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Costs And Savings Associated With Community Water Fluoridation In The United States

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ABSTRACT The most comprehensive study of US community water fluoridation program benefits and costs was published in 2001. This study provides updated estimates using an economic model that includes recent data on program costs, dental caries increments, and dental treatments. In 2013 more than 211 million people had access to fluoridated water through community water systems serving 1,000 or more people. Savings associated with dental caries averted in 2013 as a result of fluoridation were estimated to be $32.19 per capita for this population. Based on 2013 estimated costs ($324 million), net savings (savings minus costs) from fluoridation systems were estimated to be $6,469 million and the estimated return on investment, 20.0. While communities should assess their specific costs for continuing or implementing a fluoridation program, these updated findings indicate that program savings are likely to exceed costs.

A substantial body of evidence demonstrates the impact of oral health on overall health and quality of life.[1–3] Poor oral health is associated with poor nutrition; low birthweight; cardiovascular and diabetes complications; lower self-esteem; and pain affecting sleep, school performance, and work.[1,2,4,5] One of the most common diseases that affects oral health is dental caries (tooth decay).[1] Despite the implementation of interventions to prevent dental caries, it remains the most prevalent infectious chronic disease.[1] The burden of poor oral health is greater among people in households with lower incomes in rural areas with limited access to affordable treatment.[1,6–8] Furthermore, this oral disease burden is disproportionately higher among many members of racial/ethnic minority groups.[1,7,8] If resources to prevent and treat dental disease are to be allocated efficiently, it is important to understand the costs and effectiveness of oral health interventions.

In 1999 the Centers for Disease Control and Prevention (CDC) recognized community water fluoridation as one of ten great public health achievements of the twentieth century, based on the relationship between the costs of providing fluoridation and its effectiveness at reducing caries.[3] The Community Preventive Services Task Force, established by the Department of Health and Human Services (HHS) to identify population health interventions shown to save lives, increase lifespans, and improve quality of life, reaffirmed and updated its recommendation for community water fluoridation programs (CWFPs) in 2013, based on strong evidence of their effectiveness in reducing dental caries.[2] According to the Public Health Service, community water fluoridation is a safe and effective way to promote good oral health.[1,9–11] Despite this, 25.6 percent of the US population with access to community water systems in 2014 did not have access to fluoridated water, and each year many communities with these programs evaluate the costs and benefits of continuing fluoridation.[12]

The most recent comprehensive national study of CWFP costs and savings was published by CDC researchers in 2001.[13] In 2016 the Community

Preventive Services Task Force reported on CWFP benefit-cost findings[14] from the 2001 CDC study,[13] a 2005 Colorado study,[15] and four CWFP studies in other countries.[16–19] The benefit-cost ratios from these studies ranged from 1.12:1 to 135:1 and were positively associated with population size. The goal of this study is to provide an update to the CDC's 2001 CWFP estimate.[13] We developed a cost model that incorporates recent data on CWFP costs (called for in the Community Preventive Services Task Force's economic review),[14] caries increments, and dental treatment patterns and that considers methods and limitations of recent studies.[14–21]

The CDC[13] and Colorado[15] studies estimated reductions in caries attributable to one year of exposure to water fluoridation and associated savings attributable to averted treatment costs, in which those costs were estimated for both the initial treatment of averted caries and follow-up services provided over a lifetime to maintain a decayed tooth. Two of the four international studies referenced in the Community Preventive Services Task Force cost-benefit findings used similar approaches to account for additional treatments to maintain a tooth over time.[14,17,19] Thus, four of the six studies accounted for savings over a period of time. While most studies estimated savings by assuming that treatments included only one- or two-surface amalgam (silver) fillings, the Colorado study[15] and an Australian study[21] recognized a wider range of dental treatments (for example, single- or multisurface resin composite restorations and crowns).

In our estimates, we accounted for savings over a period of time and analyzed 2013 administrative data from three private dental insurance plans, similar to the Colorado study,[15] to include CWFP-averted costs for dental treatments that reflect dental practice patterns and the long-term benefit of maintaining a tooth.[1,22,23]

Study Data And Methods

According to CDC 2013 data, 73.0 percent ($n = 211{,}031{,}560$) of people who lived in communities with populations of 1,000 or more and obtained their drinking water through community water systems had access to fluoridated water.[24] We estimated 2013 CWFP costs, savings, net savings (that is, savings minus costs), and return on investment for this population, using a Markov model. Our methods adhered to recommendations of the Panel on Cost-Effectiveness in Health and Medicine.[25,26] CWFP savings and net savings were estimated from a societal perspective, using a discount rate of 3 percent.[27] Listed below are five steps used to develop the estimates. The online Appendix includes more detailed information, including model input parameters as well as model parameter assumptions and references.[28]

Developing the Estimates

▸ **Step 1: Estimate annual averted decay:** Annual treatment savings depended on averted dental decay attributable to fluoridation in 2013 and averted costs associated with treatment of dental decay that would have occurred without fluoridation. We estimated the averted decay from age-specific caries increments for teeth estimated from three waves of the National Health and Nutrition Examination Survey (1991–94, 2001–04, and 2011–12).[29]

The number of people with access to a CWFP,[24] the age distribution of the US population,[30] estimated age-specific caries increments, and an assumption of CWFP effectiveness in reducing caries were used to estimate the number of averted decayed teeth by age group from one year of exposure to water fluoridation. In the base model, we assumed that a CWFP reduced caries by 25 percent, based on national estimates, derived from past research, that account for the availability of fluoride from other sources (such as toothpaste and mouth rinses).[9,11,31]

▸ **Step 2: Estimate number and types of averted caries treatments:** Treatments for caries include restorations and extractions. The health and economic benefits associated with maintaining a tooth over a lifetime that include nutritional and other health benefits and quality-of-life considerations are well recognized[22–24] but not well quantified. Based on this fact and on methods used previously,[13,15,17,19] we assumed that every decayed tooth was treated or the cost of no treatment was the same as treatment, and that treatments included both initial and follow-up treatments to maintain a tooth over time.

Information on the types of initial and follow-up caries treatments was obtained from analysis of 1.5 million records on treatments extracted from 2013 administrative data from three private dental insurance plans that provided coverage throughout the United States. Treatments were classified into six types: single-surface amalgam, two or more surfaces amalgam, single-surface composite, two or more surfaces composite, crown, and extraction. We recognized that privately insured people might obtain a different mix of services than that obtained by people without such coverage.[1,6] In this model we assumed that services provided to people with private dental insurance represent practice standards and consumer expectations based on the benefits of maintaining a tooth over a lifetime.

For each age group, we derived the expected number of initial treatments, by type, from the estimated number of averted decayed teeth in

2013 and the expected distribution of initial treatment types. Since the dental insurance data did not indicate whether dental treatments were initial or follow-up, we used age as a proxy. We assumed the distribution of initial treatments for primary (baby) teeth was similar to that for primary teeth of children, excluding crowns, and primary teeth never required additional treatment. Based on a previous study,[15] we assumed that the distribution of initial treatments for permanent teeth was similar to that for youths ages 6–17, also excluding crowns.

To estimate the need for and number of follow-up treatments for permanent teeth, we used the number of initial restorations, the expected life of a restoration, and life expectancy.[32] The distributions of treatments for adults, according to the dental insurance data, were used to estimate the types of follow-up treatments. The distribution of first follow-up treatments was assumed to be similar to that for people ages 18–29; second follow-up treatments were assumed to be similar to those of people ages 30–41, and so on. These estimates might be conservative in that treatments for people at older ages include both initial and follow-up treatments.

▸ **STEP 3: ESTIMATE ANNUAL PROGRAM SAVINGS:** We estimated annual CWFP savings by summing averted direct and indirect treatment cost estimates for initial and follow-up treatments associated with the averted caries treatments.

Total direct treatment costs were estimated by multiplying the estimated number of each type of treatment by the estimated direct cost and summing them. The estimated direct cost for each treatment type was derived from analyses of the dental insurance data, 2013 dental charges for provided dental procedures,[33] and a dental charge-to-payment ratio,[34] assuming that payments reflected direct costs.

Averted indirect costs of treatment (that is, productivity losses expressed in dollars) were assumed to be the same for all treatments and derived from an estimate of average time spent (1.6 hours) traveling for and obtaining dental care[35] and an estimated value, in dollar units, of one hour of time ($24.35).[26,36]

▸ **STEP 4: ESTIMATE ANNUAL PROGRAM COSTS:** CWFP cost estimates were derived from a convenience sample of seventy-two water systems using data from a published study for thirty-seven CWFPs implemented in the 1980s,[37] and from thirty-five CWFPs implemented since 2004. We classified CWFPs into four groups based on the size of their service populations: Group 1 included 1,000–4,999 people; group 2, 5,000–19,999 people; group 3, 20,000–99,999 people; and group 4, 1,000,000 or more people.

For each CWFP group, we assumed that the per capita CWFP cost for the group was the median per capita cost for the CWFPs in that group. To estimate total 2013 CWFP costs for all people with fluoridation, we multiplied the median per capita cost by the number of people with fluoridation for each of the four CWFP groups and summed the resulting four values.

CWFP annual costs include annual operating and depreciated capital costs. The 2013 operating costs included costs for labor, fluoride chemicals, maintenance, and supplies. Labor costs were estimated for programs without annual labor cost data, using the assumption that one hour of labor was required per fluoride injection point per day[13,15,37] and information on hourly wage costs.[38,39] Annual fluoride chemical costs were estimated for the majority of programs using an equation that accounted for the CWFP service population, type and amount of chemical, chemical cost per pound, and natural fluoride level. Annual maintenance and supply costs were assumed to be 2.4 percent of categories 1 and 2 capital costs, described below.

One-time capital costs were allocated to three categories, each depreciated over varying numbers of years. Category 1 costs included costs for fluoride additive pumps, controls, testing and safety equipment, and their installation. Category 2 costs included costs for pipes, electrical wiring, storage tanks, other capital associated with installing the fluoride equipment, and engineering consultant fees. Category 3 capital costs included costs for building construction and land purchases; they were excluded from all but one return-on-investment estimate.

▸ **STEP 5: ESTIMATE ANNUAL NET SAVINGS:** We estimated CWFP annual net savings by subtracting estimated annual costs from estimated annual savings. The estimated CWFP return on investment was derived by dividing estimated annual net savings by estimated annual costs.

ANALYSIS We created a Markov model to estimate CWFP costs, savings, net savings, and return on investment for the 2013 US population with access to CWFPs that served 1,000 or more people. Probabilistic sensitivity analyses were conducted to incorporate uncertainty into the model by simultaneously sampling all parameter values from our base model using Monte Carlo simulations. We report resulting means and 90 percent uncertainty intervals (UIs) based on the fifth- and ninety-fifth-percentile values. The robustness of results to selected model input parameters (for example, caries increments, CWFP effectiveness, and fluoride level) was assessed by conducting simulations using alternative parameter estimates.

LIMITATIONS A number of study limitations deserve mention. Four pertain to the CWFP cost estimates. First, CWFP costs were derived from a convenience sample of seventy-two CWFPs, instead of a random sample. The cost data included costs for thirty-seven CWFPs implemented in the 1980s,[37] and thirty-five CWFPs implemented since 2004. While the data might not be representative of all recently implemented systems, it includes the largest sample of CWFP cost data for recently implemented systems.

Second, we gave careful consideration to our inclusion of data from CWFPs implemented in the 1980s. We decided to include these data based on three considerations: a comparison between the cost per fluoride injection point for the older systems, updated to 2013 dollars, to that for recently implemented CWFPs in Arkansas; the fact that the older systems reflected costs for existing CWFPs implemented during that time frame; and the inclusion of older systems resulted in a larger number of CWFPs in each size group to represent different water system characteristics.

Third, we had capital cost data for forty-nine of the seventy-two CWFPs but did not have data on the distribution of capital costs across the three categories of capital for the majority of water systems, so we used existing data to derive estimated allocations. Clearly, additional efforts should be made to obtain more comprehensive CWFP cost data for future studies. Lastly, we excluded direct and indirect costs associated with providing CWFP information to inform CWFP-related policy decisions.[14,20]

Other limitations merit attention. Although the caries increments were estimated from national data,[29] the data were cross-sectional, not longitudinal. This might have biased downward the estimates for both caries increments and averted caries. We assumed that payments for dental services reflected their direct costs and estimated payments from reported charges using a charge-to-payment ratio obtained from national data; we were not able to assess the influence of this assumption. Although we included indirect costs associated with time spent obtaining dental services, we excluded indirect costs associated with tooth decay such as quality-of-life reductions associated with missing teeth.

Finally, similar to other CWFP benefit-cost studies,[13,15] we did not adjust estimated direct or indirect savings for adverse effects of water fluoridation, based on reviews of existing evidence.[9,31,40] For example, we did not include direct or indirect costs associated with CWFP-associated dental fluorosis. Dental fluorosis is caused by excessive fluoride intake that most often manifests as barely visible lacy white markings, in milder cases, or spots on the tooth enamel; a rare, severe form includes pitting of the tooth surface.[11,31] We excluded these costs for three reasons. First, the HHS Federal Panel on Community Water Fluoridation, an interdepartmental, interagency panel of scientists, found no evidence of an association between CWFPs and severe fluorosis.[2,31] Additionally, we lacked data on direct treatment costs associated with CWFP-related nonsevere fluorosis and related indirect costs (for example, aesthetic concerns). We assumed that any direct costs associated with CWFP-related fluorosis would be small and would not have meaningfully influenced the CWFP return-on-investment findings.

In 2015 the Public Health Service updated its recommendation that community water systems fluoridate to 0.7 mg/L.[31] The previous recommendation ranged from 0.7 to 1.2 mg/L. The updated recommendation on fluoride concentration was based on the HHS Federal Panel on Community Water Fluoridation review of scientific evidence on water fluoridation, caries reduction, fluoride consumption from other sources, and fluorosis.[31] The panel concluded that evidence suggested CWFP effectiveness at reducing caries could be maintained at 0.7 mg/L and the risk of fluorosis reduced. While we were able to estimate the influence of this change on fluoride chemical costs, because of the timing of this change we were not able to include other influences. Future studies might monitor the relationship between this CWFP fluoride concentration level and CWFP effectiveness, the prevalence and costs of nonsevere fluorosis, and changes in public perception of CWFPs.

Study Results

In 2013 more than 211 million people lived in US communities with a community water fluoridation program (Exhibit 1). We conducted analyses of data from private dental insurance plans to describe treatments for decayed teeth by age (Exhibit 2). This information was used to estimate the types of averted initial and follow-up caries treatments associated with the CWFP. We estimated annual program savings by summing averted direct and indirect treatment costs. The averted direct treatment costs were estimated for averted dental treatments by multiplying the estimated number of each type of treatment by the estimated direct cost for the treatment (Exhibit 3).

Using base model input parameters, we estimated 2013 CWFP savings associated with caries averted as a result of fluoridation to be \$6,792 million (UI: \$5,472–\$8,606 million), or \$32.19 per capita. Averted indirect savings accounted for approximately 15.6 percent of total

EXHIBIT 1

Numbers of people with access to community water systems in 2013, by community size and fluoridation status

	Fluoridated		Not fluoridated		All	
Community size (no. of people)	**No. of people**	**Percent**	**No. of people**	**Percent**	**No. of people**	**Percent**
Group 1: 1,000–4,999	11,963,440	5.7	12,438,324	15.9	24,401,764	8.4
Group 2: 5,000–19,999	27,489,775	13.0	16,063,473	20.6	43,553,248	15.1
Group 3: 20,000–99,999	55,312,938	26.2	25,252,486	32.3	80,565,424	27.9
Group 4: 100,000 or more	116,265,407	55.1	24,402,594	31.2	140,668,001	48.6
All: 1,000 or more	211,031,560	100.0	78,156,877	100.0	289,188,437	100.0

SOURCE Centers for Disease Control and Prevention. Water Fluoridation Reporting System (WFRS) fact sheet (see Note 24 in text). **NOTE** In 2013 approximately nine million people had access to community water systems that served fewer than 1,000 people.

savings. The estimated cost of providing fluoridation in these communities was $324 million (UI: $294–$353 million), with CWFP net savings estimated to be $6,469 million (UI: $5,153–$8,280 million, $30.65 per capita) and the CWFP return on investment, 20.0 (UI: 15.5–26.2).

Because annual program costs varied by population size, net savings did as well. These ranged from $247 million for water systems that served 1,000–4,999 people to $3,693 million for water systems that served 100,000 people or more. Net savings for communities with 20,000 or more people accounted for a larger percentage of total net savings than those for communities with smaller populations because of the lower per capita costs of fluoridation and greater number of people served.

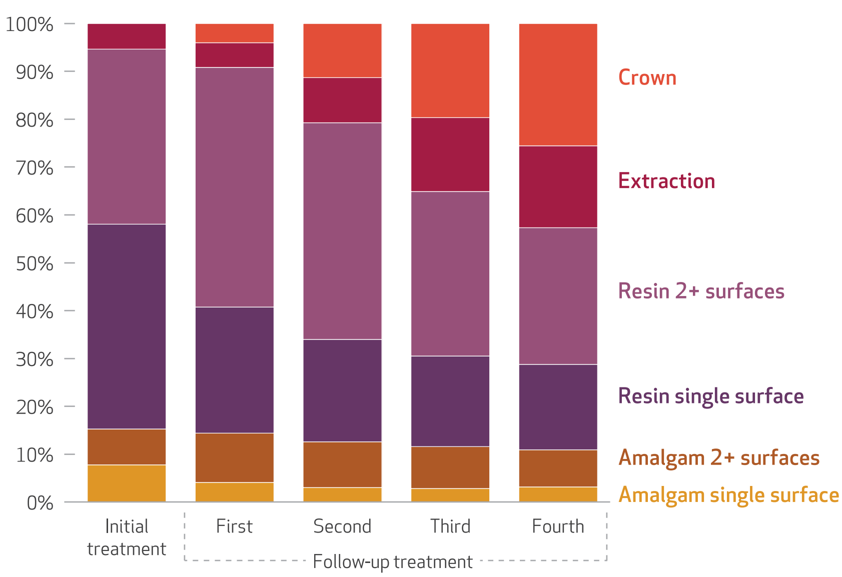
To illustrate the influence of assuming that CWFPs reduced caries by 25 percent, we estimated the return on investment using alternative assumptions. When CWFP effectiveness was assumed to be 20 percent, the estimated return on investment was 16.5 (UI: 12.8–21.3). When it was assumed to be more effective at reducing caries (that is, 30 percent), the estimated return on investment increased to 23.7 (UI: 18.3–31.5). Both estimates are within the base model's return-on-investment 90 percent UIs.

We examined the influence of including category 3 capital costs (construction and land) in the CWFP cost estimates. When those costs were included and depreciated over fifty years, the estimated return on investment was 19.6 (UI: 15.2–25.6), close to the base model estimate. We also examined the influence of our assumption that averted caries for people younger than age eighteen could result in savings associated with two to four follow-up treatments. To show how lifetime treatment costs influenced net savings, we estimated the return on investment when follow-up treatments were limited to no more than three (18.4, UI: 14.4–23.8).

The current Public Health Service recommendation for fluoride concentration is 0.7 mg/L.[11] The base model included higher fluoride concentrations, according to 2013 recommendations. We estimated a model using the 0.7 mg/L fluoride concentration; it resulted in a small 3.1 percent reduction in estimated CWFP costs and a minor increase in estimated return on investment (20.7, UI: 16.2–27.2).

EXHIBIT 2

Distributions of initial and follow-up treatments for permanent teeth, 2013



SOURCE Authors' analyses of 2013 administrative data from three private dental insurance plans. **NOTES** The information in this exhibit was used to estimate the types of averted initial and follow-up caries treatments associated with community water fluoridation programs. We assumed that the distribution of initial treatments for permanent teeth was similar to that for youths ages 6–17, excluding crowns. The distribution of treatments for primary (baby) teeth for children ages 1–8 is not shown in the exhibit. This distribution is as follows: amalgam single surface, 5.2 percent; amalgam two or more surfaces, 18.3 percent; resin single surface, 16.8 percent; resin two or more surfaces, 41.0 percent; and extraction, 18.6 percent. Amalgam and resin treatments are described in the text.

Discussion

Using updated estimates for community water fluoridation program costs, caries increments, and dental treatment patterns, we estimated that savings attributable to the programs far exceeded estimated program costs under varying assumptions of effectiveness. The estimates were derived from an economic model that incorporated data from multiple sources; because of the nature of this intervention, it would be costly to obtain actual data on benefits from a study.[14] We addressed uncertainty in our model input parameters by selecting those thought to produce conservative estimates, employed Monte Carlo simulation to provide estimates of the uncertainty of the results, and reported findings for alternative model input parameter estimates.

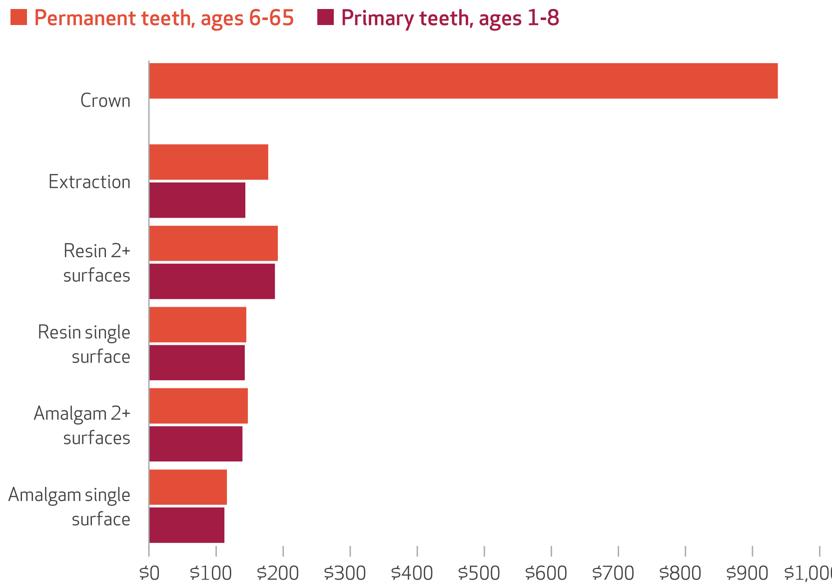
For example, we used national data to estimate age-specific caries increments. Because a large percentage of people lived in communities with fluoridated water, the estimated increments were lower than increments would be for a population without fluoridated water. Moreover, people living in communities without fluoridation likely benefited from fluoridation in other communities, a diffusion effect attributable to consumption of beverages and food produced in fluoridated communities.[41] Additionally, we estimated caries using a measure of decayed and filled teeth, similar to some recent studies,[16–18] instead of a measure of decayed and filled surfaces, as some earlier studies did.[13,15,19] Together, these three factors lowered the estimate of caries that would occur without fluoridation, biasing downward the CWFP savings estimate.

Although the lifetime benefit of good oral health is well recognized, the current literature is lacking on an adequate estimate of the costs of maintaining a decayed tooth over time. Thus, we used 2013 treatment data for people with private dental insurance to derive an estimate of those costs. We attempted to derive a conservative estimate by excluding direct costs associated with the following: crowns for initial treatments; other treatments such as bridges and implants; extractions between designated periods for first and other follow-up treatments; related procedures that occurred more than a month before or after the treatment; and travel to and from a dental provider. We also excluded indirect costs associated with tooth pain and other health and economic costs, and we excluded diffusion benefits incurred by populations who lived in communities without fluoridation, mentioned above.[41] Although beyond the scope of this study, improved estimates of such costs are needed to better evaluate oral health interventions.

While recently published CWFP benefit-cost studies reported that benefits exceeded costs, the relative difference varied by approach; the size of the populations served by the CWFPs influenced findings.[13–15,21] When those results were stratified by size, costs for some smaller systems exceeded savings. In this study we assumed that water fluoridation was associated with a 25 percent reduction in caries, similar to base estimates in the 2001 CDC[13] and 2005 Colorado[15] studies, yet we included updated estimates of caries increments and CWFP costs. Adjusted for inflation, our CWFP cost estimates were higher than those reported in the 2001 CDC[13] and 2005 Colorado[15] studies. It was difficult to compare our per capita CWFP savings and net savings findings to these studies because of other methodological differences.

EXHIBIT 3

Estimated dental payments for primary and permanent teeth, by treatment type, 2013



SOURCE Estimated direct dental costs for primary (baby) and permanent teeth by treatment type were derived from authors' analyses of 2013 administrative data from three private dental insurance plans, American Dental Association reported 2013 median charges for procedures, and 2012 Medical Expenditure Panel Survey data on the charge-to-payment ratio for general dental care. **NOTES** The information in this exhibit was used to estimate annual community water fluoridation program savings. Direct costs of treatments averted by fluoridation were estimated for averted dental treatments by multiplying the estimated number of each type of treatment by the estimated direct cost for the treatment, as shown.

Policy Implications

We found that estimated per capita savings exceeded estimated per capita costs for 211 million people with fluoridated water in 2013. This held true for all four sizes of water systems, even those that served smaller populations (1,000–4,999 people). The estimated CWFP return on investment averaged 20.0 across all sizes of water systems. During 2013 more than seventy-eight million people had access to a public water system that served 1,000 or more people that did not fluoridate the water. Our findings suggest that if those water systems had implemented fluoridation, an additional $2.5 billion might have been saved as a result of reductions in caries.

While communities might use these findings to benchmark their specific assessments of CWFP costs and savings, each community should consider its specific costs for implementing or continuing water fluoridation. There are many reasons that CWFP per capita costs vary across communities. Where a community water system serves a small population or requires that fluoride be added to the water in multiple locations, per capita costs might be relatively high. While larger communities benefit from economies of scale, factors such as multiple treatment plants or local building requirements might increase costs. Instead of using this study's estimated return on investment, communities could inform their policy decisions by identifying their specific annual costs and comparing those costs to our annual estimated per capita savings ($32.19) in averted treatment costs.

We recognize that a community's oral health burden is influenced by household income, location, and other characteristics, and, thus, so too are its CWFP benefits. Communities with higher caries increments would have greater benefits and those with lower increments, smaller benefits. Although rural communities with small populations might have higher per capita annual CWFP costs, such communities could receive higher benefits because of higher time costs associated with travel to obtain dental services and other factors that limit access.

According to the CDC, 74.4 percent of the population with access to community water systems had fluoridated water in 2014.[42] Although CWFP capital investments have already been made in these communities, more than eighty of them assessed the benefits and costs of continuing fluoridation through formal government votes or referendums in 2014 and 2015, in part as a response to budget challenges or opposition to fluoridation.[12] The fact that the United States has not yet met the Healthy People 2020 goal[43] that 79.6 percent of the population served by community water systems have optimally fluoridated water is an indication that public understanding

We found that estimated per capita savings exceeded estimated per capita costs for 211 million people with fluoridated water in 2013.

of water fluoridation and its benefits merits further study. This study provides updated information on CWFP costs and savings that could increase such understanding.

Families, communities, government, health care payers and providers, and private organizations continually evaluate opportunities to improve health outcomes, accounting for the benefits and costs of doing so. The World Health Organization classifies interventions as cost-effective if costs per disability-adjusted life-year (DALY) avoided are less than three times the per capita national annual gross domestic product and highly cost-effective if costs per DALY are less than that value.[44] In other words, cost-effective interventions need not save money. Not only is community water fluoridation effective at reducing caries, it has been found to save money in this and other recent studies.[3,13–19,21] Furthermore, CWFPs might also reduce oral health disparities within communities. Unlike other oral health interventions, access to fluoridated water is not limited by social and economic circumstances once implemented in a community. Thus, CWFP implementation and continuation should be given high consideration when assessing options to improve health and reduce health disparities. ■

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NOTES

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28 To access the Appendix, click on the Appendix link in the box to the right of the article online.

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