Section

M

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. 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;
- 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; and
- Resource Conservation and Recovery Act (RCRA) Corrective Action site with ground water contamination in Ohio obtained from the U.S. EPA RCRA Info Database.

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 (MCLs), secondary maximum contaminant levels (SMCLs), health advisory levels (HALs), action levels (lead and copper) and drinking water health advisory levels were applied.

Section M7 briefly discusses a few special studies being performed by Ohio EPA 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 website: ***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.

Program Websites

ODA - Ohio Department of Agriculture

- Pesticide and Fertilizer Regulation Program — ***agri.ohio.gov/apps/odaprs/pestfert-prs-index.aspx***
- Livestock Environmental Permitting Program — ***agri.ohio.gov/divs/dlep/dlep.aspx***

ODH - Ohio Department of Health

- Private Water Systems — ***www.odh.ohio.gov/odhprograms/eh/water/PrivateWaterSystems/main.aspx***
- Sewage Treatment Systems Program — ***www.odh.ohio.gov/odhPrograms/eh/sewage/sewage1.aspx***

ODNR - Ohio Department of Natural Resources (*ohiodnr.gov/*)

- Division of Water Resources — ***water.ohiodnr.gov/***
- Division of Mineral Resources — ***minerals.ohiodnr.gov/***
- Division of Oil and Gas Resources — ***oilandgas.ohiodnr.gov/***
- Division of Geologic Survey — ***geosurvey.ohiodnr.gov/***

Ohio EPA - Ohio Environmental Protection Agency (*epa.ohio.gov*)

- Division of Drinking and Ground Waters — ***epa.ohio.gov/ddagw/***
- Division of Surface Water — ***epa.ohio.gov/dsw/***
- Division of Environmental and Financial Assistance — ***epa.ohio.gov/defa/***
- Office of Compliance Assistance and Pollution Prevention — ***epa.ohio.gov/ocapp/***
- Division of Materials and Waste Management — ***epa.ohio.gov/dmwm/***
- Division of Environmental Response and Revitalization — ***epa.ohio.gov/derr/***

OWRC – Ohio Water Resource Council (*epa.ohio.gov/dsw/owrc.aspx*)

SCCGW – State Coordinating Committee on Ground Water (*epa.ohio.gov/ddagw/SCCGW.aspx*)

SFM/BUSTR – State Fire Marshall/Bureau of Underground Storage Tank Regulations (*com.ohio.gov/fire/*)

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

Programs or Activities	State Activity	Implementation Status*	Responsible Agency
Active SARA Title III Program	✓	E	Ohio EPA – DERR
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
Ground water classification	✓	E [c]	Ohio EPA; ODNR
Ground water quality standards (program specific)	✓	E [d]	Ohio EPA
Ground water quality investigations	✓	CE	Ohio EPA DDAGW
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 – DMRM
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 five 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 Jan. 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.

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.

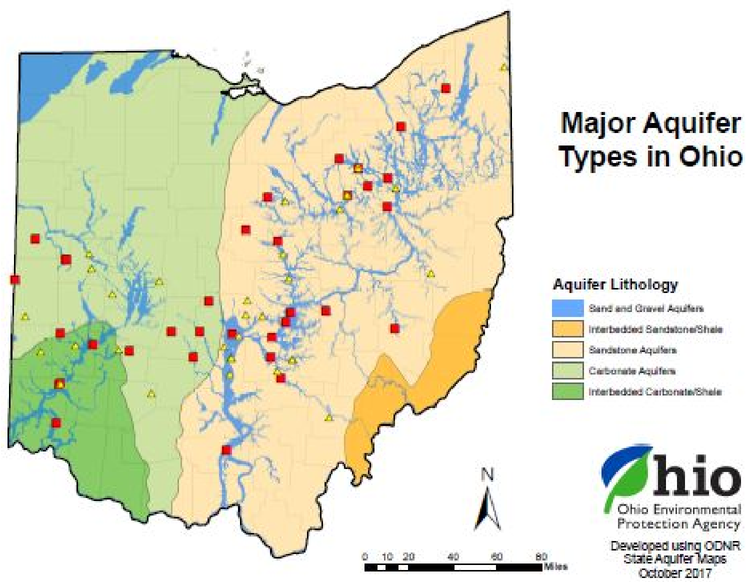

Figure M-1 — Aquifer Types in Ohio modified from ODNR Glacial and Bedrock Aquifer Maps (ODNR, 2000; ***water.ohiodnr.gov/maps/statewide-aquifer-maps****).*

Characterizing Aquifers

In a continuing effort to characterize ground water quality for the professional/technical community and the public, Ohio EPA-DDAGW is writing technical reports and fact sheets on the distribution of specific parameters in Ohio. The goal of the technical reports is to provide water quality information from the major aquifers, indicate 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 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.

Since the *Ohio 2016 Integrated Report*, a draft technical report and fact sheet on iron and manganese has been developed. The documents are based on data from AGWQMP.

Iron and Manganese in Ohio's Ground Water

Iron and manganese in ground water are controlled by three factors: the distribution of iron and manganese minerals in aquifers; the local redox conditions; and, to a lesser degree, pH. Iron is the fourth, and manganese the twelfth, most abundant element in the Earth's crust. They commonly occur in minerals or as coatings and cements in soils and rocks. Iron is widespread and exhibits similar concentrations in ground water in all major aquifers (Figure M-2). Ohio's sandstone aquifers exhibit slightly lower iron than the sand and gravel and carbonate aquifers. AGWQMP data shows manganese at lower concentrations than iron, and the carbonate aquifers show significantly lower manganese than the sandstone and sand and gravel aquifers (Figure M-3). The Pennsylvanian aquifers and associated buried valley aquifers exhibit the highest manganese, presumably due to association with the Pennsylvanian coal measures.

Both iron and manganese exhibit multiple valence states, and the minerals that include them are susceptible to changes in redox conditions. In near surface conditions, iron and manganese are generally tied up in oxide and hydroxide minerals. When these minerals are exposed to low oxygen conditions, the oxide minerals break down and manganese and iron are released into ground water. At the water table, oxygen is exchanged with the atmosphere, the ground water is oxidized, oxide minerals are stable, and little manganese or iron are present in ground water. At greater depths below the water table, the conditions are more reduced, and the microbial reduction starts dissolving the oxide minerals after dissolved nitrate is consumed/reduced. This occurs in an organized sequence: O_2 and NO_3 are consumed, and then manganese and iron are sequentially mobilized. First, manganese is released and then iron in the oxide reduction processes, resulting in elevated manganese and iron. In local environments where pH is low, the acidic nature will increase metal mobilization. There are many areas in Ohio where manganese and iron in ground water exceed U.S. EPA's secondary maximum contaminant levels in deeper aquifers.

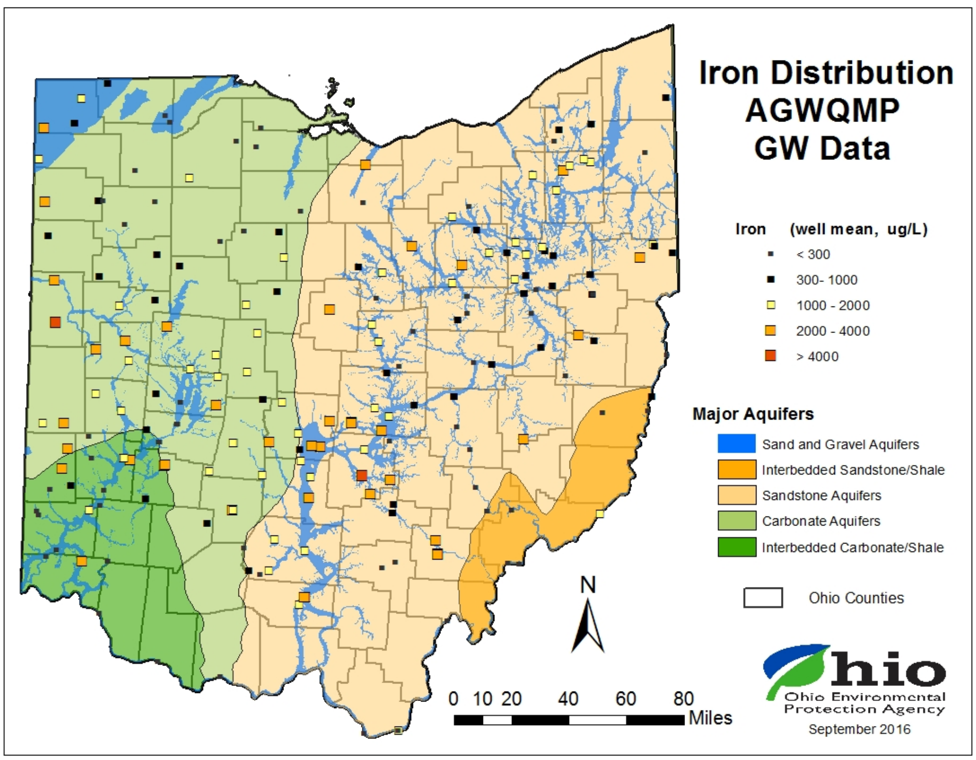

Figure M-2 — Iron distribution in AGWQMP wells, overlain on major aquifers.

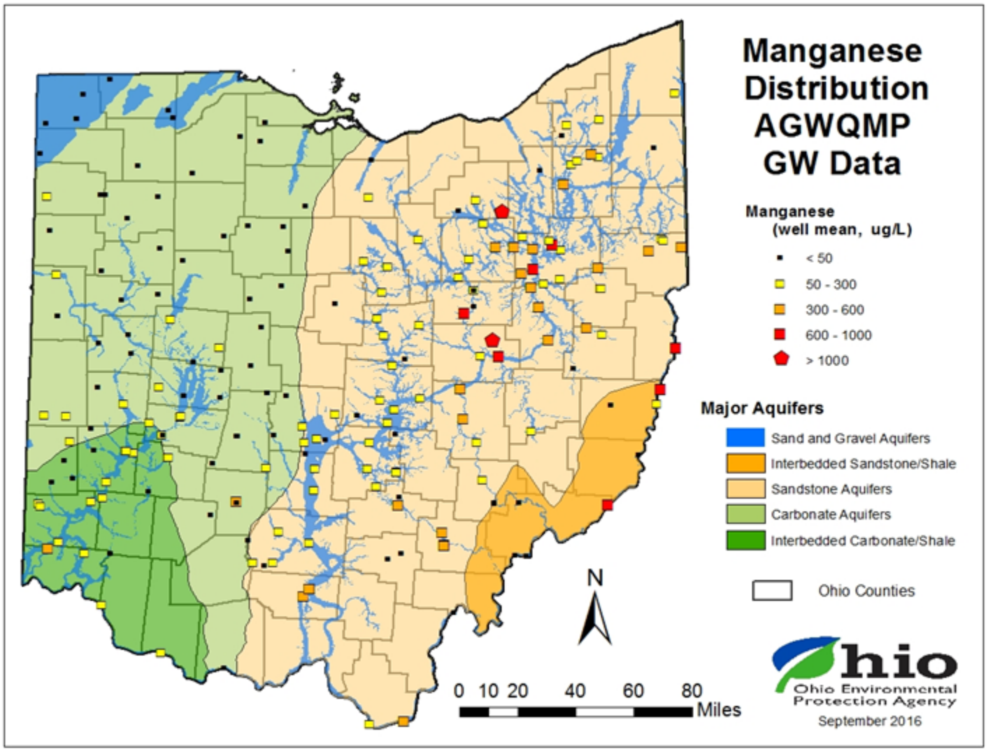

Figure M-3 — Manganese distribution in AGWQMP wells, overlain on major aquifers.

PFOA/PFOS Ground Water Sampling by Ohio EPA DDAGW

In addition to preparing technical papers and fact sheets on Ohio's ground water quality, Ohio EPA also conducts special investigations to characterize ground water contamination and determine its causes.

From September 2016 through January 2017, Ohio EPA's DDAGW sampled ground water at or near current or former portions of the following Ohio Air National Guard (OANG) facilities to determine concentrations of perfluorooctanoic acid (PFOA) and perfluorooctane sulfate (PFOS):

- Rickenbacker Air National Guard Base, Lockbourne, OH
- Springfield-Beckley Municipal Airport, Springfield, OH
- Mansfield Air National Guard Base, Mansfield, OH
- Toledo Air National Guard Base, Swanton, OH

The sampling was in partnership with the OANG, ODH and local health districts. Its purpose was to assess potential health risks to private well users due to PFOA and PFOS. These chemicals have been used in aqueous film forming foam (AFFF), which is known to have been applied to fight fuel-based fires at the airbases and could have entered the ground water due to releases during training, usage or storage.

Exposure to PFOA and PFOS above certain levels may result in adverse health effects, including developmental effects to fetuses during pregnancy or to breast-fed infants, cancer, liver damage, immune system effects and other issues. U.S. EPA has established a drinking water health advisory level for PFOA and PFOS at 70 parts per trillion (ppt).

While the National Guard Bureau (NGB) and the U.S. Air Force (USAF) had scheduled testing for PFOA and PFOS at the four bases in federal fiscal years 2017 and 2018, Ohio EPA and the OANG believed testing should be done sooner to ensure the drinking water is safe.

These Ohio EPA-DDAGW investigations were not intended to take the place of the anticipated detailed federal investigations; rather, they were focused only on evaluating off-base risks to private well users based on available information regarding local ground water conditions and the location of fire training areas.

Private wells were identified for sampling based on publicly available records, the locations of fire training areas determined from perfluorinated compounds preliminary assessment reports and input from base staff during pre-sampling visits, apparent ground water flow direction, consultation with local health departments, and field reconnaissance. Ohio EPA-DDAGW also evaluated the potential for sampling existing or newly installed monitoring wells on-base as a precursor to sampling off-base private wells.

For any exceedances of the U.S. EPA health advisory confirmed by resampling and caused by activities at a base, it was agreed the military would take action to reduce any health effect, such as providing bottled water, installation of water filtration equipment, or providing an alternative source, such as connection to a public water system.

Ohio EPA-DDAGW staff performed the ground water sampling, accompanied by local health department staff where appropriate. Private wells were sampled at an outdoor faucet to bypass any water softeners or point-of-use water filters and avoid the potential influence of items inside the home that could contain PFOA or PFOS, which have been used for many years to make carpets, clothing, fabrics for furniture, paper packaging for food, non-stick cookware, and other materials that are resistant to water, grease or stains.

The sampling protocol was consistent with DDAGW documents; however, the language was enhanced to emphasize the increased importance of factors that could influence PFOA/PFOS analysis at the parts per trillion level, including minimizing cross-contamination due to clothing, the vehicles used for travel and use of personal care products. Sample analysis were performed by Northern Lake Service Inc. (400 North Lane Avenue, Crandon, WI 54520) using U.S. EPA Method 537.

Results from sampling the four Air National Guard Bases

Nine private wells north-northwest of the northern boundary of the Springfield-Beckley Municipal Airport were sampled Nov. 29, 2016. All nine samples were found to be non-detect for PFOA and PFOS.

Two private wells northwest of Mansfield Lahm Airport (Mansfield Air National Guard Base) were sampled on Dec. 20, 2016, and one more was sampled on Jan. 3, 2017. All three samples were found to be non-detect for PFOA and PFOS.

The former Fire Training Area (FT-23) is located southeast of the current Rickenbacker Air National Guard Base property on land owned by the Columbus Regional Airport Authority (CRAA). On Aug. 31, and Sept. 1, 2016, CRAA installed four new shallow monitoring wells around FT-23. One of these monitoring wells was intended to be hydraulically upgradient of FT-23 while the other three were intended to be downgradient and were situated in between FT-23 and the identified off-base private wells.

Ohio EPA-DDAGW sampled MW-1, MW-2 and MW-3 on Sept. 14, 2016. MW-4 could not be sampled due to inadequate well development. Ohio EPA believes that the absence of detectable PFOA and PFOS in ground water samples from monitoring wells on CRAA property between FT-23 and the identified private wells in the London-Lancaster Road neighborhood to the east indicates that no health risks are occurring related to PFOA/PFOS.

From Dec. 13, 2016 through Jan. 31, 2017, 16 private wells to the east of the Toledo Air National Guard Base were sampled. While no PFOS was detected, PFOA was detected above the 70 ppt U.S. EPA HAL at one well, below the HAL but above the limit of quantitation at three wells, and below the limit of quantitation at three wells. The Ohio Air National Guard provided an alternative source of water for the residents at the home with the well above 70 ppt.

Results from Youngstown-Warren Airport/Air Reserve Station

The U.S. Air Force has begun the investigative process at Youngstown-Warren Air Reserve Station (YARS) regarding PFOA/PFOS. Ohio EPA partnered with the U.S. Air Force, ODH and the local health district to determine risk to domestic wells. Four private wells surrounding YARS were identified through their proximity to the identified fire training area. These wells were sampled on April 18 and April 25, 2017, and all four samples were found to be non-detect for PFOA/PFOS. Sampling protocols and analytical methodology used for these samples were the same as for the Ohio National Guard Bases noted above.

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 August 2017

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	38 proposed	30	30	Mostly VOCs and heavy metals; also, SVOCs, PCBs, PAHs and others
CERCLIS (non- NPL) - U.S. EPA	411	411	20	Varied
DOD/DOE	128[a]	71	68	Varied
LUST	34,992[b]	4,133	111[c]	BTEX
RCRA Corrective Action	254	206	206	VOCs, heavy metals, PCBs and others
Underground Injection	Class[d]: I -13 II – 408 III – 49 IV – 5 V – 48,586	 0 0 0 0 14,238	 0 0 0 0 NA	
State Sites [e]	776	776	264[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, BUSTR

[c] Sites in Tier 2 or Tier 3 cleanup stages. Source: Ohio's State Fire Marshal, BUSTR

[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, 38 sites in Ohio are on the NPL, most of which 30 have been found to be affecting ground water quality. The primary contaminants are volatile organic compounds (VOCs) and heavy metals. Other contaminants include semi-volatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) (non-NPL): Ohio has 411 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 approximately 35,000 sites have been found to be leaking. Of these, 5,312 have confirmed releases, with 111 having a release to ground water. The primary contaminants are the petroleum products of benzene, toluene, ethyl benzene and xylenes.

RCRA Corrective Action: Currently, 254 facilities are in RCRA corrective action. Of these, 206 have confirmed releases to ground water. The primary contaminants are VOCs and heavy metals. This information was obtained from the U.S. EPA RCRA Info Database.

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

- Class I wells inject hazardous wastes or other wastewaters beneath the lowermost aquifer;
- Class II wells inject brines and other fluids associated with oil and gas production beneath the lowermost aquifer;
- Class III wells inject fluids associated with solution mining of minerals beneath the lowermost aquifer;
- 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);
- Class V wells comprise all injection wells not included in Classes I-IV;
- Class VI wells are regulated by U.S. EPA for carbon sequestration.

The Ohio Department of Natural Resources, Division of Oil and Gas Resources regulates Class II (409) and Class III (49) wells. The number of Class II brine injection wells (one of three types of Class II wells) has leveled as their use in disposal of fluids used in oil and gas drilling and shale gas development has slowed. In addition to the 217 active brine injection wells there are 20 wells that are between the permitted and active stage. The other types of Class II wells include 127 enhanced recovery wells and 64 annular disposal wells.

Ohio EPA DDAGW regulates Class I (13), Class IV (5) and Class V (48,586) 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 August 2017, the database contained 776 sites. Of the 776 sites, 264 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. From a statewide perspective, major sources are discussed below.

The major sources of ground water contamination in Ohio are indicated in Table M-3. The 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. Of the active public water systems that use ground water, 99 percent 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 (×), 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.

Contaminant Source Discussion - All 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 5,312 USTs known to be leaking or undergoing remediation in Ohio. Of these, 1,321 are in drinking water source protection areas for public water systems using ground water. Above-ground tanks are also prevalent throughout Ohio, with 1,225 located in drinking water source protection areas 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 14 ASTs in the ground water impacts database known to be contaminating ground water from regulated hazardous waste facilities.

Landfills: Currently, there are 130 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 20 years ago, resulting in new landfills with significantly lower potential to impact ground water quality. Efforts to monitor C&DD landfills and characterize associated ground water quality impacts were initiated in 2015.

Septic Systems: More than 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 (for example, shallow fractured bedrock and sand and gravel deposits). More than 1,960 septic systems are in drinking water source protection areas. There are 220 septic systems discharging to surface water and 1,740 systems discharging to tanks, leachfields/mounds. The updated Household Sewage Treatment Systems Rules became effective on Jan. 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. Ohio EPA has records for 60,910 Class V wells. Of these, 14,159 are listed as active and 3,914 are listed as temporarily abandoned. The rest (42,837) are reported to be closed and abandoned. Of the identified wells, the majority are mine backfill wells (35,721) used to inject grout into deep mines underneath roadways. The next largest segment of Class V wells (16,459) are used to inject fluids to assist in remediating contaminated aquifers. The last major segment of Class V wells are storm drainage 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.

Hazardous Waste Sites: Ohio generates a large amount of hazardous waste. Legacy hazardous waste sites are a serious threat to ground water. There are 64 RCRA hazardous waste facilities, 18 Voluntary Action Program sites and 62 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 (1,145) and sewer lines (819) 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. Seventy-six salt storage piles were identified directly in drinking water source protection areas with 47 of these located in sensitive aquifer settings. One hundred and twenty-four are within one-half mile of a source water protection area and 79 are within a half-mile of a designated sensitive aquifer. Most of these sites had adequate covering and pads. In addition to addressing these sites, Ohio is exploring ways to encourage implementation of best management practices for proper salt storage. Alternative chemicals like acetate-based deicers in combination with reduced salt usage are being promoted in pollution prevention programs. A 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: ***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 1,250 storm drains are located within 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 1,693 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.

Fire Training Facilities: Foams containing PFOA and PFOSs are known to have been applied to fight fuel-based fires at airbases and other fire training facilities. These chemicals could have entered the ground water due to releases during training, usage or storage. Ohio EPA has performed sampling in partnership with the Ohio Air National Guard (OANG), the Ohio Department of Health and local health districts to assess potential health risks to private well users. These Ohio EPA-DDAGW investigations were not intended to take the place of the upcoming detailed federal investigations; rather, they were focused on evaluating risks to private well users based on available information regarding local ground water conditions and the location of fire training areas.

(✘) 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 10 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. Twenty-five surface impoundments are known to be contaminating ground water based on information obtained from Ohio EPA's ground water impacts database, the 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.

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 (for example, 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.

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

Contaminant Source	Highest-Priority Sources	Factors Considered in Selecting a Contaminant Source	Contaminants
Agriculture Activities			
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			
Storage and Treatment Activities			
Land application			
Material stockpiles			
Storage tanks (above/below ground)	✓	1, 2, 3, 4, 5, 6, 7	C, D, H, M, N
Surface impoundments	×	6	G, H, M
Waste piles			
Waste tailings			
Disposal Activities			
Deep injection wells			
Landfills	✓	1, 2, 3, 4, 5, 6	A, B, C, D, H, M, N
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
Other			
Fire training areas	✓	1,3	N
Hazardous waste generators			
Hazardous waste sites	✓	1, 2, 3, 4, 5, 6, 7	A, B, C, D, H, I, M, N
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, N

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)
	N. PFOS/PFOA

M6. Summary of Ground Water Quality by Aquifer

Table M-4 and Table M-5 (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-4) documents water quality for treated water (post processing) and some raw (untreated) water quality (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-5) 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 levels (MCLs), secondary maximum contaminant levels (SCMLs), health advisory levels (HALs), action levels (copper and lead), and drinking water advisory levels (sodium and sulfate). 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. HALs are levels in drinking water below which there are no adverse health effects over different time periods, such as one day, 10-day, long-term or lifetime. Action levels for lead and copper are set such that if more than 10 percent of tap water samples are above the action level, requirements may be triggered including: water quality parameter monitoring; corrosion control treatment; source water monitoring/treatment; public education; and/or lead service line replacement. Drinking water advisory levels for sodium and sulfate provide information on contaminants that can cause human health effects and are known or anticipated to occur in drinking water. The sodium drinking water advisory level applies only to adults on a low-salt diet.

Primary and secondary MCLs, HALs, action levels and drinking water advisory levels are used as practical benchmarks for water quality characterization in Table M-4 and Table M-5. For primary and secondary MCLs, 50 to 100 percent of the benchmark 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. Benchmark exceedances are used as the criteria for the impaired category for each of the five benchmarks: primary and secondary MCLs, HALs, action levels and drinking water advisory levels. Table

M-4 and Table M-5 were generated using the last 10 years of data (1/1/2007-8/17/2017). Mean concentrations of a parameter are used to decide if a public water system or well is included in the watch list (50 to 100 percent of the benchmark) or impaired category (> benchmark). 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 2007-2017 to determine the number of public water systems on the watch list and in the impaired category. A 10-year period of record was used to increase the statistical significance of the determination due to the infrequent sampling requirements (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.** A benchmark exceedance for compliance is generally an annual average, so the **decadal average presented in Table M-4 is not a compliance number**, but rather a comparison to set values, as a benchmark to identify public water systems in the watch list and impaired categories.

Table M-4 lists all parameters with MCLs, SMCLs, HALs, action levels and drinking water advisory levels and summarizes the number of public water systems in the watch list (MCLs and SMCLs only) and impaired category for both raw and treated water quality data (all five benchmarks). 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 levels. Data from active and inactive systems is included in Table M-4. For parameters with non-MCL benchmarks, treated water data is limited or absent because compliance data is generally not required for aesthetic water quality issues.

Except for 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-4 for treated water 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, HALs, action levels or drinking water advisories. That is, the water quality impacts documented are mostly aesthetic issues and are not health-based. Groups of parameters are discussed individually.

Table M-4 — Counts of public water systems where 2007-2017 decadal mean values of compliance data occur in the Watch List and Impaired Category.

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Inorganics	Aluminum	SMCL	200 µg/L	Sand and Gravel						
				Sandstone						
				Carbonate						
	Ammonia	Lifetime HAL	30 mg/L	Sand and Gravel	9					
				Sandstone	11					
				Carbonate	26					
	Antimony	MCL	6 µg/L	Sand and Gravel	284	2	1	702	6	
				Sandstone	286	5	1	712	9	1
				Carbonate	260	4		447	5	1
	Arsenic	MCL	10 µg/L	Sand & Gravel	367	60	68	705	87	44
				Sandstone	318	20	20	719	48	11
				Carbonate	316	53	51	447	65	36
	Asbestos	MCL	7x106 fibers/L	Sand and Gravel	35			169		
				Sandstone	10			50		
				Carbonate	12			62		
	Barium	MCL	2000 µg/L	Sand and Gravel	295	4		703	5	
				Sandstone	301	6	1	714	2	
				Carbonate	261	1	1	446	1	
	Barium	1/10 Day HAL	700 µg/L	Sand and Gravel	295		9	702		10
				Sandstone	301		9	714		5
				Carbonate	261		3	445		2
	Beryllium	MCL	4 µg/L	Sand and Gravel	284	2		702		1
				Sandstone	287			713		
				Carbonate	257			446		
	Cadmium	MCL	5 µg/L	Sand and Gravel	288		1	702	1	
				Sandstone	287		1	713	2	
				Carbonate	257			446		
	Cadmium	Lifetime HAL	5 µg/L	Sand and Gravel	288		1	701		
				Sandstone	287		1	713		
				Carbonate	257			445		

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Inorganics	Cadmium	1/10 Day HAL	40 µg/L	Sand and Gravel	288			701		
				Sandstone	287			713		
				Carbonate	257			445		
	Chloride	SMCL	250 mg/L	Sand and Gravel	259	5	1			
				Sandstone	293	15	10			
				Carbonate	249	3	2			
	Chromium	MCL	100 µg/L	Sand and Gravel	286			702		
				Sandstone	285	1	1	713	1	
				Carbonate	259			446		
	Chromium	1/10 Day HAL	1000 µg/L	Sand and gravel	286			701		
				Sandstone	285			713		
				Carbonate	259			445		
	Copper	Action Level	1300 µg/L	Sand and Gravel	309			603		
				Sandstone	333			624		
				Carbonate	262			356		
	Cyanide	MCL	0.2 mg/L	Sand and Gravel	275			702	1	
				Sandstone	285			713		
				Carbonate	255			446		
	Fluoride	MCL	4 mg/L	Sand and Gravel	304	1		702	6	
				Sandstone	298	1		713	1	
				Carbonate	269	21		446	20	
	Fluoride	SMCL	2 mg/L	Sand and Gravel	304	1		702	6	
				Sandstone	298	1		713	1	
				Carbonate	269	21		446	20	
	Iron	SMCL	300 µg/L	Sand and Gravel	295	14	162			
				Sandstone	295	37	144	1		
				Carbonate	278	22	140	1		1
	Lead	Action Level	15 µg/L	Sand and Gravel						
				Sandstone						
				Carbonate						
	Manganese	SMCL	50 µg/L	Sand and Gravel	264	40	106			
				Sandstone	295	32	146	1		
				Carbonate	251	42	45	1		1

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Inorganics	Manganese	Lifetime HAL	300 µg/L	Sand and Gravel	264		26			
				Sandstone	295		36	1		
				Carbonate	251		3	1		
	Manganese	1/10 Day HAL	1000 µg/L	Sand and Gravel	264		5			
				Sandstone	295		5	1		
				Carbonate	251		2	1		
	Mercury	MCL	2 µg/L	Sand and Gravel	281		1	702		
				Sandstone	287	1		713		1
				Carbonate	257	1		446		
	Nickel	Lifetime HAL	100 µg/L	Sand and Gravel	287			701		2
				Sandstone	288		1	713		2
				Carbonate	260		1	445		
	Nickel	1/10 Day HAL	1000 µg/L	Sand and Gravel	287			701		
				Sandstone	288			713		
				Carbonate	260		1	445		
	Nitrate * (Max Value)	MCL	10 mg/L	Sand and Gravel	349	16	9	1603	57	17
				Sandstone	331	6	4	2053	31	5
				Carbonate	286	6	7	1397	34	2
	Nitrate* (Max Value)	1/10 Day HAL	100 mg/L	Sand and Gravel	349			1601		1
				Sandstone	331			2053		
				Carbonate	286			1393		
	Nitrite * (Max Value)	MCL	1 mg/L	Sand and Gravel	326			1611	1	2
				Sandstone	311	1		2062	3	3
				Carbonate	269			1407	1	
	pH	SMCL	6.5-8.5 SU	Sand and Gravel						
				Sandstone						
				Carbonate						
	Selenium	MCL	50 µg/L	Sand and Gravel	284			702		
				Sandstone	288			713		
				Carbonate	258	2		446		
	Selenium	Lifetime HAL	50 µg/L	Sand and Gravel	284			701		
				Sandstone	288			713		
				Carbonate	288			445		

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Inorganics	Silver	SMCL	100 µg/L	Sand and Gravel	248		1			
				Sandstone	274			1		
				Carbonate	241		1			
	Sodium**	DW Advisory	20 mg/L	Sand and Gravel	246		94			
				Sandstone	280		141	1		
				Carbonate	241		117			
	Strontium	Lifetime HAL	4000 µg/L	Sand and Gravel	3		1			
				Sandstone	3					
				Carbonate	1		1			
	Strontium	1/10 Day HAL	25000 µg/L	Sand and Gravel	3					
				Sandstone	3					
				Carbonate	1					
	Sulfates	SMCL	250 mg/L	Sand and Gravel	291	17	15			
				Sandstone	299	12	17			
				Carbonate	270	30	83	1		
	Sulfates	DW Advisory	500 mg/L	Sand and Gravel	291		9			
				Sandstone	299		7			
				Carbonate	270		54	1		
	Thallium	MCL	2 µg/L	Sand and Gravel	282	2	1	702	3	
				Sandstone	286		1	713	2	1
				Carbonate	257	1		446		1
	Total Dissolved Solids	SMCL	500 mg/L	Sand and Gravel	119	50	30			
				Sandstone	167	71	32			
				Carbonate	144	23	79			
	Zinc	SMCL	5000 µg/L	Sand and Gravel	155					
				Sandstone	145			1		
				Carbonate	137					
	Zinc	Lifetime HAL	2000 µg/L	Sand and Gravel	155					
				Sandstone	145			1		
				Carbonate	137		1			
	Zinc	1/10 Day HAL	6000 µg/L	Sand and Gravel	155					
				Sandstone	145			1		
				Carbonate	137					

Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Public Water Systems: Raw Water: Total # public water systems	Raw Water: Watch List > 50% to 100% Standard	Raw Water: Impaired > Standard	Treated Water: Total # public water systems	Treated Water: Watch List > 50% to 100% Standard	Treated Water: Impaired > Standard
Volatile Organic Chemicals	1,2-Dichloroethane	MCL	5 µg/L	Sand and Gravel	326	1		706		
				Sandstone	321			719		1
				Carbonate	277			451		1
	1,1-Dichloroethylene	MCL	7 µg/L	Sand and Gravel	327	1		707		
				Sandstone	321		1	719		1
				Carbonate	277			451		
	1,2-Dichloropropane	MCL	5 µg/L	Sand and Gravel	328		1	707		1
				Sandstone	322			719		
				Carbonate	277			451	1	
	1,1,1-Trichloroethane	MCL	200 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277			451		
	1,1,2-Trichloroethane	MCL	5 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277			451		
	1,2,4-Trichlorobenzene	MCL	70 µg/L	Sand and Gravel	328			707		
				Sandstone	321			719		
				Carbonate	277			451		
	Benzene	MCL	5 µg/L	Sand and Gravel	327		3	707		
				Sandstone	322			719		
				Carbonate	275			451		
	Carbon Tetrachloride	MCL	5 µg/L	Sand and Gravel	328	1		707		1
				Sandstone	322	1	1	719		
				Carbonate	277			451		
	Chlorobenzene	MCL	100 µg/L	Sand and Gravel	328					
				Sandstone	321					
				Carbonate	277					
	Cis-1,2-Dichloroethylene	MCL	70 µg/L	Sand and Gravel	328			707		
				Sandstone	321			719		
				Carbonate	277			451		
	Dichloromethane	MCL	5 µg/L	Sand and Gravel	327	2	1	707	2	1
				Sandstone	316	1	1	719		1
				Carbonate	276		1	451	1	1

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Volatile Organic Chemicals	Ethyl benzene	MCL	700 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277			451		
	o-Dichlorobenzene	MCL	600 µg/L	Sand and Gravel	328			707		
				Sandstone	321			719		
				Carbonate	277			451		
	p-Dichlorobenzene	MCL	75 µg/L	Sand and Gravel	328			707		
				Sandstone	320			719		
				Carbonate	277			451		
	Styrene	MCL	100 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277	1		451		
	Tetrachloroethylene	MCL	5 µg/L	Sand and Gravel	328	3	3	707	3	
				Sandstone	322	1	2	719	1	1
				Carbonate	277			451	1	
	Toluene	MCL	1000 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277			451		
Volatile Organics	Trans-1,2-Dichloroethylene	MCL	100 µg/L	Sand and Gravel	328			707		
				Sandstone	322			719		
				Carbonate	277			451		
	Trichloroethylene	MCL	5 µg/L	Sand and Gravel	328	3		707		
				Sandstone	322		1	719	1	
				Carbonate	276	1	1	451	1	
	Vinyl Chloride	MCL	2 µg/L	Sand and Gravel	328	3	2	706		2
				Sandstone	321			719		
				Carbonate	277			451		
	Xylenes, Total	MCL	10 mg/L	Sand and Gravel	327			707		
				Sandstone	318			719		
				Carbonate	276			451		

Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Public Water Systems: Raw Water: Total # public water systems	Raw Water: Watch List > 50% to 100% Standard	Raw Water: Impaired > Standard	Treated Water: Total # public water systems	Treated Water: Watch List > 50% to 100% Standard	Treated Water: Impaired > Standard
Pesticides and Synthetic Organic Chemicals	Alachor (Lasso)	MCL	2 µg/L	Sand and Gravel	270			707		
				Sandstone	281			723		
				Carbonate	241			453		
	Atrazine	MCL	3 µg/L	Sand and Gravel	269			707		
				Sandstone	282			723		
				Carbonate	241			453		
	Benzo(a)Pyrene	MCL	0.2 µg/L	Sand and Gravel	3			94	1	
				Sandstone				47		
				Carbonate	3			19		
	Carbofuran	MCL	40 µg/L	Sand and Gravel	3			98		
				Sandstone	1			44		
				Carbonate	2			20		
	Chlordane	MCL	2 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	2,4-D	MCL	70 µg/L	Sand and Gravel	5			97		
				Sandstone	2			44		
				Carbonate	2			20		
	Dalapon	MCL	200 µg/L	Sand and Gravel	5					
				Sandstone						
				Carbonate						
	Dibromochloro-propane (DBCP)	MCL	0.2 µg/L	Sand and Gravel						
				Sandstone						
				Carbonate						
	Di(2-ethylhexyl) adipate	MCL	400 µg/L	Sand and Gravel	4			94		
				Sandstone				47		
				Carbonate	5			19		
	Di(2-ethylhexyl) phthalate	MCL	6 µg/L	Sand and Gravel	4			97		2
				Sandstone				48		
				Carbonate	5	1		21		1
	Dinoseb	MCL	7 µg/L	Sand and Gravel	5					
				Sandstone						
				Carbonate	1					

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Pesticides and Synthetic Organic Chemicals	Diquat	MCL	20 µg/L	Sand and Gravel	3			100		
				Sandstone				46		
				Carbonate	2			18		
	Endothall	MCL	100 µg/L	Sand and Gravel	3			94		
				Sandstone				47		
				Carbonate	2			19		
	Endrin	MCL	2 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	Ethylene Dibromide	MCL	0.05 µg/L	Sand and Gravel	6					
				Sandstone						
				Carbonate						
	Glyphosate	MCL	700 µg/L	Sand and Gravel	3			97		
				Sandstone				46		
				Carbonate	2			18		
	Heptachlor	MCL	0.4 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	Heptachlor Epoxide	MCL	0.2 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	Hexachlorobenzene	MCL	1 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	Hexachloro-cyclopentadiene	MCL	50 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
	Lindane	MCL	0.2 µg/L	Sand and Gravel	4			97		
				Sandstone				46		
				Carbonate	2			18		
	Methoxychlor	MCL	40 µg/L	Sand and Gravel	4			97		
				Sandstone	1			46		
				Carbonate	2			18		

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Pesticides and Synthetic Organic Chemicals	Oxamyl	MCL	200 µg/L	Sand and Gravel	3			98		
				Sandstone	1			44		
				Carbonate	2			20		
	Pentachlorophenol	MCL	1 µg/L	Sand and Gravel						
				Sandstone						
				Carbonate						
	Picloram	MCL	500 µg/L	Sand and Gravel	5			98		
				Sandstone	2			44		
				Carbonate	2			20		
	Simazine	MCL	4 µg/L	Sand and Gravel	269			707		
				Sandstone	282			723		
				Carbonate	241			453		
	Total PCBs	MCL	0.5 µg/L	Sand and Gravel	3			97		
				Sandstone	1			46		
				Carbonate	1			18		
	2,3,7,8-TCDD (Dioxin)	MCL	3×10^{-5} µg/L	Sand and Gravel				24		
				Sandstone				4		
				Carbonate				3		
	2,4,5-TP (Silvex)	MCL	50 µg/L	Sand and Gravel	5					
				Sandstone						
				Carbonate						
	Toxaphene	MCL	3 µg/L	Sand and Gravel	4					
				Sandstone						
				Carbonate						
Organic Disinfection By-Products	Total Haloacetic Acids (HAA5)	MCL	60 µg/L	Sand and Gravel	81	3	1	526	5	2
				Sandstone	51		1	406	6	4
				Carbonate	56	1	1	275	3	1
	Total Trihalomethanes (TTHM)	MCL	80 µg/L	Sand and Gravel	119	6	4	525	40	6
				Sandstone	61	2	1	406	14	2
				Carbonate	62	5	3	275	23	2
Radiological	Gross Alpha (excl & incl)	MCL	15 pCi/L	Sand and Gravel	208	1		421	2	1
				Sandstone	251	4		265	3	1
				Carbonate	176	12	3	190	3	

					Public Water Systems					
					Raw Water			Treated Water		
Chemical Group	Chemical	Std. Type	Standard	Major Aquifer	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard	Total # public water systems	Watch List > 50% to 100% Standard	Impaired > Standard
Radiological	Gross Beta	MCL	4 mrem/ yr***	Sand and Gravel	162	2	34			
				Sandstone	174	2	48			
				Carbonate	144	2	45			
	Radium 226	MCL	5 pCi/L****	Sand and Gravel	24			1		
				Sandstone	28	2	1	3		
				Carbonate	45	6	2	1		
	Radium 228	MCL	5 pCi/L****	Sand and Gravel	153			418	1	
				Sandstone	159	3	2	265	4	1
				Carbonate	147	2		187	1	
	Uranium	MCL	30 µg/L	Sand and Gravel	3					
				Sandstone	1					
				Carbonate	3					

Note: presented by major aquifer types.
Blank spaces indicate no public water systems exceed the standards (zeros left out to highlight impacted public water systems)
“nda” Indicates no data available
* Numbers for Nitrate and Nitrite are based on maximum values to reflect the acute nature of the contaminant.
** Sodium drinking water advisory level is for adults on low-salt diets.
*** 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

Table M-5 —Counts of wells where 2007-2017 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 - 100% Standard	Impaired > Standard
Inorganic Chemicals	Ammonia	Lifetime HAL	30 mg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Antimony	MCL	6 µg/L	Sandstone and Gravel			
				Sandstone	1		
				Carbonate			
	Arsenic	MCL	10 µg/L	Sandstone and Gravel	167	27	24
				Sandstone	49	3	1
				Carbonate	61	5	9
	Alkalinity	SMCL	10,000 mg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Barium	MCL	2,000 µg/L	Sandstone and Gravel	167	2	
				Sandstone	49	2	1
				Carbonate	61		
	Barium	1/10 Day HAL	700 µg/L	Sandstone and Gravel	167		4
				Sandstone	49		5
				Carbonate	61		
	Cadmium	MCL	5 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Cadmium	Lifetime HAL	5 µg/L	Sandstone and Gravel	167		
				Sandstone	49		1
				Carbonate	61		1
	Cadmium	1/10 Day HAL	40 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Chloride	SMCL	250 mg/L	Sandstone and Gravel	167	5	2
				Sandstone	49	5	2
				Carbonate	61	1	1

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells Raw Water Total # Wells	Watch List > 50 - 100% Standard	Impaired > Standard
Inorganic Chemicals	Chromium	MCL	100 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Chromium	1/10 Day HAL	1,000 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Copper	Action Level	1,300 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Fluoride	MCL	4 mg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61	6	
	Fluoride	SMCL	2 mg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Iron	SMCL	300 µg/L	Sandstone and Gravel	167	10	121
				Sandstone	49	7	32
				Carbonate	61	8	46
	Lead	Action Level	15 µg/L	Sandstone and Gravel			
				Sandstone			
				Carbonate			
	Manganese	SMCL	50 µg/L	Sandstone and Gravel	167	25	116
				Sandstone	49	4	32
				Carbonate	61	18	8
	Manganese	Lifetime HAL	300 µg/L	Sandstone and Gravel	167		48
				Sandstone	49		13
				Carbonate	61		
	Manganese	1/10 Day HAL	1,000 µg/L	Sandstone and Gravel	167		4
				Sandstone	49		3
				Carbonate	61		
	Nickel	Lifetime HAL	100 µg/L	Sandstone and Gravel	167		1
				Sandstone	49		2
				Carbonate	61		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50 - 100% Standard	Impaired > Standard
Inorganic Chemicals	Nickel	1/10 Day HAL	1,000 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Nitrate* (Max Value)	MCL	10 mg/L	Sandstone and Gravel	167	11	4
				Sandstone	49	1	
				Carbonate	61	2	
	Nitrate* (Max Value)	1/10 Day HAL	100 mg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	Nitrite* (Max Value)	MCL	1 mg/L	Sandstone and Gravel	25		
				Sandstone			
				Carbonate			
	Selenium	MCL	50 µg/L	Sandstone and Gravel	167		
				Sandstone	49	1	
				Carbonate	61		
	Selenium	Lifetime HAL	50 µg/L	Sandstone and Gravel	167		
				Sandstone	49		1
				Carbonate	61		
	Sodium	DW Advisory	20 mg/L	Sandstone and Gravel	167		122
				Sandstone	49		36
				Carbonate	61		45
	Strontium	Lifetime HAL	4,000 µg/L	Sandstone and Gravel	167		30
				Sandstone	49		5
				Carbonate	61		54
	Strontium	1/10 Day HAL	25,000 µg/L	Sandstone and Gravel	167		3
				Sandstone	49		
				Carbonate	61		22
	Sulfate	SMCL	250 mg/L	Sandstone and Gravel	167	16	2
				Sandstone	49	2	1
				Carbonate	61	9	26
	Sulfate	1/10 Day HAL	500 mg/L	Sandstone and Gravel	167		1
				Sandstone	49		1
				Carbonate	61		10

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells Raw Water Total # Wells	Watch List > 50 - 100% Standard	Impaired > Standard
Inorganic Chemicals	Total Dissolve Solids	SMCL	500 mg/L	Sandstone and Gravel	167	111	55
				Sandstone	49	31	12
				Carbonate	61	7	54
	Zinc	DW Advisory	5,000 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61	1	
	Zinc	Lifetime HAL	2,000 µg/L	Sandstone and Gravel	167		2
				Sandstone	49		
				Carbonate	61		1
	Zinc	1/10 Day HAL	6,000 µg/L	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
	pH	SMCL	7.0-10.5	Sandstone and Gravel	167		
				Sandstone	49		
				Carbonate	61		
Volatile Organic Chemicals	1,2-Dichloroethane	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	1,1-Dichloroethylene	MCL	7 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	1,2-Dichloropropane	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	1,1,1-Trichloroethane	MCL	200 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	1,1,2-Trichloroethane	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	1,2,4-Trichlorobenzene	MCL	70 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells Raw Water Total # Wells	Watch List > 50 - 100% Standard	Impaired > Standard
Volatile Organic Chemicals	Benzene	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Carbon Tetrachloride	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Chlorobenzene	MCL	100 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Cis-1,2-Dichloroethylene	MCL	70 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Dichloromethane	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Ethyl benzene	MCL	700 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	o-Dichlorobenzene	MCL	600 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	p-Dichlorobenzene	MCL	75 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Styrene	MCL	100 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Tetrachloroethylene	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Toluene	MCL	1,000 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50 - 100% Standard	Impaired > Standard
Volatile Organic Chemicals	Trans-1,2-Dichloroethylene	MCL	100 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		
	Trichloroethylene	MCL	5 µg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		1
	Vinyl Chloride	MCL	2 µg/L	Sandstone and Gravel	160	4	
				Sandstone	48		
				Carbonate	59		
	o-Xylene	MCL	10 mg/L	Sandstone and Gravel	160		
				Sandstone	48		
				Carbonate	59		

Blank spaces indicate no public water systems exceed the standards (zeros left out to highlight impacted public water systems)
"nda" Indicates no data available
* 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 p/Ci/L as standard
*** MCL is for combined Radium 226 and Radium 228

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 exceed the fluoride MCL, but 20 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 determining both watch list and impaired categories may overestimate the numbers of public water systems when compared to actual MCL, SMCL or HAL calculations which use annual averages.

The number of public water systems with **arsenic** in raw water and treated water above the MCL (139 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 M-4 because numerous public water systems have installed treatment to remove arsenic since 2006. The elevated arsenic results collected from 2007 and beyond (while treatment processes were installed and refined) are included in the 10 years of data used to generate the public water system decadal averages. These elevated values increase the decadal mean calculated for Table M-4 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-4.

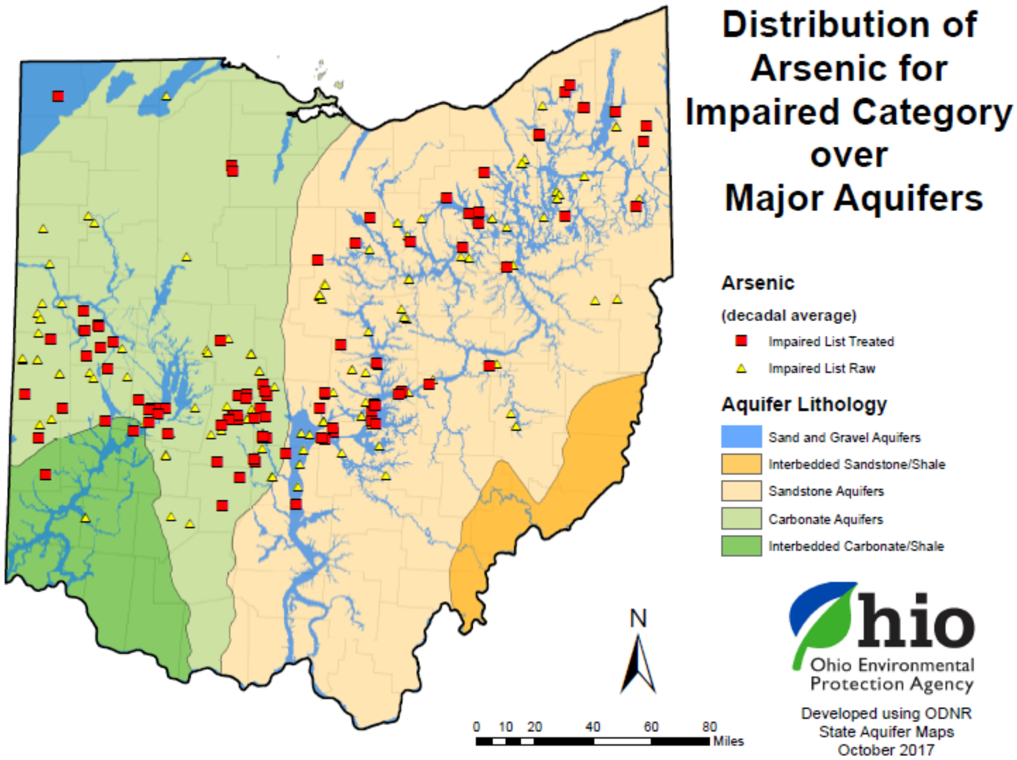

Figure M-4 — Distribution of public water systems on impaired list for arsenic for both treated and raw waters.

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-4 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 contain 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 exhibit elevated numbers of public water systems in the watch list and impaired category of Table M-4 for raw water. Table M-4 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 (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 (42 percent of carbonate vs. 10-11 percent for sandstone and sand and gravel) due to the presence of evaporates (Gypsum, $CaSO_4 \cdot 2H_2O$) in the Salina Formation in northwest Ohio.

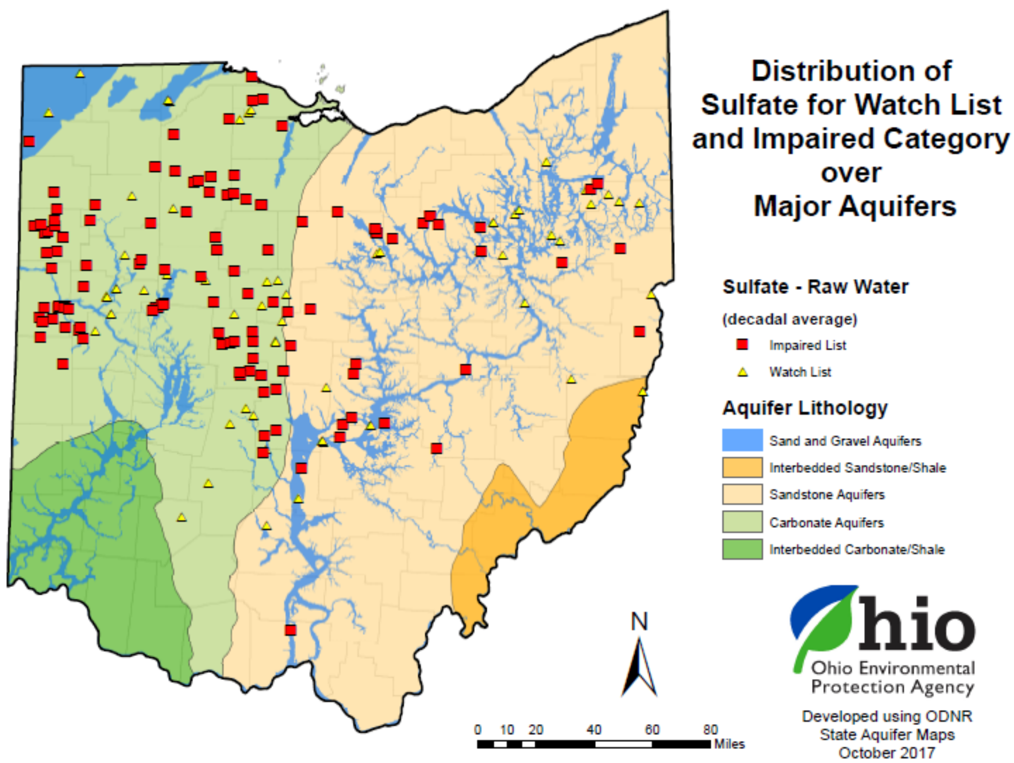

Figure M-5 — Distribution of public water systems in impaired category and on the watch list for sulfate in raw water.

For **Fluoride** results, no public water systems show up 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 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.

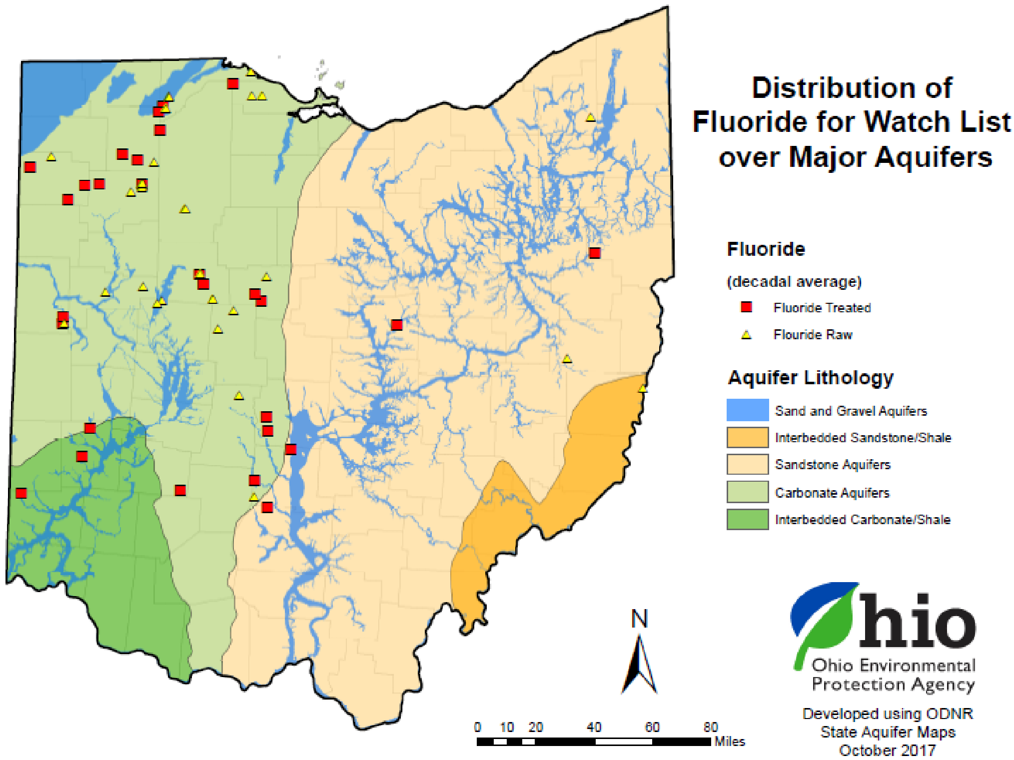

Figure M-6 — Distribution of public water systems on fluoride MCL watch list for treated and raw water.

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 2.5 percent (122 of 5,053) of public water systems in Table M-4 (treated water) have maximum nitrate greater than 50 percent of the MCL. Approximately 50 percent of these public water systems are 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 146 public water systems have been required to increase nitrate sampling to at least quarterly. For nitrate in treated water and raw water, 24 and 20 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), 2016 (149 public water systems) and 2018 (146 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.

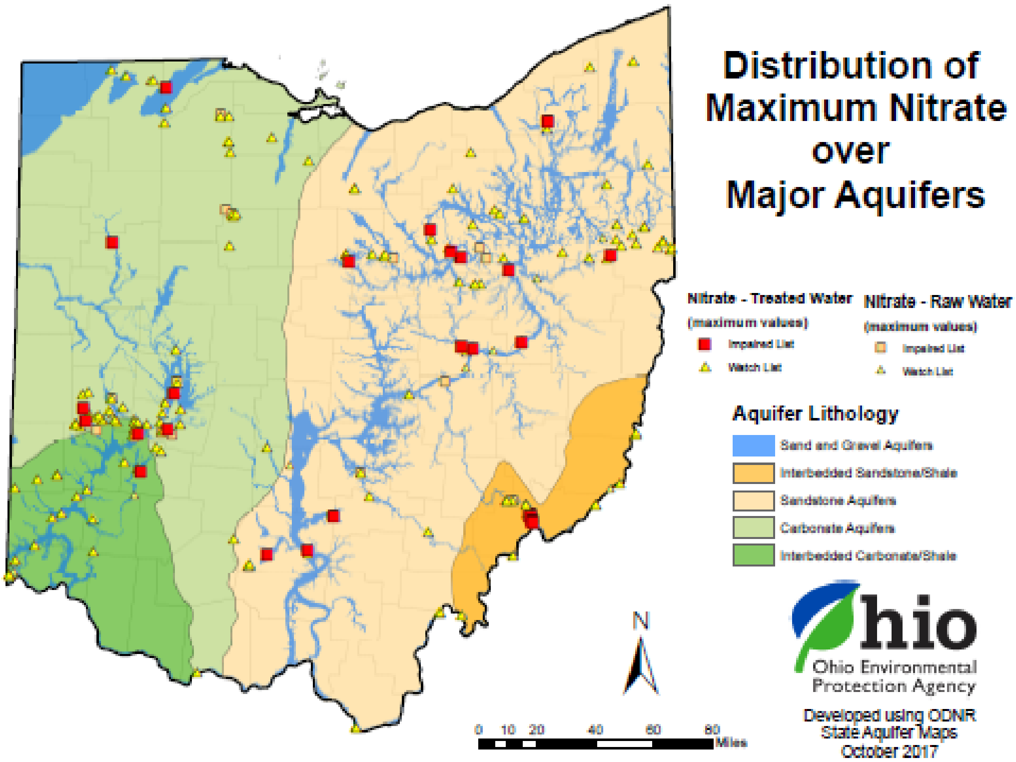

Figure M-7 — Distribution of public water systems with maximum nitrate in treated and raw water greater than the MCL.

HAL Parameters

HALs are constituent levels below which there are no adverse health effects over different time periods, such as one day, 10-day, long-term or lifetime. For HAL parameters, only an exceedance of the HAL (impaired status) was calculated in Table M-4. For raw water, a percentage of public water systems are included in the impaired category for **barium** (two percent) and **manganese** (8.5 percent). Barium and manganese exceedances are spread evenly between sand and gravel and sandstone aquifers. For treated water supplies, a very small percentage (<1 percent) of barium and **nickel** public water systems exceed their respective HAL. Two public water system wells, one in carbonate and one in sand and gravel, exceed the lifetime HAL for strontium.

Drinking Water Advisory Parameters

Exceedances of drinking water advisory levels for **sodium** and **sulfate** can cause human health effects. The sodium drinking water advisory level applies only to adults on a low-salt diet. Only an exceedance of the drinking water advisory (impaired status) was calculated in Table M-4. For raw water, a percentage of public water systems are included in the impaired category for **sodium** (41.3 percent) and **sulfate** (7.6 percent). Sodium exceedances are found most often in sandstone, then carbonate aquifers. The large percentage of public water systems with sodium exceedances may be due to oil and gas production brines, salt storage facilities or road salt applications. Sulfate exceeds the drinking water advisory level most commonly in the carbonate aquifers again due to the presence of evaporates.

Organic Parameters

Only seven organic parameters' mean concentrations for treated water samples place public water systems in the impaired category: 1,2-dichloroethane; 1,1-dichlorethylene; 1, 2-dichloropropane; carbon tetrachloride; 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-4. 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 10 years (2007 through 2017) to determine the number of wells in the watch list and impaired categories for each constituent. These numbers are listed in Table M-5 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, SMCL, HAL and drinking water advisory 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 **alkalinity, cadmium, chromium, copper, fluoride, nickel, nitrate, selenium or zinc.** Very few wells exceed the lifetime HAL for cadmium (0.07 percent), nickel (0.1 percent), selenium (0.3 percent) and zinc (0.1 percent). Six 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-4 and Figure M-6. A few well means are greater than 50 percent of the **barium** MCL, with one MCL and nine HAL impairments identified. Averages for **chloride** exceed the SMCL in five cases. Thirteen wells have chloride above 50 percent of 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.

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-4. 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. Three percent of the carbonate wells exceed 50 percent of the MCL, probably associated with sensitive karst settings and only two 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 (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 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, 57 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 (six percent and 11 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 97 percent of the SMCL.

HAL exceedances for **strontium** occur most commonly in carbonates followed by unconsolidated aquifers resulting most likely from the presence of the naturally-occurring mineral celestite ($SrSO_4$). Twenty-five ambient wells have strontium values greater than the one- and 10-day HAL of 25,000 μg/L (nine percent) while 86 wells (30 percent) exceeded the life-time HAL of 4,000 μg/L.

Organic Parameters - Detection of organic parameters at and above watch list concentrations is not common in the AGWQMP. Organic parameters, each detected at one public water system above the MCL, include carbon tetrachloride and trichloroethylene. These organic solvents were detected in public water systems raw water samples as listed in Table M-4.

Pesticides – Benzo(a)pyrene, 1,2-dibromo-3-chloropropane (DBCP), di(2-ethylhexyl) phthalate (1), ethylene dibromide (EDB), hexachlorobenzene (1) and pentachlorophenol were pesticides detected in the AGWQMP wells above their respective MCLs. 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 Table M-4 and Table M-5. 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 Table M-4 and Table M-5. 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 available in the technical report, *Major Aquifers in Ohio and Associated Water Quality (2015)*.

M7. 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, 2016 and 2018 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). A 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 and Gas Resources web page in the Shale activity section: ***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 the website hosted at OSU Extension at: ***ohiowatersheds.osu.edu/know-your-well-water***.

The relational database, GWQCP, has housed water quality data for non-compliance projects in DDAGW. It is being expanded to also house data collected through the RCRA ground water monitoring program, submitted as part of reporting requirements. This data has been housed electronically in DDAGW's Central Office and has not been readily available for use by regulators or the public. Data from more than 400 facilities with collection ranging from 1980s to the present will be available for reports and studies.

Other activities completed over the past two years include:

- Partnership with the Ohio State University Department of Microbiology to investigate bacterial communities in Ohio's ground water.
- Department of Environmental Services installs a new Laboratory Information Management System.
- Phase II of the ground water investigation at Devola, Ohio is completed.

DDAGW staff participated in a two-year project with primary investigator Mike Wilkins, Ph.D., professor in the Ohio State University School of Earth Sciences and Department of Microbiology. The aim of the study was to identify naturally occurring bacteria present in shallow Ohio aquifers using DNA-based techniques. Many of the bacteria present catalyze reactions that impact ground water quality, including the generation of dissolved iron (Fe^{2+}), and the potential resulting mobilization of arsenic. This study is the first effort to track microbial structure and function across representative aquifer systems in southern Ohio where reducing conditions lead to metal mobilization. Knowledge gained from this work will be coupled to extensive complementary geochemical parameters gathered by Ohio EPA, with the intent of enhancing the current conceptual model for metal release in Ohio aquifers. The first paper to come out of this study, *Members of the Candidate Phyla Radiation are functionally differentiated by carbon- and nitrogen-cycling capabilities* was published Sept. 2, 2017 in the journal Microbiome. Citation for this open access publication is: ***Danczak et al. Microbiome (2017) 5:112; DOI 10.1186/s40168-017-0331-1***.

The Division of Environmental Services, Ohio EPA's in-house analytical laboratory, installed a new Laboratory Information Management System (LIMS) to manage all analytical equipment output as well as software to automatically log samples required by AGWQMP field staff. The conversion to the new LIMS allows district staff to coordinate with laboratory personnel quickly and efficiently. Sample Tracking allow users to log and follow samples through the system to help manage data processing. Electronic data transfer allows for the direct flow of data from the instrument to the QA/QC office to the end user. This upgrade will ensure close contact between analysts and district staff.

Phase II of Ohio EPA's 2011 study, Unsafe Water Supply Investigation, Putnam Community Water Association, Devola, Washington County, Ohio was completed through additional ground water sampling in 2016. Conclusions of the original 2011 study were substantially confirmed through results of the 2016 study. The significant conclusion supported by both phases of the investigation is that the unsewered areas of the village of Devola are a significant source of nitrate contamination that is impacting the community's wells, at times driving the public water system's nitrate concentrations above safe drinking water standards. This contamination is determined to be the result of untreated or partially treated sewage from residences in Devola entering the ground water system and flowing to the wells.