The Cost-Effectiveness of Fluoridating Water Supplies in New Zealand

A Report for the New Zealand Ministry of Health

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Executive Summary

Fluoridation of water supplies began in New Zealand in 1954. In 1999, 57% of the population was served by fluoridated water supplies. Over the last couple of decades there has been a very substantial reduction in rates of tooth decay, and the difference in caries rates between fluoridated and non-fluoridated areas has narrowed. This report investigates whether, in the light of these recent changes, it is still cost-effective to fluoridate presently non-fluoridated water supplies or to replace existing fluoridation plant.

In a cost-effectiveness analysis, the benefits of a health intervention are measured in "natural" or physical units that are appropriate to the intervention. For this analysis, one *averted newly decayed tooth surface in a permanent tooth* was used as the natural unit for measuring the benefits of water fluoridation. The net cost of fluoridation was based on the cost of water supply fluoridation (a positive cost) and the averted costs from prevented tooth decay (savings from treatment avoided - a negative cost). Since the economics of fluoridation will vary primarily according to the population size of a community, results of the analysis were presented for a range of population sizes. Other factors, such as the age-structure and socio-economic and ethnic distributions of the community, water flow rate, naturally occurring fluoride level, and number of fluoride injection sites required also affect the economic attractiveness of fluoridation.

For the base case analysis, a societal perspective was adopted and an annual discount rate of 5% was used for both costs and benefits. It was assumed that fluoridation of a water supply began in the year 2000 and continued without interruption to the time horizon of the year 2030. A Maori population proportion of 15% was assumed. It was also assumed that there was no new decay after age 34, and, after age 45, no further dental savings from averted decay. The latter two limitations were imposed because of the scarcity of quantitative information on adult dental benefits from fluoridation, and because of the complexity of adult dental treatment from middle age onward. In general, assumptions made will have biased the analysis toward underestimation of the cost-effectiveness of fluoridation.

Information on averted decay in 5 to 12 year old children in fluoridated and non-fluoridated areas was obtained from Wellington and Canterbury Hospital and Health Services databases; information on averted decay in adults was obtained from a study conducted in the United States. No data on averted decay associated with fluoridation were available for New Zealand adults. Treatment cost data were obtained from various sources, including the Health Funding Authority. Cost of fluoridating water supplies was obtained from consultation with several providers of fluoridation equipment and services.

The results of the base case analysis showed fluoridation to be very economic for populations ranging from 1,000 to 300,000. In this range the net cost of fluoridation was negative – dental cost savings exceeded fluoridation costs. The financial break-even point – when the cost of fluoridation was equal to the dental cost savings – occurred for a population of between 800 and 900. However, as the analysis errs on the side of underestimating the benefits of fluoridation, the true break-even point may be considerably lower. For smaller communities, fluoridation may still be considered economic depending on the intangible value assigned to an averted decayed surface.

One-way sensitivity analyses were performed for a 100% Maori community, a 10% discount rate, and variation in the number of fluoride injection sites.

It was concluded that the economic argument for fluoridation is still very strong, and particularly so for communities with high proportions of children, Maori, and/or people of low socio-economic status.

This cost-effectiveness analysis has some particular strengths. It is based on recent dental data, reflecting the reduced rates of dental caries in both fluoridated and non-fluoridated areas, it includes dental treatment savings as a negative cost, it has a relatively long time horizon, and it includes an assessment of benefits to adults.

Introduction

Fluoridation of water supplies began in New Zealand in 1954. By 1999, fluoridated water supplies were serving an estimated 57% of the population. The locations of these fluoridated water supplies are shown in Appendix 1. Over the last two decades or so, there has been a dramatic reduction in the magnitude of tooth decay in both the deciduous and permanent teeth of New Zealand children in all areas, and the difference in caries rates between fluoridated and non-fluoridated areas has narrowed. The reduction in dental caries is attributable to widespread use of fluoride-containing toothpaste, as well as to the direct effect of receiving water from a fluoridated supply. In addition, the so-called "halo effect", where foods and beverages made from fluoridated water are consumed in non-fluoridated areas, has probably played a role in reducing the differences between fluoridated and non-fluoridated areas.

The general, across-the-board reductions in dental caries have raised the question of whether it is economic to fluoridate presently non-fluoridated New Zealand water supplies or to replace existing fluoridation plant. This report is a cost-effectiveness analysis that addresses this issue. It is based on the assumption that water supplies fluoridated to optimal levels do not cause adverse health effects.[1]

There are economies of scale associated with water fluoridation, and, all else being equal, we can expect that the economic attractiveness of fluoridation will rise with the size of the population served by the water supply. A key aim of this study was to estimate the minimum population for which oral health benefits from introduction of fluoridation to a water supply would be greater than water treatment costs. However, population size is only one of many factors that influences the cost-effectiveness of this public health intervention. Other factors include the following:

[1] National Research Council. Health effects of ingested fluoride. Washington DC: National Academy Press, 1993.

- The number of fluoride injection sites will have a substantial influence on the cost of fluoridating.

- Dental treatment costs will vary across the country.

- Oral health benefits vary with age, and projected birth rates and age distributions differ across communities.

- Oral health benefits will vary with socio-economic status, and the socio-economic status of communities varies widely.

- Oral health benefits will be different for Maori and non-Maori (due to differences in age structure, socio-economic status, and other factors), and ethnic mix varies across communities.

Therefore, although we have presented our results by population size, our analysis is based on a spreadsheet model that could be used to calculate a "customised" result for a community. For example, if a water supply system would require two injection sites rather than the one site in our base case, then the relevant cost components could be changed and the result recalculated. Three illustrative sensitivity analyses are presented towards the end of this report.

Methods

Economic Methodology

Cost-effectiveness analysis (CEA) is one of the two most frequently used forms of economic evaluation in health care.[2] In a CEA, the benefits of a health intervention are measured in "natural" or physical units that are appropriate to the intervention. For this study, one *averted newly decayed tooth surface in a permanent tooth* has been used as the natural unit for measuring the benefits of water fluoridation.

The results of a CEA are expressed as cost-effectiveness ratios, that is dollars per natural unit of effectiveness. Our results are thus expressed in units of dollars per averted decayed surface.

There are many benefits from averted tooth decay. The lifetime saving in dental costs is treated in our analysis as a negative cost. The many intangible benefits, such as reduction of pain and improved social interactions, are only represented in our analysis by the proxy of averted decayed surfaces.[3] Suppose it is found that the cost-effectiveness of fluoridation for a certain community is $X per averted decayed surface. It is then a decision of the users of the analysis to judge whether the intangible benefits of an averted decayed surface are worth more or less than $X.[4]

There are two components of the *net* cost of water fluoridation:

- The cost of water supply fluoridation – a positive cost.
- Averted dental costs from prevented tooth decay – a negative cost.

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[2] The other commonly used form of economic evaluation in health care is cost-utility analysis (CUA), in which benefits are measured in quality-adjusted life-years. Some economic evaluations of water fluoridation that are called cost-effectiveness analyses (CEAs) are actually cost-minimisation analyses (CMAs), in which the costs of fluoridation are compared only with the averted dental costs and the "intangible" oral health benefits are not quantified at all.

[3] For people who believe that fluoridation is undesirable there are also intangible costs.

[4] In a cost-benefit analysis (CBA), the benefit of averted decay would be expressed in dollars. In this case, such monetary valuation would have to be found through a contingent valuation survey, in which responders would be asked how much they would be willing to pay for averted decay. Such studies have many problems, and are very expensive.

Net cost of fluoridation = Cost of water supply fluoridation *minus* Averted dental costs

Since the latter may exceed the former, the net cost of fluoridation may be negative for some communities. In such a case, it is incorrect to express the result of the CEA as a cost-effectiveness ratio, since a negative ratio has no mathematical meaning; the negative net cost and the averted decay should be reported separately.

Fluoridation of a water supply incurs a stream of costs and provides streams of averted decay and associated dental cost savings stretching into the future. In a CEA, the timing of costs and effectiveness affects their value. In our results, we have expressed both costs and effectiveness in terms of their *present value (PV)*, using a real discount rate of 5%.[5]

All costs are measured in constant dollars – 1999 dollars. With our use of a *real* discount rate, there is an implicit assumption that costs of water fluoridation and costs of dental restorations are subject to the same rates of inflation throughout the time frame of the study.

$$\text{Cost-effectiveness ratio} = \frac{\text{Net present cost (dollars)}}{\text{Net present effectiveness (averted decayed surfaces)}}$$

Both the effectiveness of fluoridation and the associated averted dental costs are affected by demographic characteristics of the community served by the water supply. The more caries-prone an individual happens to be, the greater will be the benefit from fluoridation. The earlier in life decay is averted, the longer the stream of averted dental costs.

[5] For an explanation of discounting and the rationale of the choice of 5% as a suitable discount rate for economic evaluation of health interventions in New Zealand, see Wright, J.C., "Discounting in Cost-Utility Analysis. Why Is it Done and Which Rate Should the Health Funding Authority Use?", 19 Dec., 1998. (Available from author.) Discounting of costs over an amortisation period incorporates both the depreciation of capital equipment and the opportunity cost of forgone investment.

In our base case analysis, we adopt a societal perspective taking account of all benefits and costs.

Data and Assumptions

There are four components of the economic analysis.

1) Demography -- community size and age structure.
2) Averted decay .
3) Cost savings from averted decay.
4) Costs of fluoridation.

The details of each are explained for the base case economic analysis in this section of the report.

1 Demography

The following five assumptions were used in constructing the demographic component of the model.[6]

1) Fluoridation of a water supply begins in the year 2000, and continues without interruption until at least the time horizon for the analysis – the year 2030.[7]
2) There is no new averted decay after the age of 34.
3) There are no dental cost savings from averted decay after the age of 45.
4) There is no mortality in the birth cohorts who benefit from fluoridation from 2000 to 2030.
5) The effects of out-migration in the cohort are exactly counterbalanced by the effects of in-migration.

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[6] The reasoning behind the second and third assumption are explained in subsequent sections of the report.
[7] The 30 year time horizon allows for one replacement of fluoridation plant, and discounting renders any costs and benefits more than 30 years into the future insignificant.

The first three of these assumptions bias the results toward underestimation of the benefits of fluoridation, and the fourth towards overestimation, of the benefits. We expect that the third assumption would dominate the others as dental care becomes increasingly complex and expensive with age.

In the demographic sub-model, the population who will benefit from fluoridation is divided into two groups – those born in 2000 or after, and those born before 2000.

Those born in 2000 or after:
Each birth cohort benefits from fluoridation from its birth year through to 2030.

Those born before 2000:
Those aged 15 or less in the year 2000 benefit from fluoridation from 2000 to 2030.

Our base case analysis assumes that the community served by the fluoridated water supply maintains the same projected age and ethnic structure as the total NZ population in the year 2000, which is 15% Maori, 85% non-Maori. The percentage of Maori in the total population is actually projected to increase from 15% in 2000 to 19% in 2030. As we will show, the benefits to Maori currently are greater than the benefits to non-Maori. The assumption of a constant 15% Maori proportion throughout the time period of the analysis biases our results toward underestimation of the benefits of fluoridation. On the other hand, the assumption that the current differential between the effectiveness of fluoridation for Maori and non-Maori will not narrow[8] biases our results toward overestimation of the benefits of fluoridation. We have no way of estimating the direction of the net bias.

We considered the inclusion of other ethnic groups in the model, particularly Pacific Island people, since they would benefit particularly from fluoridation. However, the effectiveness of fluoridated water for Pacific Island children could not be estimated with any confidence from our data. Moreover, such detailed analysis, were it practicable, would have no implications for decisions regarding fluoridation, other than those already presented in this report.

[8] This is tantamount to assuming that the relative socio-economic status of Maori will not improve over the next 30 years.

Table 1 shows how the numbers and ages of those who would benefit from fluoridation in a community that has a population of 25,000 in the year 2000 are scaled from the total projected population of 3,869,000 in the year 2000. A similar projection for a hypothetical Maori population of 25,000 in the year 2000 is also presented in the table. The source of the demographic data for the base case is the "average" of the Department of Statistics projections from the 1996 Census.[9]

2 Estimates of averted decay

Our estimates of averted decay attributable to fluoridation are taken from two sources. For children aged from 4 to 13, New Zealand data were available. For 14 to 34 year-olds, we used the results of a study carried out in the United States.

Ages 4 to 13 years

In New Zealand, dental treatment is publicly funded up to the age of 17. Although there are few routinely collected data for adolescents, data are collected on the dental status, but not the dental treatment, of 5 to 12 year old children by the providers of school dental services. However, the providers of school dental services in the Wellington and Canterbury regions use a system that gathers detailed data on both dental status and dental treatment for each child, and these data also include a record of whether the child lives in an area provided with fluoridated water.

[9] "Projected New Zealand Resident Total Population by Single Year of Age at 30 June 1997-2051; 1996 Base. Series 4: Assuming Medium Fertility, Medium Mortality, and Long-Term Annual Migration Level 5,000."

All records for 1996 were extracted from the Wellington and Canterbury Hospital and Health Services databases, and after removing records for children aged less than 4 years old[10], the resulting dataset contained records of dental treatment for 29,097 children (aged from 4 to 13 years-old) receiving fluoridated water, and 46,825 who were receiving non-fluoridated water. Data on treatment for deciduous teeth were restricted to ages 4 to 10 and, for permanent teeth, to ages 6 to 13. We had data on extractions of deciduous teeth, but not data on extractions of permanent teeth. Extractions of permanent teeth are not usually performed in the School Dental Services.

Table 2 contains a summary of these data. For both deciduous and permanent teeth, children living in fluoridated areas had fewer fillings than children living in non-fluoridated areas at every age from 4 to 13 years. The difference is approximately twice as great for Maori children as for non-Maori children. Note that this dataset is a record of fillings and extractions, but does not include decayed but untreated teeth (although these are likely to be very few), and therefore may slightly underestimate the incidence rates of dental caries in the children studied.

There is a greater rate of premature extractions of deciduous teeth in fluoridated areas in our data. However, the result is based on a small number of extractions and, therefore, is statistically very uncertain. It is likely that this apparent anomaly is due to confounding by other variables, such as subtle differences in extraction practices between the two main areas for which data were available. Not all deciduous tooth extractions are performed because of dental caries. Many are for teeth that are about to be exfoliated and are causing problems because they become loose. Providers vary in their willingness to undertake these elective extractions.

An extraction was counted as equivalent to the five tooth surfaces (top and four sides). Since our data show extractions of deciduous teeth were more common in fluoridated areas than in

[10] Although over 95% of school-aged children use school dental services, rates of utilisation for preschool children are lower, and, as a result, only very incomplete data are available for those children. The information available to us suggests that while approximately 67 percent of 4-year olds in the Wellington and Christchurch areas are using services, only 57 percent of 3-year olds are doing so.

non-fluoridated areas, this contributes to an understatement of the case for fluoridation.

Because decay is averted in both deciduous and permanent teeth, our natural unit of effectiveness, one averted decayed surface in a *permanent* tooth, does not completely capture the total benefit in terms of averted decay. However, in the long term, the value of averted decay in deciduous teeth is less than the value of averted decay in permanent teeth because deciduous teeth are exfoliated by late childhood. Potentially, a weighting factor that expressed the intangible benefits of an averted decayed surface of a deciduous tooth as a fraction of an averted decayed surface in a permanent tooth could have been used. In the absence of any clear basis for such a weighting factor, we took the conservative approach of not counting deciduous teeth in our estimates of numbers of decayed surfaces averted (ie, a weighting factor of zero was used). This approach understates the case for fluoridation, since no value is placed on the intangible benefits of averted decay in deciduous teeth. However, we did incorporate the averted cost of filling deciduous teeth into our analysis. [11] Overall, then, averted decay in deciduous teeth is taken into account in calculation of costs, but does not contribute to the estimate of effectiveness.

Ages 14 to 34 years

Because the effect of fluoridation on teeth is now known to be largely topical (rather than systemic), it benefits people of all ages who are at risk of dental caries.[12,13] There are a number of studies showing decreases in both coronal caries and root caries for adult teeth.[14,15,16] However, there are no New Zealand data on adult dental benefits associated with fluoridation.

[11] Had we used such a weighting factor, our natural unit of effectiveness would have been "one *equivalent* averted decayed surface in a permanent tooth".

[12] Featherstone J.D. Prevention and reversal of dental caries: role of low level fluoride. Community Dent Oral Epidemiol 1999; 27: 31-40.

[13] Murray J.J. Adult dental health in fluoride and non-fluoride areas. Part 1.- Mean DMF values by age. Brit Dent J 1971; 131: 391-395.

[14] See "Water Fluoridation in New Zealand: An Analysis and Monitoring Report", Public Health Commission, 1994, p.18.

[15] Newbrun E. Effectiveness of Water Fluoridation. J Public Health Dent 1989; 49:279-289 (Special Issue).

[16] Murray JJ, Rigg-Gunn AJ, Jenkins GN. Water Fluoridation and adult dental health. In: Fluorides in Caries Control. Edition 3. Oxford: Butterworth and Heineman 1991, pp 64-75.

In the absence of New Zealand data for those aged 14 and above, the most useful data (for the purposes of this study) on the effects of fluoridation on adult teeth were obtained from a study conducted in the United States.[17] The study population consisted of 10,628 Washington state employees and their spouses, aged 20 to 34. After controlling for a number of factors, including other sources of fluoride exposure, use of antibiotics, and past use of dental services, the study found that each year of fluoridation exposure reduced decayed and filled surfaces by 0.29 surfaces (95% confidence interval: 0.19-0.39 surfaces).

We have used this estimate of 0.29 decayed and filled surfaces averted annually for non-Maori aged 14 through 34 in our base case analysis, on the assumption that the benefit accrues in the year of exposure. We believe that in doing so, we have again erred on the side of understating the case for fluoridation, for three reasons.

First, the adults in the U.S. sample were all employees (or dependent spouses) of the state of Washington. As such, they would all have had dental insurance, so the condition of their teeth would probably be better than that of the average New Zealander. The effectiveness of fluoridation rises with vulnerability to caries, particularly those in lower socio-economic groups.[18,19]

Second, in the absence of data for older aged people, we have truncated the effectiveness of fluoridation at age 34. However, older adults are at risk of caries and would be expected, therefore, to benefit from fluoridation. These benefits would be from the direct effects of fluoride on their teeth and from continuing benefits of exposure to fluoridated water in their younger years. The benefits of fluoridation extend over the whole of life.

Third, we have assumed the same effectiveness for teenagers (ages 14 through 19) as for young adults (ages 20 through 34). Our NZ data show the average annual effectiveness at age 13 to be 0.66 filled surfaces averted; it is very unlikely that a year later, it has dropped to 0.29.

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[17] Grembowski D., Fiset L., and Spadafora A. "How Fluoridation Affects Adult Dental Caries: Systemic and Topical Effects are Explored". Journal of the American Dental Association 1992; 123: 49-54.
[18] Jones C., Taylor G., Woods K., et al. Jarman underprivileged area scores, tooth decay and the effect of water fluoridation. Community Dental Health 1996; 14: 156-60.
[19] Riley JC., Lennon MA., and Ellwood RP. (1999). The effect of water fluoridation and social inequalities on dental caries in 5-year old children. International Journal of Epidemiology 1999; 28: 300-5.

We have, however, raised the 0.29 surfaces to 0.59 surfaces for effectiveness in Maori teenagers and young adults, by scaling it by the ratio of the Maori to non-Maori effectiveness at age 13.[20] Thus, for our base case analysis, in which the population served by the water supply is 15% Maori, average annual effectiveness is taken as 0.33 averted decayed surfaces.[21]

3 Cost savings from averted decay

The estimation of dental cost savings due to averted decay is difficult. Simply using the averted cost of the initial filling greatly underestimates the lifetime flow of costs that is triggered by the initial decay of a tooth surface.

One approach would be to map out a number of typical "life paths" for each tooth type, and use these as a basis for estimating streams of dental costs stemming from initial decay. This modeling exercise is potentially very complex and well beyond the scope of this study, but an example of such a life path is presented in Appendix 2.

This hypothetical life path of a molar shows that basing averted treatment costs on the increment in DMFS scores is reasonable early in an individual's life, but inaccuracy rises increasingly with time. Over 60 percent of all dental restorative work is for the *replacement* of restorations[22], and continued replacement often involves an escalation in complexity and cost of treatment.

We have used an averted decayed *surface*, rather than an averted decayed *tooth*, as our unit for the effectiveness of fluoridation, since it is a more sensitive measure. This rules out the inclusion of downstream averted dental costs like crowns and root fillings.[23]

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[20] 0.29 * 1.150 / 0.570 = 0.585.
[21] 0.85 * 0.29 + 0.15 * 0.585 = 0.334.
[22] Sheldon T; Treasure E. Dental restoration: what type of filling? Effective Health Care 1999; 5, 1-12.
[23] Even had we measured effectiveness in averted decayed teeth, estimating the full range of averted dental costs would still be extraordinarily difficult.

Although it means that our estimates of averted dentistry costs are too low, in the absence of an alternative, we have assumed the following:

- All restorations are *single surface amalgams*.
- Amalgam restorations require replacement every *eight years*.
- No restorations after age 45.[24]

Besides omitting the averted expensive "middle-age" treatments, the assumption that all averted dental treatments are simple restorations will underestimate averted costs in the teenage and young adulthood years. This is because many restorations involve approximal surfaces, and these are more costly to restore and require more frequent repair than those surfaces that receive a single surface amalgam filling .

Finally, the cost of a simple restoration is required. For an economic analysis, the cost should be the full resource cost. However, the available price information is distorted by government subsidy.

In New Zealand, routine dental care is publicly funded for children and teenagers under the age of 18. Funding for children receiving school dental services is by way of a capitation payment, and costs of individual types of restorations are not directly obtainable. The average General Dental Benefit fee paid nationally for a single surface amalgam provided for an adolescent is currently $23.81.[25] For analysis, we rounded this off to $24.[26]

For adults, dental charges vary widely across the country. One recent survey shows the cost of a single surface amalgam varying from $32 to $122.[27] This procedure typically takes 15 minutes, so its cost is traditionally estimated as about 25% of the target hourly rate. We have used $66[28] for the averted cost of a single surface amalgam for those 18 years and above.

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[24] This is required by the time horizon of the analysis and the assumption of no averted decay after age 34.

[25] Source: Health Funding Authority, Wellington.

[26] Similarly, the Dental Benefit for an extraction is $40.20, and we rounded this to $40 for the cost of extracting a deciduous tooth.

[27] "Hell's Teeth! Why is Dentistry Getting More Expensive?" Consumer, April 1999.

[28] "NZ Dental Association, "A Profile of the Average New Zealand Dental Practice" gives the average target hourly rate in March 1998 as $257. Taking a quarter of this, and increasing it by 3%, to allow for inflation into 1999 dollars, gives $66.

The large difference in the costs of restorations between children and adolescents, and adults has several causes. Dental treatment for children is largely provided by dental therapists who earn less than dentists, and generally have less expensive equipment and facilities. Economies of scale are gained through the reduced overheads of larger organisations, and the provision of school dental clinic buildings is currently funded through the Education vote. The benefits paid to dentists for treating adolescents tend to be lower than fees charged to adults for similar services.

Earlier in this report, we noted that in our calculations of present value, there is an implicit assumption that costs of water fluoridation and costs of dental restorations are subject to the same rates of *inflation* from 2000 to 2030. While we have no information on whether the costs of water fluoridation are rising faster than general inflation, we do know that dentistry costs are. Quoting from the Consumer report cited above, *"… our survey indicates that in the last four years, average charges for seven dental treatments have increased by 9% up to 25% ahead of inflation."* Again, the bias in our analysis will be toward understatement of the economic case for fluoridation.

4 Costs of fluoridating

Information on the costs of establishing and operating a fluoridation plant were obtained by consulting several equipment providers and operators of fluoridation systems. Estimates of both capital and annual operating costs for a range of population sizes are presented in Table 3.

Three types of fluoridation system are in use in New Zealand. These are:

- a powder feed system using sodium fluorosilicate or sodium fluoride;
- a slurry system using sodium fluorosilicate or sodium fluoride;
- a liquid-based system using hydrofluosilicic acid.

For the purposes of this analysis we have chosen to use the system that uses a liquid source of fluoride (hydrofluosilicic acid), containing 15% available fluoride. This material is cheaper than the alternatives, and, because it does not generate fluoride-containing dust, the use of a dust removal system for worker protection is not needed. Fluoridation systems based on hydrofluosilicic acid serve a larger proportion of the New Zealand population than the alternatives.

Use of this system requires a storage tank with bunding sufficient to hold the entire contents should there be a sudden unintended release. In addition, there is the cost of the fluoride pump and the associated pipework.

The major capital cost is for a continuous readout fluoride monitor, which feeds back to constantly adjust the level of fluoride entering the system. We have assumed that the fluoride pump would be located with other water treatment equipment. However, if a separate building to house the pump were required, this would cost approximately an extra $10,000 in initial capital investment.

For our base case, we have assumed that fluoridation of a water supply would be accomplished at a single point with one delivery pump for adding the hydrofluosilicic acid. However, a water system with several separate water sources may require a separate fluoridation system for each, and the capital costs would need to be adjusted accordingly. Once operating satisfactorily, fluoridation pumps should require minimal attention and maintenance. Labour estimates are based on a charge of $50 per hour.

The major operating expense is the cost of the hydrofluosilicic acid at about $200 per tonne. For estimating the amount of hydrofluosilicic acid required, we first obtained flow data on all New Zealand water supplies[29] and calculated a population-weighted average water use of 375 litres per person per day. Assuming a requirement of 1 gram of fluoride per cubic metre of water gave an annual cost of hydrofluosilicic acid per person of about 18 cents when the water supply contains none or very low levels of fluoride. Water supplies with higher natural levels of fluoride would require the addition of less hydrofluosilicic acid to reach optimal levels of fluoride.

[29] Personal communication, Chris Nokes, ESR.

Economies of scale for water fluoridation are shown in Figure 1. Capital investment is largely independent of the population served by the water supply. Annual costs are dominated by the amount of hydrofluosilicic acid required and assumed to rise linearly with population size increase. However, the annual cost for a population of 300,000 is only nine times more than the annual cost for a population of 1,000.

For our base case, the present value of the costs of fluoridation over the time horizon of the analysis was calculated using a discount rate of 5%, and assuming that equipment would be replaced halfway through our 30-year time frame.

We have not included anything in our analysis for the cost of community consultation, referenda, etc., if such should be necessary. This is a local issue and we do not have information that would allow us to estimate the costs of such activities. Moreover, whether the cost of community consultation would be a positive or negative cost would depend on the circumstances. If a community with fluoridated water were questioning whether or not to replace fluoridation equipment, then the cost of consultation should enter our analysis as a negative cost.

Results

Base Case

The results for the base case in Table 4 show fluoridation to be extremely attractive in economic terms for populations ranging from 1,000 through to 300,000. For all populations in this range, the net cost of fluoridation is negative – the dental cost savings exceed the fluoridation costs. Indeed, for populations above 10,000, the dental cost savings could be described as swamping the fluoridation costs.

Figure 2 shows the net costs saved as a function of population. The relationship is essentially linear above a population of about 5,000. This occurs because the water fluoridation costs become insignificant, the net costs saved are approximately equal to the dental cost savings, and the dental cost savings are proportional to population size.

The financial break-even point – when the cost of fluoridation is equal to the averted dental cost savings – occurs for a population between 800 and 900.[30] However, since our analysis errs on the side of underestimating the benefits, the true break-even point may be considerably lower. Even if our result was taken at face value, for smaller communities fluoridation may still be considered economic, depending on the intangible value assigned to an averted decayed surface. Table 5 shows the cost-effectiveness for these smaller communities in terms of dollars per averted decayed surface.

[30] The costs of fluoridation for these small communities are taken to be the same as for a population of 1,000, except for the cost of the hydrofluosilicic acid which is scaled accordingly.

Sensitivity Analyses

The results of three one-way sensitivity analyses are presented in this section.

1 Maori communities

Because the benefits of fluoridation are greater for those of lower socio-economic status[31], on average Maori will benefit more than non-Maori. The difference between Maori and non-Maori for children has already been presented in Table 2.

Since the effectiveness of fluoridation declines with age, higher birth rates and the greater proportion of children and young people among Maori raises the aggregate effectiveness.

Table 6 gives the results of the economic analysis for communities that are 100% Maori. While there are few, if any, 100% Maori communities, and certainly none at the higher population levels, a comparison of Table 6 with Table 4 shows a rapidly diverging difference. The divergence can also be seen in Figure 3.

Fluoridation of the water supply of a Maori community of 1,000 would generate a net cost saving of over $300,000 compared with the net cost saving of $17,000 for the base case community of 1000 including 15% Maori.

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[31] The variation of the effectiveness of fluoridation with socio-economic status in our dataset of New Zealand children is shown in Appendix 3.

2 Discount rate

There is a large economic and public policy literature on the choice of discount rate for public expenditure.[32] Indeed, some have argued that discounting health effectiveness is immoral since future health gains are valued less than present health gains. However, decisions implied by the results of economic analyses are frequently unaffected by the choice of discount rate.

The discount rate used in the base case is 5%. Table 7 gives the results of the analysis for a discount rate of 10%. The net cost is negative for every population 5,000 and above, although about half that calculated with a discount rate of 5% (Table 4). Figure 3 gives the comparison in graphical form. Even for a population of 1,000, fluoridation is worthwhile if the intangible benefits of an averted decayed surface are considered to be greater than $32.

3 Number of fluoride injection sites

There are many reasons why the costs of fluoridating real water supply systems may differ from those in our analysis. Some examples are:

- A different set-up of fluoridation equipment may be required, particularly for water supplies serving smaller communities.
- The water flow rate is different to the New Zealand average.
- There is already appreciable naturally-occurring fluoride in the water (although this would be unusual in New Zealand).
- Several fluoride injection points are needed.

In this sensitivity analysis, we experimented with the last of these by varying the number of injection sites from one to five. We increased all costs, except that of the hydrofluosilicic acid, in direct proportion to the number of sites.

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[32] For an excellent discussion of the choice of discount rate for the evaluation of health interventions, see Lipscomb, J., Weinstein, M.C., and Torrance, G.W. *"Time Preference"* in Gold, M.R., *et al.* (Eds), *"Cost-Effectiveness in Health and Medicine"*, New York: Oxford University Press 1996.

The results are shown in Table 8. For populations of 10,000 or more, the net cost savings are little affected by the number of injection sites, because the fluoridation cost stream is dominated by the cost of the hydrofluosilicic acid.

For a population of 1,000, there is a positive net cost associated with more than one injection site, and the cost-effectiveness ratio ranges from $92 per averted decayed surface for two sites to $402 per averted decayed surface for five sites.

Discussion

We conclude that the economic argument for installation of water fluoridation facilities for presently non-fluoridated water supplies is very strong. The results of our base case analysis and almost all the results of our sensitivity analyses show that the averted dental costs would exceed the water treatment cost for communities greater than 1,000 or so. Where a community has a substantial proportion of Maori, a socio-economic status lower than average, or a high proportion of children, the economic argument is particularly persuasive. This is even more so when it is considered that we have generally been conservative in our assumptions. Thus, our analyses considerably underestimate the benefits of fluoridation, particularly since we were unable to take into account the benefits to older people.

It is our view that one could not ask for more from a public health intervention than from water fluoridation. It is a public health intervention that:

- has well-proven efficacy
- is extremely cost-effective
- does not require heavy capital investment or operating costs
- is safe
- does not require population behaviour change
- does not require great changes to the status quo, as, for example, would be needed to improve sub-standard housing
- benefits probably anyone who retains some of their natural teeth
- benefits children especially
- has benefits that last over the whole of the lifetime
- and benefits most those whose health is poorest, namely, Maori and others of relatively low socio-economic status.

It is possible that the cost-effectiveness of fluoridating additional water supplies could diminish as more and more water supplies become fluoridated, and the halo effect becomes correspondingly stronger. It would be appropriate from time to time (say every 10 to 20 years) to re-evaluate the cost-effectiveness of extending this public health measure in New

Zealand. Given the shifting demographic structure of the New Zealand population, it is likely that the benefits of fluoridation to adults will be of more importance in any such future analysis. However, unless efforts are made to gather information on the benefits of fluoridation to adults, any future cost-effectiveness analysis will run into the problem that we encountered - a complete absence of local information on such benefits. We would, therefore, recommend that research to investigate the benefits of fluoridation in New Zealand adults be encouraged and appropriate funding be made available.

We believe this cost-effectiveness analysis has particular strengths. It is based on recent dental treatment data that reflect the reductions in decay rates in both fluoridated and non-fluoridated areas and the narrowing of the difference between these areas. We are aware of no other cost-effectiveness analysis for fluoridation that has done this. In addition, we have included dental treatment savings as a negative cost. A review of eight cost-effectiveness analyses of water fluoridation noted critically that none of them had done this, being based solely on the cost of fluoridating water supplies[33]. Further strengths of our analysis are that the time horizon of the evaluation is substantial (30 years), and we have estimated benefits to adults (up to age 45). In general, other cost-effectiveness analyses have had shorter time horizons and have been based on benefits to children only.

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[33] White, B.A., Antczak-Bouckoms, A.A., and Weinstein, M.C. (1989). "Issues in the Economic Evaluation of Community Water Fluoridation". Journal of Dental Education 53(11): 646-657.

Appendix 1: New Zealand Fluoridated Zones

Extracted from National Water Information New Zealand on 10 May 1999

Community name	Zone code	Zone name
Ashburton	ASH003AS	Ashburton
Ashhurst	ASH001AS	Ashhurst
Auckland City	AUC001AU	Auckland
Auckland City	AUC001CB	Central Business District
Auckland City	AUC001HI	Hillsborough
Auckland City	AUC001HO	Mt Hobson
Auckland City	AUC001MA	Maungawhau
Auckland City	AUC001OT	Otahuhu
Auckland South, Manukau City	AUC002EA	Earls Court
Auckland South, Manukau City	AUC002HH	High Head
Auckland South, Manukau City	AUC002MM	Manukau Misc.
Auckland South, Manukau City	AUC002PA	Papatoetoe
Balclutha	BAL001BA	Balclutha
Burnham Military Camp	BUR001BU	Burnham Camp
Clifton School	CLI002SC	Clifton School
Defence Auckland	DEF001DE	Defence Auckland
Dunedin City	DUN001BO	Booth Road, Dunedin
Dunedin City	DUN001GI	Green Island
Dunedin City	DUN001LL	Low Levels/Peninsula, Dunedin
Dunedin City	DUN001MH	Maori Hill
Dunedin City	DUN001PC	Port Chalmers
Dunedin City	DUN001RC	Ross Creek, Dunedin
El Rancho Christian Camp	ELR001ER	El Rancho Christian Camp
Eureka	EUR001EU	Eureka
Feilding	FEI001FE	Feilding
Gisborne City	GIS001GI	Gisborne City
Gordonton	GOR003GO	Gordonton
Hamilton	HAM001HA	Hamilton City
Hastings City	HAS001FL	Flaxmere
Hastings City	HAS001HA	Hastings
Havelock North	HAV001HA	Havelock North
Hawera	HAW003HA	Hawera
Hawera	HAW003NO	Normanby
Hawera	HAW003OH	Ohawe Beach
Hawera	HAW003OK	Okaiawa
Hibiscus Coast	HIB002HI	Hibiscus Coast
Hibiscus Coast	HIB002WA	Waiwera
Invercargill	INV001BL	Bluff
Invercargill	INV001IN	Invercargill City
Kaitaia	KAI008KA	Kaitaia
Linton	LIN001LI	Linton

Community name	Zone code	Zone name
Lower Hutt	LOW001EA	Eastbourne
Lower Hutt	LOW001HA	Haywards
Lower Hutt	LOW001LO	Lower Hutt
Lower Hutt	LOW001ST	Stokes Valley
Lower Hutt	LOW001WA	Wainuiomata
Masterton	MAS002MA	Masterton
Matangi	MAT003MA	Matangi
Methven Township	MET001ME	Methven Township
New Plymouth	NEW002BE	Bell Block
New Plymouth	NEW002LE	Lepperton
New Plymouth	NEW002NE	New Plymouth
New Plymouth	NEW002WA	Waitara
Newstead	NEW001NE	Newstead
North Shore	NOR001NO	North Shore
Palmerston North City	PAL001AO	Aokautere
Palmerston North City	PAL001FW	Fitzherbert West
Palmerston North City	PAL001KG	Kelvin Grove
Palmerston North City	PAL001PC	Palmerston North City
Papakura	PAP001TA	Takanini
Paraparaumu	PAR001PA	Paraparaumu
Porirua	POR001MA	Mana/Plimmerton/Paremata
Porirua	POR001PH	Porirua High Level
Porirua	POR001PL	Porirua Low Level
Porirua	POR001PU	Pukerua Bay
Porirua	POR001WH	Whitby
Pukekohe	PUK002AN	Anzac
Pukekohe	PUK002KI	Kitchener
Pukekohe	PUK002PH	Hilltop
Redhills	RED002RE	Redhills
Stratford	STR001ST	Stratford
Tamahere	TAM001TA	Tamahere
Taumarunui	TAU003TA	Taumarunui
Taupo - Lake Terrace	TAU001TC	Taupo Central & West
Taupo - Rainbow Point	TAU009TS	Taupo South
Templeview	TEM003TE	Templeview
Tisbury School	TIS001SC	Tisbury School
Tokoroa	TOK001TO	Tokoroa
Turangi	TUR001TU	Turangi
Upper Hutt	UPP001PI	Pinehaven
Upper Hutt	UPP001UP	Upper Hutt Central
Waikanae	WAI010PP	Peka Peka
Waikanae	WAI010WA	Waikanae
Waipukurau	WAI004HI	High Pressure Zone, Waipukurau
Waipukurau	WAI004LO	Low Pressure Zone, Waipukurau
Waitakere City	WAI009GL	Glen Eden / New Lynn
Waitakere City	WAI009HE	Henderson

Community name	Zone code	Zone name
Waitakere City	WAI009LA	Laingholm
Waitakere City	WAI009MO	Montana
Waitakere City	WAI009OR	Oratia
Waitakere City	WAI009TE	Te Henga
Waitakere North	WAI104WA	Waitakere North
Wellington City	WEL002BR	Brooklyn
Wellington City	WEL002CH	Churton
Wellington City	WEL002EA	Eastern Wellington
Wellington City	WEL002JO	Johnsonville
Wellington City	WEL002KA	Karori
Wellington City	WEL002KE	Kelburn
Wellington City	WEL002ON	Onslow
Wellington City	WEL002SO	Southern Wellington
Wellington City	WEL002TA	Tawa
Wellington City	WEL002WA	Wadestown
Wellington City	WEL002WE	Wellington Central
Wenderholm Regional Park	WEN003WE	Wenderholm Regional Park
Whakatane	WHA005OH	Ohope
Whakatane	WHA005WH	Whakatane

Summary of Fluoridated Supplies

Zone Count 106

Population 1,808,069

Percent Reticulation 57%

Appendix 2: A possible "life path" of a first molar.

This simple projection is based on the susceptibility of smooth tooth surfaces to decay, unless fluoride protected. With fluoride, the mesial (M) and distal (D) lesions might have been avoided, and the tooth retained.

Commonly, four or more teeth experience such a treatment sequence.

Age	**Problem**[1]	**Treatment**	**Increment in DMFS**[2]	**Costs**[3]
8	O – caries	Simple restoration	1	$50
10	B – caries	Simple restoration	1	$50
13	M – caries	MO compound restoration	1	$70[4]
16	D – caries	DO compound restoration	1	$70[4]
26	M – caries	MOD compound restoration	0	$90[5]
45	Cusps fall off	Full gold crown	1	$700
54	Pulp dies	Root filling	0	$600
75	Abscess	Extracted	0	$80
				$1,710

Notes:

1. O: occlusal surface; B: buccal surface; M: mesial surface; D: distal surface.
2. DMFS: Decayed, missing or filled surface in permanent tooth.
3. Costs based on a rough estimate of private practice costs, and, therefore, on the high side for the first four treatments.
4. Although this is a two surface compound filling, one surface is already filled, so the DMFS increment is only one.
5. New decay on the mesial surface; the dentist replaces all the fillings.

Appendix 3: Variation in the benefits of fluoridation with socio-economic status

The following table shows the mean per-child numbers of restorations in permanent teeth by age, socio-economic status (SES), and exposure to fluoridated water, based on school dental data.

Socio-economic status is defined in terms of the TFEA (Targeted Funding for Educational Achievement) scale. This scale was developed by the New Zealand Ministry of Education and applies to schools.[34] Children have been classified in terms of which school they attended. For each school, the indicator is calculated on the basis of a population-weighted sum of socio-economic indices for each of the census area units from which its pupils were drawn. Not all families will have a socio-economic status exactly equivalent to the value of the TFEA for the census area unit in which they live. The resulting misclassification would be expected to lead to some underestimation of the differential effect of SES.

The TFEA index is expressed in deciles. In the table below, "low" SES refers to deciles 1 to 3, "medium" SES to deciles 4 to 7, and "high" SES to deciles 8 to 10. The table shows that, generally, fluoridated water has greater benefits for children attending schools whose pupils are drawn from less privileged areas.

SES	**Fluoridation**	**Age (years)**							
	status	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Low	Not fluoridated	0.18	0.45	0.90	1.16	1.73	2.32	2.78	4.00
	Fluoridated	0.13	0.31	0.49	0.61	1.02	1.29	1.74	2.45
	Difference	**0.05**	**0.14**	**0.41**	**0.55**	**0.71**	**1.03**	**1.04**	**1.55**
Medium	Not fluoridated	0.12	0.33	0.65	0.96	1.44	1.88	2.44	3.79
	Fluoridated	0.06	0.21	0.44	0.59	0.79	1.07	1.81	2.48
	Difference	**0.06**	**0.12**	**0.21**	**0.37**	**0.65**	**0.81**	**0.63**	**1.31**
High	Not fluoridated	0.11	0.23	0.50	0.73	1.14	1.48	2.10	3.21
	Fluoridated	0.06	0.18	0.33	0.43	0.62	0.83	1.22	1.76
	Difference	**0.05**	**0.05**	**0.17**	**0.30**	**0.52**	**0.65**	**0.88**	**1.45**

[34] Ministry of Education Socio-economic Indicator for Schools. Data Management and Analysis Section, Ministry of Education, 1997.