Consumers and Their Drinking Water: Communicating Water Quality and Assessing the Reaction of Zerovalent Nanoiron (nZVI) with Saliva

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ABSTRACT

Human senses for taste, odor, and visual assessment allow consumers to be selective when it comes to choosing their drinking water. In addition to wanting aesthetically pleasing water to drink, consumers want to know if their water is safe and may have misconceptions on what possible health risk contaminants could be lurking in their water supply. This thesis aimed to measure reaction of zerovalent nanoiron (nZVI) in water and human saliva, evaluate consumer's perceptions of taste, odor, and risk in their drinking water, and investigate the effectiveness of community water systems in communicating water quality information to their consumers.

Since nZVI, including commercially available Nanofer 25S, is widely being used in water treatment processes and has future potential for use in fortifying foods, the exposure to these engineered nanoparticles will increase for humans and aquatic organisms. Thus, the first part of the thesis was to develop a quantitative analytical technique to measure the iron levels at environmentally relevant concentrations. Researchers developed a colorimetric assay using 1, 10-phenanthroline as an assay to determine the amount of ferrous ions produced from different iron materials, including ferrous(II)sulfate, nZVI, and goethite. Resulting ferrous ion measurements indicate that the maximum production of ferrous ions varied among the iron materials. Nanofer25S did not undergo 100% conversion to ferrous ions, as expected, goethite had no production of ferrous ions, and ferrous(II)sulfate was 100% ferrous ions. The total iron, as measured by atomic absorption for all iron materials were equal. The reactivity of these iron materials were also assessed in different water qualities ranging in salt concentrations. The capacity to produce ferrous ion did not change when added to nanopure water, tap water, and inorganic solution that is equivalent to the high ionic strength of saliva.

Toxicology data for nZVI exposure to humans and aquatic organisms are limited. For that reason, authors of this manuscript measured salivary lipid oxidation (SLO) potential for the different iron materials in human saliva. They also developed an artificial saliva recipe to ensure repeatability and comparable results among laboratories due to human saliva's variability day by day. This simulated human saliva contained salts, proteins, and lipids. Using thiobarbituric acid reactive substances (TBARs), both Nanofer25S and ferrous(II)sulfate induced in-vitro SLO with human saliva. Goethite was unreactive. SLO results from this study have implications for flavor effects of nZVI in drinking water.

The second chapter of this thesis is assessing the clarity of message communication of Consumer Confidence Reports (CCRs). In 1998, the United States Environmental Protection Agency (USEPA) mandated that community water systems (CWSs) provide annual water quality reports to their consumers. These CCRs summarize information regarding water sources, any detected contaminants, compliance with federal regulations, and educational information. Thirty CCRs across all ten USEPA regions were analyzed for clarity using the Centers for Disease Control and Prevention's (CDC) Clear Communication Index (CCI) tool. The analysis of these CCRs was a national representation of CWSs and revealed that currently distributed CCRs performed poorly on the CDC's CCI—all failing to meet the 90% passing

mark. The overall average score for all CCRs was 50.3 ± 13.5%. The clarity scores were based on seven key areas: 1) Main message and call to action; 2) Language; 3) Information design; 4) State of the science; 5) Behavioral recommendations; 6) Numbers; and 7) Risk. Improvements in all seven areas—with the lowest average scores at 3.3 ± 18.1%, 21.7 ± 26.6%, and 37.7 ± 27.1%, respectively, for state of science, language, and main message and call to action—of the CCI will greatly improve the quality and educational capabilities of CCRs. The failing scores highlight the challenges facing CWSs in communicating water quality information. This assessment can serve as a tool for water utilities to effectively prepare and distribute information to their consumers in the future. CWSs must promote a two-way dialogue with their consumers. They should address consumer's concerns and wants in the CCRs, and they should also effectively communicate risks to the consumers so that they are not under the misconception that their water is unsafe to drink. CWSs should use the CCRs as a way to educate the public and promote drinking tap water.

The last chapter of this thesis addresses the concerns that consumers may have about their drinking water and methods that could be implemented to quickly and efficiently respond to consumer complaints and contaminants with sensory properties. Just like CWSs, consumers are concerned about their water; they are the sentinels to water quality monitoring because they are uniquely positioned at the tap. Consumers are able to detect the slightest taste, odor, and appearance in their drinking water because it is well— instinctive! Thus, consumer feedback and complaint data provided to a utility should be taken seriously and stored for future comparisons. Any consumer complaint represents a fruitful data stream that should be harnessed routinely to gain knowledge about aesthetic water quality in the distribution system. Four utilities provided consumer complaints on water quality data that were categorized and visualized using radar and run-time plots. As a result, major taste, odor, and appearance patterns emerged that clarified the issue and could provide guidance to the utilities on the nature and extent of the problem.

Consumer complaint data is valuable for water quality issue identification, but CWSs should understand that even though humans readily identify visual issues with water, such as color, cloudiness, or rust, describing specific tastes and particularly odors in drinking water is acknowledged to be a much more difficult task for humans to achieve without training. This was demonstrated with two utility groups, laboratory personnel and plant operators, and a group of consumers identifying the odor of orange, 2-MIB, and DMTS. All of the groups were able to identify the familiar orange odor. However, the two utility groups were much more able to identify the musty odor of 2-MIB; this may be due to the fact that the utility groups are more familiar with raw and finished water. DMTS, a garlic-onion odor associated with sulfur compounds in drinking water, was the least familiar to all three groups. The lab personnel group was the better describers of the odor, but the results within this group still varied significantly. These results suggest that utility personnel should be mindful of consumers who complain that their water is different, but cannot describe the problem. To reduce the inability to describe an odor or taste issue, a T&O program at a utility can be beneficial.

The safety and aesthetic characteristics of drinking water is most important to consumers. They both complement each other; if consumers think their water tastes funny, they would probably assume that is unsafe to drink. Since nZVI is increasingly being introduced into the drinking water supply, researchers must be able to understand how it reacts in humans and the environment. Additionally, CCRs would be an effective method for CWSs to communicate water quality information and address any concerns consumers may have about their water. CWSs can use implement the radar and run-time plots to identify issues in the drinking water systems. Also, T&O programs will allow CWSs and their consumers to better describe and identify the issues in their drinking water as it arises so that it can be easily addressed and alleviated. Thus, promoting communication between water utilities and their consumers will improve the relationship and instill confidence in consumers about their drinking water.

DEDICATION

This thesis is dedicated to my mother and late father:
Thank you for the all sacrifices you have made. Without your unconditional love and never-ending support, I never would have made it this far.
Through these trying years, there never was a day you didn't say, "I love you, always."
For that, I am forever indebted to you both.

Love always, your daughter.

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To all of my family and friends, I can’t even begin to express my gratitude towards your support. I thought the world was crashing down on me many times, but you guys always helped me hold it up! Thank you, I love you all!

ATTRIBUTION

Chapter 1: Nanoiron Materials: Measuring total iron and ferrous ions using the phenanthroline colorimetric assay and salivary lipid oxidation using TBARs

This research was performed exclusively by K. Phetxumphou, who wrote the chapter, which was edited by Professor Dietrich.

Chapter 2: Evaluating Clarity of Message Communication for Mandated USEPA Drinking Water Quality Reports: A national assessment

K. Phetxumphou wrote this chapter, which was edited by Professor Dietrich. The CCRs were reviewed and ranked by: Professors Davy and Dietrich and graduate students K. Phetxumphou and S. Roy. K. Phetxumphou and S. Roy jointly gathered the CCR data. Professors You, Estabrooks, Davy and Dietrich participated in designing and planning the CCR research.

Chapter 3: Systematic Tracking, Visualizing, and Interpreting of Consumer Feedback for Drinking Water Quality

K. Phetxumphou performed the odor vial descriptor research in conjunction with Professor Dietrich. They jointly wrote this section of the chapter. Dr. Gallagher performed the statistical and visual data analysis of the utility consumer complaint data; Drs. Gallagher and Dietrich jointly wrote this section of the manuscript.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1.

Nanoiron Materials: Measuring total iron and ferrous ions using the phenanthroline colorimetric assay and salivary lipid oxidation using TBARs

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ABSTRACT

Through the use in environmental remediation, humans and aquatic organisms are exposed to engineered zerovalent nanoiron materials (nZVI), like Nanofer25S. Thus, quantitative analytical techniques are needed to measure iron levels at environmentally relevant concentrations. The objectives of this research are to: 1) determine amount of ferrous ions produced from different iron materials/treatments: ferrous(II)sulfate, nZVI, and goethite; and 2) determine reactivity of iron materials to produce ferrous ions within solutions of nanopure water, tap water, and simulated human saliva containing salts, proteins, and lipids. For each iron treatment, equal concentrations of total iron were added to aqueous matrices. Resulting ferrous ions, measured using a phenanthroline colorimetric assay, showed the maximum production of ferrous ions varied among the iron materials. Nanofer25S did not undergo 100% conversion to ferrous ions, goethite had no production of ferrous ions, and ferrous(II)sulfate was 100% ferrous ions. Hence, the reactivity of iron materials could directly be correlated with the amount of ferrous ions rather than total iron. However, the capacity to produce ferrous ions did not change when added to nanopure water, tap water, and inorganic solution equivalent to the high ionic strength of saliva. Thus, inorganic water quality did not have an effect on short-term total ferrous ions production from nZVI. Since nZVI may be used in treating drinking water and fortifying foods in the future, the effects on salivary lipid oxidation (SLO) in human saliva must also be explored. Using thiobarbituric acid reactive substances (TBARs), both Nanofer25S and ferrous(II)sulfate induced in-vitro SLO with human saliva. Goethite was unreactive. Hence, the researchers developed an artificial solution to simulate human saliva that revealed comparable SLO induced using human saliva. Results from this study have implications for flavor effects of nanoiron in drinking water.

INTRODUCTION

Zerovalent Iron Nanoparticles (nZVI):

Nanoparticles (1 to 100 nanometers in size) can be naturally occurring or engineered. In nature, nanoparticles are in the air, water, and the subsurface (Wigginton et al., 2007). When nanoparticles are engineered, they are produced for several applications that range in science, technology, medicine, industries, and daily consumer products (Tsuji et al., 2009). The physical and chemical properties of nanoparticles are significantly different from larger particles of the same element (Wigginton et al., 2007). Their properties such as particle size, shape, surface area, aggregation, and dispersion properties are essential in assessing environmental and toxicity impacts and reactivity (Tsuji et al., 2009; Karlsson et al., 2009; Vikesland et al., 2007). Humans and aquatic organisms are exposed to nanoiron oxides from natural and engineered sources, and in the future, may be exposed to engineered zerovalent iron nanomaterials when used for water treatment and fortifying foods. Zerovalent iron is a species that is prone to the following redox reactions with dissolved oxygen (Reaction 1) and water (Reaction 2) (Ponder et al., 2000):

$$2Fe^{0}_{(s)} + O_{2(g)} + 2H_2O \rightarrow 2Fe^{2+}_{(aq)} + 4OH^{-}_{(aq)} \qquad (1)$$

$$Fe^{0}_{(s)} + 2H_2O \rightarrow Fe^{2+}_{(aq)} + H_{2(g)} + 2OH^{-}_{(aq)} \qquad (2)$$

Researchers are interested in the reactivity of zerovalent iron and how much Fe^0 is available in the core of the particles to form Fe^{2+} (Ramos et al., 2009). The iron oxide coating is “inert” (Ramos et al., 2009), as shown in Figure 1.1.

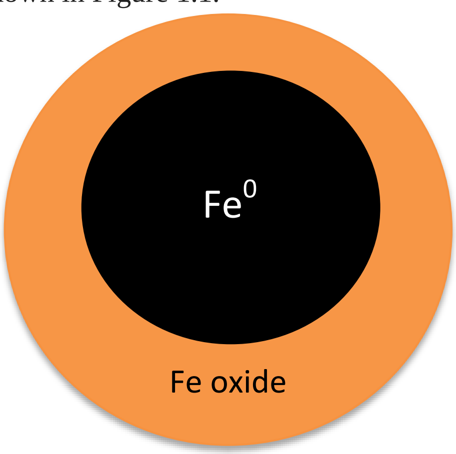

Figure 1. 1.Nano iron particle containing Fe^0 in the core and iron oxide surrounding the particle. It depicts the reduction and oxidation of iron.

Iron is the most abundant element and metal in the universe; it is an essential nutrient for humans. Iron is found in mineral ores as oxides: magnetite and hematite or bound to sulfur and carbonate: pyrites and siderites (Whyman, 1993). Other oxides of iron include goethite, akaganeite, ferrihydrite and schwertmannite and are considered “inert” (Keenan, 2009); these can exist in the aquatic environmental if they are in this stable form (Wigginton et al., 2007). It is usually in its ferrous, Fe(II), iron form in anaerobic groundwater with a concentration that ranges from 0.5 mg/L to 10 mg/L, however, concentrations as high as 50 mg/L have been reported (WHO, 2011). In surface waters, the average concentration of iron is 0.7 mg/L (WHO, 2011).

Iron oxides are naturally occurring nanoparticles and have been studied extensively in the environment. Iron nanoparticles' potential exposure to humans is unlikely because of the ubiquitous nature of iron to form oxides; once in its oxidized form of ferrous, ferric, and/or iron oxides, these iron nanoparticles are limited in mobility (Waychunans et al., 2005; Hochella et al., 2008). On the other hand, elemental iron in its reduced zerovalent form is not stable in the aquatic environment because it is highly reactive and is readily oxidized in the presence of oxygen (Keenan et al., 2009). However, more stabled engineered, zerovalent nanoiron (nZVI) particles have been produced to deal with numerous environmental issues. These applications include the removal of toxic contaminants, like nitrate, perchlorates, arsenic, hexavalent chromium, uranium, and antibiotics from drinking water, and fortifying foods (Cao et al., 2005; Fang et al., 2011; Ghauch et al., 2009; Hilty et al., 2011; Tanboonchuy et al., 2011). ZVI, and now nZVI, has wide applicability for degrading organic pollutants having electronegative atoms, such as chlorine. nZVI particles can clean up organic pollutants in ground water because they donate their electrons to the electronegative atoms, which will cause reductive dechlorination and formation of less toxic molecules (Waychunans et al., 2005; Hochella et al., 2008).

The positives of nZVI particles are their highly reductive property in removing toxic contaminants. Studies on the behavior of nZVI in the environment revealed effective capturing of surface and/or groundwater contaminants on iron oxide surfaces and its transport through drinking water systems (Waychunans et al., 2005; Hochella et al., 2008). However, this phenomenon may be a cause for major concern because the potential for toxicity to humans will also increase. A study found that nanoiron oxides were successful in binding copper contaminants from mining sites, but these compounds were found in surface waters many kilometers downstream from the mining sites (Hochella et al., 2005; Plathe et al., 2010). Additionally, another study identified samples of 20 nm particles, which contained lead and iron in its oxide hematite form, in a drinking water system (Wigginton et al., 2007; Zhao et al., 2011).

Designer engineered nanoparticles are being manufactured to enhance the mobility of nZVI. These developments involve stabilizing agents, such as surfactants, polymers, and polyelectrolytes, which raises many toxicity concerns. A study by Klimkova et al. (2010) applied nZVI to acid mine water containing a mixture of pollutants and heavy metals. The study found a significant decrease in the pollutants due to increase in pH and a decrease in oxidation–reduction potential (Klimkova et al., 2010; Roh et al., 2000), following the oxidation-reduction process: $Fe^0 + 2H^+ \rightarrow Fe^{2+} + H_2$. This process causes the precipitation of iron oxides, hydroxides, and oxyhydroxides on or close to the surface of nZVI particles (Roh et al., 2000; Phillips et al., 2003). The successful decontamination effects are promising, but this study also suggests the effects on reaction kinetics due to nZVI surface stabilizing shell. Researchers must be able to distinguish the deliverable of the Fe^0 core from the Fe oxide stabilized shell.

Nanoiron particles are valuable for in-situ remediation of aquifers with oxidized pollutants (Klimkova et al., 2008; Zhang, 2003) because it has a high reduction potential (Chen, 2010), which can cause indigenous bacteria toxicity (Chen, 2010; Diao & Yao, 2009; Xiu et al., 2010b). Bacterial effects on the gram-negative bacterium, *Escherichia coli (E. coli)*, was observed by using nZVI particles (Lee et al., 2008; Li et al., 2010; Chen, 2010); these bacterial effects were not present with other types of iron, including maghemite and F^{3+} ions (Auffan et al., 2008; Lee et al., 2008). A study by Chen et al. (2010), found that after one hour of exposure, there was 80.2% survival of *E. coli*. Additionally, gram-positive bacterium, such as *Bacillus subtilis (B. subtilis*), is highly prevalent in natural waters (Wall & Choppin, 2003). In the same study, after one hour of exposure, there was a 35.9% survival of *B. subtilis* (Chen, 2010). However, when nZVI is injected as slurry into the subsurface for ground water remediation, it will interact with natural organic matter (NOM) (Wall & Choppin, 2003) and also oxidized pollutants such as trichloroethylene (TCE) (Chen et al., 2010). The same study by Chen et al., (2010) found that in the presence of Suwannee River humic acid (SRHA), a model used for NOM, nZVI bacterial toxicity was hindered, thus, it will be important to understand the effects of NOM on bacterial and TCE degradation due to a competing process that consume Fe(0). Furthermore, this competing process suggests that greater amounts of nZVI would be needed to remediate the given TCE mass (Chen, 2010) leading to the increase need for ferrous ion measurement techniques at these environmentally relevant concentrations.

In the future, engineered nanomaterials, such as nanoiron, will be used in food and agriculture (Gray, 2010a; Derbyshire et al., 2010). There is a growing sector in introducing manufactured nanomaterials in edible products (Chaudhry et al., 2008; Beltrami et al., 2011), and nanotechnology in foods will bring new tastes, textures and sensations, less use of fat, enhanced absorption of nutrients, improved packaging, traceability, and security of food products (Beltrami et al., 2011). Furthermore, Dr. Emma Derbyshire states that, "The food industry, in particular, has the potential to play a key role in improving the utilization of iron from foods that are currently sold and using scientific and technological advances to enhance this even further (Derbyshire et al., 2010)." Iron deficiency affects 2 billion people worldwide, thus her research team believed that the food industry can help deliver bioavailable iron through foods to the public (Gray, 2010; Derbyshire et al., 2010). Hilty et al. (2011) also claims that new nanoiron compounds can allow food fortification. These researchers added magnesium or calcium to iron oxide nanoparticles by flame aerosol technology to increase solubility, which means an increase in bioavailability in humans, in dilute acid and reduce sensory changes in chocolate milk and fruit yogurts. The dark-brown color of the iron oxide is lightened with the addition of magnesium or calcium, making it possible to fortify light-colored foods, like wheat flour or extruded rice (Moretti et al., 2005; Hilty et al., 2011; Gray, 2010b). However, the risk of toxicity exposures to humans due to nanotechnology-derived foods and packaging are narrowly studied (Chaundhry et al., 2008). Thus, research on the reactivity of nanoiron particles is essential to bridge this gap of unknown effects.

Any nano iron user in the water and food industry needs a way to measure reactive irons. "One of the largest gaps that affect the investigation of the behavior of nanoparticles is the lack of quantitative analytical methods for their monitoring at environmentally relevant concentrations" (Beltrami et al., 2011). There is a need for measuring oxidized and reduced iron concentrations for the assessment of kinetics for modeling, particulate formation, and concentration changes (Faulkner et al., 1999). This method must be readily available and economically feasible when dealing with large water sample; it also must allow researchers to easily measure Fe^{o} in nZVI particles independently of iron oxides.

Salivary Lipid Oxidation (SLO):

Lipid oxidation occurs when lipids are oxidized; they can react with metals, such as iron, to form a radical that then in turn, reacts with oxygen to produce oxygenated molecules that further degrades to produce oxidative stress byproducts. Lipid oxidation is a form of oxidative stress; there is a chain reaction in which lipid oxidation involves three phases: initiation, propagation, and termination. Oxidative stress occurs when there is an imbalance between radical oxygen species and antioxidant processes in the body (Gille & Joenje, 1991). This stress damages macromolecular components of cells, such as nucleic acids, proteins, and lipids, to forms free radical species, which in turn, produces lipid peroxides (Armstrong & Browne, 1994).

Chemical species with unpaired electrons are called radicals; they are extremely unstable molecules. They are formed when covalent bonds between atoms are broken—leaving unpaired electrons (Catala, 2009). Radicals are capable of withdrawing hydrogen atoms from other surrounding molecules,

which initiates the lipid oxidation process that eventually leads to cell damage. They can be formed by mechanisms like light exposure, heat radiance, redox reactions, or transition metal reactions (Symons & Gutteridge, 1998). This research primarily focused on transition metals, such as iron, reducing oxygen to form the superoxide radical ($O_2^{\bullet-}$) according to the following reaction: $Fe^{2+} + O_2 \rightarrow Fe^{3+} + O_2^{\bullet-}$.
The superoxide radical attracts hydrogen ions and forms hydrogen peroxide (H_2O_2). According to the Fenton reaction, these hydrogen peroxide molecules can react with transition metals, such as iron as ferrous, to form a hydroxyl radical ($^{\bullet}OH$). Among the superoxide, hydrogen peroxide, and hydroxyl radicals, the hydroxyl radical is the most reactive and is believed to be accountable for the oxidation of lipids (Symons & Gutteridge, 1998).

The superoxide radical removes hydrogen atoms from lipids and forms a carbon-centered radical on the fatty acid (Gille & Joenje, 1991). The fatty acid radical then reacts with oxygen to form hydroperoxides. The hydroperoxides can react with metals such as iron to continue the lipid oxidation chain reactions (Symons & Gutteridge, 1998); these hydroperoxides species quickly decompose to form byproducts such as alkanes, aldehydes, ketones, acids, esters, and alcohols, some of which are odorous (Mallia et al., 2009; Meynier et al., 1998; Selke et al., 1977; Withycombe et al., 1971). The amount of byproducts formed ranges from picograms per liter (pg/L) to nanograms per liter (ng/L), which may seem extremely minuscule, but humans' sensory thresholds enable the byproduct detection (Fuchs et al., 2010).

Metals are known to induce lipid oxidation. The metallic odor detected when a metallic object, like when a key or penny is held, is produced by lipid oxidation of the skin surface (Glindemann et al., 2006). Lipid oxidation induced by metals has also been shown in the oral cavity of healthy humans. When one consumes ground water or tap water that contains iron and copper, it causes lipid oxidation of the saliva and epithelial cells in the mouth (Ömür-Özbek et al., 2012). A study conducted by Ömür-Özbek et al. (2012) found lipid oxidation occurring in the oral cavity of subjects after they consumed water spiked with copper and iron.

Since the 1980s, lipid oxidation have been screened and monitored using the thiobarbituric acid reactive substance (TBARs) assay; TBARs is widely used to measure oxidative stress and lipid oxidation in tissues and fluids and in drugs and foods. Additionally, malondialdehyde (MDA) is a major and stable, but odorless terminal lipid oxidation byproduct that has a visible pink tint, which is quantified in a UV-VIS spectrophotometer (Yagi, 1998). The lipid peroxidation reaction with TBARs and MDA is shown in Figure 1.2 (Shibamoto, 2006).

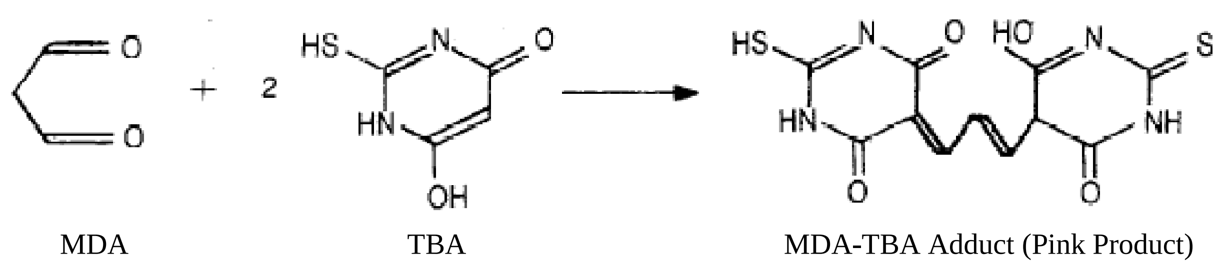

Figure 1. 2. Reaction of TBARs with MDA

The TBARs as an assay method is simple, but a time-consuming and inefficient measurement technique. It is not always an accurate measurement of MDA because other aldehydes may react with the reagent. However, it is a good indicator of oxidative stress and has effectively been used to study the effects of nutrients on free radical formation and oxidative stress on lipids (Yagi, 1998).

Lipids are naturally occurring in nature; they are organic compounds composed of fatty acids. They are insoluble in water, but are soluble in organic solvents (Defagȯ et. al., 2011). Lipids are found on the surfaces and protective layers of humans and mammal including the oral cavity, saliva, skin, digestive system, and lungs. They are also found on the outer surfaces of aquatic organisms like algae and fish and in foods such as dairy products, meats, and cooking oils.

Oral epithelial cells have fatty acids with double bonds, which are most accountable for lipid oxidation in the oral cavity. Double bonds make these unsaturated fatty acids more susceptible to attracting hydrogen atoms, which consequently, initiates the oxidation of the lipids (Symons & Gutteridge, 1998). Thus, saliva is an innovative medium to measure iron toxicity because its testing methods are noninvasive, and its collection and storage does not require expensive and extensive equipment (Defagȯ et al., 2010). Saliva also consists of two parts: 1) the organic components are lipids, from 2.4 to 80 mg/L, proteins, from 0.6 to 4.0 g/L (Larsson et al. 1996; Tenovuo 1989; Aydin 2007; Slomiany et al. 1980), and enzymes; and 2) the inorganic components are water and electrolytes such as Na^+, K^+, Cl^-, and HCO_3^- (Defagȯ et al., 2011). The electrolytes give saliva its neutral pH of 6.8 to 7.2 (Defagȯ et. al., 2011) and are dissolved in water.

The amount of lipids in whole human saliva may vary depending on dietary patterns, such as the quality and quantity of fats consumed in a diet (Defargȯ et al., 2011). Thus, researchers have reported varied total lipid concentrations. The first to quantify total saliva lipids were Mandel and Einstein (1969) at 4.8 mg/100 mL of whole saliva. Larsson et al. (1996) report total lipids at 1.3 mg per 100 ml of whole saliva. Other studies yielded higher lipid concentrations due to the method of collection and analytical techniques (Larsson et al., 1996). Researchers in this manuscript averaged whole saliva lipid studies by Mandel and Einstein (1969) due to their initial quantification of lipids in whole saliva, and Larsson et al.'s (1996) concentration due to similar secretion of whole saliva in ice-chilled tubes.

There are also lipids in aquatic plants and organisms, like algae and *Daphnia magna (D. magna),* which can be affected by nZVI in the environment. Algae are food for aquatic crustaceans, like *D. magna*, which are common food sources for fishes. Multiple studies have revealed that *D. magna* is sensitive to nZVI and can lead to immobilization or death (Albergaria et al., 2013).

Additionally, the effects of nanoiron particles in humans due to lipid oxidation in foods are unknown. Since there are lipids in foods, oxidation of lipids will be a major process that degrades and changes food quality, taste, color, and texture (Kanner, 2007). In addition, oxidation of unsaturated fatty acid can cause cytotoxic and genotoxic compounds, which are harmful to humans and animals (Addis, 1986; Kubow, 1992; Kanner, 2007). If nZVI in food fortification is promoting oxidation of lipids, there may be possible health effects as a result.

Soybean oil is used in 90% of food and is the greatest oil produced worldwide (Gunstone, 2006; Anon, 2005). It is considered the healthy oil because it is low in saturated acids and rich in polyunsaturated fatty acids. The major lipids involved in oxidation in soybeans are linoleic (53 %), oleic (23 %), linolenic (8 %), and stearic (4 %) (Leyton et al., 1987; Gunstone, 2006; Wang, 2002). Rate of oxidation is directly correlated with the degree of unsaturation, thus, linolenic is easily oxidized than linoleic (Leyton et al., 1987). Since linolenic acid is easily oxidized, it could be a problem in the food industry because of the relatively short shelf life (Gunstone, 2006). However, the concentration of linolenic is low in soybean oil. Thus, soybean oil is used for food purposes such as frying and salad oils, margarine and shortening, and mayonnaise and salad dressing (Gunstone, 2006). In the USA, 86% of all food lipids are derived from soybean oil and to put that percentage in perspective, no other oil attains a level greater than 3% (Gunstone, 2006). With the wide use of soybean oils in food lipids, it is important to recognize the oxidation behavior of its lipids.

Lipids are everywhere and can extensively be oxidized by iron materials. Increasing the use of nZVI in water treatment and fortifying foods will inadvertently affect humans and the environment. Little is known about adverse effects of nanoparticles because quantitative analytical techniques are limited in measuring the response and change in our environment (Beltrami et al., 2001). This manuscript hopes to bridge the knowledge gap and give the water and food industries a relatively easy and economically viable tool to understand iron nanoparticle reactivity and interactions.

Since nZVI particles are being widely used for water treatment and have future promises for food fortification, there also are implications of aesthetic issues in drinking water and metallic flavor in foods. To further understand the effects of nZVI on flavor and taste, researchers must understand the lipid oxidation reactivity of iron in humans, animals, and the environment. The objectives in this research are to: in the first part, 1) develop a straightforward assay to determine the amount of reactive ferrous ions that can be produced from nZVI particles of known total iron content; and in the second part, 2) to determine the reactivity of nZVI in human saliva on a total iron and ferrous ion basis; and 3) to develop an artificial saliva recipe, including salts, lipids, and proteins, that will provide comparable nZVI reactivity results across laboratories.

MATERIALS AND METHODS

Preparation of test solutions:

Preparation of iron stock solutions. Iron stock solutions were prepared before each experiment. The stock solutions were aqueous dispersions of engineered zerovalent nanoiron, Nanofer 25S (provided by from Nanoiron Ltd., Rajhrad, Czech Republic, EU), dissolved ferrous(II)sulfate (Sigma-Aldrich, PA, CAS #13463-43-g), and iron oxide material, goethite, FeO(OH), (provided by Peter Vikesland, Professor, Virginia Tech, Blacksburg, VA). According to the manufacturer, Nanofer 25S was a stabilized water dispersion of zerovalent nanoiron particles of Fe, Fe_3O_4, C and organic stabilizer.
The stock solutions were prepared by mixing the different iron materials with nanopure water, with a targeted total iron concentration of 10 mg/L in solution. Atomic Absorption Spectroscopy (Perkin-Elmer, 5100PC AAS, Waltham, MA, USA) and Inductively Coupled Plasma-Mass Spectroscopy (Thermo Electronic Corporation, X-Series ICP-MS, Waltham, MA, USA), accompanied by acid digestion, were used to quantify the total iron concentrations of each stock solution. Additionally, since pH values are important for the stability of iron in solution, the pH levels were measured for each stock solution.

Characterization of nZVI materials. The manufacturer, Nano Iron Ltd. based in Czech Republic, provided characterization information on Nanofer 25S (nanoiron particle: average particle size was < 50 nm; specific surface area was >25 m^2/g with spherical morphology; dispersion density was 1210 kg/cm). Dynamic light scattering (Beckman Coulter Inc., Zetasizer™ Nano Series, CA, USA) was used to verify the manufacturer's size distribution for Nanofer 25S; it was also used to characterize the size distribution of goethite. Size characterization of the iron materials using the Zetasizer™ required a range of 100-2000 times dilution of the solutions.

Preparation of aqueous matrices. Aqueous matrices for the phenanthroline method included: nanopure water (TDS = 0 mg/L), Blacksburg tap water (TDS = 75 mg/L), and inorganic stock solution (TDS = 3100 mg/L, equivalent to the TDS of saliva), which simulates ions in human saliva. In addition to the previous aqueous media, human saliva, soybean oil amended human saliva, and artificial saliva (including inorganic stock solution, proteins, soybean oil) were solutions for the TBARs experiments.

Constituents of human saliva mainly include ions; however, human saliva is inconsistent day by day, thus, an inorganic stock solution was developed by amending Gal et al.'s (2001), Mirlohi's (2012), and Tang's (2010) artificial saliva recipe. The inorganic stock solution included: NaCl, 0.126; KCl, 0.964; KSCN, 0.189; KH_2PO_4, 0.655; Na_2SO_4, 0.337; NH_4Cl, 0.178; $CaCl_2$, 0.155; $NaHCO_3$, 0.568 grams, which were dissolved in 1000 mL nanopure water. Calcium chloride and sodium bicarbonate concentrations were reduced by 10% from the original recipe to minimize hardness precipitation. This inorganic solution is viable until hardness precipitation from calcium and carbonates occur, which happens in approximately three days. For an artificial saliva solution, 30 mg of soybean oil and 0.54 g of mucin and 1.36 g α-amylase proteins were added to 1000 mL of inorganic stock solution. Soybean oil is the choice for lipids because of its stability for oxidization in comparison to other lipid sources like linoleic acid, which easily oxidizes in air so must be under nitrogen to complete oxidation, which is a rather tedious task (Gunstone, 2006; Leyton, 1987).

1) Phenanthroline assay to measure ferrous ion production:

Preparation of assay solutions. The phenanthroline solution is a main component of the colorimetric assay to measure ferrous iron. It was prepared by dissolving 300 mg 1, 10-phenanthroline monohydrate, $C_{12}H_8N_2H_{20}$, in 100 mL nanopure water. The prepared solution was placed on a stirring/hot plate and heated to 80˚C until all 1,10-phenanthroline monohydrate was in solution, being sure not to boil. The solution is viable until it darkens. The pH of the phenanthroline solution was 7.33. In addition to the phenanthroline solution, the ammonium acetate buffer is another main component of the colorimetric assay to measure ferrous iron. It was prepared by mixing 250 g $NH_4C_2H_3O_2$ in 150 mL nanopure water and 700 mL concentrated (glacial) acetic acid. The pH of the ammonium acetate solution was 5.47.

Development of standard curve. A standard curve is necessary to determine the total production of ferrous ion from the iron materials. A stock solution of 50 mg/L ferrous(II)sulfate stock solution was prepared; the stock solution was diluted to make standards ranging from 2 to 50 mg/L total iron. 400 uL phenanthroline and 200 uL ammonium acetate buffer solutions were added to 1 mL of each iron standard. Using a UV-VIS spectrophotometer, absorbance was read at 510 nm.

Measuring ferrous ion. Standard Methods 3500-Fe (1997) is a colorimetric assay that uses the phenanthroline complex to measure ferrous ions. This method was modified to expand the standard curve to measure ferrous from 0-12 mg/L. Light exposure was important, thus, all experimental runs were done in the dark. Using disposal cuvettes, 1,10 phenanthroline and ammonium acetate buffer were added at a 2:1 ratio with 200 uL of the buffer added first, then 400 uL of phenanthroline solution, and finally, a 1 mL sample consisting of a 1:1 dilution of aqueous media and iron treatment solution. A UV-VIS spectrophotometer was used to measure the absorbance at 510 nm; allow the orange color to develop for five minutes for nZVI and immediately color development for ferrous(II)sulfate.

2) Measuring Salivary Lipid Oxidation (SLO) using Thiobarbituric Acid Reactive Substances (TBARs):

Human subjects and saliva collection. The Virginia Tech Institutional Review Board (IRB) approved this study (IRB Project No. 06-395). Human subjects consisted of the students, faculty, and staff of VT and members of the Blacksburg community. They were recruited in person or by email and asked to donate saliva. The criteria for participation included the age of 18, no chronic oral or health problems, non-smokers, and not pregnant. The participants were required to read consent forms in accordance with the approved IRB protocols. Informed consent was given verbally by each participant.

Participants were asked to not eat or drink at least one hour prior to saliva donation. The collection process requested that subjects expectorated as much saliva as possible into 50 mL propylene tubes; the tubes were ice-chilled during the collection process. After collection, the saliva samples were kept stored in a freezer; at the end of the collection period, all saliva samples were pooled, transferred to new propylene tubes, and frozen immediately at -50˚C for up to one month until analysis. The pH levels were measured for each tube of pooled saliva samples.

Measuring salivary lipid oxidation using TBARs. The Spanier TBARs method (1991) was adjusted for aqueous samples and enabled readings at low MDA concentrations (Wang, 2009). In-vitro experiments used pooled human saliva sampled from multiple subjects, with 0% and 20% increase of lipids from normal lipids found in human saliva by adding soybean oil. Artificial saliva experiments used the artificial saliva recipe as describe earlier with inorganic stock solution, proteins, and soybean oil. The samples were prepared by combining equal volumes of saliva treatments with different iron treatments: ferrous(II)sulfate, nZVI, and goethite in 50 mL propylene test tubes. Control samples were equal volumes of nanopure water and pooled human saliva/artificial saliva in 50 mL propylene test tubes.

For each in-vitro and artificial saliva experiment, there were quadruplicates per iron treatment group and control. The test tubes were placed in a 37ºC water bath for 15 minutes to resemble the temperature and conditions in the oral cavity. After the incubation period, the samples were immediately analyzed for salivary lipid oxidation using the TBARs method, which measures iron-induced oxidative stress within the oral cavity.

RESULTS AND DISCUSSION

Measure of pH in iron treatment groups and aqueous matrices. In the three iron treatment solutions, the pH was 5.03, 6.05, and 5.11 for ferrous(II)sulfate, nZVI, and goethite, respectively. The pH for nanopure water and Blacksburg tap water were 4.36 and 7.15, respectively; the pH for the inorganic stock solution was 6.4. Normal pH levels of human saliva are found to be between 5.75 and 7.05 (Star, 1922; Clark & Carter; 1927). In this research, the pH levels in human saliva ranged from 5.56 to 6.91. With the additional of soybean oil in human saliva, the 20% lipid increase from natural saliva, the pH level was about 7. The pH for the artificial saliva used is 7.4.

Particle size of iron materials. The size distribution for the stabilized zerovalent iron suspension, Nanofer 25S, ranged from 30 to 200 nm with an average size of 87 nm (Figure 1.3), hence, the reference to nZVI for nano-sized zerovalent iron particles in this research. The iron oxide particle, goethite, however, was not considered nano-sized with an average particle size of 500 nm.

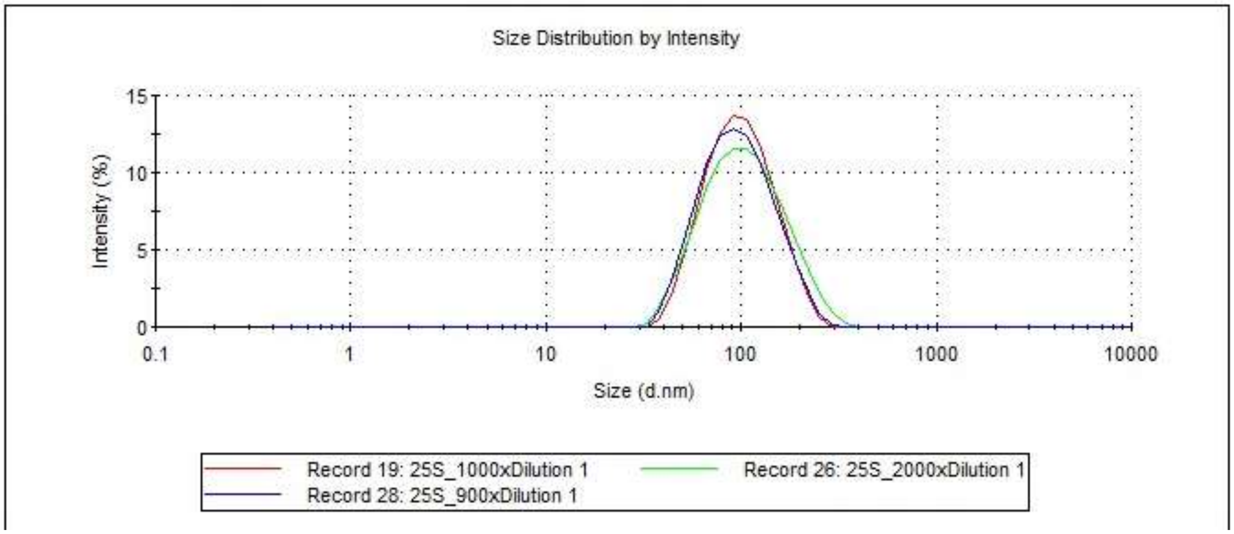

Figure 1. 3. Particle size distribution for Nanofer 25S

1) Measuring ferrous through the phenanthroline method:

Standard curve. An adjustment of the phenanthroline assay, Standard Methods 3500-Fe (1997), to fit the assay in this research was needed. As shown in Figure 1.4, the expanded standard curve was effective to ~10 mg/L Fe^{2+} due to limitation by phenanthroline's solubility. The phenanthroline did not go into solution for concentrations greater than ~3 mg 1,10-phenanthroline monohydrate per 100 mL nanopure water.

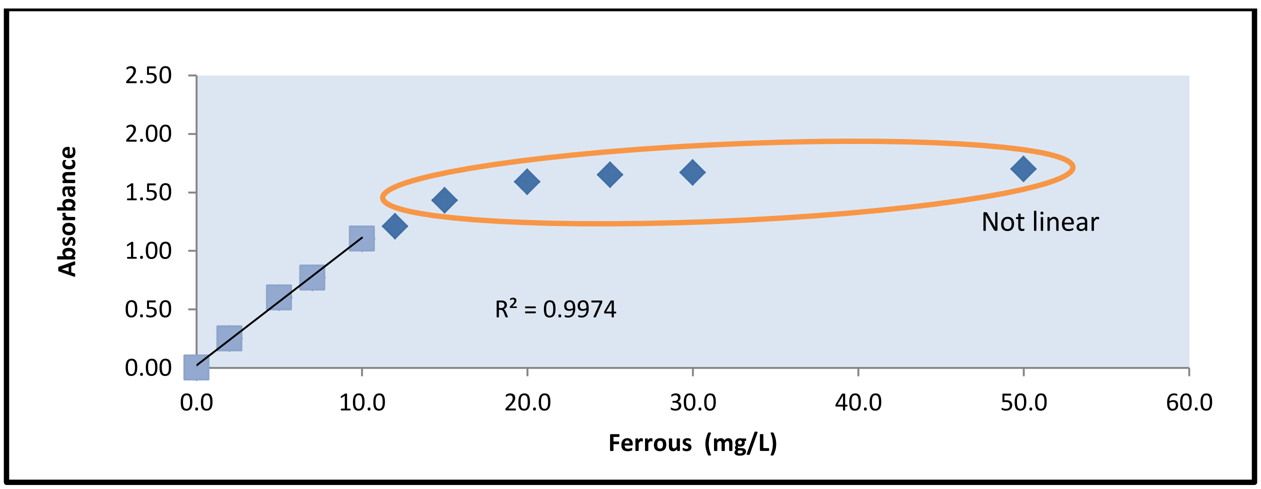

Figure 1. 4. Standard curved used in phenanthroline method

In addition to the concentration of phenanthroline, the exposure to light is a factor. All experiments must be done in the dark to prevent the photochemical reduction of ferric-phenanthroline complexes; this factor is from to the findings as discussed by Stucki (1981). Furthermore, since the samples in this research mimics oral cavity conditions and temperatures at 37˚C, experiments at temperatures below and above room temperature were needed. However, researchers found that temperatures at 15˚C and 37˚C had no significant differences or effects in the phenanthroline standard curve, thus this method is applicable at many temperatures.

Total iron can be confirmed using methods, such as HNO_3 acid digestion with AAS or Inductively ICP-MS; oxidized iron can be calculated by the difference between total and reduced iron (Faulkner et al., 1999). There is a filtration technique that separates particulate iron from soluble iron to measure both forms of iron, however, these processes are often tedious and inexact indicators in comparison to colorimetric methods (Faulkner, Gambrell, & Ashby, 1996). Stookey (1970) and Gibbs (1976) indicated that the ferrozine colorimetric assay could be used due to its interaction to form a colored-complex with ferrous and not ferric iron. However, this method requires an acid digestion step, which is not suitable for onsite analysis (Faulkner et al., 1999). Another colorimetric method to measure ferrous iron is the 1,10 phenanthroline assay used in this manuscript, which does not require acid digestion. This method can serve as a real-time analysis of reduced iron within 10 percent accuracy of ferrous measurements through ferrozine (Faulkner et al., 1999). The FerroZine® and 1, 10 phenanthroline methods are both measured using reagent packets available by the Hach Company; however, for this manuscript, researchers were able to measure higher environmentally relevant concentrations of ferrous ions at up to 10 mg/L total iron using the solution of 1,10-phenanthroline modified from Standard Methods 3500-Fe B (1997).

Measuring ferrous ion. The phenanthroline assay was used to measure the formation of ferrous ions in nanopure water. As shown Figure 1.5, by measuring absorbance levels, results for ferrous(II)sulfate show that formation of the ferrous-phenanthroline complex forms within a few seconds. However, the formation of the ferrous-phenanthroline complex for nZVI develops over time due to dissolution of Fe^0 and formation of Fe^{2+}; the total ferrous ion production levels off at about 5 minutes. The goethite did not form ferrous ions in solution as discussed further in this manuscript.

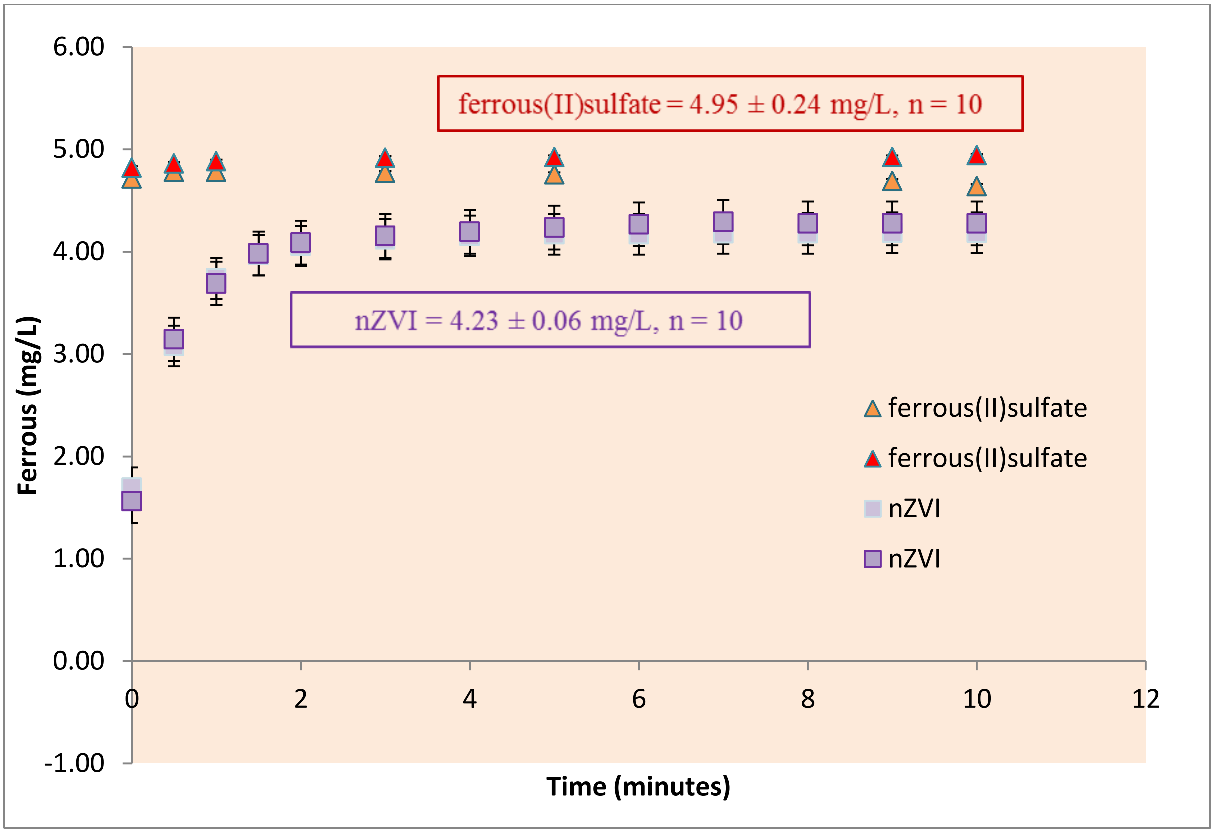

Figure 1. 5. Time for total production of ferrous ions at completion of ferrous-phenanthroline complex formations (full orange color development). Results in this graph only show 2 of 10 trial runs for each iron treatment.

The initial total iron concentrations for all iron treatments were 5 mg/L. Nanofer 25S did not undergo 100% conversion to ferrous ions as shown in Figure 1.5. As expected, ferrous(II)sulfate was 100% ferrous ions and goethite had no production of ferrous ions. Goethite is more stable and less toxic because it is already in its oxide form (Wigginton et al., 2007) and is limited in mobility (Waychunans et al., 2005; Hochella et al., 2008). Furthermore, nZVI did not undergo 100% conversion to ferrous ions like ferrous(II)sulfate because it has an iron oxide coating on the particles, as shown in Figure 1.1. By analyzing Figure 1.5 further, about 85±2% of total iron in nZVI formed ferrous ions. When authors refer to "basis by ferrous iron," it is a calculated value and they are suggesting that ~85% of the zerovalent iron in nZVI particles are forming ferrous ions and the remaining is in the oxidized form. Thus, the concentration of zerovalent nanoiron forming ferrous ions would be equal to ferrous(II)sulfate forming ferrous ions on a ferrous iron basis.

These results are important because researchers using nZVI in their experiments may be misinterpreting their data. Their results for the reactivity are often based on total iron and not ferrous ions available for reacting. Keller et. al (2012) analyzed the toxicity of ferrous(II)sulfate and nZVI to *D. magna* survival; they found that nZVI was more toxic than ferrous at low total iron concentrations. Their data, as expected, showed that Fe^{3+} had less harmful effects on the toxicity to zooplankton. However, daily survival data did show that *D. magna* experienced significant die offs for both nZVI and ferrous at concentrations approximately equal to 1 mg/L total iron between 24-48 hours exposure time. These results are not based on ferrous ions availability, which is the form that would be most toxic to *D. magna*, but on the initial total iron, which could lead to skewed results.

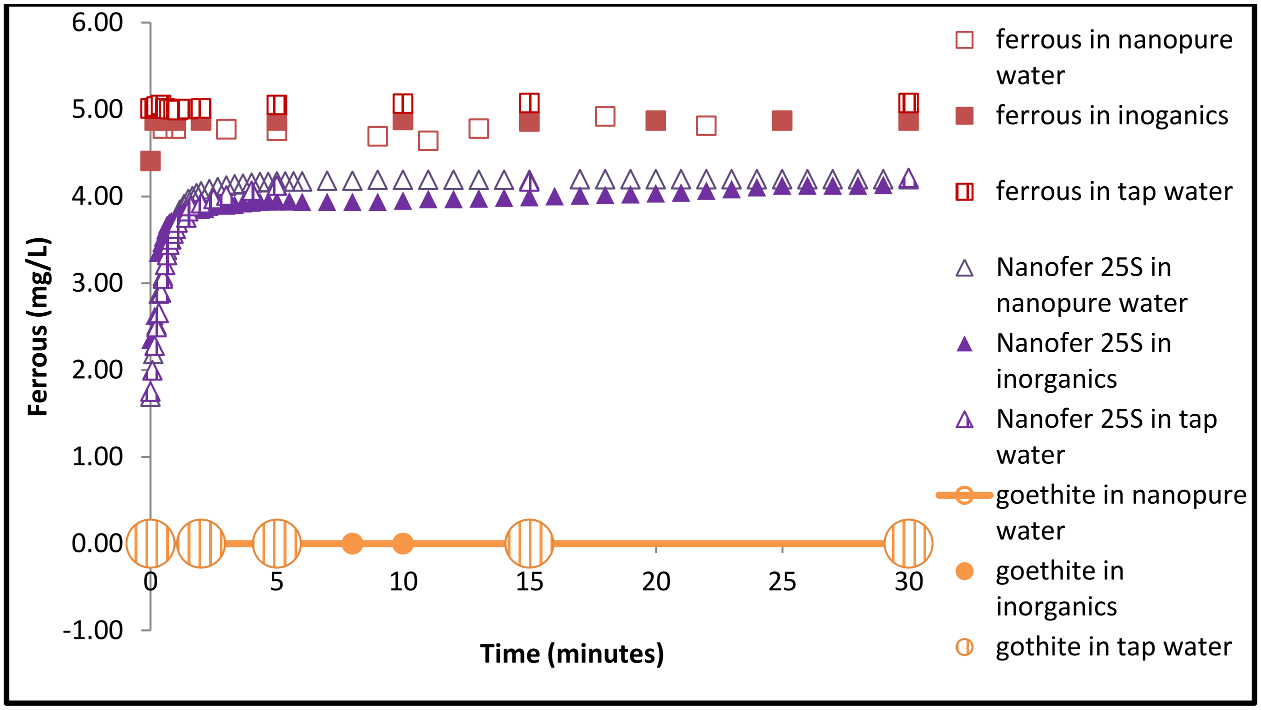

Figure 1. 6. Total production of ferrous ions from different iron treatments in nanopure water, Blacksburg tap water, and inorganic stock solution.

Although the total production of ferrous ion varied for the iron materials, the capacity to produce ferrous ions did not change when added to different aqueous matrices: nanopure water, tap water, or water containing the salts representative of saliva. Thus, inorganic water quality did not have an evidential effect on total ferrous ion production even though the form of iron material did. The results for the iron and aqueous media treatments are also shown in Figure 1.6.

2) Salivary lipid oxidation by TBARs:

SLO in-vitro experiments. Since nanoiron particles may be used in the treating drinking water and fortifying foods in the future, it is important to understand how these particles will react in the human mouth. Human saliva naturally contains approximately 3 mg total lipids per 100 mL of whole saliva (Defagò, 2010; Larsson et al., 1996). Metals induce salivary lipid oxidation (SLO) in the oral cavity when humans consume water containing metallic particles (Ömür-Özbek et al., 2012). The purpose of this experiment was to measure the ability of iron materials to induce SLO. Additionally, soybean oil, serving as an additional lipid source, was added at 20% increase in lipids from the concentration normally found in human saliva in order to enhance the oxidation of lipids by iron materials. Results show that ferrous(II)sulfate induced greater SLO than nZVI (Figure 1.7) on a total iron basis. However, on a ferrous iron basis, the trends suggest that nZVI induces more SLO. Unfortunately, the known variability (Buenger et al., 2006) in TBARs created large error bars for the data and a two-way ANOVA analysis did not reveal a statistical difference.. As expected, goethite did not induce SLO, even with additional lipids present.

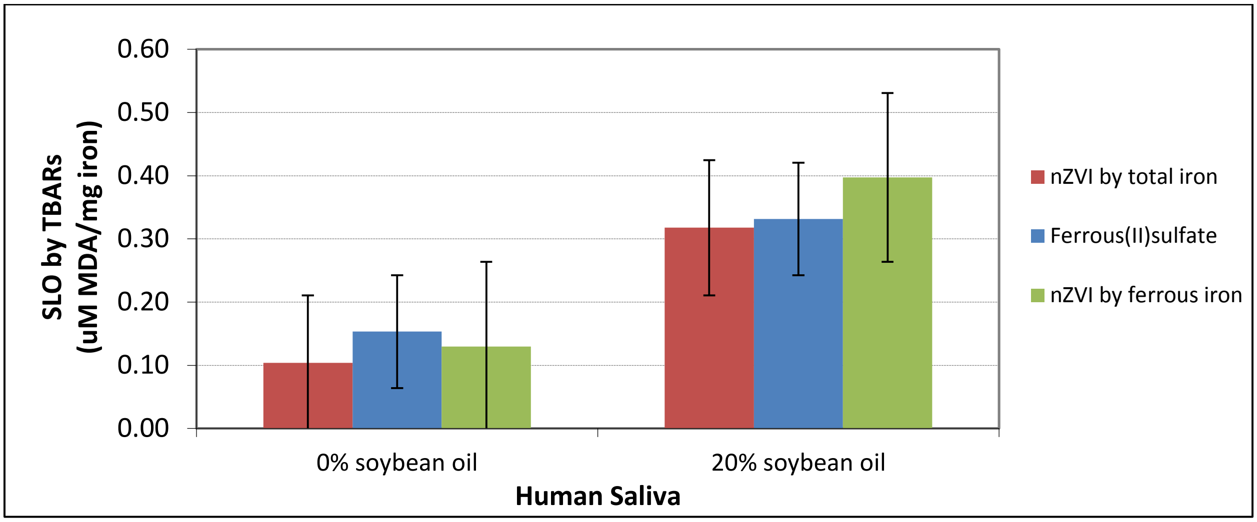

Figure 1. 7. SLO by ferrous(II)sulfate and nZVI in human saliva with 0% and 20% lipid (soybean oil) increase from normal whole human saliva. The control has been accounted for.

The increase in lipids using soybean oil increased SLO and had the same trends for both iron treatments; using a two-way ANOVA analysis, the p-value was equal to 0 between human saliva (0% soybean oil) and lipids (20% soybean oil) added to human saliva. These results reveal that soybean oil is an acceptable substitute for lipids in saliva for measuring SLO.

The data reported in Figure 1.7 is also based on zerovalent iron forming ferrous ions on a ferrous iron basis. Unlike the total iron basis, SLO by nZVI was higher than ferrous(II)sulfate for 20% lipid increase treatments; however, due to TBARs' variability, they were not statistically different using a two-way ANOVA analysis. These SLO values suggest the same findings as the measurement of ferrous ion production through the phenanthroline method. Approximately 85% of the nZVI is available for ferrous ions production in solution, thus, even if the iron treatments all start off at ~5 mg/L total iron, the portion of nZVI to form ferrous ions is ~20% less than ferrous(II)sulfate.

SLO by iron in different aqueous media. Different aqueous solutions were used: nanopure water, Blacksburg tap water, and inorganic stock solutions with proteins and lipids. Equal volumes of each aqueous media with each iron treatments were mixed. Total iron concentrations in each iron treatment stock solution were 5 mg/L. Samples were analyzed for SLO. Even though the type of iron treatment affects SLO, based on total iron, using a two-way ANOVA, there were no statistical differences for both ferrous(II)sulfate and nZVI in nanopure water, tap water, and inorganic stock solution (p-value=0.934 for tap water and inorganics; p-value=0.705 for nanopure water and tap water; and p-value=0.995 for nanopure water and inorganics). Thus, inorganic water quality with the absence of proteins and lipids does not have an effect on ferrous ion production. Goethite did not induce SLO in these aqueous matrices.

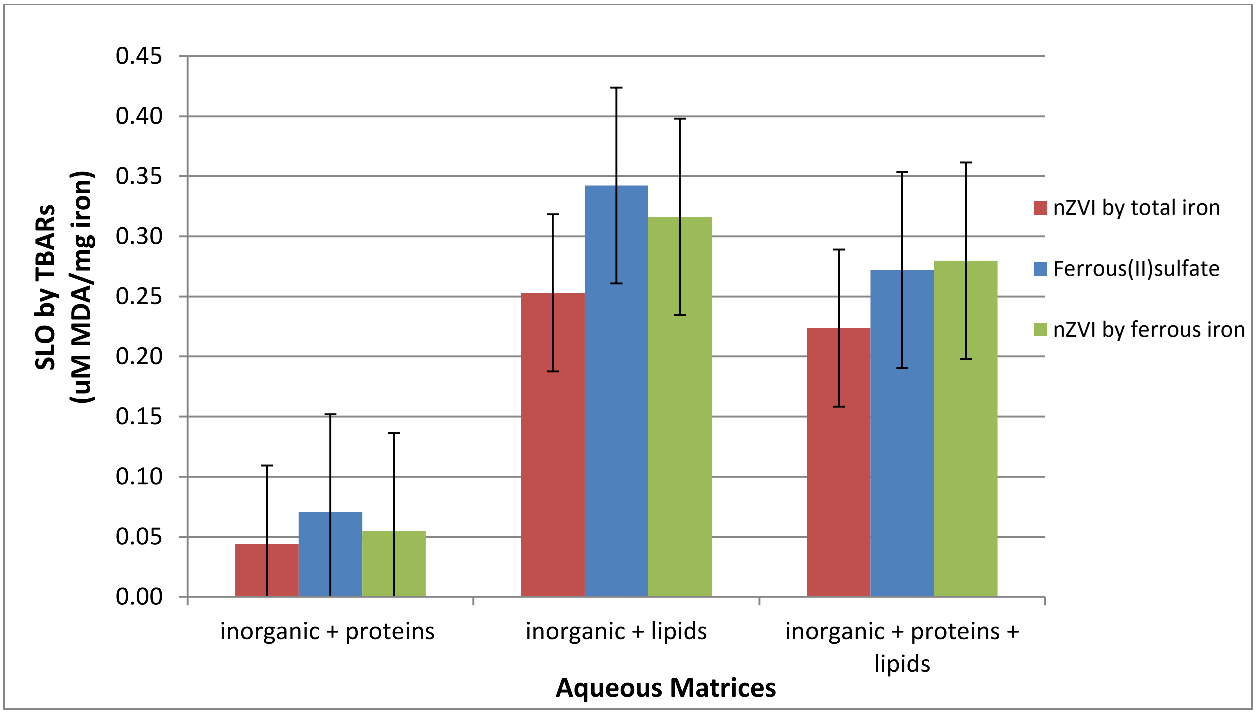

Figure 1. 8. SLO by ferrous(II)sulfate and nZVI on a total iron basis in inorganic stock solution with proteins lipids. The control has been accounted for.

For ferrous(II)sulfate, nZVI by total iron, and nZVI by ferrous iron, there were statistical differences between inorganics with proteins and inorganics with lipids (two-way ANOVA; p-values=0, <0.001, and 0 for each iron treatment, respectively); there were also statistical differences between inorganics with proteins and inorganics with proteins and lipids (p-values= <0.001, <0.001, and <0.001 for each iron treatment, respectively). For ferrous(II)sulfate, nZVI by total iron, and nZVI by ferrous iron, there were no statistical differences between inorganics with lipids and inorganics with proteins and lipids (p-values=0.106, 0.979, and 0.889 for each iron treatment, respectively). The perceived differences in Figure 1.8 between these aqueous matrices may be due to the variability in TBARs measurements; there may also be competition for iron in the presence of both proteins and lipids.

Inorganics plus proteins and lipids simulate human saliva because those components are the major constituents in human saliva. The measurement of SLO by ferrous(II)sulfate and nZVI in inorganics with proteins may be affected by iron-protein carboxylation as discussed in the study by (Ömür-Özbek et al., 2012). It is expected for the inorganic solution containing both lipids and proteins to induce SLO, as shown in Figure 1.8, with ferrous(II)sulfate statistically inducing more SLO than nZVI on a total iron basis (two-way ANOVA; p-value=0.002). However, SLO induced in artificial saliva was also analyzed on a ferrous ion basis for both iron treatments. Results suggest that, when adjusted for ferrous iron, nZVI and ferrous(II)sulfate will induce statistically comparable SLO concentrations (two-way ANOVA; p-value=0.324). The high p-value also suggests that ~85% of nZVI form ferrous ions in comparison to ~100% of ferrous(II)sulfate forming ferrous ions.

CONCLUSIONS

1) Measuring ferrous ion through the phenanthroline method:

The phenanthroline method developed in this research determined that the maximum production of ferrous ions varied among the iron materials. Approximately 85% of nZVI Nanofer25S formed ferrous ions in solution, thus, the reactivity of iron materials could directly be correlated with the amount of ferrous ions formed rather than total iron present in the material. The capacity to produce ferrous ions did not change when added to aqueous matrices with varying TDS concentrations for nanopure water, tap water, and inorganic stock solution. Thus, inorganic water quality does not have an effect on total ferrous ion production measured by the phenanthroline assay. Results from this study have implications for evaluating the effectiveness of nanoiron and correlating it to ferrous ions reactivity.

2) Salivary lipid oxidation by TBARs:

On a total iron basis, ferrous(II)sulfate induced more SLO than Nanofer25S; goethite, as expected, did not induced SLO. However, on a ferrous iron basis, the results suggested that 85% of nZVI particles, as in the phenanthroline method, induced SLO comparable to ferrous(II)sulfate. Nanopure water, tap water, and the inorganic stock solution did not induce SLO due to the absence of lipids. Data also show that soybean oil is a suitable substitute for lipids in human saliva; thus, the artificial saliva recipe developed in this manuscript is applicable to future nZVI studies in human saliva.

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CHAPTER 2.

Evaluating Clarity of Message Communication for Mandated USEPA Drinking Water Quality Reports: A National Assessment

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ABSTRACT

The United States Environmental Protection Agency (USEPA) mandates that community water systems (CWSs) provide annual Consumer Confidence Reports (CCRs), also known as water quality reports, to their consumers. These CCRs summarize information regarding water sources, any detected contaminants, compliance with federal regulations, and educational information. This research investigated the readability and understandability of thirty CCRs released between 2011 and 2013 across all 10 USEPA regions. The evaluation was based on health communication clarity using the Centers for Disease Control and Prevention's (CDC) Clear Communication Index (CCI) tool. Results revealed that all CCRs performed poorly on the CCI by failing to meet the overall 90% qualifying mark. The overall average score for all CCRs was 50.3 ± 13.5%. Even though all sampled CCRs rated below passing, the CCI can serve as a tool for water utilities to effectively prepare and distribute information to their consumers in the future. Improvements in all seven areas of clarity—with the lowest average scores at 3.3 ± 18.1%, 21.7 ± 26.6%, and 37.7 ± 27.1%, respectively, for state of science, language, and main message and call to action—of the CCI will greatly improve the quality and educational capabilities of CCRs. This national CCR assessment highlights the accents and challenges currently faced by water utilities to effectively communicate public health issues to the public.

INTRODUCTION

Congress amended the Safe Drinking Water Act in 1996, requiring all community water systems (CWSs) to provide annual water quality reports to their consumers (United States Environmental Protection Agency [USEPA], 1999). As a result, in 1998 the Consumer Confidence Report (CCR) Rule was published in the Federal Register; this rule required that CWSs distribute, by July 1st of every year, information regarding their source of water, level of any detected contaminants, compliance with drinking water rules, and other educational information to their consumers (USEPA, 1999). The USEPA Fact Sheet (2009), Appendix 2.1, further lists the major provisions that must also be included in the CCR.

CWSs, often called water utilities, may directly serve consumers or supply wholesale water to other water utility retailers. In the former case, water wholesalers are then responsible, unless a contractual agreement discusses otherwise, for providing retailers monitoring data and any other critical information for the drafting of a CCR by April 1st of every year (USEPA, 1999). Retailers must then prepare and deliver annual water quality information if they provide at least 15 service connections for year-round residents or regularly serve at least 25 residents year-round (USEPA, 1999).

Even before the initial implementation of CCR in 1999, there have been many studies on the need for water quality information (Meyer-Emerick, 2004). A nationwide study by Sarch-Roper (1999) found consumers wanted more information about their tap water and if received, will read the information (Benson et al., 2002; Meyer-Emerick, 2004). A CWS in Connecticut even released a voluntary water quality report and collected surveys before and after the release. They concluded that consumers were 2.4% more satisfied with their water supply as a result of the voluntary CCR release (Odugbesan et al., 1998).

According to the USEPA (2002), the purpose of the CCR Rule is to: "Improve public health protection by providing educational material to allow consumers to make educated decisions regarding any potential health risks pertaining to the quality, treatment, and management of their drinking water supply." As a result of the CCR Rule, public health related benefits would include (USEPA, 2009):

- "Increased consumer knowledge of drinking water quality, sources, susceptibility, treatment, and drinking water supply management.
- Increased awareness of consumers to potential health risks, so they may make informed decisions to reduce those risks, including taking steps toward protecting their water supply.
- Increased dialogue with drinking water utilities and increased understanding of consumers to take steps toward active participation in decisions that affect public health."

Bob Perciasepe, the USEPA assistant administrator for water, saw the "CCR as a door through which consumers can reach other information about their drinking water." He also stated that, "This is not a burden, but more so, an opportunity" (Berberich, 1998). Consumers often do not know where their water comes from, thus, the CCR is a chance for CWS to market themselves and improve public's confidence in water quality. CWSs should be able to communicate to consumers how they provide safe and pleasing drinking water, and it also is an opportunity to provide educational resources (Berberich, 1998). Since the CCR is considered a public health communication report, its main message should be easily conveyed and understood for all consumers.

People are interested in their drinking water quality. In 2001, through a National Consumer Water Quality Survey of over 1,000 adults, the Water Quality Association discovered that 86% of those adults had concerns regarding their drinking water quality, but only 17% of them had even received or read their CWS's CCR (Means et al., 2002). With such high desires for drinking water information, CWSs must ensure that their consumers are receiving and understanding their CCRs because data have shown that it can have positive effects on public perception. The rewards will go unclaimed if consumers do not recognize that this type of document even exists. In 1999, Benson et al. (2002) conducted surveys on the initial CCR released by 34% of Nevada's CWSs. Their study reported only a slight increase in consumer inquiries after the CCR release. Many utilities, however, were concerned about the lack of inquiries and suggested that the consumers were either unable to read and comprehend the information fully in the CCR or they were just ignoring the document completely (Benson, 2002). CCRs must be appealing to the public and importance must be place on the document or else it would be overlooked.

There do exist many barriers in communicating risk to the public; these barriers are due to the simple fact that human risk perceptions are complicated (Slovic, 1987), especially the highly technical information found in CCRs. Perceptions are persuaded and skewed by "difficulties in understanding probabilistic processes, biased media coverage, misleading personal experiences, and the anxieties generated by life's gambles" (Slovic, 1987). Research on risk perception suggest that barriers to communicating risk about drinking water in CCRs include: "public awareness of water contamination incidents, the public's general distrust of government and experts, the subjective nature of risk perception, and inability for consumers to understand scientific information" (Meyer-Emerick, 2004). In fact, there are several definitions to risk communication. Leiss (1996) defines risk communication as, "the flow of information and risk evaluations back and forth between academic experts, regulatory practitioners, interest groups, and the general public." Whereas, Bier (2001) defines it as, "an art rather than a science because despite a voluminous amount of literature, it has yielded few definitive empirical results" (Meyer-Emerick, 2004). This entanglement of definitions is due to the difficulty in communicating multiplicity of risks, in different ways, through experts with various skills to publics with unique backgrounds and ways of thinking (Bier, 2001; Meyer-Emerick, 2004).

Furthermore, there is a lack of trust in CWSs from the public for several reasons. As Meyer-Emerick (2004) states, "Personal experiences or media coverage can cause distrust in tap water and water utilities." And as Bishop (2003) says, "News releases are unpredictable and uncontrolled communication tool because reports or editors in the news media may edit the release or change them substantially, or not publish them at all." Tversky and Kahneman (1984) found that bottled water advertisements can cause "availability heuristic," which causes the public to wonder why bottled water is such a predominant process for drinking water supplies and could therefore, believe that there are potential issues surrounding the tap drinking water industry. People use taste and odor as indicators to safe drinking water. It is human intuition to avoid products that are unpleasant (Jardine et al., 1999). Hence, when consumers experience bad tasting and off-colored looking tap water, it automatically affects their perception of tap water and shapes their drinking water behavior (Renn, 1991; Dietrich, 2006).

Results from the lack of trust of CWSs from consumers also mean lack of funding. Lack of public trust is detrimental to water utilities (Meyer-Emerick, 2004) because it hinders attainable funds for infrastructure maintenance and more extensive treatment to protect public health (Meyer-Emerick, 2004). Jardine et al. (1999) advise that, "Because water utilities must ultimately depend upon their consumers to finance improvements in their systems, this trend signals future difficulties for water utilities unless they can reduce the apparent continuing erosion of consumer confidence in the quality of public drinking water supplies." Furthermore, research found that CWSs' efforts to improved quality of drinking are not translating to public confidence in their water providers (Jardine et al., 1999). McGuire (1995) may attribute this lack of public's confidence due to CWSs' lack of effective risk communication. He says that even if individuals call utilities to complain about their water, they may be told, "Yes, the water is cloudy and off-color, but it's still safe to drink." Even if a CCR or water utility representative claims that the water is safe, they are unlikely to convince consumers to drink it (Meyer-Emerick, 2004). Thus, CCRs can serve as tool to better communicate health information to the public and should also be used to address any concerns that public may have. If the public are aware of such initiatives and fully understand the water quality issue, they will be more supportive in water quality improvements (Meyer-Emerick, 2004). With increased funding, there could be increased water quality improvements.

In 2013, the CDC developed the Clear Communication Index (CCI) as a research based tool for preparing effective and clear health communication materials for the public (CDC, 2014). "The Index supports the efforts of the CDC to comply with the Plain Writing Act of 2010 and achieve goals set forth in the National Action Plan to Improve Health Literacy and the CDC Action Plan to Improve Health Literacy" (CDC, 2014). The CCI scoring has 20 questions (Appendix 2.3) and is a subjectively determined assessment tool with scores awarded in the following seven key areas (CDC, 2014): 1) Main message and call to action; 2) Language; 3) Information design; 4) State of the science; 5) Behavioral recommendations; 6) Numbers; and 7) Risk. The questions serve to enhance clarity and aid people's understanding of information (CDC, 2014). The scores from each Index were tallied to obtain an overall score (out of 100%) with scores =100% considered "perfect" and scores $\geq$ 90% considered "passing." The goal of the CCI is to improve the clarity of communication products, thus, based on research, the CDC believes that a total score of 90 or above will address most items needed to make materials easier to understand and use (CDC, 2014).

Are CCR written in a way that is clear and comprehensible to Americans and effectively communication water quality risks?—that is the major question needing an answer. According to the USEPA (2012) through the CCR Rule Retrospective Review Summary, "Stakeholders identified five areas in the CCR Rule in which the USEPA could potentially improve the effectiveness of communicating drinking water information to the public or reduce the burden of community water systems and primacy agencies." The number one area was: "1. CCR understandability" (USEPA, 2012). Consequently, the objective in this research was to assess the clarity of message communication of CCR that were issued by drinking water utilities using the Center for Disease Control and Prevention's (CDC) Clear Communication Index (CCI) tool.

MATERIALS AND METHODS

Selection of CCR. Three water utilities for three size categories were selected for each USEPA region. The USEPA has 10 set regions as shown in Figure 2.1. Size categories for utilities are based on the population served: medium (3,301-10,000); large (10,001-100,000); and very large (100,000+). The populations were confirmed through the USEPA's (2014b) and water utilities' websites or telephone conversions with utility personnel. Thus, the total number of water utilities sampled for this project was 30. The respective CCRs were selected from years 2011-2013 and obtained through the USEPA's (2014b) and CWSs' web pages. Additionally, high school completion rates and bachelor's degree statistics were obtained through the United States' Census Bureau (2014) website and based on available 2008-2012 census data.

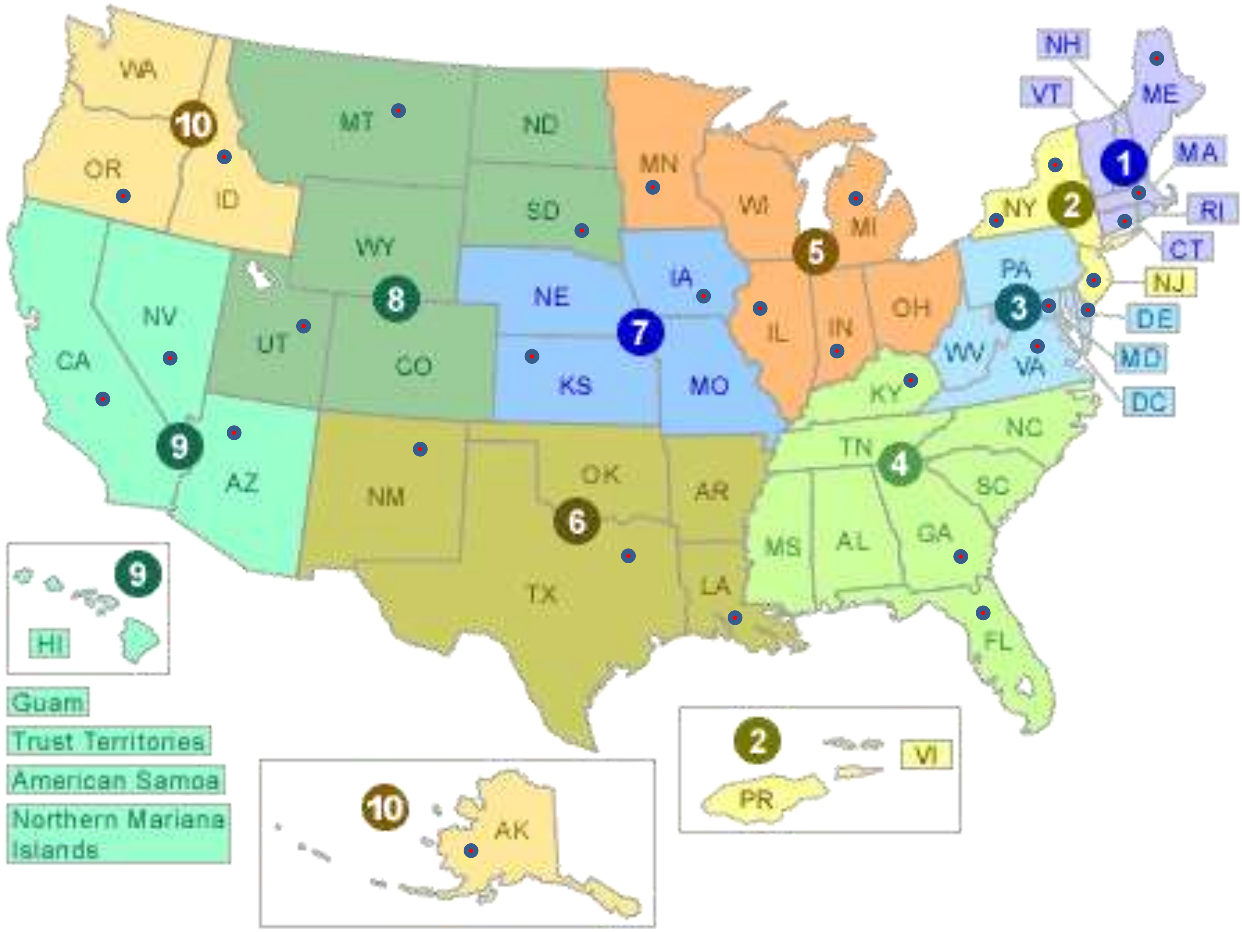

Figure 2. 1. Map of USEPA regions (USEPA, 2014a). Note that the dots are the states in which the selected CCRs are located.

Assessing clarity. Two of four CDC-CCI-trained researchers with expertise in health and/or water chemistry and quality evaluated every report independently. An environment engineer rated all 30 CCRs; the other rater was either an environmental engineer or a health scientist. The health scientists have an interest in water quality and no formal training in environmental engineering or science. The training included a two-hour session with Dr. Cynthia Baur who is from the CDC and helped developed the CCI tool. During this session, the researchers were asked to score two reference health documents individually. Afterwards, the documents were reexamined as a group with Dr. Baur leading the discussion to determine the correct evaluation techniques. Researchers were also able to ask questions that directly pertained to CCR documents, and a master cover sheet, as shown in Appendix 2.2, for all CCR evaluations was created and circulated to all raters. Additionally, the research group evaluated a CCR both individually and as a group and discussed methods for scoring and interpreting the information. The practice CCR scoring was instrumental in serving as a basis for comparison and consistency among raters across all CCRs.

The CCI scoring has 20 questions (CDC, 2014) with seven key areas: 1) Main message and call to action; 2) Language; 3) Information design; 4) State of the science; 5) Behavioral recommendations; 6) Numbers; and 7) Risk. The scores from each Index were tallied to obtain an overall score (out of 100%) with scores =100% considered "perfect" and scores $\geq$ 90% considered "passing."

The USEPA does not require that the CCR state directly whether or not the water is safe to drink. Thus, as another research method, the question, “Is the water safe to drink according to all state and federal standards and regulations?” was assessed for all CCRs. This question addressed whether the CCR effectively communicated to consumers the main health message based on reported drinking water quality information.

RESULTS AND DISCUSSION

Summary statistics for population served by the 30 CCRs. The range of completion for high school education for the 30 CCR sampled was 67.1% to 92.9%, with a median at 84.3%. Population range for bachelor’s degree education for those 25 years or older was 9.3% to 59.8%, with a median at 23.1%. In 2010, the national average for high school completion was 74.7% (Yoshida, 2013), and 15.1% of adults over 25 years old held a bachelor’s degree in 2010 (U.S. Census Bureau, 2012).

Clarity of message communication. With an exception of two CCRs, the rater scores were within 15% of each other. Unfortunately, all CCRs performed poorly on the CDC’s CCI, failing to meet the recommended 90% overall scoring qualifying mark. As shown in Figure 2.2, the range was 23.4± 4.7% to 71.8± 4.9%, with a median score at 50.5± 13.5% and an average of 50.3 ± 13.5%:

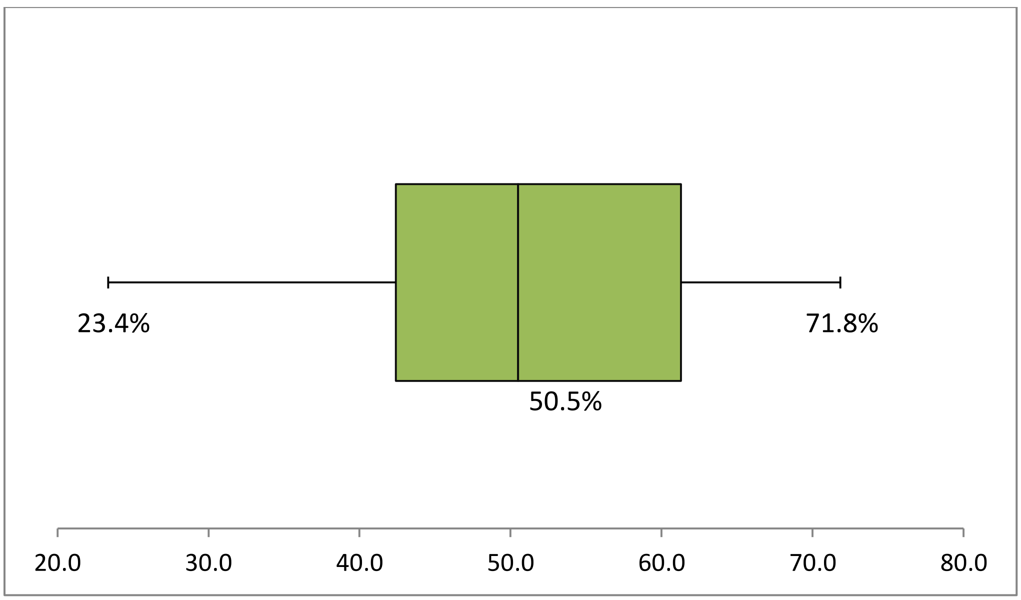

Figure 2. 2. Range of clarity of message communication scores for the 30 sampled CCRs

Utility size effect on clarity of message. The overall clarity scores for medium and large size utilities were at 49.2 ± 14.6% and 45.8 ± 17.5%, respectively, as shown in Table 2.1. The very large utilities had the highest score for all sampled utilities at 55.8 ± 9.4%. However, a one-way ANOVA (p-value = 0.582) indicated that there was no significant difference for overall clarity ratings for the medium, large, and very large utilities.

According to the data shown in Table 2.1, the average number of pages was 6.2 ± 6.1 for the 30 sampled CCRs, and 53% had pictures/images and 63% had color. CCRs from very large CWSs were all printed in color and had more pages and pictures/images than large and medium water utilities. The format difference among medium and large CWSs versus very large CWSs may be due to staff and financial capacities. Bishop's (2003) study saw a correlation between "larger utilities being more likely to have a communication officer, use a wider range of media techniques, and use public outreach, electronic communication, participatory techniques, and personal contact than smaller CWSs." Larger utilities tend to use a wide range of communication methods, promote public outreach, electronic communication, participatory techniques, and personal contact (Bishop, 2003); this may be due to more communication professionals on staff and more funding available to print images and color in CCRs. However, even though 87% of CWS in the U.S. are small systems and lack the benefits of larger CWS, utility managers should step in to the role of experts in determining the type of water quality the public will fund and other water quality communication decisions (Anadu & Harding, 2000). There must be a two-way dialogue between the utilities and public about water quality communication no matter the size or financial capacity of the CWS.

Table 2. 1. Formats of CCRs according to pages, images/pictures, and color and overall CCI scores

Parameter	Medium CWSs (n=10)	Large CWSs (n=10)	Very large CWSs (n=10)	All CWSs (n=30)
Average Number of Pages	4.7 ± 2.5	6.9 ± 8.9	7.1 ± 5.5	6.2 ± 6.1
CCRs with Images/pictures	30%	60%	70%	53%
CCRs with Color	30%	60%	100%	63%
Overall CCI Score	49.2 ± 14.6%	45.8 ± 17.5%	55.8 ± 9.4%	50.3 ± 13.5%

Clarity index scores. The average scores for the seven key index areas were poor throughout all areas. As shown in Table 2.2, behavioral recommendations scored highest at 76.7 ± 35.5% with the state of science scoring the lowest at 3.3 ± 14.9%. The information design index was second highest, followed by risk, numbers, main message and call to action, and language, decreasing in performance, respectively. There were no statistical difference among the utility sizes for 1) Main message and call to action; 2) Language; 3) Information design; 4) State of the science; 6) Numbers; and 7) Risk, with p-values= 0.582, 0.473, 0.566, 0.609, 0.135, and 0.231, respectively. The only index that was statistically different (p-value=0.041) among utility sizes was 5) Behavioral recommendations with very large utilities at 91.7 ± 23.9% performing better than medium and large utilities at 76 ± 37.6% and 61.7 ± 44.9%, respectively. The raters noted that most large utilities had pages or sections dedicated to water conversation and piping infrastructure behavioral recommendations.

Table 2. 2. Index scores for the seven key areas

Key Index Areas (# of points per area, total = 19)	Index Ratings (%)			
	Medium CWSs Performance (n=10)	Large CWSs Performance (n=10)	Very large CWSs Performance (n=10)	All CWSs Performance (n=30)
1. Main Message and Call to Action (5)	38.0 ± 26.7%	33.0 ± 27.0%	42.0 ± 28.2%	37.7 ± 27.3%
2. Language (2)	17.5 ± 24.5%	20.0 ± 25.1%	27.5 ± 30.2%	21.7 ± 26.6%
3. Information Design (3)	56.7 ± 26.7%	56.7 ± 36.0%	65.0 ± 20.2%	59.5 ± 27.6%
4. State of the Science (1)	0.0 ± 0.0%	5.0 ± 22.4%	5.0 ± 22.4%	3.3 ± 14.9%
5. Behavioral Recommendations (3)	76.7 ± 37.6%	61.7 ± 44.9%	91.7 ± 23.9%	76.7 ± 35.5%
6. Numbers (3)	40.0 ± 17.4%	46.7 ± 22.7%	35.0 ± 13.1%	40.6 ± 17.7%
7. Risk (2)	40.0 ± 41.7%	37.5 ± 45.5%	60 ± 47.6%	45.8 ± 44.9%

There was consistency across all CCRs as to why they ranked poorly according to the seven categories of the CCI. A summary of reasons why the CCRs ranked poorly is given below.

1) *Main message and call to action: Does the CCR have one obvious main message in the top, beginning, or front of the material and emphasized with visual cues? Also, does it include call(s) to action?*

CCRs typically cover four major areas—source water type, water quality, compliance with federal regulations, and educational information—and do not highlight one area as the "main" message. Although, the authors believe the main message should be whether the water is safe to drink according to state and federal regulations. The main message design should be at the top, beginning, or front of the CCR and emphasized with visual cues and graphics and identifiable without little effort from the reader. The call to action must also be after the main message. If the water is safe to drink, consumers should be able to read a prompt where they can call or go to get more information if they have any questions. If the water has any violations, there should be information on where to go for further details and what other implications are associated with the violation, i.e. health effects, and when should one should seek medical attention or where can one go to get their water tested etc.

Even if CWS did not perform well and violated federal standards, they should not be hesitant to report the findings because consumers need to know such things. Bishop (2003) states that, "Many water suppliers must communicate negative, unpleasant, or unwelcomed information regarding such developments as rate hikes, conservation measures, pollution of water sources, violations of maximum contaminant levels (MCLs), expensive infrastructure projects, and management or ownership changes." CWSs must realize that it is way better to communicate the bad news from the source itself rather than allowing it to get out another way, which will always happen (Berberich, 1998). The goal is to build confidence in the public and a first step is to not hide anything. Water utilities can be successful in communicating information to their stakeholders through 10 principles of authentic communication: communication must be truthful, fundamental, comprehensive, relevant, clear, consistent, accessible, timely, compassionate, and allow feedback (Bishop, 2003). Some people may be interested while others are not, but there should be a happy medium where there is ample information for the interested group and highlighted important messages in CCRs for the group with less time or interest. CWSs must remember that the overall goal is education (Berberich, 1998). A summary of the strengths and weaknesses of this index is shown in Table 2.3.

Table 2. 3. Strengths and weaknesses of all Index areas

Strengths	Weaknesses
1) Main Message and Call to Action	
Prompt for more information through a phone number or website	Four messages: water source, water quality, compliance , and education information
	If water quality is most important to consumers, this was not always the first topic addressed
	No visual or emphasis on main message
2) Language	
Definitions available for MCL, ppb, action level etc.	Uses language the audience does not normally use
	Uses the passive voice for the main message
3) Information Design	
Uses bulleted or numbered list with less than 7 items	Main message is not summarized in the first paragraph or section
Uses chunks with headings	
4) State of the Science	
N/a	Does not explain what authoritative sources know and don't know about the water quality
5) Behavioral Recommendations	
Many recommendations for getting more information	Does not expand much on lead, copper, or immuno-compromised prompt (generally uniform among all CCRs)
Water conservation prompts	
Lead and copper information	
Immuno-compromised prompt	
6) Numbers	
The readers do not have to conduct calculations	Up until 2013, the mandated USEPA contaminant table uses numbers the audience does not generally use, i.e. decimals (AL for lead = 0.015 ppm)
As of 2013, whole numbers are now being used to present contaminant concentrations	

(AL for lead = 15 ppb)	
7) Risk	
Prompts of risks from lead & copper	Limited prompts on the benefits from behavioral recommendations
Prompts of risk for immuno-compromised people	Risk is not explained by numeric probabilities
	Few visuals

2) *Language: Does the main message and call to action use the active voice and is the CCR written in a language the primary audience would use?*

The main message and call of action should use the active voice, but the language was typically passive. Active voice sentences tend to be less wordy and to the point than passive voice sentences, thus, the active voice is a better way to communicate a message because it has energy and directness in its structure (Hale, 2008).

Although the reviewers who were environmental engineers found the language familiar, the health scientists had strong opinions about the unfamiliarity of the terms in the CCRs: “cross-connections”, “greensand filters”, “sodium hydroxide”, “phosphoric acid”, “curb-stop”, “MCLs.”
It is unavoidable to only use language that the general public will understand in CCRs because there are contaminants, such as *Cryptosporidium*, that some consumers cannot pronounce or have even heard of (Bishop, 2003). A national survey was conducted that ask CWSs who their toughest audience was. Residential consumers were ranked as the most difficult, followed by citizen’s groups, the news media, business consumers, regulators, elected officials, and employees (Bishop, 2003). The survey also found that water quality was the toughest topic to communicate, followed by fiscal and rates, regulations, supply/conservation, and projects. Since water quality was found to be the toughest information to convey to consumers, this study further analyzed connections that were common practices, such as news releases, personal contact, written reports to elected officials, or personal letters, in communicating about this issue (Bishop, 2003). However, they found that there were no statistically significant correlations between water quality communication and communication practices and techniques to the public (Bishop, 2003). It is not uncommon to have an audience that cannot fully understand water quality information, thus, CCRs have the potential to be an effective water quality communication tool, and its improvements can increase water utilities’ communication efforts (Bishop, 2003).

The ability to successfully communicate technical and policy issues to their stakeholders, including consumers, boards, citizens’ groups, and the media, is difficult for CWSs (Bishop 2003). CWSs should know their audience and group their consumers as residential, commercial, industrial, hospitals, etc. and survey the different groups on their needs. Communicating information would include turbidity, taste and odor, and water quality statistics and any law requirements, but it can also be customized for each group. For example, cooperation with CWSs and board of health officials can facilitate hospitals and immune-deficient stakeholder groups with specific details about precautions with drinking water (Berberich, 1998). A summary of the strengths and weaknesses of this index is shown in Table 2.3.

3) *Information design: Are there bulleted and numbered lists and chunks with headings? Is the main message summarized in the first paragraph or section?*

The information conveyed should be concise and to the point in order to efficiently inform a non-technical public. Additionally, the information design of CCRs should include the use of bulleted or number lists with no more than seven items per list to better communicate the message (CDC, 2014). The information design score for all CWSs was 59.5 ± 27.6%. Most CWSs had no issue with using bulleted or numbered list; however, some lists had more than seven items with no subheadings or no list at all. Additionally, the main message was not easily identified on the first page and in the first section of most CCRs. It is imperative to make the main message easily visible and identifiable in order to effectively communicate the water quality message to the audience.

4) *State of the science: Does the material explain what authoritative sources know and don't know about the topic?*

The state of science rated poorest out of all seven indexes because CCRs did not provide a good context for water quality data related to current science in toxicity, monitoring, and regulations. CWS must realize that it is perfectly acceptable to say, for example, that they do not know what caused a spike in contaminant levels. However, they should say that the problem has been taken care of or in the process of being taken care of and list and explain all health risks associated with it. Providing too much information can lead to negative effects (Owen et al., 1999), but every single contaminant that is detected must be listed even if they are not regulated and any contaminant exceeding maximum contaminant levels should be listed with relevant health effects (Berberich, 1998). When a CCR reports that 99.5% of water samples met government standards, the remaining 0.5% sampled may cause adverse judgments being made due to heuristics thoughts about the effects and magnitude of health risks associated with the failing 0.5% (Meyer-Emerick, 2004; Fischloff, Slovic, Lichtenstein, Read, & Combs, 1978). However, the CCR should be scripted in a manner that would effectively communicate the minimal risks associated with the 0.5% even if the experts do not know how to make the risk be zero. As stated previously, CWS experts should know that it is better to communicate bad news before it gets out the public through other avenues. This continued practice will promote the public's confidence in their water utility and quality. A summary of the strengths and weaknesses of this index is shown in Table 2.3.

5) *Behavioral recommendations: Does the material include one or more behavioral recommendations for the primary audience and explain why they are important and gives specific directions on how to perform the behavior?*

Behavioral recommendations ranked highest among all index scores; however, it still performed below the 90% qualifying mark. All CCRs had a paragraph on lead and copper information, and some even dedicated whole pages on the issues surrounding those metals in drinking water. Many CCRs had recommendations such as water conservation, which is great for public education, but many CCR lacked health-based recommendations. A common health-based paragraph in the CCRs describes risks for immuno-compromised people:

> "Some people may be more vulnerable to contaminants in drinking water than the general population. Immuno-compromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. EPA/CDC guidelines on appropriate means to lessen the risk of infection by Cryptosporidium

and other microbiological contaminants are available from the Safe Drinking Water Hotline (800-426-4791)."

This paragraph has great information and targets an important group that is sensitive to water quality changes, but the message should be expanded since this is a health-based recommendation. Additionally, if CWSs can identify their audience, like a hospital, they can effectively construct a CCR that would be beneficial and educational and relevant. A summary of the strengths and weaknesses of this index is shown in Table 2.3.

6) *Numbers: Does the material include numbers the primary audience uses and explain the meaning? Does the audience have to conduct calculations?*

Numbers should be present in a way that the primary audience would understand. The EPA has a mandated table (Appendix 2.4) (USEPA, 2013b) that CWSs must use to display numbers for contaminant concentrations and violations. As depicted in the sample Table 2.4, there lies a challenge in conveying this information to the general public. A summary of the strengths and weaknesses of this index is shown in Table 2.3.

Table 2. 4. Sample contaminant table mandated by the EPA

Contaminant (In CCR units)	Updated CCR MCL	MCLG	Highest Detected Level	Range	Major Sources in Drinking Water	Health Effects
Microbiological Contaminants						
Total Coliform Bacteria	MCL: (systems that collect ≥ 40 samples/month) 5% of monthly samples are positive; (systems that collect < 40 samples/month) 1 positive monthly sample	0%	1.7%	0-1.7%	Naturally present in the environment	Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially-harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.
Radioactive Contaminants						
Alpha emitters (pCi/L)	15	0	1	0-1	Erosion of natural deposits	Certain minerals are radioactive and may emit forms of radiation known as photons and beta radiation. Some people who drink water containing beta and photon emitters in excess of the MCL over many years may have an increased risk of getting cancer.
Inorganic Contaminants			**90th percentile detected**	**# of sites above AL**		
Lead (ppb)	AL = 15	0	2	0-8	Corrosion of household plumbing systems; Erosion of natural deposits	Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.
Volatile Organic Contaminants						
Benzene (ppb)	5	0	0.5	0-0.5	Discharge from factories; Leaching from gas storage tanks and landfills	Some people who drink water containing benzene in excess of the MCL over many years could experience anemia or a decrease in blood platelets, and may have an increased risk of getting cancer.

Contaminants are listed in unfamiliar units, like pCi/L, and can only be easily understood by technical people. The general public will not be able to comprehend the significances of those reported values, thus, whole numbers should be used if possible and never should the audience have to conduct mathematical calculations. The CCR Rule Retrospective Review summary found that increasing information design will include that the USEPA report MCLs in numbers greater than or equal to 1.0 (USEPA, 2012). Numerical data intimidates many people; environmental groups suggest, "not worry about units and just express information in whole numbers…if the standard is 20 and you have 2 that's a good message consumers will understand: (Berberich, 1998). Moving away from unfamiliar numbers to whole numbers will more effectively promote understanding of drinking water quality (USEPA, 2013b). However, whole numbers may still be confusing if the public does not understand the meaning or units. In addition, the general public will not have a technical background so any mathematical calculations should be avoided; fortunately, no CWSs required their consumers to do calculations. A summary of the strengths and weaknesses of this index is shown in Table 2.3.

7) *Risk: Does the material present information that describes risk and its benefits? Are risks explained by numeric probability that is also explained to the audience?*

Most CCRs did not state the risk of threat or harm and how and why people may be affected by the water quality. All CCRs should provide an explanation following any standard violations in order to prevent adverse effects, such as public outcry and fear in consuming tap water. Such explanations should include what steps were taken to remediate the issues. Also, any public recommended behavior should address the risks and benefits from the recommendations because consumers need to know how it will affect them and their families. Probability should be avoided at all cost to convey risks; however, if probability is used to convey risk associated with drinking water, it should be explained further though texts or visual aids.

Improvements in all seven areas of the CCI will greatly improve the quality CCRs. Consumers will better understand the main message, and CWSs will benefit from consumer satisfaction in their drinking water. Water utilities should follow the suggestions in this manuscript to improve the clarity of message communication in their annual CCRs. A summary of the strengths and weaknesses of this index is shown in Table 2.3.

Is the water safe to drink according to all state and federal standards and regulations? Only 63.3% of all reports sampled directly informed the consumers whether or not the water was safe to drink according to all state and federal standards and regulations. For medium, large, and very large size, the percentage of water utilities that answer the "safe to drink" question was 60.0 ± 0.5%, 40.0 ± 0.5, and 90 ± 0.3%, respectively. Most CCRs in the medium and large category did not mention any such statements and left the consumers to interpret the complicated jargon and technical contaminants table by themselves. Additionally, when CWS claim that their water is in compliance, is the public actually confident in their findings?—maybe or maybe not. The public may carry many negative risk perceptions against drinking tap water and avoid drinking it altogether, thus, CWSs must assure the public through their CCRs or two-way dialogues about what the public wants to know.

Risk perception is intuitive risk judgment and the public subjectively judges drinking water from the tap (Slovia, 1987; Meyer-Emerick, 2004). The public's water risk perception towards their tap drinking water is recognized by and related to their experiences and environment (Anadu & Harding, 2000; Burton et al., 1978). Thus, communicating water quality risk information is a two way street for

CWSs and their consumers. Water utilities should be able to respond to concerns in their CCRs. Risk perception and communication studies have shown that CCRs can be more effective if consumer's concerns are addressed previous to circulating CCRs to the public (Meyer-Emerick, 2004). To make CCRs more effective, water utilities should "1) ask consumers what they want to know before a CCR is issued; 2) institute ongoing dialogue with consumers about water quality; and 3) survey consumers after a report is issued to measure consumer's understanding of CCR information (Meyer-Emerick, 2004)." These steps can help alleviate many risk misconceptions and further promote drinking tap water.

There is a waging war between experts and non-experts in risk communication. People's ways of thinking or mental models are knowledge structures used to understand a certain subject matter. The mental models are different among people and may be significantly different for those with more experience and understanding of a subject (Meyer-Emerick, 2004). For example, the mental models about drinking water held by utility personnel in the United Kingdom were dramatically different from the mental models held by the public (Owen et al., 1999). Understanding the mental models for experts and the general public is extremely important in drafting an effective CCR. Since the gap knowledge is so wide between experts and the public, CWSs need to place emphasis on identifying what people know at the outset, correcting misinformation, and providing accurate information as a result (Lofstedt & Frewer, 1998). This conception is important in the drinking water industry because CWSs vary from region to region across the nation and a single template for CCRs may not be effective enough.

USEPA requirements often encourage standardized CCR format and information delivery by using the CCR iWriter software available online (USEPA, 2013a); this guarantees that consumers are receiving comparable information, but it also limits the ability to educate diverse groups (Meyer-Emerick, 2004). For example, some CWS have deep underground aquifers as a water source with no violations while others may draw from a polluted river with several violations. Anadu and Harding (2000) suggest that perception is affected by the level of awareness of a drinking water problem, whether present or not, and the chronicity of it. Hence, utilities must ask their consumers what they know and do not know and what their concerns are before circulating a CCR. Some possible questions water utilities can ask their consumers include (Means et al., 2002):

- "Do you think your water is safe? Why?
- Do you feel informed about water quality?
- What could we do to improve the water quality?
- What are you willing to pay for that improvement?"

The two-way process to involve consumers in the decision making process can be done through dialogue with focus groups or private surveys (Meyer-Emerick, 2004). Some citizens are more inclined to respond in detailed, anonymous, written surveys about risks rather than in-depth face to face interactions (Sjoberg, 2000b). The priorities of individuals vary substantially due to concerns about one's own health, their family's health, or the health of their communities (Meyer-Emerick, 2004).

Two-way dialogue has been shown to be effective. The District of Columbia Water and Sewer Authority (WASA) created focus groups as a way to yield information. They invited community leaders, leaders or environmental and consumer groups, and members of the public health community in an open discussion format to find ways to better communicate important water quality information (Bishop, 2003). It was an idea exchange among stakeholders that do not necessarily get to speak to one another. They had neutral facilitators, which allowed the water utilities to effectively grasp consumer's concerns without an attempt to defend or correct those issues (Bishop, 2003). One major topic discussed was the complexity and comprehensiveness of CCRs. In order to achieve the greatest needs of stakeholders, this focus group found that simple graphics and larger-print summary statements for those who do not wish to read detailed information would beneficial (Bishop, 2003).

Water utilities must be able to communicate basic risk information to the public without increasing fears through miscommunication (Meyer-Emerick, 2004). As Zechhauser and Viscusis (1996) found, the general public does not fully comprehend quantitative risk information. Furthermore, Miller showed that three of four adults do not understand common scientific material like DNA, molecules, or radiation (Siegrist & Vceckowich, 2000) and chances are, they will not fully understand the information provided in the CCR. Water utilities must pay attention to their CCR audience and alleviate any questions or concerns as they arise (Meyer-Emerick, 2004). Communicating risk will fail unless there is a two-way process. The experts and general public both have valid contributions and must respect each other's ideals and intellect (Meyer-Emerick, 2004). The AWWA Research Foundation established that the public would continue to expect more water quality information and water utilities must meet consumer's expectations through routine dialogue with consumers in order to survive (Means et al., 2002).

Explicitly stating whether the water is safe to drink or not according to federal and state regulations are important in CCRs. This would promote consumer's confidence in their drinking water and also encourage consumers to read their CCRs further and inquire for more information. A two-way dialogue between CWSs and their consumers is important because CWSs can address any concerns their consumers may have through their CCRs. Thus, improvements in clarity of message communication in CCRs will better communicate water quality information to the general public.

RECOMMENDATIONS

- CWSs should consider taking CDC's CCI training session and implement the practices available into constructing their next CCR.
- The CCR should also directly address whether or not the water is safe to drink in accordance with all state and federal regulations and emphasized with clues and graphics on the first page and section of the document.
- CWSs should get feedback from consumers on water information they want to know and also, on how well current CCRs are in communicating water quality information.
- The USEPA should mandate that CWSs reserve opportunities for two-way dialogues with their consumers before the release of CCRs.
- Even though water utilities have constraints, i.e. mandated contaminant table from USEPA, there should be at a national level reconsideration on how to effectively convey the numbers and the tables.

CONCLUSIONS

The mandated CCR documents released nationwide by water utilities to the consumers are not adequate in informing the consumers about the safely of their drinking water. All CCR sampled scored poorly on the CDC's CCI with all scores below the qualifying 90% mark. The major issue concerning water quality communication is the public's risk perception. CWS should recognize the audience they are serving and looking for ways to create a two-dialogue between them and the public in order to effectively communicate water quality and health-based information.

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APPENDICES

Appendix 2.1 (USEPA, 2014)

EPA
United States
Environmental Protection
Agency

Consumer Confidence Report Rule: A Quick Reference Guide

Overview of the Rule

Title*	Consumer Confidence Report (CCR) Rule, 63 FR 44511, August 19, 1998, Vol. 63, No. 160
Purpose	Improve public health protection by providing educational material to allow consumers to make educated decisions regarding any potential health risks pertaining to the quality, treatment, and management of their drinking water supply.
General Description	The CCR Rule requires all community water systems to prepare and distribute a brief annual water quality report summarizing information regarding source water, detected contaminants, compliance, and educational information.
Utilities Covered	Community water systems (CWSs), all size categories.

*This document provides a summary of federal drinking water requirements; to ensure full compliance, please consult the federal regulations at 40 CFR 141 and any approved state requirements.

Public Health Related Benefits

Implementation of the CCR Rule will result in . . .	► Increased consumer knowledge of drinking water sources, quality, susceptibility to contamination, treatment, and drinking water supply management. ► Increased awareness of consumers to potential health risks so they may make informed decisions to reduce those risks, including taking steps toward protecting their water supply. ► Increased dialogue between drinking water utilities and consumers to increase understanding of the value of drinking water and water supply services and to facilitate consumer participation in decisions that affect public health.

Annual Requirements

CWSs must prepare and distribute a CCR to all billing units or service connections.	► *April 1* - Deadline for CWS that sells water to another CWS to deliver the information necessary for the buyer CWS to prepare their CCR (requirement outlined in 40 CFR 141.152). ► *July 1* - Deadline for annual distribution of CCR to customers and state or local primary agency for report covering January 1 - December 31 of previous calendar year. ► *October 1* - (or 90 days after distribution of CCR to customers, whichever is first) Deadline for annual submission of proof of distribution to state or local primacy agency. ► A CWS serving 100,000 or more persons must also post its current year's report on a publicly accessible site on the Internet. Many systems choose to post their reports at the following EPA Web site http://cfpub.epa.gov/safewater/ccr/index.cfm?action=ccrupdate. ► All CWSs must make copies of the report available on request.

Multilingual Requirements

- ► CWSs that have a large proportion of non-English speaking residents must include information in the appropriate language(s) expressing the importance of the CCR, or a phone number or address where residents may contact the CWS to obtain a translated copy of the CCR or assistance in the appropriate language.
- ► The state or EPA will make the determination of which CWSs need to include this information.

Small Water System Flexibility

- ► With the permission of the governor of a state (or designee), or where the tribe has primacy, in lieu of mailing, systems serving fewer than 10,000 persons may publish their CCR in a local newspaper.**
- ► With the permission of the governor of a state (or designee), or where the tribe has primacy, in lieu of a mailing and/or publication, systems serving 500 or fewer persons may provide a notice stating the CCR is available upon request.**

**Questions regarding whether the necessary permission has been granted should be addressed to the appropriate state or primacy agency.

For additional information on the CCR Rule

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA Web site at http://water.epa.gov/drink; or contact your state or local primacy agency's drinking water representative. Log onto the CCRiWriter Web site to use EPA's template at www.CCRiWriter.com.

Eight Content Requirements of a CCR

- *Item 1:* **Water System Information** – Name/phone number of a contact person; information on public participation opportunities.
- *Item 2:* **Source(s) of Water.**
- *Item 3:* **Definitions** – Maximum Contaminant Level (MCL); MCL Goal (MCLG); Treatment Technique (TT); Action Level (AL); Maximum Residual Disinfectant Level (MRDL); MRDL Goal (MRDLG).
- *Item 4:* **Detected Contaminants** – A table summarizing reported concentrations and relevant MCLs and MCLGs or MRDLs and MRDLGs; known source of detected contaminants; health effects language.
- *Item 5:* **Information on Monitoring for *Cryptosporidium*, Radon, and Other Contaminants** (if detected).
- *Item 6:* **Compliance with Other Drinking Water Regulations** (any violations and Ground Water Rule [GWR] special notices).
- *Item 7:* **Variances and Exemptions** (if applicable).
- *Item 8:* **Required Educational Information** – Explanation of contaminants in drinking water and bottled water; information to vulnerable populations about *Cryptosporidium*; statements on nitrate, arsenic, and lead.

Optional Information

CWSs are not limited to providing only the required information in their CCR. CWSs may want to include:

- An explanation (or include a diagram of) the CWSs treatment processes.
- Source water protection efforts and/or water conservation tips.
- Costs of making the water safe to drink.
- A statement from the mayor or general manager.
- **Information to educate customers about:** Taste and odor issues, affiliations with programs such as the Partnership for Safe Water, opportunities for public participation, etc.

Communication Tips

- Provide a consistent message. Be as simple, truthful, and straightforward as possible. Avoid acronyms, initials, and jargon.
- Provide links to useful information resources.
- Limit wordiness – write short sentences and keep your paragraphs short.
- Assume that consumers will only read the top half of the notice or what can be read in 10 seconds.
- Display important elements in bold and/or large type in the top half of the notice.
- Do not make your text size too small.
- Give a draft of your CCR to relatives or friends who are not drinking water experts and ask them if it makes sense. Ask customers for their comments when you publish the CCR.
- Use graphics, photographs, maps, and drawings to illustrate your message. Do not distract from your main message with graphics and/or pictures that do not complement your message.
- Consider printing the CCR on recycled paper and taking other steps to make the CCR "environmentally friendly." If you hope to get your customers involved in protecting or conserving water, set a good example for them to follow.
- Use the CCR as an opportunity to tell your customers about all of the things that you are doing well.

Reporting and Recordkeeping

- CWSs must:
  - Mail or directly deliver a copy of the CCR to each of their customers by July 1 annually.
  - Make a good faith effort to get CCRs to non-bill-paying consumers, using means recommended by the state.
  - Send a copy to the director of the state drinking water program and any other state agency that the state drinking water program director identifies when you mail it to customers.
  - Submit to the state a certification, within 3 months of mailing, that the CWS distributed the CCR, and that its information is correct and consistent with the compliance monitoring data previously submitted to the state.
  - Post their CCRs on the Internet (if the CWSs serve 100,000 or more people).
- CWSs may also want to send copies to state and local health departments, as well as local TV and radio stations and newspapers.

Appendix 2.2 (CDC, 2014)

CDC Clear Communication Index Score Sheet

Name of material XXX-XXX (CCR ID #)

Name of person scoring ____________________

Date __ __ / __ __ / __ __ __ __

Before you begin, identify your primary audience, their health literacy skills, your primary communication objective, and main message. You must know these 4 pieces of information to score the material accurately. If you don't have this information, wait until you do to score the material.

Note about translated materials: If the audiences for the English and non-English versions are different, you should create and score the materials separately to account for audience differences.

1. Who is your primary audience? Customers of the "Community Water System"

Note: See Appendix C of the User Guide for a list of common CDC audiences.

2. What do you know about the health literacy skills of your audience?

Consider not only reading and numeracy skills but also motivation, attention, and distractors that may affect how your audience comprehends and uses your materials. If you don't have this information, assume average or limited skills. Examples include knowing what words and numbers your audience uses to describe a health issue, their familiarity with graphs, and the amount of time they spend reading health materials.

Due to diversity among groups, assume average/limited skills.

3. What is your primary communication objective?

A communication objective is what you want your audience to think, feel, or do after they receive the message or material. For example: Increase the proportion of women between 18-25 years who intend to increase consumption of folic acid.

To provide "information on the quality of the water and characterize the risks (if any) from exposure to contaminants detected in the drinking water in an accurate and understandable manner."

4. What is the main message of the material?

Message is to provide drinking water quality data that is related to specific contaminants, source of water, compliance, and educational information, as required by the USEPA.

If you are reviewing an existing material with multiple messages, list all possible messages.

n/a

Appendix 2.3 (CDC, 2014)

CDC Clear Communication Index Score Sheet

Using the Score Sheet

The Index has a total of 20 items in 4 parts. These 20 items are presented as questions.

- Questions 1-11 in Part A are **applicable to all materials**
- Questions 12-20 in Parts B, C, and D may not apply to all materials.
- Choose one answer for each item you score.
- Only score a point when all instances of an item in the material meet the criteria.

More detailed descriptions and examples of each item can be found in the User Guide.

Part A: Core The items in this section (1-11) apply to all materials.	
Questions	**Score** *(Check one per question)*
Main Message and Call to Action	
1. Does the material contain one main message? *A message is the information you are trying to communicate to another person or group of people. If the material contains several messages, and there is no obvious main message, answer no. (User Guide page 5)* **NOTE:** If you answered **No** to Question 1, **score 0 for Questions 2-4** and **continue** to Question 5.	Yes = 1 No = 0
2. Is the main message at the top, beginning, or front of the material? *If the material is a single print page, answer yes if the main message is in the top fourth. For a Web material, answer yes if the main message is visible without scrolling. (User Guide page 6)*	Yes = 1 No = 0
3. Is the main message emphasized with visual cues? *If the main message is emphasized with font, color, shapes, lines, arrows or headings, such as 'What you need to know,' answer yes. (User Guide page 7)*	Yes = 1 No = 0
4. Does the material contain at least one visual that conveys or supports the main message? *For example, count photographs, line drawings, graphs and infographics as visuals. If the visual doesn't have a caption or labels, answer no. If the visual has human figures who aren't performing the recommended behaviors, answer no. (User Guide page 8)*	Yes = 1 No = 0
5. Does the material include one or more calls to action for the primary audience? *If the material includes a specific behavioral recommendation, a prompt to get more information, a request to share information with someone else, or a broad call for program or policy change, answer yes. If the call to action is for someone other than the primary audience, answer no. (User Guide page 10)*	Yes = 1 No = 0

Language	
6. Do both the main message and the call to action use the active voice? *If only the main message or only the call to action uses the active voice, answer no. If you answered no to #1 or #5, answer no. (User Guide page 11)*	Yes = 1 No = 0
7. Does the material <u>always</u> use language the primary audience would use? See top of Score Sheet for primary audience. *If all specialized or unfamiliar terms are explained or described (not just defined) the first time they are used, answer yes. Acronyms and abbreviations must be spelled out and explained if unfamiliar to the audience. (User Guide page 12)*	Yes = 1 No = 0
Information Design	
8. Does the material use bulleted or numbered lists? *If the material contains a list with more than 7 items, and the list is not broken up into sub-lists, answer no. If the list is for additional information or references only or at the end of the material, answer no. (User Guide page 14)*	Yes = 1 No = 0
9. Is the material organized in chunks with headings? *This item applies to prose text and lists. If the chunks contain more than one idea each, answer no. If the headings dont match the information chunks, answer no. (User Guide page 15)*	Yes = 1 No = 0
10. Is the most important information the primary audience needs summarized in the first paragraph or section? *The most important information must include the main message. (User Guide page 17)*	Yes = 1 No = 0
State of the Science	
11. Does the material explain what authoritative sources, such as subject matter experts and agency spokespersons, know and don't know about the topic? *If the material addresses both, answer yes. If the material addresses only one (what is known or not known), answer no. (User Guide page 18)*	Yes = 1 No = 0
Part A score	**Total _____ / 11**

Comments

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Part B: Behavioral Recommendations

Answer this question to determine if items 12-14 apply to the material.

Does the material include one or more behavioral recommendations for the primary audience?

- If **yes** – score items 12-14.
- If **no** – skip to Part C.

Questions	Score (Check one per question)
12. Does the material include one or more behavioral recommendations for the primary audience? *If no, STOP here and don't score Part B. (User Guide page 19)*	Yes = 1 No = 0
13. Does the material explain why the behavioral recommendation(s) is important? *If you offer only numbers to explain the importance of the behavioral recommendation with no other relevant information for the audience, answer no. (User Guide page 20)*	Yes = 1 No = 0
14. Does the behavioral recommendation(s) include specific directions about how to perform the behavior? *This may include step-by-step directions or a simple description (for example: Look for cereal with 100% daily value of folic acid). If the material includes information about when or how to contact a medical provider or health official, answer yes. If the material mentions when or how often to perform a behavior, answer yes. (User Guide page 21)*	Yes = 1 No = 0
Part B score	**Total _____ / 3**

Comments

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Part C: Numbers

Answer this question to determine if items 15-17 apply to the material.

Does the material include one or more numbers that convey or support the main message?

- If **yes** – score items 15-17.
- If **no** – skip to Part D.

Questions	Score *(Check one per question)*
15. Does the material <u>always</u> present numbers the primary audience uses? *Whole numbers are used by most audiences. The types of numbers used will vary for each audience. (User Guide page 22)*	Yes = 1 No = 0
16. Does the material <u>always</u> explain what the numbers mean? *For example, "The amount of meat recommended as part of a healthy meal is 3 to 4 ounces – it will look about the same size as a deck of cards." (User Guide page 23)*	Yes = 1 No = 0
17. Does the audience have to conduct mathematical calculations? *Adding, subtracting, multiplying, and dividing involve calculations. Calculating a common denominator for the purposes of comparison is a mathematical calculation.* **NOTE: for this item, Yes is scored 0 and No is scored 1.** *(User Guide page 24)*	Yes = 0 No = 1
Part C score **Total _____**	**/ 3**

Comments

Part D: Risk

Answer this question to determine if items 18-20 apply to the material.
Does the material present information, including numbers, about risk?

- If **yes** – score items 18-20.
- Items 19 and 20 have a "not applicable" (NA) option.
- If **no** – skip to Calculate Your Score.

Questions	Score *(Check One per Question)*
18. Does the material explain the nature of the risk? *If the material states the threat or harm and how and why people may be affected, answer yes. If the material has only the threat or harm but no explanation, answer no. For example, if the material states there are 1,000 new cases of a contagious disease in Springfield, does it also state that people in Springfield may be more likely to get the disease, why they may be more likely, and how serious the threat of the disease is? (User Guide page 26)*	Yes = 1 No = 0
19. Does the material address both the risks and benefits of the recommended behaviors? *This includes actual risks and benefits and those perceived by your audience. If the material addresses only risks or only benefits, answer no. If no behavioral recommendation is presented, answer not applicable (NA). (User Guide page 27)*	Yes = 1 No = 0 NA
20. If the material uses numeric probability to describe risk, is the probability also explained with words or a visual? *Examples of probability information in a risk message are numbers (such as 1 in 5 or 20%). If the material presents numeric risk and also uses text to explain the probability, answer yes. If the material presents numeric risk and also uses a visual to explain the probability, answer yes. If the material only presents numeric risk, answer no. If the material does not include this type of probability information, answer not applicable (NA). (User Guide page 28)*	Yes = 1 No = 0 NA

Part D score — **Total _____ / 3**

OR _____ / 2
(if you answered NA for only **1** item)

OR _____ / 1
(if you answered NA for **2** items)

Comments

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Calculate the Score for the Material

- **Step 1:** The total points that the material earned (this is the numerator).
  - A: _____ B: _____ C: _____ D: _____ = _____
- **Step 2:** The total possible points that the material could have earned (this is the denominator).
  - A: __11__ B: _____ C: _____ D: _____ = _____
- **Step 3:** The numerator divided by the denominator multiplied by 100 to get the total score.

_____ / _____ x 100 = _____

How to Interpret the Score

The purpose of the Index is to improve the clarity of communication products.

If the total score is 90 or above:

Excellent! You have addressed most items that make materials easier to understand and use.

If the total score is 89 or below:

Note which items scored 0 points. Use the descriptions and examples in the User Guide to revise and improve the material. Then apply the Index again to check your work. You can use the Index as many times as you need to revise the material to get a score of 90 or above.

Additional Comments

Appendix 2.4 (USEPA, 2013b)

Appendix A to Subpart O – Regulated Contaminants

Key

AL=Action Level
MCL=Maximum Contaminant Level
MCLG=Maximum Contaminant Level Goal
MFL=million fibers per liter
MRDL=Maximum Residual Disinfectant Level
MRDLG=Maximum Residual Disinfectant Level Goal
mrem/year=millirems per year (a measure of radiation absorbed by the body)
n/a=Not Applicable
NTU=Nephelometric Turbidity Units (a measure of water clarity)
pCi/L=picocuries per liter (a measure of radioactivity)
ppm=parts per million, or milligrams per liter (mg/L)
ppb=parts per billion, or micrograms per liter (µg/L)
ppt=parts per trillion, or nanograms per liter
ppq=parts per quadrillion, or picograms per liter
TT=Treatment Technique

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Microbiological Contaminants						
Total Coliform Bacteria	MCL: (systems that collect ≥ 40 samples/ month) 5% of monthly samples are positive; (systems that collect < 40 samples/ month) 1 positive monthly sample			0	Naturally present in the environment	Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially-harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.
Fecal coliform and *E. coli*	0		0	0	Human and animal fecal waste	Fecal coliforms and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, and people with severely-compromised immune systems.
Fecal Indicators (enterococci or coliphage)	TT		TT	n/a	Human and animal fecal waste	Fecal indicators are microbes whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term health effect, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, some of the elderly, and people with severely compromised immune systems.
Total Organic Carbon (ppm)	TT	-	TT	n/a	Naturally present in the environment	Total organic carbon (TOC) has no health effects. However, total organic carbon provides a medium for the formation of disinfection byproducts. These byproducts include trihalomethanes (THMs) and haloacetic acids (HAAs). Drinking water containing these byproducts in excess of the MCL may lead to adverse health effects, liver, or kidney problems, or nervous system effects, and may lead to an increased risk of getting cancer.

1

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Turbidity (NTU)	TT	-	TT	n/a	Soil runoff	Turbidity has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease-causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea and associated headaches.
Radioactive Contaminants						
Beta/photon emitters (mrem/yr)	4 mrem/yr	-	4	0	Decay of natural and man-made deposits	Certain minerals are radioactive and may emit forms of radiation known as photons and beta radiation. Some people who drink water containing beta and photon emitters in excess of the MCL over many years may have an increased risk of getting cancer.
Alpha emitters (pCi/L)	15 pCi/L	-	15	0	Erosion of natural deposits	Certain minerals are radioactive and may emit a form of radiation known as alpha radiation. Some people who drink water containing alpha emitters in excess of the MCL over many years may have an increased risk of getting cancer.
Combined radium (pCi/L)	5 pCi/L	-	5	0	Erosion of natural deposits	Some people who drink water containing radium 226 or 228 in excess of the MCL over many years may have an increased risk of getting cancer.
Uranium (PCi/L)	30 µg/L	-	30	0	Erosion of natural deposits	Some people who drink water containing uranium in excess of the MCL over many years may have an increased risk of getting cancer and kidney toxicity.
Inorganic Contaminants						
Antimony (ppb)	.006	1000	6	6	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	Some people who drink water containing antimony well in excess of the MCL over many years could experience increases in blood cholesterol and decreases in blood sugar.
Arsenic (ppb)	[1]0.010	1000	[1]10	[1]0	Erosion of natural deposits; Runoff from orchards; Runoff from glass and electronics production wastes	Some people who drink water containing arsenic in excess of the MCL over many years could experience skin damage or problems with their circulatory system, and may have an increased risk of getting cancer.
Asbestos (MFL)	7 MFL	-	7	7	Decay of asbestos cement water mains; Erosion of natural deposits	Some people who drink water containing asbestos in excess of the MCL over many years may have an increased risk of developing benign intestinal polyps.

[1] These arsenic values are effective January 23, 2006. Until then, the MCL is 0.05 mg/L and there is no MCLG.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Barium (ppm)	2	-	2	2	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits	Some people who drink water containing barium in excess of the MCL over many years could experience an increase in their blood pressure.
Beryllium (ppb)	.004	1000	4	4	Discharge from metal refineries and coal-burning factories; Discharge from electrical, aerospace, and defense industries	Some people who drink water containing beryllium well in excess of the MCL over many years could develop intestinal lesions.
Bromate (ppb)	.010	1000	10	0	By-product of drinking water disinfection	Some people who drink water containing bromate in excess of the MCL over many years may have an increased risk of getting cancer.
Cadmium (ppb)	.005	1000	5	5	Corrosion of galvanized pipes; Erosion of natural deposits; Discharge from metal refineries; Runoff from waste batteries and paints	Some people who drink water containing cadmium in excess of the MCL over many years could experience kidney damage.
Chloramines (ppm)	MRDL=4	-	MRDL=4	MRDLG =4	Water additive used to control microbes	Some people who use water containing chloramines well in excess of the MRDL could experience irritating effects to their eyes and nose. Some people who drink water containing chloramines well in excess of the MRDL could experience stomach discomfort or anemia.
Chlorine (ppm)	MRDL=4	-	MRDL=4	MRDLG =4	Water additive used to control microbes	Some people who use water containing chlorine well in excess of the MRDL could experience irritating effects to their eyes and nose. Some people who drink water containing chlorine well in excess of the MRDL could experience stomach discomfort.
Chlorine Dioxide (ppb)	MRDL=.8	1000	MRDL =800	MRDLG =800	Water additive used to control microbes	Some infants and young children who drink water containing chlorine dioxide in excess of the MRDL could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorine dioxide in excess of the MRDL. Some people may experience anemia.
Chlorite (ppm)	1	-	1	0.8	By-product of drinking water disinfection	Some infants and young children who drink water containing chlorite in excess of the MRDL could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of the MCL. Some people may experience anemia.
Chromium (ppb)	.1	1000	100	100	Discharge from steel and pulp mills; Erosion of natural deposits	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Copper (ppm)	AL=1.3	-	AL=1.3	1.3	Corrosion of household plumbing systems; Erosion of natural deposits	Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctor.
Cyanide (ppb)	.2	1000	200	200	Discharge from steel/metal factories; Discharge from plastic and fertilizer factories	Some people who drink water containing cyanide well in excess of the MCL over many years could experience nerve damage or problems with their thyroid.
Fluoride (ppm)	4	-	4	4	Erosion of natural deposits; Water additive which promotes strong teeth; Discharge from fertilizer and aluminum factories	Some people who drink water containing fluoride in excess of the MCL over many years could get bone disease, including pain and tenderness of the bones. Fluoride in drinking water at half the MCL or more may cause mottling of children's teeth, usually in children less than nine years old. Mottling also known as dental fluorosis, may include brown staining and/or pitting of the teeth., and occurs only in developing teeth before they erupt from the gums.
Lead (ppb)	AL=.015	1000	AL=15	0	Corrosion of household plumbing systems; Erosion of natural deposits	Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.
Mercury [inorganic] (ppb)	.002	1000	2	2	Erosion of natural deposits; Discharge from refineries and factories; Runoff from landfills; Runoff from cropland	Some people who drink water containing inorganic mercury well in excess of the MCL over many years could experience kidney damage.
Nitrate (ppm)	10	-	10	10	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.
Nitrite (ppm)	1	-	1	1	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Selenium (ppb)	.05	1000	50	50	Discharge from petroleum and metal refineries; Erosion of natural deposits; Discharge from mines	Selenium is an essential nutrient. However, some people who drink water containing selenium in excess of the MCL over many years could experience hair or fingernail losses, numbness in fingers or toes, or problems with their circulation.
Thallium (ppb)	.002	1000	2	0.5	Leaching from ore-processing sites; Discharge from electronics, glass, and drug factories	Some people who drink water containing thallium in excess of the MCL over many years could experience hair loss, changes in their blood, or problems with their kidneys, intestines, or liver.
Synthetic Organic Contaminants including Pesticides and Herbicides						
2,4-D (ppb)	.07	1000	70	70	Runoff from herbicide used on row crops	Some people who drink water containing the weed killer 2,4-D well in excess of the MCL over many years could experience problems with their kidneys, liver, or adrenal glands.
2,4,5-TP [Silvex](ppb)	.05	1000	50	50	Residue of banned herbicide	Some people who drink water containing silvex in excess of the MCL over many years could experience liver problems.
Acrylamide	TT	-	TT	0	Added to water during sewage/ wastewater treatment	Some people who drink water containing high levels of acrylamide over a long period of time could have problems with their nervous system or blood, and may have an increased risk of getting cancer.
Alachlor (ppb)	.002	1000	2	0	Runoff from herbicide used on row crops	Some people who drink water containing alachlor in excess of the MCL over many years could have problems with their eyes, liver, kidneys, or spleen, or experience anemia, and may have an increased risk of getting cancer.
Atrazine (ppb)	.003	1000	3	3	Runoff from herbicide used on row crops	Some people who drink water containing atrazine well in excess of the MCL over many years could experience problems with their cardiovascular system or reproductive difficulties.
Benzo(a)pyrene [PAH] (nanograms/L)	.0002	1,000,000	200	0	Leaching from linings of water storage tanks and distribution lines	Some people who drink water containing benzo(a)pyrene in excess of the MCL over many years may experience reproductive difficulties and may have an increased risk of getting cancer.
Carbofuran (ppb)	.04	1000	40	40	Leaching of soil fumigant used on rice and alfalfa	Some people who drink water containing carbofuran in excess of the MCL over many years could experience problems with their blood, or nervous or reproductive systems.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Chlordane (ppb)	.002	1000	2	0	Residue of banned termiticide	Some people who drink water containing chlordane in excess of the MCL over many years could experience problems with their liver or nervous system, and may have an increased risk of getting cancer.
Dalapon (ppb)	.2	1000	200	200	Runoff from herbicide used on rights of way	Some people who drink water containing dalapon well in excess of the MCL over many years could experience minor kidney changes.
Di(2-ethylhexyl) adipate (ppb)	.4	1000	400	400	Discharge from chemical factories	Some people who drink water containing di (2-ethylhexyl) adipate well in excess of the MCL over many years could experience toxic effects such as weight loss, liver enlargement or possible reproductive difficulties.
Di(2-ethylhexyl) phthalate (ppb)	.006	1000	6	0	Discharge from rubber and chemical factories	Some people who drink water containing di (2-ethylhexyl) phthalate in excess of the MCL over many years may have problems with their liver, or experience reproductive difficulties, and may have an increased risk of getting cancer.
Dibromochloro-propane (ppt)	.0002	1,000,000	200	0	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	Some people who drink water containing DBCP in excess of the MCL over many years could experience reproductive problems and may have an increased risk of getting cancer.
Dinoseb (ppb)	.007	1000	7	7	Runoff from herbicide used on soybeans and vegetables	Some people who drink water containing dinoseb well in excess of the MCL over many years could experience reproductive difficulties.
Diquat (ppb)	.02	1000	20	20	Runoff from herbicide use	Some people who drink water containing diquat in excess of the MCL over many years could get cataracts.
Dioxin [2,3,7,8-TCDD] (ppq)	.00000003	1,000,000,000	30	0	Emissions from waste incineration and other combustion; Discharge from chemical factories	Some people who drink water containing dioxin in excess of the MCL over many years could experience reproductive difficulties and may have an increased risk of getting cancer.
Endothall (ppb)	.1	1000	100	100	Runoff from herbicide use	Some people who drink water containing endothall in excess of the MCL over many years could experience problems with their stomach or intestines.
Endrin (ppb)	.002	1000	2	2	Residue of banned insecticide	Some people who drink water containing endrin in excess of the MCL over many years could experience liver problems.
Epichlorohydrin	TT	-	TT	0	Discharge from industrial chemical factories; An impurity of some water treatment chemicals	Some people who drink water containing high levels of epichlorohydrin over a long period of time could experience stomach problems, and may have an increased risk of getting cancer.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Ethylene dibromide (ppt)	.00005	1,000,000	50	0	Discharge from petroleum refineries	Some people who drink water containing ethylene dibromide in excess of the MCL over many years could experience problems with their liver, stomach, reproductive system, or kidneys, and may have an increased risk of getting cancer.
Glyphosate (ppb)	.7	1000	700	700	Runoff from herbicide use	Some people who drink water containing glyphosate in excess of the MCL over many years could experience problems with their kidneys or reproductive difficulties.
Heptachlor (ppt)	.0004	1,000,000	400	0	Residue of banned pesticide	Some people who drink water containing heptachlor in excess of the MCL over many years could experience liver damage and may have an increased risk of getting cancer.
Heptachlor epoxide (ppt)	.0002	1,000,000	200	0	Breakdown of heptachlor	Some people who drink water containing heptachlor epoxide in excess of the MCL over many years could experience liver damage, and may have an increased risk of getting cancer.
Hexachlorobenzene (ppb)	.001	1000	1	0	Discharge from metal refineries and agricultural chemical factories	Some people who drink water containing hexachlorobenzene in excess of the MCL over many years could experience problems with their liver or kidneys, or adverse reproductive effects, and may have an increased risk of getting cancer.
Hexachlorocyclopentadiene (ppb)	.05	1000	50	50	Discharge from chemical factories	Some people who drink water containing hexachlorocyclopentadiene well in excess of the MCL over many years could experience problems with their kidneys or stomach.
Lindane (ppt)	.0002	1,000,000	200	200	Runoff/leaching from insecticide used on cattle, lumber, gardens	Some people who drink water containing lindane in excess of the MCL over many years could experience problems with their kidneys or liver.
Methoxychlor (ppb)	.04	1000	40	40	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	Some people who drink water containing methoxychlor in excess of the MCL over many years could experience reproductive difficulties.
Oxamyl [Vydate] (ppb)	.2	1000	200	200	Runoff/leaching from insecticide used on apples, potatoes and tomatoes	Some people who drink water containing oxamyl in excess of the MCL over many years could experience slight nervous system effects.
PCBs [Polychlorinated biphenyls] (ppt)	.0005	1,000,000	500	0	Runoff from landfills; Discharge of waste chemicals	Some people who drink water containing PCBs in excess of the MCL over many years could experience changes in their skin, problems with their thymus gland, immune deficiencies, or reproductive or nervous system difficulties, and may have an increased risk of getting cancer.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Pentachlorophenol (ppb)	.001	1000	1	0	Discharge from wood preserving factories	Some people who drink water containing pentachlorophenol in excess of the MCL over many years could experience problems with their liver or kidneys, and may have an increased risk of getting cancer.
Picloram (ppb)	.5	1000	500	500	Herbicide runoff	Some people who drink water containing picloram in excess of the MCL over many years could experience problems with their liver.
Simazine (ppb)	.004	1000	4	4	Herbicide runoff	Some people who drink water containing simazine in excess of the MCL over many years could experience problems with their blood.
Toxaphene (ppb)	.003	1000	3	0	Runoff/leaching from insecticide used on cotton and cattle	Some people who drink water containing toxaphene in excess of the MCL over many years could have problems with their kidneys, liver, or thyroid, and may have an increased risk of getting cancer.
Volatile Organic Contaminants						
Benzene (ppb)	.005	1000	5	0	Discharge from factories; Leaching from gas storage tanks and landfills	Some people who drink water containing benzene in excess of the MCL over many years could experience anemia or a decrease in blood platelets, and may have an increased risk of getting cancer.
Carbon tetrachloride (ppb)	.005	1000	5	0	Discharge from chemical plants and other industrial activities	Some people who drink water containing carbon tetrachloride in excess of the MCL over many years could experience problems with their liver and may have an increased risk of getting cancer.
Chlorobenzene (ppb)	.1	1000	100	100	Discharge from chemical and agricultural chemical factories	Some people who drink water containing chlorobenzene in excess of the MCL over many years could experience problems with their liver or kidneys.
o-Dichlorobenzene (ppb)	.6	1000	600	600	Discharge from industrial chemical factories	Some people who drink water containing o-dichlorobenzene well in excess of the MCL over many years could experience problems with their liver, kidneys, or circulatory systems.
p-Dichlorobenzene (ppb)	.075	1000	75	75	Discharge from industrial chemical factories	Some people who drink water containing p-dichlorobenzene in excess of the MCL over many years could experience anemia, damage to their liver, kidneys, or spleen, or changes in their blood.
1,2-Dichloroethane (ppb)	.005	1000	5	0	Discharge from industrial chemical factories	Some people who drink water containing 1,2-dichloroethane in excess of the MCL over many years may have an increased risk of getting cancer.
1,1-Dichloroethylene (ppb)	.007	1000	7	7	Discharge from industrial chemical factories	Some people who drink water containing 1,1-dichloroethylene in excess of the MCL over many years could experience problems with their liver.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
cis-1,2-Dichloroethylene (ppb)	.07	1000	70	70	Discharge from industrial chemical factories	Some people who drink water containing cis-1,2-dichloroethylene in excess of the MCL over many years could experience problems with their liver.
trans-1,2-Dichloroethylene (ppb)	.1	1000	100	100	Discharge from industrial chemical factories	Some people who drink water containing trans-1,2-dichloroethylene well in excess of the MCL over many years could experience problems with their liver.
Dichloromethane (ppb)	.005	1000	5	0	Discharge from pharmaceutical and chemical factories	Some people who drink water containing dichloromethane in excess of the MCL over many years could have liver problems and may have an increased risk of getting cancer.
1,2-Dichloropropane (ppb)	.005	1000	5	0	Discharge from industrial chemical factories	Some people who drink water containing 1,2-dichloropropane in excess of the MCL over many years may have an increased risk of getting cancer.
Ethylbenzene (ppb)	.7	1000	700	700	Discharge from petroleum refineries	Some people who drink water containing ethylbenzene well in excess of the MCL over many years could experience problems with their liver or kidneys.
Haloacetic Acids (HAA) (ppb)	.060	1000	60	n/a	By-product of drinking water disinfection	Some people who drink water containing haloacetic acids in excess of the MCL over many years may have an increased risk of getting cancer.
Styrene (ppb)	.1	1000	100	100	Discharge from rubber and plastic factories; Leaching from landfills	Some people who drink water containing styrene well in excess of the MCL over many years could have problems with their liver, kidneys, or circulatory system.
Tetrachloroethylene (ppb)	.005	1000	5	0	Discharge from factories and dry cleaners	Some people who drink water containing tetrachloroethylene in excess of the MCL over many years could have problems with their liver, and may have an increased risk of getting cancer.
1,2,4-Trichlorobenzene (ppb)	.07	1000	70	70	Discharge from textile-finishing factories	Some people who drink water containing 1,2,4-trichlorobenzene well in excess of the MCL over many years could experience changes in their adrenal glands.
1,1,1-Trichloroethane (ppb)	.2	1000	200	200	Discharge from metal degreasing sites and other factories	Some people who drink water containing 1,1,1-trichloroethane in excess of the MCL over many years could experience problems with their liver, nervous system, or circulatory system.
1,1,2-Trichloroethane (ppb)	.005	1000	5	3	Discharge from industrial chemical factories	Some people who drink water containing 1,1,2-trichloroethane well in excess of the MCL over many years could have problems with their liver, kidneys, or immune systems.

Contaminant (units)	Traditional MCL in mg/L	To convert for CCR, multiply by	MCL in CCR units	MCLG	Major Sources in Drinking Water	Health Effects Language
Trichloroethylene (ppb)	.005	1000	5	0	Discharge from metal degreasing sites and other factories	Some people who drink water containing trichloroethylene in excess of the MCL over many years could experience problems with their liver and may have an increased risk of getting cancer.
TTHMs [Total trihalomethanes] (ppb)	.10/.080	1000	100/80	n/a	By-product of drinking water disinfection	Some people who drink water containing trihalomethanes in excess of the MCL over many years may experience problems with their liver, kidneys, or central nervous systems, and may have an increased risk of getting cancer.
Toluene (ppm)	1	-	1	1	Discharge from petroleum factories	Some people who drink water containing toluene well in excess of the MCL over many years could have problems with their nervous system, kidneys, or liver.
Vinyl Chloride (ppb)	.002	1000	2	0	Leaching from PVC piping; Discharge from plastics factories	Some people who drink water containing vinyl chloride in excess of the MCL over many years may have an increased risk of getting cancer.
Xylenes (ppm)	10	-	10	10	Discharge from petroleum factories; Discharge from chemical factories	Some people who drink water containing xylenes in excess of the MCL over many years could experience damage to their nervous system.

Revision History

Date	Action	Federal Register Citation
24 August 2000	Created table	63 FR 44530 (19 August 1998) as amended by 65 FR 26024 (4 May 2000)
29 January 2001	1) Revised entries for beta/photon, alpha emitters, and combined radium, and added entry for uranium 2) Revised entry for arsenic	65 FR 76749 (7 December 2000) 66 FR 7064 (22 January 2001)
27 November 2002	3) Revised health effects language for di(2-ethylhexyl) adipate (DEHA) and di(2-ethylhexyl) phthalate (DEHP) 4) Revised the placement of regulatory and health effects information for disinfection by-products (*i.e.,* bromate, chloramines, chlorite, chlorine, and chlorine dioxide), and corrected the reference "chloride dioxide" to "chlorine dioxide."	67 FR 70855
9 December 2002	5) In the table, in the first column, in the second entry, in the second line, "andipate" was changed to read, "adipate."	67 FR 73011
25 March 2003	6) Revise the arsenic rule to express the standard as 0.010 mg/L, in order to clarify the implementation of the original rule.	68 FR 14506
8 November 2006	7) Added "Fecal Indicators (enterococci or coliphage)"	71 FR 65652

CHAPTER 3.

Systematic Tracking, Visualizing, and Interpreting of Consumer Feedback for Drinking Water Quality

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ABSTRACT

Consumers are concerned about their water quality and are excellent monitors for changes in the taste, odor or appearance of their drinking water quality at the tap. Consumer feedback and complaint data provided to a utility represents a fruitful data stream that should be harnessed routinely to gain knowledge about aesthetic water quality in the distribution system. This research provides a systematic approach to interpret consumer complaint water quality data provided by four water utilities that recorded consumer complaints but did not routinely process the data. The utilities tended to write down a myriad of descriptors that were too numerous or contained a variety of spellings so that electronic "harvesting" was not possible and much manual labor was required to categorize the complaints into majors areas such as suggested by the drinking water taste-and-odor wheel or existing check-sheets. When the consumer complaint data were categorized and visualized using radar and run-time plots, major taste, odor, and appearance patterns emerged that clarified the issue and could provide guidance to the utility on the nature and extent of the problem. A caveat in using consumer complaint data is that while humans readily identifying visual issues with the water, such as color, cloudiness, or rust, describing specific tastes and particularly odors in drinking water are acknowledged to be much more difficult tasks for humans to achieve without training. This was demonstrated with two utility groups and a group of consumers identifying the odor of orange, 2-methylisoborneol (2-MIB), and dimethyl trisulfide (DMTS). All three groups readily and succinctly identified the familiar orange odor. The two utility groups were much more able to identify the musty odor of 2-MIB, which was likely familiar to them from their work with raw and finished water. DMTS, a garlic-onion odor associated with sulfur compounds in drinking water, was the least familiar to all three groups although the lab staff was the best. These results indicate that utility personnel should be tolerant of consumers who can assuredly say the water is different, but cannot describe the problem. Also, it indicated that a T&O program at a utility would benefit identification of aesthetic issues in water.

HIGHLIGHTS

- Consumer complaint data from four utilities was successfully interpreted using systematic categorization and visualization into the major descriptors of the taste and odor wheel plus descriptors of color and particulates.
- Utility personnel are better able to describe aesthetic issued in drinking water and consumers are better able to detect changes in water quality.
- Consistent terminology and routine tracking of consumer feedback using standardize check-sheets will improve communications with and between utilities and also with consumers.

INTRODUCTION

Consumer feedback on drinking water quality is an important data stream that is available to utilities for determining the effectiveness`s of treatment and distribution processes in order to deliver a high quality product to residences and businesses. Many governments [e.g., United States (USEPA, 2008), Australia (Australia, 2011), United Kingdom (DWI, 2009), City of Philadelphia (PWD, 2013)], and researchers [e.g., (Dietrich, 2006; Hrudey and Hrudey, 2007; Burlingame and Mackey, 2007; Murray et al., 2010)], advocate consumer complaint surveillance (CCS) as a valuable process control to augment chemical and microbiological water quality monitoring. Consumer complaint surveillance refers to a methodology that relies on detecting water quality problems based on consumer input. When implemented as a process control feature for assessing and maintaining water quality in the distribution system, CCS will contribute to a hazardous contaminant warning system (CWS) (USEPA, 2008; PWD, 2013) and early detection of aesthetic issues that are problematic for consumers and the water industry (Gallagher and Dietrich, 2014).

Since consumers are real-time sensors who continuously monitor water quality everywhere and everyday throughout the water distribution system, they are uniquely positioned to provide feedback. Their feedback can be specific, such as the level of chlorinous odor has changed, or general, such as the water looks, tastes or smells “different.” The ability to describe a specific taste or odor is challenging both for consumers and those trained in sensory analysis (Czerny et al., 2008). The focus of this article is on the initial process to identify aesthetic issues, which involves consumers in conjunction with utility personnel describing the issue.

Typically, when consumers report an aesthetic water quality issue, a three-prong process is used by the water industry to establish process control for the taste, odor, or appearance (color and/or particles) issue in drinking water:

1. Apply sensory analysis to describe the aesthetic issue.
2. Apply chemical analysis to determine the identity and concentration of the sensory compound(s) when the issue cannot be resolved based on sensory data.
3. Once the cause of the aesthetic issue is identified, treat and control to minimize or remove.

The effectiveness of describing aesthetic issues in drinking water is key to resolving them and depends on: 1) limits of the human senses to detect and describe a taste, odor, color, or particles; and 2) common and accurate language in the dialogue with consumers and within and among utilities; 3) tracking and categorizing consumer feedback by utility personnel. Consumers vary in their ability to detect and describe sensory issues (Lawless and Heymann, 2010); however, they are watchmen to water quality problems.

The Human Senses and Perception of Drinking Water. The senses of taste and odors are called the chemical senses as these two senses use receptors to detect specific chemical agents in drinking water from part-per-millions down to part per quadrillion concentrations (Diaz et al, 2005 Dietrich, 2006; Piriou et al., 2009). Together, taste and odor produce the sensation of flavor. Humans can more readily detect a difference in taste and odor than describe the difference. While odors are difficult for humans to classify and describe, visual cues have structure in time and space and are easier to describe and identify (Köster, 2005).

This leads to a detection threshold, which is when a person can detect the sensation but not necessarily describe it. Typically, the detection threshold is 2-4 folds lower than the recognition threshold, which is the concentration where a person can describe the taste, odor, or difference (Czerny et al., 2008; Lawless and Heymann, 2010). While it is accepted that there is variability within the human population for individual thresholds and that a range would best describe this variability, it is common to report just a single value for a threshold concentration for a population. These single values are determined through statistical methods that include geometric means or logistic regression that calculates the level at which 50% of the population detects a stimulus (Meilgaard et al., 2006; Gallagher and Cuppett, 2007; Lawless and Heymann, 2010; Lawless, 2010).

Normal humans vary in their chemical sensory capabilities due to age, genetics, health, mood, temperature, test location, time of day, and sample matrix (Dietrich, 2006; Mirlohi et al., 2011), which leads to taste or odor thresholds varying by a factor of one hundred or more from individual to individual for many drinking water compounds: nonadienal (Burlingame et al., 1992); haloanisoles (Diaz et al., 2005); cupric ion (Gallagher and Cuppett, 2007; Dietrich, 2009); geosmin and 2-MIB (Piriou et al., 2009); ferrous and ferric ion (Ömür-Özbek & Dietrich, 2010); methyl-t-butyl ether (Lawless, 2010); and manganese (Sain et al., 2014). Thus, not all consumers can detect an aqueous sensory problem for taste and odor even if it is present.

Water has different taste, odors, and appearances, and just like in food, consumers are able to notice when the water's sensory characteristics change. Personal choices in drinking water are influenced by psychological factors, including personal experience, memory and external stimuli, and physiological factors, such as biochemistry, physical body factors, health, and external factors such as humidity, temperature, etc. (Dietrich, 2006). The flavor of drinking water can come from multiple causes: 1) the chemical and microbial content of the natural water due to geology and ecology; 2) chemicals added/removed during the treatment process; and 3) inputs and reactions that occur during distribution and storage. No matter if it is treated tap water or bottled water, people are accustomed to their local water quality and products and will detect even the slightest changes. Consumers dislike inconsistency in the taste and odor and appearance of their drinking water because they often associate the changes with bad palatability and increased risk even if the changes in flavor are due benign factors such as seasonal variation (Dietrich, 2006; Burlingame and Mackay, 2007; Doria, 2010).

Utilities and Consumer Feedback

Many utilities respond individually to every water quality complaint (Lauer, 2004). While tracking the total number of consumer complaints is valuable, understanding the number and types of complaint descriptors is more valuable for identifying the aesthetic issue and implementing process control. Categorizing aesthetic complaints is currently a challenge to the water industry, which has not yet adopted standardized descriptors or categories even though they are available. The taste and odor wheel for drinking water could provide a common global language as it contains categories for four tastes (sweet, salty, sour, and bitter), eight odors (earthy-musty, chlorinous, grassy- woody, swampy-sulfurous, fragrant, fishy, medicinal, chemical), and one category of mouth feel for oral sensations (APHA, 2012: Standard Method 2170). Particulate matter and color can be identified using available decision trees and images (Booth and Brazos, 2004). Empirical observation indicates that consumers sometimes provide feedback about water quality that utilities do not understand and cannot use (Burlingame et al., 1992; Burlingame and Mackey, 2007). For example, consumers often report that the water "tastes bad," "smells bad," or "is not right." While these descriptors may be correct, they present a challenge for a utility to interpret and identify a potential cause of the taste, odor, or appearance issue.

This manuscript is the first attempt to evaluate the language that is used by utility personnel and consumers to describe and record aesthetic issues in drinking water. It is aimed toward developing a mechanism for utilities to systematically track, visualize, and interpret consumer feedback/complaint data to determine short and long-term indicators of water quality. The specific objectives were to: 1) apply categorization and visualization techniques to analyze raw utility data of recorded consumer feedback for aesthetic water quality complaints; 2) statistically examine and interpret short and longer term categorized utility data for patterns of descriptors; and 3) determine the ability and variability of consumers and utility personnel to provide descriptors for three specific odorants: orange extract, 2-methylisoborneol, and dimethyl trisulfide.

MATERIALS AND METHODS

Utility Data

Utility Selection. Utilities were selected based on their willingness to provide drinking water consumer complaint data related to water quality concerns of: taste, odor, and appearance (including "dirty water"). All of the selected complaints described only aesthetic water quality issues as the hydraulic and pressure complaints were filtered out.

Statistical Analyses. All statistical analyses were conducted in R, version 3.0.2 (R Development Core Team, 2009). Tag clouds for the raw descriptors were prepared with the word cloud and tm packages. These raw descriptors had punctuation removed, English stop words (e.g., the, e and, not, etc.) eliminated, and were converted to lower case prior to the tag cloud analysis. The complaint descriptor data were too inconsistent both across utilities and within each individual utility to be formally analyzed using standard statistical analyses. Each of the water quality complaints was recoded using categories of four tastes descriptors, six odor descriptors, five appearance descriptors, and other/blank. The descriptors selected focused on previously suggested categories (APHA, 2012; Booth and Brazos, 2004; Whelton et al., 2007), but also included terms from the utility data (e.g., film). Percent occurrences and average run lengths were created based on the recoded descriptors. Average run length describes the mean number of times the same descriptor is used in sequence. For example, an average run length of one indicates that the descriptor is always followed by a different descriptor. An average run length of three indicates that, on average, the same descriptor is used for three complaints in a row.

Descriptors for Known Odorants

Human Subjects. Since this research involved human subjects, approval from the Virginia Tech Institutional Review Board was obtained for the sensory testing (IRB 12-710). Informed consent was given verbally by each subject in accordance with the IRB. Subjects were required to be 18 or older, of any health status, but not pregnant. A total of 86 subjects, of which 48% were women, participated in various sensory tests throughout the course of the project.

Three different subject groups assessed the odors. The first group consisted of 30 (24 females) water treatment plant (WTP) laboratory staff, age 25-59. The laboratory staff consisted of chemists and microbiologists who worked in water quality labs; they had a general familiarity with chemicals odors due to their career paths, which provided educational and work opportunities to handle chemicals and solvents. Some individuals had prior sensory training, but none routinely performed sensory analysis for their work. The second group consisted of 34 WTP operators (3 females), age 19-53. None of the water treatment personnel routinely performed sensory testing or had formal odor training. The third group consisted of the general public or “consumer” group with 23 individuals (14 females), age 22-57. None of the subjects in this group had trained or routinely engaged in sensory testing.

Odorants. Three odors were selected for which the human subjects were expected to have varying familiarity. The first was expected to be familiar to most human subjects; it was the odor from a commercial orange extract (Simply Organic, Frontier Natural Products, Iowa, USA) purchased in a grocery store. The second was 2-methylisoborneol (2-MIB; musty odor) (98% pure, Supelco, Belefonte PA, USA), which is a common odor problem in drinking water. 2-MIB might be familiar to subjects if they had prior familiarity with musty smelling water or experienced the musty odor that occurs in basements, dirt, or in damp materials. The last odor was dimethyl trisulfide (DMTS; onion, garlic odor) (98% pure, Aldrich Chemical Company, USA), which depending on their prior exposure and experience, might be familiar or not to participants.

The odorants were prepared the day prior to the odor sensory tests. Each odor was presented in 40 mL glass vials (VOA, volatile organic analysis, vials) that contained half a cotton ball with a small amount of the odorant that was designed to provide a moderate to strong odor intensity to the participant; the odor intensity was confirmed by research personnel and office staff prior to presenting to the participants. For the orange extract, 300 uL of the commercial preparation was added onto a cotton ball. 2-MIB and DMTS were diluted with water and microliter aliquots were added onto the cotton balls; the masses per vial were 2×10^{-5} mg and 5.4×10^{-6} mg, 2-MIB and DMTS, respectively.

The vials containing odorants were presented to participants in a random order at room temperature. Participants were instructed to open the vial, sniff, and record their impressions of the descriptor(s). Participants waited 3-5 minutes between sniffing each odorant.

RESULTS

Utility Data

Historical Data. Table 3.1 summarizes the data provided. Results show that record length ranged from one to seven years. Analysis of consumer reported water quality issues revealed the mean number of complaints ranged from 0.56 to 2.64 per day, while the maximum number ranged from 7 to 19 per day. Normalized to consumer base, the complaint frequency ranged from 0.61 to 1.62 complaints per 1000 consumers per year. Complaint/concern frequency is caused by many factors: source water quality, engineering operations and infrastructure, economic status of the consumers, how educated the consumers are in noticing water quality changes, how easy it is to contact the utility, and how well the utility records the information.

Complaint Descriptors. For each utility, every complaint descriptor for all years of record was entered into a database. This summary of all raw descriptors for a utility was examined for patterns and consistency. One way to visualize descriptors is through the use of tag clouds. Tag clouds list each term of the raw descriptor and use increasing size and font weight to indicate a greater frequency of use. An example of the descriptor variability is depicted in Figure 3.1 for Utilities U1 and U2 based on all the actual complaint descriptors as recorded. Many related descriptors are used, which makes it difficult for a utility to track the consumer complaints and identify any underlying aesthetic issue. For Utility U1, the dominant descriptors are generic defined and undefined odors as well as appearance related cloudy, rusty, and particulates. Utility U2, on the other hand, uses a ground water source so sulfur descriptors were common. These include rotten egg, sulfur, and septic.

What is apparent after a brief examination of the tag cloud is the lack of consistency in the descriptors used. Some of these variations, for example, “sulfur” versus “rotten eggs” are due to the consumer. Others are caused by the utility’s data recording procedure including different notations or spellings for the same problem: “hydrogen sulfide” versus “h2s,” or “sullphur” and “sulfer” versus “sulfur.”

As described above, data were recoded for formal analysis. The recoding focused the numerous individual complaints as shown in Figure 3.1 into specific categories presented in Figure 3.2 as percent occurrence.

The underlying water quality and infrastructure tends to impart a typical signature for each utility. Utility U1 does not have a dominant descriptor due to the high variability of the raw descriptors shown in Figure 3.1a. “Other/blank” was the most common classification that could be used in the recoding, although rusty, particulates, and cloudy were not uncommon. Discussions with utility staff revealed the consumers believed that the water’s taste or odor was occasionally objectionable, but could not describe why. The lack of a defined taste or odor descriptor is a common occurrence and is related to fundamental human perception of odors and tastes. While humans may have low detection thresholds for finding a difference, the ability to describe the taste or odor issue is more difficult (Köster, 2005; Czerny et al. 2008).

Utility U2, with a groundwater source, tends to sulfur and septic complaints, which are consistent with the raw descriptors in Figure 3.1b. Utilities U3 and U4 evidenced a different pattern, with a much higher percentage of appearance complaints than taste and odor. Utility U3 tends to particulates, film, and cloudy complaints, and Utility U4 is dominated by rusty complaints. Discussions with Utility U4 revealed that their service area was undergoing a great deal of new construction and growth, and utility staff believed that construction activities (e.g., heavy machinery on roads) contributed to consumer reported water quality issues. Figure 3.2 also illustrates a potential challenge with the recoding approach. Utility U4 tended to classify consumer reported water appearance issues as “rusty,” but with correspondingly fewer particulate complaints. Utility U3 tended to classify complaints as “particles,” which could be rust related. Utility U4 used general categories of taste and odor and did not distinguish these complaints to any greater detail.

Figure 3.3 depicts a similar analysis by evaluating the average run length. (Utility U4 only provided monthly summaries, so average run lengths could not be calculated). In general, these patterns are similar to the percent occurrences in Figure 3.2, but there are some exceptions. In particular, an earthy-musty outbreak occurred during February 2000 for Utility U1. This resulted in a high number of sequential earthy complaints. Therefore, the earthy average run length is greater than indicated by the percent occurrence. Thus, both percent occurrence and average run length provide difference insights into the long-term patterns for each utility.

From these analyses, utilities can visualize the typical consumer complaint characteristics typical of their delivered water. These analyses serve as baselines for detecting changes. If a number of non-typical complaints arise, the utility would know that a loss of operational control or other unusual situation has arisen and can respond more appropriately. As mentioned previously, an earthy-musty outbreak occurred for Utility U1 during February 2000. A total of 42 water quality complaints were logged as a result. Figure 3.4 presents the tag cloud, percent occurrence, and average run length for Utility U1 during that month. These figures should be compared to the corresponding long-term results shown in Figures 3.1a, 3.2a, and 3.3a.

The complaint differences are striking. Over 50% of the complaints were earthy related compared to approximately 5% during the overall 7 year period of record. The average run length for earthy complaints increased from about 1.4 to almost 3.5. Keep in mind the long-term data analysis (Figures 3.1a, 3.2a, and 3.3a) set included this outbreak, partially accounting for the 1.4 run length. These summary statistical analyses are thus able to detect changes in water quality.

Descriptors of Known Odorants

This portion of the research assessed the ability and variability in recognizing and describing specific odorants. The objective was to compare and contrast the responses of consumers who might contact their water utility concerning odors in the water and water utility personnel who might receive consumer feedback.

The first row in Figure 3.5 presents data for describing the odor of an orange extract used in food preparation. The extract was a combination of chemicals extracted from oranges. Oranges have 95% of their extract composed on d-limonene, and 70-96% of extracts of lemons, grapefruits, and mandarins are comprised of d-limonene (Viuda-Martos et al., 2009). Citrus, orange, and lemon are the dominant odor descriptors used by sensory scientists to describe d-limonene (Dravnieks, 1992), There was consensus among the three groups—WTP laboratory staff, WTP operators, and consumers— that citrus, orange, and lemon were the major descriptors for this common, everyday odor. The WTP laboratory staff had the fewest number descriptors and the least diversity. The minor descriptors also tended to relate to orange, lemon, and citrus and included common consumer products like lemon-scented cleaning products ("Lemon Pledge" and duster spray) or candy (hard candy, "Sour Patch Kids"). This attribute of naming a product that contains the odor of interest rather than the odor itself is common as humans associate odors with personal experiences. Overall, the three groups were equally successful and equal in describing orange extract, which represented a familiar odor.

The second row in Figure 3.5 presents descriptors for the three groups when they assessed 2-MIB. The musty odor of 2-MIB is very common in drinking waters throughout the world (Jüttner and Watson, 2007; Piriou et al, 2009; APHA, 2012). Earthy-musty is a main category on the Drinking Water Taste and Odor Wheel (APHA, 2012). The range for the odor detection threshold is 1-10 ng/L 2-MIB (Rashash et al., 1997; Piriou et al., 2009). In sensory science, the composite terms earthy-musty-moldy and woody-resinous" are the dominant descriptors for 2-MIB (Dravnieks, 1992). The major descriptors given by the WTP laboratory staff and WTP operators were musty and earthy followed by dirt. The minor descriptors were often words similar to musty and earthy, such as moldy, grassy, mushroom, and fungus. In contrast, the consumers infrequently used musty or earthy and the major descriptor was dirt, which describes a product with the characteristic odor, rather than being an odor descriptor. There was much less consensus among the consumer group, with similar weight given to camphor, drug, wet, pond, bread, wood, chlorine, and other descriptors. Overall, the WTP personnel were more successful than the consumers in describing 2-MIB with descriptors of musty-earthy-moldy, which are applied by sensory scientists (Dravnieks, 1992).

The third row in Figure 3.5 presents descriptors for the three groups when they assessed DMTS. In actual drinking water, sulfurous odors occur as a combination of hydrogen sulfide and volatile organic sulfur compounds (VOSCs), including DMTS, that occur in groundwater (Franzmann et al., 2001), surface water (Gun et al., 2000), distribution systems (Wajon et al., 1985), and biofilms (Heitz et al., 2000). DMTS has an odor detection threshold of 9.9 ng/L in water (Czerny et al., 2008). Sensory scientists diversely described DMTS as onion-garlic, sulfidy, sickening, putrid, sour, burnt-smoky, cooked vegetables, and sweaty (Dravnieks, 1992). The WTP laboratory staff had the least diverse descriptors of all three groups, and theirs were the most similar to the sensory scientists, such as garlic and onion; they also described DMTS in terms of commonly cooked vegetables that contain this odorant, including broccoli and brussels sprouts. The WTP operators had an even more diverse set of descriptors than the laboratory staff. Many pertained to onion-garlic-sulfidy-sickening-putrid, including the dominant descriptor propane, as this fuel is augmented with sulfur-smelling ethyl mercaptan. The consumers provided descriptors that had no consensus and were largely unique descriptors for each participant; the consumer descriptors were almost absent of standard sensory descriptors related to onion-garlic-sulfidy-sickening-putrid (Dravnieks, 1992).

DISCUSSION

Utility Data

The lack of consistent descriptors and varying recording techniques, from paper to electronic, within a utility limits the ability to quickly and easily draw conclusions by examining consumer feedback. Variable descriptors for the same water quality issue also prevent analysis by automation and therefore, require a great deal of user intervention. A more formal and consistent terminology for recording consumer complaints would allow a utility to easily summarize the data with standard database/spreadsheet features, such as pivot tables and cross tabulations. Automation not only saves the utilities time in the long run, but also allows efficient generation of visual aids (radar plots, run-time plots) and allows data review in a more frequent timeframe than most utilities currently employ (Whelton et al., 2007; Ömür-Özbek, 2012).

Comparing consumer reported water quality problems across utilities would be helpful for consecutive distribution systems, utilities that wholesale water, utilities that sell water to neighboring utilities, or even utilities that use the same water source. Unfortunately, the descriptors between the four utilities participating in this project varied so much that this comparison was difficult. For example, Utility U1 records complaints with terms rusty and sewage. Utility U2 uses the terms rust and sewer, rotten egg, and sulfur. As utilities become more interconnected through water wholesaling and consecutive systems, this lack of consistency also makes automated analysis more difficult as computerized system would treat different spellings/misspellings as different types of problems. Utilities would benefit from adopting a check-sheet or computer screen with specific descriptors (Whelton et al., 2007) and implementing the drinking water taste and odor wheel (APHA, 2012) and particle identification schemes (Booth and Brazos, 2004). The utility personnel acknowledge that writing descriptors is problematic and that a check-sheet approach would be improve recording complaint data for both written and electronic data gathering (Ömür-Özbek, 2012; Gallagher and Dietrich, 2014). In Quebec, analysis indicated that an effective consumer feedback program would be one that considered the number of complaints, socio-economic level of the consumer, and detailed descriptions of the taste, odor, or color agents associated with the complaint (Montenegro et al., 2009).

Descriptors of Known Odorants

The WTP laboratory staff, WTP operators, and consumers were similar in their ability to describe the familiar odor of orange extract. They differed in their abilities to describe less common odors of 2-MIB and DMTS. The WTP laboratory staff, who routine use chemicals and evaluate water quality, were able to best describe these two odorants in the same terms as used by sensory scientists. The consumers, who use tap water and are less likely to be familiar with chemicals and water quality, were very diverse in their descriptors and used terms very unlike the sensory scientists for 2-MIB and DMTS. Consumers' main concern is the quality of the water and whether or not it is similar on a day-to-day basis and is it safe to drink. Consumer judgment of water may be different from water industry professionals because WTP professionals are focused on water quality and have access and knowledge of detailed water quality data on a daily basis.

Odor memory in humans plays a substantial role in odor recognition because when an odor is encountered, it is often remembered over very long times. However, there is an issue associated with odor memory such that one can perfectly recognize an odor, but often forgets the name and thus, associates the odor with a name of a similar odor (Jonsson and Olsson, 2003; Meilgaard et al., 2006). For example, the general public group and WTP operators in this study may have encountered the musty odors previously, but were unable to recall the name of the odor when presented with 2-MIB, thus, calling it multiple names as shown in Figure 3.5. The WTP laboratory personnel encounter the 2-MIB and DMTS odors and associations frequently in their laboratory, thus, their odor memory may be better than the other subject groups, leading to a less variable list of descriptors. Equally, humans also tend to recall a name, but associate the name with a different/similar odor and may mentally transfer the odor's characteristics with the new name (Köster et al., 2002; Meilgaard et al., 2006). This may have happened across all groups, leading to multiple odor descriptors for both 2-MIB and DMTS. Orange extract, on the other hand, had the least variable list of descriptors, and this may be due to the subjects' greater familiarity with orange smelling products and foods. Consequently, the lemon, citrus, and sweet descriptors are all odor associates with the orange-like odor from the extract. Additionally, all three test odors may be common to humans in foods and the environment, but these odors are not expected to be in water (Dietrich, 2006) and are difficult to describe in an unusual context (Köster, 2005).

For humans, knowing the name of an odor usually blocks the ability to develop a new implicit memory or description for it (Degel and Köster, 1999; Degel et al., 2001; Rouby et al., 2002). Researchers found that training in odor identification makes odors more interesting to the human senses, but humans can no longer experience the natural emotional impact of odors after they are trained (Rouby et al., 2002). Thus, sensory evaluation experts are often not good predictors of consumer reactions to products, or in this research, water quality changes. For this reason, consumers are sentinels for water quality monitoring because they are located at the water tap at all times and are prone to sense minor changes in their water quality (Dietrich, 2006; Gallagher and Dietrich, 2014). Even though the general public had more of a difficult time naming the odors of 2-MIB and DMTS than the WTP operators and laboratory personnel, they are more likely to detect a change in the water quality than the professionals. In their line of work, WTP professionals are more likely to know the names of those odors and recognize it more than the general public, but they may be hindered in detecting a variance in the odor of the water supply because they do not experience that "natural emotional impact of odors" like the average consumers would.

Identifying odors in drinking water is similar to perfume engineering, design, performance, and classification. When naïve subjects are asked to classify odorants in a perfume study, their descriptors were influenced by emotional, subjective, and past experiences; the descriptions were ambiguous, individual dependent, and difficult to materialize (Chastrette, 2002; Teixeirs et al., 2013). This study found that the more objective descriptions and formal terminology were classified by trained perfumers (Milotic, 2003; Teixeirs et al., 2013) and not regular consumers. WTP professionals may not be trained sensory panelists, but the chances of them encountering and being knowledgeable of the 2-MIB and DMTS odors in raw or treated water are far greater than the average consumer. Hence, this may be the reason why the lists of descriptors in Figures 3.5 were more objective for the WTP professionals than the general public.

Consumers have preferences for flavor in drinking water, but it is hard for them to explicitly describe a water's flavor, especially if the characteristics of the flavor are different from the expected or learned attributes, such as chlorinous or metallic/rusty tastes in tap water (Burlingame and Mackey, 2007). When consumers smell odors that they cannot describe, they often incorrectly reason the cause of the odor and make inaccurate associations (Köster, 2005; Burlingame and Mackey, 2007). For example, some consumers correctly described geosmin and 2-MIB tainted tap water as musty, moldy, dirty, mildew, earthy, potting soil, or woody, but some consumers described the off-odors as chlorine, rubber, gasoline, sulphur, petroleum, metallic, and ammonia (Song et al., 2000; Burlingame and Mackey, 2007). Another case showed that consumers inaccurately described an algae-related cucumber (nonadienal) odor episode in drinking because it was not within their logical expectation; instead, the major descriptors included "chemical" and "metallic" (Burlingame et al., 1992; Burlingame and Mackey, 2007). Consumers are unwilling to describe an odor or name an odor accurately if it is not what they expected; hence, the three subject groups had difficulty describing DMTS because the onion/garlic odor is not a logical, expected, or frequent odor in drinking water. Additionally, 2-MIB had variable descriptors as well, but the list was wider for the general public because they may not directly associate the musty odor with drinking water, unlike the WTP professionals, who often associate and identify musty odors in drinking water.

It is important for consumers and WTP professionals to identify off-odors in the water in order to ensure safe and pleasing drinking water. WTP professionals may be better at narrowing down a descriptor due to their experiences; however, consumers are important pieces to the water treatment puzzle as well because they are the first responders to off-odors in the drinking water supply. Additional research should be pursued to further help and promote consumers to effectively communicate their senses to the utility professionals and water quality industry.

To accurately describe taste and odors in water, a utility should consider training a Flavor Profile Panel of utility staff and/or consumers (Devesa et al., 2007; Desrochers, 2008) according to Standard Method 2170 (APHA, 2012) or implement other simplified and standardized taste and odor protocols used in the water industry (Dietrich et al., 2004). Providing the drinking water taste and odor wheel and a check sheet to consumers would aid them in describing aesthetic issues. Knowledge about the specific cause of the taste, odor, or appearance issue is essential to resolving the problem through changes in treatment (Cooke et al., 2001; Bae et al., 2002; Ho et al., 2002; Devesa et al., 2007) or understanding and controlling of the problem in source water (Ventura et al., 1995; Fabrellas et al., 2004; Satchwill et al., 2007; Zhang et al., 2010; Zhang et al., 2013; Zhoa et al., 2013), public distribution system (Bruchet, 1999; Khiari et al., 2002), or premise plumbing (Heim and Dietrich, 2007; Maillet et al., 2009).

CONCLUSIONS

Consumers represent aesthetic water quality sensors that are continuously present throughout the water distribution system and who are concerned about drinking water quality. The human senses can readily detect differences. Since consumers do not have the extensive water quality training and exposure as water treatment plant staff, they represent naïve interpreters of water quality which means that they are very good at finding differences although often less able to describe the specific change in water quality, It is particularly difficult for untrained and naïve consumers to describe taste and odor in drinking water; visual changes, such as rusty or a specific color or turbidity, are easier for humans to describe. Utility staff should understand and accept that describing taste and odor issues is difficult, and thus not be frustrated when consumers are only able to report that the water is "different" or "not right" and cannot describe the specific odor or taste problem.

Routine tracking, categorizing, visualizing, and interpreting consumer feedback provides an effective means of assessing water quality throughout the distribution system. To achieve this, a systematic and long-term program for recording consumer feedback should be implemented and maintained. Tracking and categorization should employ a set of standardized descriptors such as the check-sheet that was previously developed and the drinking water taste-and-odor wheel. Visualization of the information provided by consumer feedback can be achieved through a variety of existing data tools including radar and run-time plots. Applying a systematic approach to gathering and processing consumer feedback data allows the data to be readily interpreted to identify aesthetic water quality issues which consumers are excellent at detecting and may simply identify a nuisance taste, odor, or appearance issue or may be and indicator of a more serious process control or security problem. Aesthetic issues should be addressed promptly by the utility to avoid loss of consumer confidence.

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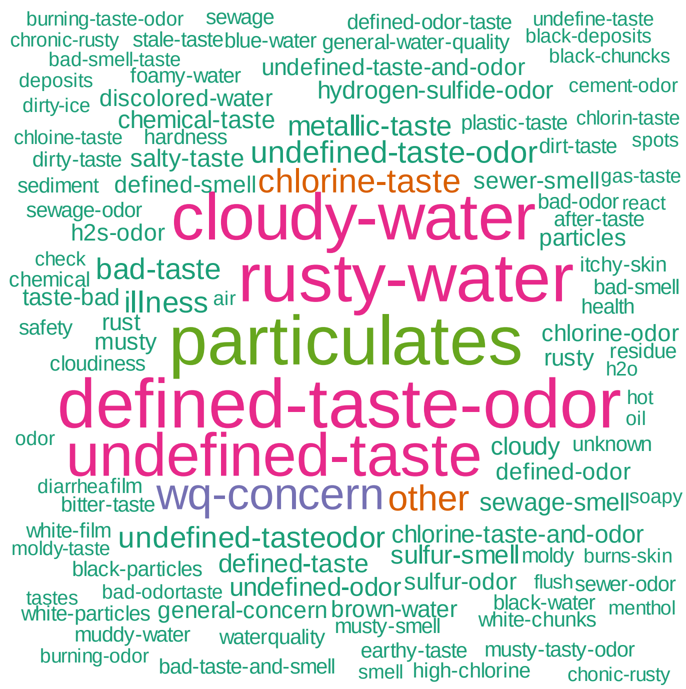
TABLES AND FIGURES

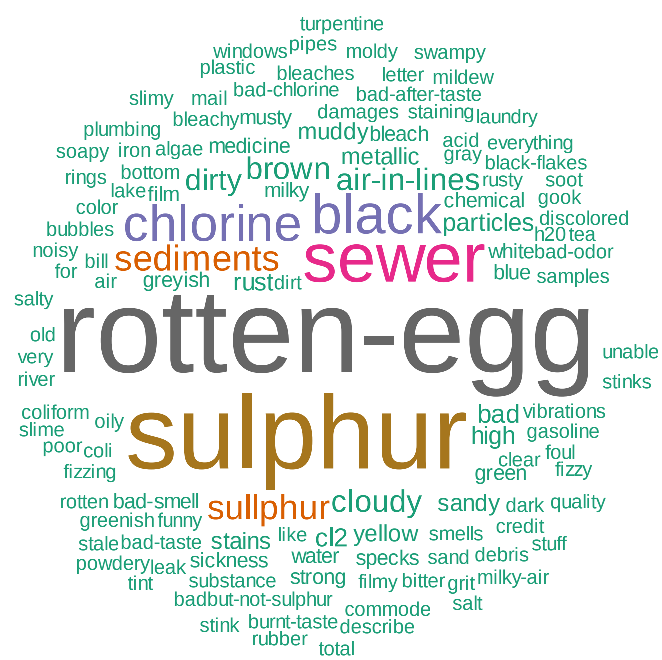
Table 3. 1. Summary Statistics for Number of Complaints

Utility ID	Service Population	Length of Record (days)	Total WQ Complaints	Mean Daily Complaint Frequency (std. deviation)	Mean complaint frequency per 1000 consumers per year
U1	330,000	2557	1421	0.56 (0.88)	0.61
U2	250,000	1461	1631	1.12 (1.35)	1.62
U3	675,000	455	768	1.69 (2.57)	0.91
U4[1]	600,000	2190	5793	2.64	1.61

[1] Utility U4 only kept summary counts by month, not daily data.



a) Utility U1



b) Utility U2

Figure 3. 1. Tag clouds of actual water quality descriptors used by consumers for (a) Utility U1 and (b) Utility U2

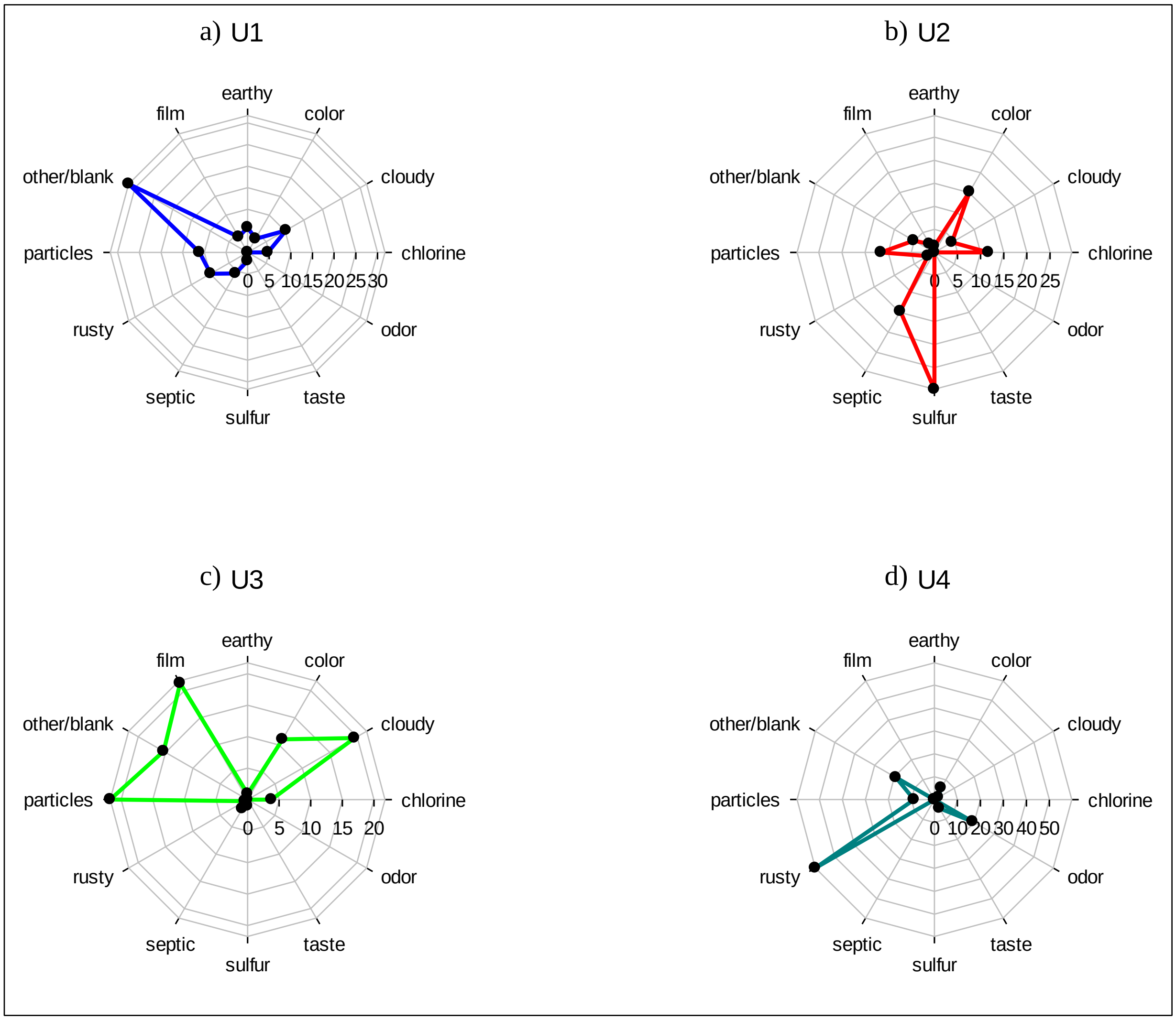


Figure 3. 2. Radar plot of complaint categories percent occurrence by utility. Note that the scale changes for each utility.

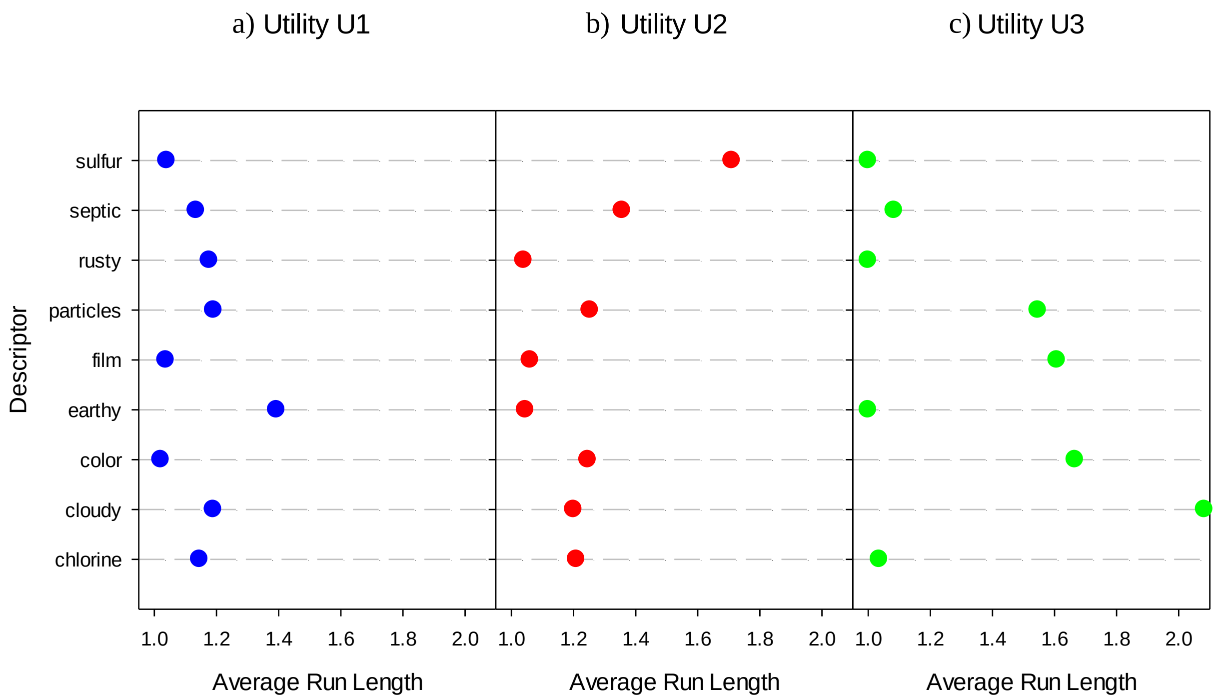
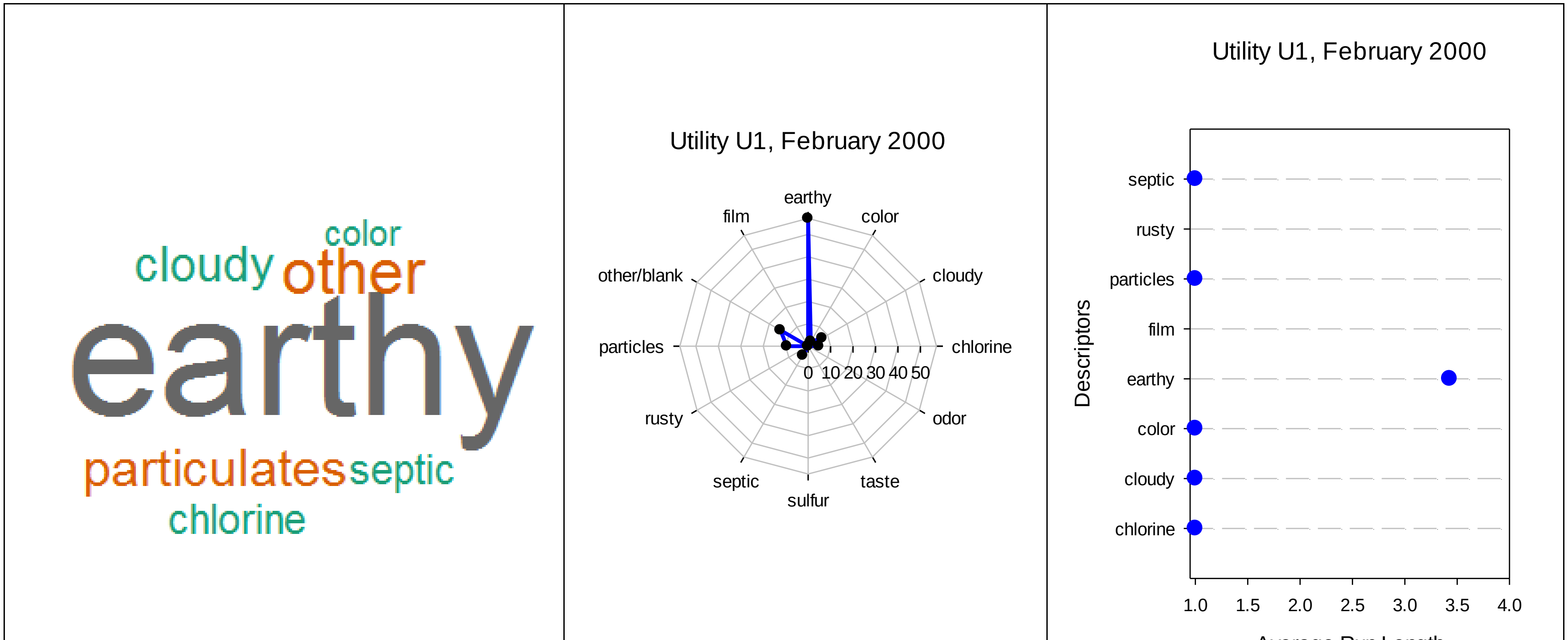


Figure 3. 3. Average run length for each descriptor category



a) Tag Cloud

b) Percent Occurrence

c) Average run length

Figure 3. 4. Tag cloud, percent occurrence, and average run length for Utility U1 in February 2000.

Odorant	WT laboratory personnel	WT plant operators	General Public
Orange Extract	lemon-lime oranges sweet fruit lemon citrus orange ketone orange-peel	lime hand-soap aromatic candy lemon orange pinesol citrus lemons lysol fruity	lemon-duster-spray lemonade oranges sweet lemon-lime lemon orange citrus sweet-lemon pledge lemon-cleaning-fluid orange-peel sour-patch-kids
2-MIB	weak-pinesol moldy-bread restroom camphor cloves medicinal mothballs dirty ammonia earthy musty leather grassy smokey old-lady-perfume	shoe-polish mushrooms moldy fungal ammonia grass musty piney earthy wet wax mold cave medicinal soil dirty flowers grassy pinesol mildew hunting-cover old-dudes	mothballs wet-wood medicinal earthy pills soil not-good moth medicine drug dirt cleaner chlorine no-idea musty mib camphor mold male-musk moldy-bread stagnant-pond
DMTS	rotten-garbage burnt-broccoli sulfur rotten putrid rotten-egg garlic rotting spice onion butter spoiled bad-fish garbage brussel-sprouts composite	hard-boiled-egg herbal garbage cheese-and-garlic-bread anchovies sulfur fishy decaying methane mothballs propane peppery medicinal decay rotten rotten-egg durian rot vitamine baby-formula garlic decaying-vegetation medicine rotten-bread	laquered natural good wood time bicarbonate idea acidic long gym wet earthy old base coal tea clothes poop drainage metallike nothing

Figure 3. 5. Tag cloud for each of the three odorants and three subject groups.