2006 MANGANESE MONITORING REPORT

Madison Water Utility

June 19, 2007

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BACKGROUND

In 2004, Madison Water Utility began receiving customer complaints about black colored water at homes in the Nakoma neighborhood, an area historically served by Well 10. Black solids are often associated with oxidized manganese. One home located on Mandan Crescent, for example, had persistent problems despite plumbing changes. While flushing the service line, an action undertaken to remove as much material as possible, a water sample was collected and found to have 244,000 parts per billion (ppb) manganese, a level nearly 1000 times the lifetime health advisory level of 300 ppb. Additional samples were collected at the original residence, three other area homes, and a neighborhood school. All of the samples had manganese levels below the EPA secondary standard of 50 ppb except for one that had 719 ppb manganese. The high manganese sample was taken from an exterior hose bib that had not been used during the winter. Subsequent samples taken from the same exterior hose bib later tested at 11 ppb manganese or less. This series of events raised concerns in the neighborhood about the safety of the tap water, which later spread to other areas of the city.

Well 10 served the Nakoma and other near west neighborhoods, mostly year-round, since it went into service in 1951. Annual manganese tests at Well 10 over the past decade have ranged from 38-60 ppb. In 2003, it was converted to a seasonal well, with planned operation from April to October each year. Major maintenance and rehabilitation work was initiated in March 2005 and continued through the fall of 2005. An aim of the work was to identify a depth zone in the well with potentially lower manganese levels; the effort proved unsuccessful. Since October 2004, Well 10 has been used on a limited basis, primarily for water main flushing, and only during the period of June to August 2006.

Two other Madison municipal wells (Well 3 and Well 29) have elevated levels of manganese. Madison Water Utility plans to abandon Well 3 following the detection of increasing levels of carbon tetrachloride at the well in 2006, and will install a pyrolusite filter at Well 29. The filter will remove manganese and iron and is expected to be in operation by January 2009.

In December 2004, in response to customer complaints in the Nakoma area, Madison Water Utility initiated unidirectional flushing in the Mandan Crescent, Tumalo Trail, and Seminole Highway area. This relatively new technique for flushing water mains directs high velocity water through a targeted water main to more effectively remove solids that have accumulated. Unidirectional flushing was used on a wider scale, in October and November 2005, to flush 29 miles of water mains in parts of the Well 10 area. In 2006, over 400 miles of pipe were cleaned with unidirectional flushing.

Madison Water Utility previously conducted a number of studies to investigate the nature and extent of manganese in pipe systems (Cantor, 2005) and the effectiveness of the new flushing technique. The current investigation is part of an on-going, comprehensive effort by the Water Utility to better understand manganese in Madison's sandstone aquifer, within the distribution system, and at the residential tap.

INTRODUCTION

Manganese is a naturally occurring element found in rock formations, soil, air, and water. While it is an essential nutrient, consuming excess amounts of manganese regardless of the source may result in human health problems. The primary source of manganese for most people is the food they eat. Nuts, grains, fruits, legumes, tea, leafy vegetables, infant formula, and some meats and fish contain substantial amounts of manganese (table 1).

Table 1. Manganese content of common foods in a human diet (Linus Pauling Institute).

FOOD	**SERVING SIZE**	**MANGANESE (mg)**
Pineapple, raw	1/2 cup, diced	1.28
Pineapple juice	1/2 cup (4 ounces)	1.24
Pecans	1 ounce	1.12
Almonds	1 ounce	0.74
Peanuts	1 ounce	0.59
Instant oatmeal (prepared with water)	1 packet	1.20
Raisin bran cereal	1 cup	1.88
Brown rice, cooked	1/2 cup	0.88
Whole wheat bread	1 slice	0.65
Pinto beans, cooked	1/2 cup	0.48
Lima beans, cooked	1/2 cup	0.48
Navy beans, cooked	1/2 cup	0.51
Spinach, cooked	1/2 cup	0.84
Sweet potato, cooked	1/2 cup, mashed	0.55
Tea (green)	1 cup (8 ounces)	0.41-1.58
Tea (black)	1 cup (8 ounces)	0.18-0.77
Madison municipal well water	2 cups (16 ounces)	0.00-0.09

Water from Madison municipal wells has manganese concentrations that range from 0.2 to 186 micrograms per liter (µg/L) or parts per billion (ppb). Sixteen wells have less than 30 ppb, five are in the range 30 to 50 ppb, and three are greater than 50 ppb manganese (table 2). Madison wells that exceed 50 ppb operate seasonally (typically June to September) to ensure sufficient water flow for fire protection during high water demand summer months but also to minimize discolored water events that may arise from the accumulation of manganese in water mains.

Manganese at the wellhead is predominantly dissolved or soluble manganese. As the water is pumped out of the ground and comes into contact with an oxygen rich environment or a strong

oxidant such as chlorine, the manganese precipitates out of solution and can settle in the water mains. Over time, significant mineral (manganese and/or iron) accumulation may occur in the pipes. Under normal flow conditions, the mineral deposits remain attached to pipe walls or as solids that settle on the bottom of the mains. However, disturbances in water flow caused by a water main break, a valve being opened or closed, hydrant flushing, or other disruption can stir up manganese (and other mineral) sediment and cause discolored water.

Table 2. Manganese (Mn) concentrations in water from Madison municipal wells.

WELL	Mn (ppb)	WELL	Mn (ppb)
3	153	17	34
6	1.2	18	7.8
7	28	19	45
8	48	20	<0.2
9	0.4	23	36
10	60	24	29
11	8.9	25	7.5
12	16	26	4.8
13	11	27	32
14	<0.2	28	24
15	6.8	29	186
16	0.3	30	14

In 2005 and 2006, the Water Utility took action to address the problem of excess manganese in the water distribution system by reducing the amount of water pumped by wells with higher levels of the mineral and by cleaning the mains with unidirectional flushing. This technique involves isolating 3000-foot pipe sections, by closing select valves, and using high velocity water to scour the pipes and remove accumulated manganese and other minerals. The flushing program is used to maintain clean pipes and to minimize colored water events. The end result is better tasting, aesthetically pleasing water at the tap. In 2006, about 50% of the City's 840 miles of water mains were cleaned using unidirectional flushing; the remaining 50% was flushed conventionally. Priority is given to service areas historically served by wells with higher levels of manganese, areas of the city with 4-inch mains, and neighborhoods in which discolored water events appear more frequently. Between April and November 2007, the Water Utility plans to flush the entire distribution system using this new technique.

Colored water events may occur even with an effective water main flushing program in place. Mineral deposition in water mains is a cumulative process that depends on the concentration of metals in the source water and time since the previous flush. Colored water events are usually random, temporary, and infrequent; water typically clears in 15-30 minutes without additional action. Running a cold-water tap at full force can usually flush out the manganese and coloration in a few minutes. People should not drink or cook with colored water, and, if the color persists, customers are urged to report the problem to the Water Utility.

There is no federal regulation for manganese concentrations in drinking water. However, there is a federal secondary standard of 50 ppb that is based on aesthetic considerations. Concentrations of manganese above 50 ppb can discolor plumbing fixtures and stain laundry. The secondary standard is not an enforceable regulation; rather it is a guideline for water utilities. In 2003, the Environmental Protection Agency (EPA) decided against establishing an enforceable National Primary Drinking Water Regulation for manganese because the agency felt that doing so was not likely to result in a meaningful health risk reduction for people served by public water systems (AWWARF, 2006). Manganese is not considered to be very toxic when ingested with food, and drinking water accounts for a relatively small proportion of manganese intake when compared to food.

A 2004 EPA report, *Drinking Water Health Advisory for Manganese*, established the lifetime health advisory level of 300 ppb manganese in drinking water. Lifetime consumption of water with less than 300 ppb is not expected to cause adverse health effects for healthy individuals. However, the report identified groups that potentially could be sensitive to manganese because they may absorb greater amounts of manganese or excrete less. Identified groups included the very young, the elderly, and individuals with liver disease. Individuals in these sensitive groups, especially infants younger than six months, should not be exposed to drinking water with greater than 300 ppb manganese for more than ten consecutive days.

This study was performed to address concerns about customer exposure to potentially high levels of manganese in drinking water and the uncertainties about the relationship between manganese levels at the well and those at residential taps. Objectives of this investigation were to determine the manganese concentrations in water arriving at customers' taps, identify the geographic extent of high manganese levels, and determine the effectiveness of unidirectional flushing in reducing manganese concentrations at the tap.

METHODS

Sample Site Identification

Properties served by Madison Water Utility were identified using the City of Madison properties database, Dane County properties database, and Madison Water Utility service database. They were grouped into well service areas as defined by Water Utility staff. Areas served by Well 3, 8, 10, and 29 were selected as study areas because these wells produce the highest amounts of manganese (>45 ppb). The remaining well areas were grouped together to serve as a reference for the four study areas.

A total of 1325 addresses were randomly selected throughout the Madison Water Utility service area. After listing all addresses in the well area, a random number generator was used to select the given number of addresses. In the problem well areas (Wells 3, 8, 10, and 29) between 5-10% of the properties were selected. Outside the problem well areas, approximately 1% of all addresses were chosen. The breakdown of sample sites by well service area is given in Table 3. Some randomly selected sites were not sampled because the hose bib was inaccessible, broken, or absent, the water was turned off, or the water was softened.

Table 3. Number of randomly selected sites initially identified.

WELL AREA	SAMPLE SITES
3	235
8	170
10	235
29	180
Other	505
TOTAL	1325

Ultimately, water samples were collected at 1,118 homes and businesses in Madison. Locations in which samples were actually collected are shown in figure 1. Site clusters in the near west, isthmus, near east, and far east highlight the higher density of sampling in the Well 10, 3, 8, and 29 service areas, respectively, and the geographic extents of these service areas.

Sample Collection

Samples were collected and labeled by well service area. Furthermore, each sample was also designated "pre-flush", "post-flush", or "post-flush 30" based on date of collection relative to water main flushing for that location. Post-flush 30 samples were collected approximately 30 days after flushing while post-flush samples were collected approximately one week after the flushing. Of the four problem well areas, pre-flush samples were only collected in the Well 10 area. Follow-up samples ("Resample") were collected at all locations that initially tested above 300 ppb manganese. Finally, the quality control samples were taken as requested by the testing laboratory. The number and type of samples from each of the four problem well areas and the collective other well service areas are shown in table 4.

Table 4. Number of samples, sorted by well area and type, collected in 2006.

WELL AREA	SAMPLE TYPE					TOTAL
	Pre-flush	Post-flush	Post-flush 30	Quality Control	Resample	
3	0	184	180	12	12	388
8	0	122	120	19	4	265
10	198	183	187	28	9	605
29	0	140	135	18	7	300
Other	425	44	0	37	11	517
TOTAL	623	673	622	114	43	2075

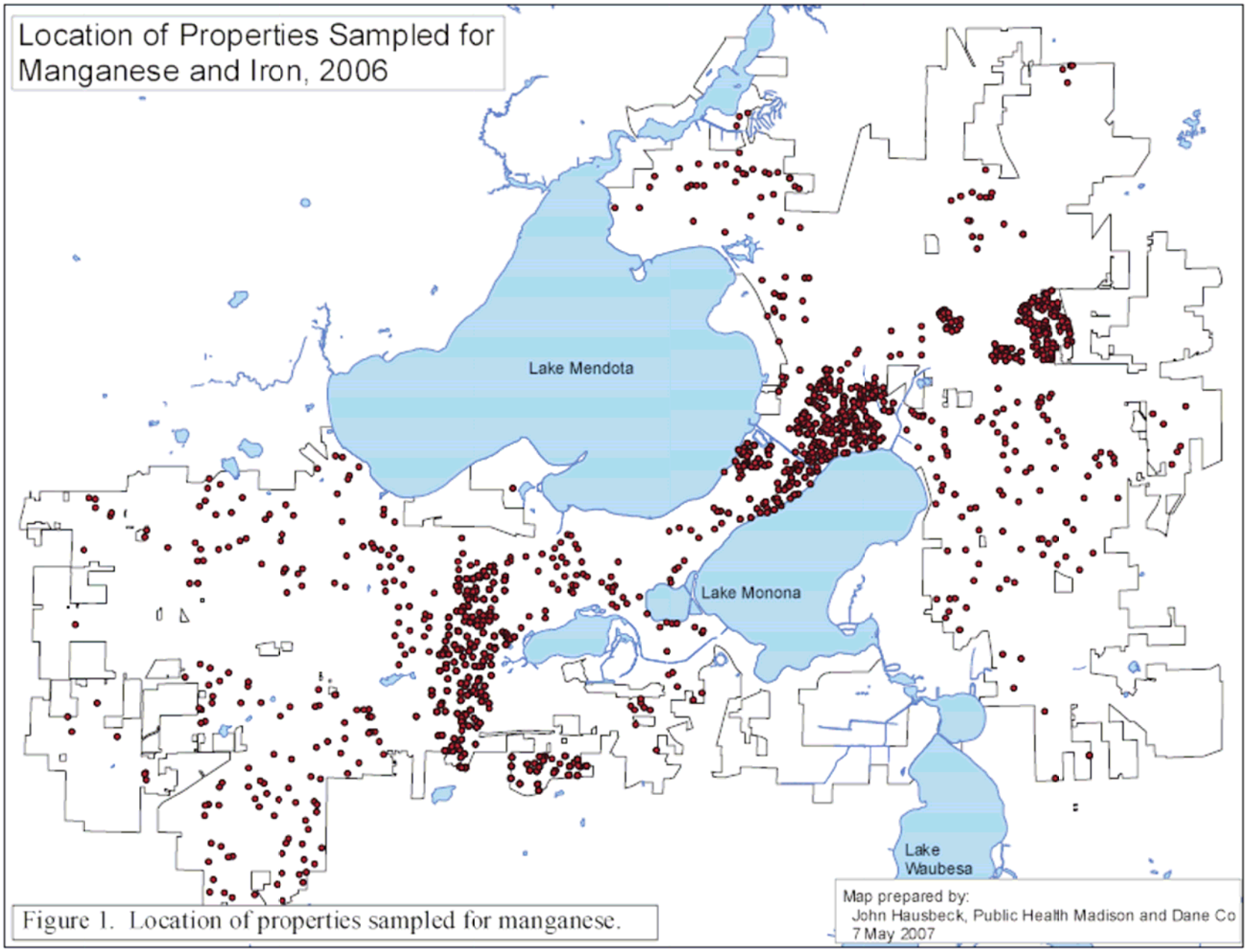

Figure 1. Location of properties sampled for manganese.

Sample Collection Protocol

Water samples were almost always collected at the exterior hose bib. This location was selected to minimize customer impact and scheduling conflicts; it allowed a greater number of samples to be collected during the sampling period. On rare occasions, samples were collected at residential kitchen taps or from basement or utility sinks in commercial buildings that did not have exterior taps. The procedure for collecting water samples was as follows:

- Draw an initial 2-liter sample and discard as waste;
- Using a Hach Sofchek Total Hardness test strip, verify that the discarded water has not been softened. If soft water, no sample is collected;
- Collect a 500-mL sample for metals (manganese and iron) analysis;
- Using a Hach Pocket Colorimeter II, measure the free chlorine residual;
- Sterilize the tap with a propane torch;
- Run the water to waste for 30-45 seconds. If the tap could not be sterilized, the water was run to waste for a longer period;
- Collect a 150-mL sample for total coliform (TC) and heterotrophic plate count (HPC) testing. Immediately place Bacti* sample on ice.

At approximately every tenth sample location, a second 500-mL water sample was collected for laboratory quality control purposes. Samples collected for metals analysis were delivered to the Environmental Testing Laboratory at the Department of Public Health for Madison and Dane County**. Water turbidity was measured at the laboratory before lowering the pH to less than 2 to preserve the samples.

RESULTS

Between May 30 and October 25, 2006, 2075 water samples were collected from throughout the distribution system and tested for manganese concentrations. The results are shown in figure 2.

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* Microbiological (Bacti) samples were collected for another study and are not discussed further in this report.

** Samples collected in the Well 3 service area on May 30th - June 2nd were analyzed at the Wisconsin State Laboratory of Hygiene.

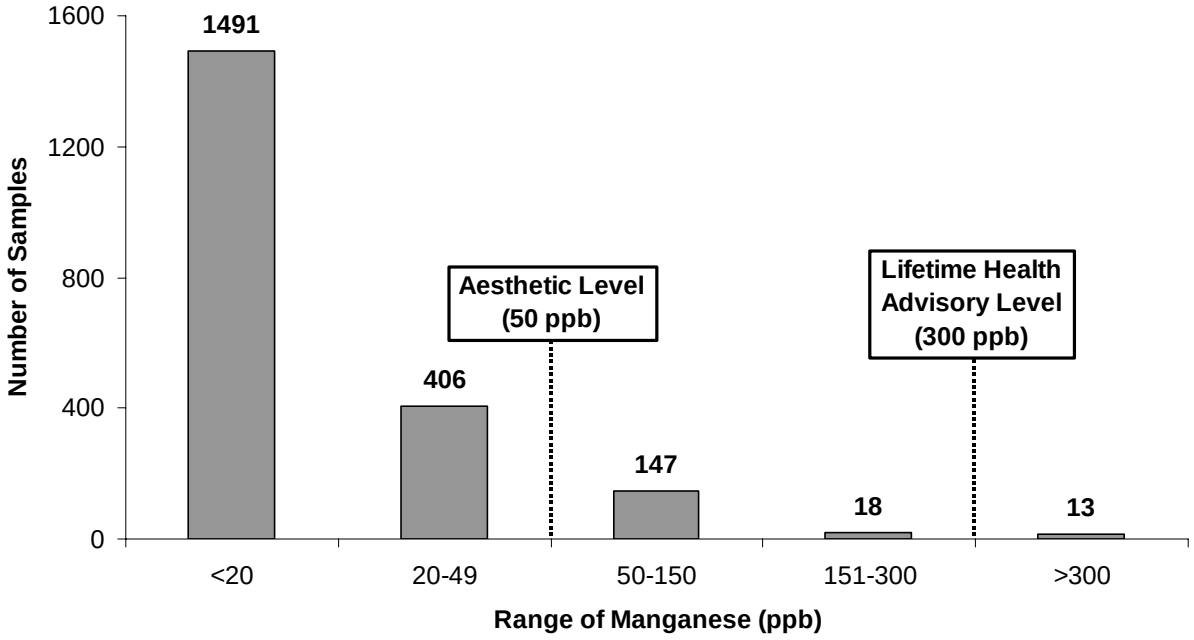

Figure 2. Manganese results for 2075 tap samples collected in 2006.

The majority of water samples had manganese below 20 ppb (72%) and 50 ppb (91%), the level at which manganese might stain laundry and plumbing fixtures. Thirteen samples, less than 1% of all samples collected, tested above the lifetime health advisory level of 300 ppb. Infrequently used hose bibs or unoccupied buildings often had elevated manganese levels (table 5).

Additional samples were collected from the eleven locations that initially tested above 300 ppb manganese (table 5). Follow-up samples collected from these locations often had levels below 50 ppb and in several cases less than 20 ppb. No sample location consistently tested above 300 ppb. Eight of the eleven properties that exceeded 300 ppb were located in problem well areas. Although the other three locations were not located in problem well areas, these locations were occasionally served by wells with intermediate to high levels of manganese.

The Water Utility also investigated whether locations served by wells with higher manganese were more likely to have higher manganese at their water taps when compared to homes served by wells with lower manganese. Figure 3 and table 6 show how the manganese concentrations for samples collected in the four problem well areas (Wells 3, 8, 10 and 29 – manganese levels that are greater than 48 ppb) compared with samples from the service areas of the remaining 20 wells, manganese of 45 ppb or less, that were combined and designated as "other". Results for the Well 10 service area were similar to the other citywide samples; greater than 95% were lower than the aesthetic level of 50 ppb and greater than 85% were below 20 ppb. The Well 3, 8, and 29 service areas had a higher proportion of samples in the 50-149 ppb manganese range (9-15%) compared to the Well 10 (2%) and other citywide samples (3.5%). Finally, a higher percentage

Table 5. Sample locations where the manganese concentration in tap water exceeded 300 ppb.

STREET	BLOCK	WELL AREA	BUILDING TYPE	SAMPLE LOCATION	SAMPLE DATE	RESULT (ppb)	COMMENTS
Amnicon Trl	800	25	Residential	Rear hose bib	9/25/06 10/19/06 10/23/06 10/25/06	***306*** 6.2 2.2 1.1	House unoccupied since June 2006
Atwood Ave	2100	8	Commercial	Basement hose bib	7/5/06 7/19/06 7/19/06 7/21/06 7/25/06 7/28/06 7/28/06	***335*** ***1530*** 31 [1] ***768*** 257 201 216 [2]	Tap unused for nearly three years; line was flushed on 7-27-06
Capitol Ct	1200	27	Commercial	Front hose bib	9/8/06 9/25/06 6/26/06 9/27/06 9/27/06	***672*** 23 12 28 [3] 5.8	Tap not regularly used
Coney Weston Pl	5000	12	Residential	Front hose bib	9/20/06 10/13/06 10/19/06 10/20/06	***847*** 3.5 13 7.8	Hydrant flushing two blocks away when initial sample collected
Eastwood Ave	2000	3	Commercial	West side hose bib	6/1/06 6/28/06 6/28/06 7/5/06 7/7/06 7/12/06	255 ***3540*** 71 [4] 56 89 15	
Elizabeth St	1200	3	Residential	East side hose bib	6/14/06 7/12/06 7/12/06 7/27/06	39 ***343*** 26 [4] 3.4	Water main flushing few blocks away for high manganese sample
Hillcrest Dr	4300	10	Residential	East side hose bib	6/8/06 8/22/06 9/15/06 10/13/06 10/19/06 10/20/06	80 119 ***368*** 90 185 31	Unoccupied House
Pennsylvania Ave	2400	3	Commercial	Exterior hose bib	5/30/06 6/8/06 6/8/06 6/13/06 6/14/06 6/26/06	***336*** 37 40 [3] 33 29 39	Hose bib unused for several months
Pulley Dr	700	29	Residential	South side hose bib	6/15/06 6/15/06 6/22/06 6/23/06 6/23/06 6/26/06 7/10/06	***10100*** 64 [4] 19 9 8.2 [2] 9.1 19	
Redland Dr	700	29	Residential	Front hose bib	6/15/06 6/22/06 6/23/06 6/26/06 7/10/06	***441*** 20 6.3 4.2 19	
Whenona Dr	1300	10	Residential	Rear hose bib	6/7/06 6/12/06 6/13/06 6/14/06 7/10/06	***747*** 3 57 11 2.9	Hydrant flushing five blocks away for initial sample

[1] Men's room tap

[2] Duplicate sample, collected for quality control

[3] Inside tap

[4] Repeat sample, second sample taken after 15-20 liters discarded

of samples from the Well 3 (45%) and the Well 8 (31%) areas had manganese in the 20-49 ppb range compared to the Well 10, 29, and other citywide areas (10%).

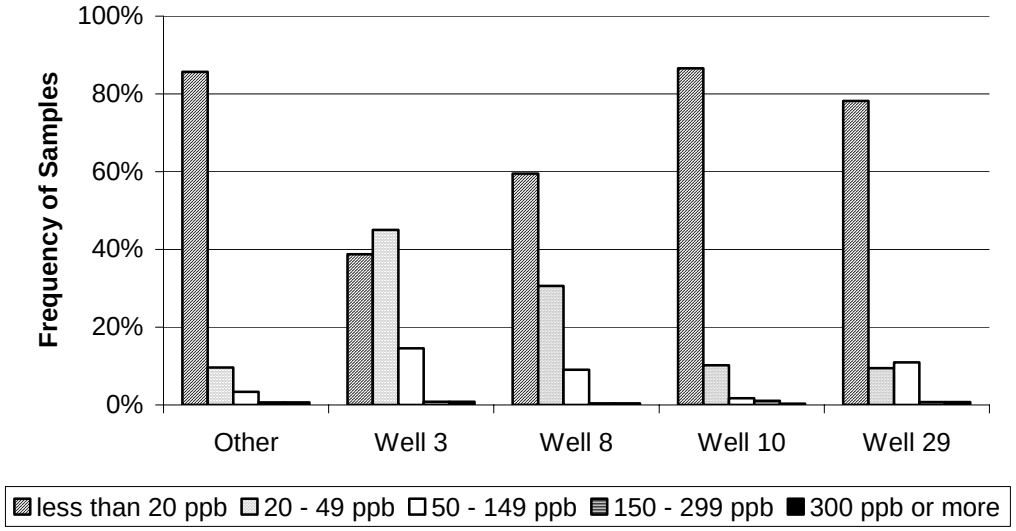

Figure 3. Problem well area sample distributions among five manganese concentration ranges.

Table 6 summarizes the data obtained from post-flush samples. The average manganese levels at taps in the Well 3, 8, 10, and 29 areas were significantly different from the average concentration at the tap in well areas served by lower manganese producing wells. Averages for samples from well areas 3, 8, and 29 were significantly higher than the average from the citywide well areas while the average of samples from the Well 10 area was significantly lower.

Table 6. Summary statistics describing manganese concentrations among post-flush samples from the four problem well areas and the reference group (composite other well areas).

	Samples	Mean (ppb)	Standard Deviation	Range (ppb)	95% Confidence Interval	p-value**
Well 3*	363	32.5	40.0	1.0 – 343	28.3 – 36.6	0.000
Well 8	242	22.9	31.9	0.5 – 335	17.9 – 26.0	0.000
Well 10	369	9.7	26.0	0.2 – 368	7.0 – 12.4	0.000
Well 29*	274	18.7	38.2	0.6 – 441	14.2 – 23.3	0.000
All other well areas	469	15.5	56.5	0.2 - 847	10.4 – 20.7	reference

* For the comparison among well areas, two sample results were removed as outliers. A sample from the Well 3 area had a concentration of 3,540 ppb and a sample from the Well 29 area had a concentration of 10,100 ppb.

** A p-value $\leq$ 0.05 means that the well area is significantly different from other areas of the city served by wells producing low levels of Mn

Geographic Extent of Elevated Manganese

Figure 4 shows the geographic distribution of water samples that had manganese above 50 ppb. The highest frequency of samples that exceeded 50 ppb manganese was collected in the Well 3 (16%), Well 8 (10%), and Well 29 (12%) service areas. Manganese concentrations in the source water from these wells range from 48-186 ppb (table 2). Three percent of samples collected in the Well 10 area had greater than 50 ppb manganese, and many of these sample locations were clustered around Well 10. Outside the high manganese well areas, 5% of the sample locations tested above 50 ppb (table 7). In addition, no samples collected from the Well 9, 11, 14, 15, 19, or 23 service areas exceeded the aesthetic standard of 50 ppb manganese. These service areas correspond to most of the north and east sides of Madison as well as the Spring Harbor and the University of Wisconsin campus area on the west side. A total of eight locations west of South Midvale Boulevard, located on Madison's near west side, tested above 50 ppb (figure 4).

Table 7. Manganese distribution among samples collected outside the four problem well areas.

Range of Manganese (ppb)	Samples (N)	Percent
0-49	445	94.9%
50-99	13	2.8%
100-149	5	1.1%
150-300	3	0.6%
over 300	3	0.6%

Impact of Unidirectional Flushing on Manganese Level

Locations in the Well 10 service area served as a subpopulation for evaluating the impact of unidirectional flushing on manganese concentrations at the tap. Three samples were collected at each sample location: one prior to flushing (pre-flush), one seven days after flushing (post-flush), and a third one month after flushing (post-flush 30). For the statistical analysis, the seven-day and one-month post-flush samples were combined into a single post-flush group. The results indicate a statistically significant difference ($p = 0.008$) in manganese concentrations between the pre-flush and post-flush samples. Unidirectional flushing reduced the average concentration of manganese by 35%. There was also a reduction in the number of sample locations that had manganese concentrations above 50 ppb. Summary statistics are reported in table 8.

Table 8. Summary statistics comparing manganese concentrations in the pre-flush and post-flush samples collected from the Well 10 service area.

Sample Type	Samples	Mean (ppb)	Standard Deviation	Range (ppb)	95% Confidence Interval
Pre-flush	198	14.7	63.2	0.3 - 747	5.9 - 23.6
Post-flush	369	9.7	25.9	0.2 - 368	7.0 - 12.4

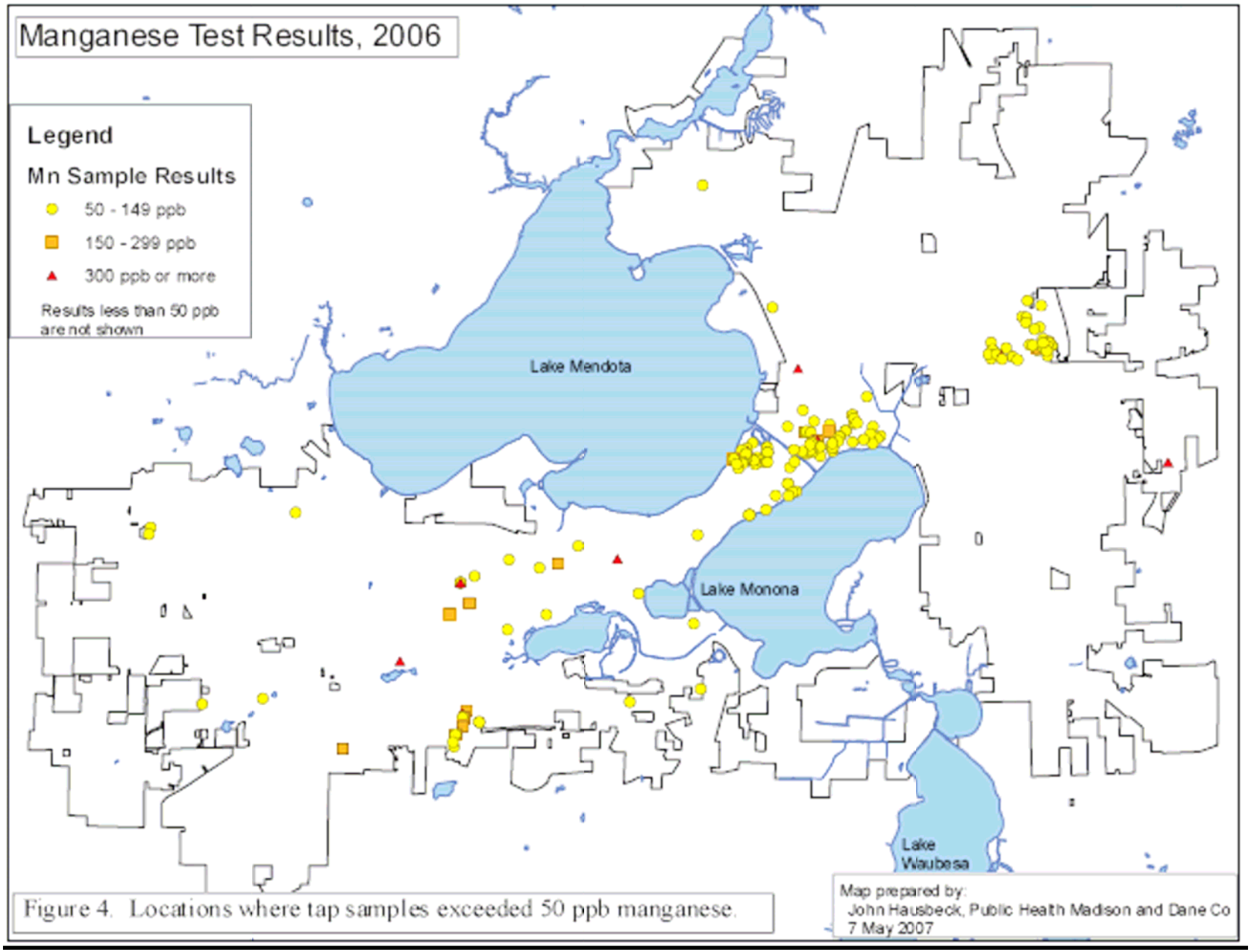

Figure 4. Locations where tap samples exceeded 50 ppb manganese.

Impact of Time Since Flushing on Manganese Level

Sample locations served by high manganese producing wells were sampled twice to determine if there was a significant change in the manganese level over time after water mains were flushed. Samples were collected approximately one week and again one month after flushing. Table 9 compares the manganese concentrations between the two sample periods. Except for the Well 29 service area, manganese levels in the one week and one month samples were not significantly different within a service area. Water samples collected in the Well 29 area showed a significant increase in the average manganese concentration between the two test periods, increasing from 11 to 26 ppb manganese over a four-week span (table 9). More work is necessary to determine what caused the manganese level to dramatically increase in the Well 29 area over the short time period; however, the rise likely reflects the relatively high manganese source water.

Table 9. Summary statistics on manganese concentrations for samples collected one week and one month after flushing for the four problem well areas.

Well Area	Sample Type	Samples	Mean (ppb)	Standard Deviation	Range (ppb)	Confidence Interval, 95%	p-value
3*	One week	184	31.7	43.3	1 – 336	25.4 – 37.9	0.87
	One month	180	33.3	36.5	1.4 – 343	27.9 – 38.7	
8	One week	122	19.6	34.1	0.5 – 335	13.5 – 25.8	0.23
	One month	120	24.3	29.4	0.7 – 216	18.9 – 29.6	
10	One week	182	9.6	16.2	0.3 – 119	7.2 – 12.0	0.23
	One month	187	9.7	32.8	0.2 – 368	5.0 – 14.5	
29*	One week	139	11.4	38.9	0.8 – 441	4.9 – 17.9	0.00**
	One month	135	26.3	36.0	0.6 – 158	20.2 – 32.4	

* Two sample results were removed as outliers; a tap sample from the well 3 area had a concentration of 3,540 ppb and a tap sample from the well 29 area had a concentration of 10,100 ppb

** Statistically significant difference

CONCLUSIONS

A majority of water samples tested below the aesthetic standard of 50 ppb manganese. Samples that exceeded the aesthetic guideline were more likely to have been collected from areas served by higher manganese producing wells such as Well 3, 8, and 29. Manganese concentrations for samples collected in the Well 10 area were lower than samples collected citywide.

Relatively few tap samples exceeded the lifetime health advisory level of 300 ppb. Locations that initially tested above this threshold routinely had significantly lower levels of manganese upon re-sampling. None of the eleven locations with a manganese above 300 ppb consistently

tested above this level. Furthermore, an infrequently used hose bib or an unoccupied house or building was often the cause of the initial high manganese level.

Geographically, locations with manganese above 50 ppb were concentrated on the isthmus, near east, and far east. These locations were primarily served by Wells 3, 8, and 29 – wells with the highest levels of manganese. Elevated manganese at residential taps does not appear to be a problem for the majority of the city, particularly in areas served by wells with low manganese levels.

Unidirectional flushing was shown to reduce manganese levels at the tap in the Well 10 service area, the only well area in which a significant number of pre-flush samples were collected. The average manganese concentration among post-flush samples was 35% lower than the average manganese concentration of pre-flush samples. Except for the Well 29 service area, manganese levels were not significantly different approximately thirty days after flushing. More work is necessary to understand why manganese levels increased in the Well 29 area. Additional study is also needed to determine the frequency with which water mains should be flushed to minimize mineral accumulation in mains and the associated aesthetic complaints of discolored or metallic tasting water that can accompany it.

RECOMMENDATIONS

- Flush sample taps for 2-3 minutes one day prior to sampling to minimize uncertainty about the potential causes of elevated manganese levels.
- Re-sample any residential tap that exceeds 100 ppb manganese.
- Collect source water (well) samples on a monthly basis from all operating wells.
- For wells that exceed 50 ppb manganese, minimize to the extent possible operation of these wells or investigate the feasibility of treatment to reduce manganese to below 10 ppb.
- Continue unidirectional flushing to remove accumulated sediment (iron/manganese) from the water mains.
- Identify 100-200 citywide locations to perform long-term monitoring; locations should be more heavily concentrated in the high manganese producing well areas.
- Refine the current understanding of temporal changes in manganese levels at the tap by collecting samples over a time series extending to twelve months after flushing.
- Develop a monitoring program to evaluate potential factors contributing to elevated manganese levels that include pipe attributes (age, diameter, material), relationship to flushing hydrant turbidity, or proximity to well service area boundaries.
- Develop a program that monitors turbidity within the distribution system with the aim of flushing water mains before water quality complaints increase.
- Establish water quality benchmarks for manganese, iron, and turbidity at the well and at residential taps.

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