

# Survey of All Water Treatment Plant Operators Who Fluoridate Drinking Water in Ohio<sup>1</sup>

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**ABSTRACT.** Ohio like several other states in the US is mandated by law to optimally fluoridate all public water systems serving over 5000 people. The purpose of this study was three-fold: 1) to determine if Ohioans on public water supplies are receiving optimally fluoridated water, 2) to determine the knowledge level of water treatment plant operators who fluoridate drinking water, and 3) to compare small and large water treatment plants. A pre-tested survey was sent to all 224 water treatment plants that adjust the fluoride concentration of drinking water in Ohio. A 100% response rate was accomplished, with 93 small and 131 large water treatment plants responding. A z-test was computed to compare proportions between small and large water treatment plants. Significance was assessed at  $p < 0.05$ . Nearly 90% of water treatment plant operators correctly identified the optimal fluoride level, however almost 30% used incorrect means of determining the optimal level. Approximately three-quarters of the water treatment plant operators were able to maintain the fluoride concentration to within 0.1 mg F/L of their optimal level. A significantly greater proportion of large water treatment plant operators were able to maintain a fluoride concentration to within 0.1 mg F/L of their optimum level when compared to small water treatment plant operators (83.2% vs 60.2%,  $z = 3.60$ ,  $p < 0.05$ ). Most water treatment plant operators are knowledgeable concerning fluoride levels, however small water treatment plant operators may need additional technical assistance to reach the level attained by large plants.

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## INTRODUCTION

One of the premier water treatment plants in Ohio is located in the state capital, Columbus. The Dublin Road Water Treatment Plant has been fluoridating Columbus water since 1973 and has recently remodeled its entrance atrium for visitors to trace the history of water treatment, particularly in Ohio. Conspicuously placed on the front wall for visitors to view is a list of five objectives of water treatment: 1) to kill disease-causing bacteria, 2) to remove unwanted chemicals, 3) to remove sediment, 4) to fluoridate water to health-approved standards, and 5) to produce water with a pleasant appearance and taste. The lay visitor would more than likely understand the intent of objectives one and five, may have some idea concerning objective two, have little or no understanding about objective three, and would probably know that fluoridation had something to do with better dental check-ups. However, visitors probably would not know the meaning of "health-approved standards." While all five objectives are important to the health and well being of Ohioans, the focus of this article will concentrate on objective four.

Water fluoridation is historically linked to its only known undesirable side effect found in the United States. Mottled enamel is a demineralization of the outer most layer of tooth structure (enamel) caused from excessive ingestion of fluoride during the years of tooth

calcification (Szpunar and Burt 1987). Mottled enamel can appear as barely noticeable whitish striations on only portions of the teeth (very mild) to heavily stained with pitting to all surfaces (very severe). In the early 1900s, a young dentist Dr Frederick McKay who trained in Philadelphia opened practice in Colorado Springs, CO, and discovered that many of his patients presented with mottled enamel, a condition he had not observed during his dental schooling (McKay and Black 1916). Thirty years later with the advent of spectrographic analysis of water, the causative factor of mottled enamel was identified as fluoride. With the discovery that high concentrations of fluoride in drinking water caused mottled enamel (now referred to as enamel fluorosis), Dr H. Trendley Dean was appointed by the US Public Health Service (USPHS) to investigate enamel fluorosis. As discovered earlier by Drs McKay (McKay 1928) and G. V. Black, Dean noted that individuals with enamel fluorosis often had less dental decay than those without enamel fluorosis. This inverse relationship between enamel fluorosis and dental caries led Dean to research the association. His most famous "21 Cities Study" which took place in Illinois, Ohio, Indiana, and Colorado was conducted to determine the optimal fluoride concentration in drinking water that decreased dental decay prevalence, while not producing a significant amount of enamel fluorosis. The result of the study showed that the optimal concentration in temperate climates was approximately 1.0 to 1.2 mg of fluoride per liter of water (mg F/liter) (Dean and others 1941; Dean and others 1942). However, Dean had noted that even with optimal levels of fluoride in drinking water, approximately 10% of children would develop very mild to mild enamel fluorosis (Dean 1936), which he accepted as a necessary by-product of the decreased dental decay prevalence.

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As had been suggested by Dean, the USPHS set the optimal fluoridation concentration in temperate climates at 1.0 to 1.2 mg F/liter. With a temperate climate, Ohio determined that its state optimal fluoridation concentration would be reported as 1.0 mg F/liter. This information is reported for each state in the *Fluoridation Census 1992* (USDHHS 1993), which is the most recent fluoridation data published by the Division of Oral Health of the Centers for Disease Control and Prevention (CDC) in Atlanta, GA. CDC is a prevention agency under USPHS and responsible for monitoring the nation's health; providing leadership in promoting health; and preventing and controlling disease, injury, and disability. In its role of monitoring health and preventing disease, CDC collects and maintains the fluoridation status for the United States. Presently, more than 134 million US residents in more than 8500 communities are receiving the benefits of optimally adjusted fluoridated water. As a state, Ohio has more than 80% of its population served by optimally adjusted fluoridated water.

While the optimal or target fluoride concentration in Ohio is set at 1.0 mg F/liter, Ohio, like every other state has a fluoridation range in which water plant operators have to operate on a day-to-day basis. The range surrounds the reported state optimal fluoridation concentration and is established by individual state environmental health programs. These programs vary from state to state and can be under the health department or a stand-alone agency responsible for natural resources, drinking water, waste water, solid waste and air. In Ohio, the state environmental health program is the Ohio Environmental Protection Agency (OEPA) which has established the adjusted range at 0.8 to 1.3 mg F/liter (Ohio Revised Code 1995). Furthermore, Ohio like several other states is mandated by law to optimally fluoridate all public water systems serving 5000 or more people (Easley 1981). Although it has been established that the optimal fluoride concentration for Ohio is 1.0 mg F/L, water treatment plant operators have never been surveyed. It is the operator who is often left out of the loop, even though the operator is a key person in determining whether public water supplies are optimally fluoridated. Their knowledge level of fluoridation is important to insure Ohio's dental health. It is also assumed that the size of the treatment plant is a factor in fluoridation due to the education level of water treatment plant operators in small versus large facilities (Kuthy and Durkee 1985). The purpose of this study was three-fold: 1) to determine if Ohioans on public water supplies are receiving optimally fluoridated water, 2) to determine the knowledge level of water treatment plant operators who fluoridate drinking water, and 3) to compare small and large water treatment plants based on selection and maintenance of the optimal fluoride concentration, factors responsible for variation in optimal fluoride level, customer usage, plant classification, and type of fluoride compound used.

## MATERIALS AND METHODS

A list of all 224 water treatment plants that adjust the fluoride concentration of drinking water in Ohio was procured from the Bureau of Oral Health Services,

Department of Health, Columbus, Ohio. With the assistance of an informal review consisting of two water treatment plant engineers, two experts from the Division of Oral Health at the Centers for Disease Control and Prevention (CDC), and the fluoridation coordinator at the Ohio Department of Health, a one-page questionnaire (Fig. 1) was developed. The survey instrument, the first of its kind, was pilot tested on 10 water treatment plant operators outside of Ohio. The pilot test was conducted outside of Ohio in order to perfect the questionnaire while at the same time not biasing Ohio water treatment plant operators. Two hundred twenty-four questionnaires were mailed with pre-addressed stamped envelopes to encourage responses. Second and third mailings were necessary to attain a 100% response rate. Small water treatment plants were defined as those treating less than one million gallons of water daily (MGD), while large water treatment plants treated one or more millions of gallons of water daily. A z-test was computed to compare proportions between small and large water treatment plants. Significance was assessed at  $p < 0.05$ .

## RESULTS

Of the 224 questionnaires mailed, all 224 water treatment plant operators who fluoridate drinking water in Ohio responded. There were 93 small water treatment plants and 131 large water treatment plants, as defined by the amount of water treated on a daily basis.

Two hundred and one water treatment plant operators correctly responded to Question 1 indicating that their optimal or target fluoride concentration was 1.0 mg F/L. An additional 20 operators declared that their optimal concentration was between 0.9 and 1.1 mg F/L. Only 3 operators reported an optimal concentration greater than or less than 0.1 mg F/L from the state optimal fluoridation concentration of 1.0 mg F/L. Furthermore, all 3 were small water treatment plants, treating between 0.1 and 0.8 MGD. They incorrectly reported optimal fluoride concentrations of 0.8 mg F/L, 1.2 mg F/L, and 1.3 mg F/L. Large water treatment plants reported the correct optimal fluoride concentration 91.6% of the time, while small water treatment plant operators were nearly as accurate at 87.1% (see Table 1).

As important as knowing the optimal fluoride concentration, is knowing correctly why that concentration was chosen. The responses to Question 2 were divided into 3 categories: most accurate reasons (using either water fluoridation manual or the policy of the Bureau of Oral Health Services, Ohio Department of Health); moderately accurate reasons (choosing the average or middle of the OEPA fluoride range); and least accurate reason (historically it has always been that concentration). Over half (58.9%) of the water treatment plant operators utilized the most accurate reasons for choosing their optimal fluoride concentration. When combining most and moderately accurate reasons, 70.1% of water treatment plant operators used at least moderately sound reasoning for choosing the optimum fluoride concentration. On the other hand, 29.9% of water treatment plant operators used least accurate reasons for choosing optimum fluoride concentration. Again large

## QUESTIONNAIRE

1. What is your "optimum" or "target" fluoride concentration? (Please circle one.)
  - a. 0.8 mg fluoride per liter
  - b. 0.9 mg fluoride per liter
  - c. 1.0 mg fluoride per liter
  - d. 1.1 mg fluoride per liter
  - e. 1.2 mg fluoride per liter
  - f. 1.3 mg fluoride per liter
  - g. Other, please specify \_\_\_\_\_ mg/L
2. How did you choose your "target" fluoride concentration? (Please circle all that apply.)
  - a. Water Fluoridation: A Manual for Engineers and Technicians
  - b. Water Fluoridation: A Manual for Water Plant Operators
  - c. Bureau of Oral Health Services, Ohio Department of Health
  - d. Historically, it has always been that concentration
  - e. Other method, please explain \_\_\_\_\_
3. How accurate is your feeder to approximate your "optimum" or "target" fluoride concentration? (Please circle one.)
  - a. Within a tenth of a mg of fluoride
  - b. Greater than a tenth of a mg of fluoride
4. What factors are responsible for any variation from your "optimum" or "target" fluoride concentration? \_\_\_\_\_
5. On an average day, how many gallons of water does your plant treat?  
\_\_\_\_\_ (MGD) millions of gallons treated daily.
6. Do you supply most of your water to: (Please circle one.)
  - a. Residential users
  - b. Commercial users
  - c. Approximately half residential and half commercial users
7. What classification is your water plant? (Please circle one.)
  - a. Classification I
  - b. Classification II
  - c. Classification III
  - d. Classification IV
8. Please indicate the fluoride compound that you presently use? (Please circle one.)
  - a. Sodium Fluoride (NaF)
  - b. Sodium Fluorosilicate formally labeled Sodium Silicofluoride ( $\text{Na}_2\text{SiF}_6$ )
  - c. Fluorosilicic Acid formally labeled Hydrofluosilicic Acid ( $\text{H}_2\text{SiF}_6$ )

Thank you.

FIGURE 1. Questionnaire sent to water plant operators.

water treatment plant operators used more accurate information for choosing their optimal fluoride concentration than small treatment plant operators, 71.8 % vs 67.7%, respectively (see Table 2).

In addition to knowing the optimal fluoride concentration and correctly choosing the optimal concentration, it is equally important to be able to maintain that fluoride concentration in drinking water. In 73.7% of the water treatment plants, the engineers claimed they were able to maintain the fluoride concentration to within 0.1 mg F/L of their optimal or target fluoride concentration.

TABLE 1

*Knowledge of optimal fluoride concentration of water treatment plant operators.*

Fluoride Concentration	Total Plants n (%)	Large Plant n (%)	Small Plant n (%)
Optimal (1.0 mg F/L)	201 (89.7)	120 (91.6)	81 (87.1)
Within +/- 0.1 mg F/L of Optimal	221 (98.7)	131 (100.0)	90 (96.8)
Greater than +/- 0.1 mg F/L of Optimal	3 (1.3)	0 (0.0)	3 (3.2)

However, over one-quarter (26.3%) of water treatment plant operators declared that their fluoride concentrations fluctuated greater than 0.1 mg F/L of optimal fluoride (see Table 3). A significantly greater proportion of large water treatment plant operators were able to maintain a fluoride concentration to within 0.1 mg F/L of their optimal level when compared to small water treatment plant operators (83.2% vs 60.2%,  $z = 3.60$ ,  $p < 0.05$ ).

TABLE 2

*Method used to choose the optimal fluoride concentration by water treatment plant operators.*

Method of Choice	Total Plants n (%)	Large Plant n (%)	Small Plant n (%)
Most Accurate	132 (58.9)	77 (58.8)	55 (59.1)
Moderately Accurate	25 (11.2)	17 (13.0)	8 (8.6)
Least Accurate	67 (29.9)	37 (28.2)	30 (32.3)

The factors responsible for variations from the optimum or target fluoride concentration were noted in Table 4. Factors responsible for variations from optimal fluoride concentrations were mainly feeder problems (19.6%), main water flow variations (16.5%), and raw water fluoride fluctuations (6.3%). When combinations of responses with feeder problems or with main water flow variation were added, the resultant percentages increased accordingly: feeder problems plus combinations (37.5%), main water flow variations plus combinations (33.9%), and raw water fluoride fluctuations (6.3%). This represents over three-quarters of the factors responsible for operators not being able to maintain a consistent fluoride level in drinking water. The difference between large and small water treatment plants revolved around main water flow variation. As one may expect large water treatment plants were less affected with variations

TABLE 3

*Accuracy in maintaining the optimal fluoride concentration by water treatment plant operators.*

Fluoride Concentration Range	Total	Large	Small
	Plants n (%)	Plant n (%)	Plant n (%)
Within +/- 0.1 mg F/L of Optimal	165 (73.7)	109 (83.2)	56 (60.2)
Greater than +/- 0.1 mg F/L of Optimal	59 (26.3)	22 (16.8)	37 (39.8)

in main water flow rates as compared to small water treatment plants. It is the small water treatment plants that need assistance to a greater degree than large water treatment plants. However, when combinations of responses were included with both feeder problems and main water flow variations, large water treatment plants indicated a higher proportion of responses than small water treatment plants. This may indicate a greater knowledge level of large water treatment plants in being able to identify other factors.

Also collected was data on type of fluoride compound used, classification of water treatment plant operator, and type of customer served. Three types of fluoride compounds are presently in use: sodium fluoride (NaF), sodium fluorosilicate ( $\text{Na}_2\text{SiF}_6$ ), and fluorosilicic acid ( $\text{H}_2\text{SiF}_6$ ). It was reported that 77.7% used NaF, 2.2% used  $\text{Na}_2\text{SiF}_6$ , and 20.1% used  $\text{H}_2\text{SiF}_6$ . While not statistically significant, large water treatment plants tended to use more  $\text{Na}_2\text{SiF}_6$  (3.1% vs 1.1%) and  $\text{H}_2\text{SiF}_6$  (22.1% vs 17.2%) than small treatment plants, respectively. On the other hand, large water treatment plants used less NaF than small plants (74.8% vs 81.7%). Question 7 on the survey asked for water treatment plant classification: in Ohio

there are 4 classifications (I, II, III, and IV), from lowest to highest in skill level of plant operators. Overall the plants reported 14.7% Class I, 30.8% Class II, 29.9% Class III, and 24.1% Class IV. Since classification of Ohio water treatment plants are based on the training level of its water treatment plant operators, it was not surprising that larger plants had more highly trained operators (Classification III and IV) than smaller plants with less trained operators (Classification I and II). All but classification category III was statistically significant when comparing large to small water treatment plants. For types of customers served, residential users accounted for 77.7% of water usage, only 2.2% went strictly for commercial use, and the remainder (20.1%) supplied a combination residential and commercial use. Larger treatment plants tended to serve commercial and combination users over smaller plants (35.2% vs 18.3%), while large plants supplied proportionally less water to residential customers than smaller plants (74.8% vs 81.7%).

## DISCUSSION

Since all water treatment plant operators who fluoride responded, we were able to analyze all Ohio water treatment plants that adjust the fluoride concentration of drinking water. As regulated by OEPA, all 224 water treatment plant operators must target their optimal fluoride concentration within the acceptable range of 0.8 to 1.3 mg F/L. More importantly, nearly 90% of operators target the state optimal level of 1.0 mg F/L. Furthermore, almost 99% of water treatment plant operators target their fluoride level at +/- 0.1 mg F/L of optimal. It is obvious that water treatment plant operators in Ohio are knowledgeable about the target concentration of public water supplies. However, it was somewhat disappointing that nearly 30% of plant operators chose the correct target level because it had always been that concentration. In both scenarios, while not statistically significant, large water treatment plant

TABLE 4

*Distribution of water treatment plants relative to factors responsible for variations from optimum fluoride concentration.*

Factors	Total Plants n (%)	Large Plant n (%)	Small Plant n (%)
Feeder problems	44 (19.6)	26 (19.8)	18 (19.4)
Main water flow variation	37 (16.5)	17 (13.0)	20 (21.5)
Raw water fluoride fluctuation	14 (6.3)	7 (5.3)	7 (7.5)
Filter backwash recycle or filter problems	11 (4.9)	7 (5.3)	4 (4.3)
Operator error	5 (2.2)	4 (3.1)	1 (1.1)
Chemical purity/density variation	4 (1.8)	2 (1.5)	2 (2.2)
Feeder problems along with other factors <sup>1</sup>	40 (17.9)	29 (22.1)	11 (11.8)
Main water flow variation along with other factors	39 (17.4)	24 (18.3)	15 (16.1)
Unknown	30 (13.4)	15 (11.5)	15 (16.1)

<sup>1</sup>Significant difference between large and small water treatment plants at the  $p < 0.05$  level.

operators more often knew the optimal level and knew the reason for it over small water treatment plant operators.

Although it is necessary for water treatment plant operators to know the correct state optimal fluoride concentration, it is equally important to be able to maintain that optimal concentration as accurately as possible. It has been determined that 1.0 mg F/L is the optimal fluoride concentration for drinking water in Ohio (USDHHS 1993). With a concentration of <1.0 mg F/L, dental decay prevalence may increase, especially in children. Studies have shown that in once optimally fluoridated communities that had their fluoride levels either decreased to sub-optimal levels or discontinued, the decline of dental decay reversed itself leading to an increase in the prevalence of dental decay (Lemke and others 1970; Kunzel 1980; Stephen and others 1987). Optimally fluoridated tap water is a major factor in the declining prevalence of dental decay in the United States (Brunelle and Carlos 1982; Brunelle and others 1983; Driscoll and others 1986; Szpunar and Burt 1988; Brunelle and Carlos 1990; Jackson and others 1995) and abroad (Ismail and others 1990; Riordan 1991; Ismail and others 1993). On the other hand, when the fluoride concentrations are greater than optimal (Ohio = 1.0 mg F/L), there is a greater likelihood for fluorosis to manifest itself (Driscoll and others 1983; Segreto and others 1984; Butler and others 1985; Driscoll and others 1986; Jackson and others 1995). Therefore, all water treatment plant operators must be held to a higher standard than OEPA control range of 0.8 to 1.3 mg F/L (Ohio Revised Code 1995).

While dental decay will continue to decrease to a point with additional fluoride added to drinking water, the increased prevalence of fluorosis does not warrant the further increase in additional fluoride above optimal. Furthermore, it has been reported that fluorosis can be perceived as an aesthetic concern by parents of children with fluorosis (Lalumandier and Rozier 1998). We found that nearly three-quarters of water treatment plant operators claimed that they were able to maintain their optimal fluoride level within 0.1 mg F/L. Again we found large water treatment plant operators more likely to maintain such accuracy over small treatment plant operators, but this time there was a significant difference.

To further compare large and small water treatment plants, the type of fluoride compound used varied with large treatment plant operators utilizing the newer compounds while the small treatment plants still use sodium fluoride. Large water treatment plants had an additional advantage in that they have proportionately more highly trained operators than the small treatment plants. Kuthy and others (1985) noted that water treatment plants with higher educated and experienced operators reported statistically greater water fluoridation compliance than facilities in which operators had less education and experience. Therefore, it should not surprise anyone that large water treatment plants have a distinct advantage over small water treatment plants, especially in maintaining a more accurate optimal fluoride concentration in drinking water.

## CONCLUSION

The majority of water treatment plant operators in Ohio know the correct optimal fluoride concentration for drinking water and are able to maintain that level within a tenth of a milligram of fluoride per liter of water. Large water treatment plant operators are more likely to maintain a consistent fluoride concentration in drinking water than small water treatment plant operators. Of interest, it is the small water treatment plant which supplies proportionately more water to residential customers than large water treatment plants. Therefore, small water treatment plants need technical assistance more than large treatment plants. All water treatment plant operators, especially those who work in small treatment plants, should receive start-up and annual training from the state drinking water engineers (CDC 1995). Operator training is an important factor in dealing with feeder problems, main water flow variations, and a variety of other factors responsible for variations in maintaining the optimal fluoride concentration. It has been reported that additional education in fluoridation will significantly increase the knowledge level of water treatment plant operators resulting in a marked improvement in compliance with fluoride levels (Kuthy and Durkee 1985). Since the major limitation of this study is that it focuses on only one state, which may not be representative of the United States, more research is needed in sampling several states from different geographical locations throughout the country.

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## The 1999 Paper of the Year Award

was presented at the Annual Meeting of the OAS  
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on  
1 April 2000  
to:

**Beth Canfield and James R. Runkle**

Department of Biological Sciences  
Wright State University  
Dayton, OH

For their paper:

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