is proposing to identify several hydrogeologic areas with rapid recharge and initiate short-term sampling programs 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 source water assessment and protection 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 include a plan to collect shallow ground water quality data in order to increase the representation of shallow ground water quality resources in our ambient ground water quality program. The AGWQMP data is dominated by ground water quality data from deeper, high volume aquifers, so including shallower wells in our ground water quality data collection effort is critical to characterizing the most sensitive of Ohio's ground water resources.

Since the late 1990s as part of the Pesticide Management Plan (ODA, 1998), Ohio Department of Agriculture has collected pesticide samples at agricultural facilities or other sites using ground water in an effort to identify herbicides in ground water. The results from this sampling produced few pesticide detections. In 2007, private water wells adjacent to railroad right-of-ways were sampled due to the high rate of herbicide application along right-of-ways. In 2008, Ohio EPA collaborated with ODA to identify several aquifer locations that are considered highly sensitive for this targeted sampling effort. The goal is to identify several sensitive aquifer areas in regions of intensive agricultural land use to sample for pesticides in the ground water. This sampling should provide additional ground water quality data in areas of sensitive aquifers.

The Ground Water Rule became final in November 2007. An internal workgroup is working to draft the state rule language and to identify the implementation approach to be used in Ohio. The final rule relies on source water monitoring triggered by a total coliform positive sample in the distribution system. This new bacteriological data collected from the public water system's raw water source may be useful in evaluating sensitive aquifers. The rule does not provide an option of using hydrogeologic sensitivity assessments to identify areas where monitoring requirements could be waived based on the geologic conditions or sample results indicate an aquifer is not vulnerable to pathogen transport. The optional assessment monitoring program, however, could be used to collect pathogen data to characterize aquifer settings considered susceptible to pathogen contamination. Data collected in assessment monitoring for pathogens in areas considered sensitive to pathogen movement will help identify areas where water wells are sensitive to total coliform and fecal contamination.

Another long-term goal is to make the ambient ground water quality data accessible to the public in simple, understandable formats. Several approaches have been discussed for increasing the accessibility of these data:

- Generate factsheets discussing ground water concentrations of specific parameters across the major aquifers in the state:

- Create a template for presenting ground water quality data on a watershed basis designed to be useful to local water users; and
- Work to develop interactive tools for selecting ground water quality data on the web.

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**2008 305(b) Report - Ohio's Ground Water Quality
Appendix A**

**Ambient Ground Water Quality Monitoring Program
Box and Whisker Plots of Inorganic Data**

Ambient Ground Water Quality Monitoring Program

Inorganic Constituent Box and Whisker Plots

This document provides a concise graphical summary, in box and whisker plot format, of the Ambient Ground Water Quality Monitoring Program inorganic data set as of December, 2007. The Ambient Ground Water Quality Network database includes results from some 5,800 raw (untreated), inorganic water samples collected over the past 30 years across 200 active and 160 inactive wells in Ohio. Active Ambient Ground Water Network wells are sampled every six or eighteen months. The primary objective of collecting statewide, raw ground water data from major aquifers is to characterize Ohio's ground water quality, which in turn can be used to enhance water resource planning and to prioritize ground water protection activities. The Ambient Ground Water Monitoring Program places a priority on collecting water quality data representative of aquifers used by public water systems. Analysis of water quality changes in space and time indicate that some of the Ambient Ground Water Quality Monitoring Program wells are influenced by land use activities. The Ambient wells are not a collection of pristine wells, but rather a collection of wells in which the water quality is considered typical of the ambient conditions of the local ground water used as source water for public water systems.

In the following box plots, the inorganic water-quality sample results are plotted on the Y-axis, while the X-axis represent the three major aquifer groupings within Ohio (sand and gravel, sandstone, and carbonate). The 2008 305(b) Report - Ohio's Ground Water Quality discusses these inorganic data and their relationship to the major aquifers in more detail. Table 4 of the 2008 305(b) Report includes means and medians for each parameter by major aquifers which complements the interpretation of these box and whisker plots. The 2008 305(b) Report is available on Ohio's Ground Water Quality Characterization Program web page at :

http://www.epa.state.oh.us/ddagw/pdu/gw_305b.html

These box plots allow the reader to effectively compare data variability across major aquifer types, and are presented in the same order and groupings as in Table 4: Field Parameters, Major Constituents, Trace Constituents, and Nutrients. The number of samples used to construct each group's box plot is indicated below its major aquifer category on the x-axis. In some cases, the Y-Axis is presented in log scale to enhance readability of the plots. Box plots which appear without "boxes" (common in Trace Elements section) have too little data variability to generate the 25th and 75th percentiles of the distribution (upper and lower box bounds). In these cases, the boxes appear collapsed to the most common data point, typically the Reporting Limit. These collapsed boxes generally occur when the "Percent Non-Detect" column of Table 4 is greater than 75%, indicating that the bulk of the data set was reported below the detection limit. In a few cases, such as for chromium, copper, lead, and nickel, some low level data exist, and so some data points are present below current reporting limits.

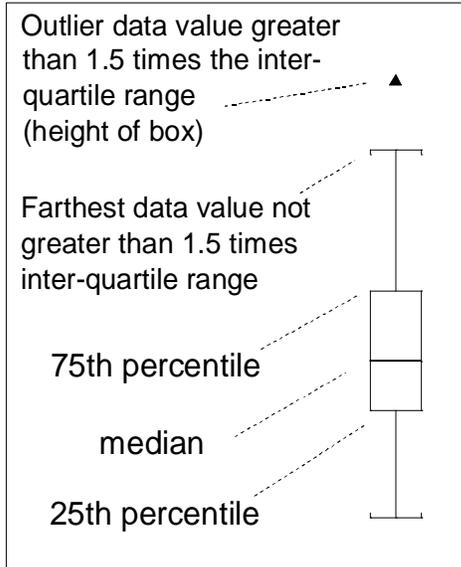
Ground Water Quality Characterization Program

Division of Drinking and Ground Waters
50 West Town Street, Suite 700
Columbus, OH 43215
(614) 644-2752

Web Page: <http://www.epa.state.oh.us/ddagw/wqcharpr.html>

Email: gwq@epa.state.oh.us

Box and Whisker Plots

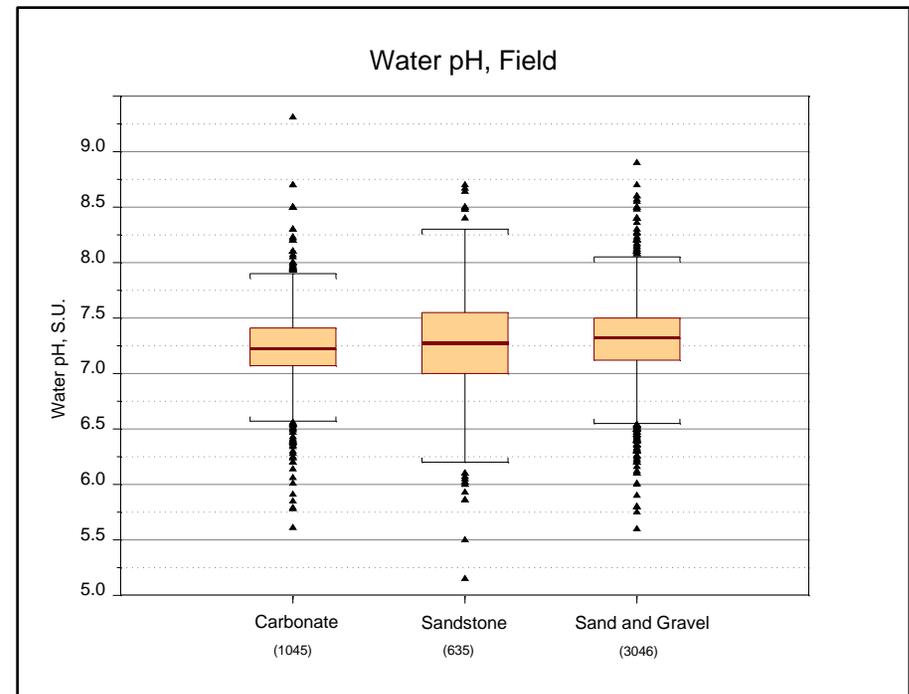
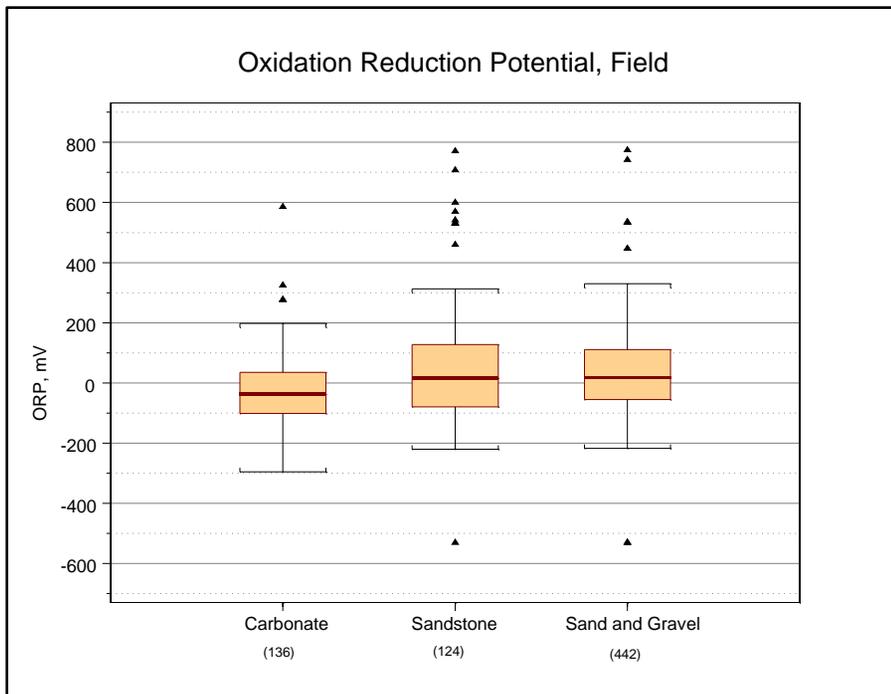
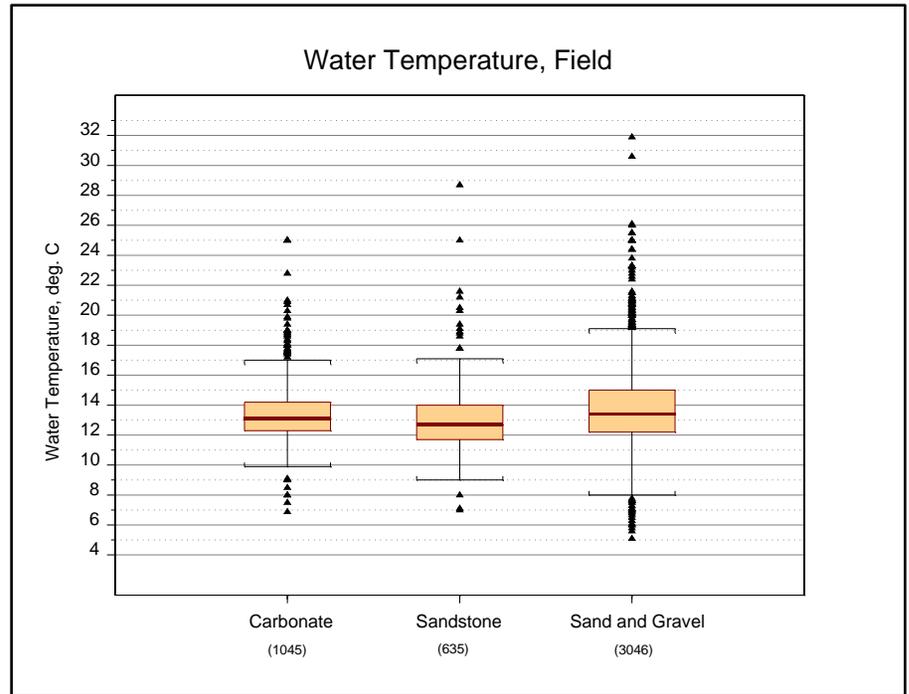


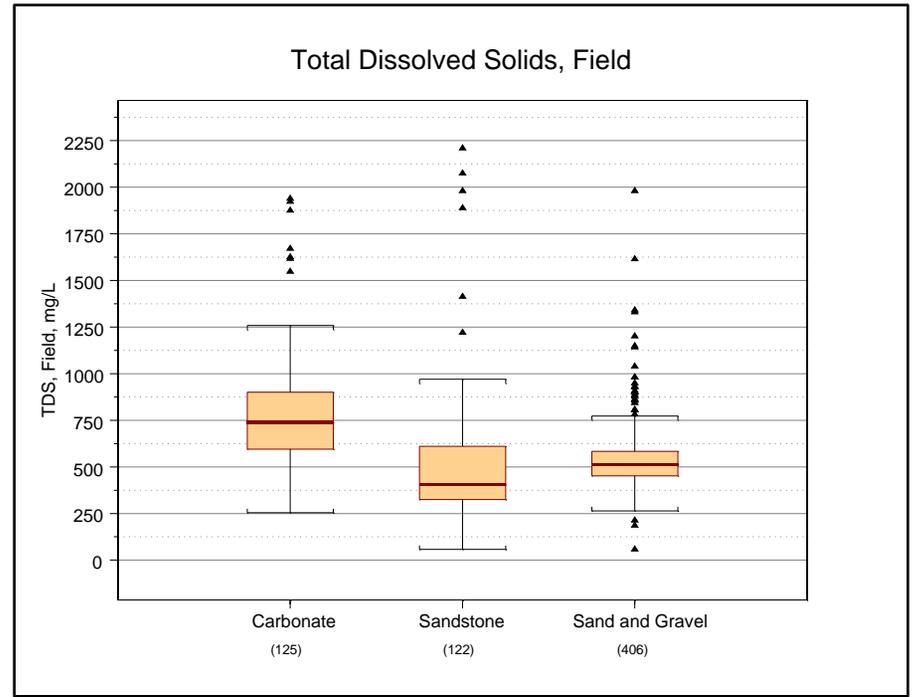
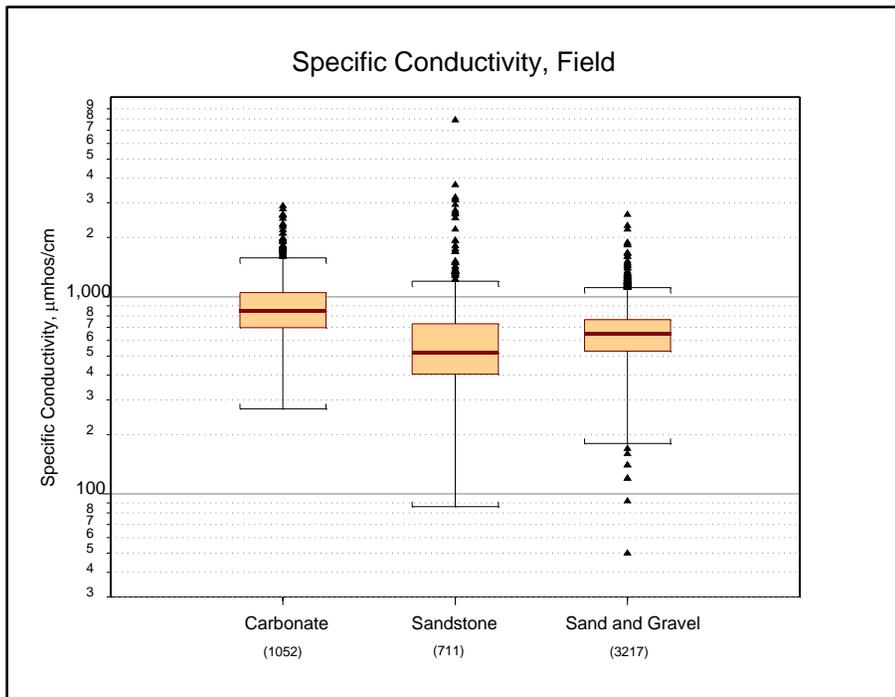
Box and Whisker Plots are an efficient graphical method for displaying the distribution of a data set. The format allows easy comparison of one distribution to those of other groups of data. The “box” itself outlines the range of half the data (the 25th to 75th percentiles, called the Inter-Quartile Range, or IQR). The median of the data set (the 50th percentile) is indicated by a horizontal bar inside the box.

The whiskers are vertical lines extending from the top and bottom of the box, and indicate the range of data (which are not outliers) above and below the 75th and the 25th percentiles, respectively. The whisker caps (horizontal bars at the ends of the whiskers) indicate the last data point which does not exceed 1.5 times the IQR. Outliers exceed this limit and are identified by individual symbols above or below the whisker caps.

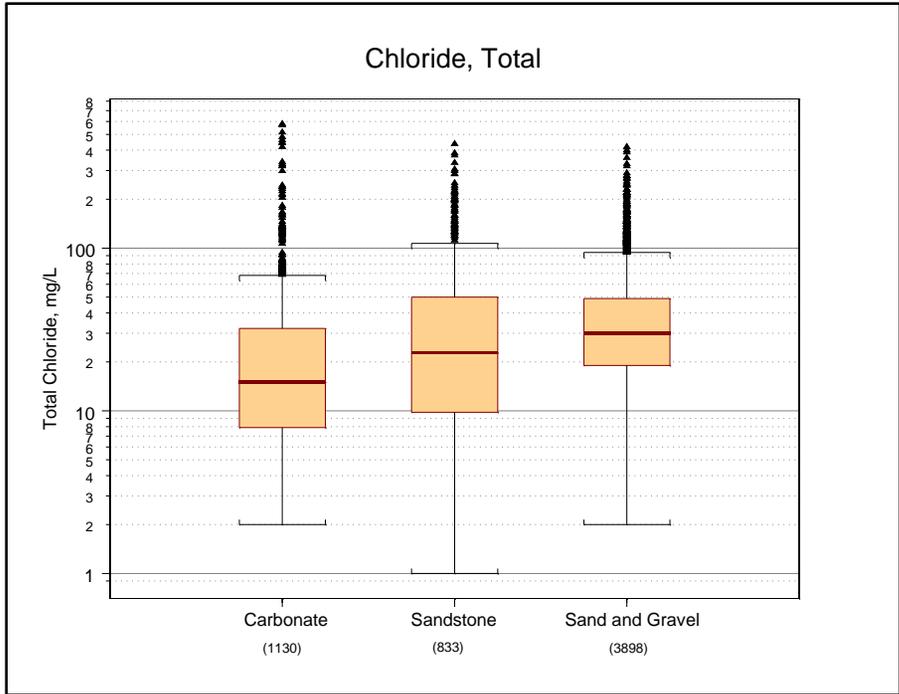
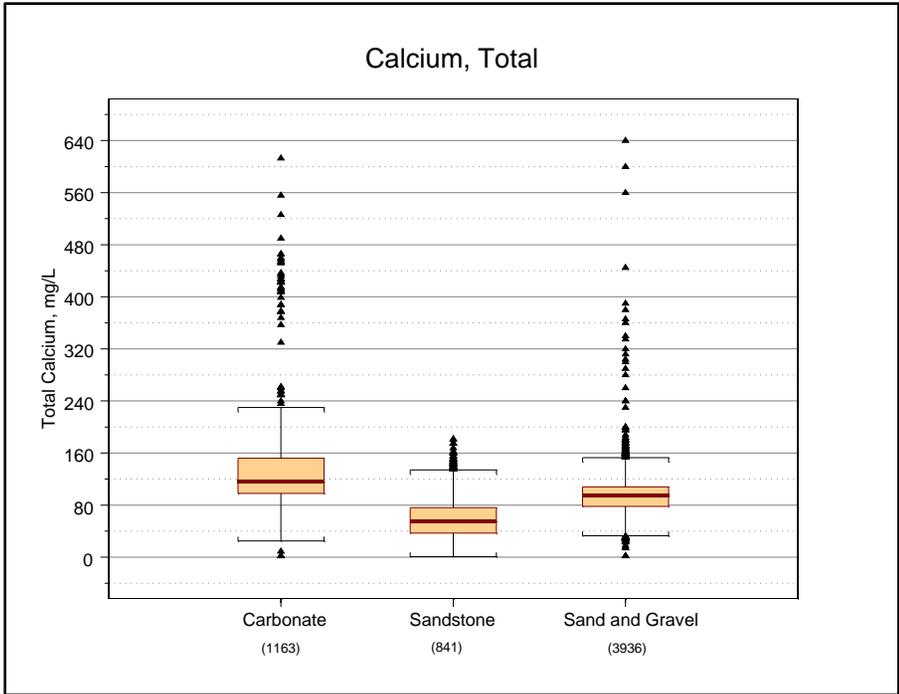
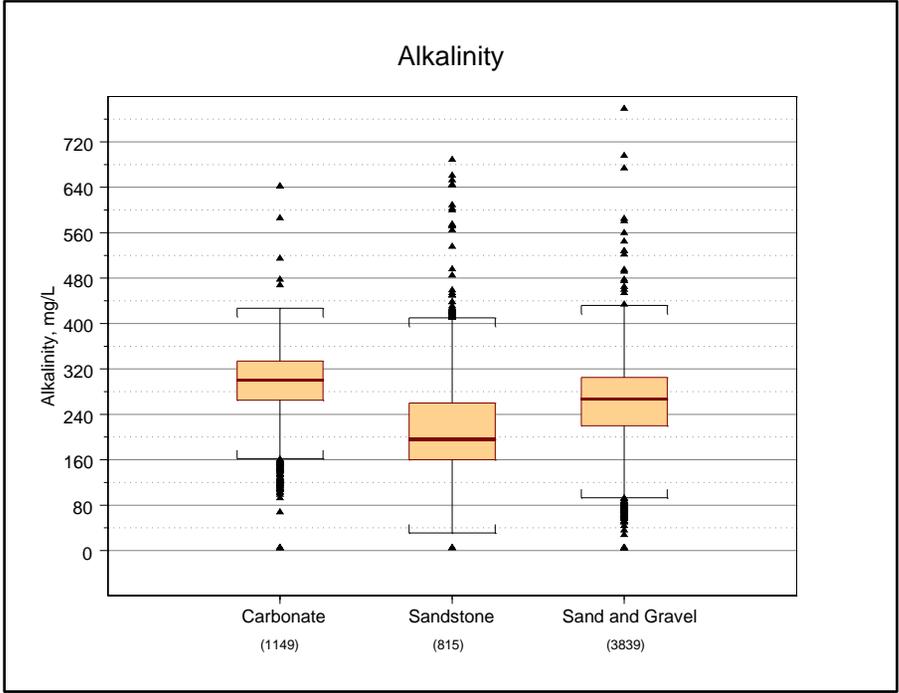
A normally distributed data set is generally indicated if the median bar is located mid-way between the top and bottom of the box. A skewed data set would have the median bar either closer to the 25th percentile (positively skewed) or to the 75th percentile (negatively skewed).

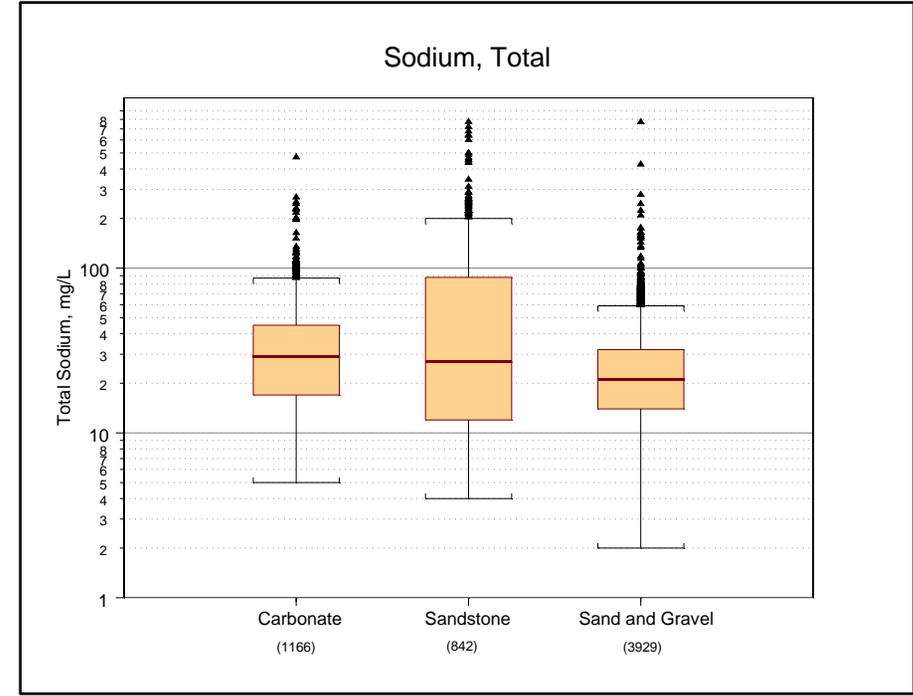
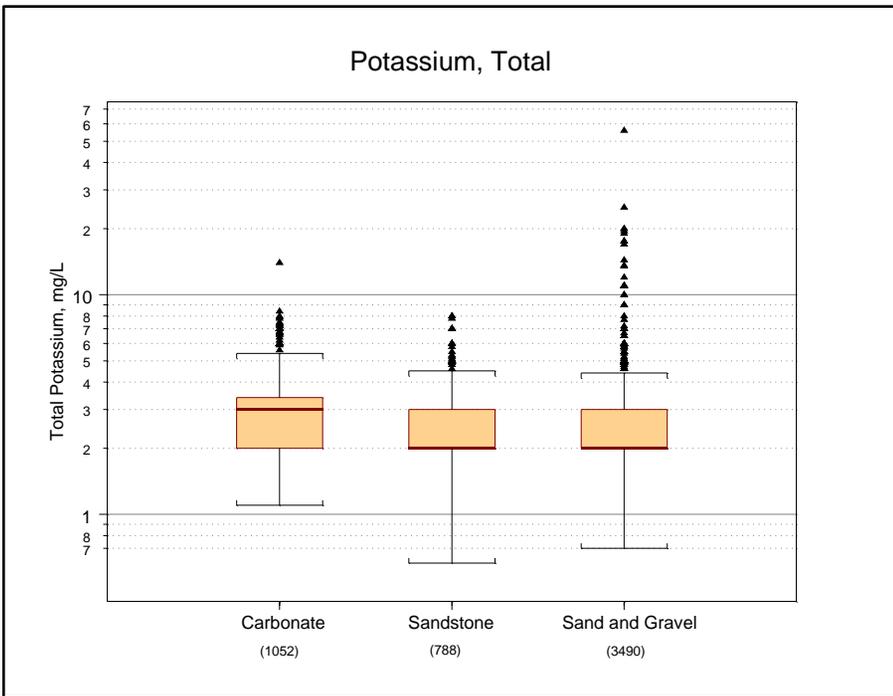
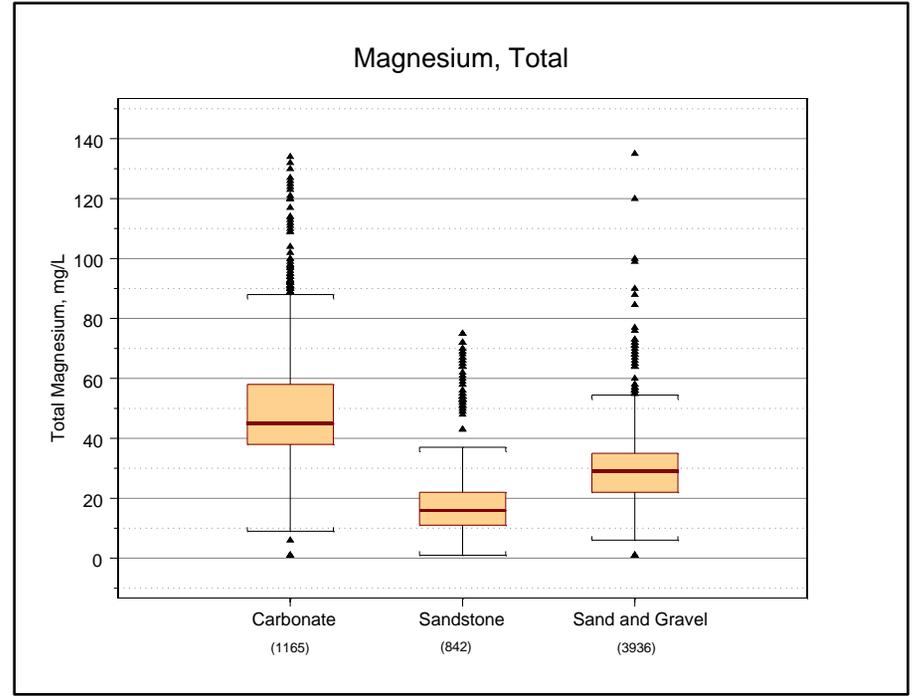
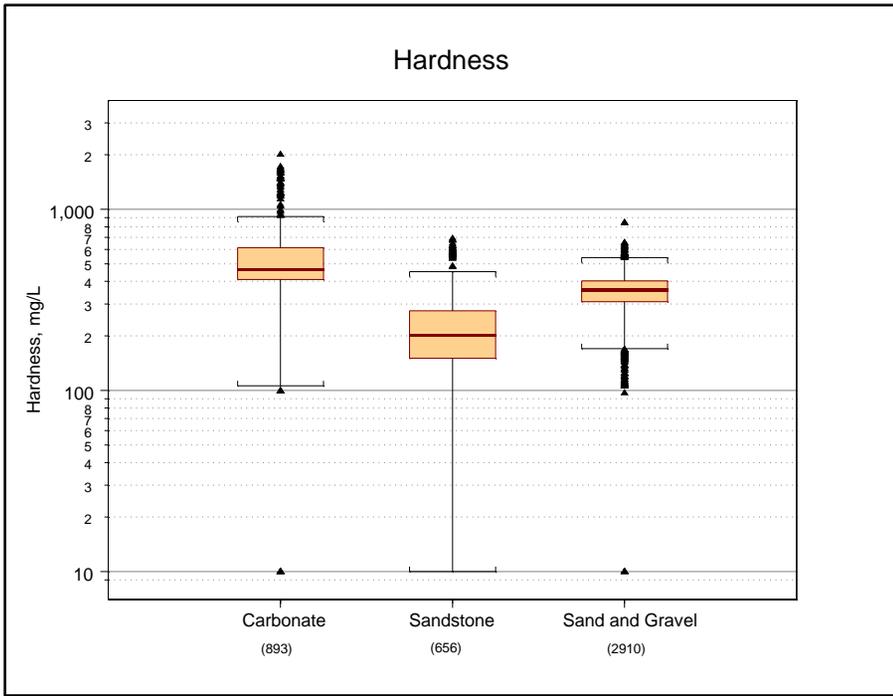
Field Parameters



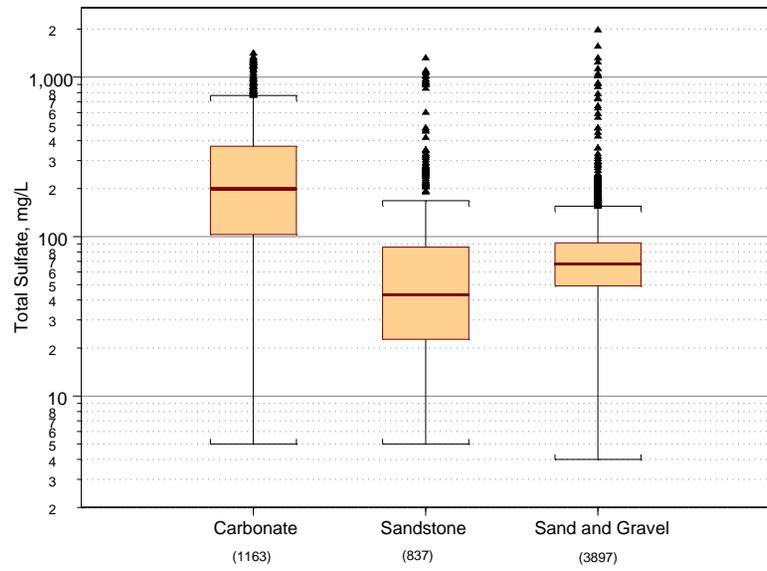


Major Constituents

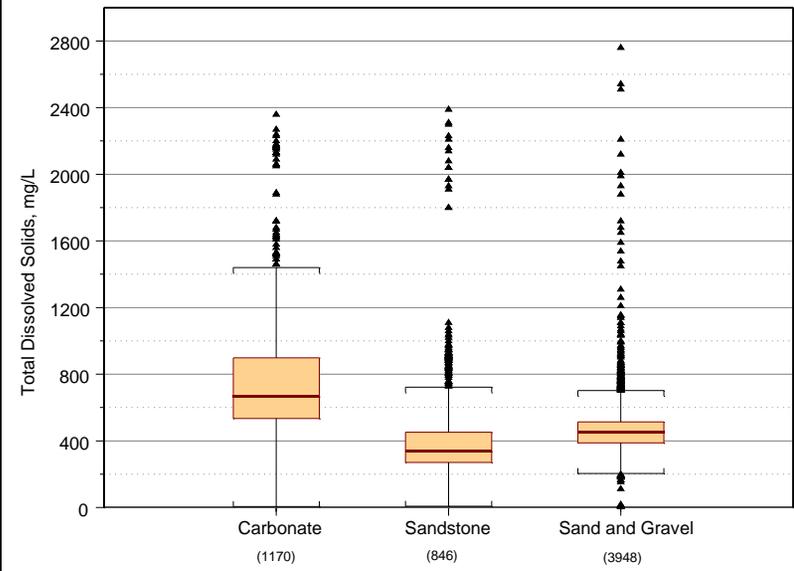




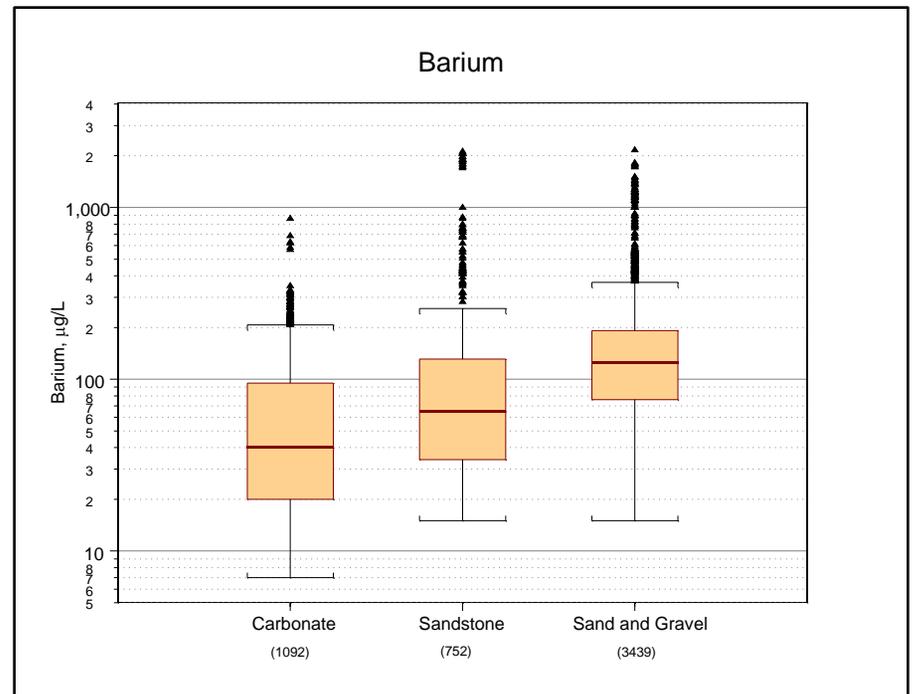
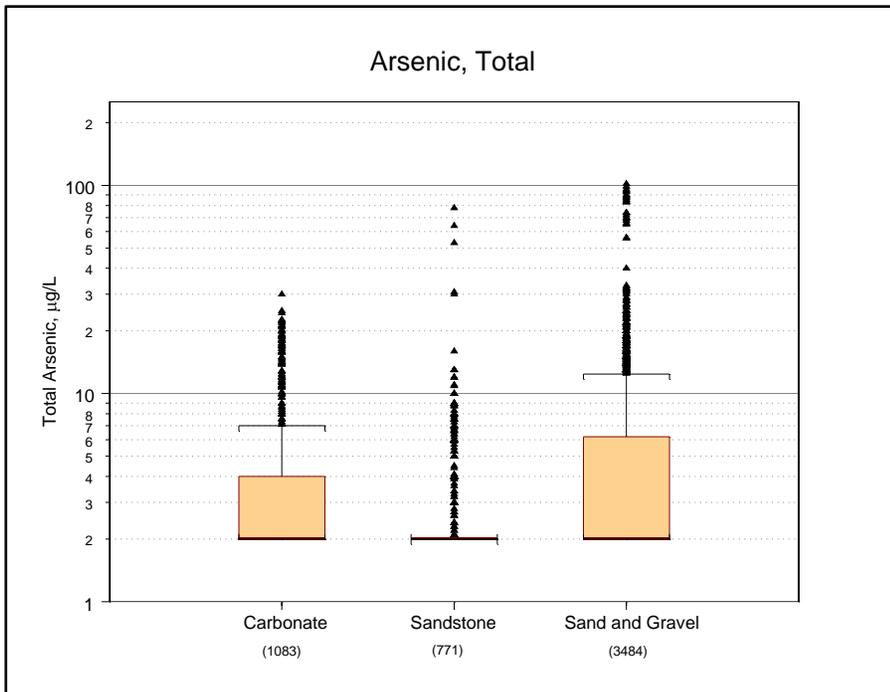
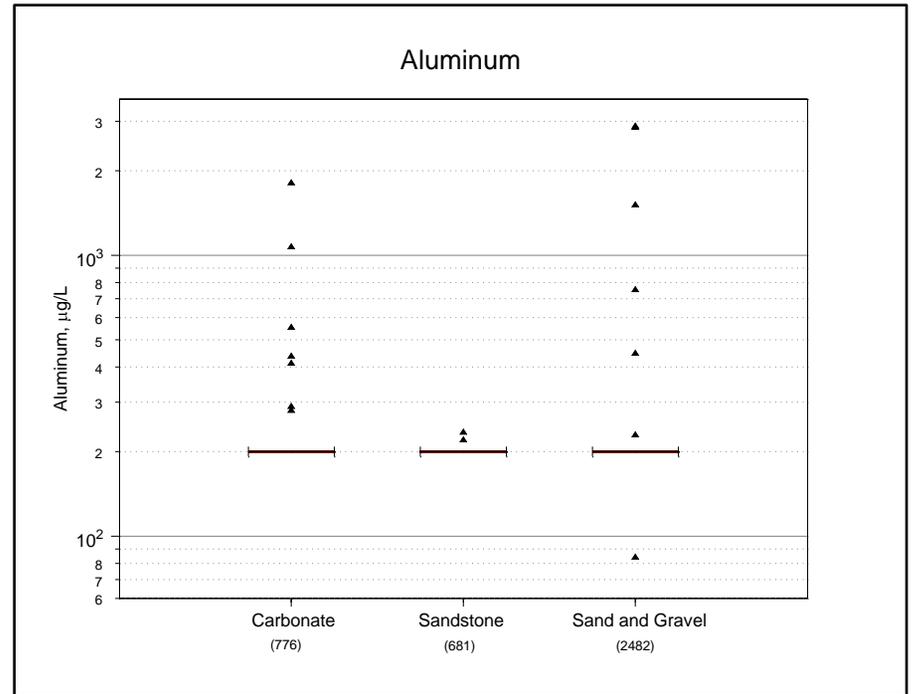
Sulfate, Total



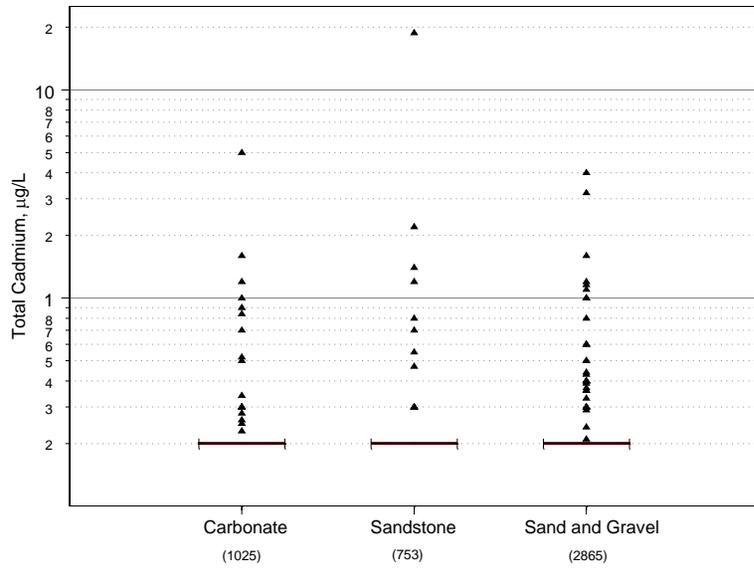
Total Dissolved Solids



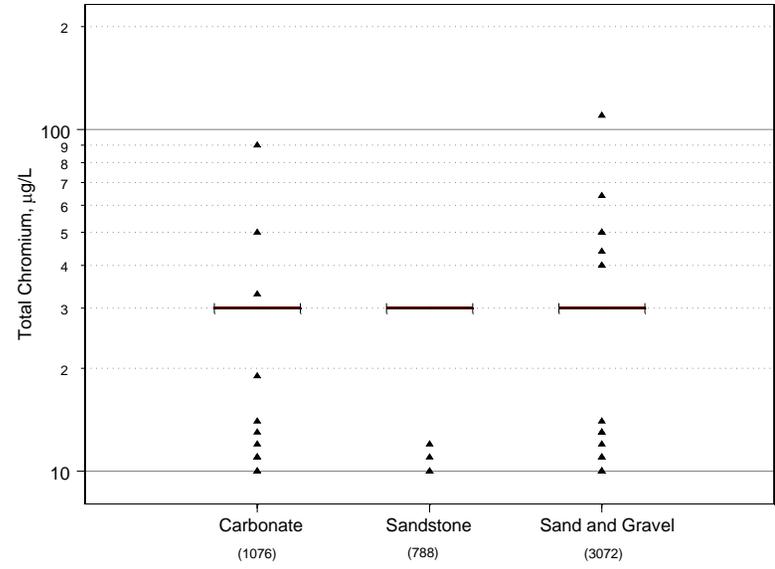
Trace Constituents



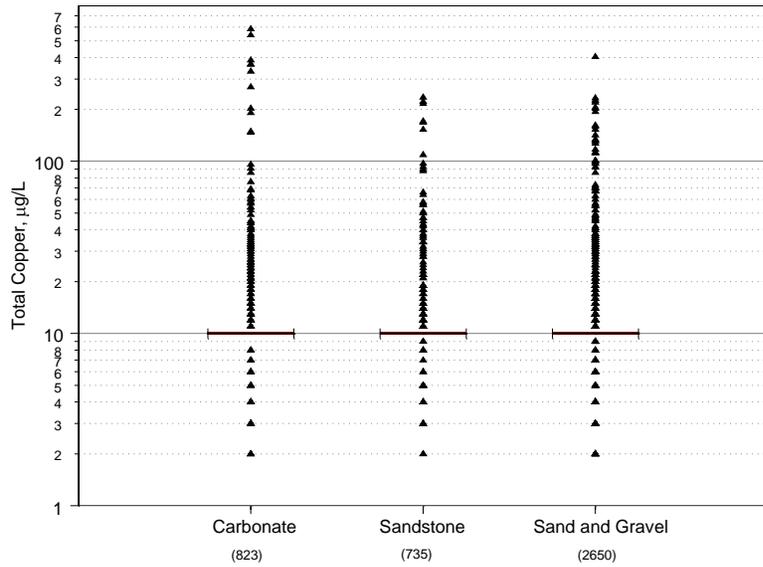
Cadmium, Total



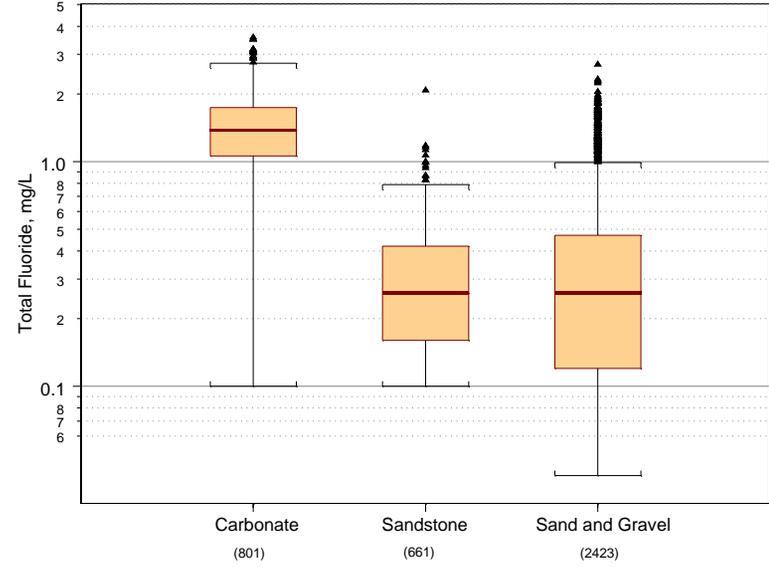
Chromium, Total

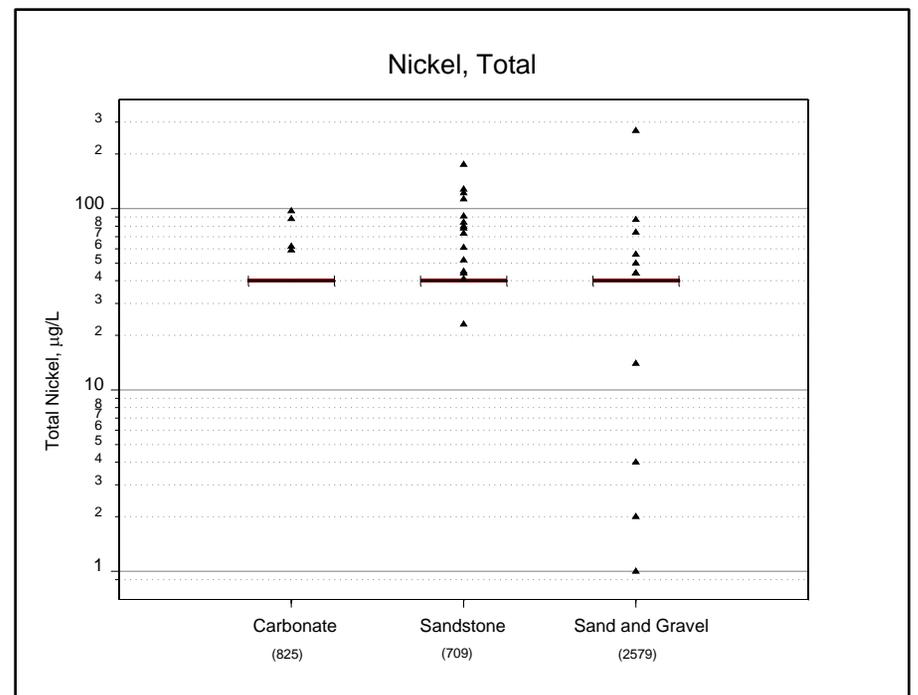
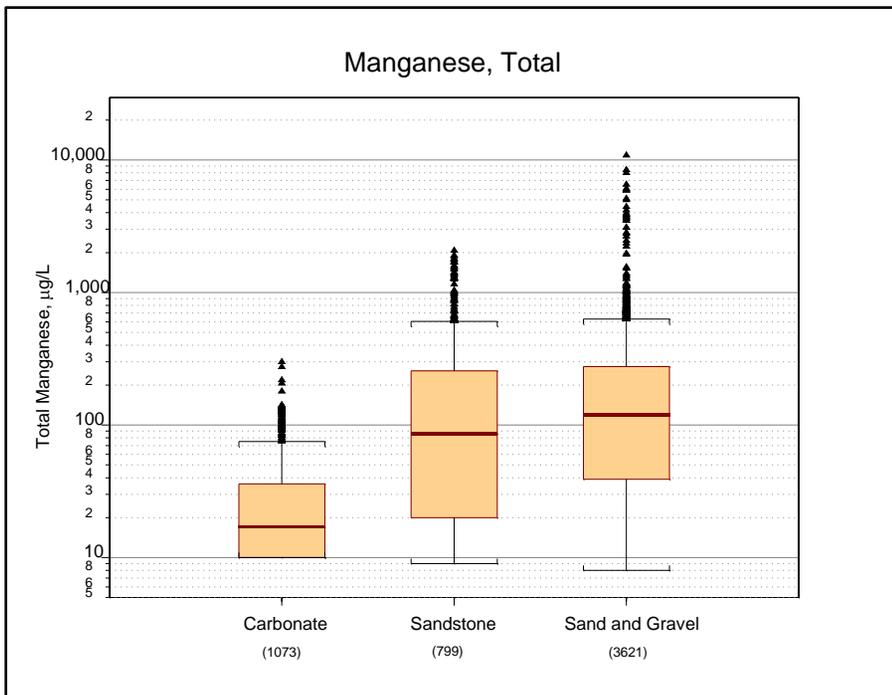
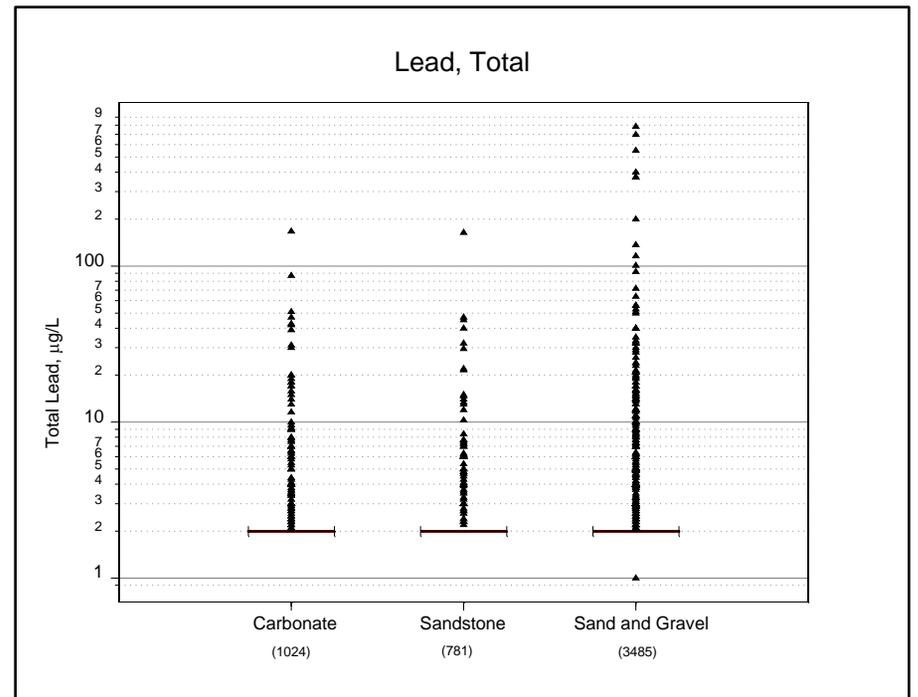
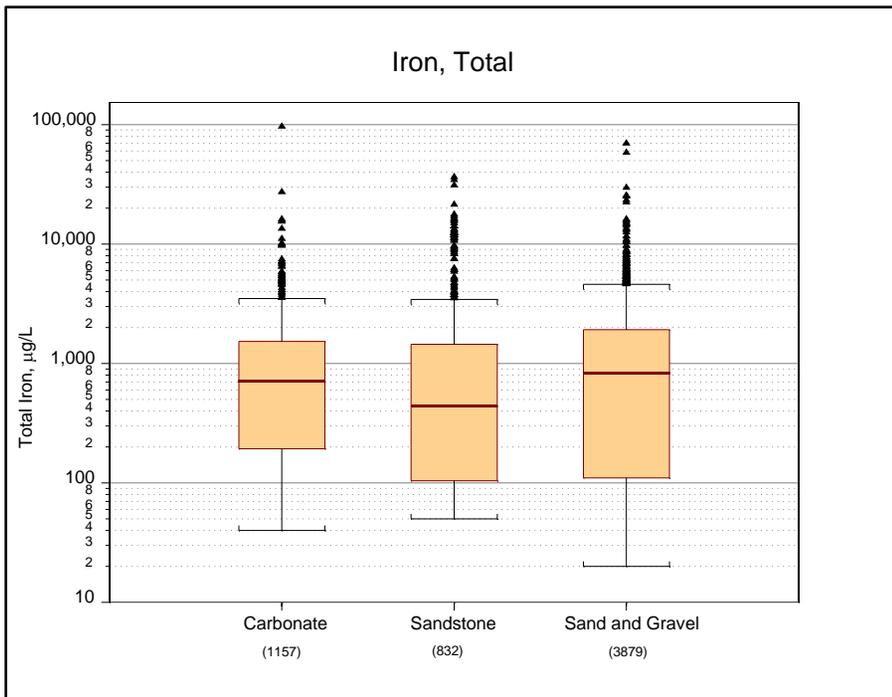


Copper, Total

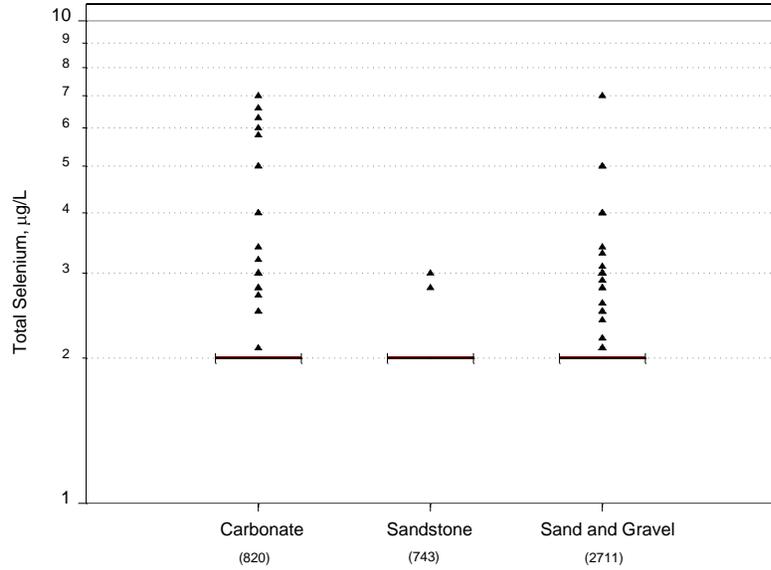


Fluoride, Total

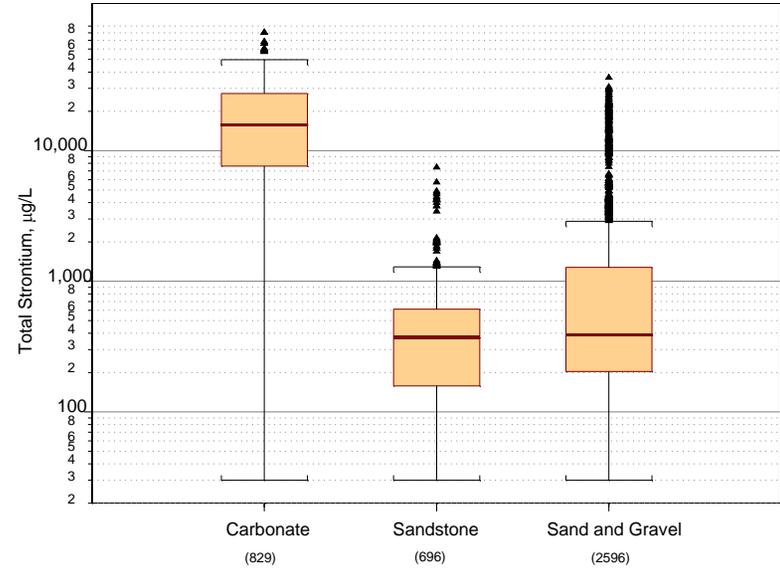




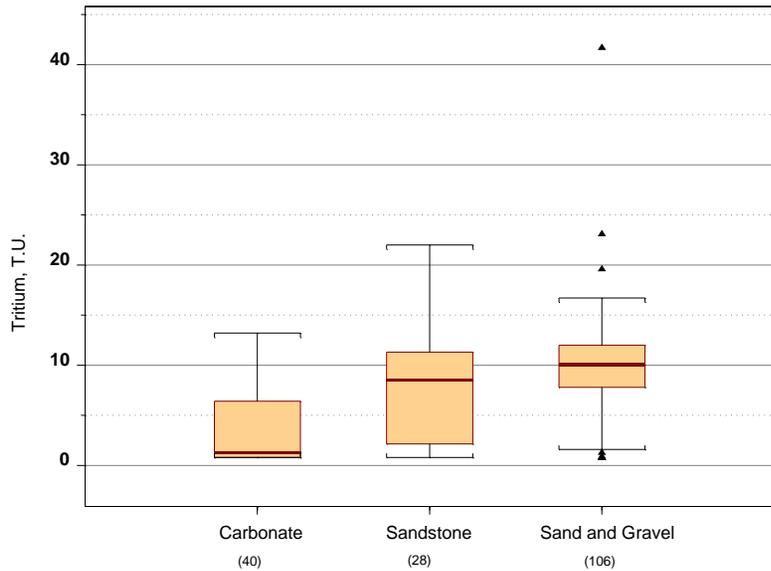
Selenium, Total



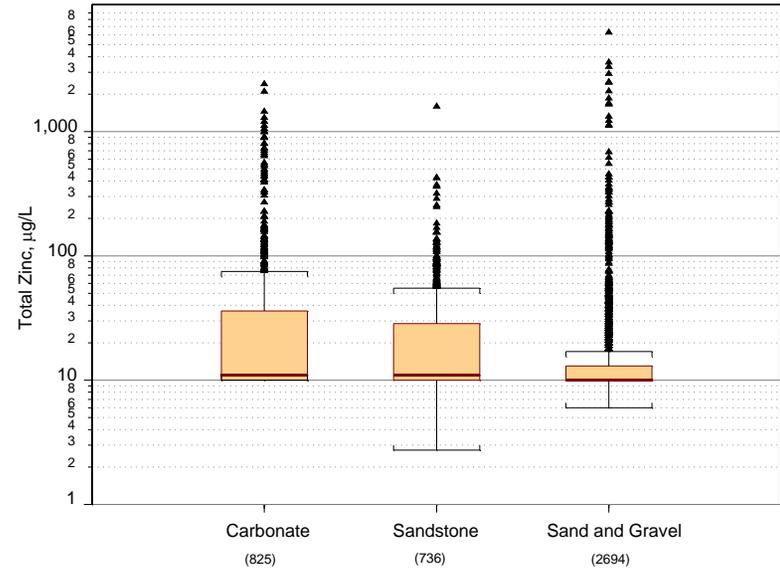
Strontium, Total



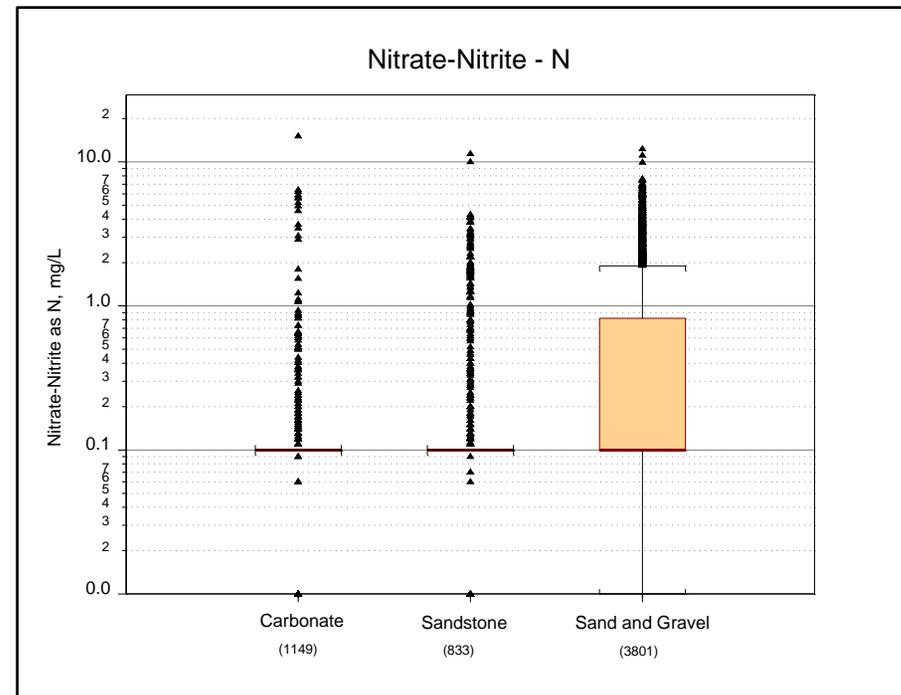
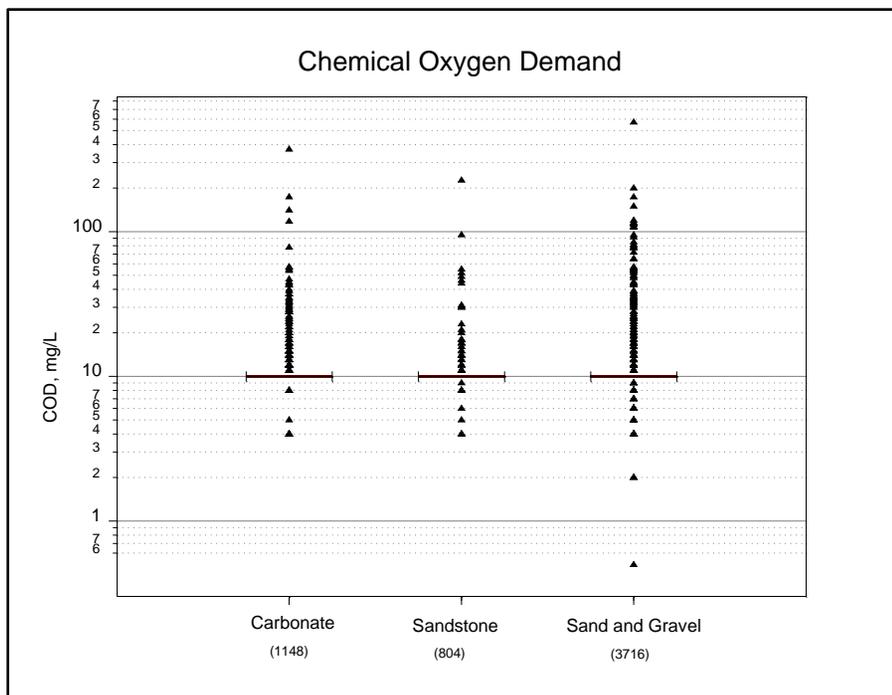
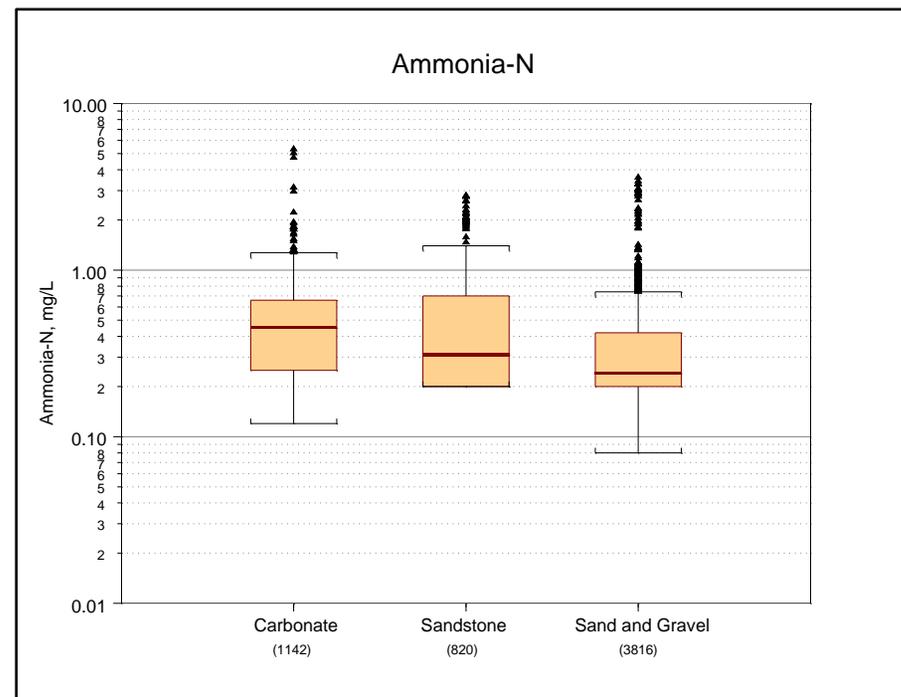
Tritium



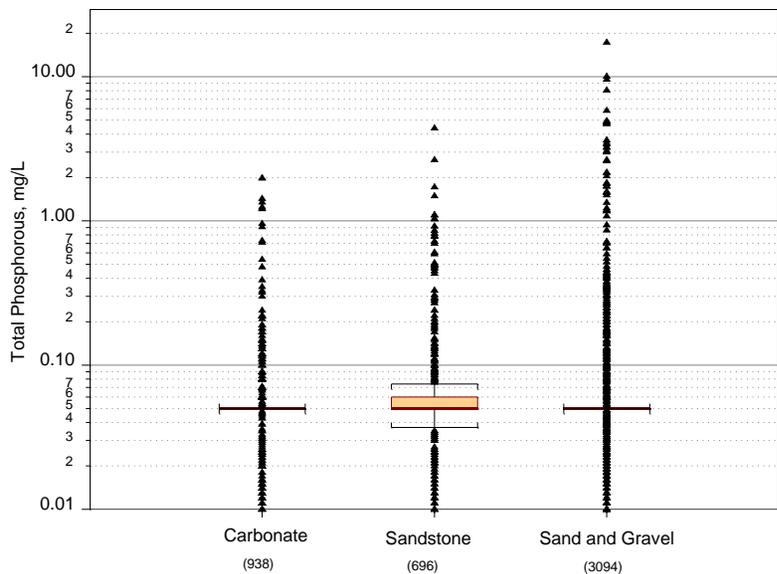
Zinc, Total



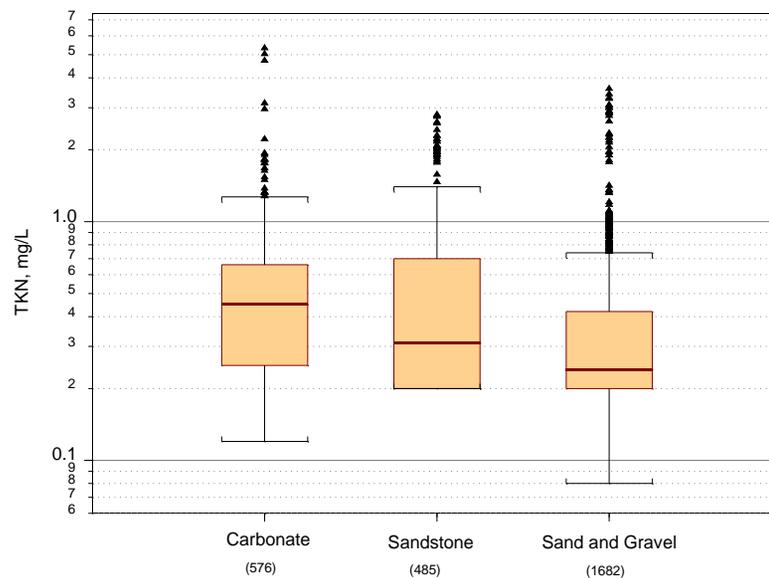
Nutrients



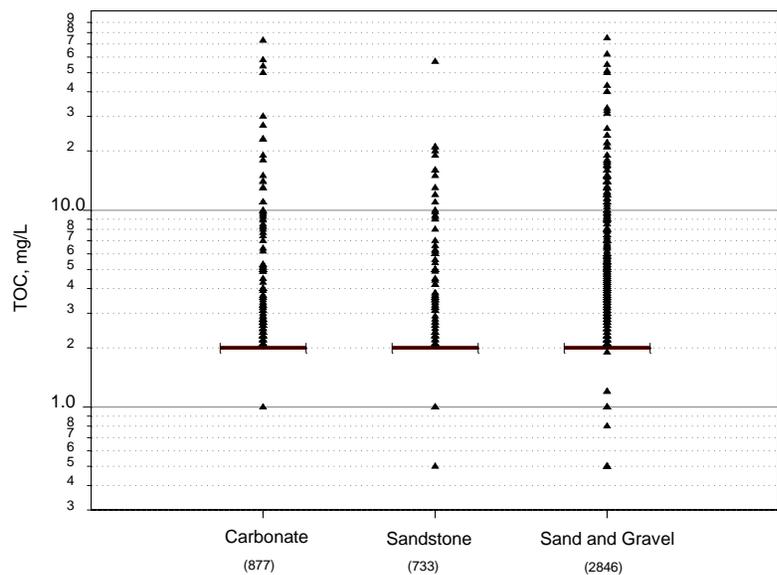
Phosphorous, Total



Total Kjeldahl Nitrogen



Total Organic Carbon



2008 305(b) Report - Ohio's Ground Water Quality Appendix B

Ambient Ground Water Quality Monitoring Program Organic Samples – Table of Results

The following table, Organic Samples - Table of Results, lists the parameters included in the organic sample packages. The organic parameters for the semi-volatile BNA analysis (Method 625), the semi-volatile pesticide analysis (Method 525.2), and volatile organic compounds (Method 524.2), are listed alphabetically by sample type. The primary purpose of this table is to indicate the number of non-detect results and to provide a simple summary of the values detected for organic parameters. The parameters that were detected more frequently were discussed in the section on the AGWQMP organic samples (page 40). In addition to the standard parameters analyzed, several tentatively identified compounds were identified and are included in the Table of Results.

The structure of the Table of Results is as follows:

First column, **Chemical Group**, is the type of organic sample analyzed;

Second Column, **Contaminant**, lists the individual parameters analyzed;

Third Column, **Sign**, indicates if the parameter was detected in any samples:

- the **+** row includes all detections for the parameter (highlighted with yellow shading) and only present for parameters with detections; and
- the **<** row includes all non-detect results.

Fourth Column, **Sample Count**, Lists the number of sample results for each parameter;

- If there are detections, they are counted on a separate row (**+**) from non-detects.

Columns 5, 6, and 7 provide the **Minimum, Average, and Maximum Values** respectively:

- for non-detect results, all these values are all equal to the non-detect value, **<0.5 µg/L**;
- for parameters with 1 detection, all these values are the detected value;
- for parameters with more than 1 detection, these values start to provide more useful information about the range of detected values.

Columns 8 and 9, **Minimum and Maximum Date**, lists the date of the first and last sample analyzed for the parameter.

Column 10, **% Non-Detect**, provides the percent of non-detect results - that is the percentage of all sample results for a parameter that are below the reporting limit:

- no percentage of non-detects is provided for the rows of detected results(**+**);
- the percentage non-detect is presented in the non-detect row (**<**);
- the TICs that have been added to the AGWQMP database have low sample counts and 0 % non-detect because they are only added when a significant detection occurs.

ORGANIC SAMPLES - TABLE OF RESULTS

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
BNA	1,2,4-Trichlorobenzene	<	390	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	1,2-Dichlorobenzene	<	390	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	1,3-Dichlorobenzene	<	390	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	1,4-Dichlorobenzene	+	1	0.6	0.6	0.6	6/8/98	6/8/98	
		<	388	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	2,4,6-Trichlorophenol (TCPH)	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	2,4-Dichlorophenol	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	2,4-Dimethylphenol	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	2,4-Dinitrotoluene	+	1	2.1	2.1	2.1	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	2,6-Dinitrotoluene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	4-Chloro-3-methylphenol	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Acenaphthene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Acenaphthylene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Anthracene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Benzo[a]anthracene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Benzo[a]pyrene	<	389	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Benzo[b]fluoranthene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Benzo[g,h,i]perylene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Benzo[k]fluoranthene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	bis(2-chloroethoxy) methane	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	bis(2-chloroethyl) ether	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Bis(2-Chloroisopropyl) ether	+	1	2.1	2.1	2.1	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	bis(2-ethylhexyl) phthalate (DEHP)	<	389	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	bis(n-octyl) Phthalate	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Bromophenyl-4 phenyl ether	+	1	5.3	5.3	5.3	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Butyl benzyl phthalate	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Chloronaphthalene-2	+	1	5.3	5.3	5.3	7/7/98	7/7/98	
	<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74	

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
	Chlorophenol-2	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Chlorophenyl-4 phenyl ether	+	1	2.1	2.1	2.1	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Chrysenes C1-C4	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Dibenzo[a,h]anthracene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Dibutyl phthalate	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Diethyl phthalate	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Dimethyl phthalate	+	1	5.3	5.3	5.3	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Dinitro-o-cresol	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Dinitrophenol, 2,4-	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Fluoranthenes, C1-C4	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Fluorenes, C1-C3	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Hexachlorobenzene	+	1	2.1	2.1	2.1	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Hexachlorobutadiene	+	1	2.1	2.1	2.1	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Hexachlorocyclopentadiene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Hexachloroethane	+	1	5.3	5.3	5.3	7/7/98	7/7/98	
		<	385	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	Indeno[1,2,3-cd]pyrene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Isophorone	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Naphthalene	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	389	<0.5	<0.5	<0.5	12/11/92	6/20/01	99.74
	nitro-Benzene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Nitrophenol, 2-	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Nitrophenol, 4-	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	n-Nitrosodiphenylamine	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	n-Nitrosodipropylamine	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Pentachlorophenol (PCP)	<	389	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Phenanthrenes, C1-C4	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
	Phenol	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
	Pyrene	<	386	<0.5	<0.5	<0.5	12/11/92	6/20/01	100.00
PEST	Acetochlor	<	13	<0.5	<0.5	<0.5	10/30/03	11/6/07	100.00
	Alachlor	<	394	<0.5	<0.5	<0.5	5/6/96	11/6/07	100.00
	Atrazine	+	1	0.4	0.4	0.4	5/15/96	5/15/96	
		<	393	<0.5	<0.5	<0.5	5/6/96	11/6/07	99.75
	Benzo[a]pyrene	<	263	<0.5	<0.5	<0.5	12/9/96	11/6/07	100.00
	bis(2-ethylhexyl) adipate	+	7	0.6	4.4	22.0	1/27/98	12/29/98	
		<	206	<0.5	<0.5	<0.5	7/16/97	11/6/07	96.71
	bis(2-ethylhexyl) phthalate (DEHP)	+	9	0.5	0.6	0.7	12/16/98	11/6/07	
		<	254	<0.5	<0.5	<0.5	12/9/96	5/3/07	96.58
	Butachlor	<	213	<0.5	<0.5	<0.5	7/16/97	11/6/07	100.00
	Cyanazine	<	382	<0.5	<0.5	<0.5	5/6/96	10/30/03	100.00
	Metolachlor	<	394	<0.5	<0.5	<0.5	5/6/96	11/6/07	100.00
	Metribuzin	<	394	<0.5	<0.5	<0.5	5/6/96	11/6/07	100.00
	Pentachlorophenol (PCP)	<	263	<0.5	<0.5	<0.5	12/9/96	11/6/07	100.00
	Propachlor	<	213	<0.5	<0.5	<0.5	7/16/97	11/6/07	100.00
	Simazine	<	394	<0.5	<0.5	<0.5	5/6/96	11/6/07	100.00
Sulfur	+	1	1000.0	1000.0	1000.0	9/28/06	9/28/06	0.00	
VOC	1,1-Dichloroethylene	<	1650	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	1,2,4-Trichlorobenzene	<	1657	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	1,2-Dibromo-3-chloropropane (DBCP)	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	1,2-Dichlorobenzene	<	1657	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	1,3-Dichlorobenzene	<	1658	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	1,4-Dichlorobenzene	+	3	0.6	0.8	1.0	6/8/98	4/12/05	
		<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.82
	Benzene	+	11	0.5	1.0	1.4	4/19/95	9/6/07	
		<	1641	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.33
	Bromoform	+	4	0.8	1.0	1.2	5/5/98	11/8/05	
		<	1649	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.76
Butane	+	3	10.0	13.3	20.0	11/15/04	5/2/06	0.00	

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
	Butyl benzene	+	2	0.5	0.6	0.6	5/5/98	4/23/03	
		<	1651	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.88
	Butylbenzene, sec-	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Butylbenzene, tert-	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Carbon tetrachloride	+	2	1.7	7.7	13.6	10/30/97	5/2/06	
		<	1652	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.88
	Chlorobenzene	+	1	0.7	0.7	0.7	5/2/06	5/2/06	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Chlorobromomethane	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Chlorodibromomethane	+	5	0.5	1.4	3.1	9/22/98	11/8/05	
		<	1647	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.70
	Chloroethane	+	1	6.6	6.6	6.6	4/23/98	4/23/98	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Chloroform	+	75	0.5	2.9	36.2	12/10/96	5/7/07	
		<	1573	<0.5	<0.5	<0.5	5/5/84	11/27/07	95.45
	Chlorotoluene, 2-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Chlorotoluene, 4-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Cumene	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Cymene	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Dibromomethane	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Dichlorobromomethane	+	6	0.5	1.1	2.0	9/22/98	5/2/06	
		<	1646	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.64
	Dichlorodifluoromethane	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Dichloroethane, 1,1-	+	5	0.6	1.1	2.0	4/23/98	10/27/05	
		<	1642	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.70
	Dichloroethane, 1,2-	+	1	1.5	1.5	1.5	6/11/97	6/11/97	
		<	1653	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.94
	Dichloroethene, trans-1,2-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
Dichloroethylene, cis-1,2-	+	39	0.5	1.2	4.3	4/19/95	9/6/07		
	<	1608	<0.5	<0.5	<0.5	11/6/89	11/27/07	97.63	

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
	Dichloromethane	+	6	1.4	14.4	43.7	5/27/97	11/8/05	
		<	1648	<0.5	<0.5	<0.5	5/5/84	11/27/07	99.64
	Dichloropropane, 1,2-	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Dichloropropane, 1,3-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Dichloropropane, 2,2-	<	1650	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Dichloropropene, 1,1-	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Dichloropropene, 1,3 cis-	<	1651	<0.5	<0.5	<0.5	5/30/91	11/27/07	100.00
	Dichloropropene, 1,3 trans-	<	1651	<0.5	<0.5	<0.5	5/30/91	11/27/07	100.00
	Diisopropyl ether	+	1	1.0	1.0	1.0	11/7/05	11/7/05	
	Ethyl benzene	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Ethylene dibromide (EDB)	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Hexachlorobutadiene	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Hexaldehyde	+	1	6.0	6.0	6.0	5/2/06	5/2/06	0.00
	Isobutane	+	4	7.0	11.8	20.0	11/8/04	5/2/06	0.00
	Methyl bromide	+	1	0.7	0.7	0.7	5/2/06	5/2/06	
		<	1649	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Methyl chloride	+	5	0.6	3.2	13.0	6/25/97	5/2/06	
		<	1647	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.70
	Methyl ethyl ketone	+	1	9.0	9.0	9.0	10/18/07	10/18/07	0.00
	Monobromobenzene	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	MTBE, Methyl tertiary butyl ethe	+	19	0.9	4.2	6.7	1/9/01	11/7/07	
		<	999	<0.5	<0.5	<0.5	9/27/00	11/27/07	98.13
	Naphthalene	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1655	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Propane	+	2	70.0	70.0	70.0	11/15/04	4/27/05	0.00
	Propylbenzene, n-	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Styrene	+	2	0.5	1.5	2.6	5/5/98	3/18/03	
		<	1651	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.88
Sulfur dioxide	+	3	20.0	40.0	60.0	10/11/06	10/11/06	0.00	
Tetrachloroethane, 1,1,1,2-	+	1	0.6	0.6	0.6	5/15/02	5/15/02		

Chem Grp	Contaminant	Sign	Sample Count	Min Value	Avg Value	Max Value	Min Date	Max Date	% Non-Detect
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Tetrachloroethane, 1,1,2,2-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Tetrachloroethylene	+	28	0.5	3.3	28.5	5/5/98	9/6/07	
		<	1623	<0.5	<0.5	<0.5	5/5/84	11/27/07	98.30
	Toluene	+	4	0.9	8.0	15.7	5/27/99	10/21/03	
		<	1647	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.76
	Trichlorobenzene, 1,2,3-	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Trichloroethane, 1,1,1-	+	11	0.5	0.7	1.4	7/22/98	10/27/05	
		<	1637	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.33
	Trichloroethane, 1,1,2-	<	1653	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Trichloroethylene	+	44	0.5	2.8	11.6	4/19/95	10/23/07	
		<	1605	<0.5	<0.5	<0.5	11/6/89	11/27/07	97.33
	Trichlorofluoromethane	+	1	0.5	0.5	<0.5	5/8/01	5/8/01	
		<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Trichloropropane, 1,2,3-	<	1652	<0.5	<0.5	<0.5	11/6/89	11/27/07	100.00
	Trihalomethanes (unspecified mix)	+	21	0.6	3.2	26.0	4/27/04	5/7/07	
		<	501	<0.5	<0.5	<0.5	4/14/04	11/27/07	95.98
	Trimethylbenzene, 1,2,4-	+	4	0.5	2.9	9.4	4/30/97	4/23/03	
		<	1649	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.76
	Trimethylbenzene, 1,3,5-	+	2	0.5	1.1	1.6	5/5/98	4/23/03	
		<	1651	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.88
	Vinyl chloride	+	7	0.5	2.0	3.6	5/5/98	3/29/06	
		<	1645	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.58
	Xylene, o-	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1651	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94
	Xylenes, m- & p- Mix	+	1	0.5	0.5	<0.5	5/5/98	5/5/98	
		<	1650	<0.5	<0.5	<0.5	11/6/89	11/27/07	99.94