
An Overview of Ground Water Quality in Ohio

M1. Introduction

Section M summarizes water quality assessment data for Ohio’s major aquifers based on information requested in the 2006 Integrated Reports Guidance and the 1997 Guidelines for Preparation of the Comprehensive State Water Quality Assessments.

Ground water protection programs for Ohio are briefly summarized in Section M2 as required by section 106(e) of the Clean Water Act. Programs to monitor, evaluate and protect ground water resources are implemented by various state, federal and local agencies. Ohio EPA is the designated agency for monitoring and evaluating ground water quality and assessing ground water contamination problems. 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. Short program descriptions are provided with links to program-based web pages to provide the most current information.

Ohio’s three major aquifer types are described briefly in Section M3. More detailed descriptions of the major aquifers and water quality of the aquifers are provided in Appendix A. Where possible, the water quality data are associated with major aquifer types. The aquifer descriptions allow the reader to associate water quality with geologic settings.

Sections M4 and M5 summarize sites with verified ground water contamination and identify the major nonpoint sources of ground water contamination in Ohio. These data were obtained from various sources including:

- Potential contaminant sources inventoried as part of Ohio EPA – DDAGW’s Source Water Assessment and Protection (SWAP) program;
- Ground Water Impacts Database (maintained by Ohio EPA – DDAGW);
- Underground injection control sites identified in Ohio EPA – DDAGW and Ohio Department of Natural Resources (ODNR) – Division of Oil and Gas Resource Management databases;
- Leaking and formerly leaking underground storage tanks from Ohio Department of Commerce – Division of Fire Marshal’s Bureau of Underground Storage Tank Regulations (BUSTR) databases; and
- Federal databases listing Department of Development/Department of Energy (DOD/DOE) facilities and National Priorities List/Comprehensive Environmental Response, Compensation and Liability Act (NPL/CERCLA) sites.

In many instances, these data are not associated with the geologic setting of the impacted aquifer, so statewide summaries are provided.

Section M6 summarizes ground water quality impairments by parameter within Ohio’s major aquifers. Two primary data sets are used in this analysis: the drinking water compliance data for public water systems; and the Ambient Ground Water Quality Monitoring Program (AGWQMP) data. The public water system compliance data represents treated (post-processing) water distributed to the public. AGWQMP is an Ohio EPA - DDAGW program created to monitor “raw” (untreated) ground water. The goal is to collect, maintain and analyze raw ground water quality data to measure long-term changes in the water quality of major

aquifer systems. Since Ohio does not have statewide ground water quality standards, comparisons to primary maximum contaminant levels (MCL) or secondary maximum contaminant levels (SMCL) for drinking water were used.

Section M7 briefly discusses ground water-surface water interaction (GW-SW) and a few special studies that provide insight on the interaction, which lead to suggestions for future ground water monitoring efforts. Section M8 presents conclusions and recommendations for future direction concerning statewide ground water monitoring and protection of Ohio’s major aquifers.

M2. Ohio’s Ground Water Programs

State Coordinating Committee on Ground Water - The State Coordinating Committee on Ground Water (SCCGW) was created in 1992 by the directors of the state agencies that have ground water program responsibilities. The purpose is to promote and guide the implementation of coordinated, comprehensive and effective ground water protection and management programs for Ohio. The SCCGW is composed of ground water technical or management staff from seven state agencies, two federal agencies and The Ohio State University Extension office. Information about the SCCGW bi-monthly meetings and meeting summaries are available on the SCCGW Web site: <http://epa.ohio.gov/ddagw/SCCGW.aspx>

Ohio Ground Water Protection Programs - Programs to monitor, evaluate and protect ground water resources in Ohio are administered by federal, state and local agencies. Ohio EPA is the designated state ground water quality management agency. The ODNR - Division of Water Resources is responsible for evaluation of the quantity of ground water resources. Ground water-related activities at the state level are also conducted by the Ohio Departments of Agriculture, Commerce (Division of State Fire Marshal), Health and Transportation. The United States Geological Survey (USGS), Ohio Water Science Center, contributes to these efforts with water resource research. Table M-1 (based on Table 5-2, U.S. EPA 305(b) Guidelines, 1997) summarizes agencies responsible for administering the various ground water programs in Ohio.

Table M-1. Summary of Ohio’s ground water protection programs.

Programs or Activities	State Activity	Implementation Status*	Responsible Agency
Active SARA Title III Program	✓	E	Ohio EPA – DERR or DMWM
Ambient ground water monitoring system	✓	E	Ohio EPA – DDAGW
Aquifer vulnerability assessment	✓	CE	ODNR – DWR Ohio EPA – DDAGW
Aquifer mapping	✓	CE	ODNR – DWR Ohio EPA – DDAGW
Aquifer characterization	✓	CE	ODNR – DWR
Comprehensive data management system	✓	UR ^a	OWRC
Consolidated Cleanup Standards	NA		
Ground water Best Management Practices	✓	E	ODNR; ODA
Ground water legislation	✓	UR ^b	All Agencies

Programs or Activities	State Activity	Implementation Status*	Responsible Agency
Ground water classification	✓	E ^c	Ohio EPA; ODNR
Ground water quality standards (program specific)	✓	E ^d	Ohio EPA
Interagency coordination for ground water protection initiatives	✓	E	OWRC; SCCGW
Nonpoint source controls	✓	CE	ODA; Ohio EPA; ODNR
Pesticide State Management Plan	✓	E ^e	ODA
Pollution Prevention Program	✓	E	Ohio EPA – DEFA (OCAPP)
Resource Conservation and Recovery Act (RCRA) Primacy	✓	E	Ohio EPA – DERR
Source Water Assessment Program	✓	E	Ohio EPA – DDAGW
State Property Clean-up Programs	✓	E	Ohio EPA – DERR
Susceptibility assessment for drinking water/wellhead protection	✓	E	Ohio EPA – DDAGW
State septic system regulations	✓	E ^f	ODH; Ohio EPA
Underground storage tank installation requirements	✓	E	SFM/BUSTR
Underground Storage Tank Remediation Fund	✓	E ^g	SFM/BUSTR
Underground Storage Tank Permit Program	✓	E	SFM/BUSTR
Underground Injection Control Program	✓	E ^h	Ohio EPA – DDAGW ODNR – DMR
Well abandonment regulations	✓	E ⁱ	ODNR; Ohio EPA – DDAGW; ODH
Wellhead Protection Program (EPA-approved)	✓	E ^j	Ohio EPA – DDAGW
Well installation regulations	✓	E ^k	Ohio EPA; ODH

* **Table Notes:** E – Established; CE – Continuing Effort; UD – Under Development; UR – Under Revision

^a Data management occurring on an agency/division level; Improvements in search engines make development of multi-agency databases a low priority.

^b Rules are required to be reviewed every 5 years by state statute.

^c Established through program-specific classifications.

^d Standards are program-specific.

^e ODA received cooperative commitment from other Ohio agencies for the Generic Pesticide Management Plan. The requirement for Specific Pesticide Management Plan was dropped.

^f The updated Household Sewage Treatment Systems Rules became effective on January 1, 2015 (Ohio Revised Code (ORC) Chapter 3718 and Ohio Administrative Code Chapter 3701-29). Larger systems are regulated by Ohio EPA under separate regulations.

^g Remediation funds are available from the Petroleum Underground Storage Tank Release Compensation Fund

^h Ohio EPA regulates Class I and V injection wells; ODNR regulates Class II and III injection wells.

ⁱ Revised guidance for sealing wells was completed March 2015 by SCCGW workgroup: Regulations and Technical

Guidance for Sealing Unused Water Wells and Boreholes^j Wellhead Protection Program has evolved to the Source Water Protection Program.

^k Technical Guidance for Well Construction and Ground Water Protection prepared by SCCGW (2000). Private Water System rules (OAC 3701-28) were last updated in 2011. Revised Water Well Standards (OAC 3745-7) for public water systems are out for comment.

Program Web Sites:

ODA - Ohio Department of Agriculture

Pesticide and Fertilizer Regulation Program <http://www.agri.ohio.gov/apps/odaprs/pestfert-prs-index.aspx>

Livestock Environmental Permitting Program <http://www.agri.ohio.gov/divs/dlep/dlep.aspx>

ODH - Ohio Department of Health

Private Water Systems

<http://www.odh.ohio.gov/odhprograms/eh/water/PrivateWaterSystems/main.aspx>

Sewage Treatment Systems Program

<http://www.odh.ohio.gov/odhPrograms/eh/sewage/sewage1.aspx>

ODNR - Ohio Department of Natural Resources

<http://www2.ohiodnr.gov/>

Division of Water Resources (DWR)

<http://water.ohiodnr.gov/>

Division of Mineral Resources (DMR)

<http://minerals.ohiodnr.gov/>

Division of Oil and Gas Resources

<http://oilandgas.ohiodnr.gov/>

Division of Geologic Survey

<http://geosurvey.ohiodnr.gov/>

Ohio EPA - Ohio Environmental Protection Agency

<http://www.epa.ohio.gov>

Division of Drinking and Ground Waters (DDAGW)

<http://www.epa.ohio.gov/ddagw/>

Division of Surface Water (DSW)

<http://www.epa.ohio.gov/dsw/>

Division of Environmental and Financial Assistance (DEFA)

<http://epa.ohio.gov/defa/>

Division of Environmental Response and Revitalization (DERR)

<http://www.epa.state.oh.us/derr/>

Division of Materials and Waste Management (DMWM)

<http://www.epa.ohio.gov/dmwm/>

OWRC – Ohio Water Resource Council

<http://www.epa.ohio.gov/dsw/owrc.aspx>

SCCGW – State Coordinating Committee on Ground Water

<http://epa.ohio.gov/ddagw/SCCGW.aspx>

SFM/BUSTR – State Fire Marshall/ Bureau of Underground Storage Tank Regulations

<http://www.com.ohio.gov/fire/>

M3. Ohio’s Major Aquifers

Introduction

Ohio has abundant surface and ground water resources. Average rainfall ranges between 30 and 44 inches/year (increasing from northwest to southeast), which drives healthy stream flows. Infiltration of a small portion of this rainfall (3-16 inches) recharges the aquifers and keeps the streams flowing between rains. Ohio’s aquifers can be divided into three major types as illustrated in Figure M-1. The sand and gravel buried valley aquifers (in blue) are distributed through the state. The valleys filled by these sands and gravels are cut into sandstone and shale in the eastern half of the state (in tans) and into carbonate aquifers (in greens) in the western half. The buried valley aquifers are productive aquifers. The sandstone and carbonate aquifers generally provide sufficient production for water wells except where dominated by shale, as in southwest and southeast Ohio. An Ohio EPA report, *Major Aquifers in Ohio and Associated Water Quality* (2015), provides more detailed descriptions of these aquifers. This report is included here as Appendix A.

Characterizing Aquifers

In a continuing effort to characterize ground water quality for the professional/technical community and the general public, DDAGW is writing technical reports and fact sheets on the distribution of specific parameters in Ohio. The goal of these reports is to provide water quality information from the major aquifers, exhibit areas with elevated concentrations and identify geologic and geochemical controls. This information is useful for assessing local ground water quality, water resource planning and evaluating areas where specific water treatment may be necessary. A series of parallel fact sheets targeted for the general public provide basic information on the distribution of the selected parameters in ground water. The information in the fact sheets is presented in a less technical format, addresses health effects, outlines treatment options and provides links to additional information.

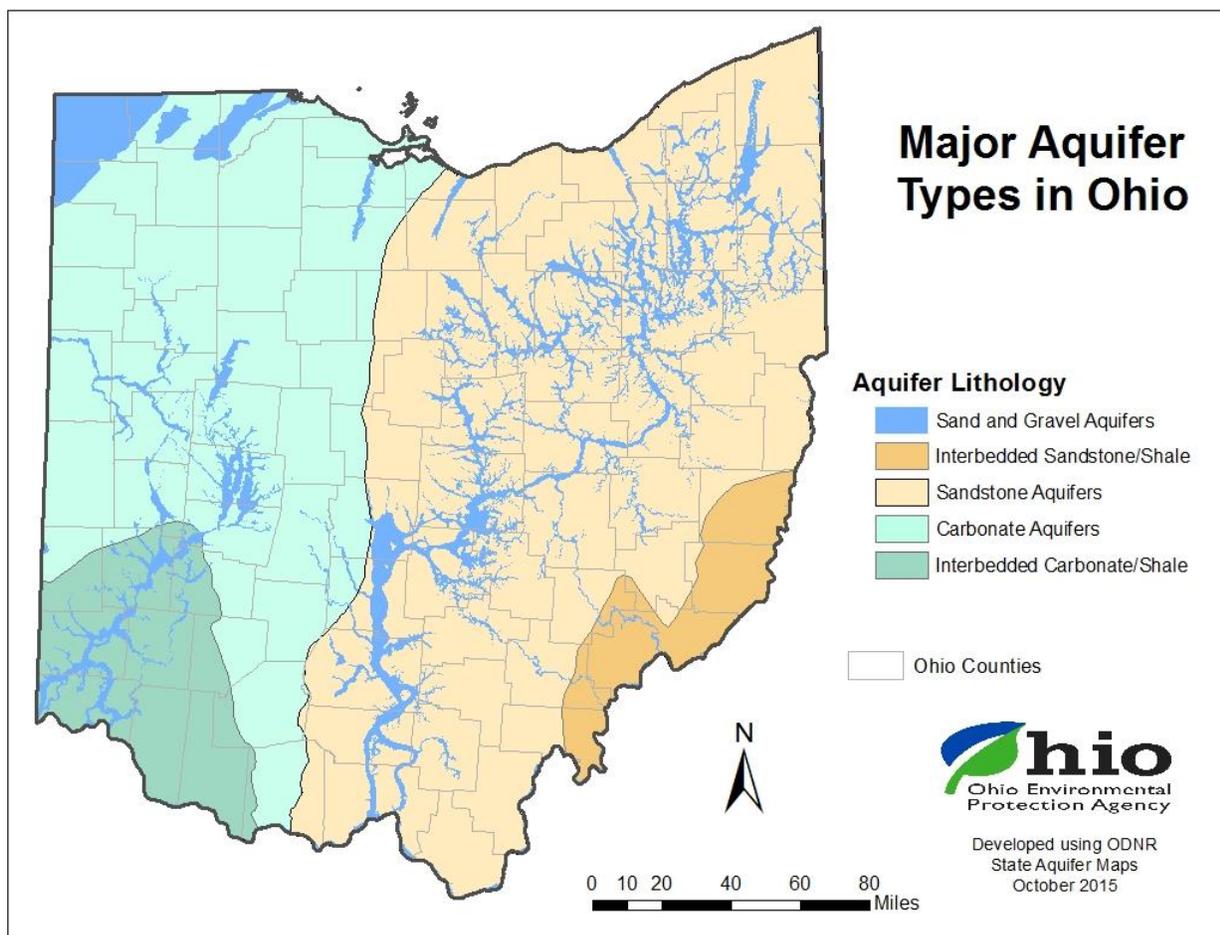


Figure M-1. Aquifer types in Ohio modified from ODNR glacial and bedrock aquifer maps
(ODNR, 2000; <http://water.ohiodnr.gov/maps/statewide-aquifer-maps>)

Since the Ohio 2014 Integrated Report, technical reports and fact sheets on reduction-oxidation (redox) control of water quality and distribution of strontium have been completed. The **Major Aquifers in Ohio and Associated Water Quality** report, included as Appendix A, was also completed and then updated in October 2015. The redox report is not structured around a constituent or group of constituents like the other technical reports. However, **Reduction-Oxidation (Redox) Control in Ohio's Ground Water Quality** was completed to help ground water users understand the influence redox processes have on water quality. The redox condition of water is a conceptual framework for understanding the behavior of some common water quality parameters. For example, the iron staining of plumbing fixtures, ground water with a rotten egg smell and the presence of arsenic all relate to the redox state of the water. All bodies of water, from aquifers to streams to glasses of water, have redox states that are mediated by microbes and electron transfer reactions. The technical report focuses on a general understanding of redox as it relates to ground water quality, using Ohio raw water data to illustrate these relationships. Figure M-2 illustrates the depth related redox pair reactions (on right) with their redox zones (on left). Generally, ground waters are more reduced with increased depth below the water table. The report also includes several examples that show how redox concepts can be applied to understand the behavior and persistence of some common ground water contaminants, both natural and anthropogenic.

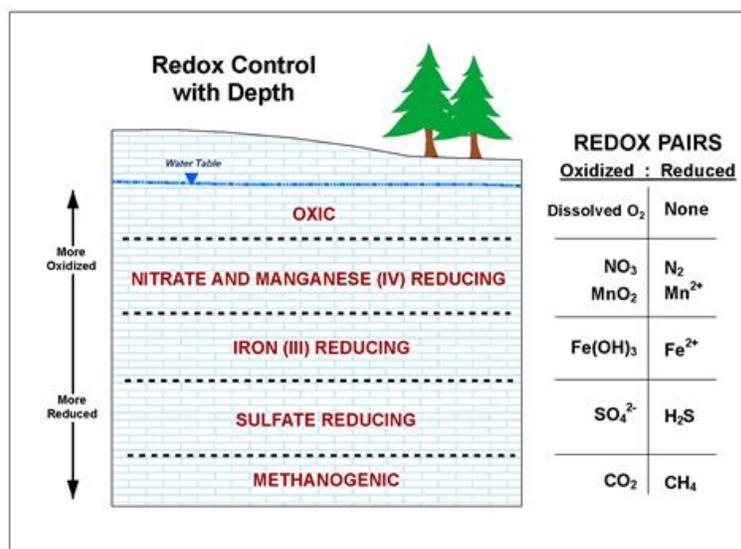


Figure M-2. Sequence of redox sensitive parameter changes with depth.

Strontium Distribution and Source

Based on the initial occurrence data on strontium collected for the Unregulated Contaminant Monitoring Rule 3 (UCMR3), the U.S. EPA made a preliminary determination in October 2014 to develop a drinking water standard for strontium. The U.S. EPA is continuing to evaluate information about strontium prior to making a final determination, but a final decision is not expected in 2016. Strontium concentrations in raw water in portions of Ohio carbonate aquifers are above health advisory levels. A draft technical report, *Strontium in Ohio's Ground Water* was generated to identify the areas in Ohio with elevated strontium and to identify the geologic and geochemical controls for the distribution.

In Ohio, the Silurian and Devonian carbonate aquifers in the western half of the state exhibit regional areas with strontium well averages up to 40,000 µg/L in raw water based on AGWQMP data. The sandstone aquifers exhibit the lowest strontium concentrations and the sand and gravel aquifers are intermediate. Strontium exceeds the life-time health advisory level (4,000 µg/L) in raw water in over 85 percent of the carbonate wells and 15 percent of the sand and gravel wells in the AGWQMP. The current distribution of the carbonate aquifers is controlled by the Findlay Arch and glacial erosion. The highest levels of strontium in ground water (>25,000 µg/L) occur within a north-south belt along and to the east of the crest of the Findlay Arch as illustrated in Figure M-3.

Strontium replaced calcium and/or magnesium during the depositional processes of marine carbonates and evaporite minerals. The Late Paleozoic secondary mineralization remobilized and/or added additional strontium and concentrated celestine along fractures and other open structures in carbonate aquifers. Natural dissolution of limestone, dolomite and gypsum are certainly contributing strontium to the groundwater, but the highest concentrations of strontium are not associated with the highest concentrations of calcium, magnesium and sulfate. Thus, it appears celestine also contributes strontium to ground water. Two factors likely to control the dissolution of celestine (SrSO₄) are the presence of gypsum and redox conditions. Gypsum is more soluble than celestine, so dissolution of gypsum should reduce the dissolution of celestine by raising the sulfate concentration. However, when reducing conditions cause the reductive dissociation of sulfate, the lowered sulfate concentrations increase the dissolution of sulfate

minerals, including celestine. The highest strontium concentrations are associated with stratigraphic units with little gypsum, indicating celestine is a significant contributor to the higher strontium concentrations.

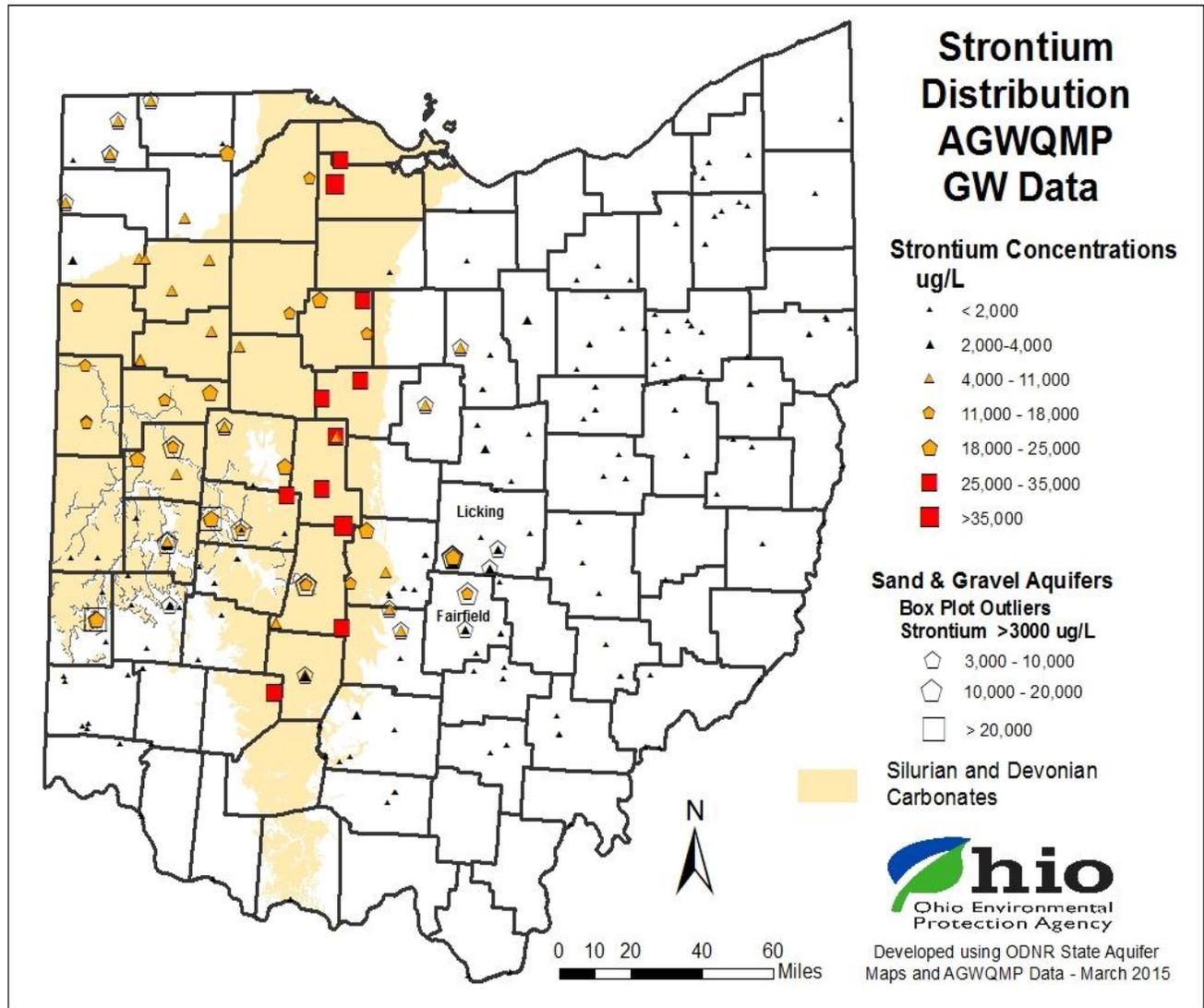


Figure M-3. Strontium distribution in Ohio.

M4. Site-Specific Ground Water Contamination Summary

Table M-2 (based on Table 5-3, U.S. EPA 305(b) Guidelines, 1997) provides a summary of the sites that have verified ground water contamination in Ohio. These data come from various state programs and the quality of these data is variable. Because the specific hydrogeologic settings for many of these sites is not included in the databases or is unknown, only a statewide summary is provided. Additional information is provided below for each program or subset of sites listed in Table M-2.

Table M-2. Ground Water Contamination Summary.

Hydrogeologic Setting: Statewide

Data Reporting Period: As of November, 2015

Source Type	Number of sites	Number of sites that are listed and/or have confirmed releases	Number of sites with confirmed ground water contamination	Contaminants
NPL - U.S. EPA	37 6 proposed	37	25	Mostly VOCs and heavy metals; also, SVOCs, PCBs, PAHs and others
CERCLIS (non-NPL) - U.S. EPA	419	419	20	Varied
DOD/DOE	128 ^a	71	68	Varied
LUST	35,147 ^b	1,904	165 ^c	BTEX
RCRA Corrective Action	160	160	160	VOCs, heavy metals, PCBs and others
Underground Injection	Class ^d : I – 10 II – 411 III – 48 IV – 5 V – 49,727	0 0 0 0 14,238	0 0 0 0 NA	
State Sites ^e	772	772	254 ^f	Varied GW Impacts
Nonpoint Sources	NA	NA	NA	

Notes: NA - Numbers not available

^a Includes DOE, DOD, FUSRAP and FUD sites

^b Includes only active LUST sites - Source: Ohio's State Fire Marshal, Bureau of Underground Storage Tank Regulations

^c Sites in Tier 2 or Tier 3 cleanup stages. Source: Ohio's State Fire Marshal, Bureau of Underground Storage Tank Regulations

^d Class I and V injection wells are regulated by Ohio EPA. Class II and Class III injection wells regulated by the Ohio Department of Natural Resources, Division of Oil and Gas Resources. Class IV injection wells are illegal in Ohio, except where approved as part of remediation plan.

^e Facilities in Ohio EPA's Ground Water Impacts database

^f A site is considered to be contaminating ground water if the "Uppermost Aquifer" or "Lower Aquifer" is noted to be impacted, as documented in Ohio EPA's Ground Water Impacts database.

Federal National Priorities List (NPL): Currently, 37 sites in Ohio are on the NPL, most of which (25) have been found to be affecting ground water quality. The primary contaminants are volatile organic chemicals (VOCs) and heavy metals.

CERCLIS (non-NPL): Ohio has 419 sites in the federal CERCLIS database.

DOD/DOE: The 128 sites on this list are the Department of Defense (DOD)/Department of Energy (DOE) sites in Ohio, including those that are Formerly Used Defense Sites (FUDS) and Formerly Utilized Sites Remedial Action Program (FUSRAP) sites. Of these, 68 have had confirmed releases to ground water.

Leaking Underground Storage Tanks (LUST): In Ohio, underground storage tanks (USTs) are under the jurisdiction of the State Fire Marshal, Bureau of Underground Storage Tank Regulation (BUSTR). Current data indicates that more than 35,000 sites have been found to be leaking. Of these, 1,904 have confirmed releases, with 165 having a release to ground water. The primary contaminants are the petroleum products of benzene, toluene, ethyl benzene and xylenes (BTEX).

RCRA Corrective Action: Currently, 160 facilities are in RCRA corrective action. All of these have confirmed releases to ground water. The primary contaminants are VOCs and heavy metals. This information was obtained from the RCRA Facility Database, an internal DDAGW tracking system.

Underground Injection: There are five classes of underground injection wells:

- 1) Class I wells inject hazardous wastes or other wastewaters beneath the lowermost aquifer;
- 2) Class II wells inject brines and other fluids associated with oil and gas production beneath the lowermost aquifer;
- 3) Class III wells inject fluids associated with solution mining of minerals beneath the lowermost aquifer;
- 4) Class IV wells inject hazardous or radioactive wastes into or above aquifers (these wells are banned unless authorized under a federal or state ground water remediation project);
- 5) Class V wells comprise all of the injection wells not included in Classes I-IV.

The Ohio Department of Natural Resources, Division of Oil and Gas Resources regulates Class II (411) and Class III (48) wells. The number of Class II brine injection wells (one of three types of class II wells) is increasing because of their use in disposal of fluids used in oil and gas drilling and shale gas development. In addition to the 210 active brine injection wells there are 17 wells that are drilled or being drilled and 18 that are permitted.

Ohio EPA DDAGW regulates Class I (10), Class IV (5) and Class V (+49,727) wells. Although owners and operators of Class V wells are required to register or permit their wells, there are still many that are unknown and unregistered throughout the state.

State Sites: State sites include landfills, RCRA-regulated hazardous waste facilities, unregulated sites (pre-RCRA) and sites investigated through the Voluntary Action Program (VAP). Ground water contamination summary information concerning many of these sites is tracked in the Ground Water Impacts Database, maintained by Ohio EPA - DDAGW. The database consists of sites with verified contaminant release to ground water. As of November 2015, the database contained 772 sites. Of the 772 sites, 254 have affected ground water quality within the uppermost aquifer or lower aquifer.

M5. Major Sources of Ground Water Contamination

Data show much of Ohio's ground water is of high quality and has not been widely influenced by anthropogenic activities, but individual cases of contamination are documented every year from point (site-specific locations) and nonpoint sources. Ohio has a diverse economy and the state uses and produces a range of potential contaminants applied, stored and disposed of in various land use practices. Consequently, ground water quality is susceptible to contamination from a range of substances and a variety of land use activities. Selecting major sources of contamination is subjective because the selection is scale-dependent. For an individual with contaminated water, the major source is the source that contaminates their well, regardless of the major sources identified for the state. From a statewide perspective, major sources are discussed below.

The ten major sources of ground water contamination in Ohio are indicated in Table M-3 (Table 5-1, U.S. EPA 305(b) Guidelines, 1997) by checks (✓). These data were obtained from two main sources: Ohio's Source Water Assessment and Protection (SWAP) Program and DDAGW's Ground Water Impacts Database. The SWAP Program has completed an inventory of the potential sources of ground water contamination in the delineated Drinking Water Source Protection Areas. This inventory is updated when the SWAP delineation is revised, for example, when new wells are approved. Ninety-nine percent of active public water systems that use ground water have had an inventory conducted, an analysis of the aquifer's susceptibility to contamination completed and a determination of whether the ground water quality has been impacted by anthropogenic activities. The Ground Water Impacts Database provides information regarding sites where contamination of ground water has been confirmed. These data were evaluated and those sources of highest concern were given a check mark (✓) in Table M-3.

Some of the "potentially high priority" sources, indicated by crosses (✖), were selected based on professional knowledge of the types of sources that exist in Ohio. These sources, such as animal feedlots and mining, are limited in their extent, or are concentrated in regions of the state and may not be sited close to public water system well fields. Thus, they do not rank in the highest priority sources. However, where they are prevalent, these sources may be a threat to local ground water resources, especially in areas with sensitive hydrogeologic settings. Land use activities within sensitive areas have a greater potential of affecting ground water quality

Table M-3. Major sources of potential ground water contamination.

Contaminant Source	Highest-Priority Sources	Factors Considered in Selecting a Contaminant Source	Contaminants
<i>Agriculture Activities</i>			
Agricultural chemical facilities			
Animal feedlots	✖	4, 5, 6, 8	E, J, K, L
Drainage wells			
Fertilizer applications (manure application)	✓	1, 2, 3, 4, 5, 8	E, J, K, L
Irrigation practices			
Pesticide applications			
On-farm agricultural mixing and loading			
Land application of manure			
<i>Storage and Treatment Activities</i>			
Land application			
Material stockpiles			
Storage tanks (above/below ground)	✓	1, 2, 3, 4, 5, 6, 7	C, D, H, M
Surface impoundments	✖	6	G, H, M
Waste piles			
Waste tailings			
<i>Disposal Activities</i>			
Deep injection wells			
Landfills	✓	1, 2, 3, 4, 5, 6	A, B, C, D, H, M
Septic systems	✓	1, 2, 3, 4, 5, 6	E, H, J, K, L
Shallow injection wells	✓	1, 2, 3, 4, 5, 6, 8	C, D, G, H, M
<i>Other</i>			
Hazardous waste generators			
Hazardous waste sites	✓	1, 2, 3, 4, 5, 6, 7	A, B, C, D, H, I, M
Large industrial facilities			
Material transfer operations			
Mining and mine drainage	✖	6, 8	G, H
Pipelines and sewer lines	✓		D, E, J, K, L
Salt storage and road salting	✓	6	G
Spills	✖	6	C, D, H, M
Transportation of materials			
Urban runoff (storm water management, storm drains)	✓	2, 4	A, B, C, D, G, H, J
Small-scale manufacturing and repair shops	✓	4, 6	C, D, H, M

Notes: (✓) Highest Priority
 (✖) Potentially High Priority

Factor and Contaminant codes on next page.

FACTORS	CONTAMINANTS
1. Human health and/or environmental risk (toxicity)	A. Inorganic pesticides
2. Size of the population at risk	B. Organic pesticides
3. Location of the sources relative to drinking water sources	C. Halogenated solvents
4. Number and/or size of contaminant sources	D. Petroleum compounds
5. Hydrogeologic sensitivity	E. Nitrate
6. State findings, other findings	F. Fluoride
7. Documented from mandatory reporting	G. Salt/Salinity/brine
8. Geographic distribution/occurrence	H. Metals
	I. Radionuclides
	J. Bacteria
	K. Protozoa
	L. Viruses
	M. Other (VOCs)

Contaminant Source Discussion - All of the sources listed in Table M-3 are potential contaminant sources in Ohio and each may cause ground water quality impacts at a local scale. The sources identified as “highest priority” or “potentially high priority” are listed below in the order presented in Table M-3 and discussed briefly to provide additional information.

(✓) Highest Priority Sources

- **Fertilizer Applications:** Use and handling of fertilizers, manure and biosolids can cause ground water pollution. Human and animal biosolids used as fertilizer and chemical fertilizers contribute to nitrate contamination in ground water. Nitrate concentrations in ground water represent one of the better examples of the widespread distribution of nonpoint source pollution. Non-agricultural sources, such as lawn fertilization, sludge application and septic systems also contribute to localized nitrate ground water contamination. Public water systems utilizing sand and gravel aquifers have higher average nitrate levels than public water systems using sandstone and carbonate aquifers, primarily due to the higher vulnerability of unconsolidated aquifers and the shallower nature of the sand and gravel aquifers.
- **Storage Tanks (Underground and Above-ground):** There are 1,904 USTs known to be leaking or undergoing remediation in Ohio. Of these, 332 have been located in drinking water source protection areas for public water systems using ground water. Above-ground tanks are also prevalent throughout Ohio, with 1,284 located in a drinking water source protection area for public water systems using ground water. Many of these are smaller tanks used to store fuel oil for heating individual homes and many are old and rusty with no containment in the event of a leak or spill. Leaking above-ground storage tanks (ASTs) from commercial and industrial facilities are less of an issue, although catastrophic failure can create significant pollution problems to both ground water and surface water. There are only 21 ASTs in the Ground Water Impacts database known to be contaminating ground water from regulated hazardous waste facilities.
- **Landfills:** Currently, there are 128 landfills with documented ground water contamination in Ohio. This constitutes 50 percent of the sites known to be affecting ground water quality based on information in Ohio EPA’s Ground Water Impacts database. Most likely, these are from older, unlined landfills (many of which are closed) or construction and demolition debris landfills (C&DD) with limited

construction standards. The current siting, design and construction standards for landfills are more stringent than twenty years ago, with the result that new landfills have significantly lower potential to impact ground water quality. Efforts to monitor C&DD landfills and characterize associated ground water quality impacts were reduced in 2015.

- **Septic Systems:** Over 1,000,000 household wastewater systems, primarily septic tanks and leach fields, or in some cases injection wells, are present throughout the rural and unsewered suburban areas of Ohio. A number of these systems are improperly located, poorly constructed, or inadequately maintained and may cause bacterial and chemical contamination of ground water which may supply water to nearby wells. Improperly operated and maintained septic systems are considered significant contributors to elevated nitrate levels in ground water in vulnerable geologic settings (e.g., shallow fractured bedrock and sand and gravel deposits). Over 2,000 septic systems are located in drinking water source protection areas. The updated Household Sewage Treatment Systems Rules became effective on January 1, 2015 (Ohio Revised Code Chapter 3718 and Ohio Administrative Code 3701-29) and should help correct deficiencies of failing septic systems.
- **Shallow Injection Wells:** Class V injection wells are widespread throughout the state. High concentrations of Class V injection wells are most likely found in areas with sensitive sand and gravel aquifers. It is estimated that Ohio has over 50,000 class V injection wells. The fact that these wells are used to inject fluids directly into vulnerable aquifers in the State is the main cause for concern. These shallow injection wells provide a direct pathway for nonpoint source contamination and illegal waste disposal into vulnerable aquifers. Ohio has closed 591 motor vehicle waste disposal wells (e.g., oil, radiator fluids, etc.) since 2000.
- **Hazardous Waste Sites:** Ohio generates a large amount of hazardous waste. Legacy hazardous waste sites are a serious threat to ground water. There are 63 RCRA hazardous waste facilities, 15 Voluntary Action Program sites and 61 unregulated hazardous waste remediation sites (pre 1980) with documented releases to ground water (uppermost or lower aquifer) based on the Ground Water Impacts Database.
- **Pipelines and Sewer Lines:** Pipelines and sewer lines all have potential for failure with release of the transported material. In addition, the construction of these lines, with the pipe embedded in permeable material, allows the trench to provide rapid flow paths for other surface contaminants. This is especially true if the trench is dug into fractured bedrock. Numerous gas, oil and industrial pipelines (1,215) and sewer lines (831) have been inventoried in drinking water source water protection areas.
- **Salt Storage and Road Salting:** The widespread use of salt or mixtures of salt and sand for deicing roads has been documented as a nonpoint source contributor of sodium and chloride contamination of shallow ground water (Jones and Sroka 1997; Mullaney et al. 2009). Spreading of salt on roads certainly contributes to ground water quality impacts, but the greatest local impact is associated with salt storage. In 2012-2014, Ohio EPA documented impacts to ground water at numerous salt storage facilities, including salt storage piles in drinking water source protection areas. Eighty-one (81) salt storage piles were identified in or near drinking water source protection areas with 62 of these located in sensitive aquifer settings. Most of these sites had adequate covering and pads. Ten sites were selected for additional investigation, two of which exhibited elevated chloride concentrations in ground water due to leaching of brine from the salt pile. In addition to addressing these sites, Ohio is exploring ways to encourage implementation of BMPs for proper salt storage.

Alternative chemicals like acetate-based deicers in combination with reduced salt usage are being promoted in pollution prevention programs. The workgroup, consisting of members from the Ohio Water Resources Council and the State Coordinating Committee on Ground Water, developed guidance for salt storage in 2013:

Recommendations for Salt Storage: Guidance for Protecting Ohio's Water Resources, located on the web at: <http://epa.ohio.gov/portals/35/owrc/SaltStorageGuidance.pdf>

- **Suburban Runoff (including storm drains and storm water management):** With expanding suburban areas, nonpoint source contamination from suburban/urban runoff is an increasing source of ground water contamination, in contrast with most of the other sources discussed. In addition, the practice of constructing storm water retention basins increases the likelihood that storm water runoff infiltrates into ground water. More than 1,200 storm drains have been located in drinking water source protection areas, with many of these going directly to nearby water bodies. Elevated chloride is documented in urban areas within glacial aquifers by Mullaney et al. (2009) and positive trends in chloride concentrations in Ambient Ground Water Quality Monitoring data are present at some sites.
- **Small-Scale Manufacturing and Repair Shops:** Small-scale manufacturing and repair shops include 1693 facilities in drinking water source protection areas. These include: auto and boat repair shops and dealers, gas stations, junk yards, equipment rental and repair, machine shops, metal finishing and welding shops and other various small businesses. These businesses typically handle chlorinated solvents (for cleaning) and petroleum products. Limited knowledge of best management practices for handling and disposing of these products increases the risk of impacting ground water.

(*) Potentially High Priority Sources

- **Concentrated Animal Feeding Operations (CAFO):** The growth of CAFOs in numbers and size makes them a significant potential source if the waste is not properly managed. The ground water threats associated with CAFOs are captured in other categories as well, such as manure, sludge and fertilizer application and surface impoundments, so they are not considered one of the ten highest priority sources. Improper storage or management of the animal waste is the greatest threat to ground water contamination in sensitive hydrogeologic settings, but land application in solid or liquid form also poses risks for ground and surface water contamination.
- **Surface Impoundments:** Surface impoundments are one of the most common waste disposal concerns at RCRA facilities. Historically, they have been a major source for ground water contamination. Older impoundments were not subject to the same engineering standards as newer impoundments and, consequently, the probability of fluids leaching to the ground water was greater. Current siting and engineering requirements have improved this situation. Fifty-four (54) surface impoundments are known to be contaminating ground water based on information obtained from Ohio EPA's Ground Water Impacts database, the vast majority being from regulated and unregulated hazardous waste facilities.
- **Mining and Mine Drainage:** The bedrock (Pennsylvanian Units) that underlies eastern Ohio includes significant coal resources. The disruption of the stratigraphic units and oxidation of sulfides associated with coal mining produces ground water contamination by acid mine waters. Acid mine waters are considered a significant threat to ground water in mined areas.

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- **Spills and Leaks:** Leaks and spills of hazardous substances from underground tanks, surface impoundments, bulk storage facilities, transmission lines and accidents are major ground water pollution threats. More than a thousand leaks and spills are reported each year. This release of chemicals on to the surface and into near surface environments is certainly one of the greatest threats to ground water quality. The development of shale gas and associated hydrofracturing activity in eastern Ohio has raised concerns about potential for aquifer impacts. Historically, the surface management of brines has been the greatest cause of ground water contamination associated with oil production and hydro fracking activities (State Oil and Gas Agency Groundwater Investigations; and Their Role in Advancing Regulatory Reforms, GWPC, August 2011). Revised regulations address the management and disposal of oil and gas production brines with the preferred mode of disposal as injection into Class II injection wells.

The major sources of ground water contamination listed include point and nonpoint sources in roughly equal proportions. In strict terms, a point source is a discharge from a discernable, confined and discrete conveyance, but in practical terms, the distribution or spatial scale of a contaminant controls the designation of a source as point or nonpoint. For example, salt applied for de-icing along roads exhibits nonpoint source behavior, while salt stockpiles behave more like point sources, with the potential for continual release of concentrated brine that may affect ground water quality. This dichotomy is typical of many agricultural contaminants, manure spreading versus storage, fertilizer application versus storage or mixing sites. In Ohio, we generally have better documentation of ground water contamination associated with point source contamination than nonpoint source contamination due to the extensive ground water monitoring programs at regulated facilities.

Rapid runoff in glacial till areas overlying much of Ohio and drainage tiling have protected many of Ohio's aquifers from traditional nonpoint source pollution sources such as nitrate, chloride, pesticides or bacteria. In sensitive settings (e.g., sand and gravel aquifers, shallow bedrock aquifers), indicators of nonpoint source pollution are more clearly identified in Ohio's Ambient Ground Water Quality Monitoring Program and the public water system compliance monitoring data. However, these monitoring programs do not focus on shallow aquifers, which have a higher likelihood of being influenced by nonpoint source pollution such as agricultural practices.

M6. Summary of Ground Water Quality by Aquifer

Tables M-4A and M-4B (Table 5-4, U.S. EPA 305(b) Guidelines, 1997) summarize water quality compliance data from Ohio public water systems and raw water data from the AGWQMP, respectively. The compliance data for public water systems in Ohio (Table M-4A) documents water quality for treated water (post processing) and some raw (untreated) water quality (like new well samples). Parameters generally unaffected by standard treatment, such as nitrate, may be used to characterize Ohio's ground water quality because post treatment values are similar to ground water values. DDAGW created the AGWQMP program (Table M-4B) to monitor "raw" (untreated) ground water. This program's goal is the collection, maintenance and analysis of raw ground water quality data to measure long-term changes in the water quality of the Ohio's major aquifer systems.

Ohio does not have statewide ground water quality standards, so data for the major aquifers are compared to primary maximum contaminant level (MCL) or secondary maximum contaminant level (SCML). Primary MCLs are the highest level of a contaminant that is allowed in public drinking water and are set as close to MCL Goals (a health-based standard) as feasible using the best available treatment technology and economic

considerations. Primary MCLs are enforceable standards. Secondary MCLs are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.

Primary and secondary MCLs are used as practical benchmarks for water quality characterization in Tables M-4A and M-4B. Fifty percent of the MCL to 100 percent of the MCL is used as the range for the “**watch list**” determination. The public water systems or wells identified in this category may warrant additional monitoring to identify increasing trends. MCL exceedances are used as the criteria for the “**impaired**” category. Tables M-4A and M-4B were generated using the last 10 years of data (1/1/2005-12/31/2014). Mean concentrations of a parameter are used for deciding if a public water system or well is included in the watch list (50 percent to 100 percent MCL) or impaired category (> MCL). Maximum concentrations of nitrate and nitrite are reported in these tables instead of averages, due to the acute nature of their health concerns.

Public Water System Compliance Data

Mean values were calculated from public water system compliance data for 2005-2014 to determine the number of public water systems on the watch list and in the impaired category. A ten-year period of record was used to increase the statistical significance of the determination due to the infrequent sampling requirements (e.g., once per three-year period). **public water systems included in the impaired category may not match Safe Drinking Water Act regulatory determinations of a violation due to the method of calculation.** An MCL exceedance for compliance is generally an annual average, so the **decadal average presented in Table M-4A is not a compliance number**, but rather a comparison to MCL values, as a benchmark to identify public water systems in the watch list and impaired categories.

Table M-4A lists all parameters with MCLs (and SMCLs) and summarizes the number of public water systems in the watch list and impaired category for both raw and treated water quality data. The results for each parameter are further divided into major aquifer type categories. The total number of public water systems with data used in these determinations is presented to allow comparison of the total number of public water systems to those that exhibit elevated concentrations of MCL parameters. Data from active and inactive systems is included in Table M-4A. For parameters with SMCLs, treated water data is limited or absent because compliance data is generally not required for aesthetic water quality issues.

Table M-4A. Counts of public water systems where 2005-2014 decadal mean values of compliance data occur in the Watch List and Impaired Category.

Note: presented by major aquifer types.

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Antimony	MCL	6 µg/L	Sand and Gravel	268	2		703	6	
				Sandstone	285	5	1	707	7	1
				Carbonate	246	4		449	5	1
	Arsenic	MCL	10 µg/L	Sand & Gravel	344	59	66	706	87	44
				Sandstone	309	20	20	714	48	11
				Carbonate	301	53	50	449	65	36
	Asbestos	MCL	7x10 ⁶ fibers/L	Sand and Gravel	35			169		
				Sandstone	10			50		
				Carbonate	11			62		
	Barium	MCL	2 mg/L	Sand and Gravel	278	4		704	5	
				Sandstone	294	6	1	709	2	
				Carbonate	245	1	1	448	1	
	Beryllium	MCL	4 µg/L	Sand and Gravel	268	2		703		1
				Sandstone	286			708		
				Carbonate	244			448		
	Cadmium	MCL	5 µg/L	Sand and Gravel	274		1	703	1	
				Sandstone	286		1	708	2	
				Carbonate	244			448		
	Chloride	SMCL	250 mg/L	Sand and Gravel	248	5	1			
				Sandstone	285	15	10			
				Carbonate	236	3	2			
	Chromium	MCL	0.1 mg/L	Sand and Gravel	271			703		
				Sandstone	284	1	1	716	1	
				Carbonate	246			448		
	Cyanide	MCL	0.2 mg/L	Sand and Gravel	259			703	1	
				Sandstone	284			708		
				Carbonate	242			448		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Fluoride	MCL	4 mg/L	Sand and Gravel	286	1		703	6	
				Sandstone	291	1		708	1	
				Carbonate	254	21		448	20	
	Iron	SMCL	0.3 mg/L	Sand and Gravel	278	14	163			
				Sandstone	286	37	144	1		
				Carbonate	267	22	141	1		1
	Manganese	SMCL	0.05 mg/L	Sand and Gravel	251	40	107			
				Sandstone	286	32	146	1		
				Carbonate	238	42	45	1		1
	Mercury	MCL	2 µg/L	Sand and Gravel	266		1	703		
				Sandstone	286			708		1
				Carbonate	244			448		
	Nitrate * (Max Value)	MCL	10 mg/L	Sand and Gravel	329	16	10	1608	57	17
				Sandstone	322	6	4	2053	31	5
				Carbonate	274	6	8	1413	37	2
	Nitrite * (Max Value)	MCL	1 mg/L	Sand and Gravel	306			1616	1	
				Sandstone	305			2061	3	2
				Carbonate	256			1421	1	3
	Selenium	MCL	50 µg/L	Sand and Gravel	269			703		
				Sandstone	287			708		
				Carbonate	245	2		448		
	Silver	SMCL	0.1 mg/L	Sand and Gravel	238		1			
				Sandstone	273			1		
				Carbonate	229		1			
	Solids, Total Dissolved	SMCL	500 mg/L	Sand and Gravel	116	50	30			
				Sandstone	159	71	32			
				Carbonate	137	23	79			

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Sulfate	SMCL	250 mg/L	Sand and Gravel	273	17	15			
				Sandstone	292	12	17			
				Carbonate	255	30	83			
	Thallium	MCL	2 µg/L	Sand and Gravel	267	2	1	703	3	
				Sandstone	285		1	708	2	1
				Carbonate	244	1		448		1
	Zinc	SMCL	5.0 mg/L	Sand and Gravel	145					
				Sandstone	142			1		
				Carbonate	124					
Volatile Organic Chemicals	1,2-Dichloroethane	MCL	5 µg/L	Sand and Gravel	308	1		706		
				Sandstone	319			716		1
				Carbonate	263			453		1
	1,1-Dichloroethylene	MCL	7 µg/L	Sand and Gravel	309			707		
				Sandstone	319		1	716		1
				Carbonate	263			453		
	1,2-Dichloropropane	MCL	5 µg/L	Sand and Gravel	310		1	707		1
				Sandstone	320			716		
				Carbonate	263			453	1	
	1,1,1-Trichloroethane	MCL	200 µg/L	Sand and Gravel	310			707		
				Sandstone	320			716		
				Carbonate	263			453		
	1,1,2-Trichloroethane	MCL	5 µg/L	Sand and Gravel	310			707		
				Sandstone	320			716		
				Carbonate	263			453		
	1,2,4-Trichlorobenzene	MCL	70 µg/L	Sand and Gravel	310			707		
				Sandstone	319			716		
				Carbonate	263			453		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Volatile Organic Chemicals	Benzene	MCL	5 µg/L	Sand and Gravel	309		2	707		
				Sandstone	320			716		
				Carbonate	261			453		
	Carbon Tetrachloride	MCL	5 µg/L	Sand and Gravel	310			707		
				Sandstone	320	1	1	716		
				Carbonate	263		1	453		
	Chlorobenzene?	MCL	100 µg/L	Sand and Gravel	310			707		
				Sandstone	319			716		
				Carbonate	263			453		
	Cis-1,2-Dichloroethylene	MCL	70 µg/L	Sand and Gravel	310			707		
				Sandstone	319			716		
				Carbonate	263			453		
	Dichloromethane	MCL	5 µg/L	Sand and Gravel	309	2	1	707	2	1
				Sandstone	314	1	1	716		1
				Carbonate	262		1	453	1	1
	Ethyl benzene	MCL	700 µg/L	Sand and Gravel	310			707		
				Sandstone	320			716		
				Carbonate	263			453		
	o-Dichlorobenzene	MCL	600 µg/L	Sand and Gravel	310			707		
				Sandstone	319			716		
				Carbonate	263			453		
	p-Dichlorobenzene	MCL	75 µg/L	Sand and Gravel	310			707		
				Sandstone	318			716		
				Carbonate	263			453		
	Pentachlorophenol	MCL	1 µg/L	Sand and Gravel	5			96		
				Sandstone				43		
				Carbonate	1			19		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Volatile Organic Chemicals	Styrene	MCL	100 µg/L	Sand and Gravel	310			707		
				Sandstone	320			716		
				Carbonate	263	1		453		
	Tetra-chloroethylene	MCL	5 µg/L	Sand and Gravel	310	3	3	707	3	
				Sandstone	320	1	2	716	1	1
				Carbonate	263			453	1	
	Toluene	MCL	1000 µg/L	Sand and Gravel	310			707		
				Sandstone	319			716		
				Carbonate	263			453		
	Trans-1,2-Dichloroethylene	MCL	100 µg/L	Sand and Gravel	310			707		
				Sandstone	320			716		
				Carbonate	263			453		
	Trichloroethylene	MCL	5 µg/L	Sand and Gravel	310	3		707		
				Sandstone	320		1	716	1	
				Carbonate	262	1	1	453	1	
	Vinyl Chloride	MCL	2 µg/L	Sand and Gravel	310	3	2	706		2
				Sandstone	319			716		
				Carbonate	263			453		
Xylenes, Total	MCL	10 mg/L	Sand and Gravel	309			707			
			Sandstone	316			716			
			Carbonate	262			453			
Pesticides and Synthetic Organic Chemicals	Alachor (Lasso)	MCL	2 µg/L	Sand and Gravel	259			708		
				Sandstone	280			717		
				Carbonate	232			453		
	Atrazine	MCL	3 µg/L	Sand and Gravel	258			708		
				Sandstone	281			717		
				Carbonate	232			453		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Pesticides and Synthetic Organic Chemicals	Benzo(a)pyrene	MCL	0.2 µg/L	Sand and Gravel	3			95	1	
				Sandstone				47		
				Carbonate	2			20		
	Carbofuran	MCL	40 µg/L	Sand and Gravel	3			96		
				Sandstone				43		
				Carbonate	1			19		
	Di(2-ethylhexyl) adipate	MCL	400 µg/L	Sand and Gravel	4			95		
				Sandstone				47		
				Carbonate	4			20		
	Di(2-ethylhexyl) phthalate	MCL	6 µg/L	Sand and Gravel	4			98		2
				Sandstone				48		
				Carbonate	4	1		22		2
	Dinoseb	MCL	7 µg/L	Sand and Gravel	5					
				Sandstone						
				Carbonate	1					
	Diquat	MCL	20 µg/L	Sand and Gravel	3			99		
				Sandstone				44		
				Carbonate	1			18		
	Endothall	MCL	100 µg/L	Sand and Gravel	3			95		
				Sandstone				47		
				Carbonate	1			20		
	Ethylene Dibromide	MCL	0.05 µg/L	Sand and Gravel	6					
				Sandstone						
				Carbonate						
	Glyphosate	MCL	700 µg/L	Sand and Gravel	3			96		
				Sandstone				44		
				Carbonate	1			18		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Public Water Systems					
					Raw Water			Treated Water		
					Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL	Total # public water systems	Watch List > 50% to 100% MCL	Impaired > MCL
Pesticides and Synthetic Organic Chemicals	Methoxychlor	MCL	40 µg/L	Sand and Gravel	4			96		
				Sandstone	1			44		
				Carbonate	1			18		
	Simazine	MCL	4 µg/L	Sand and Gravel	258			708		
				Sandstone	281			717		
				Carbonate	232			453		
	Total Polychlorinated Biphenyls (PCBs)	MCL	0.5 µg/L	Sand and Gravel	3			96		
				Sandstone	1			44		
				Carbonate				18		
Organic Disinfection By-Products	Total Haloacetic Acids (HAA5)	MCL	60 µg/L	Sand and Gravel	80	3	1	528	4	2
				Sandstone	51		1	404	8	3
				Carbonate	55	1	1	276	3	2
	Total Trihalomethanes (TTHM)	MCL	80 µg/L	Sand and Gravel	119	6	4	527	38	6
				Sandstone	61	2	1	403	14	2
				Carbonate	61	5	3	276	22	2
Radiological	Gross Alpha (incl. + excl.)	MCL	15 pCi/L	Sand and Gravel	271	1		419	1	
				Sandstone	293	5		261	2	1
				Carbonate	246	15	3	187	2	
	Gross Beta	MCL	4 mrem/yr**	Sand and Gravel	152	2	34			
				Sandstone	169	2	48			
				Carbonate	137	2	45			
	Radium 226	MCL	5 pCi/L***	Sand and Gravel	22			1		
				Sandstone	27	2	1	3		
				Carbonate	43	6	2	1		
	Radium 228	MCL	5 pCi/L***	Sand and Gravel	142			421	1	
				Sandstone	155	3	2	265	4	1
				Carbonate	140	2		187	1	

Blank spaces indicate no PWSs exceed the standards (zeros left out to highlight impacted public water systems); "nda" indicates no data available

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- * Numbers for nitrate and nitrite are based on maximum values to reflect the acute nature of the contaminant.
 - ** If Gross Beta result is less than 50 pCi/L no conversion to mrem/yr is necessary - table used 50 pCi/L as standard.
 - *** MCL is for combined Radium 226 and Radium 228

With the exception of a new well analysis, there are no requirements for collecting and reporting raw water data, so the number of public water systems with raw water data is less than the number with treated water data. The public water system data were linked to geologic settings using the DDAGW Source Water Assessment data, which allowed the breakout of the data by major aquifer. In this analysis, any detection in raw water data was used to generate public water system averages. For treated water data, public water system averages were generated only if there were at least two detections of a parameter. The inorganic parameters that place numerous public water systems in the watch list and impaired category warrant additional analysis.

The number of public water systems in the watch list and the impaired categories of Table M-4A are generally low; however, several parameters do exhibit higher numbers of public water systems in these groups. Fortunately, most of these occurrences are for secondary MCLs, not primary MCLs. That is, the water quality impacts documented are mostly aesthetic issues and are not health-based. Groups of parameters are discussed individually.

Inorganic Parameters MCL Parameters

Only a few public water systems fall into the watch list or the impaired MCL category based on inorganic parameters. For treated water data, parameters with MCLs and no public water systems in the impaired category (values > MCL) include, **asbestos, barium, cadmium, chromium, cyanide, fluoride and selenium**. The use of detection limits at or greater than 50 percent of the MCL and using the reporting limit for the non-detect value can result in public water systems placed in the watch list with no detection of the parameter. The data has been reviewed to assure that public water system in the watch list have detected the parameter. Factors limiting the number of public water systems in these categories include limited solubility of the substance in water, low crustal abundance, local geology and possibly treatment. For example, in treated water, no public water systems that exceed the fluoride MCL, but 27 public water systems that draw water from carbonate aquifers, exceed 50 percent of the MCL. This association is controlled by secondary fluorite mineralization along fractures and voids in limestone in northwest Ohio.

Several parameters including **antimony, beryllium, mercury and thallium** have low numbers of public water systems in the MCL impaired category for treated water. This small number is consistent with the low solubility and scarcity of these metals in Ohio's geology. The use of decadal averages for building both watch list and impaired categories may overestimate the numbers of public water systems when compared with actual MCL or SMCL calculations which use annual averages.

The number of public water systems with **arsenic** in raw water and treated water above the MCL (136 and 91, respectively) is consistent with the number of public water systems that DDAGW worked with to reduce arsenic to meet the 2006 revised MCL of 10 µg/L. These systems are associated with reduced ground water and local areas of naturally occurring arsenic. Sand and gravel and carbonate aquifers are more likely than the sandstone aquifers to exhibit arsenic-impaired ground water. The number of public water systems currently exceeding the arsenic MCL is significantly less than what is listed in Table M4-A because numerous public water systems have installed treatment to remove arsenic since 2006. The elevated arsenic results collected from 2005 to 2006 and beyond (while treatment processes were installed and refined) are included in the ten years of data used to generate the public water system decadal averages. These elevated values increase the decadal mean calculated for Table M4-A and thus, result in impaired systems on a decadal mean, but these systems are currently serving water below the Arsenic MCL. Figure M-4 illustrates the distribution of the public water systems with arsenic in treated and/or raw water greater than the MCL as listed in Table M-4A.

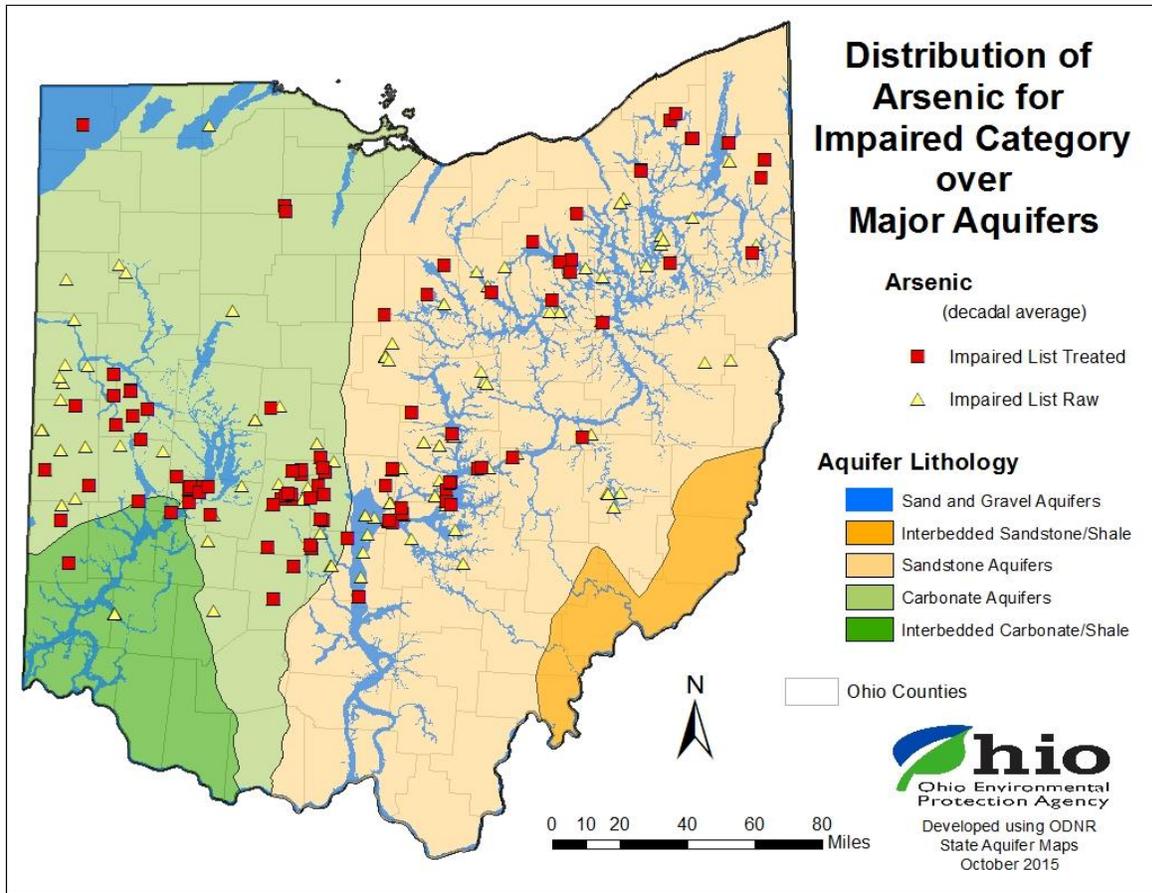


Figure M-4. Distribution of public water systems on impaired list for arsenic for both treated and raw waters.

SMCL Parameters

Secondary MCL parameters for drinking water are directed at non-health related issues such as taste and odor. public water systems do not collect compliance data for most parameters with SMCLs. Table M-4A utilized only compliance data and, consequently, it includes little data for treated water for parameters with SMCLs. The raw water data collected through new well samples, however, provides information on the distribution of these parameters.

Multiple public water systems display elevated **chloride**. The largest numbers of public water systems with elevated chloride are associated with the sandstone aquifers followed by sand and gravel aquifers and carbonate aquifers. This may be related to limited natural oil and gas deposits occurring within aquifers, contamination of local aquifers from surface handling of oil and gas production brines, local salt storage facilities overlying sensitive aquifers, road salt application, or septic systems. Transportation routes are concentrated in the broad, flat buried valleys and consequently, large salt piles are stored on these broad valleys, which are sensitive aquifers. Activities to address chloride contamination are discussed in the Major Sources of Ground Water Contamination section.

Iron and manganese, have similar oxidation-reduction solubility controls as arsenic and widespread distribution and thus exhibit elevated numbers of public water systems in the watch list and impaired category of Table M-4A for raw water. Table M-4A utilized only compliance data so little data for treated water is included for iron and manganese. The raw water concentration for Fe and Mn are controlled by the increased solubility of iron

and manganese in reduced waters. The deeper wells generally exhibit more reduced conditions (e.g., reduced interaction with the atmosphere) and, consequently, elevated iron and manganese. Iron is a common element and is present in all three major aquifers. For manganese, the carbonate aquifer is least likely to exhibit concentrations above the SMCL. Many public water systems remove iron and manganese, so the percentage of public water systems that exhibit impairments in treated water is significantly lower than in raw water.

Sulfate also has an SMCL and only raw water data exists for identifying water quality impacts. A significant number of public water systems exhibit elevated sulfate in the both the watch and impaired categories as illustrated in Figure M-5. Although these sites are distributed in all major aquifers, the carbonate aquifers in NW Ohio exhibit the highest percentage of public water systems on the watch list and in the impaired category (44 percent of carbonate vs. 10-12 percent for sandstone and sand and gravel) due to the presence of evaporates (Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in the Salina Formation in northwest Ohio.

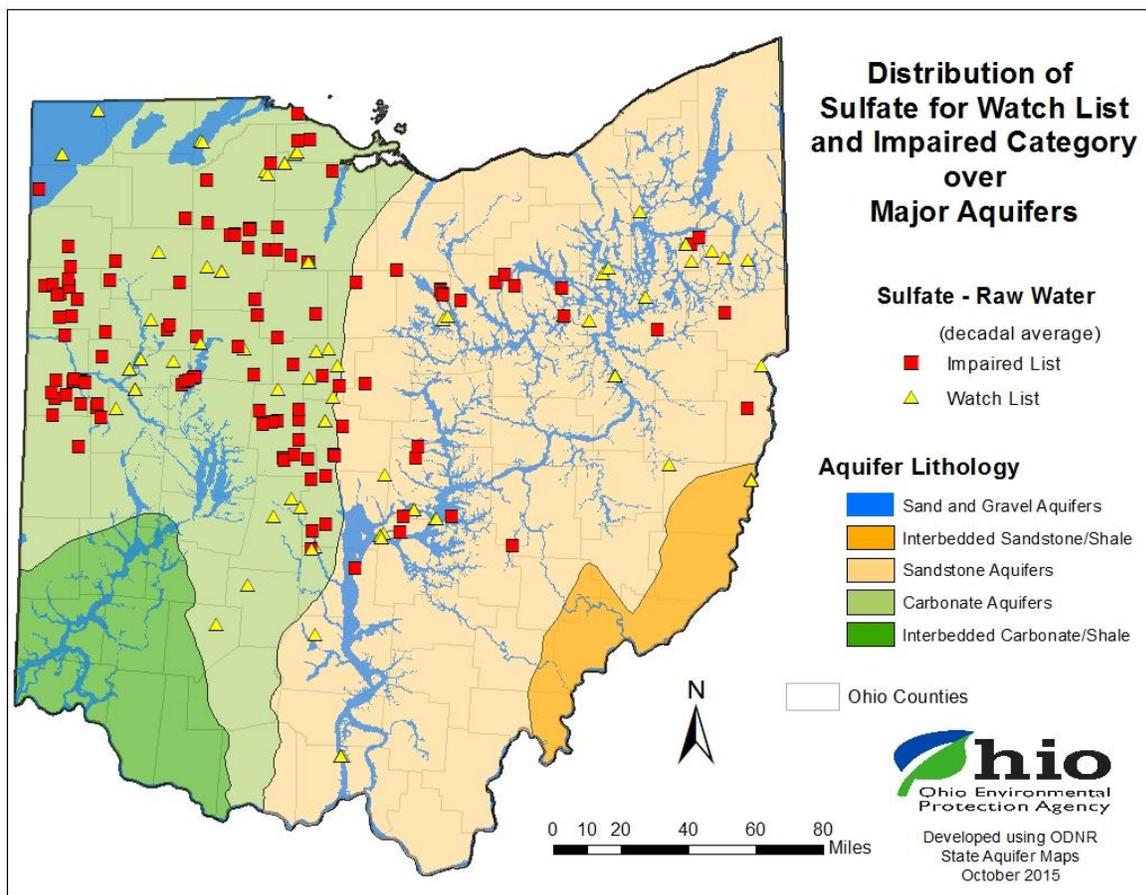


Figure M-5. Distribution of public water systems in impaired category and on the watch list for sulfate in raw water.

Fluoride has no public water systems in the impaired category for raw or treated water, however, a number of public water systems exhibit watch list concentrations in treated and raw water. Fluoride is unusual in that it has a primary and secondary MCL and the SMCL is 50 percent of the MCL. Thus, all of the systems on the watch list for the MCL exceed the SMCL. The distribution of the fluoride watch list systems for both raw and treated water are plotted in Figure M-6. The Fluoride Technical Report (2012) describes how fluorite, which was deposited as a secondary mineral in fractures in the carbonate aquifers, controls the distribution of elevated fluoride.

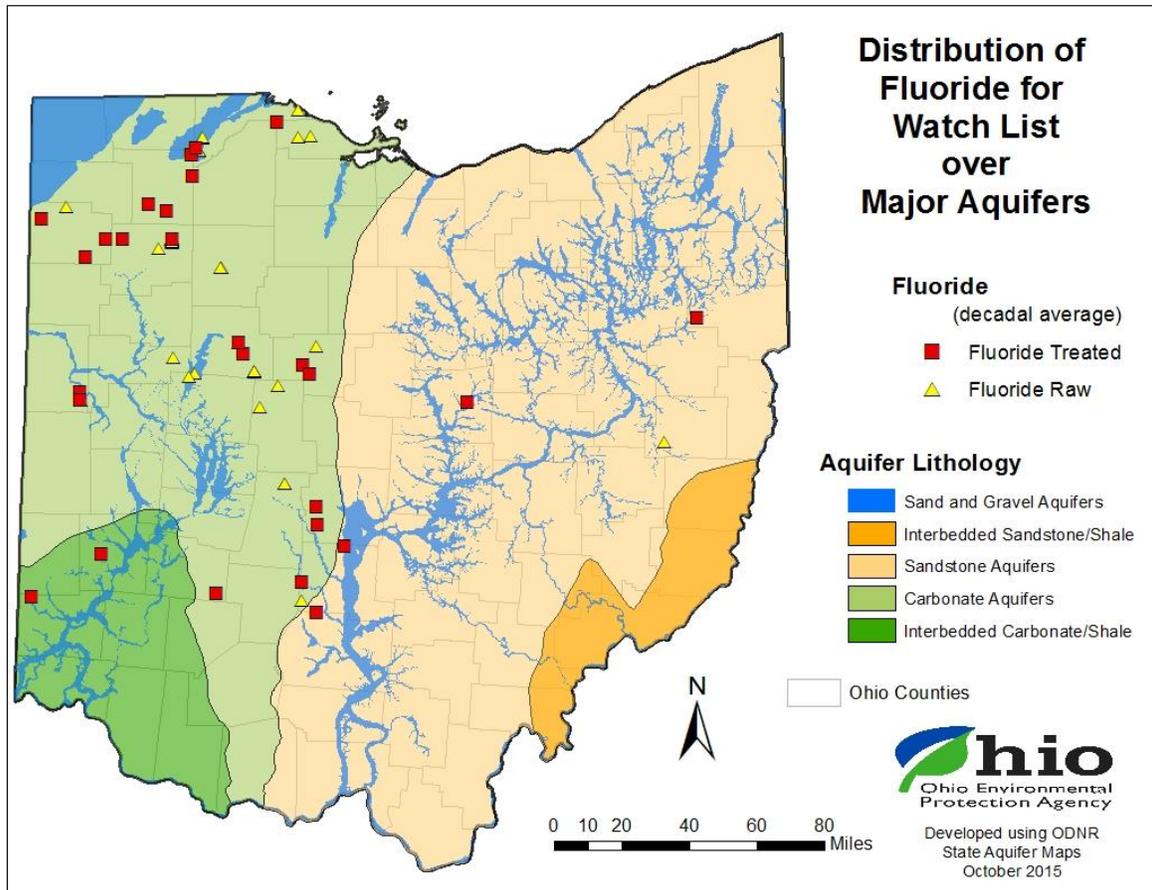


Figure M-6. Distribution of public water systems on fluoride MCL watch list for treated and raw water.

For **nitrate and nitrite**, maximum values were used rather than average values to reflect the acute nature of the nitrogen MCLs. As a parameter that is stable in oxidized environments, nitrate is more likely to be present in shallower wells. Approximately 2.9 percent (149 of 5074) of public water systems in Table M-4A (treated water) have maximum nitrate greater than 50 percent of the MCL. Approximately 50 percent of these public water systems are located in sand and gravel aquifer settings. A public water system that exceeds 50 percent of the nitrate MCL is required to sample for nitrate on a quarterly basis. Thus, over the last decade, at least 150 public water systems have been required to increase nitrate sampling to at least quarterly. For nitrate in treated water and raw water, 24 and 22 public water systems fall into the impaired category, respectively. public water systems with maximum results greater than the MCL do not necessarily indicate an MCL exceedance, which is an annual average.

public water systems with elevated nitrate tend to be associated with more sensitive aquifers such as buried valleys and areas of thin glacial drift over bedrock. Stable nitrate (where decadal averages are relatively high) tend to be found in systems that combine a shallow aquifer with rapid pathways between surface and ground water and stable oxic or sub-oxic ground water. The number of public water systems with maximum nitrates in treated water in the watch list or impaired categories has decreased since 2010 based on the 2010 (243 public water systems), 2012 (227 public water systems), 2014 (181 public water systems) and 2016 (149 public water systems) Integrated Reports. This is encouraging, but probably reflects improved treatment or use of alternative sources, rather than reduction in nitrate loading. Figure M-7 illustrates the distribution of the public water systems with maximum nitrate above the MCL for both raw and treated water. The public water systems in Figure M-7 tend to cluster along buried valley aquifers, but some occur in bedrock aquifers below thin till or overburden.

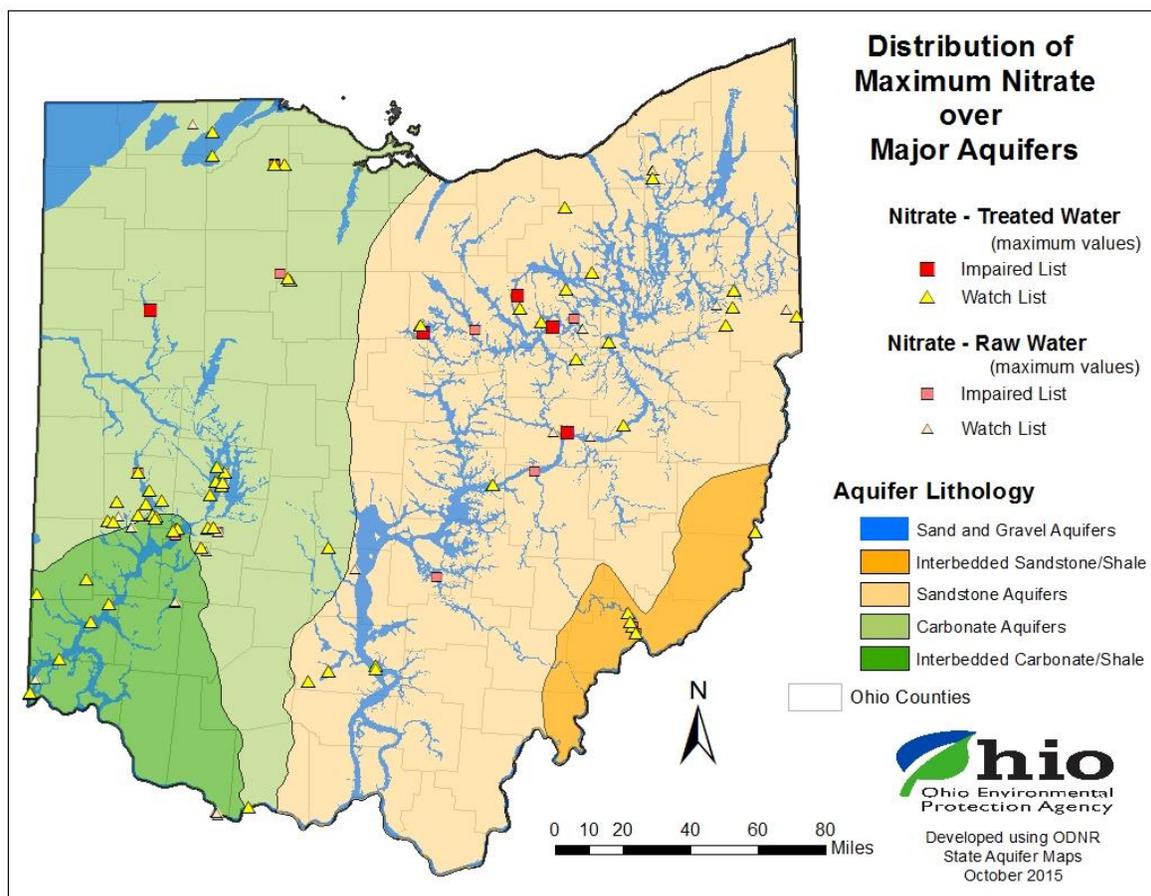


Figure M-7. Distribution of public water systems with maximum nitrate in treated and raw water greater than the MCL.

Organic Parameters

For the organic parameters, the mean concentration of treated water samples for six organic parameters has placed public water systems in the impaired category: **1,2-dichloroethane, 1,1-dichloroethylene, 1, 2-dichloropropane, dichloromethane, tetrachloroethylene and vinyl chloride**. Two of these parameters are common solvents and the third is a compound used to make plastic. Dichloromethane (methylene chloride) is a known lab contaminant, but it is also possible that it can leach to ground water before it volatilizes, so it is included in Table M-4A. In addition to the public water systems identified above, there are about 15 public water systems that are not using a production well or are using air strippers to remove VOC contamination

from ground water prior to use. The raw water data may include some of these systems, but if these ground water-based public water systems were not removing VOC contaminants, additional constituents would be identified as impaired.

Pesticides and Synthetic Organics

One pesticide and synthetic constituent is identified as impaired, **di(2-ethylhexyl)phthalate**. These data confirm that although we see impact from pesticides and other organic compounds migrating to major aquifers, the protection that the till cover and tile drainage provide to protect Ohio ground water is significant.

Radiological Parameters

For treated water, several public water systems are included on the watch list and the impaired category for **gross alpha** and **radium 228**. The limited number of public water systems in the watch list and impaired category is consistent with the Ohio's geologic setting having few natural sources of radionuclides. The exceptions are uranium associated with reduced geologic settings like glacial tills, the Ohio Shale and coal deposits, but these settings are generally not utilized as aquifers. Gross beta compliance monitoring focuses on anthropogenic sources of radiation. The distribution of radionuclides is discussed in the DDAGW technical report *Radionuclides in Ohio's Ground Water* (July 2015).

Ambient Ground Water Quality Monitoring Data

Mean values were calculated from the AGWQMP data (raw water) for each well over the past ten years (2005 through 2014) to determine the number of wells in the watch list and impaired categories for each constituent. These numbers are listed in Table M-4B by parameter and major aquifer. The number of wells used in the determinations is also presented to provide the relative number of wells that exhibit ground water quality with elevated concentrations of MCL parameters. A limited number of AGWMP wells are listed in the watch list and impaired category, as was the case for the public water system compliance data. The results for groups of parameters are discussed below.

Inorganic Parameters

The AGWQMP does not collect data for **antimony (except for one sandstone well), asbestos, beryllium, cyanide, mercury, nitrite, silver and thallium**, so no comparison can be made to the public water system data. These parameters are not analyzed due to their historically low concentrations in Ohio ground water. No well waters are impaired (have decadal averages that exceed the MCL or SMCL) for **barium, cadmium, chromium, fluoride, selenium and zinc**. Several wells exceed 50 percent of the fluoride MCL. These wells produce water from the carbonate aquifer, as was seen with public water systems in Table M-4A and Figure M-6. A few well means are greater than 50 percent of the **barium** MCL, but as stated above, no impairments were identified. Averages for **chloride** exceed the SMCL in a few cases. Ten wells have chloride above 50 percent of the SMCL and an additional three wells exceed the SMCL. The source of contamination is likely associated with improper storage of salt for road deicing, oil and gas drilling brine disposal, brines in bedrock aquifers with a history of oil production, or road deicing.

Table M-4B. Counts of wells where 2003-2013 decadal mean values of AGWQMP data occur in the Watch List and Impaired Category (maximum values used for nitrate).

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganic Parameters	Antimony	MCL	6 µg/L	Sand and Gravel	nda	nda	nda
				Sandstone	1		
				Carbonate	nda	nda	nda
	Arsenic	MCL	10 µg/L	Sand and Gravel	165	23	26
				Sandstone	40	3	
				Carbonate	57	8	6
	Barium	MCL	2 mg/L	Sand and Gravel	165	2	
				Sandstone	40	1	
				Carbonate	57		
	Cadmium	MCL	5 µg/L	Sand and Gravel	165		
				Sandstone	40		
				Carbonate	57		
	Chloride	SMCL	250 mg/L	Sand and Gravel	165	7	1
				Sandstone	40	2	1
				Carbonate	57	1	1
	Chromium	MCL	0.1 mg/L	Sand and Gravel	165		
				Sandstone	40		
				Carbonate	57		
	Fluoride	MCL	4 mg/L	Sand and Gravel	165		
				Sandstone	40		
				Carbonate	57	5	
	Iron	SMCL	0.3 mg/L	Sand and Gravel	165	11	116
				Sandstone	40	1	29
				Carbonate	57	7	44
	Manganese	SMCL	0.05 mg/L	Sand and Gravel	165	23	116
				Sandstone	40	3	28
				Carbonate	57	15	9
	Nitrate * (max values)	MCL	10 mg/L	Sand and Gravel	165	11	1
				Sandstone	40	1	
				Carbonate	57	2	
	Selenium	MCL	50 µg/L	Sand and Gravel	165		
				Sandstone	40		
				Carbonate	57		
	Solids, Total Dissolved	SMCL	500 mg/L	Sand and Gravel	165	109	55
				Sandstone	40	24	11
				Carbonate	57	4	53
	Sulfate	SMCL	250 mg/L	Sand and Gravel	165	16	2
				Sandstone	40	2	2
				Carbonate	57	10	23

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
	Zinc	SMCL	5.0 mg/L	Sand and Gravel	165		
				Sandstone	40		
				Carbonate	57		
Volatile Organic Chemicals	1,2-Dichloro-ethane	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	1,1-Dichloro-ethylene	MCL	7 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	1,2-Dichloro-propane	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Benzene	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Carbon Tetrachloride	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Cis-1,2-Di-chloroethylene	MCL	70 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Dichloro- methane	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57	1	
	Styrene	MCL	0.1 mg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Tetrachloro-ethylene	MCL	5 µg/L	Sand and Gravel	160		
				Sandstone	38		
				Carbonate	57		
	Trichloro-ethylene	MCL	5 µg/L	Sand and Gravel	160		
Sandstone				38			
Carbonate				57		1	
Vinyl Chloride	SMCL	2 µg/L	Sand and Gravel	160	4	1	
			Sandstone	38			
			Carbonate	57			
Pesticides	Alachor	MCL	2 µg/L	Sand and Gravel	16		
				Sandstone	2		
				Carbonate	2		
	Atrazine	MCL	3 µg/L	Sand and Gravel	16		
				Sandstone	2		
				Carbonate	2		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
	Simazine	MCL	4 µg/L	Sand and Gravel	16		
Sandstone				2			
Carbonate				2			

Blank spaces indicate no wells exceed the standards (zeros left out to emphasize impacted wells).

“nda” indicates no data available

* Numbers for nitrate and nitrite are based on maximum values to reflect the acute nature of contaminant.

** MCL is for combined Radium 226 and Radium 228

For **nitrate**, well maximums were used rather than averages to reflect the acute nature of the nitrate MCL. This approach makes it difficult to compare the nitrate numbers to numbers for other parameters in Table M-4B. Nitrate is stable in oxidized environments and, thus, is more likely to be detected in shallower wells that have rapid exchange pathways with the atmosphere and surface water. In the AGWQMP, the sand and gravel wells are generally the shallowest and consequently, would be expected to exhibit the largest number of wells with elevated nitrate concentrations. This is the case with about seven percent of the sand and gravel wells exceeding 50 percent of the MCL. Four percent of the carbonate wells exceed 50 percent of the MCL, probably associated with sensitive karst settings and only two and-one-half percent of the sandstone wells are on the watch list for (maximum) nitrate. The AGWQMP tends to collect samples from higher production wells located deeper in aquifers; consequently, it is not the best program to evaluate ground water quality in shallow (e.g., 25 to 50 feet), sensitive aquifer settings.

Arsenic, iron, manganese, total dissolved solids (TDS) and sulfate mean concentrations result in significant numbers of wells on the watch list and in the impaired category. These are the same parameters identified in the public water system compliance data, with the addition of TDS. TDS is not required or collected for public water systems compliance data. Except for arsenic, all of these parameters have SMCLs and treatment is generally not required. Many public water systems remove iron, with the additional benefit of manganese and arsenic removal, since arsenic and iron solubility are controlled by similar redox controls. Sulfate in the AGWQMP is elevated in carbonate aquifers due primarily to the presence of evaporates in the Salina Formation, in the upper portion of the Silurian carbonate aquifer. For the carbonate aquifers, 58 percent of the ambient sites exceed 50 percent of the SMCL for sulfate, which is significantly higher than the percentage of sandstone and sand and gravel aquifers (10 percent and 4.5 percent respectively). The elevated TDS in raw water results from the relative solubility of aquifer material and the residence time for ground water in all of Ohio’s major aquifers. The carbonate aquifers generally have higher mean TDS, but all three main aquifers exhibit high percentages of ambient sites with TDS exceeding 50 percent of the SMCL.

Organic Parameters - Detection of organic parameters at and above watch list concentrations is not common in the AGWQMP. Detected organic parameters above the MCL include dichloromethane, trichloroethylene and vinyl chloride. These organic solvents were detected in public water systems raw water samples as listed in Table M-4A.

Pesticides – No pesticides were detected in the AGWQMP wells above 50 percent of the MCL. The AGWQMP does not analyze for pesticides on a regular basis, as reflected in the low number of wells listed for pesticides, due to the lack of pesticide detections during several sampling rounds in the late 1990s. This sampling and consultations with the Ohio Department of Agriculture regarding its pesticide sampling results,

suggests that further pesticide data collection is not cost-effective for the AGWQMP. Review of available data supports the conclusion that the glacial till provides protection for Ohio's ground waters based on low detections rates and low concentrations detected. Nevertheless, local sensitivity and improper use of pesticides can lead to pesticide impacts. The historic data points to the greatest impacts occurring at the mixing sites or areas of spills.

Radiological Parameters – Radiological parameters are not included in the AGWQMP sampling.

Comparison of Public Water System and AGWQMP Data

Overall, we see similar trends in the public water system compliance and the AGWQMP data. This confirms that the AGWQMP data are appropriate for identifying long-term trends in the ground water quality of the major aquifers utilized by the public water systems. Thus, the AGWQMP goal of monitoring and characterizing the ground water quality utilized by public water systems in Ohio is validated by these empirical data.

It is interesting that the ground water quality differences documented between the major aquifers in AGWQMP data based on major components are not obvious in Tables M-4A and M-4B. The major elements or components (Ca, Mg, Cl, Na, K, sulfate and alkalinity) are generally the parameters utilized to identify water types. However, Ca, Mg, K and alkalinity do not have MCLs or SMCLs, so MCL and SMCL comparisons are limited in their capacity to delineate geochemical differences among waters from different aquifers. Chloride and sulfate do have SMCLs and exhibit significant differences between the major aquifers as noted above in Tables M-4A and M-4B. Treatment, such as softening, of public water system-distributed water can mask differences in water quality between major aquifers.

The most recognizable geochemical differences between the major aquifers in Ohio relate to the concentrations of calcium, magnesium, bicarbonate and strontium. These differences relate to the higher solubility of carbonate rocks and the long water-rock reaction time of ground water. The carbonate waters are characterized by elevated calcium, manganese, bicarbonate and strontium compared to water in sandstone and sand and gravel aquifers. The higher percentages of public water systems that exhibit watch list and impaired category results for TDS and sulfate in the carbonate aquifers reflects the dissolution of gypsum within the carbonate stratigraphy. Summary data from the AGWQMP provides a description of Ohio's major aquifers and their water quality and are presented in the technical report, *Major Aquifers in Ohio and Associated Water Quality (2015)*, which is included as Appendix A to this chapter.

M7. Ground Water-Surface Water Interaction

DDAGW special studies generally focus on water quality impacts in ground water associated with recharge in sensitive geologic settings. Thus, special studies provide information on the ground water- surface water (GW-SW) interaction related to surface water recharge and contaminants transported with recharge. Two technical reports completed in 2014-2015 and ongoing projects document elements of the GW-SW interaction. Brief summaries of these studies are provided below.

The technical report *Reduction-Oxidation (Redox) Control in Ohio's Ground Water Quality (2014)* describes the control redox conditions have on several common water quality parameters, such as nitrate, manganese, iron and sulfate. This document describes how microbes mediate electron transfer reactions and promotes understanding of redox as it relates to water quality. This document provides tools for anyone reviewing ground water quality data to identify the relative position of the aquifer in the redox range from oxic to methanogenic, if selected parameters are analyzed. The oxic portion occurs at the surface of the water table

and is controlled by oxygen exchange with the atmosphere and/or the migration of oxidized surface water recharge to the aquifer. The Hydrogeologic Sensitivity Assessment (HSA) procedure developed for the Ground Water Rule uses redox conditions as an indicator of the time of travel for surface recharge to reach the production aquifer. If *E. coli* is found in aquifers with reducing conditions, it is interpreted to indicate that rapid recharge pathways are present. Since *E. coli* is not well adapted to the vadose and aquifer environments, it is unlikely to survive long enough to make the trip from the surface unless hydrogeologic barriers are short circuited, allowing rapid migration of surface recharge to the production aquifer. Thus, the HSA utilizes indications of rapid recharge to evaluate sensitivity of local aquifers to pathogen migration.

The draft *Strontium in Ohio's Ground Water* technical report documented the elevated strontium associated with the carbonate aquifers as described in section M-3 and illustrated in Figure M-3. The Unregulated Contaminant Monitoring Rule 3 data show that multiple public water systems using surface water exhibit elevated strontium. This is attributed to the influence of baseflow during low flow conditions and documents the direct link between ground water and surface water. Figure M-8 illustrates the relationship between strontium and discharge in the Sandusky River at the Fremont gauging station. The influence of elevated strontium in ground water can cause problems for facilities requesting discharge permits. These examples document why we need to maintain the efforts to integrate ground water and surface water.

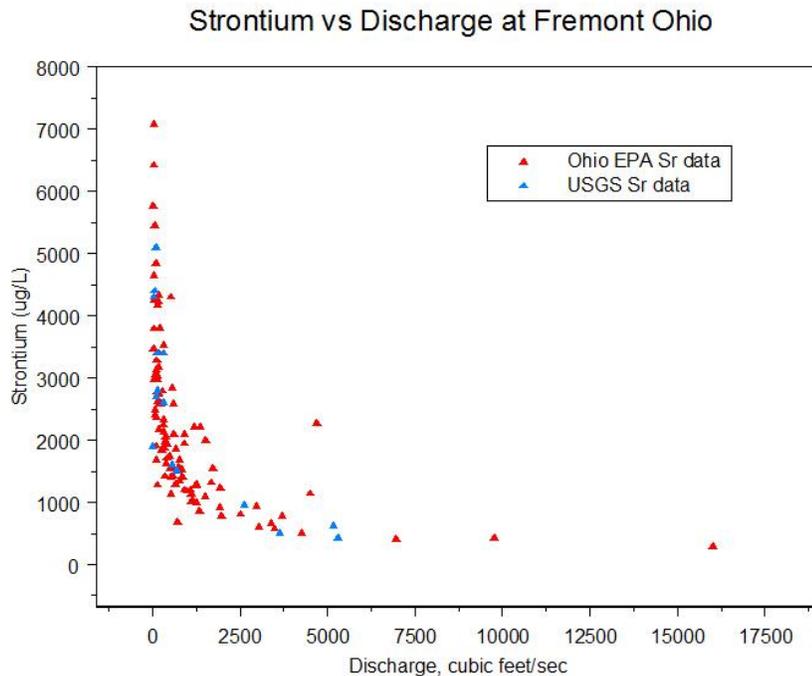


Figure M-8. Strontium in surface water in the Sandusky River at Fremont

The Division of Drinking and Ground Waters continues to sample three ODNR observation wells selected for ground water quality monitoring in conjunction with the water level data collected by ODNR. The purpose is to evaluate correlations between static water level and water quality at a high sampling density. Samples have been collected monthly since June 2012 and, starting in May 2014, the sampling was shifted to quarterly. Starting in July 2014, samples to characterize the microbial community structure, function and activity and to identify microbial signatures of metal release in ground water, were collected by Dr. M. Wilkins and graduate students at The Ohio State University. Preliminary results will be evaluated in 2016.

M8. Conclusions and Future Directions for Ground Water Protection

Ohio is fortunate that ground water is plentiful across the state. With the exceptions of a few areas that exhibit effects of over-pumping, decreasing static water levels have not been documented across extensive areas. Some new, high-yielding agricultural wells are being installed, but the duration of pumping is generally limited, so annual recharge appears to replenish the aquifer. Although the quantity of ground water appears stable, the documentation of water quality impacts in this document illustrate that continued protection of ground water resources is necessary. Ground water contamination can eliminate the potential use of water resources, just like diminished quantities. If other water sources are not available, additional treatment will increase the cost of providing a needed resource.

As documented in the previous sections, numerous sites exhibit ground water contamination from anthropogenic and natural point and nonpoint sources. The alternative to combat natural sources of contamination that cause impairment of drinking water is to develop and install treatment that removes the contamination or to locate another water source. The options for managing anthropogenic sources are more numerous, with the most constructive focusing on prevention of releases that migrate to ground water. Instituting best management practices (especially for the use of fertilizers and salt storage), implementing appropriate siting criteria for new waste storage and disposal sites and improving design for material storage and waste disposal facilities are proactive approaches to prevent releases to ground water. These kinds of proactive practices are critical to the sustainability of Ohio's high quality ground water resources.

The ongoing implementation of the Source Water Protection Program (SWAP) for Ohio's public water systems helps raise awareness of ground water quality issues and promotes source water protection planning. The SWAP potential contaminant source inventory data was instrumental in identifying and ranking major sources of contamination near public water systems, as listed in Table M-3 in the 2012, 2014 and 2016 Integrated Reports. SWAP staff has also had key roles in the development of several guidance documents to help protect ground water in association with the SCCGW.

Generally, awareness and concern about ground water resources is increasing. State agencies are working together to develop appropriate guidance or guidelines for activities that may threaten ground water. This is documented by the development of the *Recommendations for Geothermal Heating and Cooling Systems* (February 2012) and *Recommendations for Salt Storage* (February 2013). The most recent guidance is the updated *Regulations and Technical Guidance for Sealing Unused Water Wells and Boreholes*, finalized in March 2015. ODNR, in conjunction with several other agencies, has revised and developed fact sheets and best management practices to provide information on water resource issues associated with shale gas development. These documents are available on the ODNR Division of Oil & Gas Resources Web Page in the Shale activity section: <http://oilandgas.ohiodnr.gov/shale#SHALE>

To help provide well owners information on water quality, Ohio EPA worked with ODH and OSU Extension on the development of a new Web-based water quality interpretation tool for private well owners. In the "Know Your Well" tool, water sample results from a lab sheet are entered into the tool and with one click, well owners are provided with the standard for the parameter of interest, the natural range in ground water in Ohio for comparison, recommendations on actions, health effects and treatment options if applicable. The tool is part of this website hosted at OSU Extension at: <http://ohiowatersheds.osu.edu/know-your-well-water>

In 2013, a new relational database, GWQCP, was completed for DDAGW. This database houses water quality data for non-compliance projects in DDAGW. The completion of reports for pulling data from the database, user's guides and updates of the Operating Procedures Document were completed in 2014, with final

review in 2015. Thus, the database and documentation are now in place. Other activities completed over the past two years include:

- A discussion of future directions for the GW Characterization Program
- Extended sampling interval for geochemically stable wells
- Addition of new sandstone and carbonate wells

The Ambient Ground Water Quality Monitoring Program continues to collect high quality raw water data. The long-term nature of these data, dating back to the 1960's for some wells, allows evaluation of long-term ground water time series, which are extremely valuable for appraising the sustainability of the resource. These data from active public water system production wells place a priority on collecting water quality data to evaluate and characterize the ground water resource that is utilized. The GWQCP staff works to use ground water quality data to support and direct activities of the DDAGW as well as to provide these data to the public and other programs.

With the new database and documentation in place, the current focus of the Ground Water Characterization Program is to analyze the data and to increase the availability of these data to the public. The main approach to accomplish this will be to continue to generate the technical reports and fact sheets, with reports on iron & manganese, nitrate, chloride and barium to be completed next year. This effort will continue to document the value of the AGWQMP data. Other goals for the AGWQMP are to work to include the wells in the National Ground Water Monitoring Network, include methane in the parameter list and continue to anticipate future water quality needs.

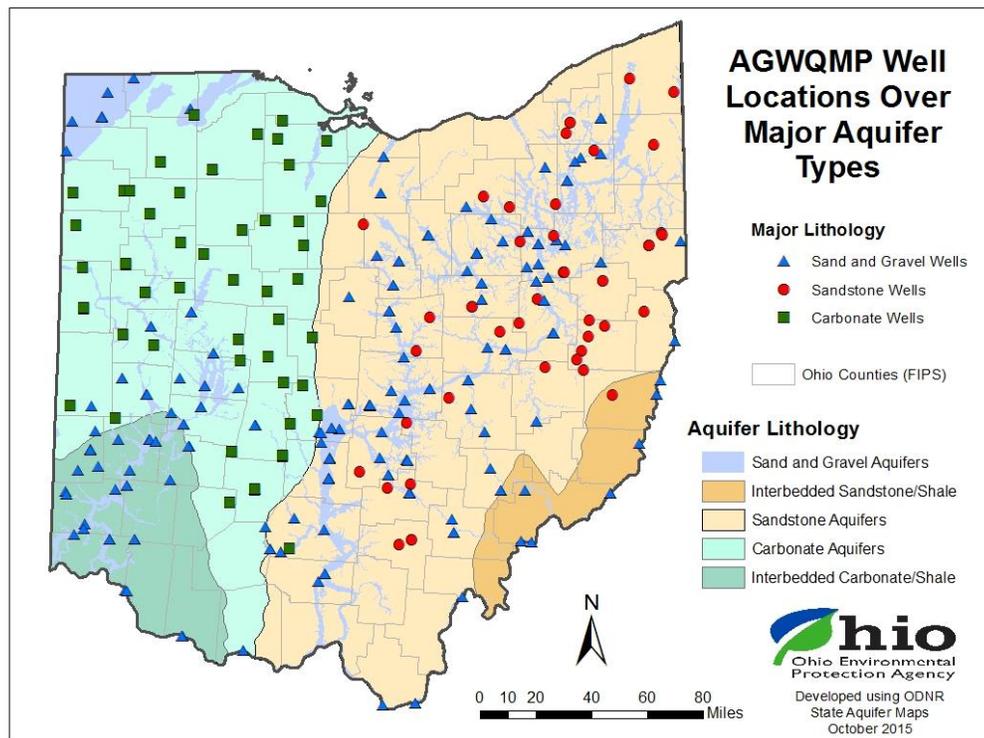
Ohio's ground water resources are relatively well-protected from surface contamination due to the layer of low-permeability glacial till that overlies approximately two-thirds of the state. Long-term efforts to protect ground water quality need to focus on aquifers subject to rapid recharge from the surface, such as shallow fractured bedrock, karst bedrock and shallow sand and gravel units.

Ground Water Section Appendix

Appendix A – Major Aquifers in Ohio and Associated Water Quality

This technical report provides a description of Ohio’s major aquifers and their distribution. The water quality of these aquifers is described by providing mean, median, minimum and maximum values for all AGWQMP (raw water) data from active wells by aquifer type. Well means are also presented as boxplots for individual constituents, in the report appendix. This provides a visual representation of the variability of parameters within and between the major aquifer types.

Major Aquifers in Ohio and Associated Water Quality



Division of Drinking and Ground Waters
Technical Series on Ground Water Quality
October 2015

The Technical Series on Ground Water Quality:

This series of reports provides information to the professional/technical community about ground water quality in Ohio's aquifers. These reports use data from:

- the ambient ground water quality monitoring program; and
- the public water system compliance programs.

These data, representative of raw water, are used to characterize the distribution of selected parameters in ground water across Ohio. The goal is to provide water quality information from the major aquifers, exhibit areas with elevated concentrations, and identify geologic and geochemical controls. This information is useful for assessing local ground water quality, water resource planning, and evaluating areas where specific water treatment may be necessary.

A series of parallel fact sheets, targeted for the general public, provide basic information on the distribution of the selected parameters in ground water. The information in the fact sheets is presented in a less technical format, addresses health effects, outlines treatment options and provides links to additional information.

Disclaimer

The Ohio EPA, Division of Drinking and Ground Waters (DDAGW) is providing information in this technical series as a public service. While Ohio EPA believes this information to be reliable and accurate, some data may be subject to human, mechanical or analytical error. Therefore, Ohio EPA does not warrant or guarantee the accuracy of these data. Because of the variability inherent in ground water data, caution must be taken in extrapolating point-data beyond the collection site. The accuracy, completeness, suitability and conclusions drawn from the information presented here are the sole responsibility of the user.

Technical Series
Major Aquifers in Ohio and Associated Water Quality

Abstract

The major aquifers are described and ground water quality data is presented that characterizes them. The data presented provides ranges of constituent concentrations typical of the major aquifers across Ohio. These data are representative of source water utilized by public water systems (raw or untreated water). These data are not pristine, since a number of the AGWQMP wells are impacted by elevated chloride, nitrate and organic parameters sourced from surface activities. The inherent variability in ground water means care must be taken when extrapolating point data beyond the collection site. However, the information compiled in this report is the best summary available for the general water quality of Ohio's major aquifers, and is presented to help evaluate water quality in local aquifers.

Introduction

The purpose of this report is to:

- Summarize information on Ohio's major aquifers;
- Discuss factors that influence the water quality within aquifer types; and
- Present water quality data representative of the major aquifers.

This information is intended to help evaluate local water quality by providing ranges of parameter concentrations typical of Ohio's major aquifers for comparison. The water quality data presented has been collected by Ohio EPA's Ambient Ground Water Quality Monitoring Program (AGWQMP) and is representative of raw or untreated water.

Ohio's Major Aquifers

Ohio has abundant surface and ground water resources. Average precipitation ranges between 30 to 44 inches a year (increasing from northwest to southeast), which drives healthy stream flows. Infiltration of a small portion of this precipitation (3-16 inches) recharges the aquifers and keeps the streams flowing.

Ohio's aquifers can be divided into three major types as illustrated in Figure 1 (modified from ODNR Statewide Aquifer Maps, 2000). The sand and gravel buried valley aquifers (in blue) are distributed as thin bands through the state. The valleys filled by these sands and gravels are cut into sandstone and shale in the eastern half of the state (in tans) and into carbonate aquifers (in greens) in the western half. The sandstone and carbonate aquifers generally provide sufficient production for water wells except where dominated by shale, as in southwest and southeast Ohio.

Sand and Gravel Aquifers

The unconsolidated sand and gravel units, typically associated with buried valley aquifers, are Ohio's most productive water-bearing formations. These valleys were cut into the bedrock by pre-glacial and glacial streams and were subsequently back-filled with deposits of sand, gravel and other glacial drift by glacial and alluvial 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.

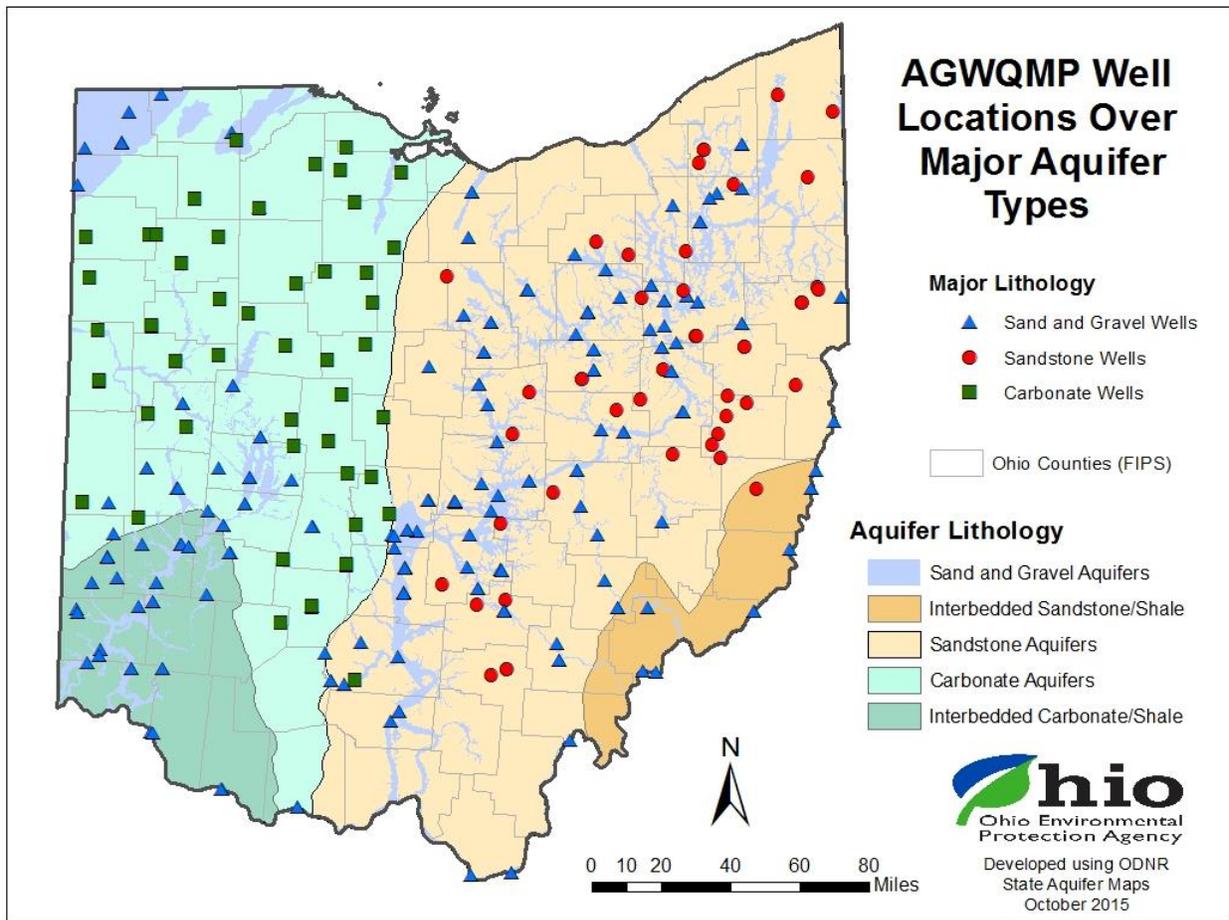


Figure 1. Aquifer Types in Ohio modified from ODNR Glacial and Bedrock Aquifer Maps.

In addition to the buried valley aquifers, lenses of sand and sand and gravel within glacial tills may be productive, although generally providing lower yields than the buried valley aquifers. Outwash/kame and beach ridge deposits are also important sand and gravel aquifers in local areas. Several other types of extensive sand and gravel aquifers are included in Figure 1. In the northwest corner of the state, the triangular area of sand and gravel units bordering Michigan and Indiana includes sheets of outwash or sand and gravel that occur between sheets of glacial till. The large patches of sand and gravel just east of the triangular outwash deposits are reworked delta deposits of the Oak Opening Sands. Present day stream processes deposit alluvial sand and gravel deposits that also serve as aquifers if the alluvial deposits are thick enough.

Water production from the coarser-grained and thicker sand and gravel deposits ranges up to 500 to 1,000 gallons per minute (gpm). However, lower yields from sand and gravel aquifers are more common. The production depends on the type, distribution, permeability, and thickness of aquifer materials and well construction parameters, such as borehole diameter, screen length, and development. Yields of these unconsolidated aquifers are illustrated on the ODNR web site at: <http://water.ohiodnr.gov/maps/statewide-aquifer-maps> in the Example Maps created from SAMP Data section.

Sandstone Aquifers

In eastern Ohio, Mississippian and Pennsylvanian sandstones and conglomerates are the dominant bedrock aquifers (Figure 1). Sandstone and conglomerate units of variable thickness and areal extent are interbedded with numerous layers of siltstone and shale with minor amounts of limestone, clay, and coal. The sandstones generally dip a few degrees to the southeast, toward the Appalachian Basin. Some of the thicker sandstones and conglomerates can yield 50 to 100 gpm, but 25 gpm is good for these aquifers. The more productive stratigraphic units include:

- **Pennsylvanian Sharon through Massillon Formations, and the Homewood Sandstone within the Pottsville and Allegheny Groups** - These sandstones, including some conglomerates, were deposited on a stable coastal plain with rising sea level. These aquifers are most commonly used in the northern areas of eastern Ohio. To the southeast, farther into the Appalachian Basin, the water is generally too saline for drinking.
- **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 also extend to the southeast, farther into the Appalachian Basin, but as with the Pennsylvanian units, the water becomes too saline for drinking.

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 five gpm are common in these areas as illustrated in Figure 2 (from the ODNR web page at: <http://water.ohiodnr.gov/maps/statewide-aquifer-maps> in the Example Maps Created from SAMP Data section.

Carbonate Aquifers

Carbonate bedrock is the dominant aquifer in western Ohio (Figure 1). Silurian and Middle Devonian limestone and dolomite reach a total thickness of 300 to 600 feet, and are capable of yielding from 100 to over 500 gpm. Higher production units are associated with fractures and dissolution features that increase the permeability. 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

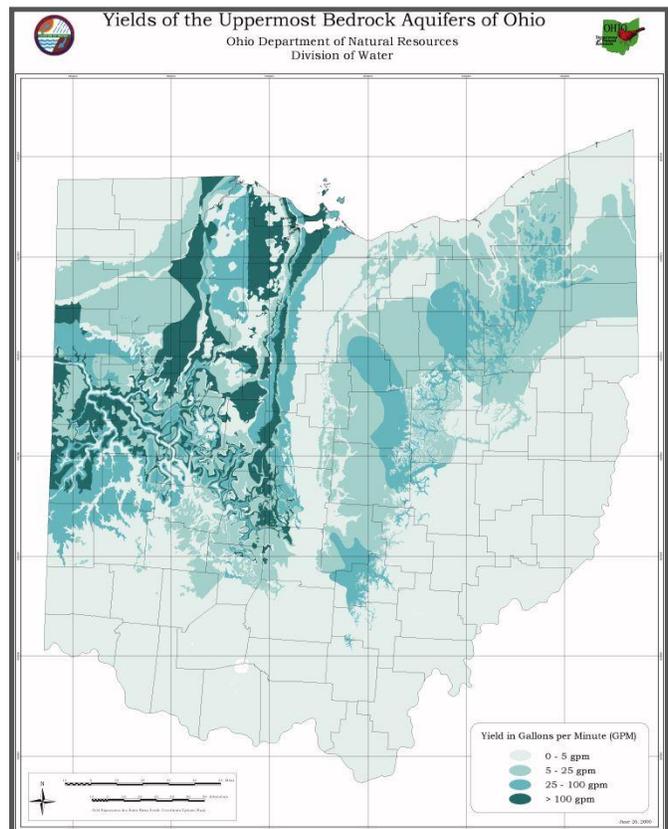


Figure 2. Typical yields for bedrock aquifers.

the Undifferentiated Salina Dolomite and equivalent evaporites. The Devonian Columbus and Delaware Limestones, exposed along the eastern edge of the Silurian Dolomites, and equivalent Devonian units in the northwest corner of Ohio (Detroit River Group, Dundee Limestone, Silica Formation, and Ten Mile Creek Dolomite) are productive carbonate aquifers. These carbonates were generally deposited in warm, shallow seas with limited input of sediment from continental sources. Where the Devonian limestone is overlain by 100 feet or more of Devonian shale, the water quality is poor and generally cannot be considered a drinking water source.

Southwestern Ohio is underlain by inter-bedded lower Ordovician carbonates and shales. These units are dominated by shale (Figure 1). As a result, well yields are generally less than 10 gpm, and in many areas, are less than one gpm (Figure 2). Consequently, in southwestern Ohio (as in southeastern Ohio), public water systems depend on the buried valley aquifers as the main ground water source. These low yielding aquifers are only practical for low volume use. Ohio EPA has little water quality data from shale-dominated wells, and consequently, they are 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 Devonian shale in central Ohio is clearly illustrated in Figure 2 as the area of low yields (0-5 GPM) that separates the carbonate aquifers in the west from the sandstone aquifers to the east. Where the north trend of the shales meets Lake Erie, the shale curves eastward along the Lake Erie shoreline as illustrated in Figure 2 by the band of low yields there. In addition, to the low yield, hydrogen sulfide is frequently present, which causes water quality problems.

Ground Water Quality by Aquifer Type

General Considerations

The overall ground water quality in Ohio is described here using the Ambient Ground Water Quality Monitoring Program (AGWQMP) database, which consists of approximately 6,000 inorganic and 2,600 organic water quality samples distributed across 282 active wells. Figure 1 illustrates the distribution and aquifer type of AGWQMP wells. As described above, the major aquifers include unconsolidated sand and gravel units deposited on sandstone bedrock in eastern Ohio and carbonate bedrock in western 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 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 major aquifer type. Water-rock interaction along flow paths imparts distinct geochemical signatures which are reflected in the ground water quality. 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 types 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 vary, however, 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 residence time; however, agriculture tile drains in many of these glacial soils can short circuit flow paths to surface water and thus, reduce the

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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. Sand and gravel aquifers, for example, commonly have short residence times, leading to lower salinity. 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 3 is a box plot indicating the distribution of well depths by aquifer type for the AGWQMP wells. The median depth in the carbonate aquifers (~225 feet) is slightly greater than the median depth in the sandstone aquifers (~220 feet). The median depth for the sand and gravel aquifers (~ 90 feet) is less than one-half the depth of the carbonate or sandstone aquifers, suggesting shorter residence times for sand and gravel aquifers compared to bedrock aquifers.

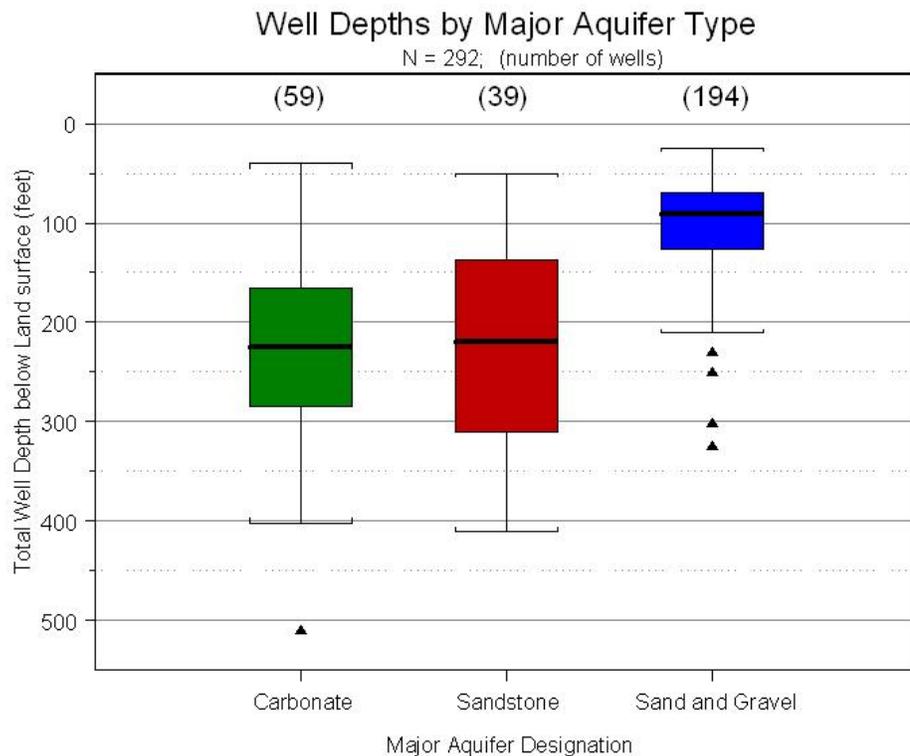


Figure 3. Box plot of active AGWQMP well depths by aquifer type.

Inorganic Parameter Mean Values

Ambient ground water quality data presented in Table 1 (starting on page 10) summarize the geochemistry by major aquifer type for all active AGWQMP wells. This table provides the arithmetic mean, median, minimum value, maximum value, standard deviation, total number of samples, number of samples below the reporting limit, and the percent non-detect for all individual inorganic and field

parameter results in each aquifer type as of July 2015. Brief descriptions of several of these parameters are provided to aid in understanding the data. For instance, the reporting limit was used for the non-detect values in calculating means and standard deviation. The “non-detect” column records the percent of analyses with results below the 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 coincide with the current reporting limit due to changes in analytical methods. AGWQMP sampling started in 1973, and changes in analytical methods resulted in multiple reporting limits for some constituents. 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.

Table 1 summarizes the accumulation of over 164,000 raw, inorganic ground-water data results gathered at 282 active and standby wells across Ohio over 40 years of sampling. Consistent sampling protocol, analytical procedures, and long site histories lend a unique significance to these data. Table 1 is the best summary available for the general water quality of Ohio’s major aquifers, which provides the source water for Ohio’s public drinking water systems using ground water. Note, 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 public water systems.

The data listed in Table 1 is organized into four categories:

- **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;
- **Trace Constituents** – such as arsenic or cadmium; concentrations in range of µg/L; and
- **Nutrients** – components required by organic systems for growth; concentrations in mg/L.

The statistical parameters in Table 1 were generated using individual sample result values. This is complemented by a graphical summary using box and whisker plot diagrams based on means for each well in Appendix A. In Appendix A box plots, the inorganic results are plotted on the Y-axis, while the X-axis represent the three major aquifer groupings (sand and gravel, sandstone, and carbonate).

Use of Primary and Secondary MCLs

Maximum Contaminant Levels (MCLs) are health-based regulatory standards for permissible concentrations of constituents in drinking water delivered to the public. Secondary Maximum Contaminant Levels (SMCLs) are advisory limits applied to distribution water at public water systems for aesthetic water quality issues, such as taste and odor. Because AGWQMP data are obtained from raw (untreated) ground water, which is unregulated, any exceedance of an MCL or SMCL by an AGWQMP data point has no legal or regulatory consequence for the public water system. However, since MCLs and SMCLs are widely known, they represent a practical benchmark for discussion. MCLs and SMCLs are included in the first column of Table 1 and included on the boxplots in Appendix A for constituents that have established regulatory values.

Seven of the primary constituents for which health based MCLs exist are monitored in raw water through the AGWQMP. These are arsenic (10 µg/L), barium (2 mg/L), cadmium (5 µg/L), chromium (100 µg/L), fluoride (4 mg/L), nitrate-nitrite as N (10 mg/L), and selenium (50 µg/L). Additionally, copper and lead have action levels (not MCLs or SMCLs) of 1.3 mg/L and 0.015 mg/L respectively. As indicated by the

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Ambient Ground Water Quality Table 1, no constituent exceeds a MCL based on averages by aquifer type. Arsenic exhibits the highest concentrations as a percentage of the MCL; nevertheless, mean concentrations for all three aquifer types are well below the arsenic MCL of 10 µg/L (sand and gravel = 5.41 µg/L, sandstone = 2.48 µg/L, carbonate = 3.75 µg/L). However, 30 active AGWQMP wells have raw water means that exceed the arsenic MCL of 10 µg/L. If these wells are public water system wells, treatment would be required to bring arsenic concentrations below the MCL in the distributed water. Means for barium, cadmium, chromium, fluoride, nitrate-nitrite, and selenium are also below MCLs within all three aquifer systems. Individual well means indicate no MCL exceedances for barium, cadmium, chromium, fluoride, nitrate, and selenium, but three AGWQMP wells have barium means greater than 75 % of the MCL.

Nine constituents with established SMCLs are monitored by the AGWQMP. These 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). The SMCL levels are exceeded by the aquifer means for several of these constituents as exhibited in Table 1, and by individual well means in Appendix 1.

Volatile Organic Compounds

Volatile organic compounds (VOCs) have been monitored in untreated water for the AGWQMP since the mid-1980s with a standard sampling frequency of 18 months. A reporting level of 0.5 µg/L (ppb) has been used consistently. Fortunately, the detection rate for VOCs is low, about 0.29 percent (506 detections from 172,077 results), but their presence usually indicates water quality impact from land use activities. AGWQMP sampling protocols may increase the sampling frequency if VOCs are detected; currently, 15 active AGWQMP wells are sampled for organics every six months to help evaluate potential for migration of VOC plumes into public water system wells. The higher VOC sampling frequency of wells with VOC detections increases the detection rates. In some cases, wells with VOC detections are abandoned by public water systems and are no longer available for sampling by the AGWQMP.

The five VOCs representative of point source origins that exhibit the highest rate of detections in active AGWQMP wells are listed in Table 2. The parameter name, the number of detections, the number of sites with detections, and the range of detections are listed below.

Parameter	Number of detections	Number of sites with detections	Range of results (µg/L)	Maximum Contaminant Level (MCL)
Trichloroethylene	68	8	0.5-44.2	5
cis-1,2-Dichloroethylene	59	11	0.5-4.92	70
loroethylene	53	6	0.5-28.5	5
Methyl tertiary butyl ether (MTBE)	33	4	0.5-6.73	none
1,1,1,Trichloroethane	11	2	0.5-1.39	5

Chlorinated solvents are the primary chemical group in Table 1. These include trichloroethylene (TCE), cis-1,2-dichloroethylene, tetrachloroethylene (PCE), and 1,1,1-trichloroethane (1,1,1- TCA). These solvents were developed over the last century as cheaper and more practical alternatives to petroleum solvents. PCE and TCE have been in industrial use over 60 years. PCE is widely used for dry cleaning. PCE and TCE can both undergo dechlorination (loss of a chlorine) leading to the daughter products 1,1-dichloroethylene, cis- and trans-1,2-dichloroethylene, which ultimately degrade into vinyl chloride. As a group, their concentrations in ground water are quite low, well below MCLs, but maximum values for TCE (14 results at one site) and PCE (2 of 53 results) are above MCL. 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. MTBE, a gasoline additive (oxygenate), is also included in the top five list, but 29 of the 33 detections occur at one well and concentrations are generally decreasing in this well.

Most of the wells with VOC impact are associated with sensitive aquifers, which is not surprising considering the point source nature of most VOC sources. From a practical standpoint, most detections of VOCs should be considered water quality impacts, as there are few natural sources of these man-made chemicals. There are, of course, exceptions to this generalization, such as benzene from crude petroleum in aquifers known for oil production down dip or in associated stratigraphic units. The limited detection data and anthropogenic association of these organic compounds make them of little use in characterizing water quality, beyond the fact that their presence usually indicates water quality impacts from land use activities.

Trihalomethanes (THM) are the most frequently detected organic compounds in AGWQMP wells (119 detections at 33 sites), including chloroform, bromoform, dichlorobromomethane, and chlorodibromomethane. However, the source of these compounds is not always clear. The maximum value detected in active wells, 37 µg/L, is well below the MCL of 80 µg/L. Trihalomethanes are a byproduct of disinfection using chlorine, and are not uncommon in public water system distribution water. Thus, if there is backflow from the distribution system to the AGWQMP sample location (leaking foot valve or poor sample tap location), or if the well has been disinfected recently, THMs may be present. A third possibility is that treated water from lawn watering or leaks in the distribution system or sewer lines is recharging local wells. The source of THMs in a well is not always clear, consequently, unlike the VOC detections, THM detections cannot always be attributed to land use impacts.

Summary

The major aquifers are described and water quality data is presented that characterizes them. The data presented provides ranges of constituent concentrations typical of the major aquifers across Ohio. These data are representative of source water utilized by public water systems (raw or untreated water). These data are not pristine, since a number of the AGWQMP wells are impacted by elevated chloride, nitrate and organic parameters sourced from surface activities. The inherent variability in ground water means care must be taken when extrapolating point data beyond the collection site. However, the information compiled in this report is the best summary available for the general water quality of Ohio's major aquifers, and is presented to help evaluate water quality in local aquifers.

References Cited

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Ohio Department of Natural Resources (ODNR), 2000. Statewide Aquifer Mapping Project 1997-2000 (Unconsolidated and Consolidated); web link: <http://soilandwater.ohiodnr.gov/maps/statewide-aquifer-maps>

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Table 1 – Ambient Ground Water Quality Data

Ambient Ground Water Quality Monitoring Data Summary for Results from Active Wells by Major Aquifer as of July 2015

FIELD PARAMETERS										
MCL/ SMCL	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
	Oxidation-Reduction Potential (ORP) mV	Sand and Gravel	56.9	32	-520	815	129	1675	NA	NA
		Sandstone	105	69	-530	902	210	372	NA	NA
		Carbonate	-25.0	-22	-301	799	143	402	NA	NA
7.0-10.5 S.U.	pH, Field S.U.	Sand and Gravel	7.32	7.33	5.6	8.6	0.33	3471	NA	NA
		Sandstone	7.24	7.24	5.67	8.7	0.46	668	NA	NA
		Carbonate	7.21	7.19	5.22	8.7	0.31	967	NA	NA
	Specific Conductivity µmohms/cm	Sand and Gravel	692	680	120	2375	202	3414	NA	NA
		Sandstone	634	533	68	3420	318	654	NA	NA
		Carbonate	930	880	270	3030	291	960	NA	NA
500 ^s mg/L	Total Dissolved Solids, Field mg/L	Sand and Gravel	531	517	187	1726	141	1622	NA	NA
		Sandstone	477	382	44	2605	256	371	NA	NA
		Carbonate	745	697	293	2170	206	404	NA	NA
	Water Temperature Degrees C	Sand and Gravel	13.4	13.1	3.3	31.9	2.11	3427	NA	NA
		Sandstone	12.5	12.3	6.4	18.8	1.4	654	NA	NA
		Carbonate	13.2	12.9	6.9	19	1.6	955	NA	NA

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MAJOR COMPONENTS										
MCL/ SMCL	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
	Alkalinity, Total as CaCO ₃ mg/L	Sand and Gravel	257	265	5	587	66.2	4002	7	0
		Sandstone	205	196	33.1	496	74.9	776	0	0
		Carbonate	295	306	92.6	642	67.4	1049	0	0
	Calcium, Total mg/L	Sand and Gravel	92.8	93	<2.0	300	23.7	4065	1	0
		Sandstone	57.1	58	<2.0	167	26.7	781	3	0
		Carbonate	123	114	26	584	39.6	1063	0	0
250 ^s mg/L	Chloride mg/L	Sand and Gravel	40.6	32	<2.0	474	34	4046	130	3
		Sandstone	54	31.9	<2.0	899	74.5	778	49	6
		Carbonate	28.1	16	<2.0	420	34.9	1045	101	10
	Hardness, Total as CaCO ₃ mg/L	Sand and Gravel	347	352	<10.0	953	83.9	3524	2	0
		Sandstone	213	214	<10.0	541	86.4	702	1	0
		Carbonate	505	450	110	2060	165	935	0	0
	Magnesium, Total mg/L	Sand and Gravel	28.2	29	<1.0	81	9.42	4066	9	0
		Sandstone	16.5	16	<1.0	35	6.97	781	5	1
		Carbonate	49.8	43	11	147	18.4	1063	0	0
	Potassium, Total mg/L	Sand and Gravel	2.41	2.0	<0.9	20	1.04	3925	984	25
		Sandstone	2.34	2.0	<1.0	6.5	0.76	771	264	34
		Carbonate	2.82	2.1	<1.3	11.6	1.2	1035	109	11
	Sodium, Total mg/L	Sand and Gravel	26.4	22	<4.0	427	20.2	4069	107	3
		Sandstone	60.1	28	<5.0	754	73.6	781	26	3
		Carbonate	35.5	28	<5.0	239	26.6	1062	19	2
250 ^s mg/L	Sulfate mg/L	Sand and Gravel	74.4	64.7	<5.0	640	44	4052	29	1
		Sandstone	52.4	41.7	<5.0	271	48.8	782	83	11
		Carbonate	245	176	<5.0	1830	207	1065	3	0
500 ^s mg/L	Total Dissolved Solids mg/L	Sand and Gravel	457	448	<10.0	2120	116	3965	1	0
		Sandstone	391	332	48	1850	183	742	0	0
		Carbonate	722	638	264	3200	274	1035	0	0

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TRACE CONSTITUENTS										
MCL/ SMCL	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
50-200 ^S µg/L	Aluminum µg/L	Sand and Gravel	202	<200	<200	2880	55.7	3393	3385	100
		Sandstone	201	<200	<200	448	11.5	726	721	99
		Carbonate	208	<200	<200	2050	103.2	892	884	99
10 µg/L	Arsenic, Total µg/L	Sand and Gravel	5.41	<2.0	<2.0	102	8.42	3899	1992	51
		Sandstone	2.48	<2.0	<2.0	89.7	3.42	764	644	84
		Carbonate	3.75	<2.0	<2.0	30	3.66	1043	600	58
2000 µg/L	Barium µg/L	Sand and Gravel	154	116	<15.0	2160	175	3867	61	2
		Sandstone	237	78	<15.0	2120	421	753	72	10
		Carbonate	73.2	49	<7.0	568	68.0	1039	91	9
	Bromide µg/L	Sand and Gravel	82.6	58.2	<20	1680	98.7	1172	137	12
		Sandstone	156	44.8	<20	4080	341	270	31	11
		Carbonate	140	100	<20	920	157	289	91	31
5 µg/L	Cadmium, Total µg/L	Sand and Gravel	0.21	<0.2	<0.2	4.0	0.1	3652	3622	99
		Sandstone	0.23	<0.2	<0.2	18.8	0.67	765	756	99
		Carbonate	0..21	<0.2	<0.2	1.6	0.07	1022	1003	98
100 µg/L	Chromium, Total µg/L	Sand and Gravel	20.5	<30	<2.0	64	13.3	3707	3690	100
		Sandstone	19.7	<30	<2.0	30	13.5	771	770	100
		Carbonate	21.5	<30	<2.0	50	12.9	1025	1010	99
1300 ^{AL} µg/L	Copper µg/L	Sand and Gravel	11.3	<10	<2.0	758	26.9	3500	2496	71
		Sandstone	12.1	<10	<2.0	235	22.2	754	503	67
		Carbonate	15.7	<10	<2.0	586	44.4	918	583	64
4 mg/L 2 ^S mg/L	Fluoride mg/L	Sand and Gravel	0.39	0.24	<0. 02	2.71	0.36	3289	1053	32
		Sandstone	0.31	0.25	<0.1	1.28	0.17	713	161	23
		Carbonate	1.39	1.38	<0.1	3.58	0.62	879	24	3
300 ^S µg/L	Iron, Total µg/L	Sand and Gravel	1188	687	<20	58400	1576	4053	837	21
		Sandstone	1348	335	<50	31200	3237	779	187	24
		Carbonate	1095	814	<50	27300	1667	1066	110	10
15 ^{AL} µg/L	Lead, Total µg/L	Sand and Gravel	3.79	<2.0	<1.0	1590	33.6	3894	3568	92
		Sandstone	2.78	<2.0	<2.0	164	6.72	770	684	89
		Carbonate	3.11	<2.0	<2.0	167	8.08	1009	869	86

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TRACE CONSTITUENTS										
MCL/ SMCL	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
50 ^s µg/L	Manganese, Total µg/L	Sand and Gravel	195	121	<8.0	5130	230	3971	547	14
		Sandstone	225	89	<9.0	2220	358	774	146	19
		Carbonate	32	18	<10	300	33.8	1038	273	26
	Nickel, Total µg/L	Sand and Gravel	26.7	<40	<1.0	269	18.6	3460	2651	77
		Sandstone	26.4	<40	<2.0	175	19.4	734	634	86
		Carbonate	27.9	<40	<2.0	88	17.4	918	664	72
50 µg/L	Selenium, Total µg/L	Sand and Gravel	2.04	<2.00	<2.00	25	0.54	3536	3425	97
		Sandstone	2.05	<2.00	<2.00	17.7	0.62	758	735	97
		Carbonate	2.05	<2.00	<2.00	10	0.5	915	884	97
	Strontium, Total µg/L	Sand and Gravel	1894	366	<30	36400	4351	3455	5	0
		Sandstone	443	386	<30	1830	355	732	5	1
		Carbonate	16927	15300	<30	51600	11269	919	2	0
5000 ^s µg/L	Zinc, Total µg/L	Sand and Gravel	21.7	<10	<6.0	3340	90.9	3523	2413	68
		Sandstone	30.0	10	<10	902	63.3	752	352	47
		Carbonate	70.7	11	<10	4090	272	918	419	46

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NUTRIENTS										
MCL/ SMCL	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	0.21	0.07	0.1	3.41	0.35	4011	1675	42
		Sandstone	0.36	0.18	0.5	2.30	0.45	772	220	28
		Carbonate	0.41	0.35	0.5	5.93	0.47	1054	118	11
	Chemical Oxygen Demand mg/L	Sand and Gravel	13.7	<10	<2.0	200	9.27	3943	3624	92
		Sandstone	14.5	<10	<6.0	269	13.4	765	720	94
		Carbonate	14.9	<10	<10	371	15.4	1053	888	84
10 mg/L	Nitrite & Nitrate NO2 +NO3 as N mg/L	Sand and Gravel	0.77	<0.10	<0.09	12.3	1.29	3877	2089	54
		Sandstone	0.48	<0.10	<0.1	7.4	0.89	763	531	70
		Carbonate	0.38	<0.10	<0.1	15.1	1.02	1036	902	87
	Phosphorus mg/L	Sand and Gravel	0.08	<0.05	0.003	17.3	0.5	3668	2554	70
		Sandstone	0.09	0.05	0.01	4.4	0.26	725	341	47
		Carbonate	0.05	<0.05	0.01	4.37	0.16	976	647	66
	Total Kjeldahl N mg/L	Sand and Gravel	0.39	0.24	<0.08	6.75	0.40	2756	1153	42
		Sandstone	0.50	0.27	<0.2	3.82	0.51	609	241	40
		Carbonate	0.54	0.44	<0.2	7.04	0.54	731	141	19
	Total Organic Carbon mg/L	Sand and Gravel	2.44	<2.0	<0.5	75	3.07	3517	3176	90
		Sandstone	2.15	<2.0	<0.5	20	1.01	724	680	94
		Carbonate	2.51	<2.0	<2.0	73	4.12	778	820	88

* 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.

S Secondary MCL

AL Action Level

Appendix A

Ambient Ground Water Quality Monitoring Program Inorganic Constituent Box and Whisker Plots

This document provides a concise geochemical summary, in box and whisker plot format, of the Ambient Ground Water Quality Monitoring Program (AGWMP) inorganic data set as of July 2015. The Box and Whisker plots from the Ambient Ground Water Quality Network database include results from 6000 raw (untreated), inorganic water samples collected over the past 40 years across more than 200 active wells. Active (AGWMP) wells are sampled every six, eighteen or thirty-six 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 is used to enhance water resource planning and to prioritize ground water protection. The AGWMP 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 AGWMP wells are influenced by land use activities. The wells are considered typical of the local ground water used as source water for public water systems.

In the following box plots, the water-quality results are first averaged by well, then grouped by the three major aquifer types in Ohio to display the numerical data distributions. Water quality results are plotted on the y-axes, while the x-axes represent the three major aquifer categories (carbonate, sandstone, and sand and gravel). These box plots allow the reader to visually compare data variability across major aquifer types. The analyzed constituents are presented in the following order: Field Parameters; Major Constituents; Trace Constituents; and Nutrients. The number of wells used to construct each group's box plot is indicated above the x-axis.

The y-axis is presented in linear or in log 10 scale, whichever enhances readability. Box plots that appear without "boxes" (common in Trace Constituents section) have too little data variability to generate separation of 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. Collapsed boxes generally occur when more than 75% of the data are below the reporting limit. In the case of chromium and nickel, high reporting limits in early data distort the representation of variability of these data. In both of these cases, the lower (current) reporting limit was used for all non-detect results to more accurately represent the distribution of chromium and nickel.

Construction and interpretation details for a generic box plot are found on the next page of this report.

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Email: gwq@epa.state.oh.us

Box and Whisker Plots

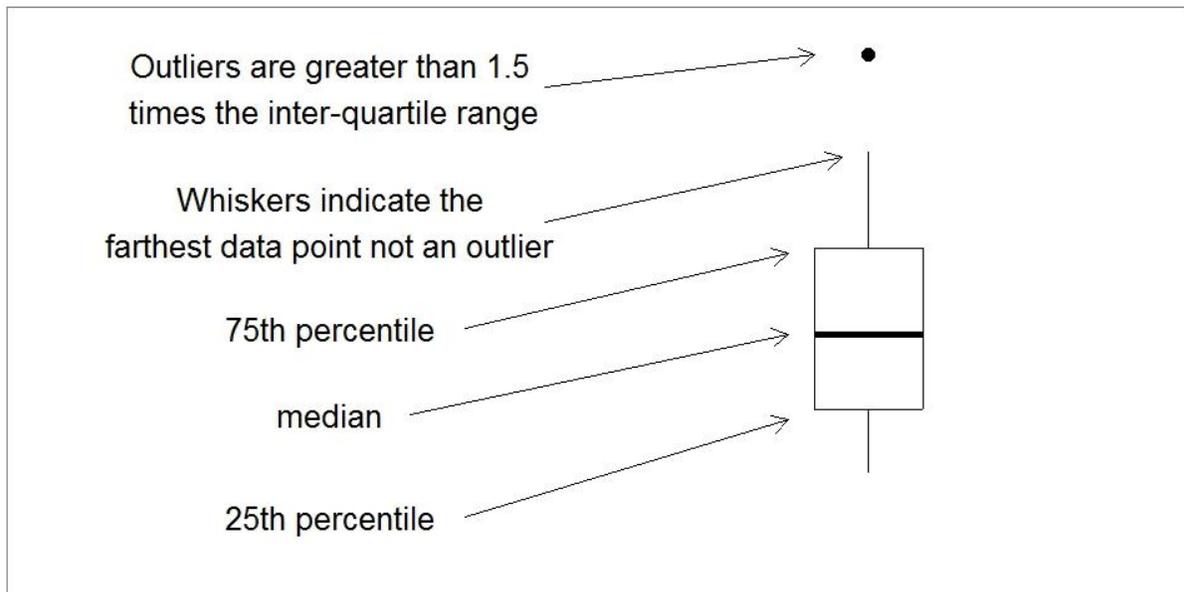


Figure 1

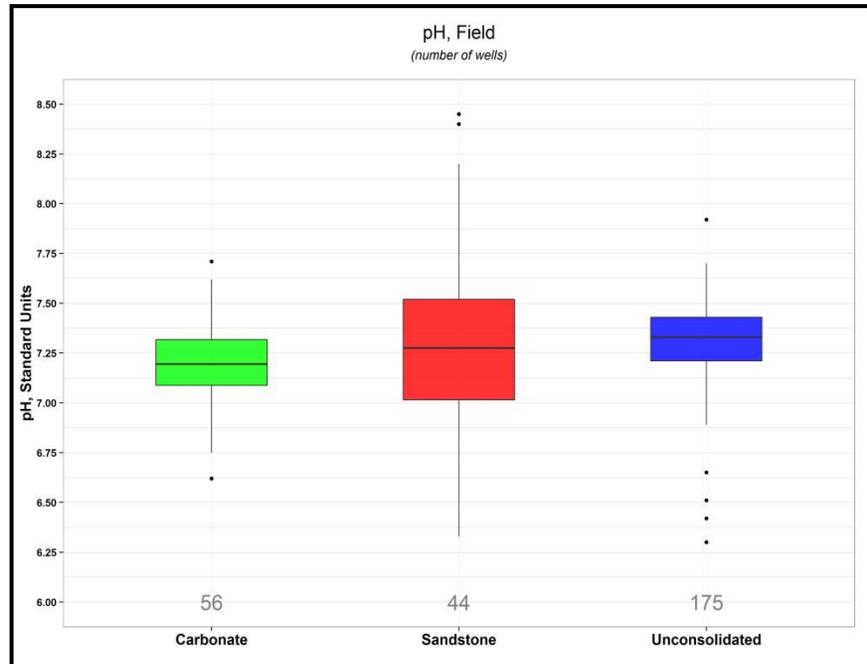
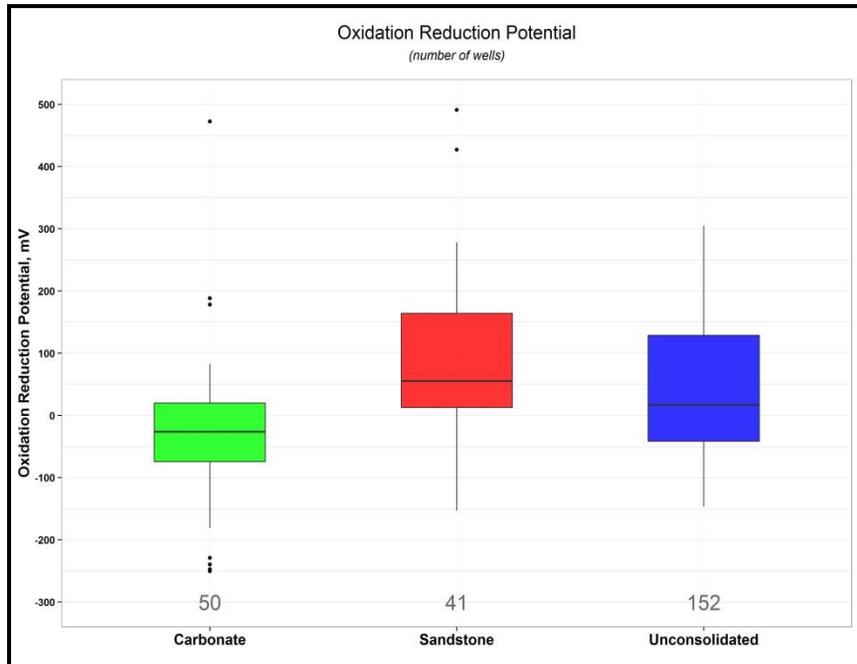
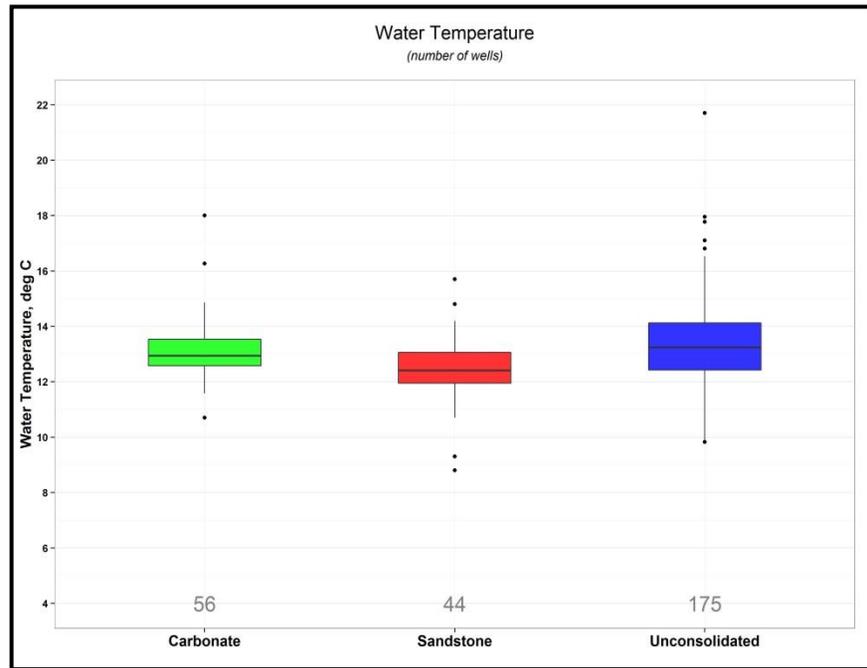
Explanation of Box Plot construction.

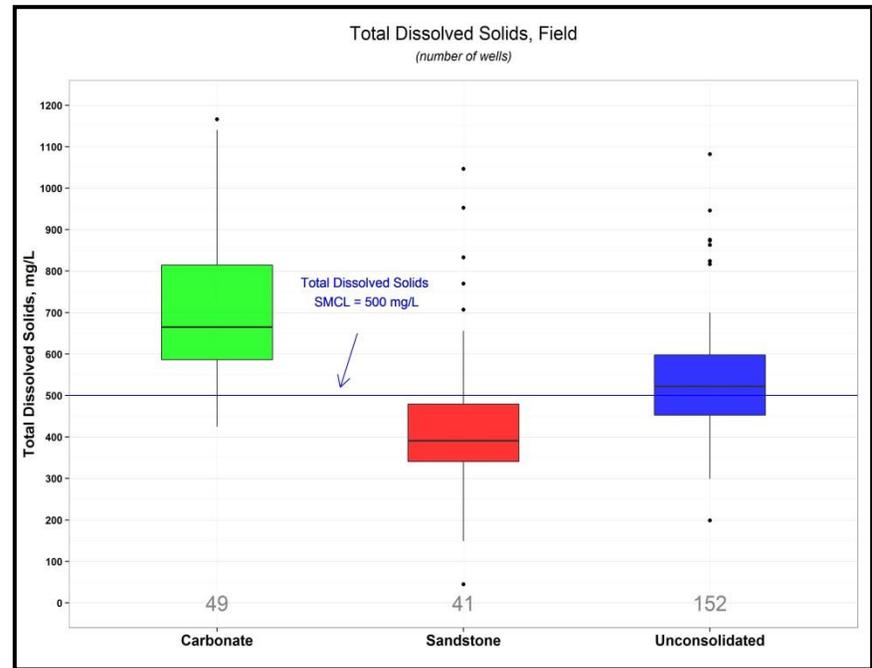
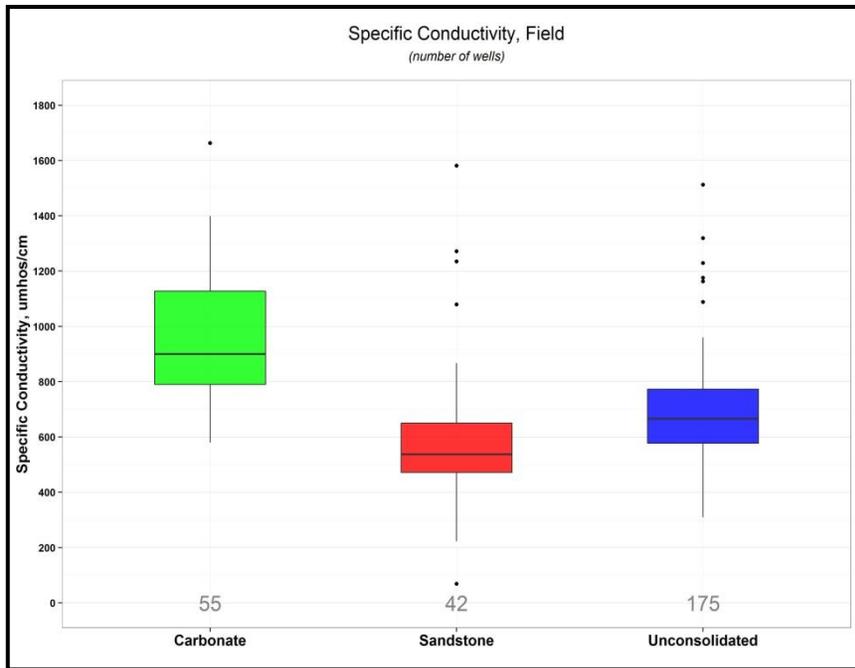
Box and Whisker Plots are an efficient graphical method for displaying the distribution of a data set. The format allows easy comparison of one distribution to those of other groups of data. The elements of a typical boxplot are indicated in Figure 1. The “box” itself outlines the range of half the data (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 thick 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 extent of the whiskers indicates the position of the last data point which does not exceed 1.5 times the IQR. Outliers exceed 1.5 times the IQR, and are identified by individual symbols above or below the whiskers.

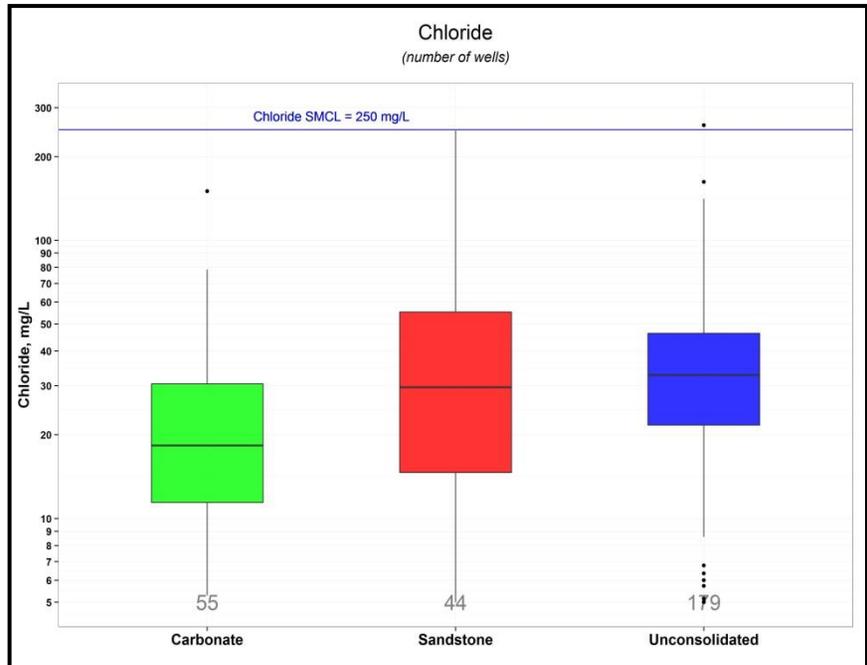
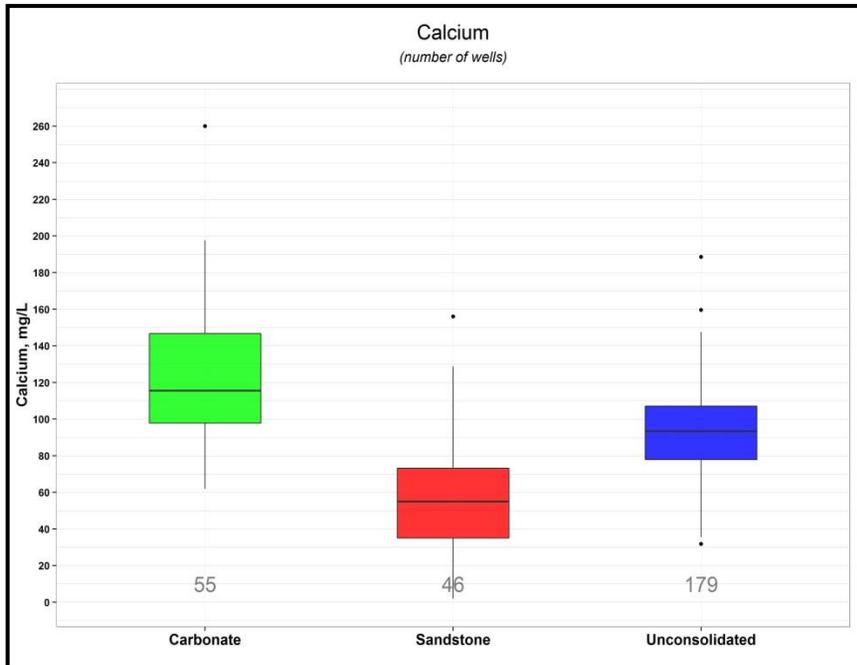
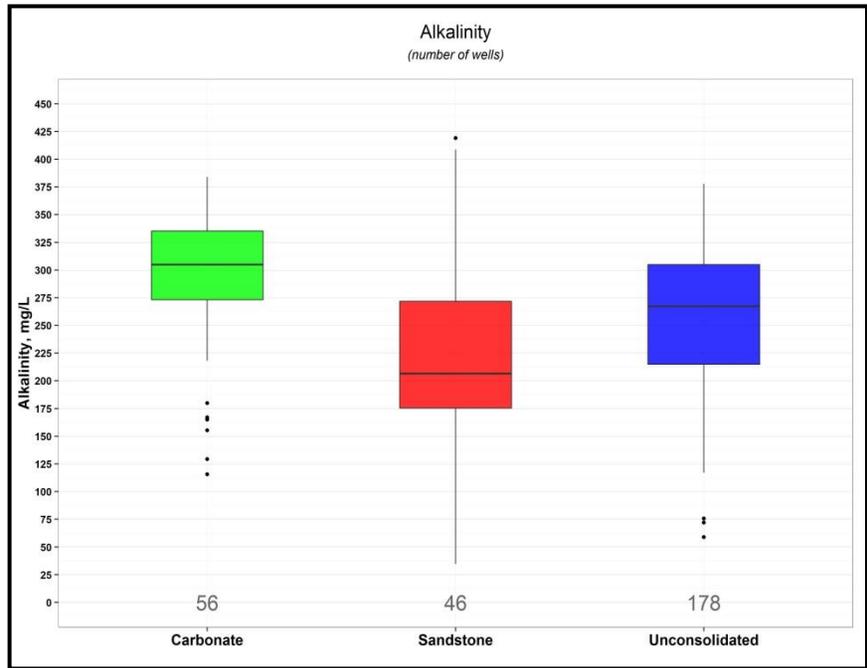
A normally distributed data set is indicated if the median bar is located mid-way between the top and bottom of the box, i.e. if the median is equidistant between the 25th and 75th percentiles. A skewed data set would have the median bar either closer to the 25th percentile (positively skewed) or to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

Field Parameters

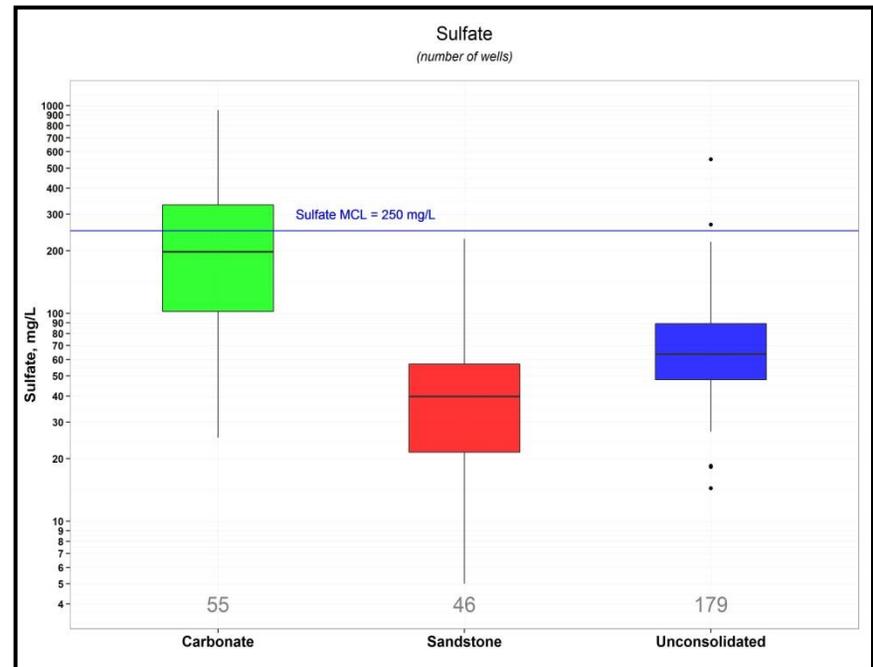
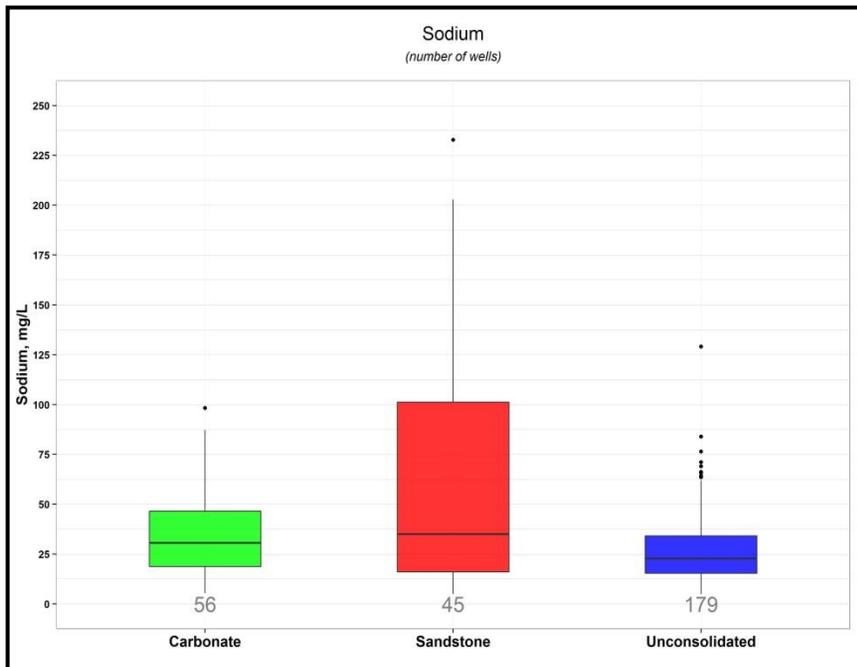
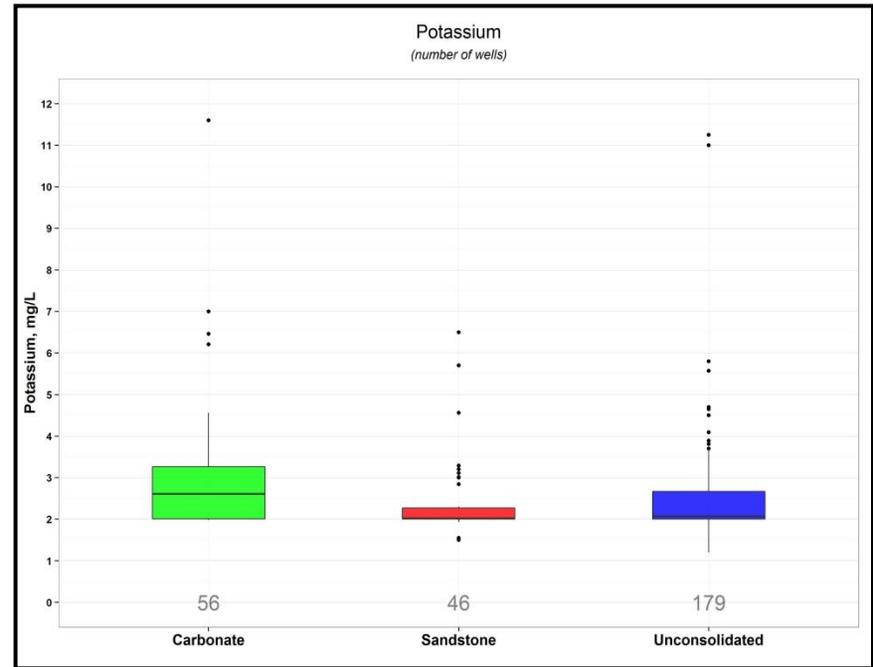
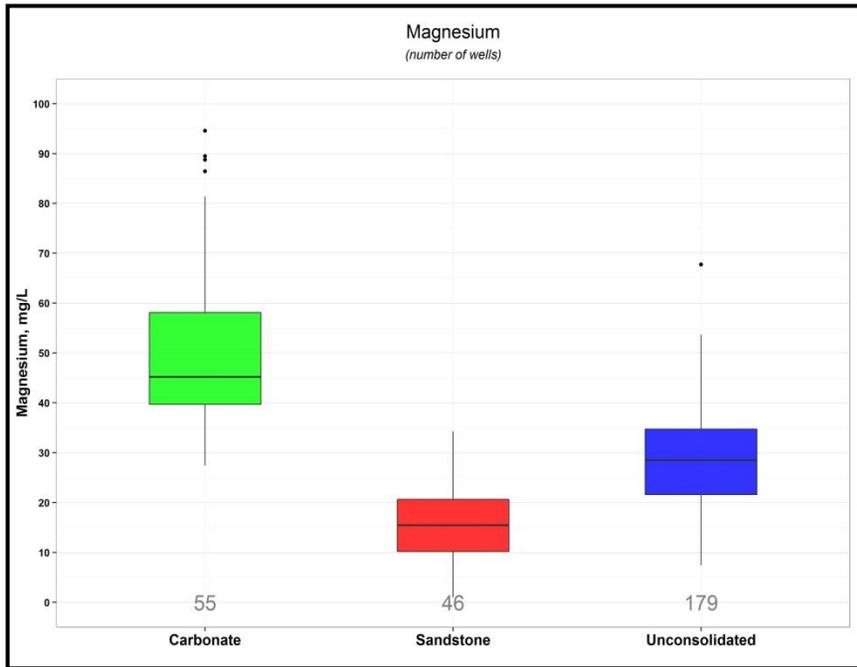


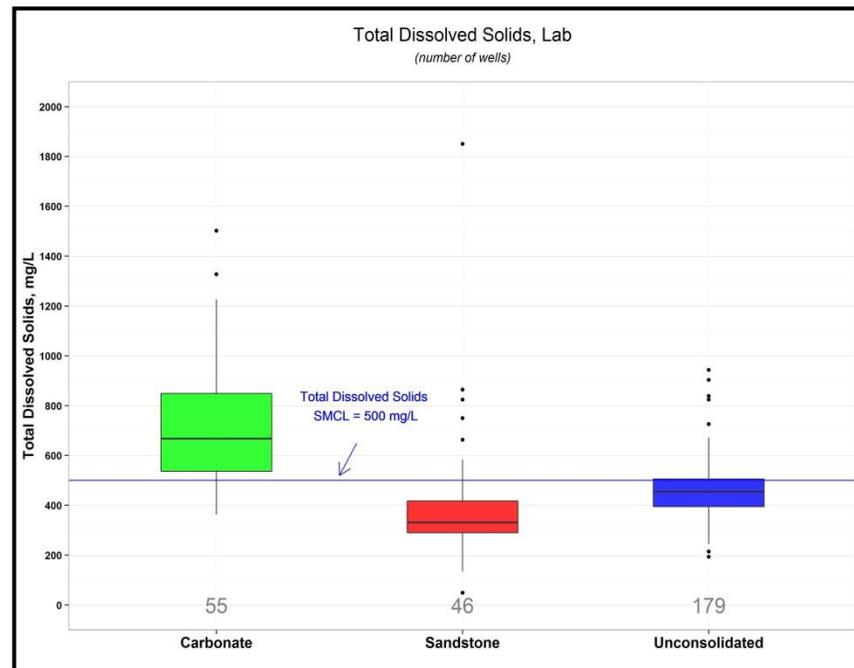


Major Constituents

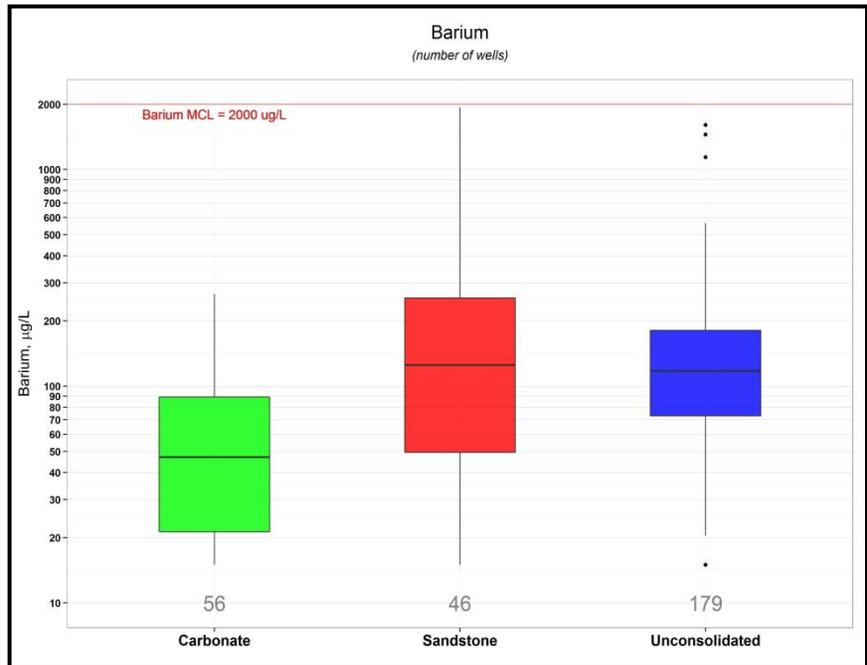
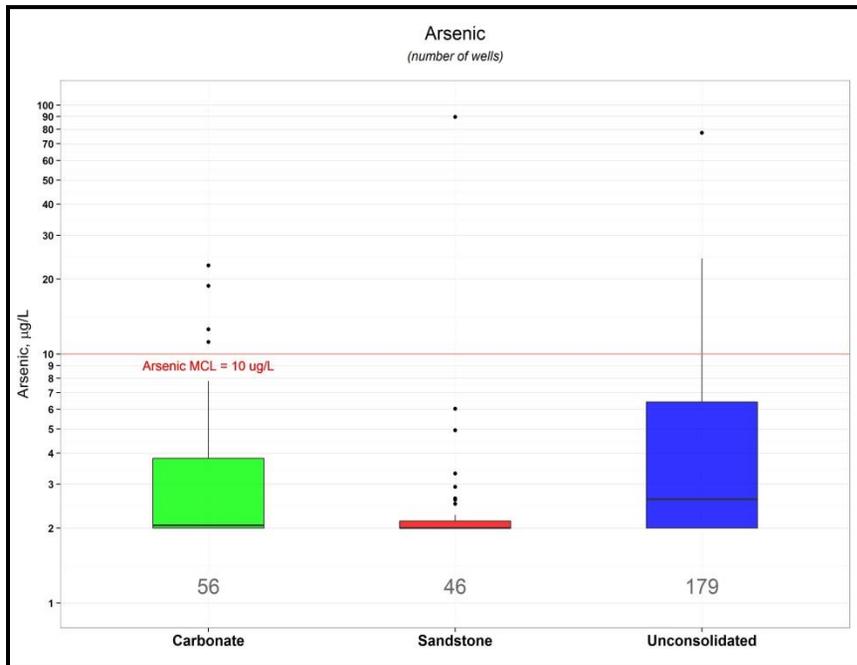
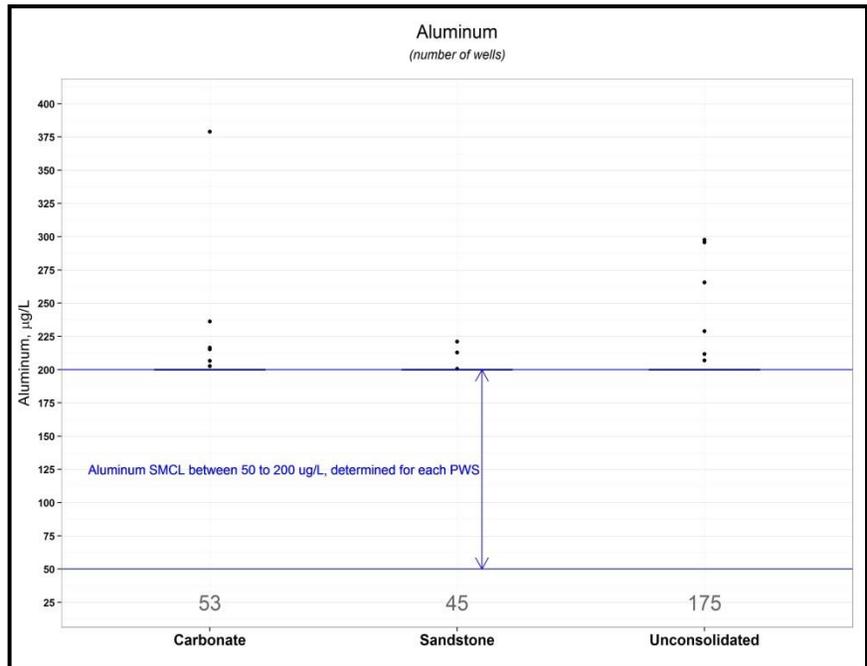


Major Aquifers in Ohio and Associated Water Quality

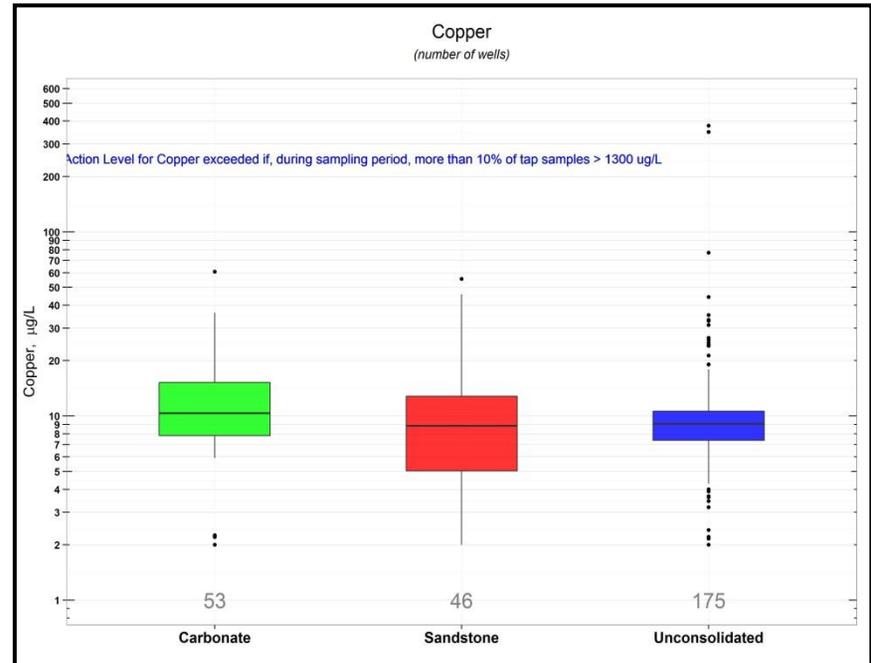
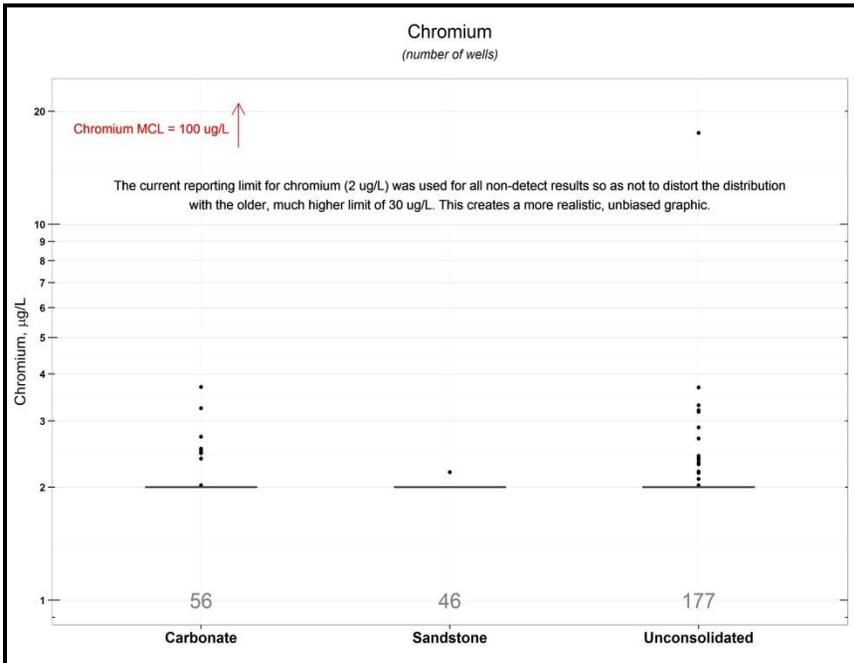
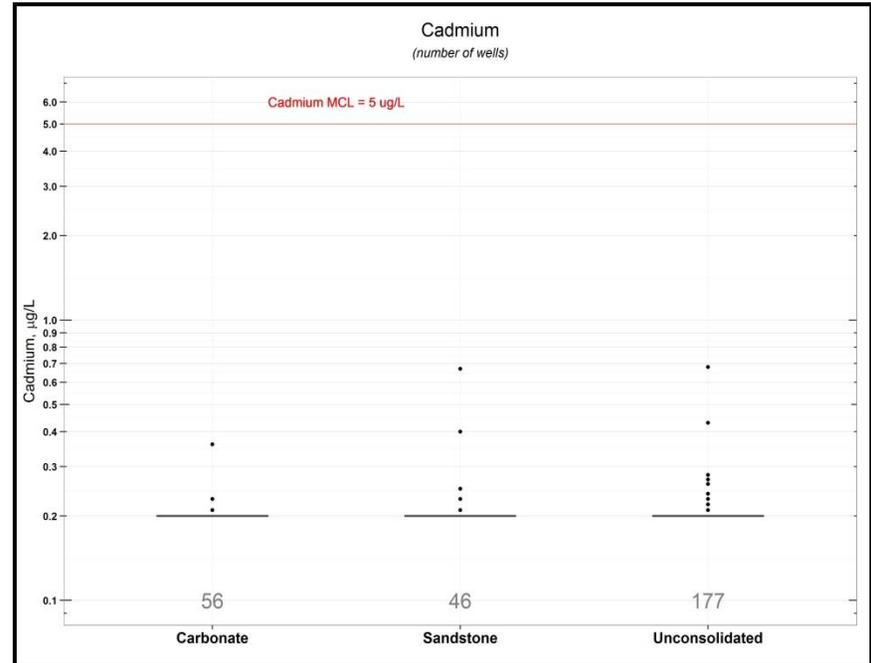
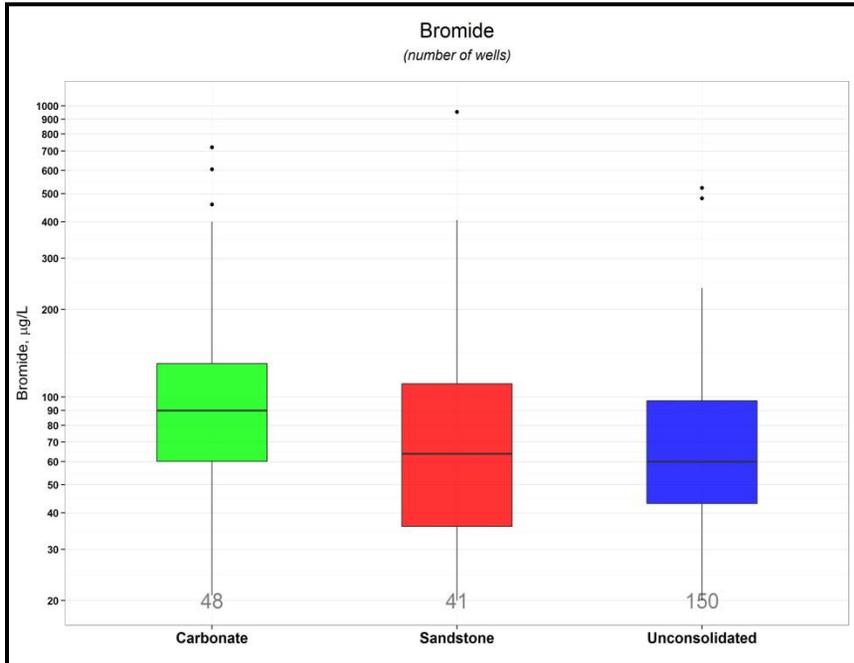




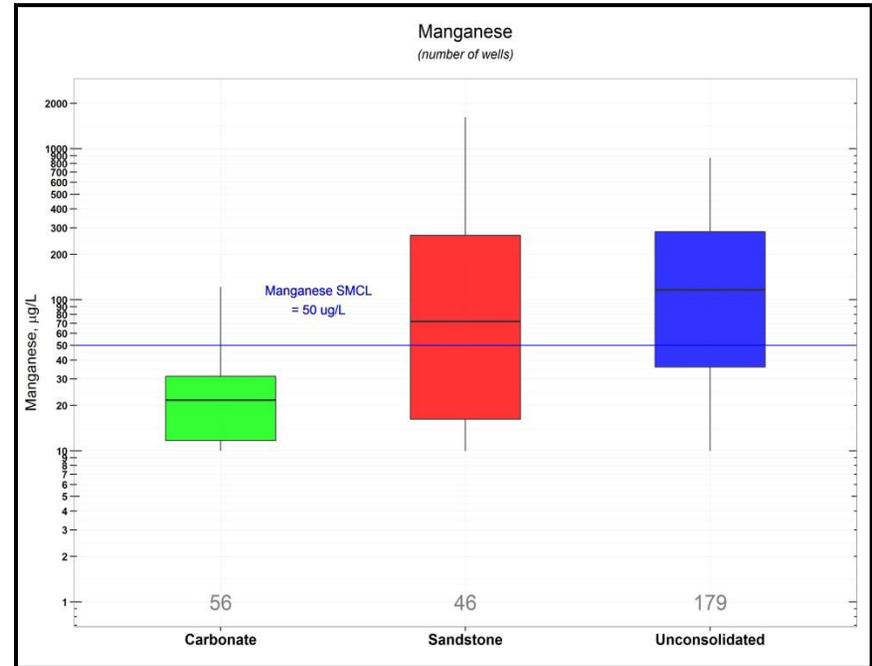
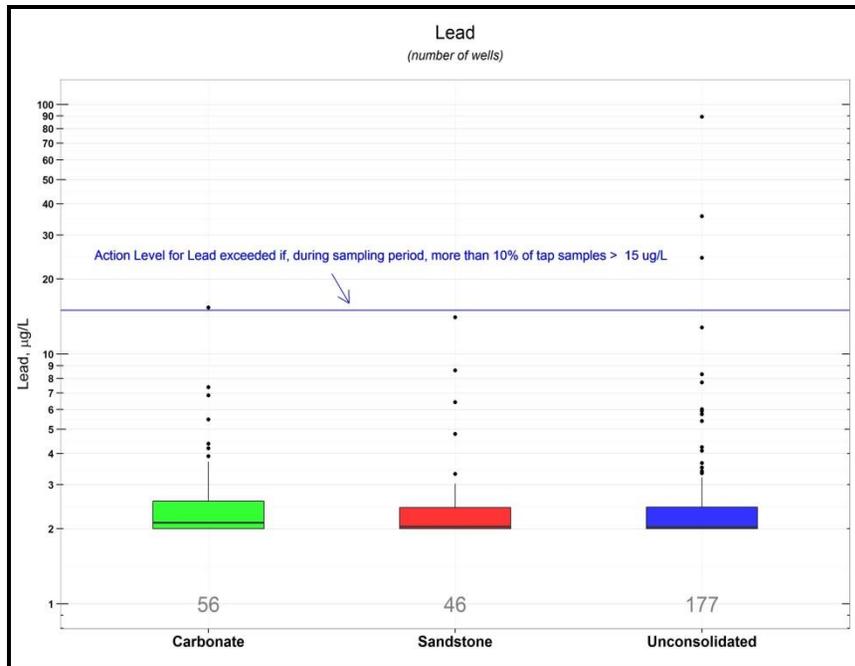
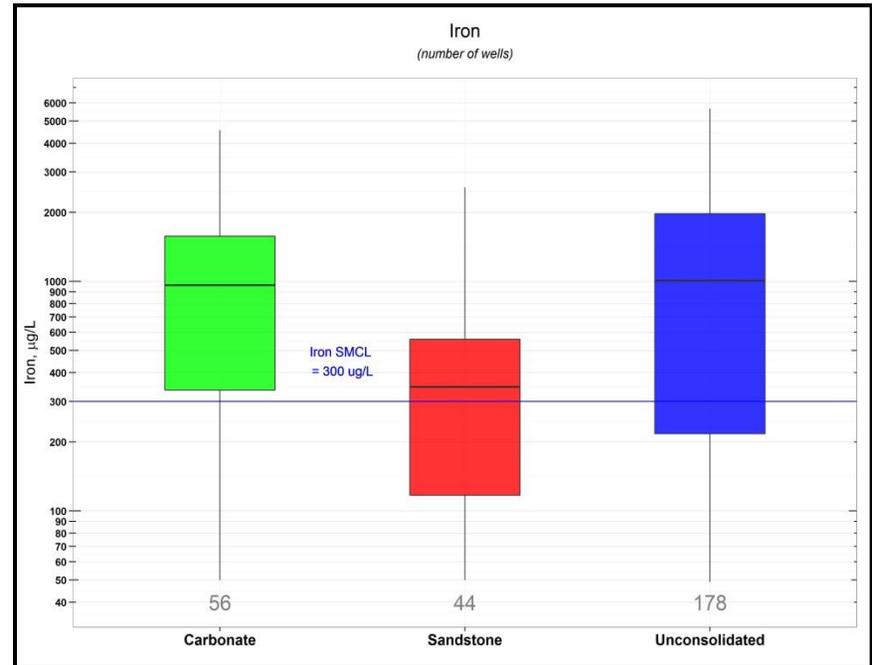
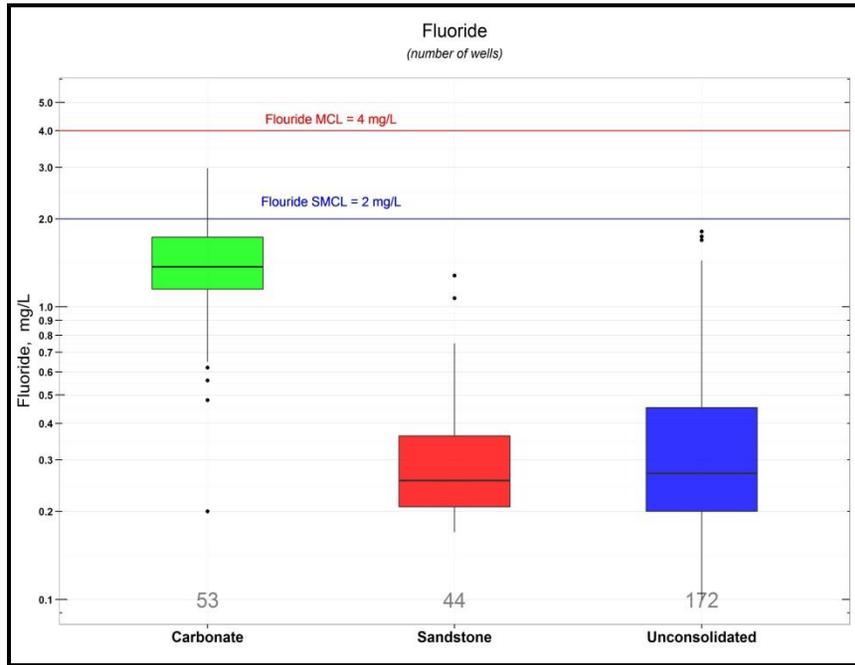
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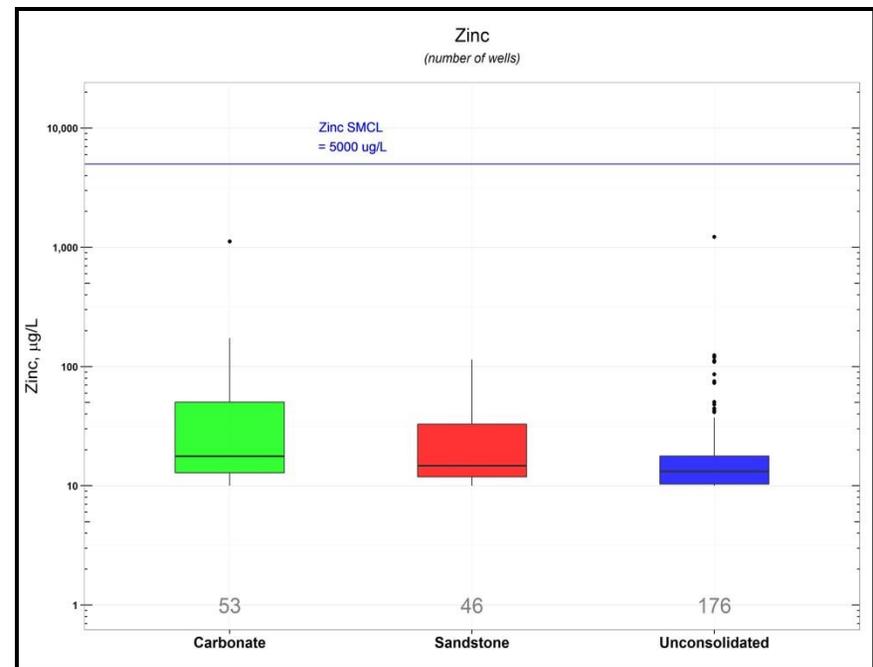
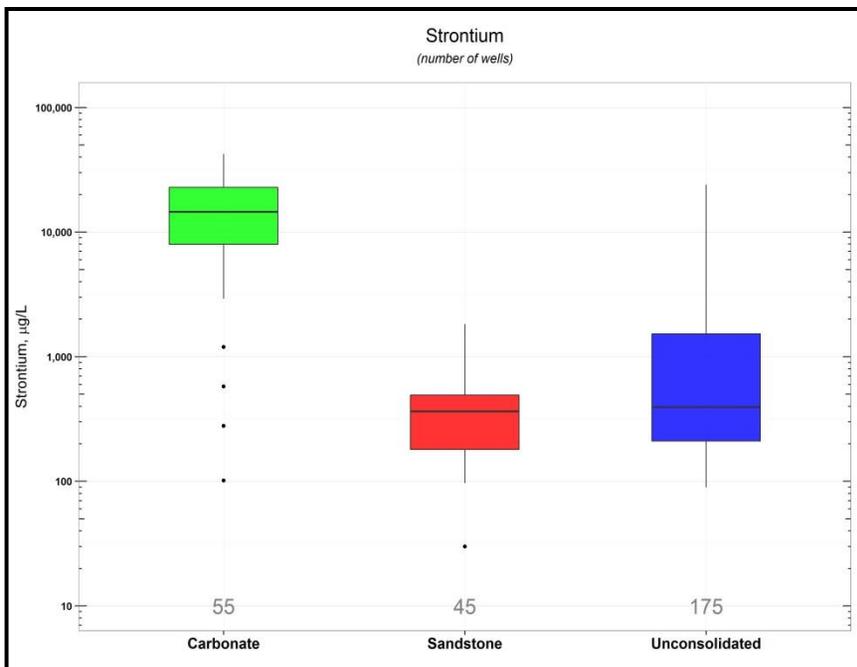
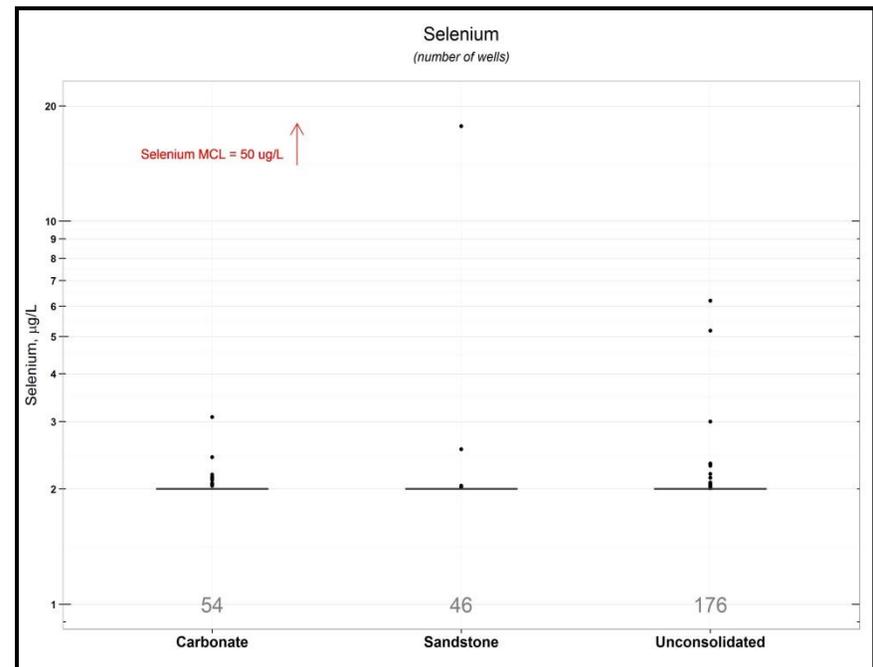
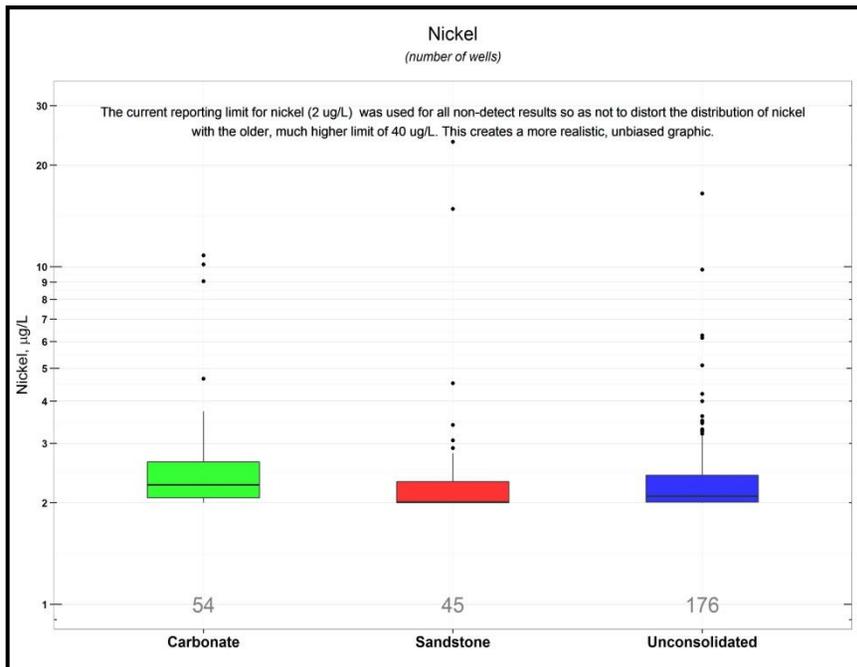
Major Aquifers in Ohio and Associated Water Quality



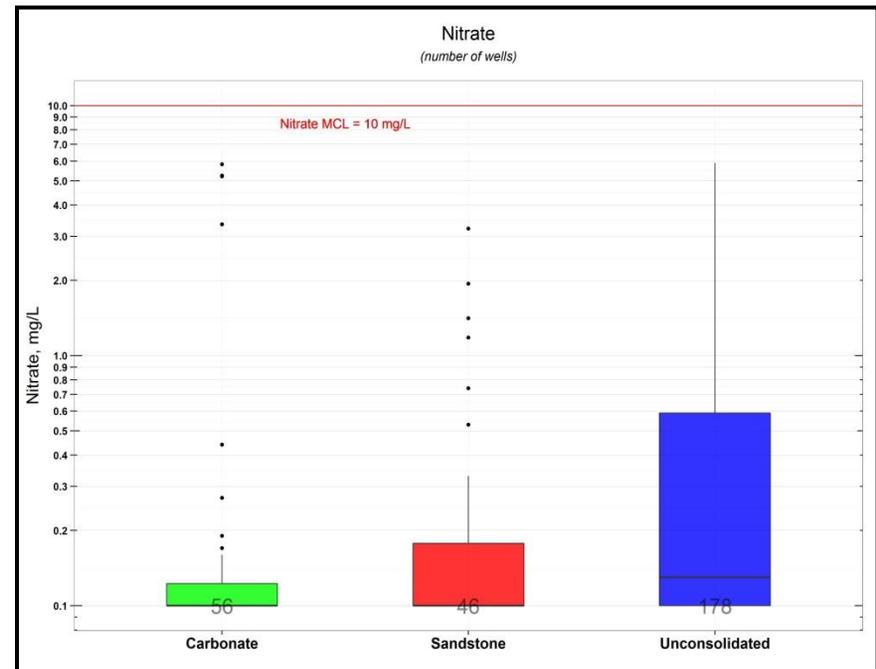
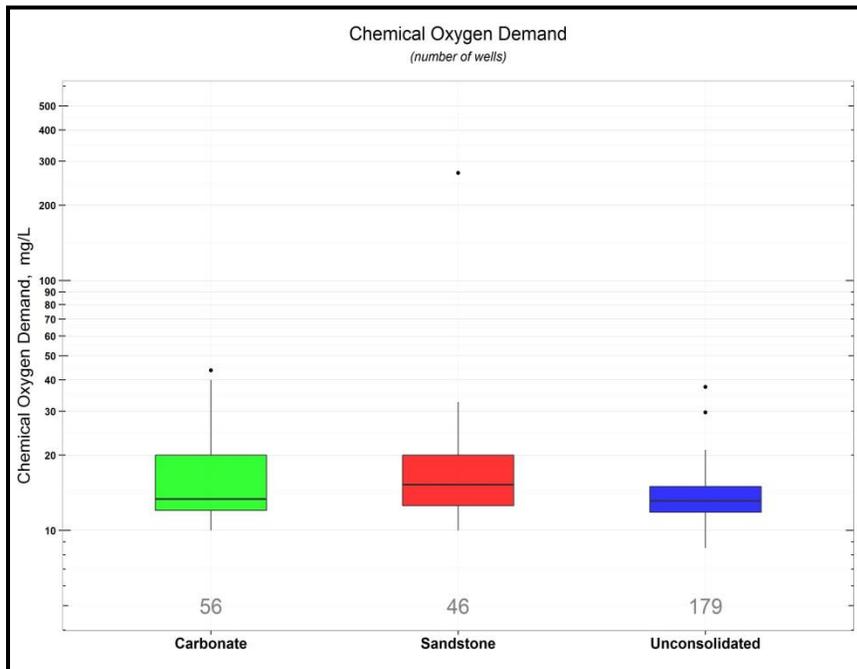
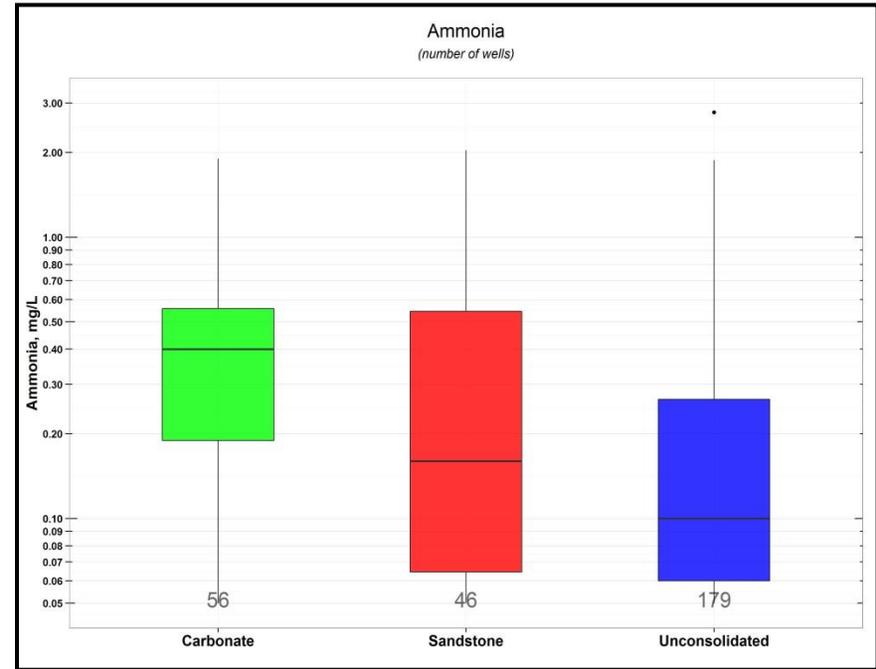
Major Aquifers in Ohio and Associated Water Quality



Major Aquifers in Ohio and Associated Water Quality



Nutrients



Major Aquifers in Ohio and Associated Water Quality

