Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells

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Abstract

According to the Connecticut Department of Environmental Protection (DEP) files more than 80 locations (involving one or more bedrock water wells) have been identified where concentrations of manganese have exceeded the State action level of 0.5 mg/L. In Connecticut, manganese concentrations have been observed to range up to 100 mg/L. A number of potential anthropomorphic causes of the anomalous well concentrations have been proposed. By law, if wells are contaminated the DEP is charged with providing an alternative water supply. In cases of rural private wells, the solution applied is an expensive filter system that is usually maintained by the DEP or local health officials. Recent analyses of the DEP data files suggest that the high manganese concentrations observed are strongly correlated with turbidity. There are two possible explanations for this observation. The high manganese levels may be an artifact of leaching metals from suspended rock flour or fragments of rusted well casing when the samples are collected and then preserved by acidification, which is the standard approach for the collection of samples of water for metals analyses. In cases in which samples are not preserved in the field, standard protocol for metal analysis by inductively coupled plasma (ICP) (e.g. EPA Method 6010) calls for the pretreatment with acid if the water sample exhibits turbidity greater than 1 NTU. ICP has become the most common method of analysis for metals. In this study we have tested the acidification hypothesis by conducting systematic laboratory leaching studies and field tests that involve collecting filtered and unfiltered samples. The results of the study indicate that acidification of turbidity, caused from suspended rock flour or weathered well casing material, can cause manganese to be leached into solution and result in a false positive indication of dissolved manganese contamination.

INTRODUCTION

Background

According to the Connecticut Department of Environmental Protection (DEP) files more than 80 wells have been identified where concentrations of manganese have exceeded the State action level of 0.5 mg/L (Real-Munroe, 2008). The action level was set by the Department of Public Health to ensure protection against manganese toxicity and neurological hazards if the water is used for drinking purposes. Manganese concentration levels above 0.05 mg/L are reported to produce noticeable changes in color, odor, or taste in water. In Connecticut, concentrations have been observed to range up to 100 mg/L. Statistical studies indicate the manganese levels are anomalous with respect to background levels in Connecticut and throughout New England, which average about 0.1 mg/L (Robbins, 2007a, Robbins and Goldman, 2007). A number of potential anthropomorphic causes of the anomalous well concentrations have been proposed (Robbins, 2007b). These relate to conditions that can either lower pH or lower redox (Eh). These geochemical changes result in converting immobile Mn^{+4} to soluble Mn^{+2}. It should be noted that manganese is a major constituent in Connecticut rocks. It also occurs in the relatively insoluble oxide form ($Mn^{+4}O_2$) coating mineral grains in soil and on fracture surfaces. Manganese is a major constituent in the steel used in well casing here in Connecticut. In fact, manganese is present in almost all steel alloys. Manganese stabilizes austenite and, in combination with sulfur, prevents the formation of iron sulfide (FeS) on the surface of the steel during the process of lamination thus, increasing the steel's capacity to harden (Corporación Venezolana de Guayana, 2009 personal comm.). Oxidation of the steel well casing commonly occurs creating a coating of manganese dioxide along with ferric oxide and hydroxides.

The redox of the ground water may be lowered by releasing biodegradable organic substances into the subsurface, such as septic or sewer effluent, fuel oil, blasting agents, stumps and vegetation buried at construction sites, and fertilizer. The pH of the ground water may be lowered by exposing rocks at the surface to rainwater at construction sites. Rainwater seeping into the fractures at the surface has a pH on the order of 4.5, sufficient to increase the solubility of manganese in the ground water by several orders of magnitude (Hem, 1970). Another mechanism to lower the pH would be exposing rocks rich in pyrite to the surface. Oxidation of the pyrite by rainwater produces sulfuric acid, which would cause manganese to leach from the rock.

Connecticut General Statues Section 22a-471, charges the DEP to provide an alternative water supply to contaminated wells. In cases of manganese contamination to domestic wells, the long-term solution applied is an expensive (in excess of $5000 dollars) reverse osmosis filter system that is usually maintained by the DEP or local health officials. Our initial analyses of DEP data files suggest that the high manganese concentration observed is strongly correlated with turbidity. This is exemplified by Figure 1 below for a home monitored periodically over a three-year period.

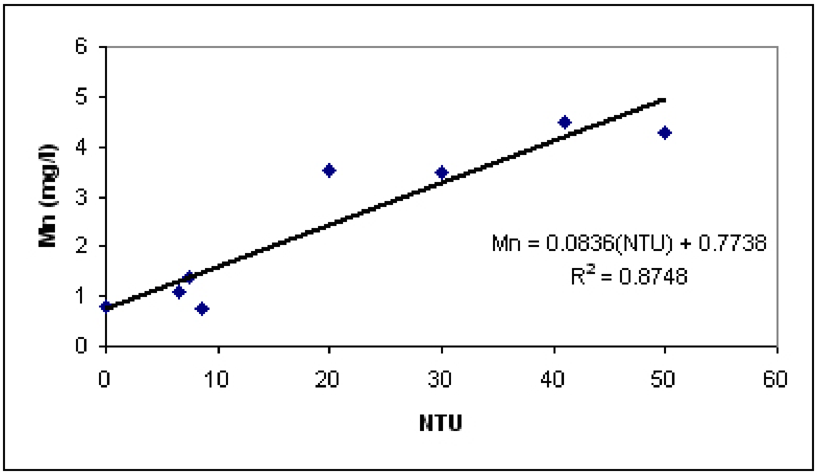

Figure 1: Example correlation of manganese and turbidity in water samples from a home monitored periodically over a three-year period.

There are two possible explanations for this observation. The high manganese levels may be an artifact of leaching metals from suspended rock flour or fragments of oxidized well casing when the samples are collected and then preserved by acidification. Acid preservation is a standard approach used by the Department of Public Health (DPH) when groundwater samples are collected for metal analyses. Even if samples are not preserved in the field, the standard protocol for metal analysis by inductively coupled plasma (ICP), (e.g. EPA Method 6010/ICP), is pretreatment of samples with acid if they exhibit turbidity greater than 1 NTU. The ICP method has become the most common method for the analysis of metals used by the DPH laboratory and private certified laboratories in the State, laboratories also check the pH of the samples when they arrive at the lab, if the pH is more than 2, samples may be acidified by the laboratory and then stored until analyzed.

Problem Statement

Currently the DEP is faced with having to find alternative water supplies and installing expensive filter systems when rural wells are found to have manganese levels that exceed the State action level. Such systems have to be perpetually maintained. If indeed the problem were an artifact of turbidity leaching, the solution would simply require particulate filtering at greatly reduced expense. The high levels of manganese observed may impact obtaining certificates of occupancy by homeowners, require local health officials to use resources to address the problem, and create anxiety for homeowners worried about the health of their families and the value of their property.

Objective

The objective of this study is to test the hypothesis that acidification in preserving water well samples and/or pretreatment for ICP analysis could be the cause of the anomalous manganese levels. To test this hypothesis we conducted leaching studies using rock flour obtained from wells drilled in different locations around the state and oxidized well casing.

METHODOLOGY

Laboratory Experiments

Rock Flour Testing

Leaching studies were conducted on samples of rock flour obtained from standard air percussion drilling of domestic wells in different rock types in Connecticut. Metamorphic and igneous rocks such as schists, gneisses and granite underly 75% of the State of Connecticut. The remaining 25% of the state is underlain by clastic sedimentary rocks (i.e. brownstone) and intrusions of basalt (Burton et al, 2003). Samples from the following rock formations were tested: Hebron Gneiss, Straits Schist, Trap Falls Schist, New London Gneiss, and Portland Arkose. The Hebron Gneiss is composed of andesine, quartz, biotite, and K-feldspar. The Straits Schist is composed of layers of amphibolite, marble, calc-silicate rock, and quartzite. The Trap Falls Schist is generally composed of quartz, sodic plagioclase, biotite, muscovite, sillimanite, kyanite, and garnet. The mineralogy of the New London Gneiss consists of oligoclase, biotite, quartz, plagioclase, K-feldspar, and magnetite. Portland Arkose is a feldspar-rich sandstone which is composed predominantly of quartz and at least, 25% feldspar (YNHTI, 2009).

The first test performed was an EPA Method 3010, Synthetic Precipitation Leaching Procedure (SPLP) test to evaluate the extent of which the rock flour will leach manganese under pH conditions (4-5) that simulate rainwater.

The second test was designed to evaluate the effects of acidification on leaching of manganese (Mn) from rock flour when mixed with deionized water. Testing of the deionized water showed no detections of manganese. Its turbidity was 0 NTUs and its pH was 6.95. Rock flour samples were oven dried for 24 hours at 100-110°C. The dried rock flour samples were mixed with deionized water in a 1:1 weight ratio (about 300 grams each) in one-liter polyethylene bottles. Half of the mixed samples were treated with nitric acid while the other half were not. A solution of nitric acid was prepared by diluting 1N nitric acid with deionized water to obtain a volume ratio of 1:7, HNO_3:H_2O which resulted in a pH of 1.365. The acid solution was added to the rock flour deionized mixture in three polyethylene bottles in three different amounts (15 µL, 180 µL, and 345µL). The polyethylene bottles were stored at room temperature. Half the bottles were analyzed after one week and the other half after three months. It should be noted that EPA protocol allows storage of preserved samples for six months after analysis. The analyses consisted of the following: measurement of pH, Oxidation-Reduction Potential (ORP), turbidity, electrical conductivity (EC), temperature (T), and dissolved oxygen (DO); measurement of dissolved manganese on three aliquots (10 ml each) using a Hach test kit; measurement of dissolved iron on three aliquots (25ml each) using a Chemets kit; laboratory measurement of dissolved iron and manganese on an unfiltered aliquot (250 ml); and laboratory measurement of dissolved iron and manganese on an aliquot (250 ml) filtered with a 0.45 micron syringe filter. The Hach test kit uses the Periodate Oxidation Method and a colorimeter for quantification. To prepare the aliquots for manganese analysis using the Hach kit, a 0.45 μm syringe filter was used to filter out turbidity which could influence the Hach kit colorimetric analysis. The use of the 0.45 μm filter typically produced turbidity levels below 1 NTU. Turbidity was measured using a Orbeco-Hellige, model 966 portable turbidity meter. Quantification of dissolved iron with the Chemets kit entailed a color comparison. Laboratory analysis for iron and manganese was also conducted at the University of Connecticut, Center for Environmental Sciences and Engineering Laboratory (CESE lab) using EPA method 6010 (ICP). It should be noted that the laboratories used in this study typically check the pH of the incoming water samples. If the pH is more than 2 then the water sample is preserved to a pH of 2. This is usually done by adding concentrated trace metal grade nitric acid. In addition, if a request for total metals analyses is made to the laboratory, the laboratory acidifies the sample first and then the sample is filtered. If a request for dissolved metal analyses is made to the laboratory then the sample is filtered first and then acidified.

Well Casing Testing

To evaluate whether dissolved manganese could be generated by the leaching of well casing, the following testing was performed. Well casing typically used in domestic wells in Connecticut was analyzed using X-ray fluorescence spectroscopy (XRF) to measure the elemental composition of manganese. The composition was measured at two different places on the casing.

The leaching test consisted of the following: a cutting (1.375’ long, 0.54’ outer diameter, 0.34’ inner diameter cylinder) from well casing was placed inside a polyethylene container and submerged partially in 1.5 gallons of deionized water. The water level was allowed to fluctuate on the weekly basis to simulate the weathering of the casing under conditions of water table fluctuations. Weekly water level adjustment was performed and recorded immediately after extracting water samples to be used for analysis. Approximately 2000 ml of deionized water was added between weekly measurements. Concentrations of dissolved manganese and iron, in both filtered and unfiltered samples, were monitored using the Hach and the Chemets kit. The pH was also monitored. The test ran for approximately two months.

Immediately following the deionized weathering test the casing was exposed to acidic conditions. Nitric acid was added until the pH was approximately 2. On average, approximately 90 mL of 1N nitric acid was added each time the water level adjustment was performed. The acid leaching test was continued for approximately one month. Because the concentrations of dissolved iron and manganese exceeded the maximum detectable concentrations of the portable test kits, the samples were submitted to the CESE laboratory for analysis.

Other Laboratory Testing

The deionized water used in the experiments was tested for manganese, pH and turbidity by the CESE laboratory to establish background levels.

Private Well Water Quality Testing

To evaluate whether filtering and acidification affects the manganese and iron concentrations, four homes were sampled on four different locations in the state. The procedure used to collect water samples from private wells consisted of the following steps: 1) Water samples were taken at locations prior to any filter, water treatment system, and the water storage tank. 2) The cold tap water was allowed to run for approximately five minutes prior to taking a sample if there was not much water use (flushing toilet, shower, etc.) for a few hours prior to sampling, otherwise two minutes was considered appropriate. 3) One-liter plastic bottles were used to collect water samples for the metal analyses. The samples were not acidified in the field. Samples were tested in the field for dissolved manganese, dissolved iron, turbidity, DO, pH, EC, T and ORP. 4) At each home, two samples were collected, one was filtered and the other was not. Given the low turbidity, the samples were filtered using a 0.45 micron syringe filter. 5) Once water samples were taken, they were placed in a cooler and maintained at 4 ± 2 degrees centigrade. 6) Water samples were submitted to either the CESE laboratory or the DPH laboratory for analysis via ICP.

RESULTS AND DISCUSSION

Rock Flour Testing

Table 1 provides a summary of pH, oxidizing conditions, and conductivity of the test samples. The July sampling represents one week of leaching whereas the October sampling represents three months of leaching. The July samples had near neutral pH, were oxidizing and had moderate levels of turbidity and low conductivity. The samples in October showed an increase in pH and moderate level of alkalinity.

Table 1 – Physical parameters of samples in the deionized water leaching tests

TEST DATE	**JULY 2009**					**OCTOBER 2009**	
Rock Formation (Town)	**pH**	**ORP**	**DO**	**Turbidity**	**Conductivity**	**pH**	**Alkalinity**
		mV	mg/L	NTUs	µS/cm		mg/L
Hebron Gneiss (Deep River)	7.4	191	9.03	27.3	225	7.9	82
Straits Schists (Chesire#1*)	7.7	144	11.12	88.7	160	8	65
Trap Falls (Chesire#2*)	7.8	183	7.34	64.5	303	8.3	154
New London Gneiss (Deep River)	7.4	119	9.41	24.1	383	NA	NA
Portland Arkose (Guilford) (350’)	7.6	118	15.06	38.8	200	8.1	118
Portland Arkose (Guilford) (250’)	7.8	212	12.85	133.6	43	8.1	163
Portland Arkose (Durham)	7.7	214	7.65	125.2	50	7.2	31
Straits Schists (Burlington)	7.3	220	8.28	12.8	142	NA	NA

Notes:
NA = Not Analyzed
(250') = sample taken at a depth of 250 feet below ground surface

Table 2 shows the results of the SPLP tests. Under the SPLP test conditions, both manganese and iron exhibited low leachability. Only the Portland Arkose had a leachate concentration that exceeded the drinking water standard for manganese.

Table 2 – SPLP test results.

Rock Formation	**[Fe]**	**[Mn]**	**[Fe]**	**[Mn]**
(Town)	CESE Lab	CESE Lab	Calculated	
	(mg/L)	(mg/L)	µg/g	µg/g
Hebron Gneiss	0.579	0.009	28.8	0.4
(Deep River)				
Straits Schists	1.371	0.028	68.4	1.4
(Chesire#1*)				
Trap Falls	0.391	0.007	19.7	0.4
(Chesire#2*)				
New London Gneiss	0.081	0.02	4.0	1.0
(Deep River)				
Portland Arkose (Guilford) (350’)	0.078	0.071	3.9	3.5
Portland Arkose (Guilford) (250’)	0.087	0.005	4.4	0.3
Portland Arkose	0.266	0.013	13.1	0.6
(Durham)				
Straits Schists	0.162	0.002	8.0	0.1
(Burlington)				

Table 3 summarizes the deionized water leaching tests. The initial analysis were based on the Hach and the Chemets kits. It was found that little manganese and iron leached out initially. The October samples were acidified prior to sending them to the laboratory. The October filtered values of iron and manganese represent dissolved concentrations and were low although two of the samples exceeded the drinking water standards. The unfiltered but acidified samples exhibited much higher values of manganese and iron. All the unfiltered samples tested for manganese were above the drinking water standard and three of the samples were above the Department of Health action level (0.5 mg/L). Also, the unfiltered concentrations of iron and manganese, with one exception, appeared highly correlated ($R^2 > 0.9$) as shown on Figure 2.

Table 3 – Manganese and Iron leaching from rock flour when mixed with deionized water but not acidified.

TEST DATE>>	**JULY 2009**		**OCTOBER 2009**			
Rock Formation	**[Mn]**	**[Fe]**	**[Mn]**	**[Fe]**	**[Mn] Filtered**	**[Fe] Filtered**
(Town)	Hach	Chemets	CESE Lab	CESE Lab	CESE Lab	CESE Lab
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Hebron Gneiss	0.6	<1	0.443	26.89	0.014	ND
(Deep River)						
Straits Schists	0.1	<1	0.256	16.61	0.006	ND
(Cheshire#1*)						
Trap Falls	0.2	<1	1.228	81.37	0.076	ND
(Cheshire#2*)						
New London Gneiss	0.3	<1	NA	NA	NA	NA
(Deep River)						
Portland Arkose	0.1	<1	0.622	17.26	0.088	ND
(Guilford)(350’)						
Portland Arkose	0.4	<1	1.627	44.62	0.020	ND
(Guilford)(250’)						
Portland Arkose	0.2	<1	0.097	1.716	0.049	ND
(Durham)						
Straits Schists	0.2	<1	0.384	43.85	0.013	ND
(Burlington)						

Notes:
Note 1: Blank samples were Non-Detect.
Note 2: “Cheshire #1” is at a different location than “Cheshire#2” but within same town.
Note 3: The Hach test kit has a precision error of ±0.2 mg/L
Note 4: NA = Not Analyzed
Note 5: ND means Non-detect
Note 6: Chemets test kit was used to measure dissolved iron
Note 7: All samples unfiltered unless noted

Figure 2: Correlation of manganese and iron.

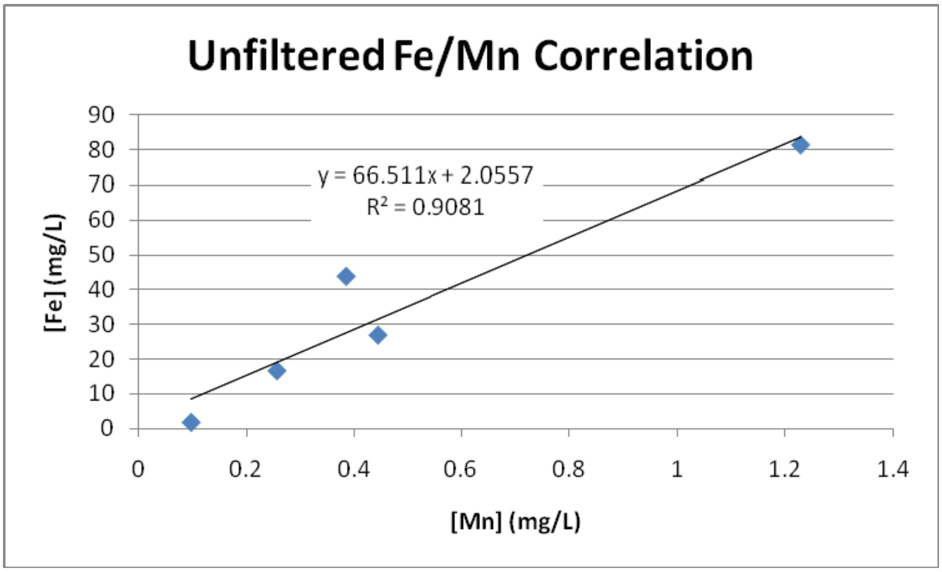

Table 4 shows the results from the rock flour acidification test after one week of exposure to the acidic conditions. Overall, the filtered samples had very low concentrations of manganese and iron in comparison to the unfiltered samples. In certain cases, unfiltered samples were orders of magnitude higher than the filtered samples. In general, concentrations of iron and manganese in unfiltered samples were higher at lower pH. The Hach kit manganese measurements for the filtered samples were near the detection limit for the method. The Hach kit manganese results for the unfiltered samples differed significantly from the results of the laboratory. Although the results are different, they showed similar trends when comparing the unfiltered versus the filtered samples. The difference between the Hach kit results and the laboratory results may be due to differences in degree of turbidity in the aliquots that were used for measurements.

It should be noted that the rock flour from different formations reacted differently to the addition of nitric acid. When a fixed amount of nitric acid was added to the rock flour solution, some of the samples were found to resist a drop of pH (i.e. Trap Falls C2, ΔpH=1; Portland Arkose 250’, ΔpH= 0.988) while others exhibited a considerable drop in pH (i.e. New London Gneiss ΔpH= 4.54; Portland Arkose Du, ΔpH= 4.876). The differences likely refer the buffering capacity of the different rock formations. The resistance to pH changes is most noticeable in unfiltered samples. Since the rocks contain little carbonate, if any, the buffering may be due to the hydrolosis which involves the feldspars releasing bicarbonate.

Table 4 – Manganese leachability from rock flour solution when subjected to incremental acidic conditions.

sample ID	ROCK FORMATION							
	Hebron Gneiss (D)							
	Unfiltered (mg/L)				Filtered (mg/L)			
Acidification	**pH**	**Mn (H)**	**Mn (C)**	**Fe (C)**	**pH**	**Mn (H)**	**Mn (C)**	**Fe (C)**
High	4.867	4.9	7.419	472.9	2.674	0.4	0.018	1.085
Medium	6.700	1.3	NA	NA	5.417	0.3	NA	NA
Low	6.961	1.3	7.167	472.2	6.918	0.6	0.009	0.459
	Straits Schists (C1)							
High	3.300	2.4	2.216	158.6	2.690	0.1	0.007	0.551
Medium	6.433	1.3	NA	NA	4.541	0.1	NA	NA
Low	6.883	2.1	1.495	110.5	6.512	0.2	0.001	0.118
	Trap Falls (C2)							
High	6.800	4.6	45.440	1823.0	2.913	0.3	0.012	0.148
Medium	7.071	1.9	NA	NA	6.702	0.7	NA	NA
Low	7.105	1.1	14.070	894.0	7.074	0.5	0.013	0.114
	New London Gneiss (D)							
High	2.860	0.7	1.362	47.0	2.722	0	0.060	0.409
Medium	6.652	0.3	NA	NA	6.665	0.2	NA	NA
Low	6.718	0.7	0.913	26.6	5.840	0.1	0.042	0.340
	Portland Arkose 350’ (G)							
High	5.227	4.0	3.808	173.8	2.732	0.1	0.031	0.052
Medium	6.795	0.9	NA	NA	6.940	0.3	NA	NA
Low	6.988	1.8	1.554	50.9	6.167	0.3	0.033	0.036
	Portland Arkose 250’ (G)							
High	6.812	1.6	4.058	115.5	2.824	0.2	0.014	0.134
Medium	7.074	1.1	NA	NA	7.378	0.1	NA	NA
Low	7.218	0.9	3.728	135.6	6.484	0.3	0.011	0.075
	Portland Arkose (Du)							
High	2.824	0.8	0.601	26.7	2.690	0.2	0.017	0.275
Medium	4.264	1.9	NA	NA	3.353	0	NA	NA
Low	6.644	3.0	0.442	21.5	6.637	0.3	0.014	0.275
	Straits Schists (B)							
High	3.605	3.4	1.304	200.4	2.773	0.2	0.002	0.031
Medium	6.585	1.0	NA	NA	4.862	0	NA	NA
Low	7.066	15.8*	0.200	21.7	6.904	0.1	0.002	0.010

Notes for Table 4 above:

1. (H) means test performed with Hach kit; (C) means analytical test performed by CESE Metals Lab using ICP technique; (D) means sample taken from Deep River, CT; (C1) means sample taken from location #1 in Cheshire, CT; (C2) means sample taken from location #2 in Cheshire, CT; (G) means sample taken from Guilford, CT, (Du) means sample taken from Durham, CT; (B) means sample taken from Burlington, CT.
2. (*) Visual observation of unfiltered sample Straits Schists (B) showed significant turbidity.
3. ("letter") after rock formation refers to the first letter of the town's name where the rock flour sample was taken from.
4. High, Medium and Low refer to the different acidification levels. (See rock flour testing methodology section).

Weathered Casing Exposed to Deionized Water and Acidic Conditions

Table 5 shows results from the XRF test on the casing. It was found that both fresh and weathered casings have an average of 22% manganese by weight. Table 6 shows test results of the leachability of manganese and iron from the casing when immersed in deionized water. It can be noted that oxidation of iron was visually noticeable within 24 hours. As can be seen the amount of manganese leachate increased as a function of the duration of testing. A possible explanation for these observations is that the casing continued to oxidize with time and generated an increase in turbidity in the water. Upon acidification in the laboratory (starting after the October 2 sampling), an increase in manganese and iron concentrations was occurred.

Table 5 – XRF test results on the fresh and weathered casings.

XRF Test	**Mn**	**Fe**
	mg/Kg	mg/Kg
Casing		
Fresh	214,426	5,988,352
Weathered	228,455	6,707,609

Table 6 – Mn and Fe leaching of a weathered casing in deionized water.

Test Date	pH	Mn	Fe
		mg/L	mg/L
8/7/2009	6.7	NT	NT
9/11/2009	6.43	0.6	NT
9/18/2009	5.65	0.3	NT
9/25/2009	5.46	1.9	NT
10/2/2009	5.59	5.4	NT
10/10/2009	4.68	10.59	412.5
10/26/2009	4.32	32.01	818.3

Note: NT = Not Tested

Private Well Water Quality Testing – Home Case Studies

Table 7 shows the results from groundwater testing of homes in Connecticut. Two out of the four homes show manganese levels exceeding the National Secondary Drinking Water Standard. One of the homes (Bethany) exhibited a manganese concentration above the state action level of 0.5 mg/L. A home in Colchester had iron concentration well above the National Secondary Drinking Water Standard. Both of the homes that showed NSDWRS exceedances in either manganese or iron had acidic pH levels in their groundwater. Alkalinity and turbidity levels appeared to be normal when compared to the NSDWRS.

Table 7 – Groundwater testing from homes.

CASE STUDIES						
		[Mn]	**[Fe]**	**Ph**	**Alkalinity**	**Turbidity**
		(mg/L)	(mg/L)		(mg/L)	NTU
Criteria>>	**MCL/NSDWRS>>**	0.05	0.3	6.5-8.5	300	5
Test Date	**Home Location**					
7/31/2009	Bethany	1.326	0.169	6.2	27	<0.2
10/29/2009	Colchester #1	0.195	12.91	6	NA	3
10/29/2009	Colchester #2	ND	ND	6.9	27	0.8
6/18/2009	Broad Brook	<0.04	0.09	7.4	79	2

Notes: NA = Not Analyzed; ND = Not Detected
MCL = Maximum Contaminant Level (MCL)
NSDWRS = National Secondary Drinking Water Regulations

CONCLUSIONS

Based on laboratory and field testing, manganese concentrations being reported from wells in the in Connecticut may be an artifact of sample preservation and analytical preparation. The results of this study demonstrate that the leaching of rock derived turbidity and weathered well casing can result in false positive exceedance of regulatory standards when samples are acidified.

RECOMMENDATIONS

In order to avoid the false positive problem, the following is recommended:

1. In conducting well testing for manganese and other metals, a test should be performed to determine whether or not the metals are dissolved or an artifact of turbidity leaching. The test should consist of dividing water samples into two aliquots: One aliquot should be filtered using an inline filter and the other should be left unfiltered. The samples should then be preserved with acid. If the unfiltered sample concentration is higher than the filtered, the filtered sample concentration should be relied upon for characterizing the dissolved metal concentration.

2. Caution must be taken when obtaining an unfiltered and unpreserved groundwater sample, in consideration of the procedure followed by water quality laboratories. Typically, laboratories acidify a non-acidic sample (i.e., when the pH > 2) first and then the sample gets filtered (if the turbidity is > 1) if a total metal analysis by ICP is requested.

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