State of the Science:
Community Water Fluoridation

Web Report #4641

Subject Area: Water Quality
State of the Science:
Community Water Fluoridation
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EXECUTIVE SUMMARY

This report assesses the current practice of community water fluoridation (CWF). It describes the history and science of CWF and examines positions for and against CWF. The report also includes case studies of fluoridation practices and policies in six U.S. cities. The following sections describe the important points from this report.

HISTORY AND CURRENT PRACTICES

- In 1945, Grand Rapids, Michigan was the first city to practice CWF.十五 years of fluoridation data of schoolchildren showed a 60 percent decrease in decayed, missing, or filled teeth (NIDCR, 2014).
- CWF practices are reported to the Centers for Disease Control and Prevention (CDC) by 40 states (around 91 percent of utilities in the United States). CWF in the United States is currently practiced in approximately 16,000 utilities, which is about 38 percent of the utilities that report. Of those utilities that serve over 100,000 people, 90 percent add fluoride to their water. Many of the utilities that do not fluoridate are small systems.
- Since 1950, about 300 U.S. utilities have voted in some way to stop fluoridation. This represents less than 2 percent of systems who report that they fluoridate. There are many reasons that utilities choose to stop fluoridation, such as citizen opposition, cost savings, and natural sources of fluoride meeting CDC’s recommended concentration for tooth protection.

BENEFITS

- Drinking optimally fluoridated water is a good way to decrease the risk of tooth decay. Although fluoride is present in toothpaste, dental applications, and mouthwashes, these are temporary doses. Only drinking optimally fluoridated water provides the consistent fluoride concentration in the saliva and dental plaque that prevents oral bacteria from attacking tooth enamel and causing decay (Toumba and Curzon, 2001).
- The World Health Organization (WHO) stated in 2004 that poor dental health disproportionately impacted the least affluent segments of society in the United States. Both minorities and people living below the poverty line have higher rates of decayed and missing teeth (Hudson et al., 2007). WHO endorses CWF wherever it is feasible to implement, especially because it provides protection against dental problems for higher risk subgroups.
- The 1986 – 1987 Oral Health of United States Children survey found that reductions in dental caries plateaued at 0.7 to 1.2 mg/L of fluoride. Therefore, the 2015 U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation recommendation of 0.7 mg/L should be effective at reducing the risk of dental caries (NIDR, 1992).
CONCERNS

- There are health-related concerns including, but not limited to dental fluorosis, skeletal fluorosis, neurological effects, carcinogenicity, and endocrine disruption. Most of these concerns are cited by research done in areas of the world where there is endemic fluoride exposure due to naturally high water concentrations and high air concentrations due to coal burning. Generally, these concerns are not applicable to areas that practice CWF. Adverse effects of fluoride on the endocrine system have not been adequately researched to date.
- There are concerns about the safety of the additives used in CWF. These concerns include the possibility of the additives not completely dissociating in water (and being a health risk) and the concern for utility worker safety when handling the additives. Research indicates that the additives do completely dissociate in water and do not pose a health risk. Utility workers undergo training and certifications to protect their health as well as public health.
- There are some ethical concerns about CWF. Some view it as a forced form of mass medication, whose dosage cannot be controlled, and with no easy way to opt out. An alternate position is that the public has democratic representation at the state and local levels and has some control over CWF practices in their area. An individual in a community that practices CWF would need to remove the fluoride or purchase non-fluoride containing water in order to opt out.
- Cost-effectiveness of CWF has been brought up on both sides of fluoridation arguments. Fluoridation costs large utilities’ customers less than $1 annually per customer. The benefits have been estimated to be about $30 per customer annually in cost savings (per person) associated with caries treatment (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

CASE STUDIES

Six U.S. cities were studied in this report. Their fluoridation practices, policies, and discussions were examined and compiled. These case studies included cities that practice fluoridation and some that do not. The cities range in geographical location and populations. Cities included in the study are:

- Dallas, Texas (fluoridate to CDC recommendation)
- Phoenix, Arizona (fluoridate to CDC recommendation)
- Portland, Oregon (does not fluoridate)
- Albuquerque, New Mexico (does not fluoridate due to natural fluoride sources)
- Milwaukee, Wisconsin (fluoridate to CDC recommendation)
- Fort Collins, Colorado (fluoridate to CDC recommendation)
CHAPTER 1
INTRODUCTION

Community water fluoridation has been practiced in the United States since 1945. However, opposition to community water fluoridation has been increasing in the United States (Blumenthal, 2015). Many different concerns with fluoridation and fluoride exposure have been brought up by organizations and individuals. This report presents information on community water fluoridation (CWF), which includes its history, fluoride sources, and applicable standards. The report addresses some concerns about CWF and reviews case studies of fluoride debates in six U.S. cities. This report examines the latest science in an objective manner and does not make any recommendations on policy regarding community water fluoridation.
CHAPTER 2
FLUORIDATION HISTORY

HISTORY OF COMMUNITY WATER FLUORIDATION

In the early 1900s, researchers started to look into brown tooth discolorations in Colorado Springs, where 90 percent of people born in the area had some form of these discolorations. In the 1930s after studying communities that had similar dental conditions, the link was made between tooth discoloration and elevated fluoride levels in the drinking water. Through researching the cause of the discolorations, personnel at the Dental Hygiene Unit at the National Institute of Health (NIH) found that teeth with these discolorations (now known as dental fluorosis) were resistant to decay.

In order to test the theory that fluoride might help reduce the risk of tooth decay at low levels, the City of Grand Rapids, Michigan voted to add fluoride to their water (NIDCR, 2014). In 1945, Grand Rapids, Michigan became the first city to fluoridate its water to accomplish two things: to test large-scale community water fluoridation practices and to improve the oral health of Grand Rapids citizens. During the 15-year monitoring of Grand Rapids’ schoolchildren, there was a 60 percent decrease in tooth decay among those born after the addition of fluoride, compared to those born before (NIDCR, 2014).

The results of the Grand Rapids experiment showed significant improvement just seven years after fluoridation where a decrease in decayed, missing or filled teeth (DMF) was observed. In Figure 2.1, the DMF rate of children before fluoridation (1944-1945) is compared to after fluoridation was implemented (1951-1952). Data from Grand Rapids is also compared to data from Muskegon, MI and Aurora, IL. Grand Rapids and Muskegon had the same source water and similar treatment practices but only Grand Rapids implemented community water fluoridation. The city of Aurora, IL was chosen to establish an expectancy curve because it had a natural fluoride concentration of 1.2 mg/L (whereas Grand Rapids was feeding fluoride to obtain a 1 mg/L concentration). In Grand Rapids, dental caries in 6-year old children declined by 66.6 percent and 16-year old children experienced an 18.1 percent decline (Arnold et al., 1953).
Note: The impact of community water fluoridation in Grand Rapids is shown in the difference between the solid and dashed lines on the graph.

Figure 2.1 Comparison of dental caries experienced in permanent teeth of continuous resident schoolchildren of Grand Rapids and Muskegon, Mich., and Aurora, IL.

In the 1960s, 90 percent of adolescents had at least one permanent tooth with a cavity but that percentage had declined in 2004 to 60 percent. Adults have seen a decline as well, as all groups have experienced benefits of better dental care, diet and fluoridated water consumption (Dye et al., 2007). Tooth decay remains one of the most chronic childhood diseases and studies have shown that it varies by race/ethnicity and economic status. A recent study from the American Dental Association (ADA) has shown that minorities, disabled people and those of lower socioeconomic status are at the highest risk of tooth decay (Campbell, 2013).

Community water fluoridation (CWF) programs have been implemented across the country since 1945 and the Centers for Disease Control and Prevention (CDC) estimated that over 75 percent (210 million) of Americans drink water fluoridated to levels that prevents tooth decay (CDC, 2015). In 1982, the U.S. Public Health Service (PHS) suggested that the optimal level of water fluoridation to prevent tooth decay be between 0.7 and 1.2 mg/L. In 1986, the Environmental Protection Agency (EPA) set the maximum contaminant level (MCL) for fluoride in drinking water at 4 mg/L. The MCL still stands as the only enforceable limit on fluoride in drinking water and is only applicable to source waters with natural fluoride. The concentration recommended by the PHS and the CDC has been adjusted since 1982. The new recommendation is 0.7 mg/L, which
is currently believed to be the optimum level of fluoride that will prevent tooth decay and have a low risk of dental fluorosis (Public Health Reports (PHS), 2015).

The option to fluoridate drinking water is left up to state and local governments (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Some states have mandated fluoridation for certain utilities and some states allow individual communities to decide. Fluoride mandates and stipulations for all 50 states are tabulated in Appendix A. Twelve states have mandated fluoridation and the mandate is usually contingent upon the size of the utility. For instance, fluoridation might be required for plants that serve over 5,000 people.

The CDC provides technical support and guidance to those utilities that have decided or are required by their state to fluoridate. They provide training for plant operators, engineering support, and technical support on facility management and operations. The CDC also provides a detailed outline of recommendations for utilities that includes personnel management, reporting, training, inspections, monitoring, technical requirements for specific systems, and safety procedures for CWF (CDC, 2015d). The CDC collects data in its Water Fluoridation Reporting System (WFRS) on whether or not each participating utility fluoridates, and for some they also report the level of fluoride in their water (CDC, 2015b).

**FLUORIDATION PRACTICES IN THE UNITED STATES**

There are 40 states that report the fluoridation status (adding fluoride or not) of each utility to the CDC (CDC, 2015b). These data were combined with data from the Safe Drinking Water Information System (SDWIS) and were used to illustrate fluoridation practices in the United States – see Figure 2.2 (EPA, 2013). These data show that more utilities classified as large and very large practice CWF (76 and 87 percent, respectively) than smaller utilities (between 25 and 60 percent). This is partially due to budget and personnel constraints on smaller plants. The figures in this chapter label utilities as “fluoridated” or “not fluoridated”. These labels indicate whether a utility practices CWF and does not indicate any natural water fluoride levels.

The communities that have utilities serving greater than 100,000 people were mapped and were categorized as either fluoridating or not fluoridating to illustrate the practices of large utilities across the country. There are about 299 utilities in the United States that are classified as very large, and the CDC obtained information on fluoridation practices from 290 of them. Figure 2.3 shows utilities in the United States that serve over 100,000 people (who report their fluoridation status to the CDC), extracted from Figure 2.2 for clarity. This figure better illustrates that a majority of large plants practice CWF.

The same plants serving over 100,000 people, from Figures 2.2 and 2.3 are mapped in Figure 2.4. The green markers indicate that the utility fluoridates and the red marker indicates that it does not fluoridate. This map shows most of the very large utilities that do not fluoridate are located in Florida, where groundwater is primarily used as drinking water sources. The 36 very large utilities that do not fluoridate were investigated further. Table 2.1 shows the fluoride levels in source waters from each of these plants (very large plants that do not practice CWF). These data were obtained from individual utility water quality reports for 2014, unless otherwise noted. It can be seen that five of these utilities have naturally occurring fluoride near the CDC recommended concentration of 0.7 mg/L, meaning that only 31 very large utilities do not have optimally fluoridated water.
Fluoridation in the United States

Source: Data taken from EPA 2013 and CDC 2015b.

Note: The data presented in Figure 2.2 does not include the states of California, Connecticut, Hawaii, Maryland, Montana, New Jersey, New Mexico, Ohio, South Dakota, Washington or Wyoming, as they do not report data to CDC.

Figure 2.2 Fluoridation in the United States by population served
It should be noted that most very small and small utilities are not equipped to feed fluoride into their systems. It would require funding to obtain equipment and trained utility workers to add fluoride to many of those utilities. These small utilities are also often supplied by groundwater sources, which may have naturally occurring fluoride.

*Source:* Data taken from EPA 2013 and CDC 2015b.

Note: The data presented in Figure 2.3 does not include the states of California, Connecticut, Hawaii, Maryland, Montana, New Jersey, New Mexico, Ohio, South Dakota, Washington or Wyoming, as they do not report data to CDC.

**Figure 2.3**  Utilities serving over 100,000 people fluoridation practices
Source: Data taken from EPA 2013 and CDC 2015b.

Note: White lettering indicates utilities that fluoridate. Red lettering indicates utilities that do not fluoridate. The data presented in Figures 2.2, 2.3 and 2.4 and Table 2.1 do not include the states of California, Connecticut, Hawaii, Maryland, Montana, New Jersey, New Mexico, Ohio, South Dakota, Washington or Wyoming as they do not report data to CDC.

**Figure 2.4** Utilities serving over 100,000 people fluoridation practices map
Table 2.1
US utilities serving over 100,000 people that do not fluoridate and their natural fluoride levels

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<th>PWS name</th>
<th>State</th>
<th>County</th>
<th>Source</th>
<th>Fluoride levels lower range</th>
<th>Fluoride levels upper range</th>
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Source: Water quality reports 2014
* Data from 2013
** Data from 2008
BDL - Below detection limit
DNR - Did not report

Even though fluoridation is practiced in most large cities, as illustrated in the figures above, small selections of communities have recently rejected community water fluoridation. According to the Fluoride Action Network, the number of communities that have rejected fluoridation across all 50 states is around 310 (Fluoride Action Network, 2015). These numbers are based on the number of references to newspaper articles that were accessed by the organization. The 310 utilities that have rejected CWF represent about 2 percent of the utilities in the CDC database that
fluoridate. Out of the 40 states that report information to the CDC, about 15,440 communities continue to artificially fluoridate their water.

**DOCUMENTED HEALTH BENEFITS OF FLUORIDE**

Fluoride exposure has been documented to reduce the number and severity of dental caries – also known as cavities. Dental caries are permanently damaged (holes and openings) of the tooth surface. There are multiple reasons why people can develop dental caries and these can include improper dental care and increased sugar intake. Bacteria, which often thrive on sugar, produce acids in their biofilm (called plaque) that can remove the minerals in tooth enamel. Untreated cavities can lead to pain, sensitivity, infection and tooth loss. The most common treatment for minor cavities is filling the cavity with material that replaces the hard surface of the tooth. More severe problems can lead to the entire tooth being removed. Tooth decay is most common in children and elderly people (Mayo Clinic, 2015a). Cavities can cause significant deterioration of a person’s quality of life and can affect their ability to accomplish everyday tasks; therefore, it is an important public health issue.

Fluoride helps prevent tooth decay in multiple ways. Fluoride decreases demineralization of tooth enamel by altering the tooth’s chemical make-up. Hydroxyapatite (HAP) is a mineral naturally found in tooth enamel; its chemical formula is Ca\(_5\)(PO\(_4\))\(_3\)OH. When fluoride is applied to teeth, the fluorine ion (F\(^-\)) replaces the hydroxyl molecule (OH\(^-\)) to create fluoroapatite (FAP), chemical formula Ca\(_5\)(PO\(_4\))\(_3\)F. FAP shows higher resistance to acids and its presence in enamel makes teeth more resistant to demineralization and therefore resistant to tooth decay. Fluoride has also been shown to negatively impact harmful oral bacteria that cause tooth decay. Recently a study showed that fluoride reduces the adhesion ability of harmful oral bacteria that cause plaque and subsequently tooth decay. If the bacteria that commonly cause plaque have lowered adhesion abilities, they are easier to remove via brushing and the risk of tooth decay is lowered (Loskill et al., 2013).

A constant low concentration of fluoride in saliva and dental plaque encourages FAP production and keeps the risk of tooth decay low. Drinking optimally fluoridated water is an effective way to consistently keep the fluoride concentrations in the mouth at appropriate levels to prevent tooth decay. Dental products, professional fluoride applications and mouth washes elevate the fluoride levels in saliva and dental plaque to an optimum level for shorter periods of time after application, whereas drinking fluoridated water keeps fluoride levels optimum all day long (Toumba and Curzon, 2001).
CHAPTER 3
FLUORIDE SOURCES

FLUORIDE IN DRINKING WATER

Fluoride is an abundant naturally occurring ion and can be found in drinking water sources across the world. Fluorine does not occur naturally in the elemental state, but is often as an ion with a negative one charge (F⁻) or associated with other elements to form molecules or compounds such as hydrogen fluoride, sodium fluoride and fluorosilicic acid (FSA). The types of rocks and minerals in surrounding areas usually determine raw water’s fluoride levels. Erosion and subsequent dissolution of rocks and minerals that contain fluoride can increase the levels of fluoride in nearby water sources, especially groundwater (WHO, 2004). Most drinking water sources have some naturally occurring fluoride, but it varies across regions and has not been documented to exceed 10 mg/L in the United States. Naturally occurring fluoride is regulated by the Safe Drinking Water Act. The current standards will be discussed later in this report.

Since 1945, artificial fluoridation of drinking water has increased in the United States. Community water fluoridation is practiced at 38 percent of the utilities that report fluoridation practices to the CDC, where 32 percent of US utilities report that information. The CDC estimated that 68.8 percent of people who receive their water from public water systems were drinking optimally fluoridated water in 2000 (Committee on Fluoride, 2006). The CDC and the Public Health Service (PHS) publish recommendations for optimal levels for CWF. The optimum level is considered to be 0.7 mg/L, which will prevent tooth decay and has only a small risk for dental fluorosis (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

Fluoride is added to drinking water when levels are below the recommended value of 0.7 mg/L or a locally mandated level (many states still require the 0.8 to 1.2 mg/L range and have not yet changed to the 2015 CDC/PHS recommendation). Since fluorine (F) is very reactive and does not occur in its elemental state in nature, fluorides are used as additives in CWF practices. There are three additives that are commonly used in CWF, and they include fluorosilicic acid (H₂SiF₆), sodium fluoride (NaF) and sodium fluorosilicate (Na₂SiF₆). All three of these compounds help create fluoridated water that is comparable to naturally occurring fluoride (Finney et al., 2006). FSA achieves complete dissolution and ionic disassociation, which means that there are silicon, hydrogen and fluoride ions in the water and not fluorosilic acid at the end of the treatment process (equation 3.1). The reactions of sodium fluoride and sodium fluorosilicate can be seen in equations 3.2 and 3.3.

\[ H₂SiF₆ + 4H₂O \rightleftharpoons 6H^+ + 6F^- + Si(OH)₄ \] \hspace{1cm} (3.1)

\[ NaF + H₂O \rightleftharpoons Na^+ + F^- \] \hspace{1cm} (3.2)

\[ Na₂SiF₆ + 4H₂O \rightleftharpoons 4HF^- + 2NaF + Si(OH)₄ \] \hspace{1cm} (3.3)

The compound most often used, especially in large water plants, is fluorosilicic acid (H₂SiF₆) due to the transportation convenience and cost effectiveness of it being in a liquid state. Smaller plants tend to use sodium fluoride (NaF) which is transported and stored as a solid. In addition to fluoridation compounds, many other chemicals are routinely added to water throughout

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the treatment process. The addition of chlorine to drinking water for disinfection began being practiced at surface water plants in 1908, and is typically fed in liquid form by large utilities (some still use gas form but many are moving to a liquid form). Other chemicals are used in the water treatment process for a variety of reasons. Caustic soda is used as a pH buffer, phosphoric acid as a corrosion inhibitor and aluminum sulfate and different polymers are used as coagulant aids. Chemicals such as these, and others that are used in the water treatment process, require special care when handling. Utility workers are properly trained and certified to ensure their own safety as well as the safety of the public.

OTHER SOURCES OF FLUORIDE

People are exposed to fluoride in other ways besides drinking water. In the United States, most people use fluoridated toothpaste and/or other dental products such as mouthwashes. In 1955, the first fluoridated toothpaste entered the consumer market and now most toothpaste is fluoridated to prevent tooth decay. PHS estimates that 90 percent of toothpaste on the market has fluoride in it (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Fluoride mouth rinses as well as professionally applied fluoride treatments are also common sources of fluoride. Generally, toothpaste contains 1000-1500 mg of fluoride per kg of toothpaste and is a reasonable concentration for topical applications (WHO, 2004). Some popular toothpaste brands (Colgate and Sensodyne) contain sodium fluoride (NaF) and some (Crest) contain stannous fluoride (SnF₂) as fluoridating agents (Drugs, 2015).

In addition to the topical fluoride exposure that dental products provide, the exposure by accidental ingestion of these products should also be considered. Toothpaste and mouthwash that have been accidentally swallowed (not recommended by manufacturers) accounts for 20 percent of fluoride intake in children between the ages of 1 and 3 years (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

Instead of community water fluoridation, many countries, including France, Germany, Switzerland, Jamaica and Costa Rica have chosen to fluoridate salt. The goals of this practice are similar to CWF; to provide fluoride to citizens at a level to prevent tooth decay. The first studies on the effectiveness of fluoridated salt were in Switzerland, Hungary and Columbia between 1965 and 1985. The number of teeth with signs of caries was reduced by 50 percent in these areas. Jamaica has been fluoridating 100 percent of the salt designated for human consumption since 1987 and have seen a 50 percent reduction in the mean number of decayed, missing, and filled teeth (Marthaler and Peterson, 2005). Fluoridated salt can reach consumers in many different ways including use of table salt, cooking and baking with salt in private homes, use of salt in processed and pre-made foods as well as at restaurants. Fluoride is often found in the form of sodium fluoride (NaF) or potassium fluoride (KF) in fluoridated salts (Marthaler and Peterson, 2005).

In addition to ingestion of water or salt and the use of dental products, people can be exposed to fluoride through the air. The ambient air concentrations of fluoride vary greatly by geographical region across the world. Natural background concentrations are around 0.5 ng/m³. There are some places such as certain provinces in China that have indoor air fluoride concentrations between 16,000 and 46,000 ng/m³ due to the indoor combustion of high-fluoride containing coal. In the Netherlands, there are air fluoride concentrations up to 70 ng/m³ (WHO, 2004). In China, the burning of high fluoride coal has led to endemic occurrences of skeletal and dental fluorosis. The coals in China can have fluoride contents up to 1230 mg/kg with a mean of 167 mg/kg. This is higher than either Australian or Canadian coal, which have upper ranges of
about 500 mg/kg (Wu et al., 2004). One study in China collected information about indoor air concentrations of fluoride in areas that had a high amount of dental and skeletal fluorosis and found that the average indoor air fluoride concentrations were around 74.4 µg/m³ (Ando et al., 1998). The concentrations reported by Ando et al. in China are about five orders of magnitude higher than the natural background air concentrations referenced by the WHO. The ambient air concentrations of fluorides in the United States were less than 1 µg/m³ in 2003 near cities and even lower in rural areas (USHHS, 2003).

Total exposure to fluoride varies greatly with geographical location and can depend on factors such as fluoride concentrations in drinking water, food, beverages, the air, and dental products. Some studies reported that the total fluoride exposure can range between 0.46-5.4 mg/day for an individual. In places where fluoride content in coal is high, such as China, the daily intake of fluoride can be 2.3 mg from the air and 8.9 mg from food. Volcanic regions have naturally high fluoride content in the water and can lead to exposure up to 30 mg/day (WHO, 2004).
CHAPTER 4
FLUORIDE STANDARDS AND RECOMMENDATIONS

In the United States, the U.S. Environmental Protection Agency (EPA) is responsible for establishing and enforcing standards to protect the health of both the human population as well as the environment. Under The Safe Drinking Water Act, the EPA is required to establish allowable concentrations for different pollutants in drinking water. The maximum contaminant level (MCL) is an enforceable standard that the EPA has concluded causes no known or expected adverse effects to human health. There are also secondary maximum contaminant levels (SMCL) that are non-enforceable guidelines to address drinking water aesthetic, cosmetic or technical effects. The MCL for fluoride in drinking water is 4 mg/L and is accepted as a concentration that is not likely to cause skeletal fluorosis. The SMCL for fluoride is 2 mg/L and is recommended to reduce the risk of cosmetic dental fluorosis. These standards restrict the amount of naturally occurring fluoride in drinking water, and are not recommended for artificial fluoridation (Committee on Fluoride, 2006).

The MCL is set as close as possible to the maximum contaminant level goal (MCLG) as possible. The MCLG is determined by examining health effects of contaminants and uses that information to establish an exposure level that no documented or expected adverse health effects would occur. A margin of safety is added to establish the final MCLG (Committee on Fluoride, 2006). In 1986, the EPA set the MCLG for fluoride at 4 mg/L to prevent against (clinical stage II) skeletal fluorosis. The level was based on the lowest observable adverse effect level (LOAEL) of 20 mg/day, which was based on case studies by Moller and Gudjonsson in 1932. It was assumed that an adult would consume the recommended 2 L of water a day. They then applied a factor of safety of 2.5 (Committee on Fluoride, 2006).

Three adverse health effects were used to evaluate the MCLG effectiveness at protecting public health: severe enamel fluorosis, skeletal fluorosis and bone fracture. Only severe enamel fluorosis was considered as an adverse health effect (as opposed to mild forms), where pitting of teeth and enamel loss occurs. It was determined that the MCLG did not protect against severe enamel fluorosis, but the SMCL of 2 mg/L did. It was determined that more research needed to be done on fluoride ingestion, fluoride concentration in the bones and the stage of skeletal fluorosis and the prevalence of bone fractures to be sure that the MCLG protected against these effects (Committee on Fluoride, 2006). The EPA concluded that stage III, or “crippling” skeletal fluorosis was rare in the United States but there was not enough research to conclude whether stage II would be avoided with the MCLG of 4 mg/L.

The U.S. Public Health Service (PHS) establishes recommendations for community water fluoridation. These recommendations are the optimal level of fluoridation for preventing cavities but do not cause dental fluorosis. The current recommendation, released in 2015, for the optimal level of fluoride is 0.7 mg/L. This was revised from the previous recommendation of 0.7-1.2 mg/L that was established in 1962. The reasoning for the change in recommendation was based on the increasing exposure to fluoride from other sources such as dental products, current evidence on water intake among children, and trends in dental fluorosis (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). A survey by the Oral Health of United States Children reported that the occurrence of dental fluorosis was negligible at 0.7 mg/L water fluoride concentrations (NIDR, 1992). The survey also found that reduction in cavities plateaued at fluoride concentrations between 0.7 and 1.2 mg/L and concluded that the new recommendation should have the same level of tooth decay prevention as the older

Communities that artificially fluoridate their water are encouraged to accept the PHS recommendation but are not legally held to any fluoride concentration other than the MCL. For obvious economic reasons, utilities usually do not fluoridate more than is recommended by the PHS or their state. Some states have requirements for fluoridation that are slightly higher than the newly recommended value of 0.7 mg/L but generally fall within the older recommendation between 0.7 and 1.2 mg/L.
CHAPTER 5
CONCERNS WITH FLUORIDE IN DRINKING WATER

This section addresses concerns that have been brought up by the public, the science community and community organizations. It aims to give an objective review of the available information and the latest science on community water fluoridation and general fluoride exposure. There are many different concerns that have been cited and include, but are not limited to the following:

- Health concerns of fluoride exposure
  - Dental fluorosis
  - Skeletal fluorosis
  - Neurological effects
  - Carcinogenicity
  - Endocrine disruption
- Dosage control
- Health concerns of fluoride additives used in CWF
- Ethical concerns
- Cost effectiveness

HEALTH CONCERNS

There has been an increase in opposition to CWF in recent years in the United States as well as internationally. Partially in response to opposition in Ireland, the Irish Health Research Board recently released its findings of a systematic review of the health impact of consuming artificially fluoridated water with concentrations between 0.4 and 1.5 ppm. This review examined over 140 peer reviewed journal articles on the health effects of fluoride up until 2014 (Sutton et al., 2015). This review is very useful in helping to evaluate the preponderance of information that is available on the subject matter and will be referenced throughout this section.

Dental Fluorosis

Exposure to higher levels of fluoride during tooth development in children can sometimes lead to a visible change in the color of the tooth enamel. This is referred to as dental fluorosis. Fluoride exposure can occur through ingestion of fluoridated drinking water, fluoridated dental products, and food containing fluoride. The EPA estimates that around 20 percent of fluoride ingestion by children is attributed to accidental swallowing of fluoride toothpaste (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Inhalation of fluoride from the air is another exposure pathway.

Dental fluorosis symptoms include white lacy markings on teeth and when there are high exposure cases, such as in endemic areas where there are naturally high fluoride concentrations in drinking water, dental fluorosis can exhibit as brown staining and pitting of teeth (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Mild dental fluorosis is cosmetic in nature and does not affect the functionality of the tooth enamel. Moderate to severe dental fluorosis can affect the functionality of the tooth enamel and the
structural integrity of the tooth but the prevalence of severe fluorosis is close to zero when water fluoride levels are below 2 mg/L (Committee on Fluoride, 2006).

The prevalence of dental fluorosis has increased since the 1980s in the United States but almost exclusively in the very mild or mild form. The increase in dental fluorosis is one of the main reasons that the PHS altered its recommended concentration for CWF. Concerns about dental fluorosis were raised when the new PHS recommendation for CWF concentration was released for public comment. The PHS concluded through evaluation of studies and surveys, that the new recommendation will decrease the risk for mild dental fluorosis while still reducing the risk of tooth decay. The cases of fluorosis in the United States are mostly very mild to mild cases (90 percent) and severe dental fluorosis is very rare (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

Concerns about the fluoride exposure to formula-fed infants and the increased risk of fluorosis was also mentioned in public comments regarding the new CWF concentration recommendation. The PHS acknowledged that there may be an increased chance of dental fluorosis in formula fed infants. The PHS recommended using low fluoride bottled water if infants are in areas where the water has fluoride in it. This should be practiced either part of the time or all of the time when mixing formula (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Most infant formulas contain low levels of fluoride and mixing it with water that has fluoride in it regularly can increase the chance of dental fluorosis. Children who are developing their permanent teeth are more susceptible to dental fluorosis than people whose permanent teeth are fully developed. An infant who is only consuming formula mixed with fluoridated water could get higher doses of fluoride than the 2 mg/L SMCL, which is intended to reduce the risk of dental fluorosis. The CDC does not encourage formula feeding infants when breastfeeding is an option, as this is nutritionally ideal for infants, regardless of the fluoride levels (CDC, 2015c).

**Skeletal Fluorosis**

Skeletal fluorosis is a medical condition that can occur after high and prolonged ingestion of fluoride. Its symptoms include stiffness and pain in joints in the early stages and in advanced cases (crippling skeletal fluorosis), the bone structure can change and ligaments can start to calcify (WHO, 1998). Fluoride accumulates in the bone, but for skeletal fluorosis to occur, a long term and high level of fluoride exposure must occur (Committee on Fluoride, 2006). The EPA indicates in the Integrated Risk Information System (IRIS) that the development of crippling skeletal fluorosis requires the consumption of around 20 mg/day over about a 20-year period. The EPA cites that there have been no documented occurrences of crippling skeletal fluorosis in the United States at levels below the MCL of 4 mg/L. They estimate the total fluoride consumption from diet (around 0.01 mg/day) and water consumption (8 mg/day for consuming 2L of water at 4 mg/L) of a 70 kg adult to be about 0.12 mg fluoride/kg/day or 8 mg/day. This is much lower than the 20 mg/day that would be required to develop crippling skeletal fluorosis (EPA 1987). At a water level of 0.7 mg/L, one would need to drink about 14 L of water per day for every day for 20 years to reach the 20 mg/day value. The review by the Irish Health Research Board found that skeletal fluorosis is only a potential health issue in areas with naturally high fluoride levels (anything greater than the WHO limit of 1.5 ppm) and that areas where CWF is practiced it is not an issue (Sutton et al., 2015). The WHO limit of 1.5 ppm was used as a reference for the Irish review.
because that review included studies that occurred all over the world, and different governments have different limits and standards and different exposure rates.

Neurological Effects

There have been concerns that fluoride in drinking water can be associated with lowered IQ and neurological effects. The studies that are often cited were conducted in endemic areas of the world with naturally high fluoride levels in drinking water (up to 11 mg/L). The Irish review examined six cross-sectional studies and six reviews that examined the neurological or IQ effects that fluoride levels in drinking water may have. Most of the studies were deemed to be of low quality and were not of a design to prove or disprove any theories. The review pointed out many research deficiencies associated with the studies on the neurological effects of fluoride exposure. Research deficiencies included omitting the ranges of fluoride exposures, not addressing other causes for reduced IQ such as other chemicals and mineral deficiencies (arsenic or lead exposure and iodine and iron deficiencies), and not addressing other sources of fluoride besides drinking water such as air and food (Sutton et al., 2015). The review also described multiple studies done in China that did not define low versus high water fluoride levels and/or low versus high IQ.

Mental IQ is difficult to measure objectively in studies. Lack of a standard testing or procedures occurs throughout the literature on the matter (Sutton et al., 2015). Failure to address other sources of fluoride and other possible chemicals that could lead to lowered IQ is a significant flaw in these studies. Many of the studies were carried out in China, where drinking waters have naturally high fluoride levels. China also has historically high concentrations of fluoride in the air, due to the burning of high fluoride content coal indoors with low ventilation. A study on the fluoride levels in Chinese coal found that the mean coal fluoride concentrations was 167 mg/kg, with ranges up to 1230 mg/kg of fluoride. This was compared to Australian and Canadian coal, which had 110 and 154 mg/kg, respectively. The main sources of fluoride in villages with endemic fluorosis is from the clay that they mix with coal to make coal-clay that people burn inside poorly ventilated homes (Wu et al., 2004). Ando et al. also found that indoor fluoride air concentrations in some areas of China reached around 7.4x10⁻⁵ mg/L, almost five orders of magnitude higher than natural background concentrations (Ando et al., 1998). A significant exposure to fluoride from the air must be addressed in any studies conducted in geographical areas where high fluoride coal is being burned.

The Irish review indicated that lowered IQ as a result of fluoride exposure has not been reported for areas with CWF. Because of the low quality of the many studies in areas with high levels of naturally occurring fluoride it is difficult to draw conclusions about the relationship between drinking water fluoride levels and IQ or the level of neurological effects.

Carcinogenicity

Concerns have been raised about fluoride exposure’s potential to cause cancer, specifically osteosarcoma, a cancer of the bone. One study that was conducted linked osteosarcoma to fluoride exposure using residence history and corresponding community water fluoride levels. The study reported a statistically significant correlation between osteosarcoma and water fluoride levels in young males but not females (Bassin et al., 2006). Later a study conducted on confirmed bone cancer patients was done. The fluoride content of cancerous benign bone tumors was measured for these patients. This procedure is a more accurate indication of fluoride exposure and its relation to
bone cancer than of residence history. The researchers measured fluoride levels in bone tumors where the investigators were blinded to the status of the bone specimen (cancerous or benign). Each specimen was tested twice and if the fluoride concentration was over 10 percent different between the two tests, it was tested a third time. This last study found no statistically significant association between bone fluoride levels and osteosarcoma (Kim et al., 2011).

**Endocrine Disruption**

A substance is considered an endocrine disruptor when it alters the endocrine system in the body. The endocrine system consists of glands, hormones and receptors that help to regulate many different biological processes. Disruption in this system can lead to health problems such as thyroid disease and diabetes. The review done by the Irish Health Research Board acknowledged many different papers on the topic and concluded that there were inconsistent results, where some showed links between fluoride exposure and different health effects involving the endocrine system and some showed none (Sutton et al., 2015). The PHS cited the National Research Council’s report in 2006 that came to similar conclusions that there was not enough consistent data on the subject and that some studies had insufficient information on nutritional practices and other factors that might confound the results. The NRC called for more research on the matter to characterize the mechanisms, both direct and indirect, of fluoride’s effect on the endocrine system and to establish factors that would determine responses (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

**Dosage Control**

Community water fluoridation’s effectiveness and safety is reliant on some assumptions about public water consumption. Because an individual’s fluoride dose is dependent upon water intake there can be variability in fluoride consumption. While it is true that water consumption can vary by individual, the MCL is intended to protect against even large water intakes. The MCL of fluoride was based upon the oral reference dose (RfD) that has shown no-observable adverse effects. The RfD is an estimate of daily exposure that is likely to be without an appreciable risk of harmful effects over a lifetime. The oral reference dose for fluoride is 0.06 mg/kg/day, which includes effects on vulnerable groups such as children. This dose is not expected to put anyone in the population at risk of skeletal fluorosis, even when drinking the full recommended 2 L of water a day. The RfD was determined by estimating the dosage of a 20 kg child, drinking 1 L of water a day at the no-observable adverse effects level (NOAEL) of 1 ppm. This corresponds to 0.06 mg/kg/day. The NOAEL was found as having no-observable adverse effect in children studied with varying fluoride exposure, where the parameter of interest was dental fluorosis (EPA 1987).

The estimated fluoride exposure for skeletal fluorosis to occur is 20+ mg of fluoride a day for at least 20 years. Consider a 70 kg adult, who drinks 2 L of water per day and the water has 4 mg/L of fluoride (the MCL). This dosage corresponds to about 0.11 mg/kg/day, or 7.7 mg/day (EPA 1987). This is far from the 20 mg/day that it would take to cause crippling skeletal fluorosis, even if an adult drank more than 2 L of water a day. This 70 kg adult would have to consume 5 L of water a day at the MCL (4 mg/L fluoride) for 20+ years to be at risk for severe skeletal fluorosis. Consider the same adult of 70 kg drinking 2 L of water a day but now with the PHS recommended fluoride level. If this adult consumes optimally fluoridated water at 0.7 mg/L, they will receive 1.4 mg a day, or 0.02 mg/kg/day, of fluoride. This is a fraction of the fluoride exposure that is needed...
to cause severe skeletal fluorosis. Therefore, the PHS recommendation of 0.7 mg/L is highly unlikely to cause skeletal fluorosis. This 70 kg adult would have to consume 28.6 L of water at the recommended CWF level (0.7 mg/L fluoride) a day for 20+ years to be at risk of severe skeletal fluorosis. The oral reference dose for severe skeletal fluorosis (20 mg/day for a 70 kg adult consuming 2 L water per day) as well as other fluoride concentrations of interest are illustrated in Figure 5.1.

Note: CWF indicates the CDC recommended fluoride levels for community water fluoridation. NOAEL indicates the no observable adverse health effects level of dental fluorosis (based on 20 kg child consuming 1 L water per day). SMCL indicates the EPA’s non-enforceable secondary maximum contaminant level to prevent dental fluorosis. MCL indicates the EPA’s enforceable maximum contaminant level for naturally occurring fluoride. The Oral Reference Dose is the fluoride exposure that the EPA estimates would cause severe skeletal fluorosis (based on a 70 kg adult consuming 2 L water per day).

**Figure 5.1 Regulations and reference fluoride concentrations in water**

A recent study by EE&T on CWF practices by utilities in the United States indicated that water utilities were able to consistently meet target fluoride goals (Brown et al., 2014). The study examined fluoride levels of 40 U.S. water systems (32 surface water and 8 groundwater) over the course of a year (2012) and compared the measured levels to their target fluoride levels. The CDC recommends that utilities maintain an upper fluoride level no more than 0.5 mg/L above their target level and no more than 0.1 mg/L below their target level (CDC, 1995). Some U.S. states, including California, require that 80 percent of daily samples each month must be within this CDC control range. The data showed that the water systems studied were able to meet this 80 percent criterion.
There have been concerns that the chemicals being used to provide drinking water with fluoride ions (F⁻) do not completely disassociate and could be harmful, that there is not enough data on the safety of the chemicals and that they are difficult to handle. Compounds are used to add fluoride to water because fluorine (F) does not occur naturally in a free state, but occurs in combination with other elements to form compounds. The PHS and the CDC have concluded that the additives used in CWF completely disassociate into their ions and that no intermediates are present at the end of the treatment process (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). Some common compounds/chemicals that are used to fluoridate water include sodium fluoride, fluosilicic acid (FSA), and sodium fluorosilicic acid (SFSA). Fluorosilicic acid and sodium fluorosilicic acid are used in 90 percent of artificially fluoridated water (Maas et al., 2007). These specifically are used most frequently due to their convenience and cost effectiveness of being in a liquid state.

Some of the concerns about the safety of these compounds are that they do not completely disassociate in water (splitting into ions) and could be harmful if ingested. Studies have shown that
these compounds achieve complete dissolution and ionic disassociation at the conditions and concentrations that are added to drinking water (Finney et al., 2006). The chemical reactions that occur during the hydrolysis of these compounds were shown previously in equations 1-3. The ions that are present after dissolution of the compounds are comparable to the ions found in natural waters and are safe to drink. One study examined the difference in human response to ingesting water with natural fluoride, water fluoridated with sodium fluoride (NaF) and water fluoridated with FSA. The conclusions of this study were that the “major features of fluoride metabolism are not affected differently by the chemical compounds commonly used to fluoridate water nor are they affected by whether the fluoride is present naturally or added artificially” (Whitford et al., 2008).

One study indicates that FSA does not completely disassociate and that intermediates in drinking water could help to leach lead from copper pipes. One study in particular examined the lead dissolving properties of [SiF₆]²⁻ by itself as well as in combination with chloramines and free chlorine, which are both used for disinfection in the water treatment process. They found that combinations of these ions can produce more leaching of copper pipes than either the disinfectants or the fluoridating agents alone (Maas et al., 2007). However, in actual distributed potable water practicing lead and copper corrosion control, the corrosion control methods would prevent lead and copper dissolution.

The concern that there is not enough specific data on the safety of the chemicals used in CWF does not appear warranted. The additives that are used in CWF are all subject to standards, testing and certification involving the American Water Works Association (AWWA), NSF International and the American National Standards Institute (ANSI). Standard 60: Drinking Water Treatment Chemicals – Health Effects is often a required standard by states (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). When the additive chemicals meet all applicable standards, there are still safety protocols that utility workers must follow for their own protection as well as the publics. Some additives, such as fluorosilicic acid can be harmful to eyes and skin of utility workers and proper eye and skin protection must be worn while working with it (ScienceLab.com, 2013). Standard safety protocols are carefully followed by trained utility workers throughout the entire water treatment process. All 50 states require plant operators to pass a certification exam to prove that they are capable of performing various treatment processes. There are also more stringent certifications and experience requirements for working in large water plants (WorkforWater.org, 2015).

**ETHICAL CONSIDERATIONS**

Ethical concerns have been brought up that argue that fluoride is a medicine and CWF is a form of forced mass medication. One argument against this concern is that states and communities are responsible for deciding whether to fluoridate or not and therefore, there are opportunities to oppose fluoridation at the state or community level. There have been cases that have gone through the court system that have legally challenged CWF and it has been concluded by the courts that it is a “proper means of furthering public health and welfare” (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).

There are examples of publically accepted mass distribution of medicine-like substances besides fluoride. Iodine in salt and vitamin D in milk are both publically accepted means of distributing nutrients and substances that better the welfare of the public. Iodine deficiency and vitamin D deficiencies can cause many different adverse health effects (Zeratsky 2015). Addition
of Iodine to salt occurred in the United States in the early 1920s, addition of vitamin D to milk in 1932 and the addition of vitamin B to bread and flour in the 1940’s. These practices have successfully addressed population-wide nutrient deficiencies and improved public health by preventing the symptoms of these deficiencies (Samaniego-Vaesken et al., 2012).

If a community does practice CWF or have natural fluoride in the water source then a consumer can only avoid the fluoride by removing it or buying bottled water without fluoride.

COST-EFFECTIVENESS

Community water fluoridation costs taxpayers money, just like any public or utility service. The cost-effectiveness of fluoridation has been brought into question as being inefficient due to the availability of other fluoride sources and the usage of public water for many other uses besides drinking. The PHS cites recent studies of fluoridation that continue to show that CWF is a cost-effective way to distribute fluoride to all socio-economic classes. The cost of fluoridation varies throughout communities, but the PHS estimated that it is varies from $0.50, at utilities serving ≥20,000, to $3.70 per person annually at utilities serving ≤5,000. On average, the PHS estimates that it costs about $93.00 per person per year for maintenance dental care. The PHS further estimates that the savings CWF gives consumers is between $28.70 (larger communities) and $35.90 (smaller communities) per person annually in dental costs for fillings and other tooth decay treatment (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). CWF provides an affordable way to prevent expensive and disruptive tooth decay to lower socioeconomic classes, who are often more susceptible to tooth decay (Campbell, 2013).

The CDC estimates that 17 percent of children between the ages of 2 and 17, 38 percent of adults between 18 and 24 and 40 percent of adults over 65 did not receive dental care in 2013 (National Center for Health Statistics 2015). Despite the recent passage of the Affordable Care Act, which requires all Americans to have health insurance, dental benefits are not mandated for inclusion and many Americans still do not have access to dental care. Fluoridated water is seen by some to improve the quality of life of Americans who do not receive dental care by preventing tooth decay.

SUMMARY

Concerns with community water fluoridation (CWF) and fluoride exposure have been examined based on the latest science. Many concerns with CWF were health related. Each of these concerns was addressed and a balance of scientific studies showed that none of these issues poses a risk to public health at CWF levels. There was insufficient evidence to make conclusions about the effects of fluoride on the endocrine system and more research is needed on the topic. The dosing of fluoride in water systems was analyzed and it was concluded that the fluoride consumption can vary through CWF due to water consumption variation. However, the average or even maximum water consumption does not approach fluoride exposures that would pose health risks. Concerns about the safety of chemical additives used in CWF were addressed and no evidence was found that would indicate that these could be a public health risk because they completely dissociate in water. Concerns about distributing fluoride in drinking water as a form of mass medication that people cannot easily opt out of was also discussed. It was found that because courts have upheld CWF and that state and local authorities have the freedom to choose
fluoridation practices that CWF is an ethical practice. It was finally concluded that the monetary benefits of reducing tooth decay and its associated treatments outweighs the cost of CWF. A summary of concerns about fluoride and the findings reported here can be seen in Table 5.1.

Table 5.1  
Summary of fluoridation concerns

<table>
<thead>
<tr>
<th>Topic of concern</th>
<th>Summary of concerns about CWF</th>
<th>Summary of findings regarding concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental fluorosis</td>
<td>Cases of dental fluorosis in the United States have increased, but almost entirely in the mild and very mild forms (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).</td>
<td>Mild and very mild dental fluorosis does not affect the functionality of the tooth enamel and is considered a cosmetic affect. Severe dental fluorosis (with brown discolorations and mottling of enamel) has not been documented associated with CWF fluoride levels (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). PHS recommended lower CWF levels to prevent mild fluorosis. Bottle fed infants should avoid water with fluoride.</td>
</tr>
<tr>
<td>Skeletal fluorosis</td>
<td>Can be a potential health risk in areas with endemic water and air fluoride levels (Sutton et al., 2015).</td>
<td>EPA has estimated that it would require 20+ mg/day over the course of 20 years for clinical skeletal fluorosis to occur. These exposure levels are not approached in areas that practice CWF (EPA 1987).</td>
</tr>
<tr>
<td>Neurological effects</td>
<td>Chinese studies have shown links between water fluoride levels and reduced mental IQ (Sutton et al., 2015).</td>
<td>Chinese studies are inconsistent with testing and reporting IQ and fluoride levels. Many do not examine other parameters besides fluoride water levels that may affect IQ such as air and food fluoride concentrations, other environmental contaminants, deficiencies etc. Lowered IQ because of fluoride exposure has not been documented in areas that practice CWF (Sutton et al., 2015).</td>
</tr>
<tr>
<td>Carcinogenicity</td>
<td>Statistically significant correlation between osteosarcoma and water fluoride levels in males based on residence history (Bassin et al., 2006).</td>
<td>No statistically significant correlation between osteosarcoma and fluoride levels in cancerous and benign bone tumors (Kim et al., 2011). This method is a more accurate procedure for determining fluoride exposure than residence history.</td>
</tr>
<tr>
<td>Endocrine disruption</td>
<td>Evidence of endocrine disruption is inconsistent where some studies show correlation and some do not. NRS felt the studies showing a relationship were not conducted in a way to conclude any relationship. The National Research Council called for more research on the matter to characterize the mechanisms of fluorides effect on the endocrine system and to establish factors that would determine response (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).</td>
<td></td>
</tr>
<tr>
<td>Dosage Control</td>
<td>Fluoride exposure through water cannot be precisely controlled due to varying water consumption throughout populations.</td>
<td>Based on the oral reference dose, a 70 kg adult would have to consume 28 L of water a day at 0.7 mg/L to approach 20 mg/day and do this for 20+ years to develop clinical skeletal fluorosis. (EPA 1987).</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Topic of concern</th>
<th>Summary of findings that support concern</th>
<th>Summary of findings that refute concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety of fluoride additives</td>
<td>If additives do not completely dissociate in water they may help to leach lead from copper pipes when they are present with chloramines and free chlorines (Maas et al., 2007).                                                                                                                                 Studies have shown that additives do completely dissociate in drinking water (Finney et al., 2006). Studies have also shown that fluoride is not metabolized any differently for natural or artificially fluoridated water (Whitford et al., 2008). Lead and copper controlled by CCT.</td>
<td></td>
</tr>
<tr>
<td>Ethical concerns</td>
<td>There is no easy way for people to opt out of fluoridated water once it has been established in their community and some people propose that this is a form of forced mass medication.                                                                                                                                   U.S. courts have upheld that practicing CWF is &quot;a proper means of furthering public health and welfare&quot; (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015). State and local communities decide and often vote on fluoridation practices. It is correct that an individual would have to remove the F or buy non-fluoridated water.</td>
<td></td>
</tr>
<tr>
<td>Cost effectiveness</td>
<td>For large utilities, it costs the water customers less than $1 annually (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).                                                                                                                                      Benefits of CWF have been estimated around $30 annually. This includes dental treatment for tooth decay (U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation 2015).</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 6
CASE STUDIES

Six major cities were examined as part of a review U.S. fluoridation policy. The intent of the case studies is to give an overview of how other cities have handled community water fluoridation and learn from their experiences. Each case study includes the history of water fluoridation including natural conditions in the area and community policy and actions that led to policy changes. The arguments from people for and opposed to fluoridation in each city is also discussed.

Through researching these case studies, it was found that many people across many cities had similar arguments for and against fluoridation. Many of the concerns and benefits associated with the debate on fluoridation have been discussed in this report.

<table>
<thead>
<tr>
<th>Arguments against fluoridation</th>
<th>Arguments for fluoridation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental fluorosis</td>
<td>Cavity prevention</td>
</tr>
<tr>
<td>Endocrine effects</td>
<td>Savings in dental treatment costs</td>
</tr>
<tr>
<td>Neurological effects</td>
<td>Equity of dental benefits across socioeconomic classes</td>
</tr>
<tr>
<td>Carcinogenicity</td>
<td>Backing of important government and state agencies</td>
</tr>
<tr>
<td>Dosage control</td>
<td>Lack of proof for potential health concerns at CWF fluoride levels</td>
</tr>
<tr>
<td>Safety and contamination of chemical additives</td>
<td>Historical decline of cavities in fluoridated areas</td>
</tr>
<tr>
<td>Cost-effectiveness</td>
<td>Cost-effectiveness</td>
</tr>
<tr>
<td>Ethical concerns</td>
<td></td>
</tr>
</tbody>
</table>

DALLAS, TX

The Dallas Water Utility serves about 1.25 million people in the state of Texas. The source water for the City of Dallas is surface water containing natural fluoride below the optimal carries prevention concentration (below 0.7 mg/L). The Dallas Water Utility uses hydrofluorosilicic acid (HFS) to fluoridate their water. Dallas currently fluoridates to the Public Health Service (PHS) recommendation of 0.7 mg/L.

In 1965, the City Manager of Dallas authorized a resolution that would approve the addition of fluoride to the Dallas water supply. In 1966, the City Council passed an ordinance to be voted on by the public that would ban fluoridation. Later that year, the citizens voted against the ordinance and Dallas Water Utilities began adding fluoride to the water supply. In 2014, a small group of citizens in Dallas appealed to the City Council to stop fluoridation (ADA, 2015). The group received the support of some Councilmen, mostly based on the argument against the expenses associated with fluoridation, when the group attempted to halt the contract renewal for purchasing HFS (ADA, 2015). The group tried to stop the contract in an effort to stop fluoridation. For the city to stop fluoridation, a vote would have to be conducted, but the purchase contract only needed the votes of the Councilmen (K. DelRegno personal communication). The contract for HFS was for $640/ton and corresponded to between $4.74 and $6.33 per million gallons of water treated (DelRegno, 2014). The addition of HFS to Dallas’ water costs about $600,000, equating to about $0.25 per person annually (DelRegno, 2014). In addition to concerns with fluoridation costs, there
were also arguments against fluoride based on potential health concerns, similar to those concerns previously discussed in this report (Kalthoff, 2014). After hearing the group’s concerns through many presentations, the City Council voted 13-2 in favor of renewing the City’s contract to buy HFS for the next three years (ADA, 2015). See Figure 6.1 below.

**Figure 6.1    Community water fluoridation timeline for Dallas, TX**

**PHOENIX, AZ**

The City of Phoenix’s water system serves about 1.5 million people in the State of Arizona. The Phoenix surface drinking water source contains about 0.3 mg/L natural fluoride (Mann, 2012). The city fluoridates the water to 0.7 mg/L using HFS, costing them about $528,000 annually ($0.39 per person annually) (Gardiner, 2012).

In 1988, the Arizona Environmental Quality Commission made the recommendation to the City of Phoenix to fluoridate their drinking water (Mann, 2012). This recommendation was partially in response to a group of local citizens called the “Coalition for Fluoridation” that made a request to the mayor and City Council to add fluoride to Phoenix’s water (Mann, 2012). In 1989, after the City Council heard input from the Environmental Quality Commission, experts and citizens, the Council voted to begin fluoridation (Mann, 2012). In 2012, a concerned citizen brought the issue of fluoridation back to the City Council. She asked for the subject to be re-evaluated based on the newest available science because she believed there was serious health risks associated with community water fluoridation. She began researching fluoride exposure after her doctor told her to stay away from fluoride due to her hypothyroidism. Her concerns were mostly about the potential effects that fluoride has on the endocrine system (Forsythe, 2012). She initiated a fluoridation debate at a Council meeting and many other people in the community joined in the discussion. The points for and against fluoride discussed previously in this report were brought up throughout the discussion (Phoenix City Council, 2012a).
Questions about the cost of fluoridation were brought up by Councilmen during this discussion. In a later meeting, the cost and estimated savings of fluoridation were presented to the Council. It was estimated that fluoridation saves Phoenix residents about $22 million annually ($15 per person annually) (Phoenix City Council, 2012b). This was compared to the annual fluoridation cost for citizens of about $0.39 per year. After hearing the viewpoints of concerned citizens and experts and evaluating the cost and benefits of fluoridation, the City Council voted to continue fluoridating its drinking water in 2012. See Figure 6.2 below.

**Figure 6.2  Community water fluoridation timeline for Phoenix, AZ**

**PORTLAND, OR**

Portland Water serves about 900,000 people in the State of Oregon (Ryan, 2013). Their source water is from the Bull Run Watershed, locally known for its freshness and purity. The Bull Run Watershed is located in the Mt. Hood National Forest and is a restricted area where public access is not allowed. Restricted entry into the watershed is mandated and enforced by federal, state and local laws.

Residents and lawmakers in the Portland area are focused on protecting the Bull Run Watershed. In addition to protecting their source water, Portlanders have been resistant to any chemical additives in their drinking water. Portland is the largest city that chooses not to fluoridate and is the only one of the thirty largest cities in America that does not fluoridate (Ryan, 2013). The decision not to fluoridate Portland’s drinking water has been affirmed multiple times. It was voted on and defeated in the 1950’s and again in 1962 before the City Council finally approved fluoridation in 1978. In 1980, that decision was reversed. The issue was brought up again in 2014, when the Mayor backed an ordinance to start fluoridation, which was then approved by the City Council. This ordinance was challenged by the citizens of Portland whose tens of thousands of signatures forced the ordinance to go to a public vote. Before the vote, a public hearing was conducted where 227 people voiced their opinions at a six and a half hour meeting on community water fluoridation. The ordinance was defeated 60-40 percent on voting day, not allowing fluoridation to begin (Kost, 2013).
Citizens that were against fluoridation often cited environmental concerns as their reason for voting against fluoride. Portland’s citizens are often much more concerned about environmental issues and practice more natural medicine than many other populations, making them more resistant to supplementing the drinking water. One news article read, “It’s easy to sow fear about chemicals being dumped into pure, natural resources” in Portland (Weber, 2013). It went on to describe that the citizens of Portland were very susceptible to this fear and potentially more so than other areas of the country.

Many proponents of fluoride argued equality across socioeconomic classes as a benefit of fluoride. They cited poor childhood dental health statistics for the State of Oregon as a reason that the children of Portland would benefit from fluoridation. About 35 percent of Oregon’s children suffer from untreated tooth decay as of 2007. Proponents argued that the neighboring state of Washington has half this percentage and that Washington’s large cities practice fluoridation (Murphy, 2013). Many rebuttals to these arguments conceded that these issues were indeed public health problems, but that the answers did not lie in community water fluoridation. The citizens called for increased funding for pediatric dental care for families that could not afford dental care as an alternative to fluoridation. After this debate over community water fluoridation, it is unlikely that Portland’s water will be fluoridated in the future. See Figure 6.3 below.

Figure 6.3 Community water fluoridation timeline for Portland, OR
The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) provides drinking water to more than 650,000 in the Middle Rio Grande of the State of New Mexico. ABCWUA provides drinking water from both ground water and surface water. The ground water system consists of more than 90 wells and a surface water treatment plant that distribute water throughout the metropolitan area. Each of the wells and surface water sources has varying concentrations of naturally occurring fluoride (ABCWUA, 2014a). The average fluoride level of all sources was reported in 2014 to be about 0.5 mg/L (ABCWUA, 2014b).

Albuquerque started fluoridating its water in 1972 after a public election in which citizens voted for an ordinance to start community water fluoridation. Voters agreed to the ordinance at 57 percent and it was later upheld by a district court judge. In 2003, state lawmakers created ABCWUA, which replaced the City of Albuquerque’s water division (Uyttebrouck, 2014b). ABCWUA did not adopt the 1972 city ordinance, but continued to fluoridate to target levels between 0.9 and 1.2 mg/L (ABCWUA, 2014a). In 2011, ABCWUA decided to stop supplemental fluoridation after 39 years (Uyttebrouck, 2014b). Their reasoning to end the practice was based upon the preliminary CDC recommendation of an optimal fluoride levels of 0.7 mg/L and the fact that the average fluoride concentration in Albuquerque entry points was 0.7 mg/L in 2011 (ABCWUA, 2011). Utility representative David Morris said to the Albuquerque Journal that the decision was based on the fact that the natural fluoride concentrations had the recommended concentrations (Uyttebrouck, 2014a). The 2011 decision to stop fluoridation had a stipulation that the ABCWUA would revisit the issue when government agencies (CDC and PHS) made final recommendations on optimal fluoride levels (Uyttebrouck, 2014b).

In 2014 when these recommendations were finally published, ABCWUA again broached the topic. Town Hall meetings were held for ABCWUA to hear from experts and to discuss community water fluoridation with the public. Many opinions were heard at the public hearing on April 9, 2014 where experts as well as concerned citizens and professionals expressed their support or concerns (ABCWUA, 2014a). Their arguments included the typical fluoride arguments previously discussed. The cost to start fluoridating in 2014 would have cost ABCWUA about $400,000 initially and about $100,000 annually and this may have played into the final decision (ABCWUA, 2014a). ABCWUA voted on April 23, 2014 not to add fluoride to the water in Albuquerque. They stated that the natural fluoride in the water system is “enough to provide some dental benefit without exceeding the interim recommendation” (the 2014 CDC recommendation of 0.7 mg/L) (ABCWUA, 2015). Per the adopted resolution by the Board, ABCWUA staff will provide a recommendation regarding future fluoridation when the recommendation is complete and guidance on meeting the optimal level is developed. See Figure 6.4 below.
MILWAUKEE, WI

The City of Milwaukee serves about 650,000 people in the State of Wisconsin. It spends about $540,000 annually to add hydrofluosilicic acid to their drinking water supply. There is also some naturally occurring fluoride (0.5 mg/L) in Milwaukee’s surface source water (MWW, 2014).

The City of Milwaukee started adding fluoride to the water supply in 1953 by decision of the Common Council (MWW, 2015). In 1955, an important case in the history of water fluoridation occurred between Froncek (a Milwaukee citizen) and the City of Milwaukee. Froncek challenged the City’s fluoridation practices, arguing that fluoride was not protecting against infections or contagious diseases and is therefore not necessary in public drinking water. The Supreme Court of Wisconsin rejected the plaintiffs’ concerns and ruled that there is no requirement that public health measures be based strictly on preventing or treating infectious or contagious diseases (Froncek v. City of Milwaukee, 1955). The issue did not arise again until 2012 when a City Councilmen (Aldermen), Jim Bohl, brought it up again. Alderman Bohl advocated removing fluoride from the City’s water supply as soon as possible. Some of his arguments and direct quotes from the Steering and Rules Committee meeting on May 31, 2012 can be seen below with some caveats in parenthesis (City of Milwaukee, 2012):

- He considered fluoride as a “toxic by-product” of the fertilizer industry.
- He called fluoride a toxin more lethal than lead (no citation).

Figure 6.4  Community water fluoridation timeline for Albuquerque, NM

1970: 57% of citywide vote approved ordinance for fluoride addition

2003: Albuquerque Benalillo County Water Utility Authority created. Did not adopt ordinance of 1970, but continued fluoridation

2011: ABCWUA voted to stop fluoridation until new government recommendations released

2014: New recommendations came out and ABCWUA voted to not add additional fluoride stating that naturally occurring fluoride levels were sufficient to meet dental health goals
- Presented that many developed countries in Europe do not fluoridate and have seen the same decline in carries as areas with fluoridation (in fact many countries in Europe fluoridate their salt). He also compared the United States to Canada quite frequently when discussing how dental health does not correspond to fluoridation (Canada’s health care system is structured differently than the U.S. system).
- He called fluoride a “corrosive toxin metal” (fluorine (F) or fluorides (F⁻) are not metals).
- He discussed the uses of fluoride in pesticides and poisons and indicated that fluoride’s “uses in water are no different than uses as a pesticide” (It is in fact very different, as the fluoride additives used to fluoridate drinking water undergo hydrolysis and completely dissociate in the water. The conditions that are involved with the application of pesticides in the environment are not comparable to the chemical or physical conditions in drinking water plants).
- He used the different fluoride levels enforceable by the EPA and recommended by the CDC to discredit these organizations, saying that there is no consistency that their facts are “all over the place” (the EPA enforceable MCL of 4 mg/L is not the recommended CWF fluoride level).

The Common Council acknowledged the information that Alderman Bohl, his guests and the community presented. The Council voted to continue to fluoridate, but to reduce the fluoride level to the CDC recommended level of 0.7 mg/L from the 1.1 mg/L that was in place at the time. The ordinance that was passed also included a stipulation that the Milwaukee Water Works provide residents with information on the potential risks that fluoride exposure can pose to infants. Due to the potential risk of dental fluorosis in infants consuming fluoridated water, the City advocated breastfeeding instead of formula (Taylor, 2012). See Figure 6.5 below.

**Figure 6.5** Community water fluoridation timeline for Milwaukee, WI
The City of Fort Collins serves about 200,000 in the State of Colorado. Currently Fort Collins fluoridates its water to the CDC recommendation of 0.7 mg/L using hydrofluosilicic acid (City of Fort Collins, 2015). They spent about $57,500 in 2001 on community water fluoridation (Ft Collins, 2003).

Fort Collins, Colorado first proposed CWF in 1954 with a public vote and it was voted down. In 1967, a group of citizens brought it back to the voters and the public voted once again, with a different outcome - CWF was approved and practiced. In 2001, the Fort Collins Water Board advised the City Council to cease fluoridation and cited mostly cost concerns but also some health concerns as well (Fischbach and Smith, 2003). The Water Board is an advisory board for the City Council that offers advice on issues regarding water, wastewater, stormwater and policy issues such as planning, development and design in these areas (Fort Collins Water Board, 2015). The City Council initiated a Fluoride Technical Study Group to review the current science on fluoridation and make a policy recommendation with support from the Larimer County Board of Health, Fort Collins Utility Dept., and the Health District of Northern Larimer County (Ft Collins, 2003). This group reviewed and evaluated scientific information on the risks and benefits of fluoride. The group’s recommendations were released in its 2003 report. Recommendations included continuing CWF using the lower end of the recommended fluoride concentration of 0.7 mg/L, making climate appropriate adjustments of fluoride levels to correspond with changes in water consumption, adding lead testing of the hydrofluorosilicic acid to standard operating procedures, instructing the city to discuss reducing fluoride treatments for children drinking city water with area dentists, and increasing fluoride education to parents of children under the age of two to encourage the use of un-fluoridated toothpaste (Anderson, 2003). This report discussed the typical health concerns that fluoride may pose and presented a cost-benefit analysis of fluoride specifically for the City of Fort Collins (Ft Collins, 2003).

After considering the findings and recommendations in the technical study group report, the City Council voted to continue water fluoridation in Fort Collins in 2003. A small organized group of citizens who referred to themselves as the Fort Collins Clean Water Advocates were unhappy with the results of the council vote and collected adequate signatures to force a public vote on an ordinance that would ban fluoridation.

The community response to this proposed ordinance was significant. Citizens that supported the City Council’s previous decision to continue fluoridation in Fort Collins reached out to over 250 dental professionals and every Colorado congressional representative. The group encouraged local dentists to discuss fluoridation with their patients and received endorsements from every congressional representative in Colorado. In 2005, the citizens of Fort Collins voted once more to continue to add fluoride to their water. See Figure 6.6 below.
SUMMARY

Case studies were done to illustrate the practices, policies and discussions that have occurred in some large U.S. municipalities regarding CWF. The experiences of six utilities were evaluated. Because of community deliberations and often citywide votes, four decided to continue to practice community water fluoridation (CWF) and fluoridate to the CDC recommended concentration of 0.7 mg/L. Portland, Oregon decided not to fluoridate their water due to a variety of concerns and Albuquerque, New Mexico has sufficient natural fluoride levels in their source water once the recommended level was dropped to 0.7 mg/L when they elected not to add additional fluoride. A summary of the findings from these case studies is in Table 6.1.
<table>
<thead>
<tr>
<th>City</th>
<th>Date</th>
<th>Overview of deliberation</th>
<th>Key points</th>
<th>Outcome</th>
<th>Current fluoridation practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas, TX</td>
<td>2014</td>
<td>Anti-fluoridation groups lobbied city council to reject the contract to purchase hydrofluorosilic acid.</td>
<td>Health concerns</td>
<td>City Council passed the contract at 13 members in favor to 2 members not in favor.</td>
<td>Fluoridate to 0.7 mg/L</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>2012</td>
<td>Citizen with hypothyroidism sparked debate. Cost was evaluated by the City Council.</td>
<td>Endocrine effects Health concerns Cost vs benefits</td>
<td>City Council voted to continue community water fluoridation</td>
<td>Fluoridate to 0.7 mg/L</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>2014</td>
<td>Mayor of Portland backed an ordinance to start fluoridation and City Council passed it. Citizens collected enough signatures to force a public vote.</td>
<td>Environmental Industry Dental Health Health Concerns</td>
<td>Public voted against fluoridation 60%-40%</td>
<td>Does not fluoridate</td>
</tr>
<tr>
<td>Albuquerque, NM</td>
<td>2014</td>
<td>ABCWUA stopped fluoridation in 2011 because natural fluoride levels met recommended level.</td>
<td>Cost vs benefit Natural Fluoride Levels</td>
<td>ABCWUA voted to continue not fluoridating</td>
<td>Adequate Natural Fluoride Levels</td>
</tr>
<tr>
<td>Milwaukee, WI</td>
<td>2012</td>
<td>Alderman Jim Bohl proposed an ordinance to ban fluoridation.</td>
<td>Health concerns</td>
<td>Steering and Rules Committee voted to keep fluoridating but reduce the target level from 1.1 mg/L</td>
<td>Fluoridate to 0.7 mg/L</td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td>2005</td>
<td>Water Board recommended ceasing fluoridation. City Council developed Technical Study Group to evaluate fluoridation. Group released findings and recommended to keep fluoridating. City Council made a decision and citizens forced a public vote.</td>
<td>Cost vs benefit Health Concerns</td>
<td>City Council and then Citizens voted to keep fluoridating</td>
<td>Fluoridate to 0.7 mg/L</td>
</tr>
</tbody>
</table>
## APPENDIX A:
### STATE MANDATED FLUORIDATION

<table>
<thead>
<tr>
<th>State</th>
<th>State mandated fluoridation (stipulations)</th>
<th>State</th>
<th>State mandated fluoridation (stipulations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>no</td>
<td>Montana</td>
<td>no</td>
</tr>
<tr>
<td>Alaska</td>
<td>no</td>
<td>Nebraska</td>
<td>yes (1,000+)</td>
</tr>
<tr>
<td>Arizona</td>
<td>no</td>
<td>Nevada</td>
<td>yes (400,000 +)</td>
</tr>
<tr>
<td>Arkansas</td>
<td>yes (5,000+)</td>
<td>New Hampshire</td>
<td>no</td>
</tr>
<tr>
<td>California</td>
<td>yes (10,000 +)</td>
<td>New Jersey</td>
<td>no</td>
</tr>
<tr>
<td>Colorado</td>
<td>no</td>
<td>New Mexico</td>
<td>no</td>
</tr>
<tr>
<td>Connecticut</td>
<td>yes (20,000+)</td>
<td>New York</td>
<td>no</td>
</tr>
<tr>
<td>Delaware</td>
<td>yes (public)</td>
<td>North Carolina</td>
<td>no</td>
</tr>
<tr>
<td>Florida</td>
<td>no</td>
<td>North Dakota</td>
<td>no</td>
</tr>
<tr>
<td>Georgia</td>
<td>yes (state funded plants)</td>
<td>Ohio</td>
<td>yes (5,000+)</td>
</tr>
<tr>
<td>Hawaii</td>
<td>no</td>
<td>Oklahoma</td>
<td>no</td>
</tr>
<tr>
<td>Idaho</td>
<td>no</td>
<td>Oregon</td>
<td>no</td>
</tr>
<tr>
<td>Illinois</td>
<td>yes</td>
<td>Pennsylvania</td>
<td>no</td>
</tr>
<tr>
<td>Indiana</td>
<td>no</td>
<td>Rhode Island</td>
<td>no</td>
</tr>
<tr>
<td>Iowa</td>
<td>no</td>
<td>South Carolina</td>
<td>no</td>
</tr>
<tr>
<td>Kansas</td>
<td>no</td>
<td>South Dakota</td>
<td>yes (500+)</td>
</tr>
<tr>
<td>Kentucky</td>
<td>yes (1,500+)</td>
<td>Tennessee</td>
<td>no</td>
</tr>
<tr>
<td>Louisiana</td>
<td>yes (5,000+)</td>
<td>Texas</td>
<td>no</td>
</tr>
<tr>
<td>Maine</td>
<td>voted on by the community</td>
<td>Utah</td>
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<tr>
<td>Maryland</td>
<td>no</td>
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<td>Massachusetts</td>
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<td>Michigan</td>
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<td>Washington</td>
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<tr>
<td>Minnesota</td>
<td>yes</td>
<td>West Virginia</td>
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<tr>
<td>Mississippi</td>
<td>yes (2,000+)</td>
<td>Wisconsin</td>
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<tr>
<td>Missouri</td>
<td>no</td>
<td>Wyoming</td>
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REFERENCES


http://fluoridealert.org/researchers/states/alaska/.


http://www.oregonlive.com/portland/index.ssf/2013/05/portland_fluoride_for_the_four.html.


ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
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<tbody>
<tr>
<td>ADA</td>
<td>American Dental Association</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>AWWA</td>
<td>American Water Works Association</td>
</tr>
<tr>
<td>BDL</td>
<td>below detection limit</td>
</tr>
<tr>
<td>CDC</td>
<td>United States Centers for Disease Control and Prevention</td>
</tr>
<tr>
<td>CWF</td>
<td>community water fluoridation</td>
</tr>
<tr>
<td>DMF</td>
<td>decayed, missing, or filled teeth</td>
</tr>
<tr>
<td>DNR</td>
<td>did not report</td>
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<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<tr>
<td>FAP</td>
<td>fluoroapatite</td>
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<tr>
<td>FSA</td>
<td>fluorosilicic acid</td>
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<tr>
<td>GW</td>
<td>groundwater</td>
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<tr>
<td>HAP</td>
<td>hydroxyapatite</td>
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<tr>
<td>HFS</td>
<td>hydrofluorosilicic acid</td>
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<tr>
<td>LOAEL</td>
<td>lowest observable adverse effect level</td>
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<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
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<tr>
<td>MCLG</td>
<td>maximum contaminant level goal</td>
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<tr>
<td>NIDCR</td>
<td>National Institute of Dental and Craniofacial Research</td>
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<td>NIDR</td>
<td>National Institute of Dental Research</td>
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<tr>
<td>NIH</td>
<td>National Institutes of Health</td>
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<tr>
<td>NOAEL</td>
<td>no-observable adverse effects level</td>
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<tr>
<td>NRC</td>
<td>National Research Council</td>
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<tr>
<td>PHS</td>
<td>U.S. Public Health Service</td>
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<tr>
<td>RfD</td>
<td>oral reference dose</td>
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<td>SDWIS</td>
<td>Safe Drinking Water Information System</td>
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<tr>
<td>SFSA</td>
<td>sodium fluorosilicic acid</td>
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<td>SMCL</td>
<td>secondary maximum contaminant level</td>
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<tr>
<td>SW</td>
<td>source water</td>
</tr>
<tr>
<td>USHHS</td>
<td>United States Department of Health and Human Services</td>
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</table>
WFRS  Water Fluoridation Reporting System
WHO  World Health Organization
WRF  Water Research Foundation