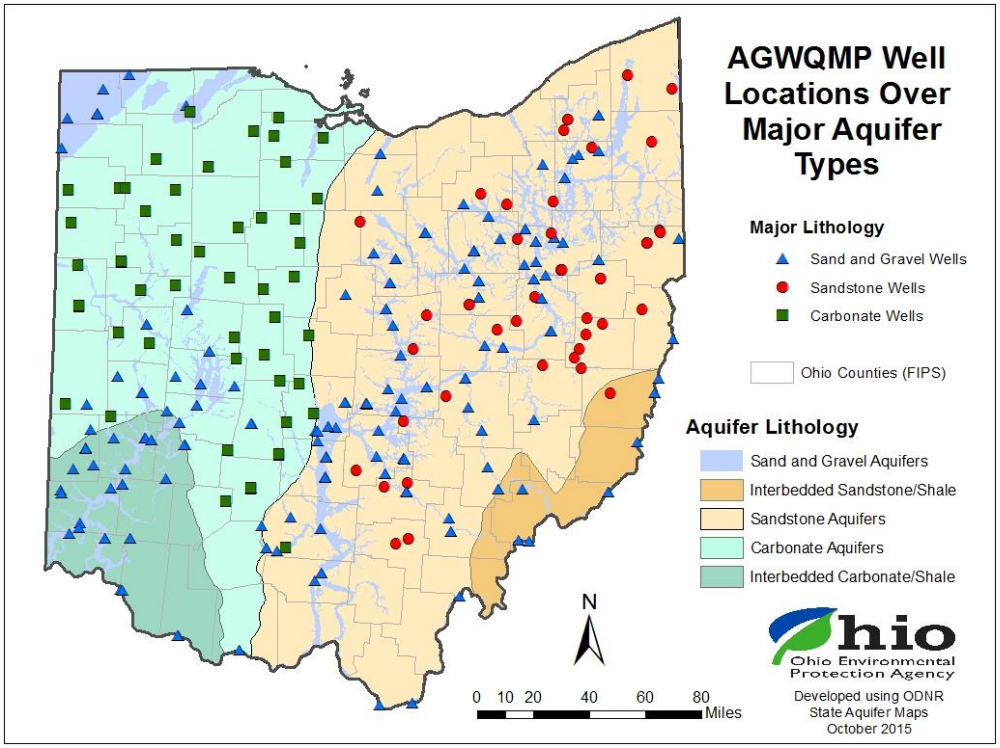
Ohio Environmental Protection Agency

Major Aquifers in Ohio and Associated Water Quality



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

The Technical Series on Ground Water Quality:

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

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

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

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

Disclaimer

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

Ohio's Major Aquifers

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

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

Sand and Gravel Aquifers

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

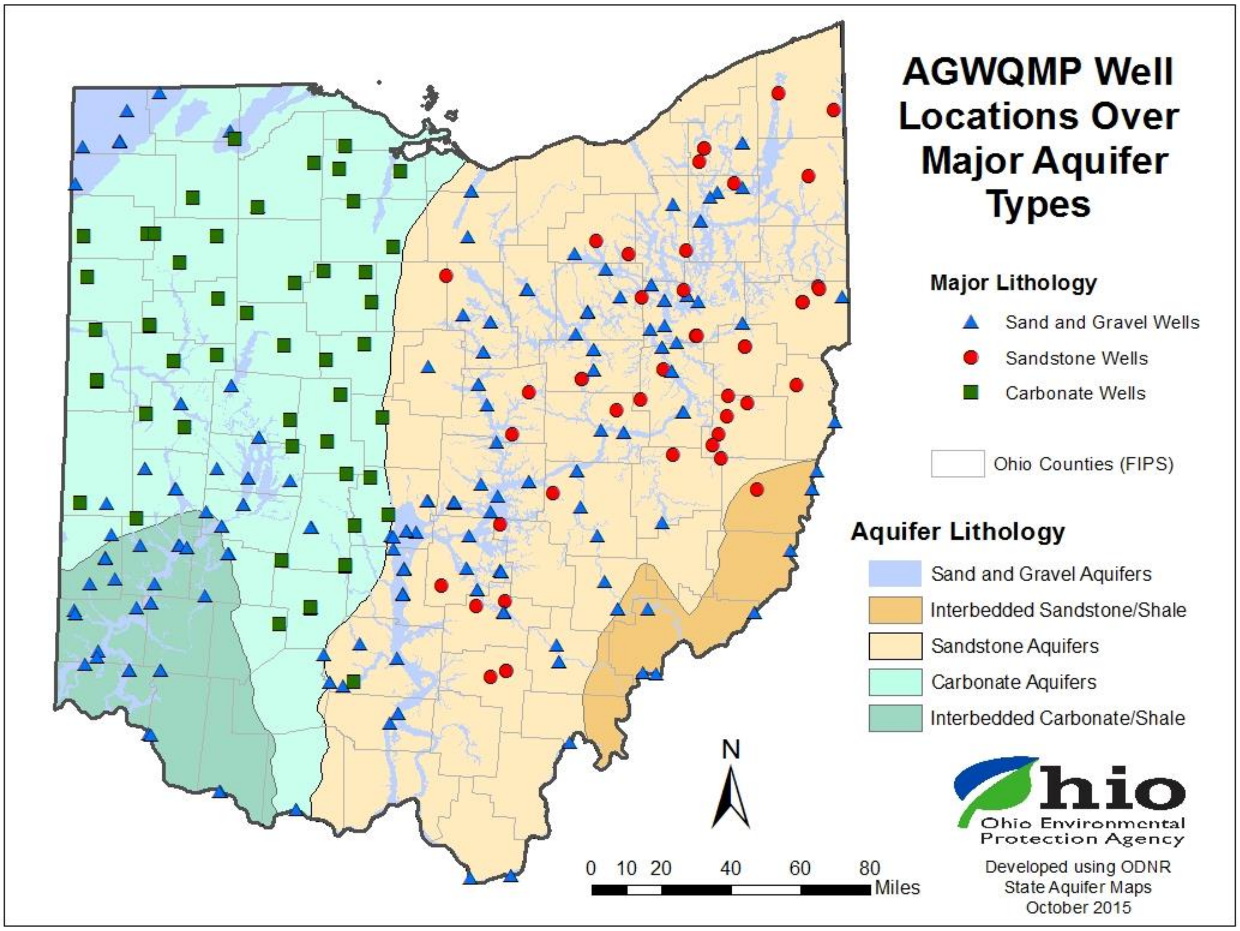

Figure 1. Aquifer Types in Ohio modified from ODNR Glacial and Bedrock Aquifer Maps.

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

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

Sandstone Aquifers

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

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

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

In southeastern Ohio, Upper Pennsylvanian and Permian stratigraphic sections include low-yielding aquifers. The bedrock consists of varied sequences of thin-bedded shales, limestones, sandstones, clays, and coals of the Pennsylvania Conemaugh and Monongahela Groups and the Permian Dunkard Group. Yields below five gpm are common in these areas as illustrated in Figure 2 (from the ODNR web page at: http://soilandwater.ohiodnr.gov/maps/statewide-aquifer-maps in the Example Maps Created from SAMP Data section.

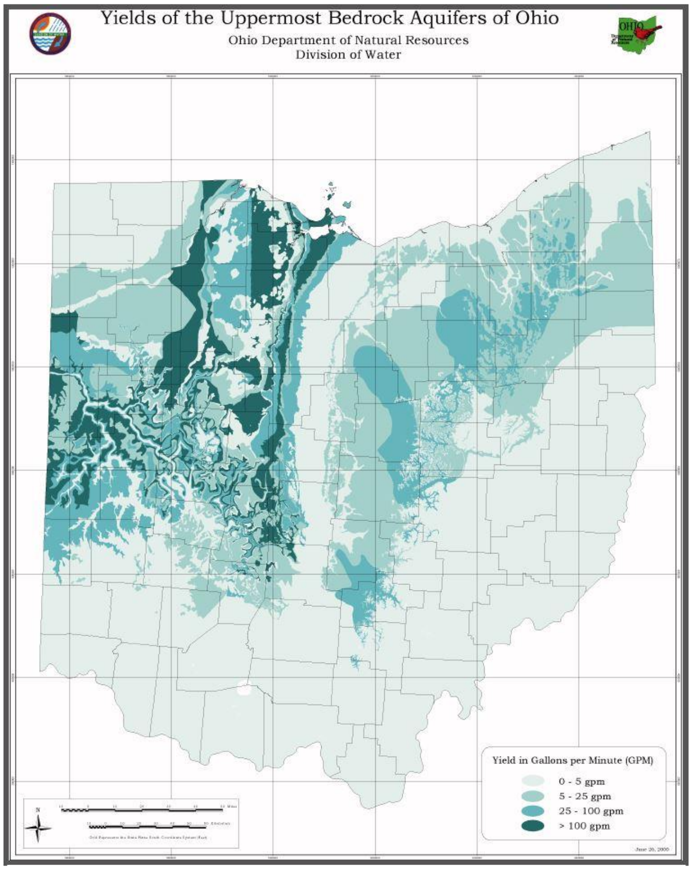

Figure 2. Typical yields for bedrock aquifers.

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 2,600 organic water quality samples distributed across 282 active wells. Figure 1 illustrates the distribution and aquifer type of AGWQMP wells. As described above, the major aquifers include unconsolidated sand and gravel units deposited on sandstone bedrock in eastern Ohio and carbonate bedrock in western Ohio. The majority of the wells used in this characterization are public water supply production wells, usually developed within higher yielding zones with good water quality. This effort supports the goals of the AGWQMP - to collect, analyze, and describe the source (ambient) ground water quality used by public water systems across the state.

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

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

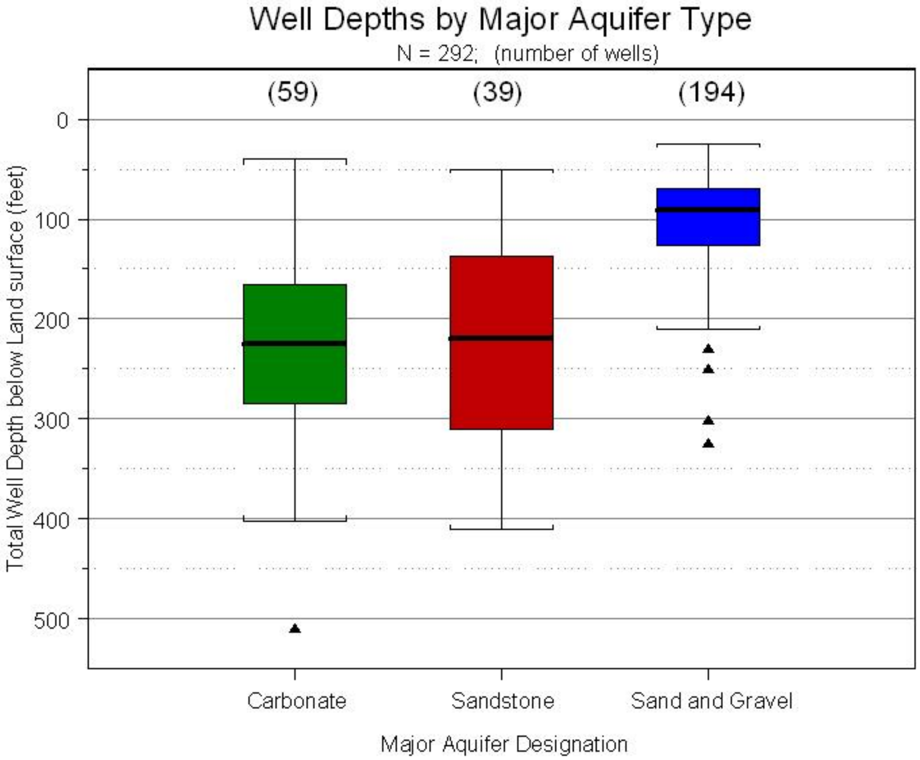

Figure 3. Box plot of active AGWQMP well depths by aquifer type.

Inorganic Parameter Mean Values

Ambient ground water quality data presented in Table 1 (starting on page 10) summarize the geochemistry by major aquifer type for all active AGWQMP wells. This table provides the arithmetic mean, median, minimum value, maximum value, standard deviation, total number of samples, number of samples below the reporting limit, and the percent non-detect for all individual inorganic and field parameter results in each aquifer type as of July 2015. Brief descriptions of several of these parameters are provided to aid in understanding the data. For instance, the reporting limit was used for the non-detect values in calculating means and standard deviation. The “non-detect” column records the percent of analyses with results below the reporting limit (rounded to the nearest percent). The presence of a less than sign (<) in the minimum value field (column 5) indicates the minimum value is the reporting limit. The minimum value may not coincide with the current reporting limit due to changes in analytical methods. AGWQMP sampling started in 1973, and changes in analytical methods resulted in multiple reporting limits for some constituents. The estimates of the number and percentages of non-detect data (columns 8 and 9) may also be influenced by changes in the reporting limits.

Table 1 summarizes the accumulation of over 164,000 raw, inorganic ground-water data results gathered at 282 active and standby wells across Ohio over 40 years of sampling. Consistent sampling protocol, analytical procedures, and long site histories lend a unique significance to these data. Table 1 is the best summary available for the general water quality of Ohio's major aquifers, which provides the source water for Ohio's public drinking water systems using ground water. Note, however, that some wells in the AGWQMP network have been influenced by anthropogenic sources, such as nitrates or VOCs. Thus, the water quality presented is not pristine, but rather is typical of the ground water quality of aquifers utilized for source water by the public water systems.

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

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

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

Use of Primary and Secondary MCLs

Maximum Contaminant Levels (MCLs) are health-based regulatory standards for permissible concentrations of constituents in drinking water delivered to the public. Secondary Maximum Contaminant Levels (SMCLs) are advisory limits applied to distribution water at public water systems for aesthetic water quality issues, such as taste and odor. Because AGWQMP data are obtained from raw (untreated) ground water, which is unregulated, any 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 constituents that have established regulatory values.

Seven of the primary constituents for which health based MCLs exist are monitored in raw water through the AGWQMP. These are arsenic (10 µg/L), barium (2 mg/L), cadmium (5 µg/L), chromium (100 µg/L), fluoride (4 mg/L), nitrate-nitrite as N (10 mg/L), and selenium (50 µg/L). Additionally, copper and lead have action levels (not MCLs or SMCLs) of 1.3 mg/L and 0.015 mg/L respectively. As indicated by the Ambient Ground Water Quality Table 1, no constituent exceeds a MCL based on averages by aquifer type. Arsenic exhibits the highest concentrations as a percentage of the MCL; nevertheless, mean concentrations for all three aquifer types are well below the arsenic MCL of 10 µg/L (sand and gravel = 5.41 µg/L, sandstone = 2.48 µg/L, carbonate = 3.75 µg/L). However, 30 active AGWQMP wells have raw water means that exceed the arsenic MCL of 10 µg/L. If these wells are public water system wells, treatment would be required to bring arsenic concentrations below the MCL in the distributed water. Means for barium, cadmium, chromium, fluoride, nitrate-nitrite, and selenium are also below MCLs within all three aquifer systems. Individual well means indicate no MCL exceedances for barium, cadmium, chromium, fluoride, nitrate, and selenium, but three AGWQMP wells have barium means greater than 75 % of the MCL.

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

Volatile Organic Compounds

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

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

Table 2. Most Frequently Detected VOCs in AGWQMP Wells.

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

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

PCE and TCE can both undergo dechlorination (loss of a chlorine) leading to the daughter products 1,1-dichloroethylene, cis- and trans-1,2-dichloroethylene, which ultimately degrade into vinyl chloride. As a group, their concentrations in ground water are quite low, well below MCLs, but maximum values for TCE (14 results at one site) and PCE (2 of 53 results) are above MCL. The usage of multiple solvents or the degradation of one solvent to another can explain the occurrence of mixtures of these compounds found in some AGWQMP wells. MTBE, a gasoline additive (oxygenate), is also included in the top five list, but 29 of the 33 detections occur at one well and concentrations are generally decreasing in this well.

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

Trihalomethanes (THM) are the most frequently detected organic compounds in AGWQMP wells (119 detections at 33 sites), including chloroform, bromoform, dichlorobromomethane, and chlorodibromomethane. However, the source of these compounds is not always clear. The maximum value detected in active wells, 37 µg/L, is well below the MCL of 80 µg/L. 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 distribution system or sewer lines is recharging local wells. The source of THMs in a well is not always clear, consequently, unlike the VOC detections, THM detections cannot always be attributed to land use impacts.

Summary

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

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Dumouchelle, D., and M.C. Schiefer, 2002. Use of Streamflow Records and Basin Characteristics to Estimate Ground-Water Recharge Rates in Ohio. Ohio Department of Natural Resources Division of Water. Columbus Ohio. Bulletin 46.

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

Table 1 – Ambient Ground Water Quality Data

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

FIELD PARAMETERS

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

MAJOR COMPONENTS

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
	Alkalinity, Total as $CaCO_3$ mg/L	Sand and Gravel	257	265	5	587	66.2	4002	7	0
		Sandstone	205	196	33.1	496	74.9	776	0	0
		Carbonate	295	306	92.6	642	67.4	1049	0	0
	Calcium, Total mg/L	Sand and Gravel	92.8	93	<2.0	300	23.7	4065	1	0
		Sandstone	57.1	58	<2.0	167	26.7	781	3	0
		Carbonate	123	114	26	584	39.6	1063	0	0
250 ^{S} mg/L	Chloride mg/L	Sand and Gravel	40.6	32	<2.0	474	34	4046	130	3
		Sandstone	54	31.9	<2.0	899	74.5	778	49	6
		Carbonate	28.1	16	<2.0	420	34.9	1045	101	10
	Hardness, Total as $CaCO_3$ mg/L	Sand and Gravel	347	352	<10.0	953	83.9	3524	2	0
		Sandstone	213	214	<10.0	541	86.4	702	1	0
		Carbonate	505	450	110	2060	165	935	0	0
	Magnesium, Total mg/L	Sand and Gravel	28.2	29	<1.0	81	9.42	4066	9	0
		Sandstone	16.5	16	<1.0	35	6.97	781	5	1
		Carbonate	49.8	43	11	147	18.4	1063	0	0
	Potassium, Total mg/L	Sand and Gravel	2.41	2.0	<0.9	20	1.04	3925	984	25
		Sandstone	2.34	2.0	<1.0	6.5	0.76	771	264	34
		Carbonate	2.82	2.1	<1.3	11.6	1.2	1035	109	11
	Sodium, Total mg/L	Sand and Gravel	26.4	22	<4.0	427	20.2	4069	107	3
		Sandstone	60.1	28	<5.0	754	73.6	781	26	3
		Carbonate	35.5	28	<5.0	239	26.6	1062	19	2
250 ^{S} mg/L	Sulfate mg/L	Sand and Gravel	74.4	64.7	<5.0	640	44	4052	29	1
		Sandstone	52.4	41.7	<5.0	271	48.8	782	83	11
		Carbonate	245	176	<5.0	1830	207	1065	3	0
500 ^{S} mg/L	Total Dissolved Solids mg/L	Sand and Gravel	457	448	<10.0	2120	116	3965	1	0
		Sandstone	391	332	48	1850	183	742	0	0
		Carbonate	722	638	264	3200	274	1035	0	0

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

TRACE CONSTITUENTS

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

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

* Records with '<' represent reporting limit

§ NA denotes not applicable

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

S Secondary MCL

AL Action Level

Appendix A

Ambient Ground Water Quality Monitoring Program

Inorganic Constituent Box and Whisker Plots

This document provides a concise geochemical summary, in box and whisker plot format, of the Ambient Ground Water Quality Monitoring Program (AGWMP) inorganic data set as of July 2015. The Box and Whisker plots from the Ambient Ground Water Quality Network database include results from 6000 raw (untreated), inorganic water samples collected over the past 40 years across more than 200 active wells. Active (AGWMP) wells are sampled every six, eighteen or thirty-six months. The primary objective of collecting statewide, raw ground water data from major aquifers is to characterize Ohio's ground water quality, which in turn is used to enhance water resource planning and to prioritize ground water protection. The AGWMP places a priority on collecting water quality data representative of aquifers used by public water systems. Analysis of water quality changes in space and time indicate that some of the AGWMP wells are influenced by land use activities. The wells are considered typical of the local ground water used as source water for public water systems.

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

The y-axis is presented in linear or in log 10 scale, whichever enhances readability. Box plots that appear without "boxes" (common in Trace Constituents section) have too little data variability to generate separation of the 25th and 75th percentiles of the distribution (upper and lower box bounds). In these cases, the boxes appear collapsed to the most common data point, typically the Reporting Limit. Collapsed boxes generally occur when more than 75% of the data are below the reporting limit. In the case of chromium and nickel, high reporting limits in early data distort the representation of variability of these data. In both of these cases, the lower (current) reporting limit was used for all non-detect results to more accurately represent the distribution of chromium and nickel.

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

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

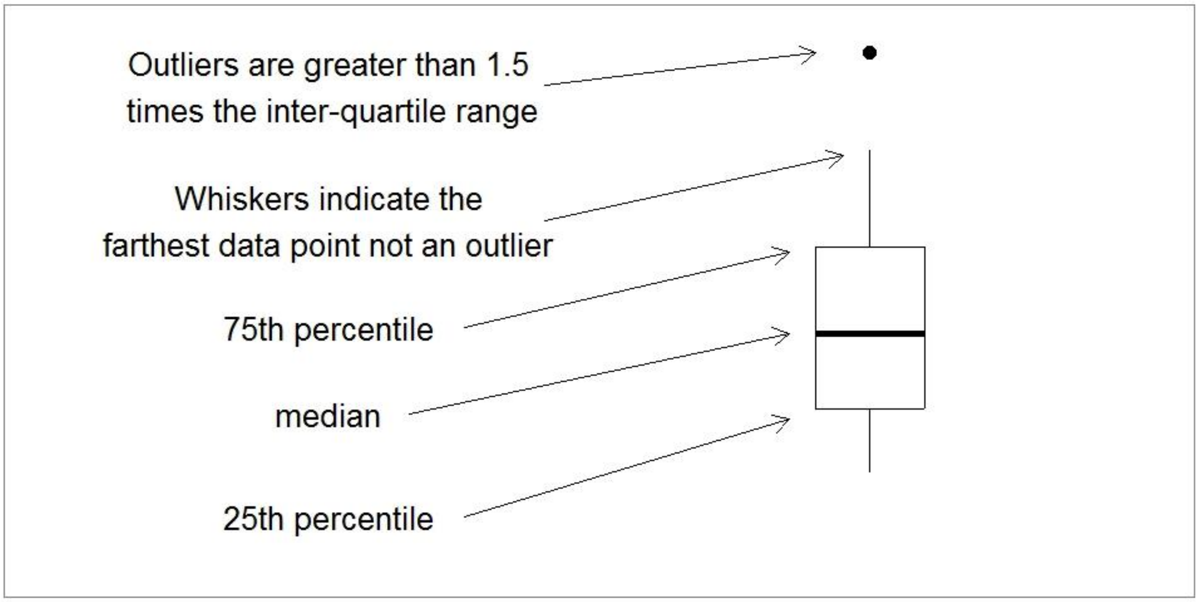


Figure 1

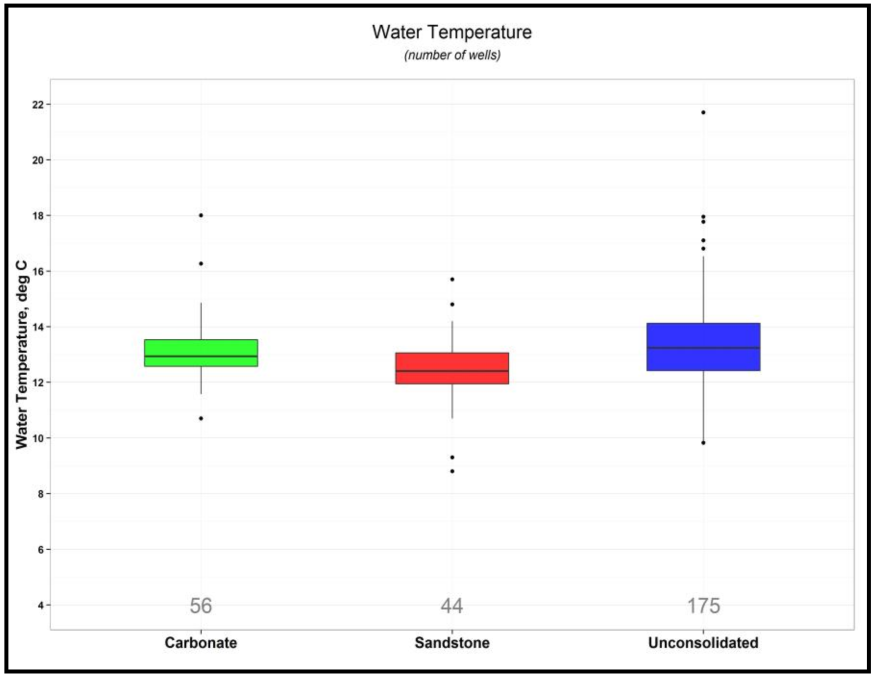
Explanation of Box Plot construction.

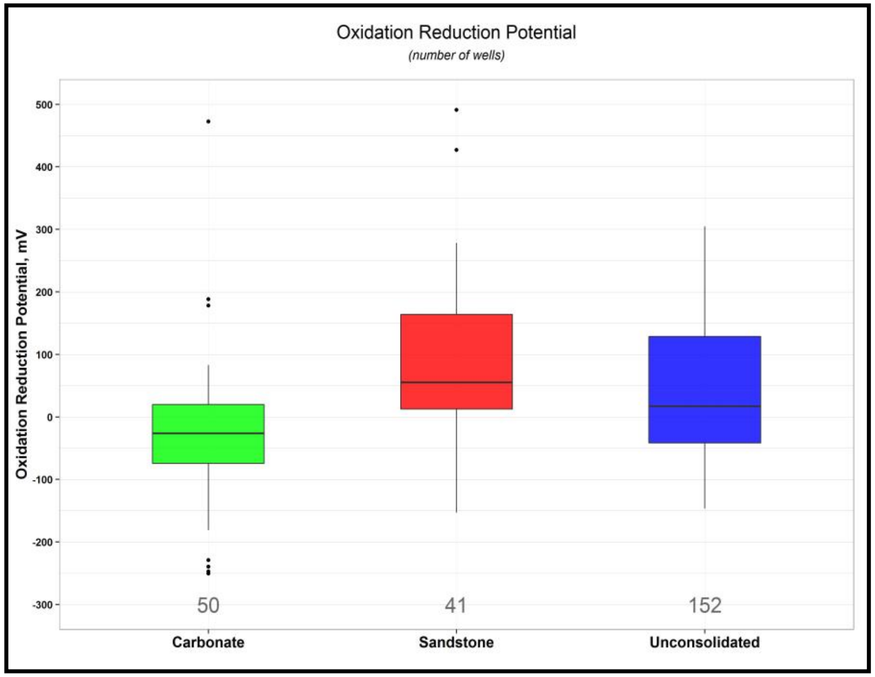
Box and Whisker Plots are an efficient graphical method for displaying the distribution of a data set. The format allows easy comparison of one distribution to those of other groups of data. The elements of a typical boxplot are indicated in Figure 1. The "box" itself outlines the range of half the data (the 25th to 75th percentiles, called the Inter-Quartile Range, or IQR). The median of the data set (the 50th percentile) is indicated by a thick horizontal bar inside the box.

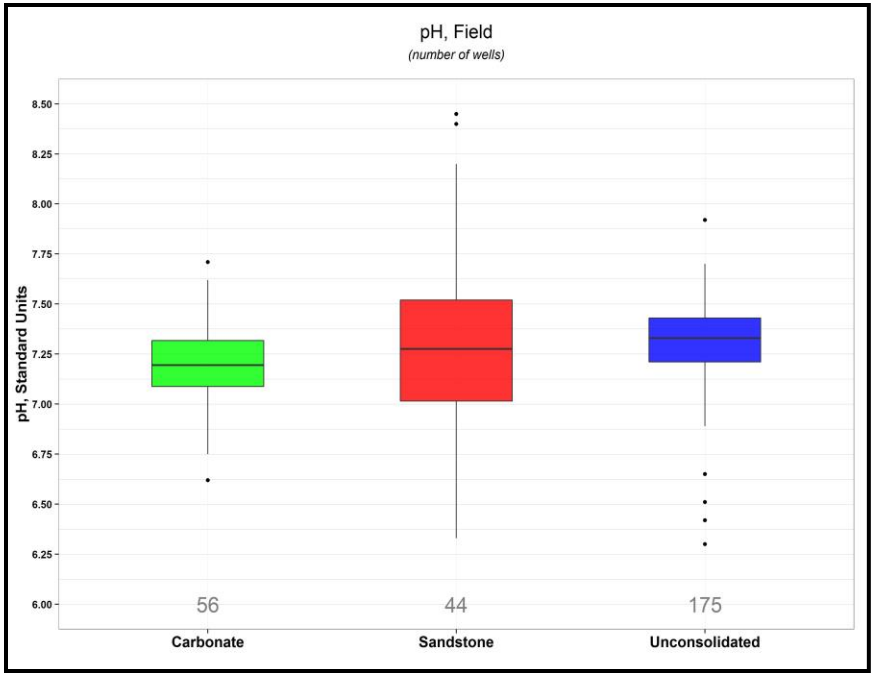
The whiskers are vertical lines extending from the top and bottom of the box, and indicate the range of data (which are not outliers) above and below the 75th and the 25th percentiles, respectively. The extent of the whiskers indicates the position of the last data point which does not exceed 1.5 times the IQR. Outliers exceed 1.5 times the IQR, and are identified by individual symbols above or below the whiskers.

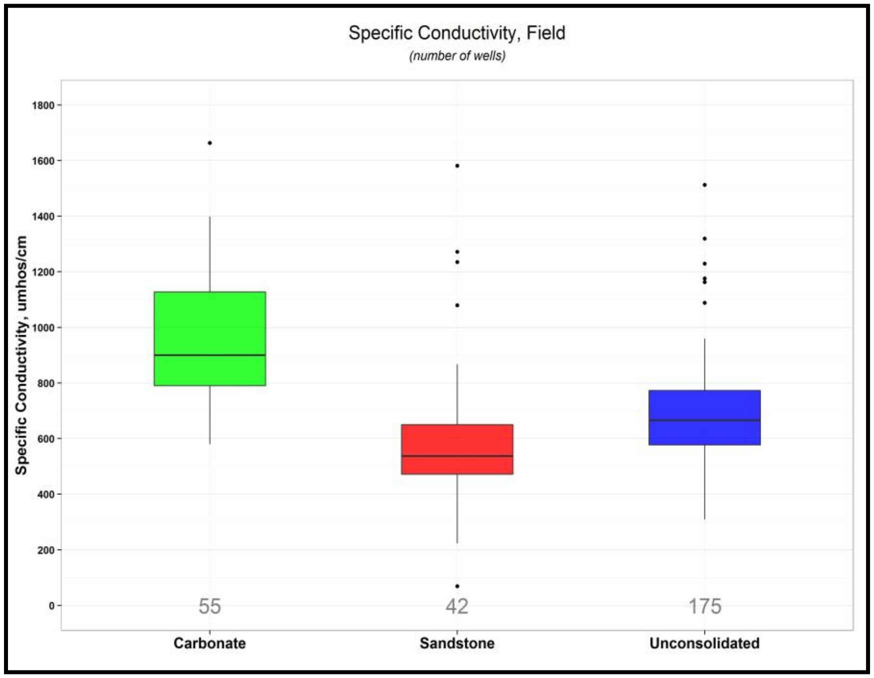
A normally distributed data set is indicated if the median bar is located mid-way between the top and bottom of the box, i.e. if the median is equidistant between the 25th and 75th percentiles. A skewed data set would have the median bar either closer to the 25th percentile (positively skewed) or to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

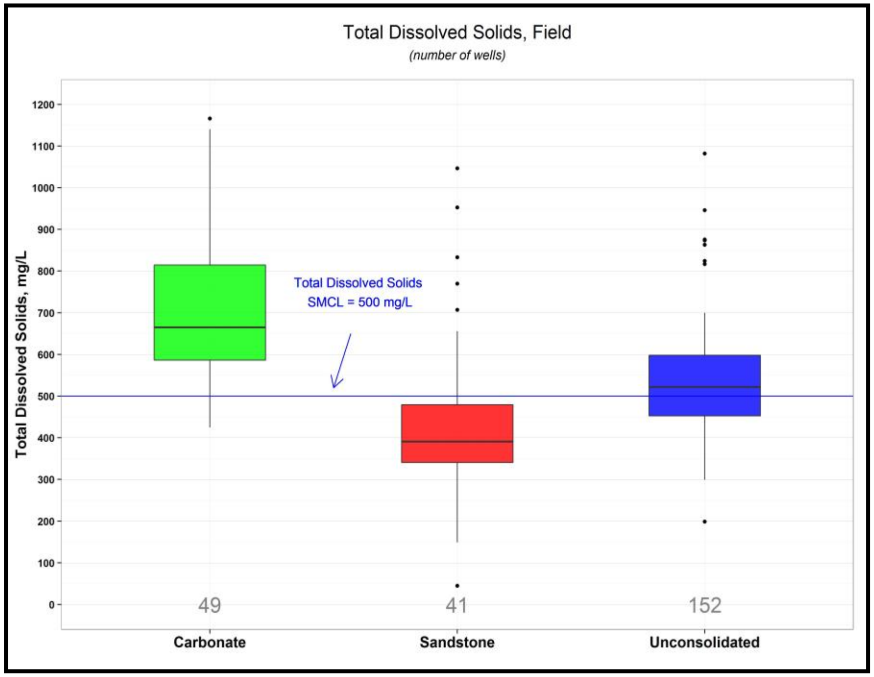
Field Parameters



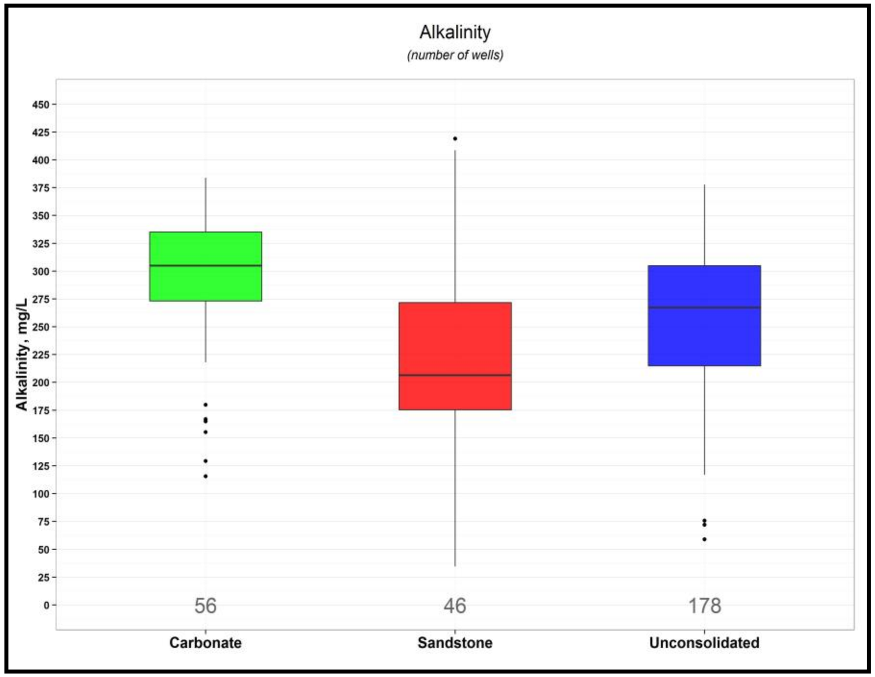


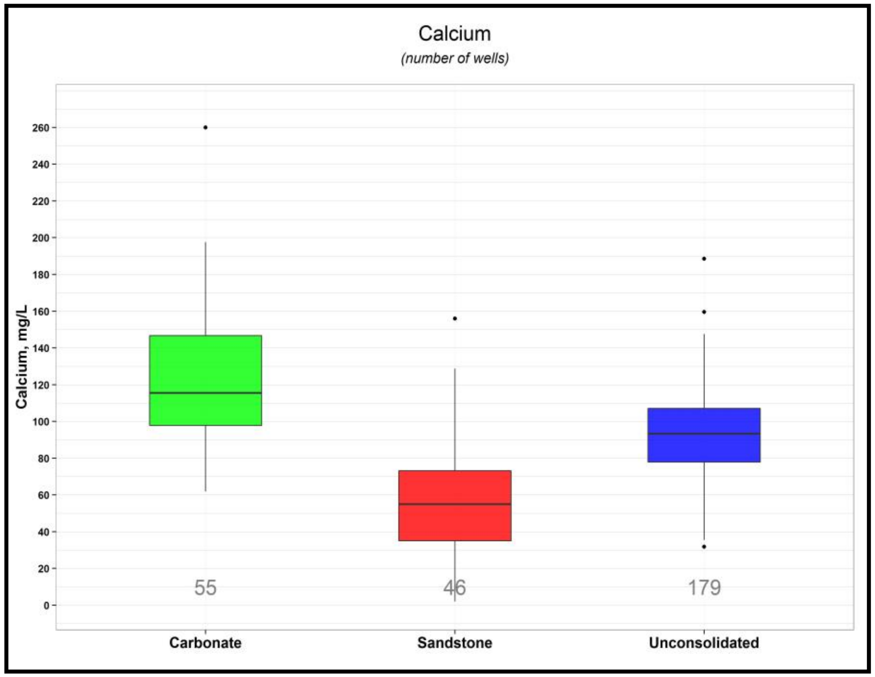


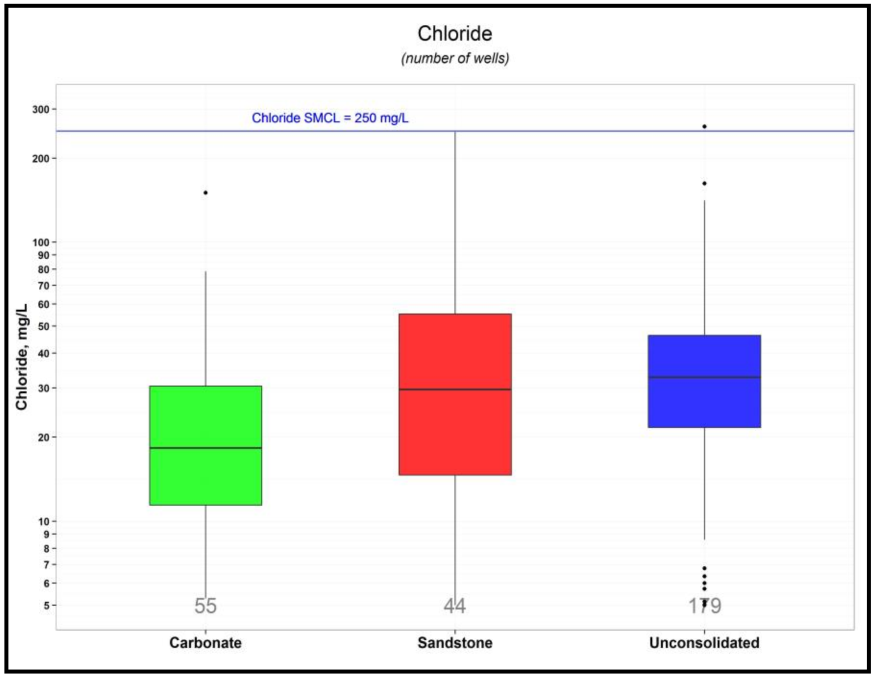

Specific Conductivity, Field
(number of wells)
Specific Conductivity, umhos/cm
1800
1600
1400
1200
1000
800
600
400
200
0
55
42
175
Carbonate
Sandstone
Unconsolidated

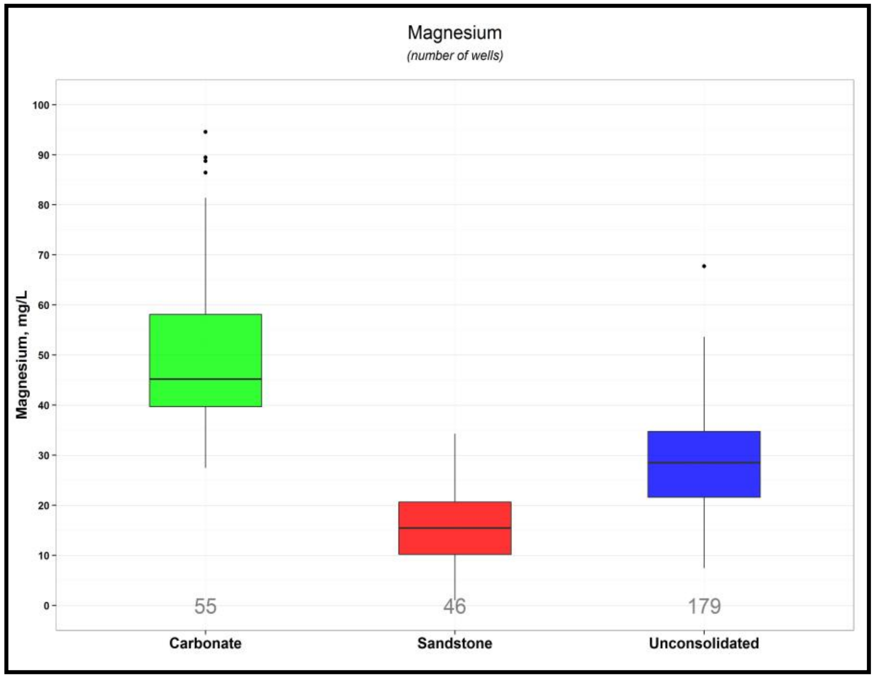

Total Dissolved Solids, Field
(number of wells)
Total Dissolved Solids, mg/L
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Total Dissolved Solids
SMCL = 500 mg/L
49
41
152
Carbonate
Sandstone
Unconsolidated

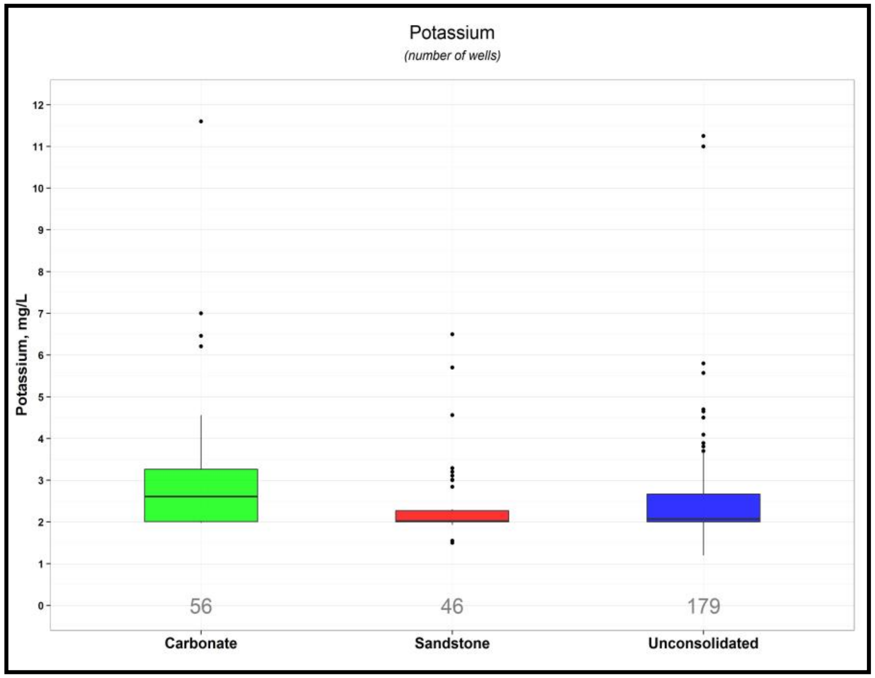
Major Constituents

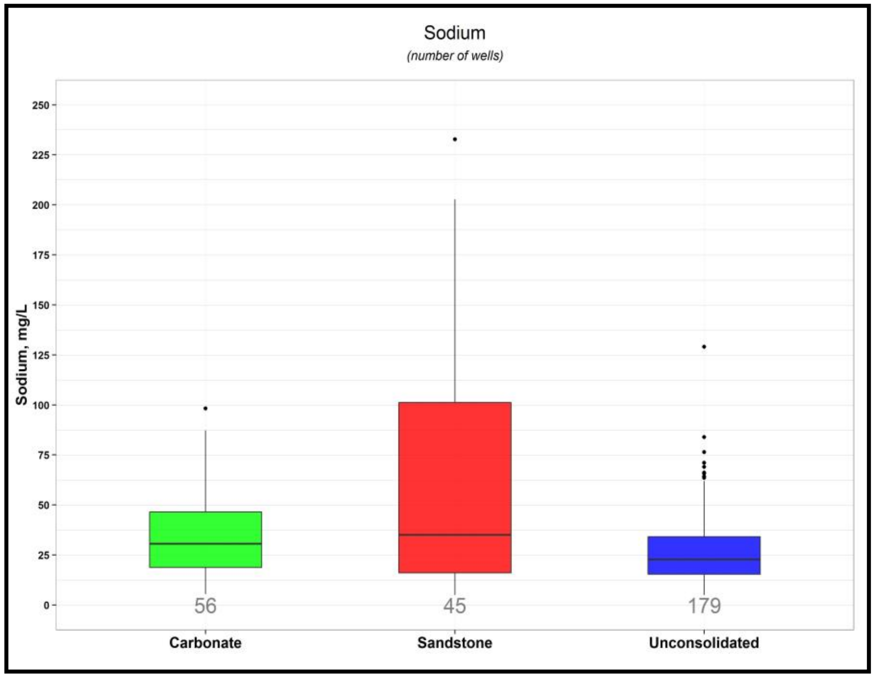


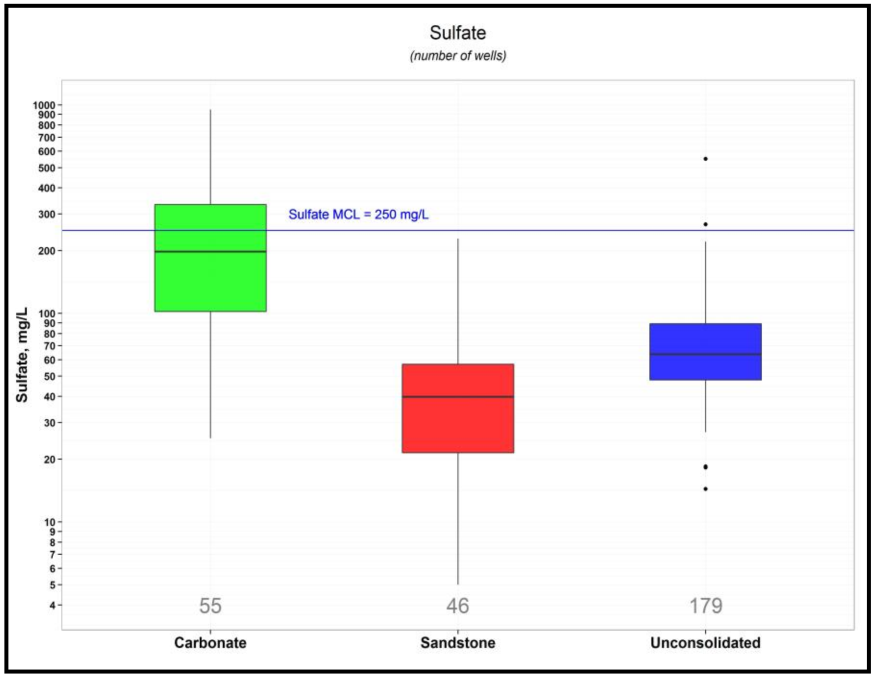


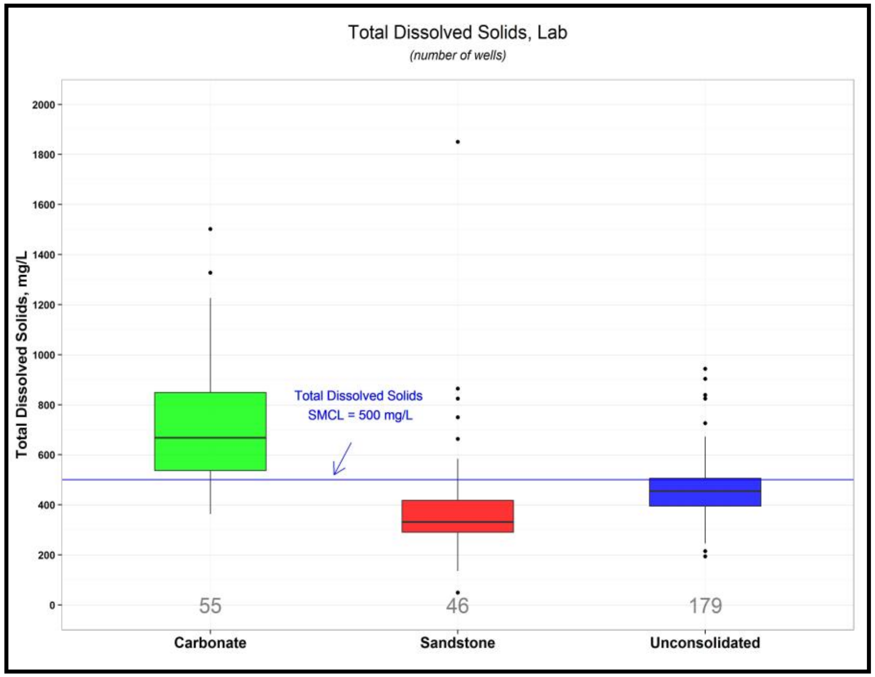



Magnesium
(number of wells)
Magnesium, mg/L
100
90
80
70
60
50
40
30
20
10
0
55
46
179
Carbonate
Sandstone
Unconsolidated

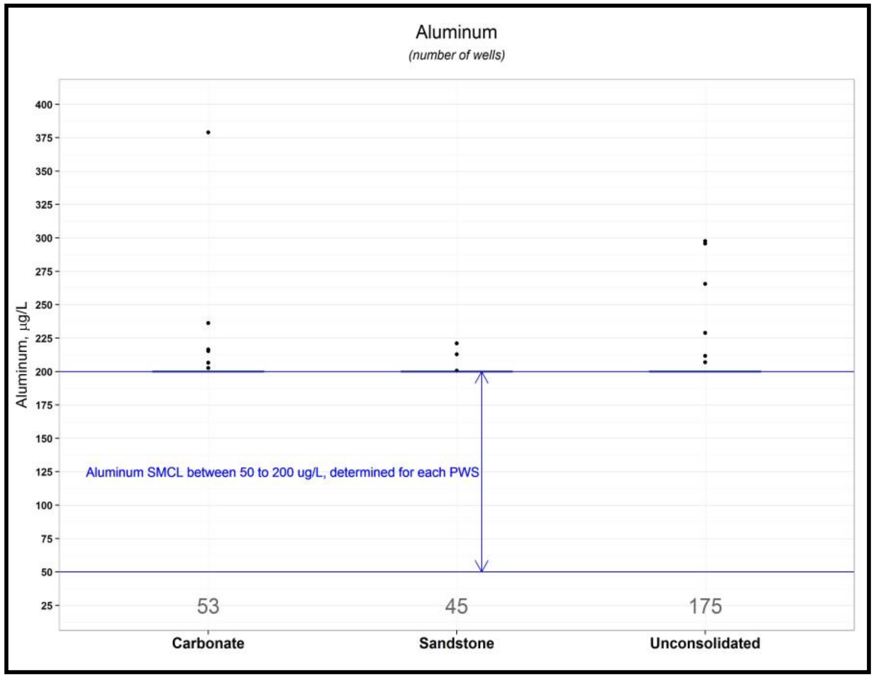

Potassium
(number of wells)
Potassium, mg/L
12
11
10
9
8
7
6
5
4
3
2
1
0
56
46
179
Carbonate
Sandstone
Unconsolidated

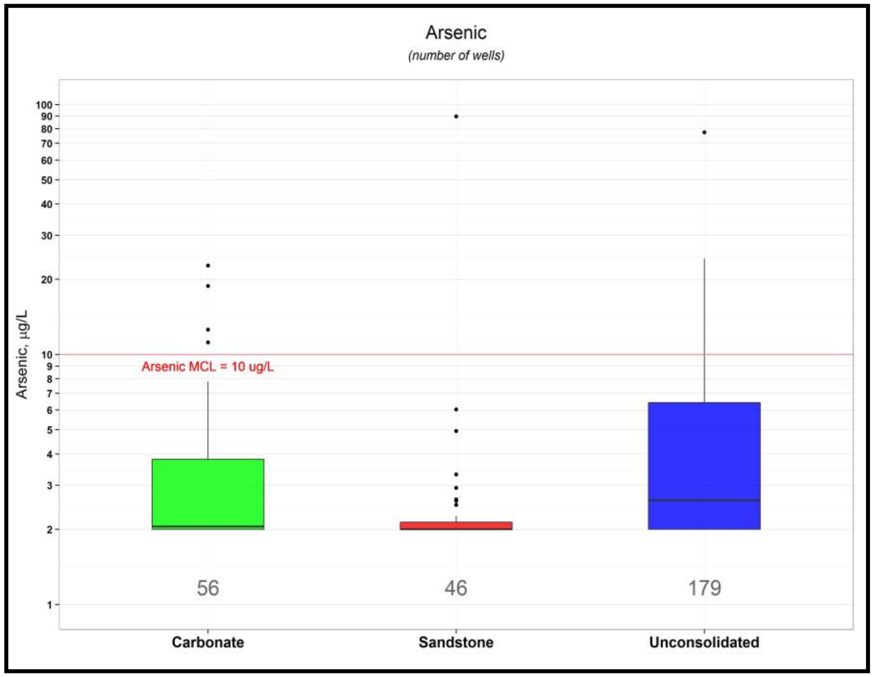

Sodium
(number of wells)
Sodium, mg/L
250
225
200
175
150
125
100
75
50
25
0
56
45
179
Carbonate
Sandstone
Unconsolidated

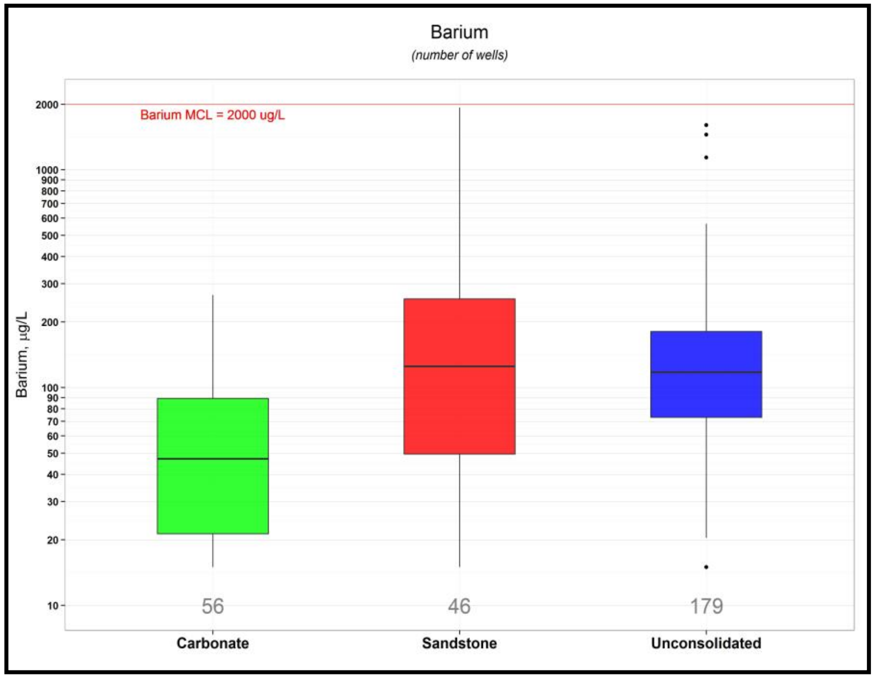

Sulfate
(number of wells)
Sulfate, mg/L
Sulfate MCL = 250 mg/L
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
55
46
179
Carbonate
Sandstone
Unconsolidated

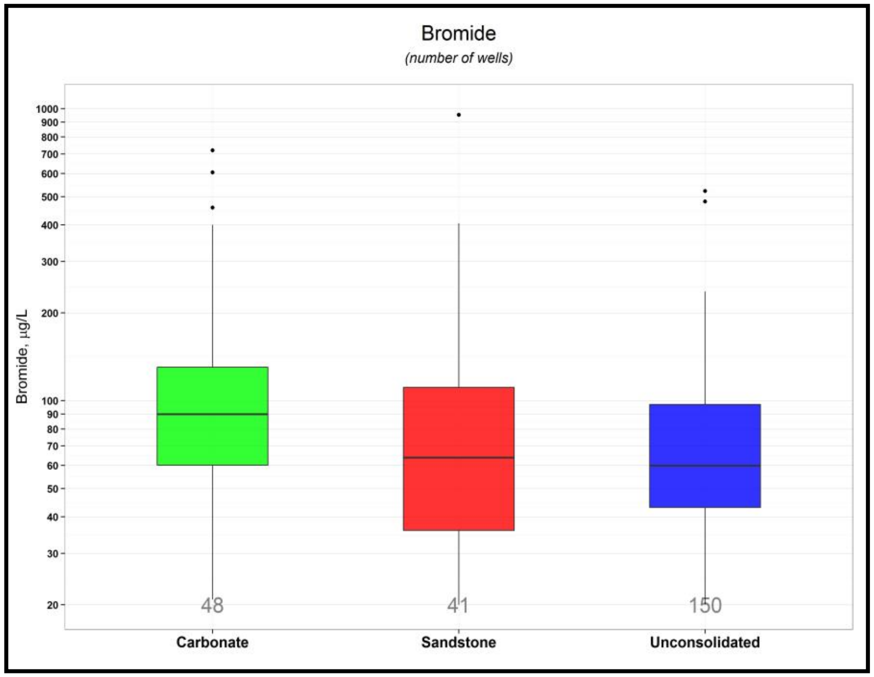

Total Dissolved Solids, Lab
(number of wells)
Total Dissolved Solids, mg/L
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Total Dissolved Solids
SMCL = 500 mg/L
55
46
179
Carbonate
Sandstone
Unconsolidated

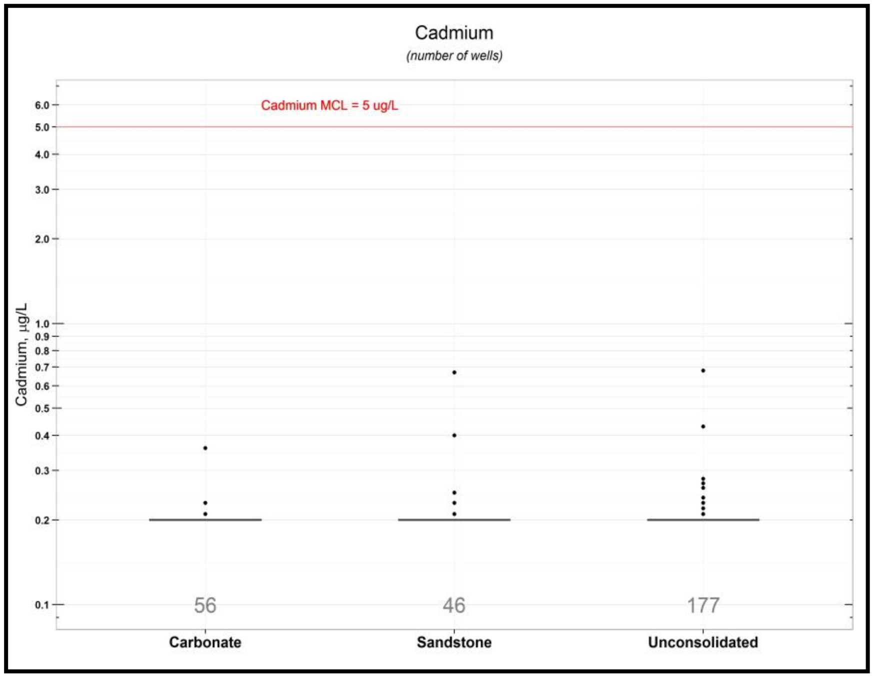
Trace Constituents

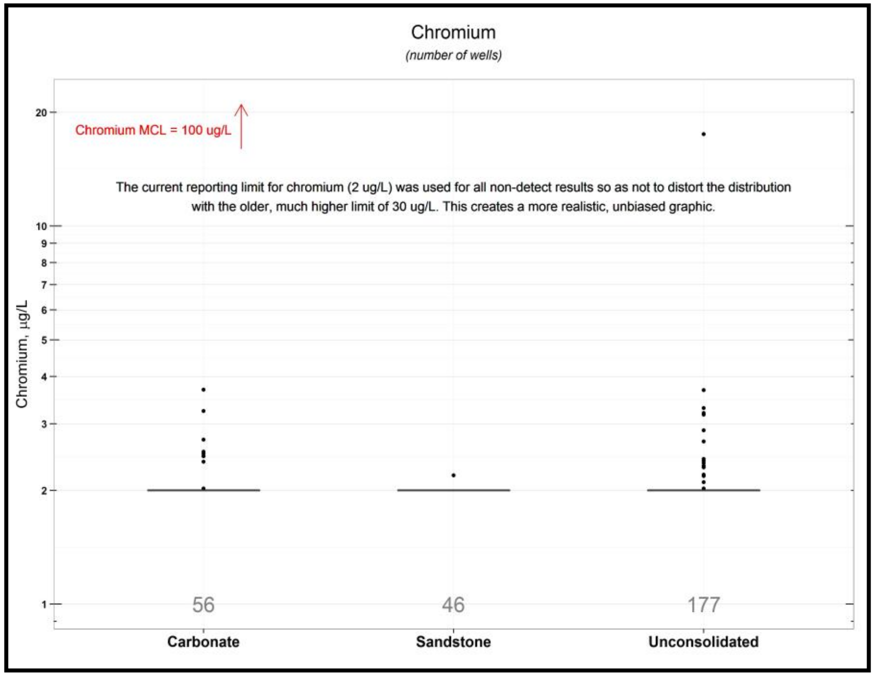




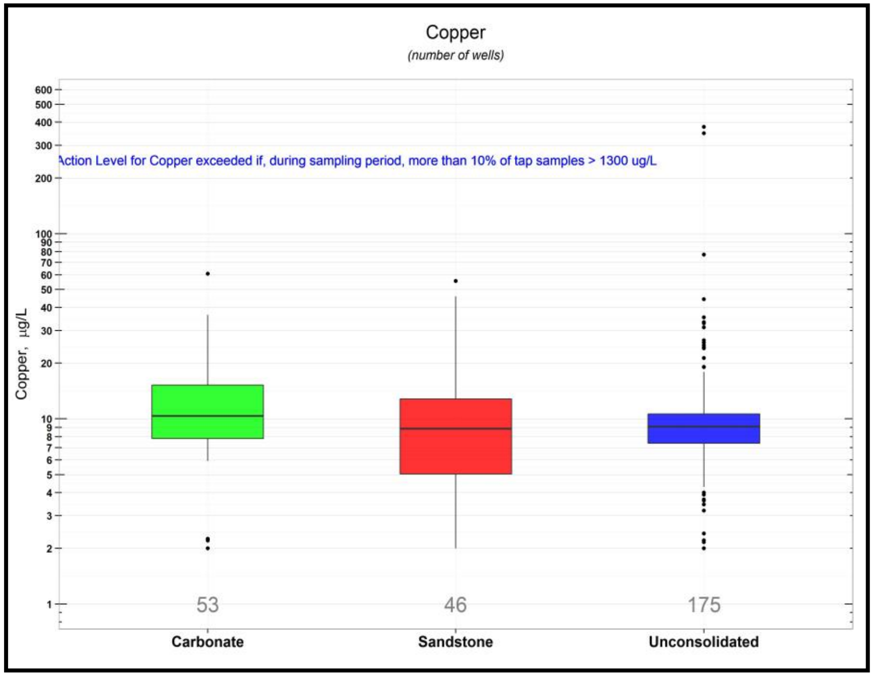




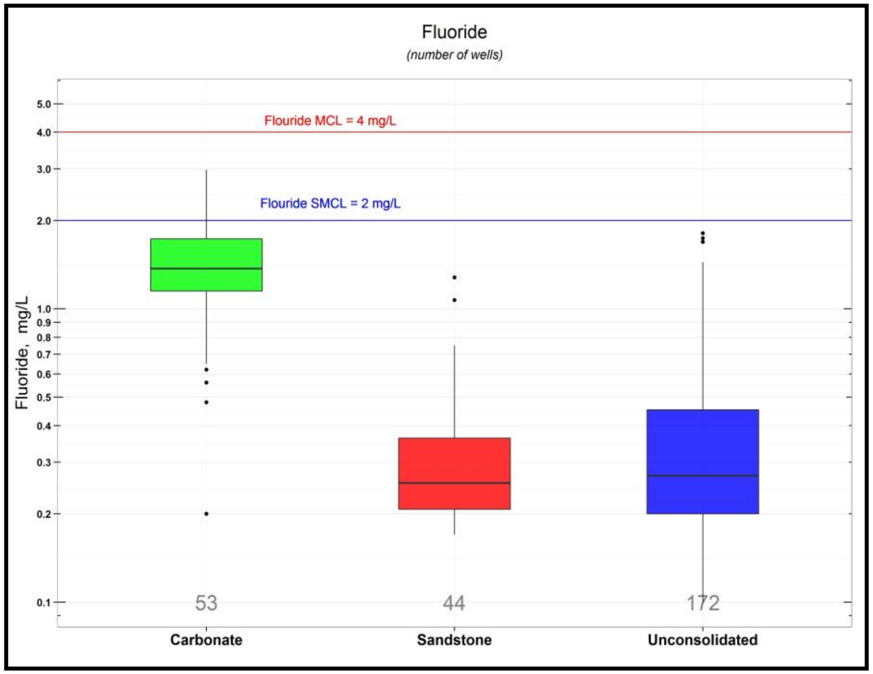


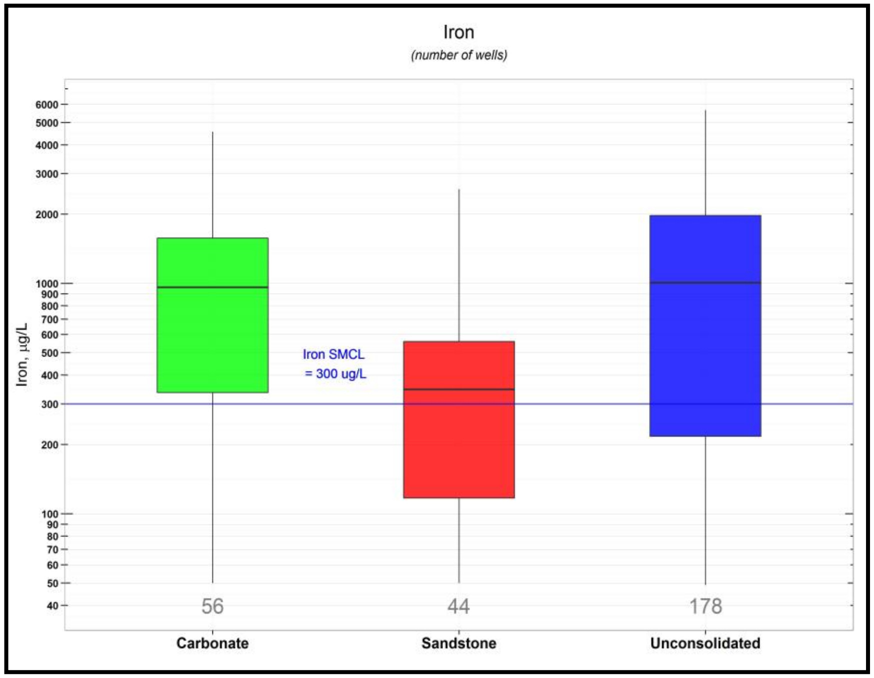


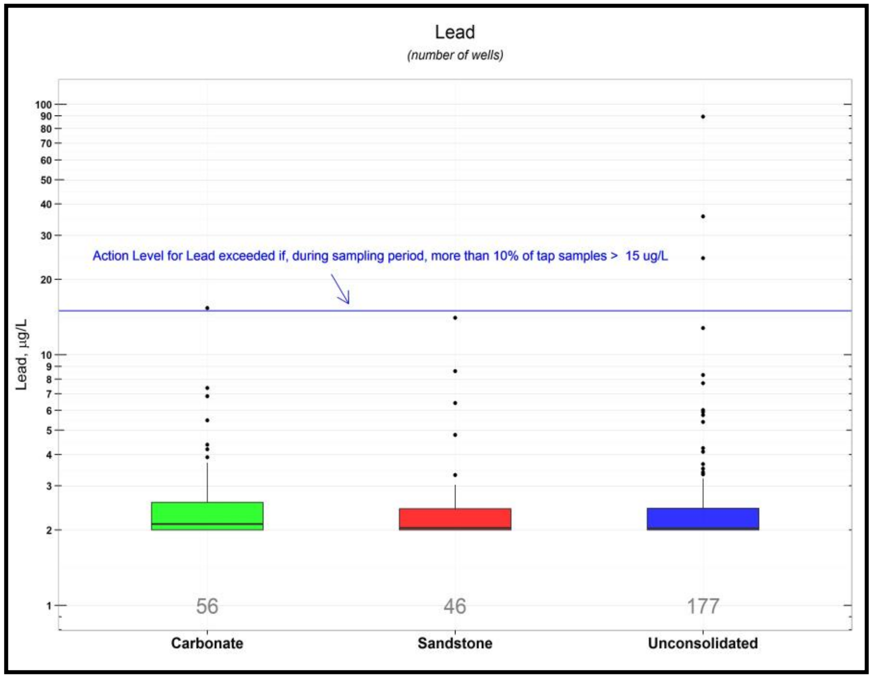
The current reporting limit for chromium (2 ug/L) was used for all non-detect results so as not to distort the distribution with the older, much higher limit of 30 ug/L. This creates a more realistic, unbiased graphic.

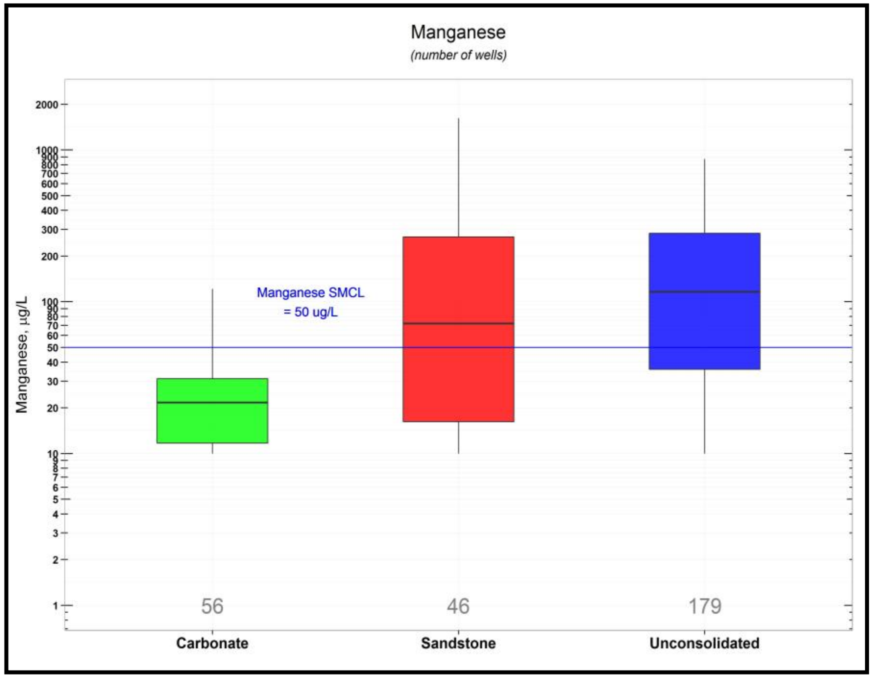


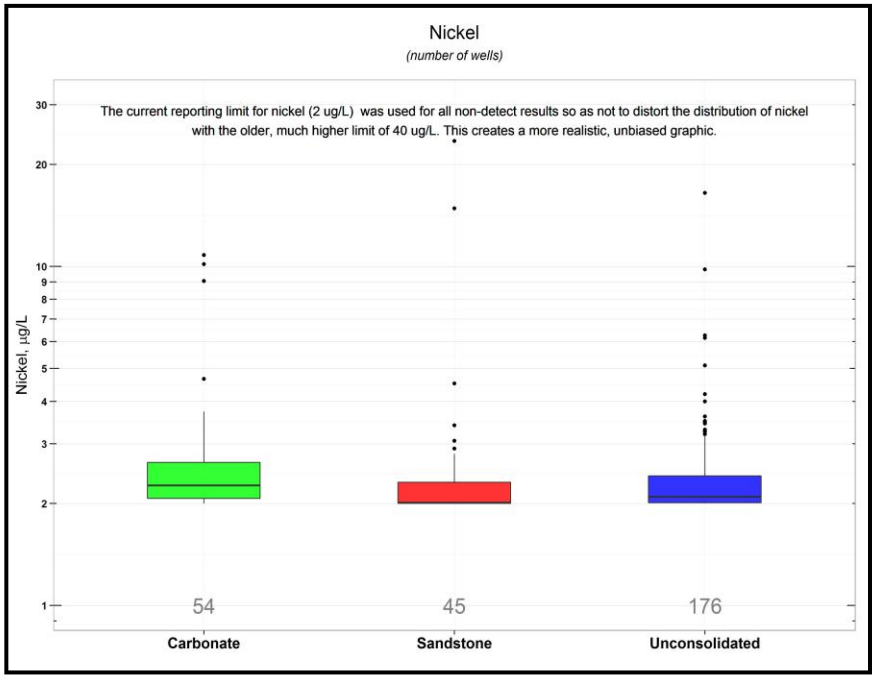
Action Level for Copper exceeded if, during sampling period, more than 10% of tap samples > 1300 ug/L

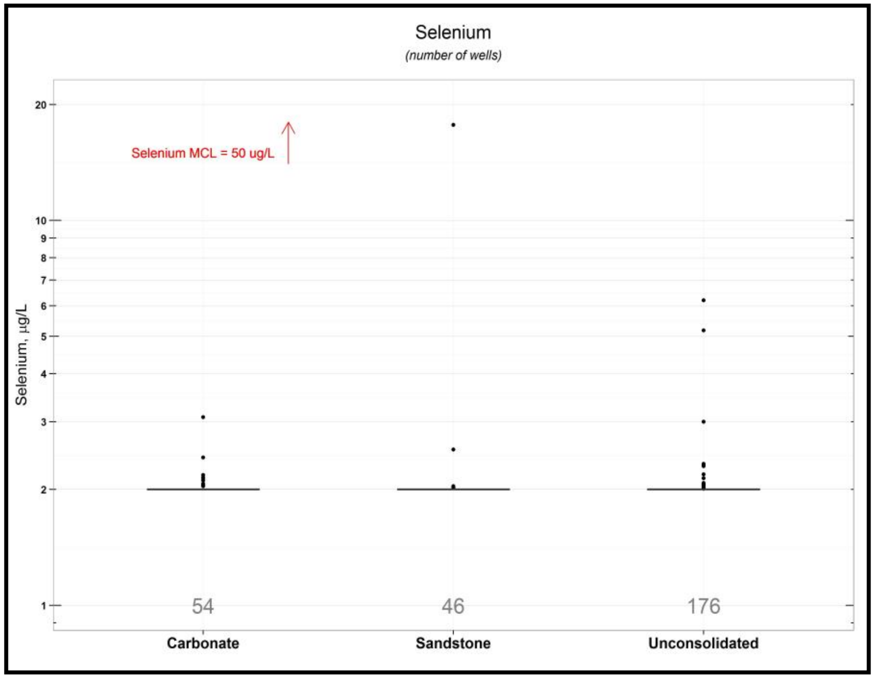

Fluoride
(number of wells)
Flouride MCL = 4 mg/L
Flouride SMCL = 2 mg/L
Fluoride, mg/L
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
53
44
172
Carbonate
Sandstone
Unconsolidated

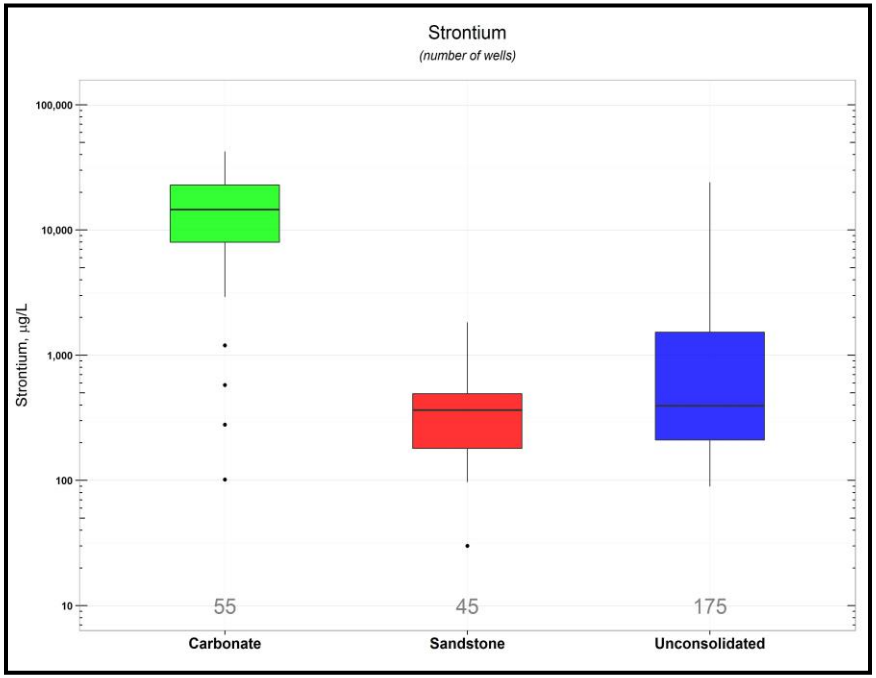

Iron
(number of wells)
Iron SMCL
= 300 ug/L
Iron, µg/L
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
56
44
178
Carbonate
Sandstone
Unconsolidated

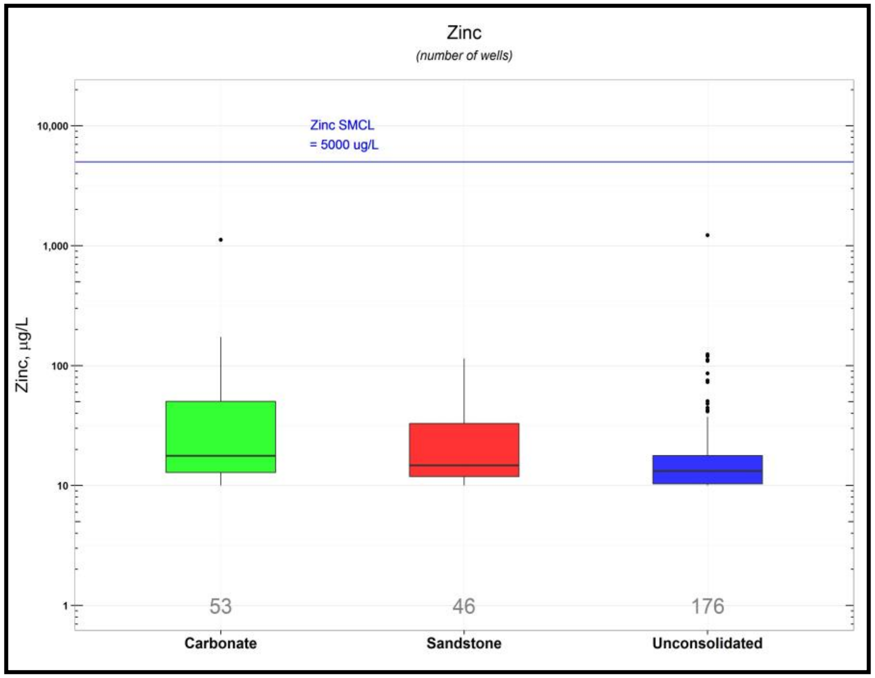

Lead
(number of wells)
Action Level for Lead exceeded if, during sampling period, more than 10% of tap samples > 15 ug/L
Lead, µg/L
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
56
46
177
Carbonate
Sandstone
Unconsolidated


Manganese
(number of wells)
Manganese SMCL
= 50 ug/L
Manganese, µg/L
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
56
46
179
Carbonate
Sandstone
Unconsolidated

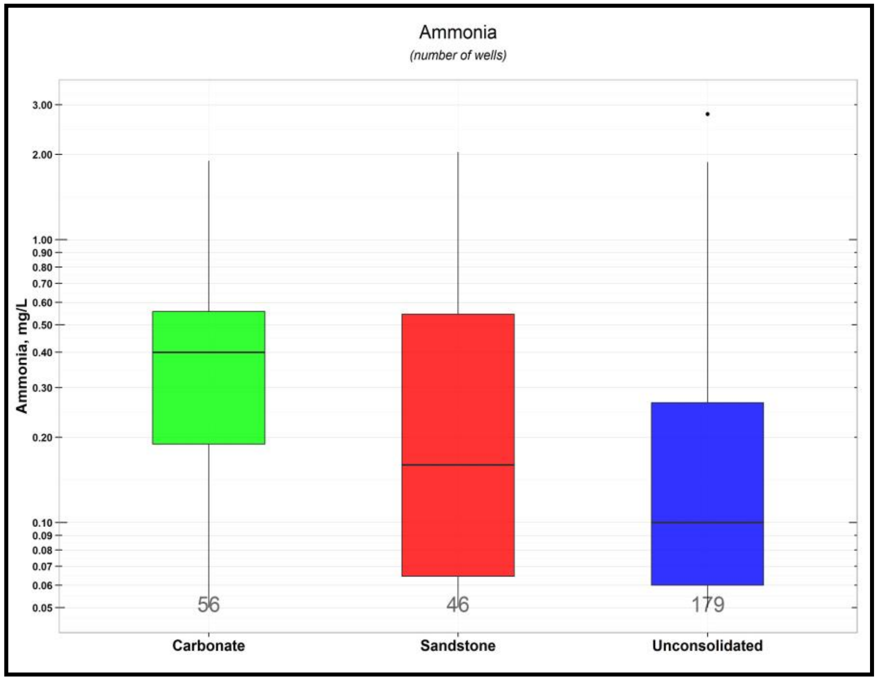

Nickel
(number of wells)
The current reporting limit for nickel (2 ug/L) was used for all non-detect results so as not to distort the distribution of nickel with the older, much higher limit of 40 ug/L. This creates a more realistic, unbiased graphic.
Nickel, µg/L
30
20
10
9
8
7
6
5
4
3
2
1
54
45
176
Carbonate
Sandstone
Unconsolidated

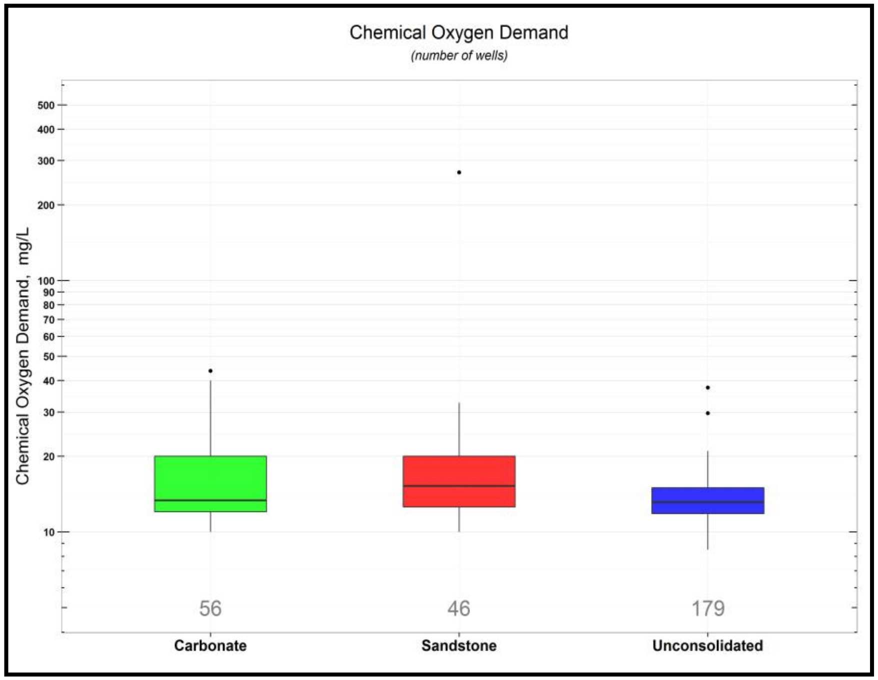

Selenium
(number of wells)
Selenium MCL = 50 ug/L
Selenium, µg/L
20
10
9
8
7
6
5
4
3
2
1
54
46
176
Carbonate
Sandstone
Unconsolidated

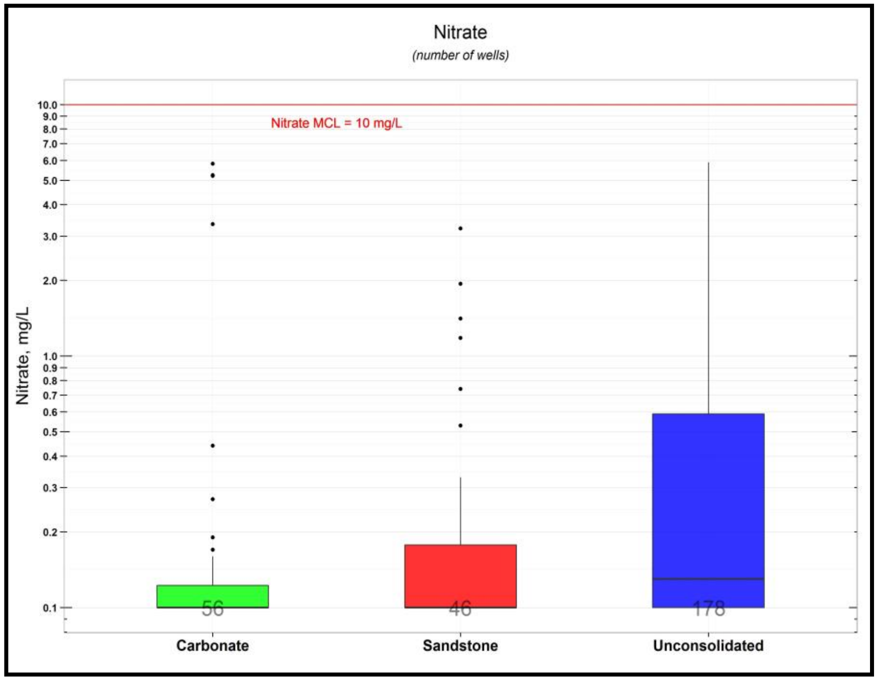

Strontium
(number of wells)
Strontium, µg/L
100,000
10,000
1,000
100
10
55
45
175
Carbonate
Sandstone
Unconsolidated

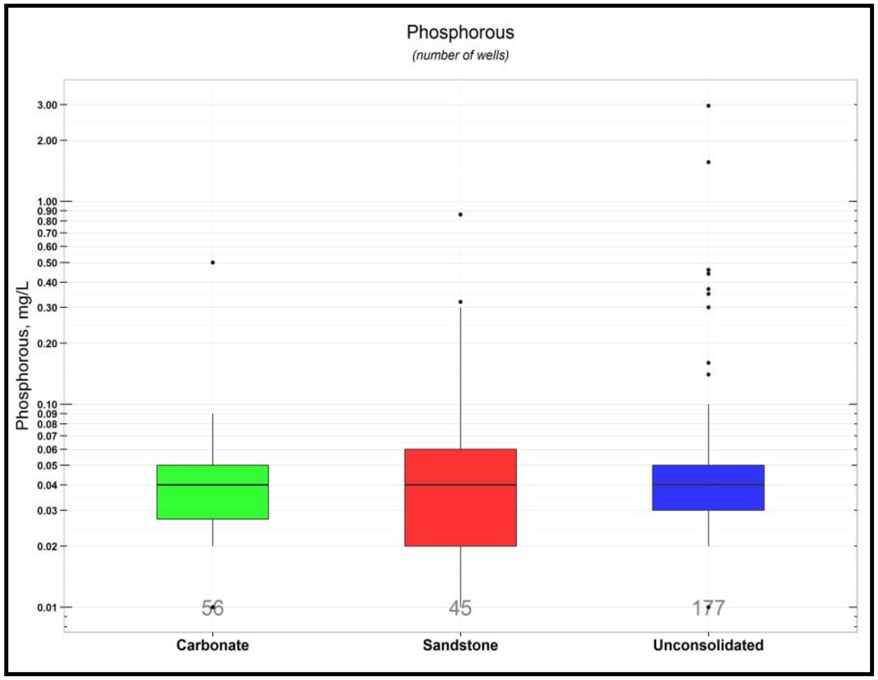

Zinc
(number of wells)
Zinc SMCL
= 5000 ug/L
Zinc, µg/L
10,000
1,000
100
10
1
53
46
176
Carbonate
Sandstone
Unconsolidated

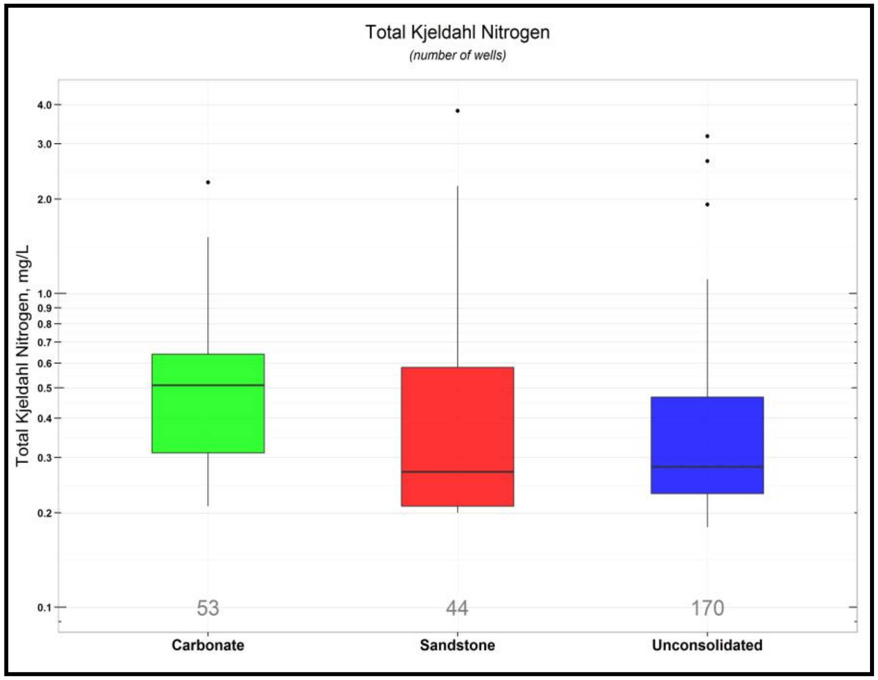
Nutrients

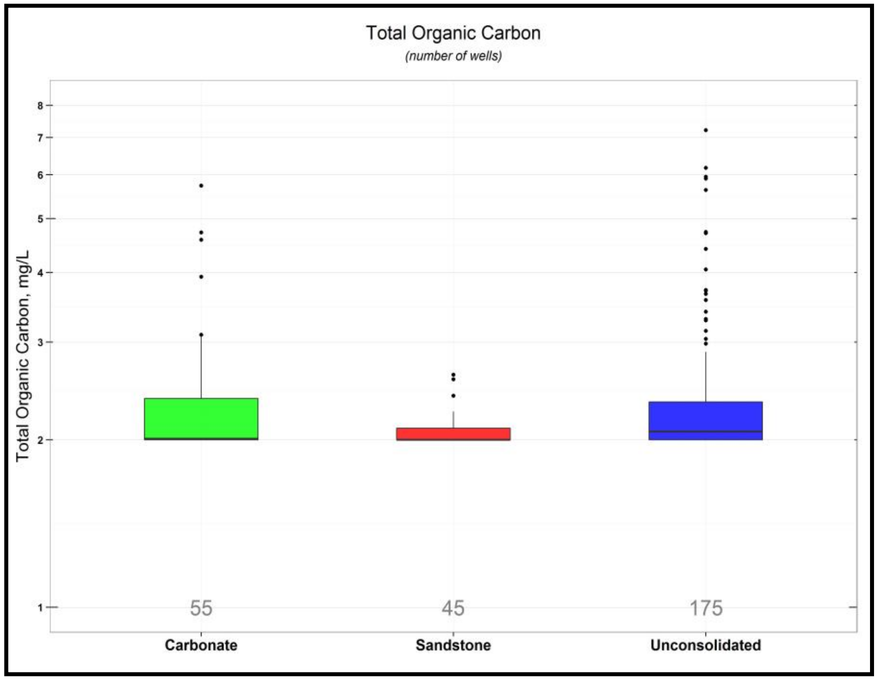

Ammonia
(number of wells)
Ammonia, mg/L
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.09
0.08
0.07
0.06
0.05
56
46
179
Carbonate
Sandstone
Unconsolidated


Chemical Oxygen Demand
(number of wells)
Chemical Oxygen Demand, mg/L
500
400
300
200
100
90
80
70
60
50
40
30
20
10
56
46
179
Carbonate
Sandstone
Unconsolidated


Nitrate
(number of wells)
Nitrate MCL = 10 mg/L
Nitrate, mg/L
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
56
46
178
Carbonate
Sandstone
Unconsolidated


Phosphorous
(number of wells)
Phosphorous, mg/L
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
56
45
177
Carbonate
Sandstone
Unconsolidated


Total Kjeldahl Nitrogen
(number of wells)
Total Kjeldahl Nitrogen, mg/L
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
53
44
170
Carbonate
Sandstone
Unconsolidated


Total Organic Carbon
(number of wells)
Total Organic Carbon, mg/L
8
7
6
5
4
3
2
1
55
45
175
Carbonate
Sandstone
Unconsolidated