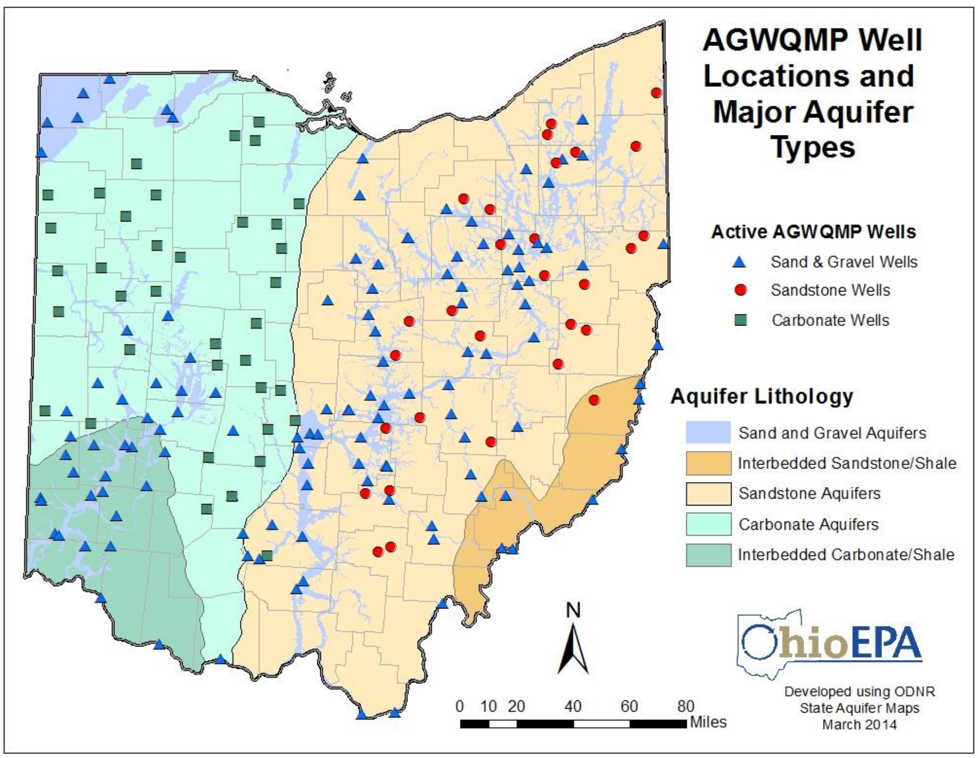
Major Aquifers in Ohio and Associated Water Quality



Division of Drinking and Ground Waters
Technical Series on Ground Water Quality
April 2014

The Technical Series on Ground Water Quality:

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

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

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

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

Disclaimer

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Technical Series
Major Aquifers in Ohio and Associated Water Quality

Abstract

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

Introduction

The purpose of this report is to:

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

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

Ohio's Major Aquifers

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

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

Sand and Gravel Aquifers

The unconsolidated sand and gravel units, typically associated with buried valley aquifers, are Ohio's most productive water-bearing formations. These valleys were cut into the bedrock by pre-glacial and glacial streams and were subsequently back-filled with deposits of sand, gravel and other glacial drift by glacial and alluvial processes as the glaciers advanced and receded. Buried valley aquifers are found beneath and adjacent to the Ohio River, its major tributaries, and other pre-glacial stream channels such as the Teays River.

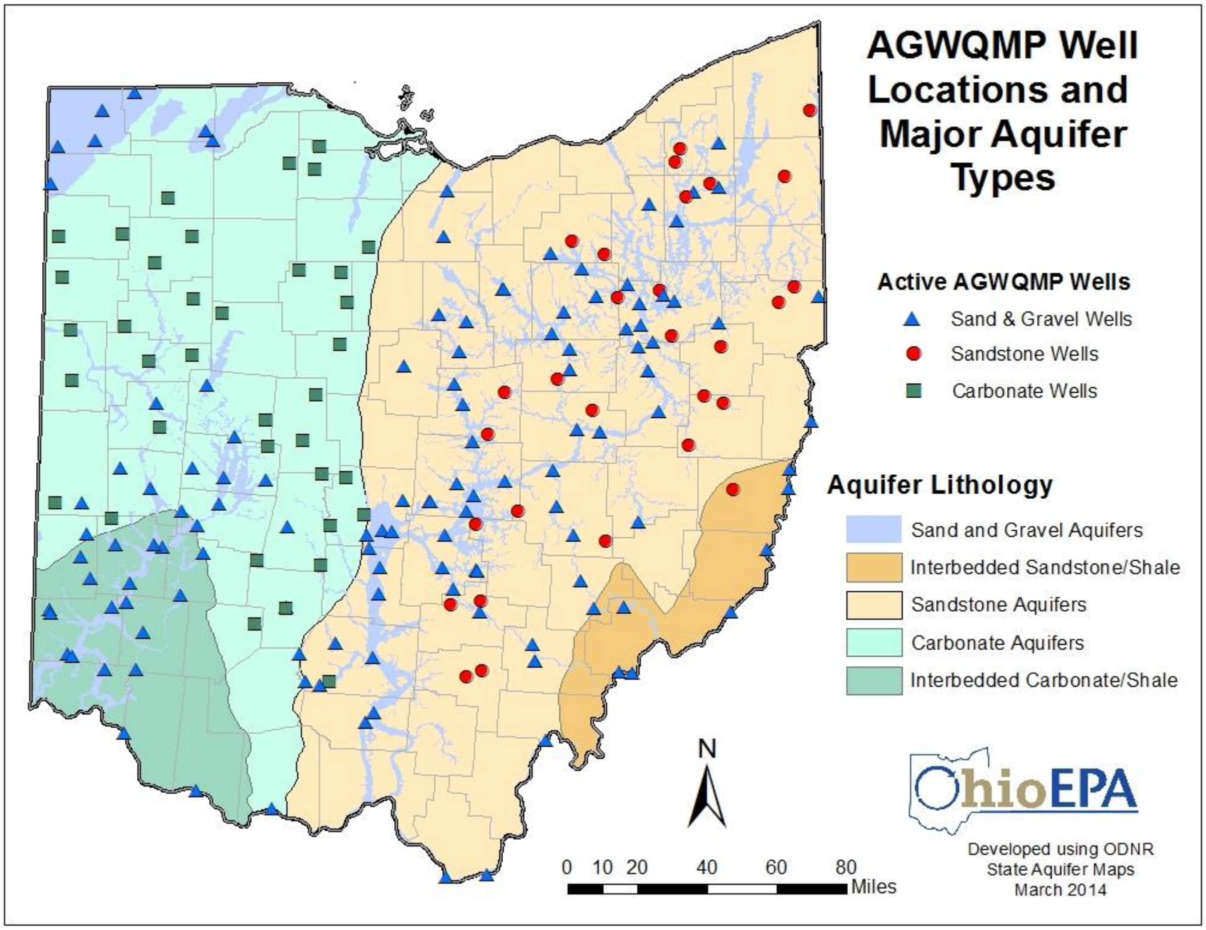

Figure 1. Aquifer Types in Ohio modified from ODNR Glacial and Bedrock Aquifer Maps.

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

Water production from the coarser-grained and thicker sand and gravel deposits ranges up to 500 to 1,000 gallons per minute (gpm). However, lower yields from sand and gravel aquifers are more common. The production depends on the type, distribution, permeability, and thickness of aquifer materials and well construction parameters, such as borehole diameter, screen length, and development. Yields of these unconsolidated aquifers are illustrated on the ODNR web site at: http://www.dnr.state.oh.us/water/samp/unyldsml/tabid/4234/Default.aspx

Sandstone Aquifers

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

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

- **Mississippian Berea Sandstone, Cuyahoga Group, Logan and Blackhand Formations** - These siltstones and sandstones with minor conglomerate were sorted and deposited in deltaic complexes from material eroded from the Acadian Mountains (Late Devonian uplift) to the east. These units also extend to the southeast, farther into the Appalachian Basin, but as with the Pennsylvanian units, the water becomes too saline for drinking.

In southeastern Ohio, Upper Pennsylvanian and Permian stratigraphic sections include low-yielding aquifers. The bedrock consists of varied sequences of thin-bedded shales, limestones, sandstones, clays, and coals of the Pennsylvania Conemaugh and Monongahela Groups and the Permian Dunkard Group. Yields below five gpm are common in these areas as illustrated in Figure 2 (from the ODNR web page at: http://www.dnr.state.oh.us/water/samp/bdrkyldsml/tabid/4215/Default.aspx)

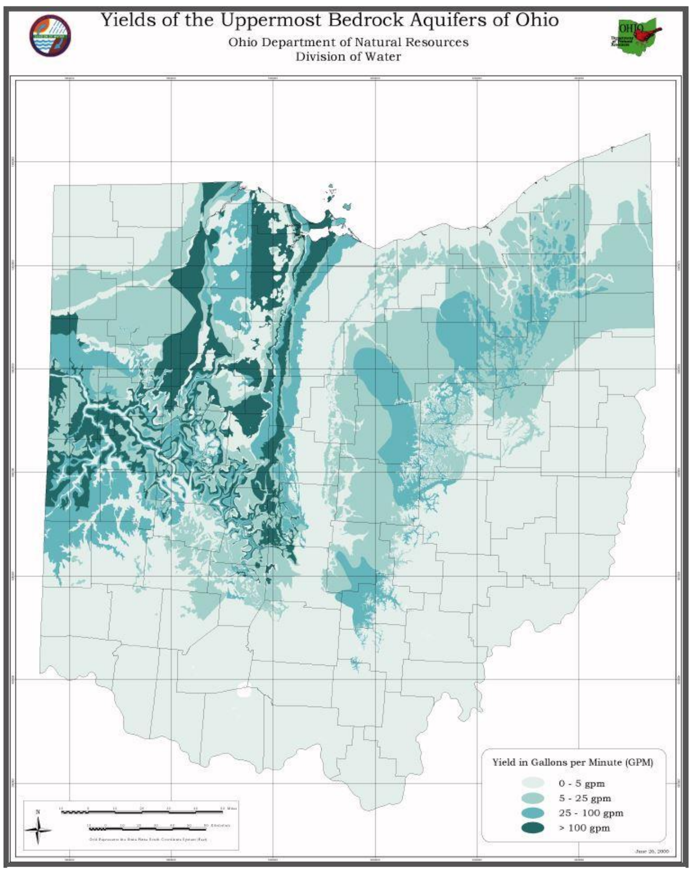

Figure 2. Typical yields for bedrock aquifers.

Carbonate Aquifers

Carbonate bedrock is the dominant aquifer in western Ohio (Figure 1). Silurian and Middle Devonian limestone and dolomite reach a total thickness of 300 to 600 feet, and are capable of yielding from 100 to over 500 gpm. Higher production units are associated with fractures and dissolution features that increase the permeability. The high production aquifers, in order of deposition, are fractured or karst Silurian sub-Lockport/ Lockport Dolomite and equivalent units, the Salina Group, consisting of the Tymochtee and Greenfield Dolomites, and the Undifferentiated Salina Dolomite and equivalent evaporites. The Devonian

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

Southwestern Ohio is underlain by inter-bedded lower Ordovician carbonates and shales. These units are dominated by shale (Figure 1). As a result, well yields are generally less than 10 gpm, and in many areas, are less than one gpm (Figure 2). Consequently, in southwestern Ohio (as in southeastern Ohio), public water systems depend on the buried valley aquifers as the main ground water source. These low yielding aquifers are only practical for low volume use. Ohio EPA has little water quality data from shale-dominated wells, and consequently, they are not discussed further in this report. Another area with low yields is the region of Devonian shale that overlies the Columbus and Delaware Limestone aquifers. The narrow north-south trending area of Devonian shale in central Ohio is clearly illustrated in Figure 2 as the area of low yields (0-5 GPM) that separates the carbonate aquifers in the west from the sandstone aquifers to the east. Where the north trend of the shales meet Lake Erie, the shale curve eastward along the Lake Erie shoreline as illustrated in Figure 2 by the band of low yields there. In addition, to the low yield, hydrogen sulfide is frequently present, which causes water quality problems.

Ground Water Quality by Aquifer Type

General Considerations

The overall ground water quality in Ohio is described here using the Ambient Ground Water Quality Monitoring Program (AGWQMP) database, which consists of approximately 6,000 inorganic and 2,000 organic water quality samples distributed across 337 active and inactive wells. Figure 1 illustrates the distribution and aquifer type of AGWQMP wells. As described above, the major aquifers include unconsolidated sand and gravel units deposited on sandstone bedrock in eastern Ohio and carbonate bedrock in western Ohio. The majority of the wells used in this characterization are public water supply production wells, usually developed within higher yielding zones with good water quality. This effort supports the goals of the AGWQMP - to collect, analyze, and describe the source (ambient) ground water quality used by public water systems across the state.

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

Increased residence time in an aquifer typically leads to higher salinity and greater mineralization of the water, depending on the solubility of the aquifer minerals present. Sand and gravel aquifers, for example, commonly have short residence times, leading to lower salinity. These younger waters are generally shallower, and are more likely to be affected by contamination from land use activities. Older, deeper waters, such as found in the carbonate aquifers of northwestern Ohio, may follow much longer flow paths, allowing the water ample time to establish a geochemical equilibrium with the rock system. Figure 3 is a box plot indicating the distribution of well depths by aquifer type for the AGWQMP wells. The median depth in the carbonate aquifers (~225 feet) is slightly greater than the median depth in the sandstone aquifers (~220 feet). The median depth for the sand and gravel aquifers (~ 90 feet) is less than one-half the depth of the carbonate or sandstone aquifers, suggesting shorter residence times for sand and gravel aquifers compared to bedrock aquifers.

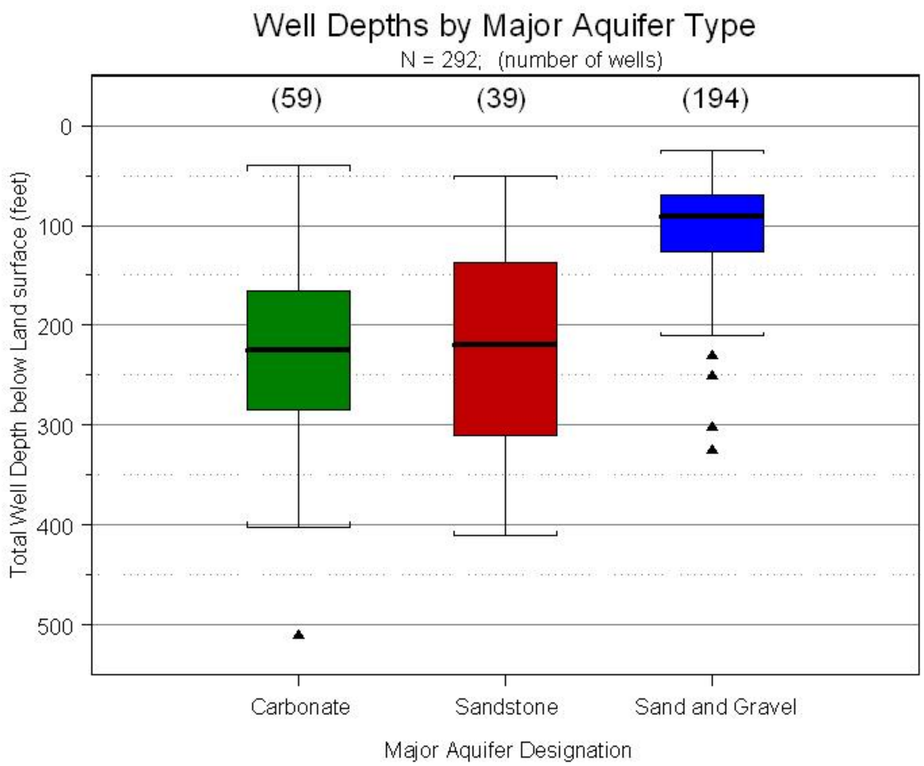

Figure 3. Box plot of active AGWQMP well depths by aquifer type.

Inorganic Parameter Mean Values

Ambient ground water quality data presented in Table 1 (starting on page 10) summarize the geochemistry by major aquifer type for all active AGWQMP wells. This table provides the arithmetic mean, median, minimum value, maximum value, standard deviation, total number of samples, number of samples below the reporting limit, and the percent non-detect for all individual inorganic and field parameter results in each aquifer type as of July 2013. Brief descriptions of several of these parameters are provided to aid in understanding the data. For instance, the reporting limit was used for the non-detect values in calculating means and standard deviation (in some cases, zeros are recorded as the reporting limit). The "non-detect" column records the percent of analyses with results below the current reporting limit (rounded to the nearest percent). The presence of a less than sign (<) in the minimum value field (column 5) indicates the minimum value is the reporting limit. The minimum value may not coincide with the current reporting limit due to changes in analytical methods, as AGWQMP sampling started in 1973, resulting in multiple reporting limits. The estimates of the number and percentages of non-detect data (columns 8 and 9) may also be influenced by changes in the reporting limits.

Table 1 summarizes the accumulation of over 160,000 raw, inorganic ground-water data results gathered at 260 active and standby wells across Ohio over 40 years of sampling. Consistent sampling protocol, analytical procedures, and long site histories lend a unique significance to these data. Table 1 is the best summary available for the general water quality of Ohio's major aquifers, which provides the source water for Ohio's public drinking water systems using ground water. Note, however, that some wells in the AGWQMP network have been influenced by anthropogenic sources, such as nitrates or VOCs. Thus, the water quality presented is not pristine, but rather is typical of the ground water quality of aquifers utilized for source water by the public water systems.

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

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

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

Use of Primary and Secondary MCLs

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

Seven of the primary constituents for which health based (MCLs) exist are monitored in raw water through the AGWQMP. These are arsenic (10 µg/L), barium (2 mg/L), cadmium (5 µg/L), chromium (100 µg/L), fluoride (4 mg/L), nitrate-nitrite as N (10 mg/L), and selenium (50 µg/L). Additionally, copper and lead have action levels (not MCLs or SMCLs) of 1.3 mg/L and 0.015 mg/L respectively. As indicated by the Ambient Ground Water Quality Table 1, no constituents exceed a MCL based on averages by aquifer type. Arsenic exhibits the highest concentrations as a percentage of the MCL; nevertheless, mean concentrations for all three aquifer types are well below the arsenic MCL of 10 µg/L (sand and gravel = 5.69 µg/L, sandstone = 2.51 µg/L, carbonate = 3.72 µg/L). Only a single well (sand and gravel) recorded a mean arsenic concentration above the old MCL of 50 mg/L, with a value of 75.6 µg/L. However, 34 active AGWQMP wells have raw water mean values of arsenic that exceed the new arsenic MCL of 10 µg/L. If these wells are public water system wells, treatment may be required to bring the arsenic concentrations below the MCL in the distributed water. Mean concentrations for barium, cadmium, chromium, fluoride, nitrate-nitrite, and selenium were also below the associated MCLs within all three aquifer systems. Individual well means indicate no health based MCL excedences for barium, cadmium, chromium, fluoride, nitrate, and selenium.

Nine parameters with established SMCLs are monitored by the AGWQMP. These constituents are : aluminum (0.05 - 0.2 mg/L), chloride (250 mg/L), fluoride (2.0 mg/L), iron (0.3 mg/L), manganese (0.05 mg/L), pH (7-10.5 SU), sulfate (250 mg/L), total dissolved solids (TDS, 500 mg/L), and zinc (5 mg/L). The SMCL levels are exceeded in several of these constituents as exhibited in Table 1.

Volatile Organic Compounds

Volatile organic compounds (VOCs) have been monitored in untreated water for the AGWQMP since the mid-1980s with a standard sampling frequency of 18 months. A reporting level of 0.5 µg/L (ppb) has been used consistently. Fortunately, the detection rate for VOCs is low, about 0.25 percent, but their presence indicates water quality impact from land use activities. AGWQMP sampling protocols increase the sampling frequency if VOCs are detected; currently 17 active AGWQMP wells are sampled for organics every six months to help evaluate potential for migration of VOC plumes into public water system wells. The higher VOC sampling frequency of wells with VOC detections increases the detection rates. In some cases, wells with VOC detections are abandoned by public water systems and are no longer available for sampling by the AGWQMP.

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

Table 2. Most Frequently Detected VOCs in Active AGWQMP Wells.

Parameter	Number of detections	Number of sites with detections	Range of results (µg/L)	Maximum Contaminant Level (MCL)
Trichlorloroethylene	45	7	0.5-2.34	5
Tetrachloroethylene	34	4	0.5-2.5	5
cis-1,2-Dichloroethylene	32	7	0.5-4.3	70
Methyl tertiary butyl ether (MTBE)	31	5	0.5-6.73	none
1,1,1,Trichloroethane	13	4	0.5-1.39	5

Chlorinated solvents are the primary chemical group in Table 1. These include trichloroethylene (TCE), tetrachloroethylene (PCE), cis-1,2- dichloroethylene, and 1,1,1- trichloroethane (1,1,1- TCA). These solvents were developed over the last century as cheaper and more practical alternatives to petroleum solvents. PCE and TCE have been in industrial use over 60 years. PCE is widely used for dry cleaning.

PCE and TCE can both undergo dechlorination (loss of a chlorine) leading to the daughter products 1,1-dichloroethylene, cis- and trans-1,2-dichloroethylene, which ultimately degrade into vinyl chloride. As a group, their concentrations in ground water are quite low, well below MCLs. The usage of multiple solvents or the degradation of one solvent to another can explain the occurrence of mixtures of these compounds found in some AGWQMP wells. MTBE, a gasoline additive (oxygenate), is also included in the top five list, but 28 of the 31 detections occur at one well.

Trihalomethanes (THM) are the most frequently detected organic compounds in AGWQMP wells (55 detection at 32 sites), including chloroform, dichlorobromomethane, and chlorodibromomethane. However, the source of these compounds is not always clear. The maximum value detected in active wells, 26 µg/L, is well below the MCL of 80 µg/L. Thrihalomethanes are a byproduct of disinfection using chlorine, and are not uncommon in public water system distribution water. Thus, if there is backflow from the distribution system to the AGWQMP sample location (leaking foot valve or poor sample tap location), or if the well has been disinfected recently, THMs may be present. A third possibility is that treated water from lawn watering or leaks in the sewer system are recharging local wells. The source of THMs in a well is not always clear, consequently, unlike the VOC detections, THM detections cannot always be attributed to land use impacts.

Most of the wells with VOC impact are associated with sand and gravel aquifers. This is not surprising considering the point source nature of most VOC sources and the sensitivity of the buried valley, sand and gravel aquifers. From a practical standpoint, any detection of VOCs should be considered a water quality impact, as there are few natural sources of these man-made chemicals. The limited detection data and anthropogenic association of these organic compounds make them of little use in characterizing water quality, beyond the fact that their presence indicates water quality impacts from lane use activities.

Summary

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

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Ohio Department of Natural Resources (ODNR), 2000. Statewide Aquifer Mapping Project 1997-2000 (Unconsolidated and Consolidated); web link: http://www.dnr.state.oh.us/tabid/4218/Default.aspx

Table 1 – Ambient Ground Water Quality Data

Ambient Ground Water Quality Monitoring Data Summary for Results from Active Wells by Major Aquifer as of July 2013

FIELD PARAMETERS

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value *	Maximum Value	Standard Deviation	Number of Samples	Number § Below Rep. Limit	Percent § Non-detect
	Oxidation-Reduction Potential (ORP) mV	Sand and Gravel	52.6	28.5	-520	815	135	1092	NA	NA
		Sandstone	100	69	-530	881	208	248	NA	NA
		Carbonate	-13.5	-19.0	-268	778	124	248	NA	NA
7.0-10.5 S.U.	pH, Field S.U.	Sand and Gravel	7.33	7.33	5.60	8.6	0.33	2972	NA	NA
		Sandstone	7.24	7.24	5.67	8.7	0.46	636	NA	NA
		Carbonate	7.22	7.19	6.20	8.7	0.31	804	NA	NA
	Specific Conductivity µmohms/cm	Sand and Gravel	710	700	195	2375	194	2320	NA	NA
		Sandstone	725	557	86	7900	586	571	NA	NA
		Carbonate	938	880	270	2070	275	610	NA	NA
500 S mg/L	Total Dissolved Solids, Field mg/L	Sand and Gravel	533	517	187	1726	144	1100	NA	NA
		Sandstone	520	398	57	2210	379	283	NA	NA
		Carbonate	746	692	304	1505	201	257	NA	NA
	Water Temperature Degrees C	Sand and Gravel	13.5	13.19	5.1	31.9	2.11	2030	NA	NA
		Sandstone	12.6	12.5	8.5	18.8	1.5	625	NA	NA
		Carbonate	13.2	13.0	6.9	19	1.57	794	NA	NA

MAJOR COMPONENTS										
MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
	Alkalinity, Total as CaCO3 mg/L	Sand and Gravel	264	267	<5.0	775	67.9	3440	6	0
		Sandstone	197	196	<5.0	1500	115	745	1	0
		Carbonate	306	300	92.6	642	67.1	886	0	1
	Calcium, Total mg/L	Sand and Gravel	93.1	94	<2.0	300	24.1	3494	1	0
		Sandstone	59.4	58	<2.0	167	30.6	754	7	1
		Carbonate	123	114	26	255	36.0	898	0	0
250 S mg/L	Chloride mg/L	Sand and Gravel	39.6	32	<2.0	474	32.9	3476	102	3
		Sandstone	49.5	31	<2.0	494	61.3	749	61	8
		Carbonate	28.4	15.7	<2.0	420	36.4	881	80	9
	Hardness, Total as CaCO3 mg/L	Sand and Gravel	348	352	<10.0	953	85.6	3025	2	0
		Sandstone	223	212	<10.0	716	113	679	1	0
		Carbonate	504	449	110	956	159	787	0	0
	Magnesium, Total mg/L	Sand and Gravel	28.3	29	<1.0	81	9.5	3494	9	0
		Sandstone	17.9	17	<1.0	80	10.8	754	9	1
		Carbonate	49.5	43	11	106	18.3	899	0	0
	Potassium, Total mg/L	Sand and Gravel	2.37	2.0	<0.9	17	0.99	3381	848	25
		Sandstone	2.39	2.0	<1.0	8.0	0.86	743	242	33
		Carbonate	2.81	2.0	<1.3	8.4	1.17	874	84	10
	Sodium, Total mg/L	Sand and Gravel	26.1	22	<4.0	427	20.1	3496	96	3
		Sandstone	72.2	29	<5.0	824	108	754	40	5
		Carbonate	35.4	27	<5.0	239	27.4	898	16	2
250 S mg/L	Sulfate mg/L	Sand and Gravel	76.2	66	<5.0	640	46.1	3479	25	1
		Sandstone	82.5	43.1	<5.0	1320	166	751	98	13
		Carbonate	240	173	<5.0	1000	199	899	1	0
500 S mg/L	Total Dissolved Solids mg/L	Sand and Gravel	459	450	<10.0	2120	118	3399	1	0
		Sandstone	441	338	54	2390	344	742	0	0
		Carbonate	718	638	324	3200	267	874	0	0

TRACE CONSTITUENTS										
MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
50-200[S] µg/L	Aluminum µg/L	Sand and Gravel	202	<200	<200	2880	57.8	2914	2908	100
		Sandstone	201	<200	<200	448	11.1	701	697	99
		Carbonate	207	<200	<200	2050	93.5	746	739	99
10 µg/L	Arsenic, Total µg/L	Sand and Gravel	5.59	<2.0	<2.0	102	8.79	3351	1668	50
		Sandstone	2.51	<2.0	<2.0	78	3.24	736	605	82
		Carbonate	3.72	<2.0	<2.0	25.7	3.61	883	503	57
2000 µg/L	Barium µg/L	Sand and Gravel	158	119	<15.0	2160	179	3320	39	1
		Sandstone	215	73	<15.0	2120	411	728	100	14
		Carbonate	73.7	46	<7.0	568	69.9	879	78	9
	Bromide µg/L	Sand and Gravel	149	60.7	<20	1680	111	814	93	11
		Sandstone	144	51.6	<20	1300	239	209	38	18
		Carbonate	87.8	100	<20	920	179	181	38	21
5 µg/L	Cadmium, Total µg/L	Sand and Gravel	0.17	<0.2	0	3.2	0.11	3139	3112	99
		Sandstone	0.19	<0.2	0	18.8	0.69	737	728	99
		Carbonate	0.18	<0.2	0	1.6	0.10	863	847	98
100 µg/L	Chromium, Total µg/L	Sand and Gravel	22.1	<30	<2.0	50	12.6	3184	3168	99
		Sandstone	21.4	<30	<2.0	30	12.9	744	742	100
		Carbonate	23.5	<30	<2.0	50	11.8	865	851	98
1300 [AL] µg/L	Copper µg/L	Sand and Gravel	11.0	<10	<2.0	405	17.5	3009	2200	73
		Sandstone	13.7	<10	<2.0	235	23.4	726	486	67
		Carbonate	16.3	<10	<2.0	586	46.0	770	499	65
4 mg/L 2[S] mg/L	Fluoride mg/L	Sand and Gravel	0.40	0.25	0	3.04	0.4	2812	845	30
		Sandstone	0.32	0.25	<0.10	1.18	0.17	697	164	24
		Carbonate	1.35	1.35	<0.10	3.58	0.62	736	19	3
300 [S] µg/L	Iron, Total µg/L	Sand and Gravel	1183	708	<20	29700	1419	3488	707	20
		Sandstone	1446	376	<50	34600	3386	752	160	21
		Carbonate	1102	810	<50	27300	1644	901	81	9
15 [AL] µg/L	Lead, Total µg/L	Sand and Gravel	4.51	<2.0	<1.0	2710	58.3	3488	3055	91
		Sandstone	2.96	<2.0	<2.0	164	7.32	742	633	89
		Carbonate	3.18	<2.0	<2.0	167	8.65	852	733	86

TRACE CONSTITUENTS										
MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
50 [S] µg/L	Manganese, Total µg/L	Sand and Gravel	191	120	<8.0	5130	223	3422	467	14
		Sandstone	225	99	<9.0	2220	351	747	132	18
		Carbonate	31.9	17	<10	300	34.2	875	225	26
	Nickel, Total µg/L	Sand and Gravel	29.0	<40	<1.0	269	17.8	2969	2380	80
		Sandstone	28.8	<40	<2.0	175	8.15	711	619	87
		Carbonate	30.8	<40	<2.0	88	16.1	769	603	78
50 µg/L	Selenium, Total µg/L	Sand and Gravel	2.03	<2.00	<2.00	10.9	0.38	3039	2944	97
		Sandstone	2.02	<2.00	<2.00	5.5	0.21	730	712	98
		Carbonate	2.03	<2.00	<2.00	5.0	0.22	766	737	96
	Strontium, Total µg/L	Sand and Gravel	1957	371	<30	36400	4542	2965	4	0
		Sandstone	544	375	<30	5740	759	709	19	3
		Carbonate	16367	14700	<30	51600	11154	767	2	0
5000 [S] µg/L	Zinc, Total µg/L	Sand and Gravel	20.3	<10	<6.0	1860	55.3	3028	2059	68
		Sandstone	30.8	10	<10	902	57.2	725	349	48
		Carbonate	71.8	11	<10	4090	265	770	354	46

NUTRIENTS										
MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
	Ammonia mg/L	Sand and Gravel	0.22	0.08	0	3.41	0.36	3449	1390	40
		Sandstone	0.37	0.17	0	2.30	0.49	744	210	29
		Carbonate	0.41	0.35	0	5.93	0.50	890	96	11
	Chemical Oxygen Demand mg/L	Sand and Gravel	13.3	<10	<2.0	200	9.25	3391	3085	91
		Sandstone	13.4	<10	<6.0	172	8.43	734	689	94
		Carbonate	14.0	<10	<10	371	16.1	888	754	85
10 mg/L	Nitrite & Nitrate NO2 +NO3 as N mg/L	Sand and Gravel	0.73	<0.10	0	12.3	1.27	3346	1857	55
		Sandstone	0.41	<0.10	0	4.32	0.82	734	539	73
		Carbonate	0.25	<0.10	0	7.38	0.85	872	764	88
	Phosphorus mg/L	Sand and Gravel	0.32	<0.05	0	810	14.4	3154	2183	69
		Sandstone	0.09	0.05	0	4.4	0.26	695	319	46
		Carbonate	0.05	<0.05	0	4.37	0.17	819	524	69
	Total Kjeldahl N mg/L	Sand and Gravel	0.37	0.24	0	4.49	0.40	2323	959	41
		Sandstone	0.52	0.29	0	6.75	0.61	587	221	38
		Carbonate	0.55	0.44	0	7.04	0.59	596	116	19
	Total Organic Carbon mg/L	Sand and Gravel	2.42	<2.0	<0.5	62	2.72	3026	2732	90
		Sandstone	2.35	<2.0	<0.5	57	2.97	698	635	91
		Carbonate	2.61	<2.0	<2.0	73	4.50	778	667	86

* Records with '<' represent reporting limit

§ NA denotes not applicable

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

S Secondary MCL

AL Action Level

Appendix A

Ambient Ground Water Quality Monitoring Program

Inorganic Constituent Box and Whisker Plots

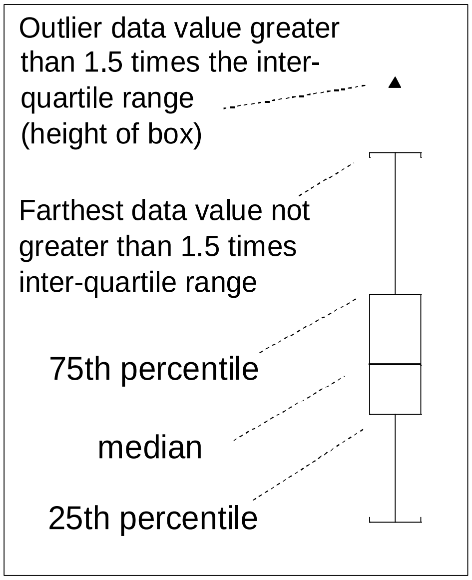
This document provides a concise graphical summary, in box and whisker plot format, of the Ambient Ground Water Quality Monitoring Program (AGWMP) inorganic data set as of January 1, 2013. The Box and Whisker plots from the Ambient Ground Water Quality Network database include results from some 5500 raw (untreated), inorganic water samples collected over the past 40 years across 200 active wells in Ohio. Active (AGWMP) wells are sampled every six or eighteen months. The primary objective of collecting statewide, raw ground water data from major aquifers is to characterize Ohio's ground water quality, which in turn is used to enhance water resource planning and to prioritize ground water protection activities. The Ambient Ground Water Monitoring Program places a priority on collecting water quality data representative of aquifers used by public water systems. Analysis of water quality changes in space and time indicate that some of the AGWMP wells are influenced by land use activities. The Ambient wells are considered typical of the local ground water used as source water for public water systems.

In the following box plots, the inorganic water-quality sample results are plotted on the Y-axis, while the X-axis represent the three major aquifer groupings within Ohio (sand and gravel, sandstone, and carbonate). These box plots allow the reader to effectively compare data variability across major aquifer types, and are presented in the same order and groupings as in Table 1: Field Parameters, Major Constituents, Trace Constituents, and Nutrients. The number of wells used to construct each group's box plot is indicated above its major aquifer category on the x-axis.

In some cases, the Y-Axis is presented in log scale to enhance readability of the plots. Box plots which appear without "boxes" (common in Trace Elements section) have too little data variability to generate different 25^{th} and 75^{th} percentiles of the distribution (upper and lower box bounds). In these cases, the boxes appear collapsed to the most common data point, typically the Reporting Limit. These collapsed boxes generally occur when the "Percent Non-Detect" column of Table 1 is greater than 75%, indicating that the bulk of the data set was reported below the detection limit. Construction details for a box plot are found on the following page of this report.

Ground Water Quality Characterization Program
Division of Drinking and Ground Waters
50 West Town Street, Suite 700
Columbus, OH 43215
(614) 644-2752
Web Page: http://www.epa.ohio.gov/ddagw/gwqcp.aspx
Email: gwq@epa.state.oh.us

Box and Whisker Plots

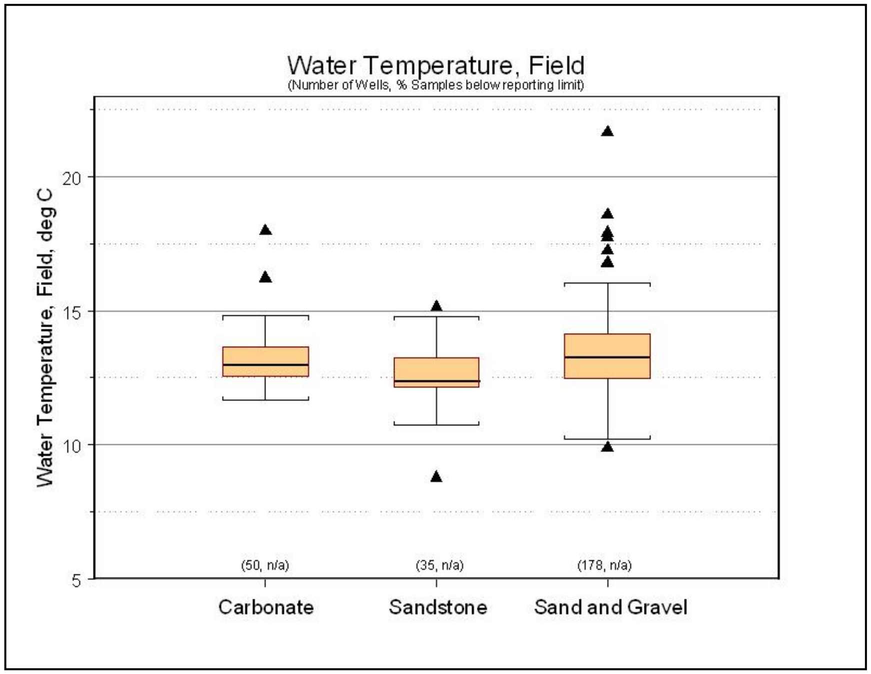


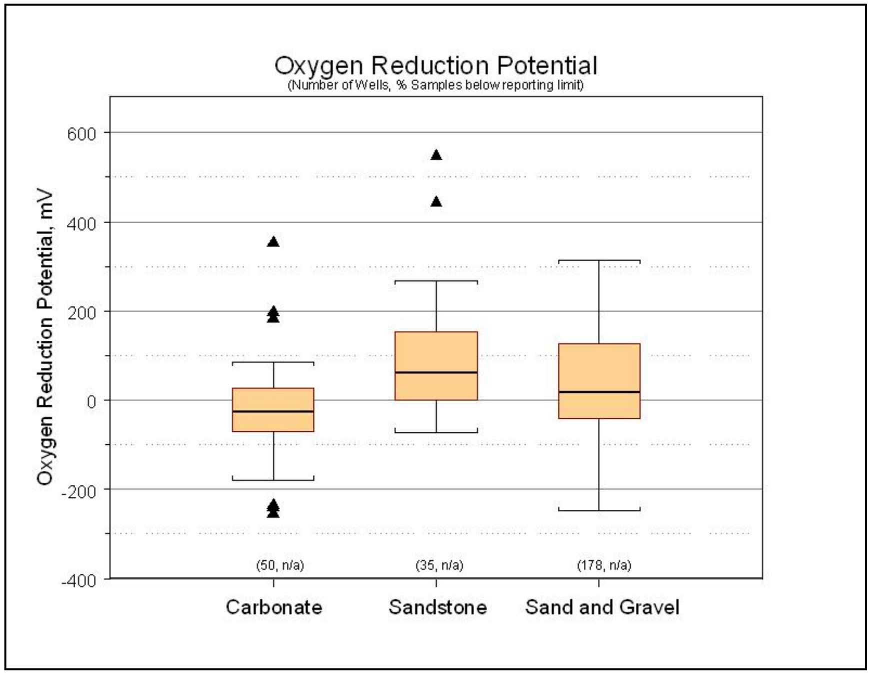
Box and Whisker Plots are an efficient graphical method for displaying the distribution of a data set. The format allows easy comparison of one distribution to those of other groups of data. The “box” itself outlines the range of half the data (the 25th to 75th percentiles, called the Inter-Quartile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

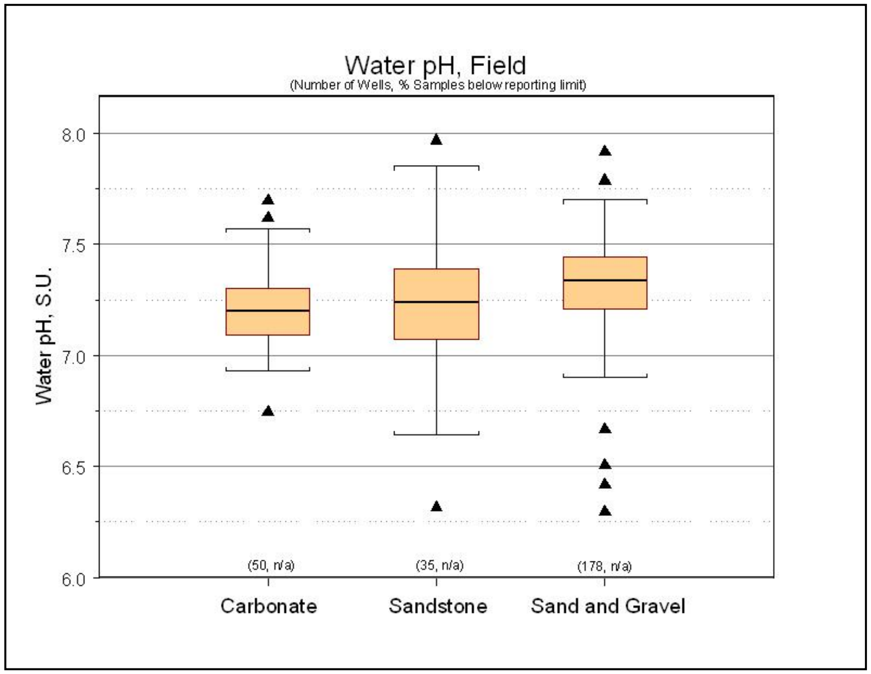
The whiskers are vertical lines extending from the top and bottom of the box, and indicate the range of data (which are not outliers) above and below the 75th and the 25th percentiles, respectively. The whisker caps (horizontal bars at the ends of the whiskers) indicate the last data point which does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

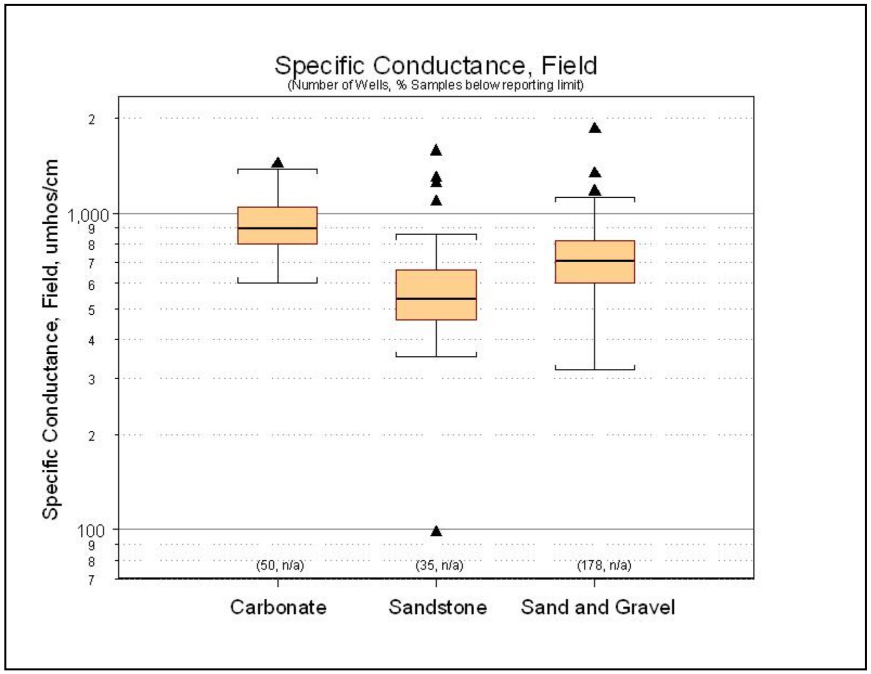
A normally distributed data set is generally indicated if the median bar is located mid-way between the top and bottom of the box. A skewed data set would have the median bar either closer to the 25th percentile (positively skewed) or to the 75th percentile (negatively skewed).

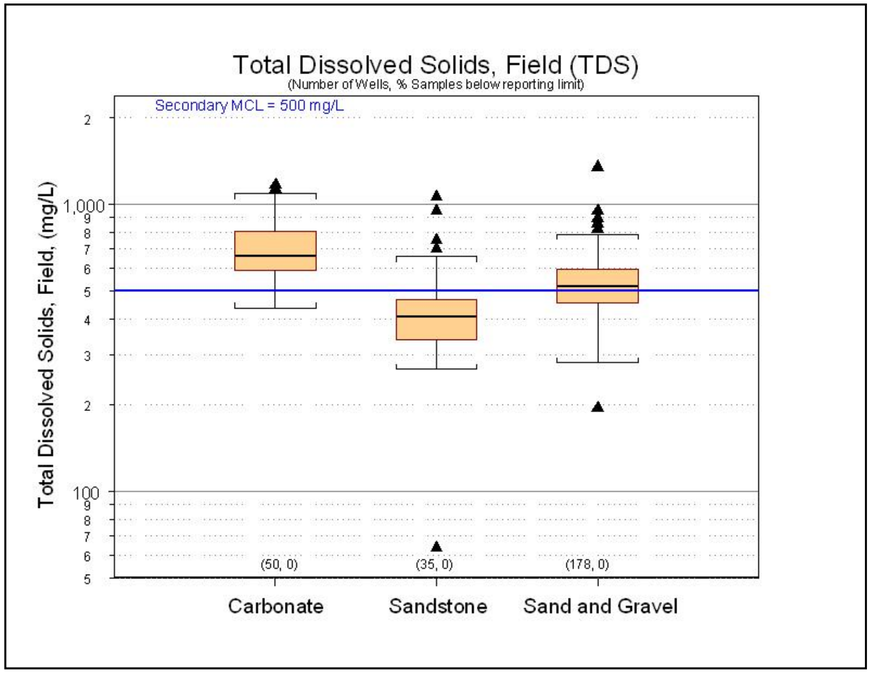
Field Parameters



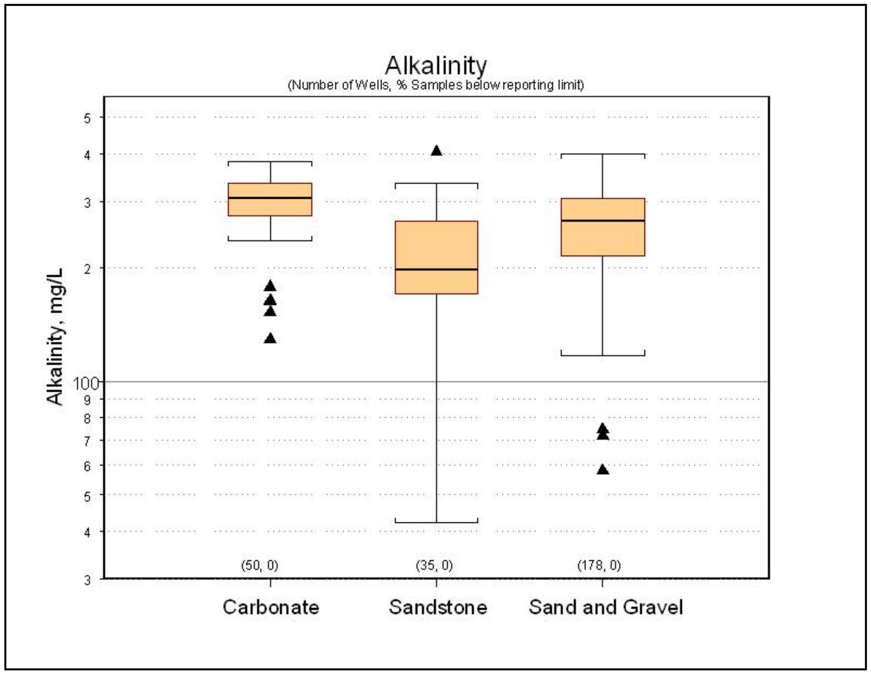


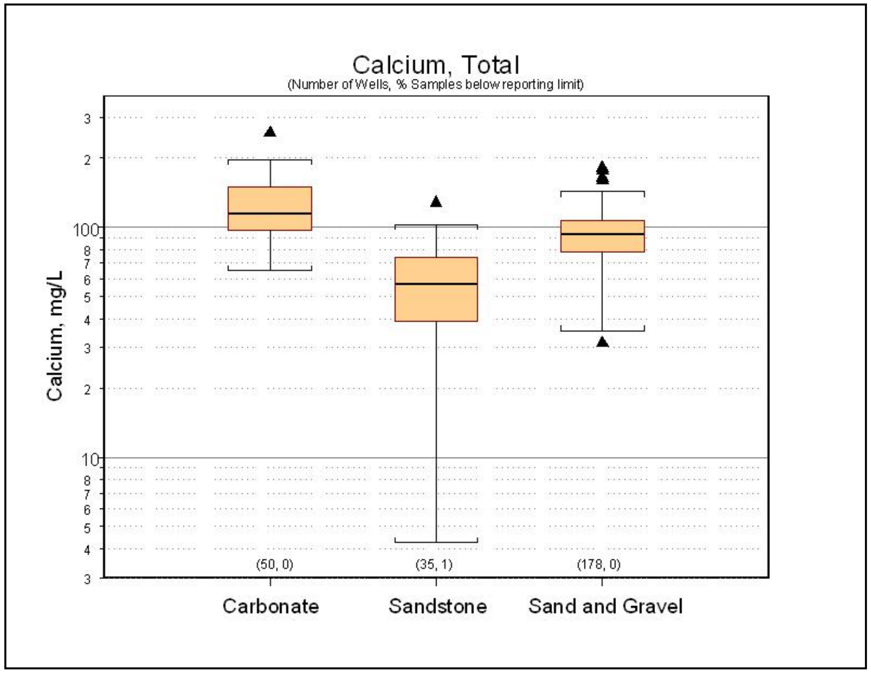


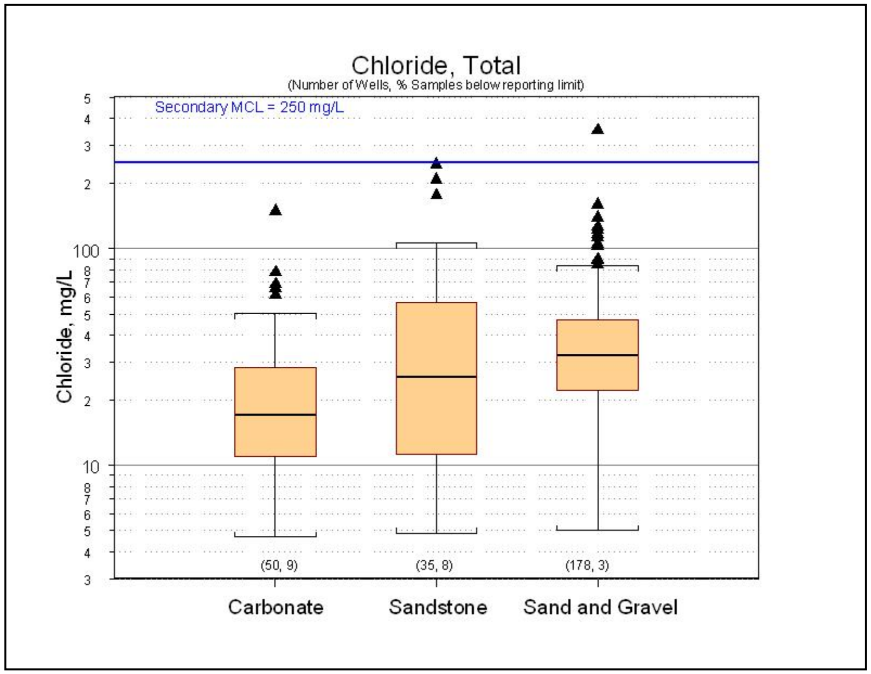

Specific Conductance, Field
(Number of Wells, % Samples below reporting limit)
Specific Conductance, Field, umhos/cm
1,000
100
(50, n/a)
(35, n/a)
(178, n/a)
Carbonate
Sandstone
Sand and Gravel

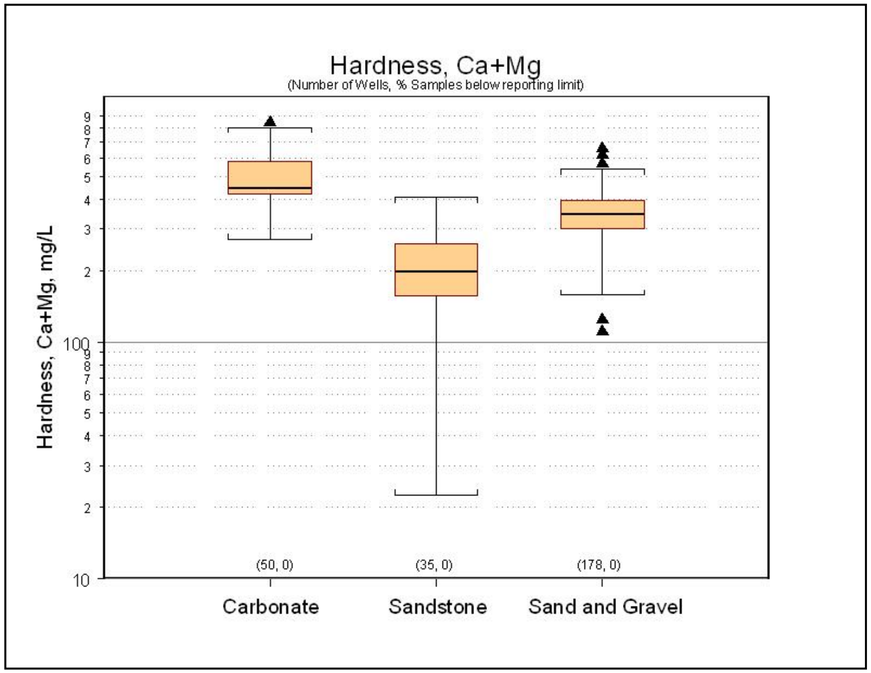

Total Dissolved Solids, Field (TDS)
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 500 mg/L
Total Dissolved Solids, Field, (mg/L)
1,000
100
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

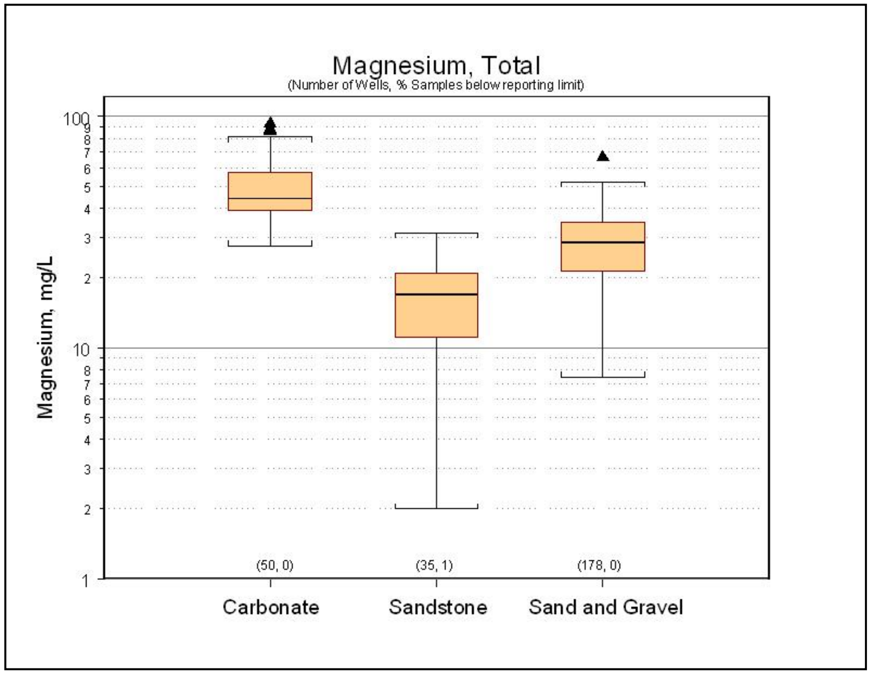
Major Constituents

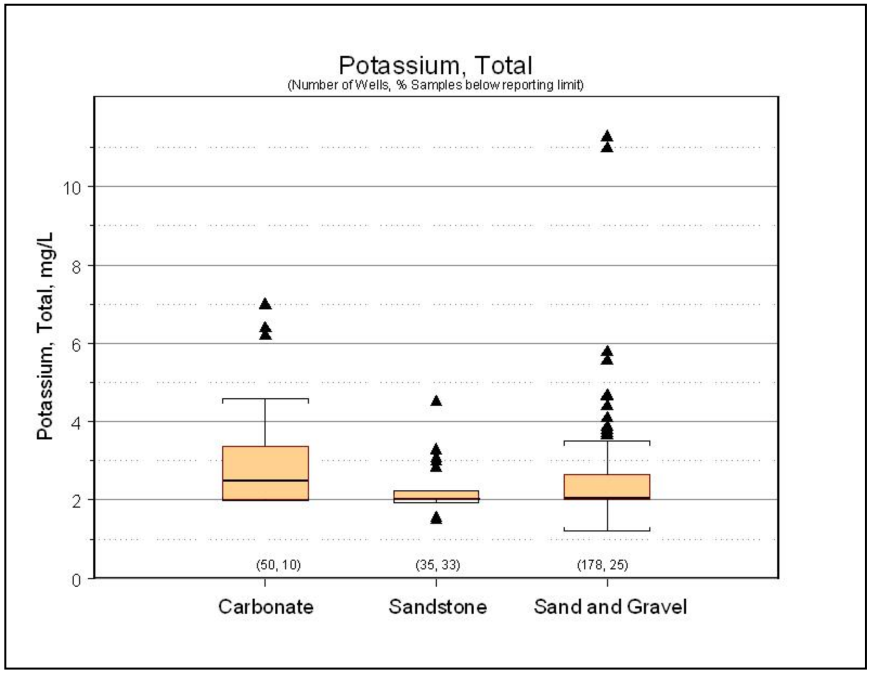


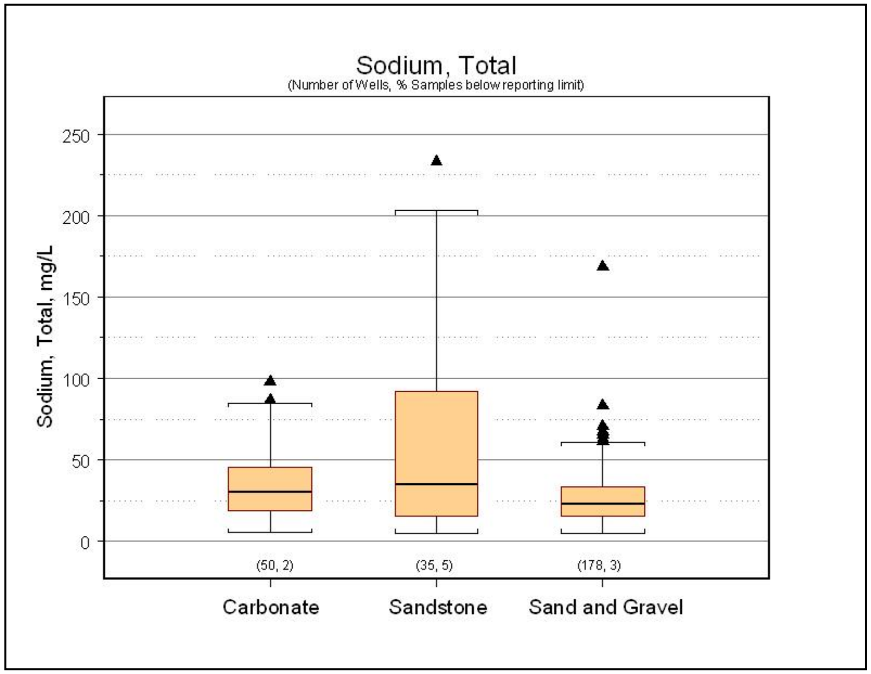


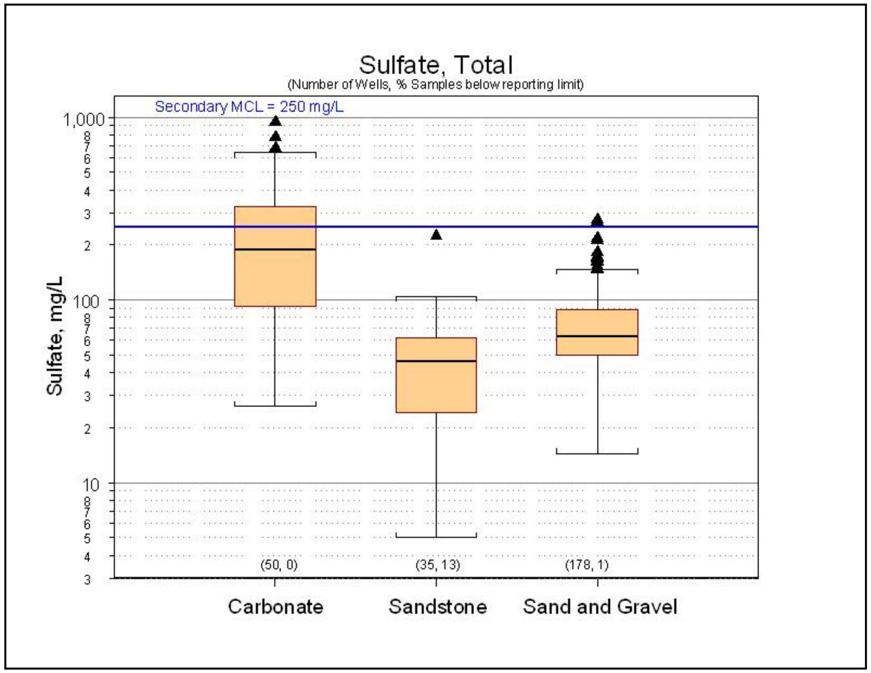


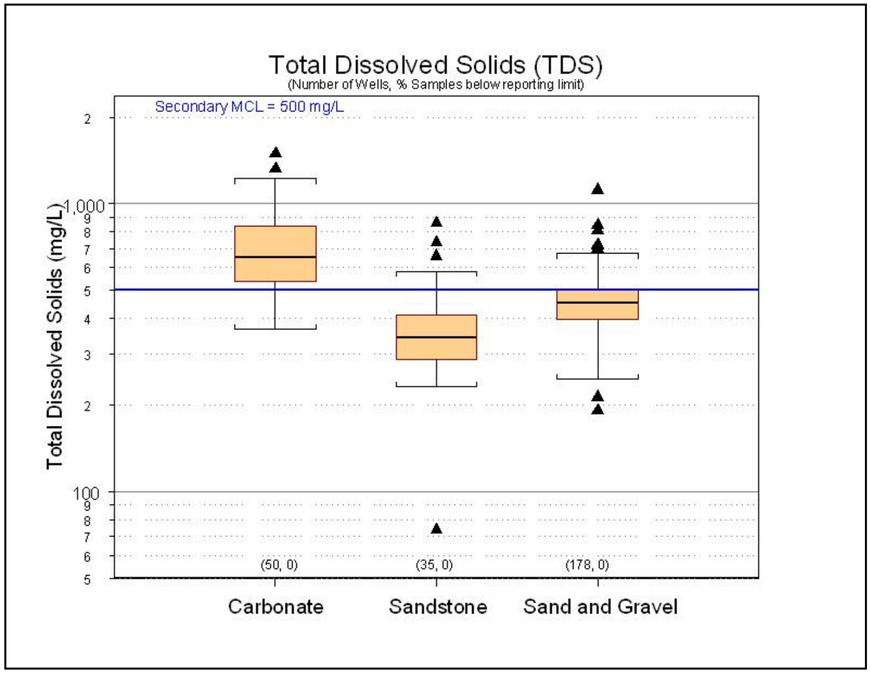

Hardness, Ca+Mg
(Number of Wells, % Samples below reporting limit)
Hardness, Ca+Mg, mg/L
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel


Magnesium, Total
(Number of Wells, % Samples below reporting limit)
Magnesium, mg/L
(50, 0)
(35, 1)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

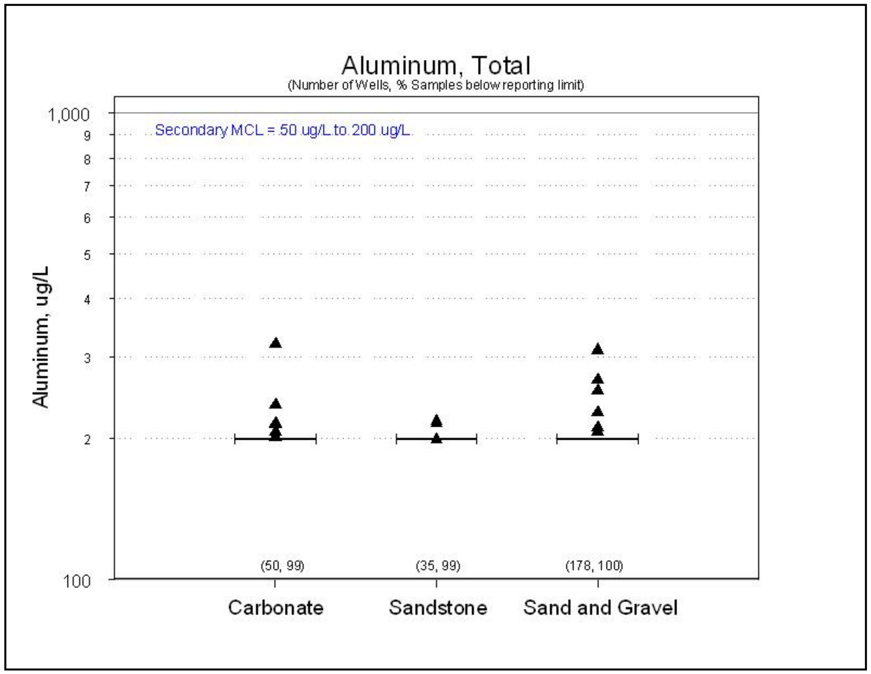

Potassium, Total
(Number of Wells, % Samples below reporting limit)
Potassium, Total, mg/L
(50, 10)
(35, 33)
(178, 25)
Carbonate
Sandstone
Sand and Gravel

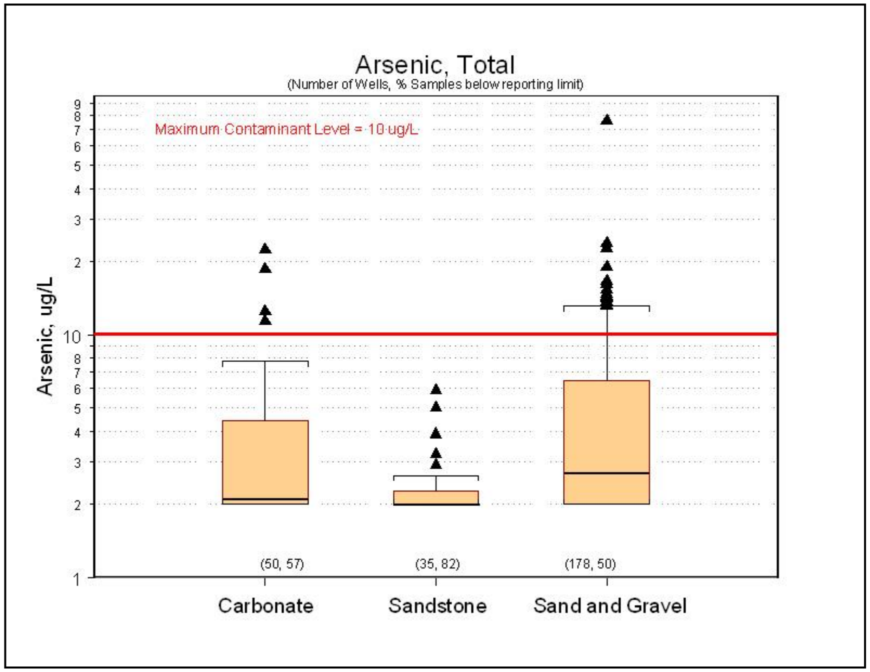

Sodium, Total
(Number of Wells, % Samples below reporting limit)
Sodium, Total, mg/L
(50, 2)
(35, 5)
(178, 3)
Carbonate
Sandstone
Sand and Gravel

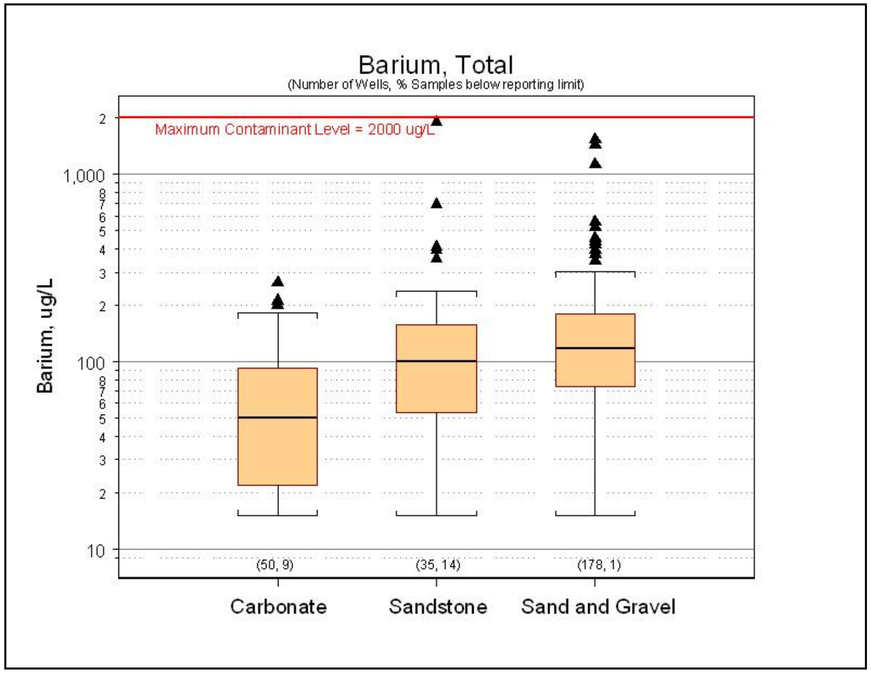

Sulfate, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 250 mg/L
Sulfate, mg/L
1,000
100
10
(50, 0)
(35, 13)
(178, 1)
Carbonate
Sandstone
Sand and Gravel

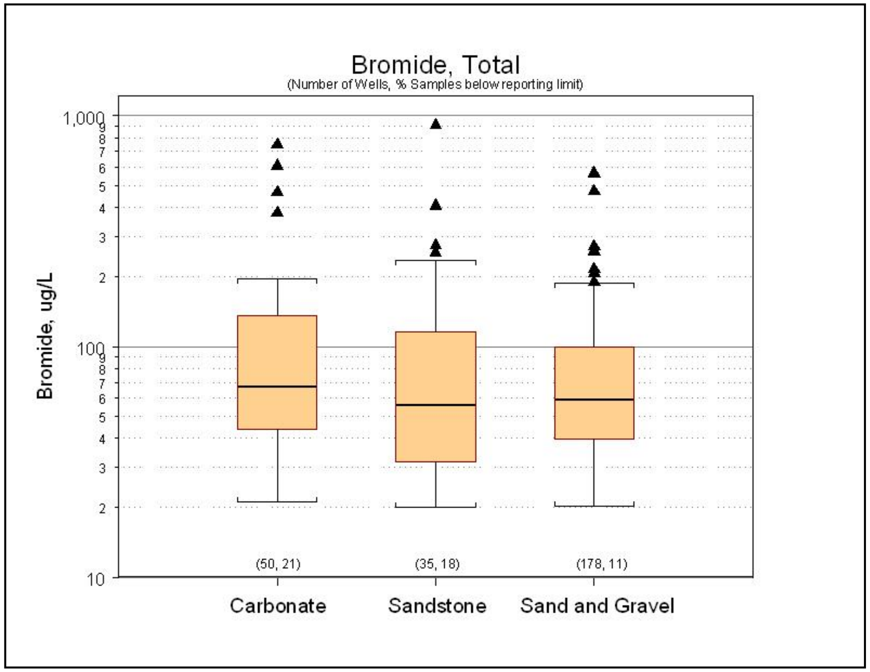

Total Dissolved Solids (TDS)
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 500 mg/L
Total Dissolved Solids (mg/L)
1,000
100
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

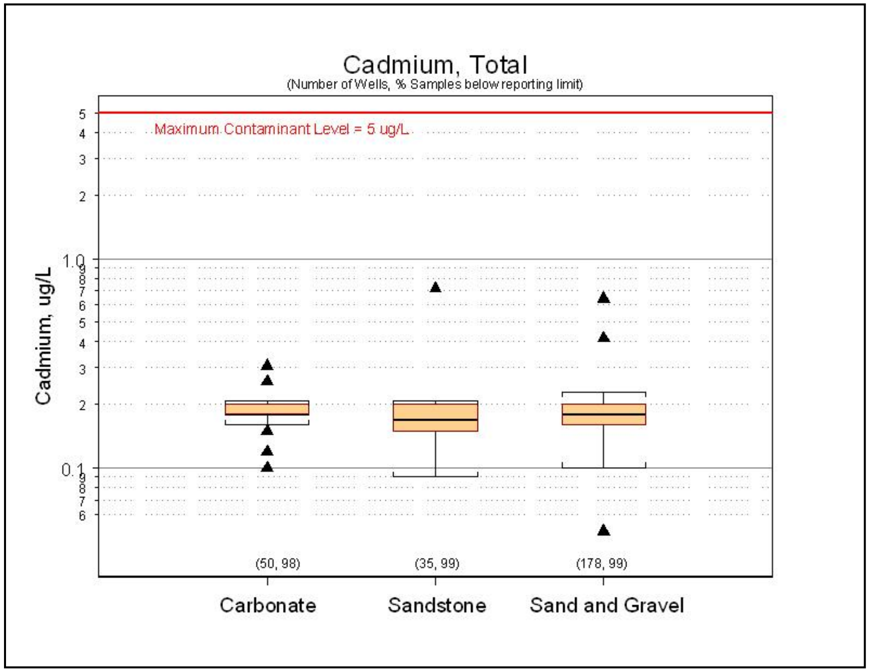
Trace Constituents

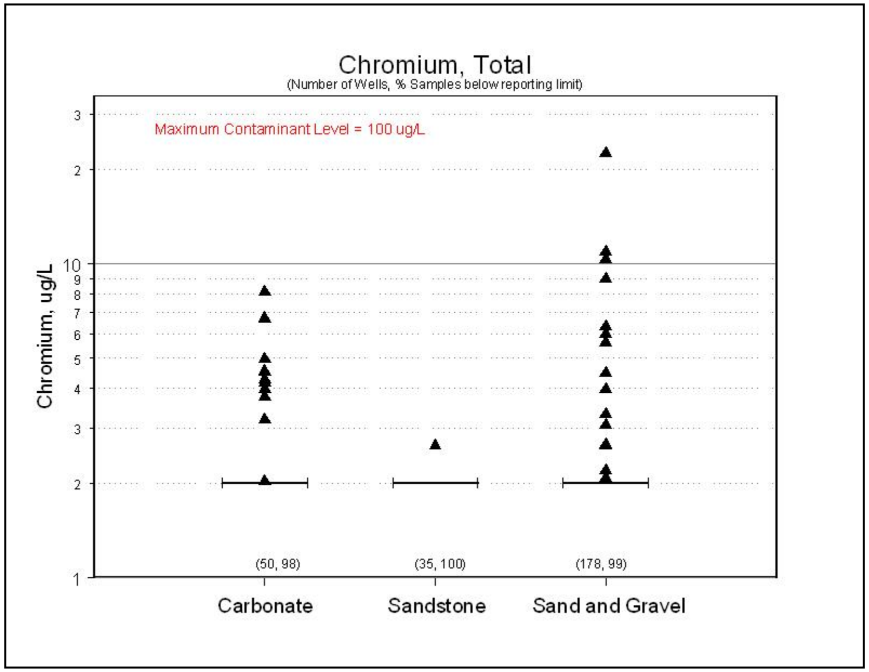


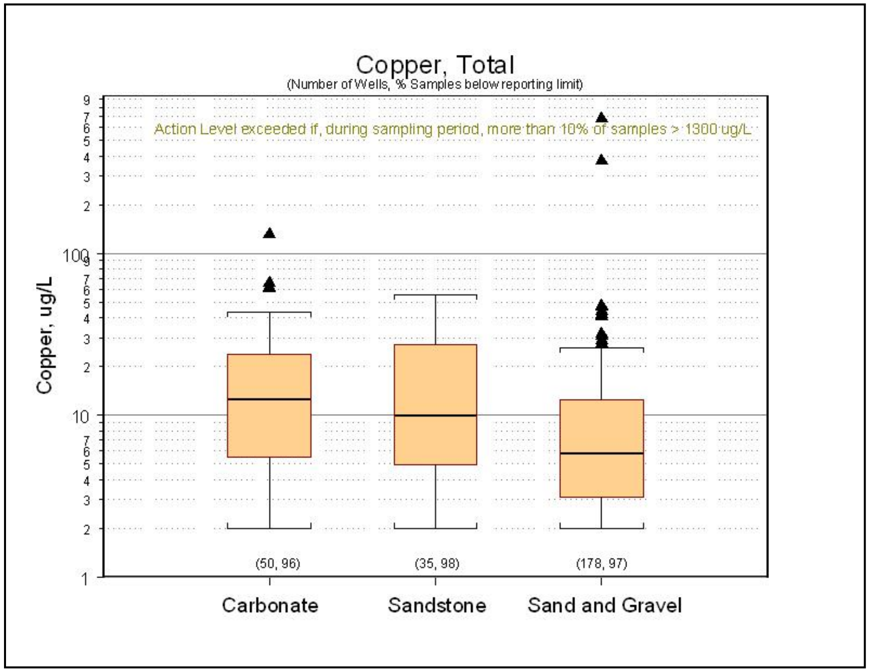


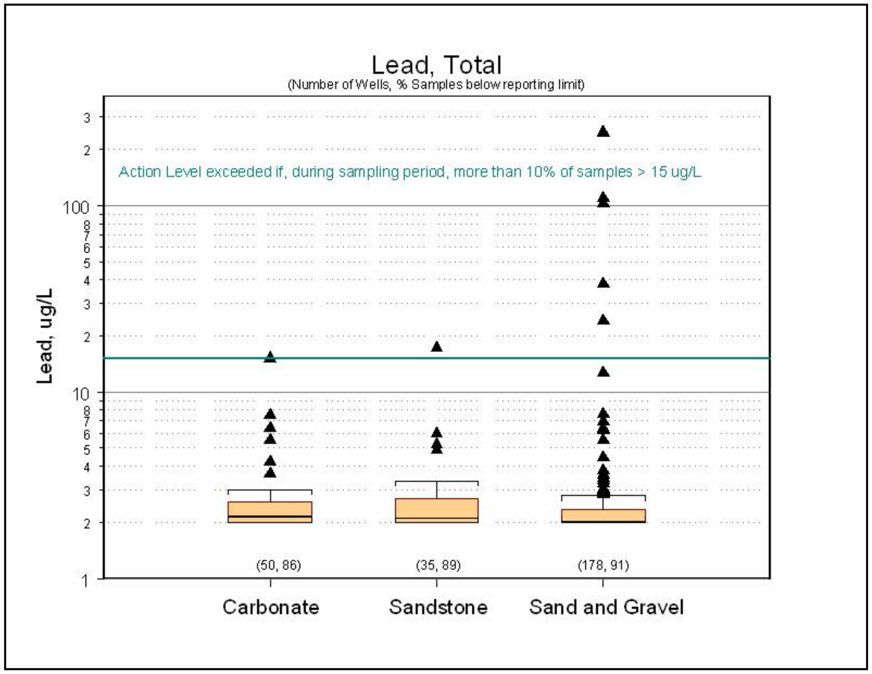


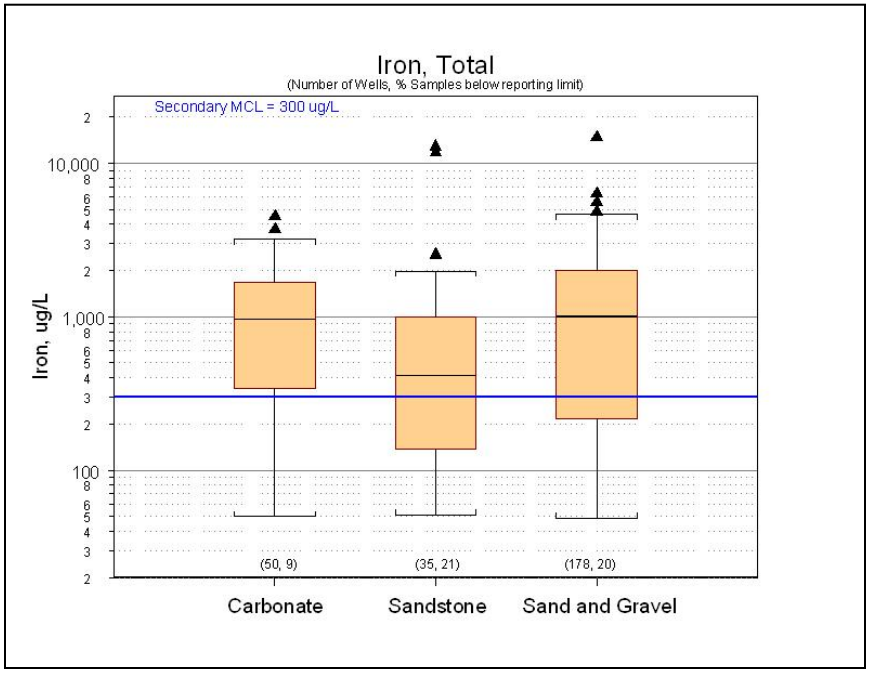

Bromide, Total
(Number of Wells, % Samples below reporting limit)
Bromide, ug/L
(50, 21)
(35, 18)
(178, 11)
Carbonate
Sandstone
Sand and Gravel

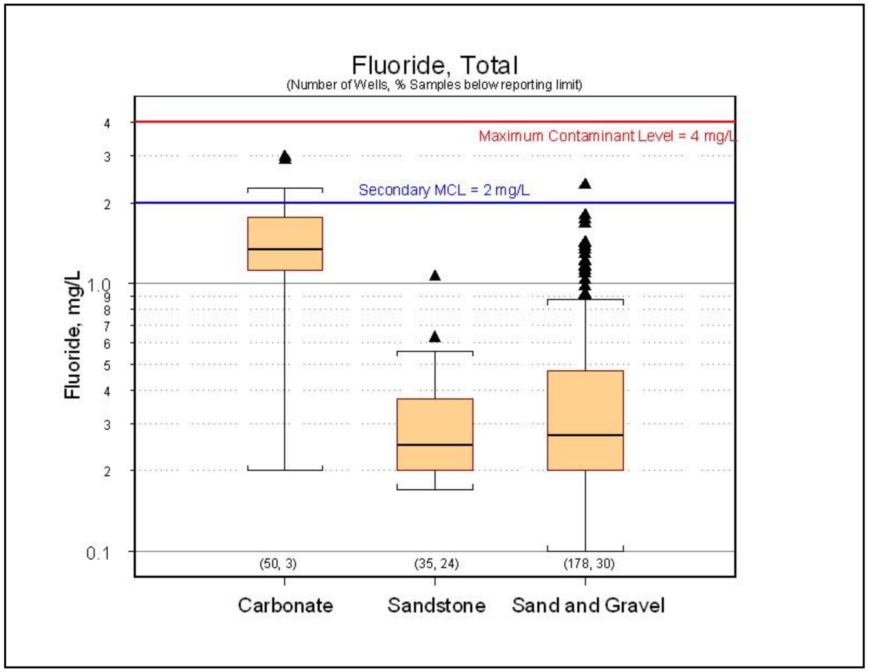

Cadmium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 5 ug/L
Cadmium, ug/L
(50, 98)
(35, 99)
(178, 99)
Carbonate
Sandstone
Sand and Gravel

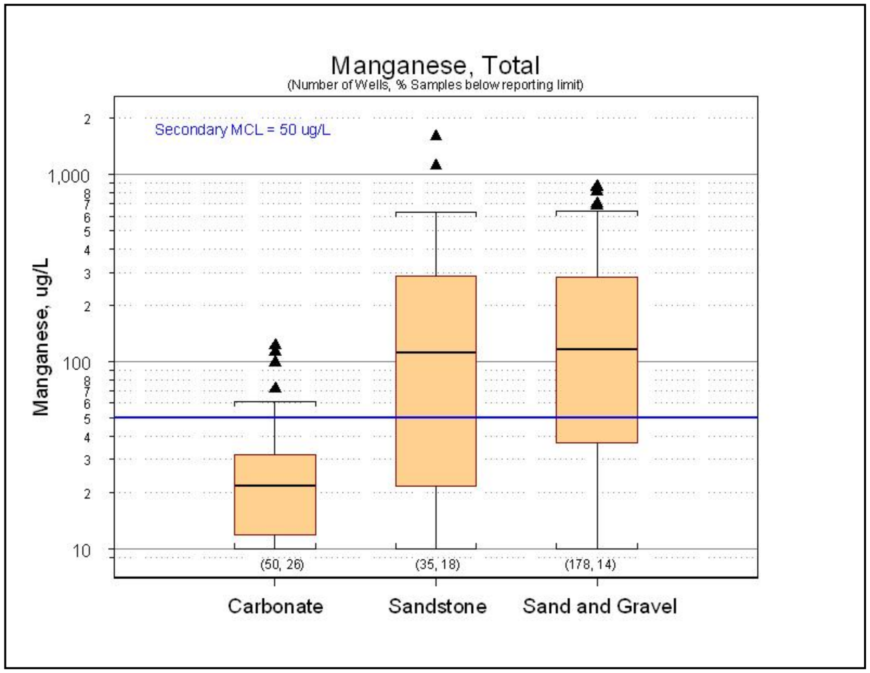

Chromium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 100 ug/L
Chromium, ug/L
(50, 98)
(35, 100)
(178, 99)
Carbonate
Sandstone
Sand and Gravel

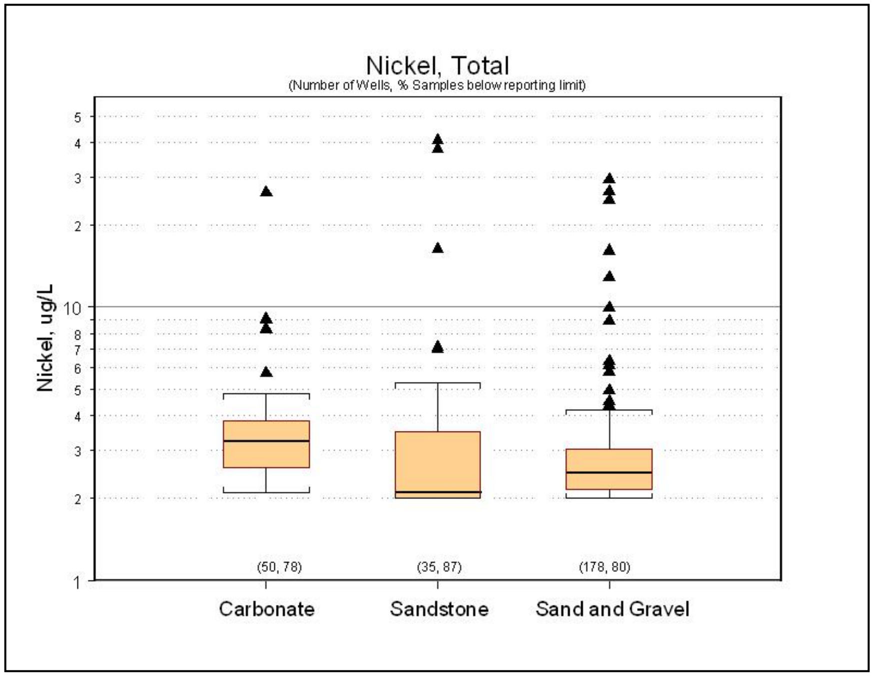

Copper, Total
(Number of Wells, % Samples below reporting limit)
Action Level exceeded if, during sampling period, more than 10% of samples > 1300 ug/L
Copper, ug/L
(50, 96)
(35, 98)
(178, 97)
Carbonate
Sandstone
Sand and Gravel

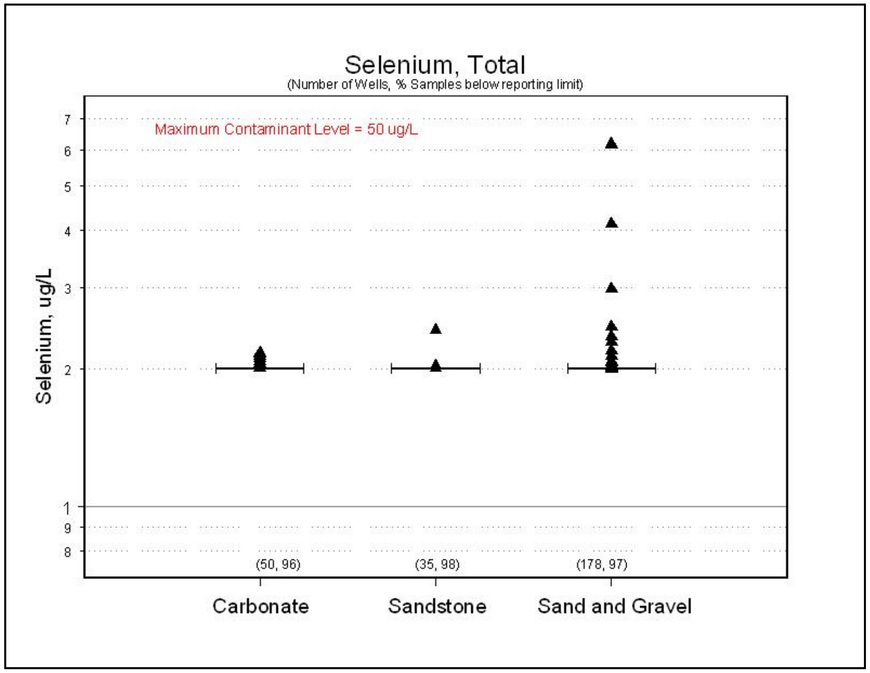

Lead, Total
(Number of Wells, % Samples below reporting limit)
Action Level exceeded if, during sampling period, more than 10% of samples > 15 ug/L
Lead, ug/L
(50, 86)
(35, 89)
(178, 91)
Carbonate
Sandstone
Sand and Gravel

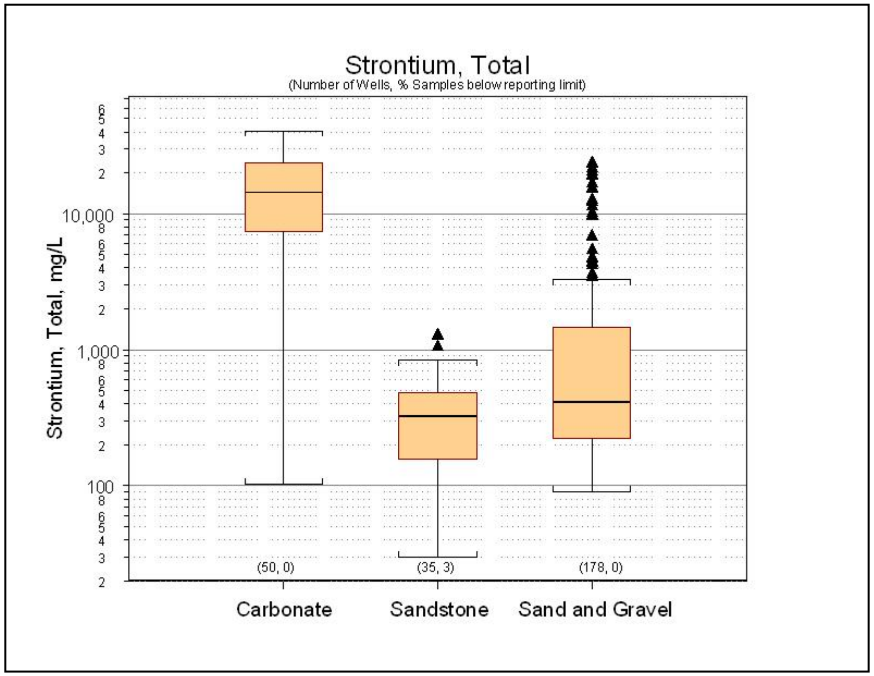

Iron, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 300 ug/L
Iron, ug/L
(50, 9)
(35, 21)
(178, 20)
Carbonate
Sandstone
Sand and Gravel

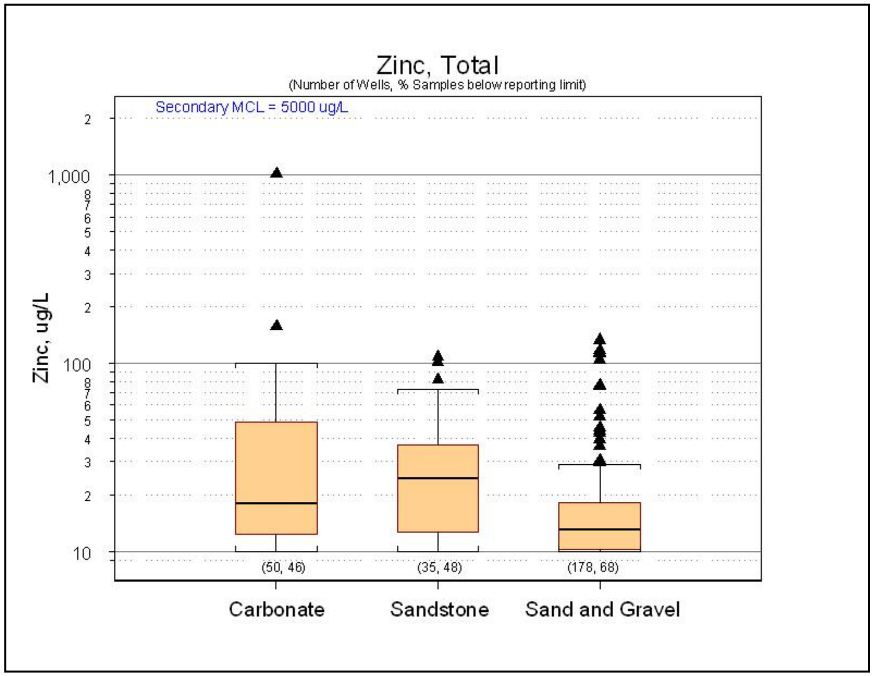

Fluoride, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 4 mg/L
Secondary MCL = 2 mg/L
Fluoride, mg/L
(50, 3)
(35, 24)
(178, 30)
Carbonate
Sandstone
Sand and Gravel


Manganese, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 50 ug/L
Manganese, ug/L
(50, 26)
(35, 18)
(178, 14)
Carbonate
Sandstone
Sand and Gravel

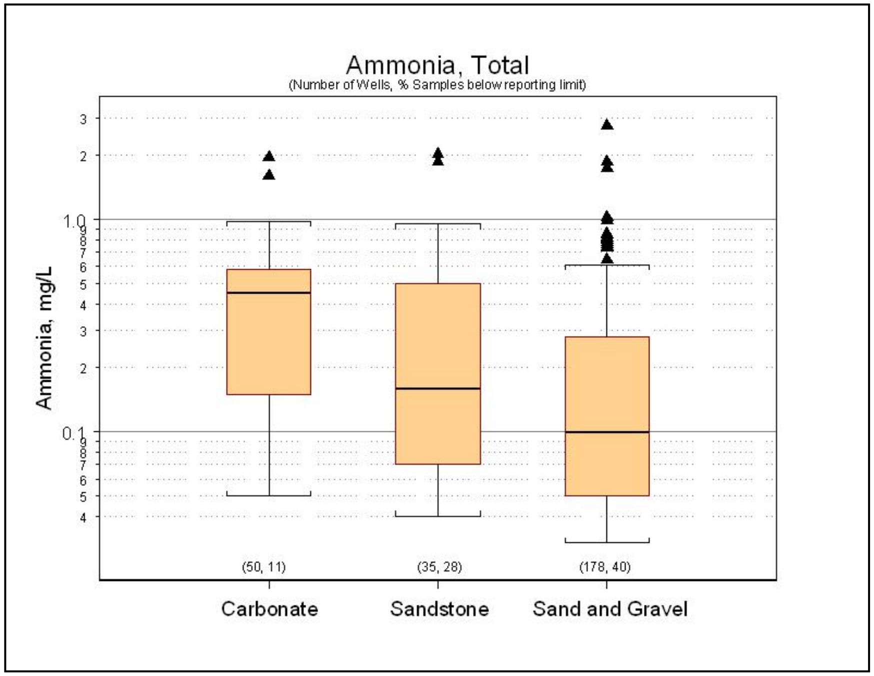

Nickel, Total
(Number of Wells, % Samples below reporting limit)
Nickel, ug/L
(50, 78)
(35, 87)
(178, 80)
Carbonate
Sandstone
Sand and Gravel

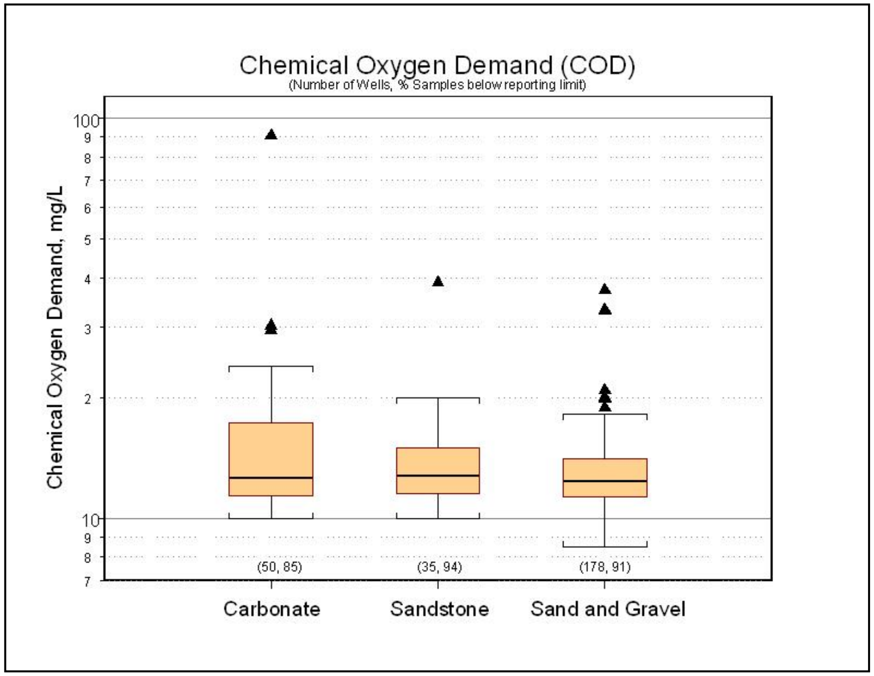

Selenium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 50 ug/L
Selenium, ug/L
(50, 96)
(35, 98)
(178, 97)
Carbonate
Sandstone
Sand and Gravel

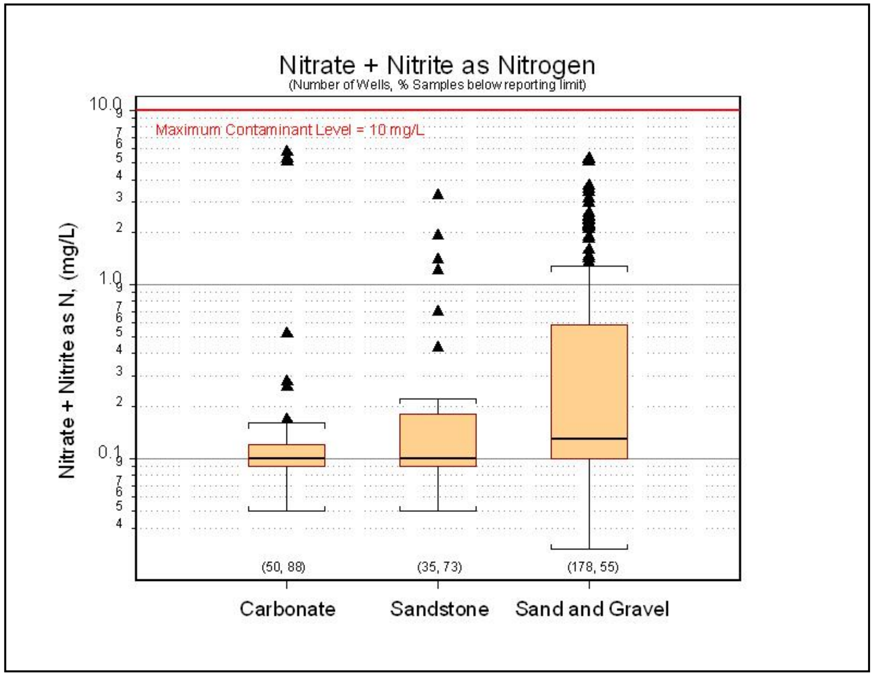

Strontium, Total
(Number of Wells, % Samples below reporting limit)
Strontium, Total, mg/L
(50, 0)
(35, 3)
(178, 0)
Carbonate
Sandstone
Sand and Gravel


Zinc, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 5000 ug/L
Zinc, ug/L
(50, 46)
(35, 48)
(178, 68)
Carbonate
Sandstone
Sand and Gravel

Nutrients


Ammonia, Total
(Number of Wells, % Samples below reporting limit)
Ammonia, mg/L
(50, 11)
(35, 28)
(178, 40)
Carbonate
Sandstone
Sand and Gravel


Chemical Oxygen Demand (COD)
(Number of Wells, % Samples below reporting limit)
Chemical Oxygen Demand, mg/L
(50, 85)
(35, 94)
(178, 91)
Carbonate
Sandstone
Sand and Gravel


Nitrate + Nitrite as Nitrogen
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 10 mg/L
Nitrate + Nitrite as N, (mg/L)
(50, 88)
(35, 73)
(178, 55)
Carbonate
Sandstone
Sand and Gravel