Manganese in Madison’s Drinking Water

Abstract

Public concern over events of manganese-discolored drinking water and the potential for adverse health effects from exposure to excess manganese reached a high level in 2005. In response, Public Health Madison Dane County, together with the Madison Water Utility, conceived and implemented a public health/water utility strategy to quantify the extent of the manganese problem, determine the potential for adverse human health effects, and communicate these findings to the community. This strategy included five basic parts: taking an inventory of wells and their manganese levels, correlating manganese concentration with turbidity, determining the prevalence and distribution of excess manganese in Madison households, reviewing the available scientific literature, and effectively communicating our findings to the community. The year-long public health/water utility strategy successfully resolved the crisis of confidence in the safety of Madison’s drinking water.

Introduction

Drinking-water safety has been at issue in recent years in the United States, and particularly in Wisconsin, following the 1993 Cryptosporidium outbreak in Milwaukee (Centers for Disease Control and Prevention [CDC], 1996; MacKenzie et al., 1994). Lead as a contaminant of municipal drinking water has also been of concern (Schlenker, 1989). In Madison, complaints of discolored tap water, associated with ruined clothing, stained bathroom fixtures, and clogged ice-makers were received by the Madison Water Utility (MWU) and Public Health Madison Dane County (PHMDC) since at least 2003 and increased during the later half of 2005. Also, complaints in 2005 more frequently expressed public health concerns referencing recent scientific evidence linking excess manganese exposure with Parkinson’s syndrome, Attention Deficit Hyperactivity Disorder, and other ailments. In response, Madison Mayor Dave Cieslewicz formed a working group including leadership of MWU, PHMDC, the mayor’s office, and citizens to address drinking water manganese and human health risks.

Manganese, a known component of the city’s deep-aquifer, mineral-rich, “hard” water, had previously been identified as a water quality problem due to its propensity to precipitate out of solution, unevenly accumulate as sediment in city water pipes, resuspend with changes in hydrostatic pressure, and arrive in high concentrations at seemingly random households. One especially turbid sample collected by a homeowner from a street lateral measured 224 mg Mn/L, over 4,000 times the U.S. Environmental Protection Agency (U.S. EPA) secondary maximum contaminant level (SMCL) of 0.05 mg Mn/L, a nonenforceable, aesthetic guideline based on staining and taste considerations. The 2003 U.S. EPA determination of manganese as a potential health hazard (U.S. EPA, 2003) and its more cautionary 2004 “Drinking Water Health Advisory for Manganese” (U.S. EPA, 2004) raised citizen concern beyond aesthetics. Members of the public questioned the water utility’s assurance that Madison’s occasionally discolored water was not a health hazard. Ongoing media attention stimulated public concern (Seeley, 2006).

In early 2006, PHMDC, the local public health agency resulting from the merger of the Madison Health Department and the Dane County Division of Public Health, in collaboration with the mayor’s working group, identified a public health/water utility strategy including five action steps. Two actions involved organizing and synthesizing information already available. Two involved systematic sampling and analysis of drinking water. The fifth action was to effectively communicate with the public, in a timely manner, actual risks and appropriate responses. The methods and results of this strategy are described here to assist other communities to better address similar water quality problems. The strategy, based on an intense integration of public health and water utility operations at the administrative/leadership and technical levels, took the better part of a year to implement but did resolve Madison’s manganese issue. Operationally, the public health director, also a physician, advised the utility on human health issues, joined with the utility director and the mayor to directly address the public, and was officially appointed to the utility board of directors. The public health environmental epidemiologist also spoke at public meetings while working closely with utility engineers to understand utility infrastructure and operations and advise them on appropriate quality control, scientific sampling, and customer communication.
Methods

The public health/water utility strategy included five action steps: well inventory, manganese/turbidity correlation, prevalence and distribution of excess manganese, scientific data review, and public information.

Well Inventory

In order to identify and target areas at greatest risk, as a first order of business, PHMDC and MWU staff assembled data on manganese concentrations at the wellheads for each of MWU’s 24 active wells, available from PHMDC laboratory records collected to comply with state and federal drinking-water-quality regulations. The data were arranged into easily understood tables and published in press releases and on PHMDC and MWU Web pages.

Manganese/Turbidity Correlation

In order to better assess the potential harm of ingesting discolored or turbid (cloudy) water, as well as the safety of ingesting clear water, MWU collected 234 water samples over a period of several weeks from fire hydrants during flushing. The PHMDC laboratory tested the samples for turbidity, iron, and manganese. Manganese concentration and turbidity in both clear and turbid water were correlated using pair-wise methods with Stata Statistical Software: Release 9 (StataCorp, 2005). These data were depicted in an easy-to-understand scattergram with Microsoft Excel software.

Staff collected water samples into acid-cleaned sample containers. Manganese and iron analyses were performed using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES EPA Method 200.7 Rev. 4.4) techniques (U.S. EPA, 1994). Total recoverable manganese and iron were determined after acid digestion of the water samples. Turbidity was measured in the laboratory with a HACH Model 2100N Turbidimeter as an indicator of suspended particulates (American Public Health Association, 1998). The laboratory quality control protocol followed U.S. EPA method requirements and PHMDC laboratory’s standard operating procedures. In order to determine the flushing end point of 1 nephelometric turbidity unit (NTU), MWU staff measured turbidity while flushing fire hydrants using a Hach 2100P Portable Turbidimeter.

Prevalence and Distribution of Excess Manganese Determination

In order to establish the prevalence and distribution of tap water above U.S. EPA’s lifetime health advisory guideline of 0.3 mg Mn/L, PHMDC and MWU staff worked together to collect water samples from 2,075 households. Areas served by high manganese wells (concentration Mn ≥ 40 µg/L) were selected as study areas and represented 75% of the samples collected. The remainder of the city, which receives water from low manganese wells (concentration Mn < 40 µg/L), served as the control area. Households were selected with a stratified random sampling protocol to ensure that sufficient numbers of households were selected from each study and control area. Staff identified all available households in each well area using MWU records and City of Madison and Dane County GIS databases. Approximately 10% of the households in each of the study areas and 1% of the households in the control area were randomly selected using a random number generator. This process involved sorting all existing household units in a given study or control area by their parcel
number, numbering them sequentially, and matching the sequential numbers with the random numbers generated.

Water samples were drawn from outdoor hose bibs of each selected household in the study and control areas. Manganese, iron, and turbidity were measured in each sample as described above. To determine if tap water manganese concentrations in the study areas were significantly different from those of the reference area, analysis of variance (ANOVA) tests were performed after sample results were log normalized (Motulsky, 1995). All statistical analyses were performed using Stata Statistical Software: Release 9 (StataCorp, 2005). The sampling and analysis required approximately three months of intense effort by water utility field and public health laboratory staff.

Scientific Data Review
In order to accurately assess the human health hazards presented by exposure to levels of manganese actually found in Madison tap water, PHMDC director and epidemiologist reviewed official documents of U.S. EPA and Agency for Toxic Substances and Disease Registry (ATSDR), other published scientific literature, and consulted with local and national experts. In addition, the City of Madison Mayor and Dane County Executive petitioned ATSDR to perform a health consultation in cooperation with PHMDC.

Public Information
In order to provide complete information to the public and to effectively address concerns related to health, communications were composed by public health and water utility staff and approved by the mayor, water utility director, and public health director. Public health and water utility staff distributed these communications through one or more of the following pathways, depending on the target audience: mailed to targeted households or physicians, issued press releases, posted on the PHMDC and MWU Web sites, and published as advertisements in local newspapers. Six community meetings, and two public, joint sessions of the board of health for Madison and Dane County and the board of water commissioners were held, at which the mayor, water utility and public health directors, and the epidemiologist spoke and responded to questions and complaints. Complaints focused especially on risks for vulnerable groups like infants, individuals with kidney and liver disease, and issues like infant formulas and water filters.

Results
An inventory of water quality at the well-heads of Madison’s 24 active wells showed a wide range of manganese concentrations from <0.001 mg Mn/L to 0.164 mg Mn/L, with an average of 0.028 mg Mn/L. Twenty-one wells produced water below the SMCL of 0.05 mg Mn/L, although well 8 was borderline at 0.048 mg Mn/L. Three wells (well 3 at 0.088 mg Mn/L, well 10 at 0.053 mg Mn/L, and well 29 at 0.124 mg Mn/L) produced water above the SMCL but below U.S. EPA health advisory guideline for lifetime exposure of 0.3 mg Mn/L (U.S. EPA, 2004). No wells produced manganese above the health advisory guideline.

Testing of 234 low-turbidity, fire hydrant water samples showed a positive correlation between turbidity and manganese concentration (Figure 1). The average manganese concentration of water at or below 1 NTU, the designated flushing end point, was 0.082 mg Mn/L with no samples exceeding 0.3 mg Mn/L. Approximately one-third of samples between 1 and 5 NTUs, in increasing proportions, exceeded 0.3 mg Mn/L. Above 5 NTUs (the level at which water is visibly discolored or cloudy), samples generally exceeded 1 mg Mn/L, indicating a hazard to human health, if consumed regularly over an extended period of time (Banta & Markesbery, 1977; Bouchard, LaForset, Vadelac, Bellinger, & Mergler, 2007; Kondakis, Leotsinidis, & Papapetropoulos, 1989; Wasserman et al., 2005; Woolf, Wright, Amarasiriwardena, & Bellinger, 2002). Ninety-one percent of the 2,075 tap water samples tested were below the SMCL of 0.05 mg Mn/L, 8% were between 0.05 and 0.3 mg Mn/L, and 0.6% exceeded U.S. EPA health advisory guideline of 0.3 mg Mn/L (Figure 2). On repeat testing, all of the 11 households with initial levels above 0.3 mg Mn/L registered acceptable levels.

Review of official guidelines and scientific data concerning the human health hazards of drinking water manganese revealed U.S. EPA health advisory guideline of 0.3 mg Mn/L to be based on studies associating a Parkinson’s-like, neurological syndrome in adults with long-term (defined as months to years), daily consumption of drinking water with manganese concentrations greater than 1 mg Mn/L (Kondakis, Leotsinidis, & Papapetropoulos, 1989; U.S. EPA, 2004). U.S. EPA built in a large margin of safety by setting its health advisory guideline at 0.3 mg Mn/L and further extrapolated that infants and individuals with reduced liver function should not be exposed to drinking water above the 0.3 mg Mn/L level even for short periods of time (defined as 10 days or more) (U.S. EPA, 2004). More recent studies report a ten-year-old child with subtle memory and learning difficulties after consuming water containing 1.2 mg Mn/L (Wasserman et al., 2005) and a greater incidence of hyperactivity in school-age children with long-term exposure to well water containing an average of 0.6 mg Mn/L (Bouchard, LaForset, Vadelac, Bellinger, & Mergler, 2007).
Sequential information and advice communicated to the public included statements “not to drink or cook with discolored water,” “infants and individuals with liver disease living in two well areas not to drink tap water at all” (rescinded after flushing and testing showed safe levels), and “household tap water safe for all to consume” (communicated after approximately three months of sampling and analysis, targeted unidirectional flushing, and the temporary or permanent closure of three wells). PHMDC responded to inquiries and concerns with telephone consultation, home water testing, and home visiting, if requested, by department staff for environmental inspection and nutritional counseling. The requested ATSDR health consultation, although not delivered until mid-2007, confirmed the PHMDC findings of “no apparent public health hazard (Nehls-Lowe, in press).”

**Discussion**

Establishing early on that only four of Madison's 24 wells produced water near or above the SMCL of 0.05 mg Mn/L, defining the wells' geographic service areas, and communicating that information to the public helped to reassure the majority of the city's population of the safety of their water (Figure 3). Just as importantly, it allowed PHMDC and MWU to focus assessment, communication, and remediation efforts where they were most needed. We showed that manganese concentrations and turbidity were correlated, that visibly turbid water (5 NTU and above) was likely to have manganese concentrations in excess of 1 mg Mn/L (therefore a health hazard and not to be ingested), and that the fire hydrant-flushing-standard of 1 NTU was adequate to ensure that hazardous water was not being introduced into the delivery system. This confirmed what common sense suggested: “Don’t drink dirty water.” The feasibility and value of field turbidity testing was also established.

Turbidity testing at the fire hydrant left unanswered what proportion of clear water (<5 NTU) delivered to households might, by way of precipitation and resuspension of manganese in piping systems, be excessive (>0.3 mg Mn/L). After approximately three months of intense effort by water utility field and public health laboratory personnel, resolution of this issue was achieved through analysis of a large, random selection of household tap water samples. This analysis determined the prevalence and distribution of excessive manganese concentrations in household drinking water. Fortunately, excessive concentrations were found only rarely and in no case were they persistent. Rather, they appeared to be the result of accumulated sediment at unutilized or underutilized taps, easily cleared by standard flushing.

Review of scientific literature revealed that long-term, daily exposure to manganese in drinking water at high concentrations (>1 mg Mn/L) could indeed be hazardous (Banta & Markesbery, 1977; Bouchard, LaForset, Vadelac, Bellinger, & Mergler, 2007; Konidakis, Leotsinidis, & Papapetropoulos, 1989; Wasserman et al., 2005; Woolf, Wright, Amarasiriwardena, & Bellinger, 2002). The occasional documented exposure to high concentrations of manganese in Madison's drinking water, however, did not constitute a human health hazard. Our study did not directly address exposure prior to 2006 but it did establish that local drinking water containing manganese in excess of 1 mg Mn/L is usually discolored. It is unlikely that visibly discolored water would have been regularly consumed over a period of time long enough to have resulted in adverse health effects.

The public health/water utility strategy described here was based on an intense integration of public health and water utility operations at the administrative/leadership and technical levels. The two agencies took the better part of a year to implement the strategy but did resolve Madison’s manganese issue.

**Conclusion**

The crisis of confidence in Madison’s drinking water that had been building during 2005 was dissipated during the second half of 2006 through extensive sampling and analysis of household tap water and effective communication with the public. We attribute this success to the collaborative efforts of PHMDC, MWU, and other stakeholders including concerned Madison residents. 

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