Report prepared for the Ministry of Health

Review of the benefits and costs of water fluoridation in New Zealand

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Executive summary

The Ministry of Health commissioned us to provide an updated evaluation of the benefits and costs of water fluoridation, in the New Zealand setting. In doing so, we take an economist's perspective; we look at the national cost-effectiveness and cost-benefit of fluoridation, and comment briefly on disparities.

Oral health is a major issue in New Zealand

The most recent survey of New Zealanders' oral health found oral health had improved considerable in the past 20 to 30 years; however, it also found New Zealand remains a relatively high-caries population.

Dental decay accounts for approximately 1 percent of all health loss in New Zealand due to early death, illness or disability. This burden exists despite public provision of dental services for children and widespread use of fluoride toothpaste. The 'burden' of the disease from dental decay is equivalent to three-quarters that of prostate cancer, and two-fifths that of breast cancer in New Zealand.

Water fluoridation involves the controlled addition of fluoride to a public drinking water supply to optimum levels to improve oral health. In New Zealand natural fluoride levels in water supplies vary but are generally low compared with other countries, at less than 0.2 parts per million (ppm, equivalent to 0.2 mg/L). The Ministry of Health recommends adjusting fluoride levels to between 0.7 and 1.0 ppm in drinking water as the most effective and efficient way of preventing dental decay.

Public supply of drinking water covers 3.8 million New Zealanders, approximately 85 percent coverage. Approximately 56 percent of people on public drinking water supply currently receive fluoridated water. District councils manage public water supplies and are responsible for making the decision whether to add fluoride to water supplies for oral health benefit.

Strong evidence for benefits of water fluoridation

A large body of epidemiological evidence over 60 years, including thorough systematic reviews, confirms water fluoridation prevents and reduces dental decay across the lifespan. The evidence for this benefit is found in numerous New Zealand and international studies and reports. However, the precise amount that dental decay is reduced by is difficult to estimate.

Our estimates for the benefit of water fluoridation are as follows:

- In children and adolescents, a 40 percent lower lifetime incidence of dental decay (on average) for those living in areas with water fluoridation. This estimate is based on the New Zealand Oral Health Survey (NZOHS).
- For adults, a 21 percent reduction in dental decay for those aged 18 to 44 years and a 30 percent reduction for those aged 45+ (as measured by tooth surfaces affected). This estimate is based on the Australian National Survey of Adult Oral Health (NSAOH).

We selected this study rather than the 2009 NZOHS findings for adults because, unlike the 2009 NZOHS, the Australian study took into account lifetime exposure to water fluoridation.

- 48 percent reduction in hospital admissions for treatment of tooth decay, for children up the age of four years. This estimate is based on the findings of the Public Health England Monitoring Report 2014.

Fluoridation is materially cost-saving

We estimate that adding fluoride to New Zealand's water treatment plants classified as medium (i.e. those supplying populations over 5,000), is cost-saving; and for those plants classified as minor (i.e. those supplying populations over 500) it is likely to be cost-saving. We estimate the net discounted saving over 20 years for minor and above plants to be $1,401 million, made up of a cost of fluoridation of $177 million and cost offsets of $1,578 million from reduced dental decay. We estimate the 20-year discounted net saving of water fluoridation to be $334 per person, made up of $42 for the cost of fluoridation and $376 savings in reduced dental care. In short, there is a 9 times payoff; adjusting the discount rate from 3.5 percent to 8 percent results in a 7 times payoff. The costs of fluoridating water treatment plants fall to district councils. The benefits accrue to the health system in a small way and largely to individuals.

Dental care benefits are made up of a combination of reduced fillings (initial and replacements), fewer tooth extractions, and a reduction in childhood hospitalisations for treatment of dental decay. We estimate water fluoridation results in 8 million fewer teeth affected by decay, which is an average of 2 per person over 20 years. This represents a 22 percent reduction in the number of teeth affected by decay, combined across the total population. (We also assumed a 30 percent reduction in decayed tooth surfaces.)

This positive result is robust to significant changes in assumptions. Further, our assumptions around dental costs avoided are likely to be at the lower end of what patients face.

Water fluoridation tends to be more expensive per person in smaller areas, as the cost depends on the number and size of treatment plants serving a population. Costs for councils will differ for a number of reasons, including and beyond those identified in our data-set. Therefore, individual council appraisal is recommended so the correct benefit profile and capital and operating costs can be assigned to each council's situation.

Quality of life benefits are material

We estimate provision of fluoridated water to all of New Zealand reticulated water supplies over 20 years would result in between 8,800 and 13,700 quality adjusted life years (QALYs) gained. At an individual level, the average health benefit per person due to a reduction in dental decay is expected to be between 0.002 and 0.003 QALYs (discounted, i.e. approximately equivalent to an additional 1 to 1.5 days of life at full quality of life). In comparison to almost all other health spending, these quality benefits are from a cost-saving intervention, rather than being paid for.

Greater benefit expected for those with higher levels of decay

Equally important in health interventions to overall efficiency of the intervention are the distributional effects. There is strong evidence water fluoridation reduces dental decay regardless of ethnicity, socioeconomic status and age. We expect the relative impact of water fluoridation is the same across ethnic groups and deprivation. Because of the increased amount of dental decay among Maori and those who are most deprived, we expect these groups to have a greater absolute benefit from water fluoridation.

1. Introduction and context

The Ministry of Health commissioned us to provide an updated understanding of the benefits and costs of water fluoridation in the New Zealand context. The intention is this will be useful information for decision-making in relation to current and future water fluoridation practice.

In 1999, the Ministry of Health commissioned the Institute of Environmental Science and Research (ESR) to complete a cost-effectiveness analysis of water fluoridation.[1] The aim of the analysis was to provide an updated evaluation of the benefits and cost of water fluoridation in the New Zealand setting, from 2000 to 2030. ESR found water fluoridation reduced dental decay in children and the cost savings from reduced dental care outweighed the cost of water fluoridation in towns with over 1,000 people.

Some fifteen years on, water fluoridation remains a public health policy matter of significant debate in New Zealand, with little increase in population coverage of water fluoridation having been achieved. In this period, the evidence base on the benefits of water fluoridation among children and adults has been considerably strengthened through several systematic reviews of the epidemiological evidence. Furthermore, the 2009 NZOHS has provided comprehensive information on the current oral health status of New Zealand adults and children.

The Ministry of Health strongly recommends local authorities fluoridate drinking water supplies to prevent dental decay and improve oral health. The Ministry recommends extension of water fluoridation schemes where technically feasible. Specifically the Ministry recommends the adjustment of the natural levels of fluoride in drinking water upwards to 0.7 to 1.0mg/L to improve oral health. The Ministry's policy and recommendations are consistent with other leading international health agencies such as the World Health Organisation, and other countries such as Australia that have widespread community water fluoridation coverage. The advice is based on international evidence, systematic reviews of current evidence on the safety and effectiveness of water fluoridation and relevance to the New Zealand context.[2]

A recent report on the safety and effectiveness of community water fluoridation, '*Health effects of water fluoridation: A review of the scientific evidence*', published in August 2014 by the Royal Society of New Zealand and the Office of the Prime Minister's Chief Science Advisor, specifically considered the New Zealand evidence on dental decay and the effect of water fluoridation. The report concluded:

> *'The World Health Organisation (WHO), along with many other international health authorities, recommends fluoridation of water supplies, where possible, as the most effective public health measure for the prevention of dental decay.*
>
> *A large number of studies and systematic reviews have concluded that water fluoridation is an effective preventive measure against tooth decay that reaches all segments of the population, and is particularly beneficial to those most in need of improved oral health. Extensive analyses of potential adverse effects have not found evidence that the levels of fluoride used for community water fluoridation schemes contribute any increased risk to public health, though there is a narrow range between optimal dental health effectiveness*

and a risk of mild dental fluorosis. The prevalence of fluorosis of aesthetic concern is minimal in New Zealand, and is not different between fluoridated and non-fluoridated communities, confirming that a substantial proportion of the risk is attributable to the intake of fluoride from sources other than water (most notably, the swallowing of high-fluoride toothpaste by young children). The current fluoridation levels therefore appear to be appropriate.

This analysis concludes that from a medical and public health perspective, water fluoridation at the levels used in New Zealand poses no significant health risks and is effective at reducing the prevalence and severity of tooth decay in communities where it is used.'

1.1 Structure of this report

This report is structured into the following key sections:

- **Oral health and why it is important**

  We open with definitions of key concepts in relation to oral health, including an explanation of how the extent of dental decay can be measured. We provide a profile of oral health disease in NZ and an overview of policy settings and strategic drivers, to illustrate why improved oral health is important for the health and well-being of the NZ population. We discuss other interventions and treatments for improving oral health.

  We explain why and how water is fluoridated. We give an overview of the history of water fluoridation practice, both globally and in New Zealand.

- **Clear positive evidence for water fluoridation**

  In this section, we provide an overview and interpretation of the extensive international literature and New Zealand-specific data relating to the effectiveness and safety of water fluoridation.

- **Cost of water fluoridation**

  We detail our estimates of fluoridating public water supplies across New Zealand. These estimates take into account the number and size of water treatment plants.

- **Fluoridation proves to be highly cost-effective**

  We detail the methods used to estimate the reduction in dental decay and the associated cost savings; leading to an estimate of the net savings from investing in water fluoridation.

- **Quality of life benefits are significant**

  We quantify the improvement in health outcomes from water fluoridation in terms of quality adjusted life years (QALYs) in order to enable comparisons to health benefits of other investments in health.

- **Disparities likely to be reduced**

  We summarise and quantify the likely reduction in disparities in dental disease due to water fluoridation.

2. Oral health and why it is important

The World Health Organisation (WHO) defines oral health as:

> *'a state of complete physical, mental and social well-being, not merely the absence of dental decay, oral and throat cancers, gum disease, chronic pain, oral tissue lesions, birth defects … and other diseases that affect the oral dental and craniofacial tissues.'*[3]

The WHO Global Oral Health Programme emphasises that oral health is integral and essential to general health, and is one of several determinants of quality of life.[4] Oral health encompasses not only the aesthetics of having good teeth and a nice smile; most importantly it is critical to the good health and well-being of children and adults. Disorders and diseases of the teeth and mouth remain the most common of any of the long-term conditions, they are largely preventable, their impact on individuals and society is high and they are expensive to treat.[7]

Dental caries and periodontal disease are considered the two main current threats to natural teeth; these two diseases have historically been considered the most important global oral health burdens.[7] We confine our evidence and discussion to the oral disease dental caries. This is because fluoride delivered through water fluoridation specifically acts to protect against dental caries.

2.1 Dental decay and its consequences are more significant than generally realised

2.1.1 Consequences of oral disease

Oral disease causes pain and suffering, impairment of function and self-consciousness. Oral disease and its consequences can have a profound effect on an individual's quality of life and ability to gain employment. Furthermore, millions of school and work hours are lost globally due to pain and infection from dental diseases or from the time required to treat them.[5,6]

An emerging body of evidence also suggests that poor oral health affects general health and has risk factors in common with other chronic diseases. Research has shown associations between poor oral health and conditions such as diabetes, respiratory disease, heart disease, oral cancer and premature, low-birth-weight babies.[7]

Globally, the greatest burden of oral disease falls on poor and disadvantaged populations. The current pattern of oral disease reflects distinct risk profiles related to living conditions, behavioural and environmental factors, oral health systems and implementation of schemes to prevent oral disease. As such, oral disease is a significant issue of health equity.

Oral disease is a serious and common public health problem and represents a considerable burden to the public and the public health system. WHO has stated that oral disease is the fourth most expensive disease to treat.[8]

Measuring severity of dental decay experience

Below we summarise the common methods used to measure dental decay.

DMFT index

The DMFT is a standardised index used for measuring the severity of dental decay. It is defined as an index of dental decay experience measured by counting the number of decayed (D), missing (M) and filled (F) teeth (T).

In terms of their practical application, the terms are used to describe the extent of decay as follows:

- D – untreated decay;
- M – Missing tooth due to dental decay or periodontal disease (not used for other reasons); missing teeth may be replaced with a bridge or crown; and
- F – Filling; on average two of the tooth surfaces are filled in New Zealand.

The score relates to the number of teeth affected, with the maximum score being the total number of adult teeth, 32. As dental decay progresses the DMFT score increases, while also the relative proportions of D, M, and F change.

Upper-case letters (DMFT) indicate measures relating to adult teeth, while lower-case letters (dmft) indicate measures of the extent of dental decay in primary/baby teeth in children.[7]

DMFS index

The DMFS is a similar measure to DMFT; it is another index of dental decay experience measured by counting the number of decayed (D), missing (M) and filled (F) surfaces (S) of permanent teeth. Five surfaces of each tooth are assessed.[7]

Percent caries-free

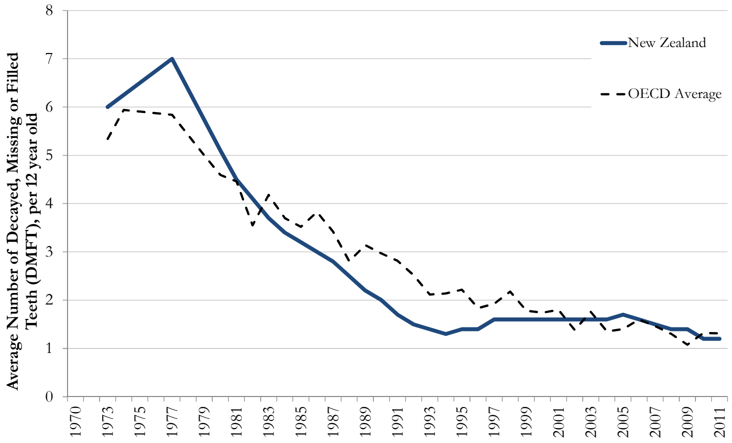
Percent caries-free is another term commonly used in relation to the measurement of dental decay. It is the percentage of the population that has no dental decay. Caries-free is defined as:

> *'Having no teeth that were decayed, missing due to pathology (dental decay or periodontal disease), or filled (i.e. a dmft/DMFT score of 0).'*[7]

2.1.2 Historical rates of dental decay

The rate of dental decay has been falling in developed countries over the last four decades. This can be seen in the rates of decay in 12 year olds between 1970 and 2011, which across the OECD countries have fallen from an average of 5 to 6 teeth affected by dental decay in 1970 to 1 to 2 in 2011; this is depicted in Figure 1 below. The rates for New Zealand have followed this international trend. Most of the reduction happened between 1970 and 1990. In the last 20 years dental decay rates have remained at approximately similar levels.

Figure 1 Dental decay rates in 12 year olds as measured by DMFT, between 1970 and 2011



Source: data from OECD stat extract;[9] graph created by Sapere.

2.2 Oral health in NZ is improving, but tooth decay is still a major concern

The most detailed information on oral health across New Zealand is the 2009 New Zealand Oral Health Survey (NZOHS) commissioned by the Ministry of Health. A total of 4,906 New Zealanders were surveyed with 3,196 having dental examinations. The survey was conducted between February and December 2009.[7]

The NZOHS found that the oral health of New Zealanders has improved considerably over the past 20 to 30 years. However, New Zealand remains a relatively high dental decay population.[7]

The survey confirmed the international trend of increasing tooth retention among adults and older adults, with New Zealand adults retaining more of their teeth for longer, with the implication that more teeth are at risk of dental decay than in the past. Within this picture of improved oral health and increased tooth retention, there were concerning levels of tooth decay. The survey found both children and adults were caries-active. Among children:

- 1 in 5 children aged 2–4 years were affected by dental decay.
- Less than half of children aged 5–11 years (42.5 percent) and 12–17 years (44 percent) had not been affected by decay in their primary and/or permanent teeth.
- By age 18–24 years, only one in five (22.7 percent) had teeth unaffected by decay.

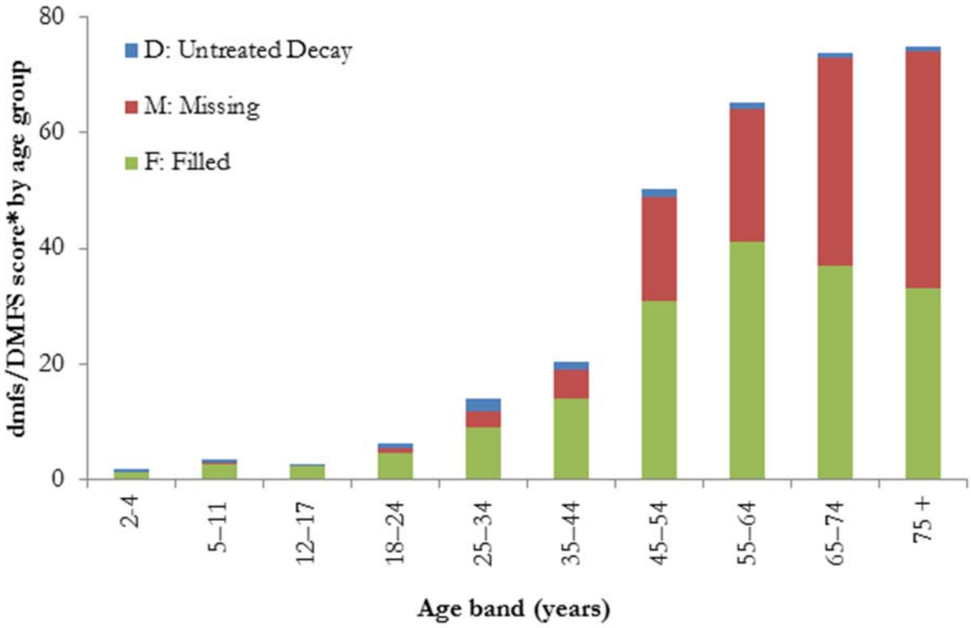
Among adults aged 18 years and over, one in three had untreated active decay on the crowns of their teeth. Older adults, aged 75 years and over, had a similar prevalence of untreated decay on the crowns of their teeth as other adult age groups, but they had the highest prevalence of untreated root decay, with 29 percent affected.

The survey reported on protective factors and behaviours for oral health such as access to fluorides, through tooth-brushing with fluoride toothpaste and access to fluoridated drinking water. The survey found that only two thirds (65 percent) of adults with natural teeth brushed twice daily with fluoride toothpaste of the recommended concentration (i.e. 1000 ppm or more; 'regular strength'). For children aged 2–17 years, less than half (43 percent) met the Ministry of Health's recommendation of brushing twice daily with fluoride toothpaste of at least 1000 ppm fluoride. Among pre-schoolers aged 2–4 years, only 15 percent met the Ministry's recommendation for daily oral care practices.

Although not specifically designed as a fluoridation study, as residential fluoridation history was not collected, the survey did provide the first opportunity to look at the effect of fluoride on dental health across all age groups in the population. The 2009 NZOHS found that children and adults living in fluoridated areas at the time of the survey had statistically significantly lower lifetime experience of dental decay (i.e. lower dmft/DMFT) than those living in non-fluoridated areas. Among children and adolescents, this reduction in experience of tooth decay was calculated to be 40 percent on average.

Figure 2 below provides a snapshot of the severity of dental decay experience at the tooth surface level in New Zealand by age group, based on the 2009 NZOHS.

Figure 2 Snapshot of average severity dental decay experience (dmfs/DMFT score) among dentate children and adults in New Zealand in 2009, reported by age group



*For age groups 2–4 and 5–11, the results are for primary teeth (dmfs); other age group results are for permanent teeth (DMFS).
Source: Data reported in the NZOHS;[7] graph created by Sapere.

The New Zealand Burden of Diseases, Injuries and Risk Factors Study published by the Ministry of Health in 2013 found dental decay is estimated to account for approximately 1 percent of all health loss in New Zealand that is due to early death, illness or disability, as reported in the burden of diseases study.[10] The annual loss in disability adjusted life years (DALYs)[i] from dental decay is estimated to be 7,500 (equivalent to 7,500 years lived at full

[i] A DALY is measured similarly to a QALY. It is a measure of both life years lost and years lived with a disability (with more debilitating diseases creating a greater DALY loss).

health). The 'burden' of disease from dental decay is equivalent to three-quarters that of prostate cancer, and two-fifths that of breast cancer in New Zealand.

Disparities in oral health are clear

The 2009 NZOHS shows that whilst oral health in adults has continued to improve over the last three decades, Maori, Pacific Peoples and people living in high deprivation areas experience worse oral health outcomes.

Among adults, these disparities were higher levels of untreated decay and missing teeth, poorer self-reported oral health and higher prevalence of one or more negative oral-health-related quality-of-life impacts.[7]

Maori, Pacific Peoples and people living in high deprivation areas also reported poorer access to dental services.[7]

2.3 Adding fluoride to water supplies

Water fluoridation involves the controlled addition of fluoride to a public water supply.

Fluoride occurs naturally in most water sources. In New Zealand natural fluoride levels in water supplies vary but are generally low in comparison with other countries, at less than 0.2 parts per million (ppm, equivalent to 0.2 mg/L).

The Ministry of Health recommends the adjustment of fluoride to between 0.7 and 1.0 parts per million in drinking water as the most effective and efficient way of preventing dental decay. The maximum acceptable value of fluoride for drinking water in New Zealand is 1.5 ppm.[11]

Fluoride promotes oral health in a variety of ways as outlined below:

- Decreasing de-mineralisation.
- Increasing re-mineralisation in early cavities.
- Inhibiting the process that metabolises sugar to produce acid (the cause of dental decay).

2.4 A 60-year history in New Zealand

The use of water fluoridation first began in New Zealand in Hastings in 1954.[12] A Commission of Inquiry was held in 1957 and then water fluoridation use rapidly expanded in the mid-1960s.

The decision to introduce fluoridated water is made by district councils, who have the power to supply water for their district (section 379, Local Government Act 1974).

Currently a little over half of the New Zealand population receive fluoridated drinking water. This contrasts markedly with Australia where currently over 90 percent of the population receives fluoridated drinking water. The cities of Auckland, Wellington and Dunedin comprise the greatest population coverage of water fluoridation. Larger centres that currently do not fluoridate include Whangarei, Tauranga, Napier, New Plymouth, Rotorua, Nelson, Blenheim, and Christchurch.

There has been controversy around water fluoridation, with increasing public debate and consideration of the issue by district councils over recent years[13,14]. As a means of supporting an increase in the proportion of the population receiving the benefits of community water fluoridation, the Ministry of Health has a drinking-water fluoridation subsidy. District councils may receive a subsidy of around 50 percent to cover capital costs (i.e. set-up costs) when they are initiating water fluoridation. The drinking-water fluoridation subsidy replaces the subsidies that were made for water fluoridation under the Ministry's Sanitary Works Subsidy Scheme.[15]

2.4.1 Current status in New Zealand

Public supply of water covers 3.8 million New Zealanders, approximately 85 percent coverage; 56 percent of those people receive fluoridated water.[ii] 39 of 66 councils do not add fluoride to their water supplies. It is noteworthy that Auckland Council (Auckland Super City) accounts for two thirds of the population that has fluoridated water.

Some districts have public water supplies covering a relatively small proportion of the land mass, but still provide water to over half their population. This is due to the clustering of populations around cities.

The map below (Figure 3) summarises the water fluoridation status by district councils across New Zealand. The map is colour coded by the proportion of the population with fluoride added to their reticulated water supply; the districts shaded green are those with less than 10 percent of their population with fluoridated water. Much of the South Island is shaded green.

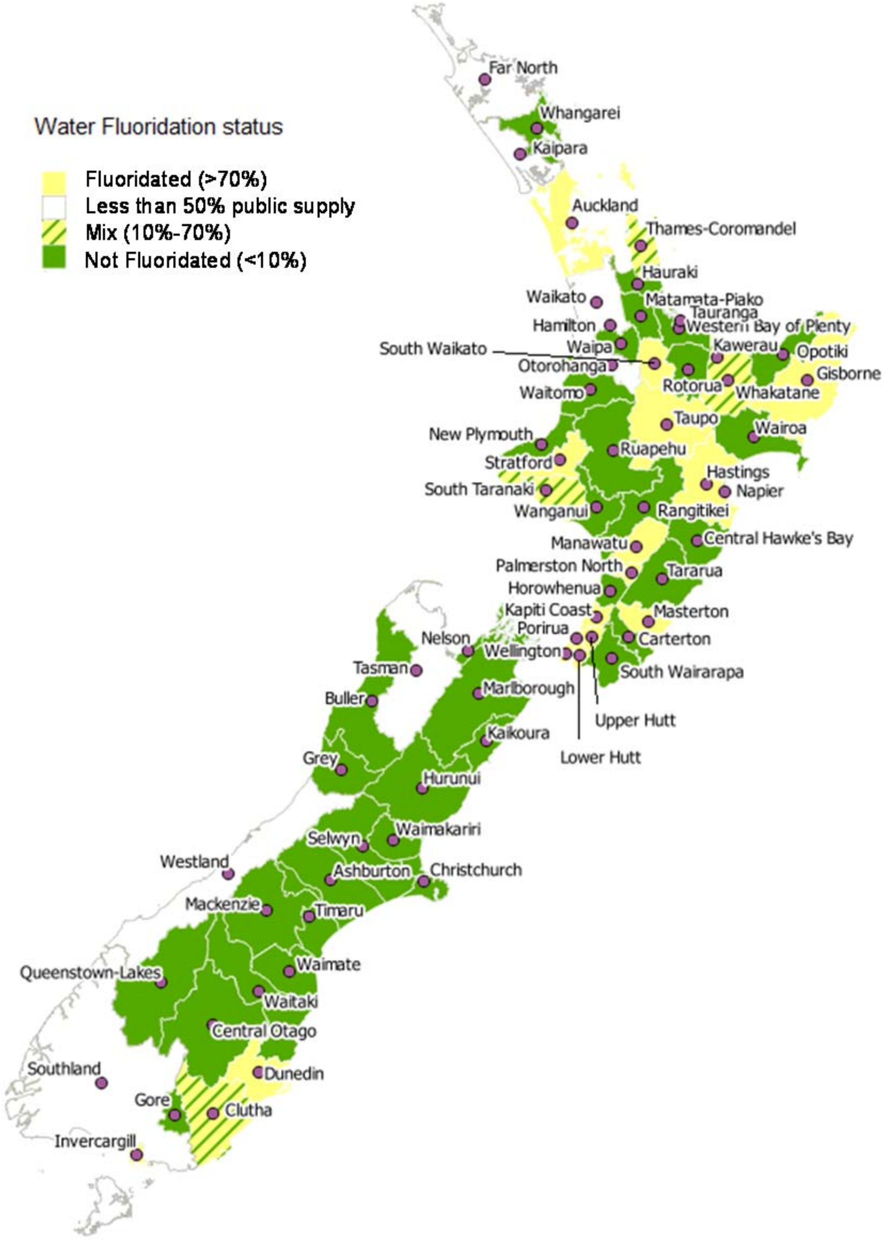
Yellow depicts districts with fluoridated water supplied to over 70 percent of their population. Larger cities in the North Island are generally shaded yellow.

There are a few districts that have between 10 percent and 70 percent water fluoridation coverage; this is depicted as a mix of green and yellow.

The water fluoridation status of districts with low levels (under 50 percent) of public water supply is not reported; these districts are likely to have low levels of water fluoridation as fluoridation of private water supplies is uncommon.

ii Note that this estimate is based on recording a community as 'fluoridated' if any of the plants supplying it have fluoridated water. This is the same approach taken by ESR for the production of statistics in relation to fluoridation.

Figure 3 Water fluoridation status for reticulated water supplies in NZ, by district council, as of January 2014



Source: Data supplied by the Institute of Environmental Science and Research; figure created by Sapere.

3. Significant reduction in dental caries for the New Zealand population

There is strong international and New Zealand evidence that water fluoridation reduces dental decay; however, the precise amount that dental decay is reduced by is difficult to estimate. Studies report varying levels of benefit. This variation is explained in part by the reduction in dental decay over time, improvements in other dental treatments, differences in study populations, and the adjustment for duration of exposure to water fluoridation. We spend some time discussing these parameters as they are critical in our economic analysis.

3.1 Evidential assessment

We worked with dental experts to determine appropriate values for key parameters within our modelling.

There are two main perspectives for considering the applicability of evidence, namely:

Internal validity: studies with higher internal validity are more likely to accurately estimate the effect of an intervention (e.g. water fluoridation) on the population studied. A key determinant of the internal validity is the study type. The hierarchy of study types is ranked from highest to lowest as follows:

- Systematic reviews and meta-analyses;
- Randomised controlled trials with low risk of bias;
- Randomised controlled trials;
- Cohort studies;
- Case-control studies;
- Cross sectional surveys; and
- Case reports.

External validity, which refers to the generalisability of the study for application of the intervention to the intended population (i.e. New Zealanders at the present time and in the future). This includes consideration of factors such as whether there are differences in the population or the environment/system within which the intervention will be implemented. As such, key factors we considered, working with the dental experts, include:

- *Population:* Were the people included in the study similar in terms of key characteristics?
- *Comparator intervention:* Was the intervention delivered in the same way as would be expected in the real world? For instance, was the level of fluoride added in the studies to the current NZ recommended level of 0.7–1.0 ppm and what was the duration of exposure to the intervention?
- *Context:* Are there factors in the context/system within which the target population that will mean the effect in the studies will differ in the real world?

3.2 Evidence of reductions in dental decay among children associated with water fluoridation

The majority of the studies on the benefits of water fluoridation are of children. Although there is variability in individual studies, the results of meta-analysis are fairly consistent with the result of the NZOHS. Other recent New Zealand studies in children also report similar results to the NZOHS.

Table 1 below summarises the key evidence relating to the reduction in dental decay associated with water fluoridation among children. We discuss the 2009 NZOHS and other studies in more detail below.

Table 1 Summary of key evidence for benefits of water fluoridation in children

Study (year of publication)	Population	Study type	Reduction in dental decay
2009 New Zealand Oral Health Survey (2010)[7]	1431 NZ children surveyed in 2009; 987 dentally examined	Cross-section	40%[a]
York report (2000)[28]	29 studies from countries around the world published between 1951 and 1999	Meta-analysis of before-and-after studies Prospective studies	38%[b]
Rugg-Gunn and Do (2012)[16]	30 evaluations of primary teeth, published after 1990	Meta-analysis. Most evaluations included were based on cross-sectional studies; some before-and-after studies were included	30–59%[c]
	53 evaluations of permanent teeth, published after 1990		50–59%[c]
Cochrane (2015)[17]	9 studies with 44,268 participants	Meta-analysis of before-and-after studies Prospective studies	35%[d]

[a] NZOHS: result reported as a 1.7 ratio of means; based on dmfs/DMFS.

[b] York report: figure calculated by Sapere. In the York report the average dmft/DMFT across the studies was 3.8 with water fluoridation and 6.1 without water fluoridation (Appendix F of the York report).

[c] Rugg-gunn and Do reported the 'Modal score'.

[d] Cochrane reported on reduction in dmft.

3.3 2009 NZ Oral Health Survey found a 40 percent reduction in dental decay, on average, among children and adolescents

We understand the 2009 New Zealand Oral Health Survey (NZOHS)[7] provides the most reliable estimate in terms of the estimated impact of water fluoridation on the oral health of New Zealand children and adolescents. The survey included a large number of participants from a randomised sample taken across all of New Zealand and provides high-quality recording of data and high levels of reliability of reporting the clinical data. The NZOHS surveyed 1,431 children aged 2 to 17 years, 987 of whom had a dental examination.

The data were also adjusted for confounding factors to make comparisons more accurate and meaningful. Adjustment variables included standardisation, age, sex, ethnicity and socioeconomic deprivation.

There were many results reported in the NZOHS oral health survey, including a section on the effects of water fluoridation. Results were compared for those living within and those living outside areas with water fluoridation, although this comparative reporting was relatively limited because assessing the effect of water fluoridation was not one of the objectives of the study. Questions on lifetime exposure to fluoridated water were not included in the interview.

The measures reported were dmft/DMFT (decayed teeth) and dmfs/DMFS (decayed tooth surfaces). Both measures reported those living in areas with water fluoridation had 40 percent lower incidence of dental decay (both results were statistically significant). The absolute difference in dental decay was 1.0 less tooth and 1.6 less surfaces for those living in areas with water fluoridation.

3.3.1 Other NZ evidence is generally supportive of the findings of the NZOHS

We identified the following literature:

- **Effect of water fluoridation in 9 year old children living in Auckland is supportive of NZOHS findings; with a greater effect when controlling for duration of exposure to water fluoridation**
  A study compared the effect of water fluoridation by comparing dental outcomes in 9 year olds who have lived continually in either an area with (175 children) or without water fluoridation (149 children).[iii] Additional to these groups were children who spent time living in both fluoridated and non-fluoridated areas. The study reported those who have continually lived in fluoridated areas as being under half as likely to have dental decay, compared to children continuously living in non-fluoridated areas (odds ratio of 0.42, controlling for gender, ethnicity, socioeconomic status and toothpaste use). This

[iii] The date range of dental examinations is not stated. The article was published in 2009.

reduction is 50 percent greater than reported in the NZOHS, and is likely to be due to adjusting for duration of water fluoridation exposure.

Children who live in an area with water fluoridation (but have not always) were compared to children continuously living in non-fluoridated areas. In this comparison, there was less difference in dental outcomes[18] (odds ratio of 0.59).

- **Southland children study reports results similar to NZOHS**
  In 2002, 436 children (aged 9 or 10) across Invercargill, Gore, Winton and Queenstown were examined for differences in enamel defects. The study reported those living in fluoridated areas had half the severity of decay, compared to those living in areas without fluoridated water (measured by DMFS, controlling for other contributing (confounding) factors).[19]

- **Wellington and Christchurch comparison study reports similar results to NZOHS findings**
  Data from 1996 were used to compare the dental outcomes of 14,942 children living in areas with and without water fluoridation. The data included dental outcomes for children aged between 5 and 12 living in either Wellington or Christchurch (~95 percent and ~5 percent water fluoridation coverage respectively).[20]

  Five year olds living in fluoridated areas had a rate of 60.9 percent caries-free, compared to 54.1 percent in non-fluoridated areas. When controlling for other variables, it was estimated those living in fluoridated areas were 0.59 (95 percent CI 0.53–0.65) times as likely (i.e. 41 percent less likely) to have dental decay.[20]

  Twelve year olds living in fluoridated areas had a rate of 51.7 percent caries-free, compared to 41.6 percent in non-fluoridated areas. When controlling for other variables, it was estimated that those living in fluoridated areas were 0.62 times as likely (i.e. 38 percent less likely) to have dental decay (95 percent CI 0.56–0.69).[20]

  The relative reduction in having dental decay observed in this study is similar to the rates of caries-free reported in the NZOHS, when comparing 5–11 year olds.

- **Otago study on general anaesthesia for treatment of dental decay reports a reduction in decay**
  1,396 cases of children aged 1 to 6 years of age who underwent general anaesthesia found that those living in areas with fluoridated water had fewer teeth affected (3.9 versus 4.9 $p<0.05$), and were 2.4 months older when they presented. The data were based on records of Otago children and only included cases due to extensive early childhood dental decay.[21]

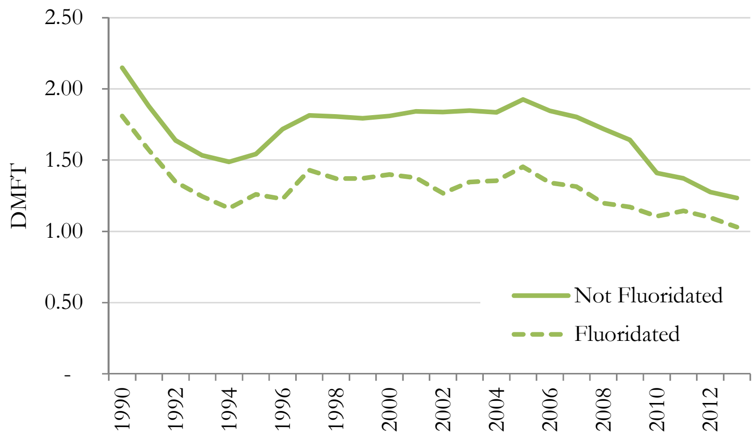
- **Northland study is inconclusive**
  Between 2007 and 2009 Kaitaia and Kaikohe added fluoride to their water supplies. Over two years there was a reduction in children's dental decay. Two other areas in Northland (Dargaville and Kawakawa/Moerewa) were used as control groups as neither area used water fluoridation.[12] The study was inconclusive, as the fluoridated areas did not consistently show better improvements in dental outcome than the non-fluoridated areas.

3.3.2 Community Oral Health Service data have limitations in reporting effectiveness of water fluoridation

OECD countries report standardised dental decay measures. These measures include the percent caries-free and the average dmft score for 5 year olds and the average DMFT score for 12 year olds (i.e. age 5 data refer to primary teeth and age 12 data refer to permanent teeth). The Ministry of Health has published routinely collected oral health data from the Community Oral Health Service (formerly the School Dental Service) for children aged 5 years and children in Year 8 from 1990 to 2013.[22] The Community Oral Health Service (COHS) encompass approximately 80 percent of 5 and 12 year olds. This level of coverage has been fairly stable across the 23 years reported.

The graph below shows that dental outcomes have been improving since 2007 for Year 8 children attending schools with no water fluoridation, resulting in a narrowing of the difference of those attending schools with and without fluoridated water, when measured as the average DMFT score (the same pattern exists when measuring percent caries-free). This trend seems to be consistent across district health boards, and is consistent for children aged 5 years old. Fluoridation status was not based on the child's home so may not provide an accurate measure of their fluoride intake.

Figure 4 DMFT score for 12 to 13 year olds across New Zealand, comparing those attending schools in areas with and without water fluoridation*



Source: Ministry of Health Data; analysis by Sapere.

*The pattern and relative effect are similar for 5 year olds, when measuring primary teeth (dmft).

The data have not been adjusted for other variables that may affect dental decay experience apart from water fluoridation status of the school. The lack of adjusting for other variables is important because the areas with fluoridation and without have differing demographics. Fluoridated areas tend be urban rather than rural. By way of example, Auckland and Wellington account for the majority of the population with fluoridated water.

Further, the provision of publicly funded dental treatment for children is influenced by the risk of tooth decay in the area and access to fluoride. This will likely lead to children without access to fluoridated water receiving more dental preventative treatment, such as topical fluoride applications, which would result in the reduction of the observed benefit of water fluoridation.

Between 1995 and 2004 there was increased dental decay as measured by DMFT (the increase was greater in children who attended schools without fluoridated water) and no improvement in caries-free (average across fluoridated and non-fluoridated areas). This decline in oral health outcomes led to two main reviews: a DHBNZ-led review of the School Dental Service (SDS)[23] and a Review of Maori Child Oral Health Services.[24] Following these reviews, the government announced a major reinvestment programme in child and adolescent oral health services. The reinvestment programme was staged between 2006 and 2009.[25] Since then there have been improvements in oral health measures. However, the improvements are predominantly in areas without fluoridated water.

3.3.3 International evidence supports the NZOHS findings for children

The benefits of water fluoridation reported for children in the NZOHS are replicated in overseas studies.

We understand the York report published in 2000[28] is the key meta-analysis in the literature. This analysis included studies published between 1951 and 1999. The York report focused on the evidence for children and reported a 38 percent reduction in dental decay for those children in areas with water fluoridation.[iv] Other meta-analyses often cited the York report as their point of reference and extended the analysis with recent studies.[26,27]

A more recently published meta-analysis (Rugg-Gunn and Do 2012) reported results for studies published between 1990 and 2010. They reported the benefit of water fluoridation as a 30 to 59 percent reduction in dental decay.[v] This result is in line with the results of the York report, which gives us confidence the results of the York report are still relevant today. Most evaluations included were based on cross-sectional studies, and some before-and-after studies were included.

The York report finds significant benefit

The York report meta-analysis included information from 26 studies.[28] The observations made in these studies were between 1944 and 1997. The studies included in the meta-analysis were published between 1951 and 1999. Most of the studies (23 out of 26) were before-and-after studies, i.e. start with two groups without fluoride and add fluoride to one group then see what the difference in dental decay between the two groups is over time. A large number of studies were excluded because they were cross-sectional studies and therefore did not meet the inclusion criteria of being evidence level B or above (level B: evidence of moderate quality and has moderate risk of bias).

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iv Figure calculated by Sapere. In the York report the average dmft/DMFT across the studies was 3.8 with water fluoridation and 6.1 without water fluoridation (Appendix F of the York report).

v Rugg-Gunn and Do reported the 'Modal score', with 30–59 percent for primary teeth and 50–59 percent for permanent teeth.

The results of the meta-analysis were that on average, dental decay was lower in areas with water fluoridation compared to those without, when measured by percent caries-free and by dmft/DMFT. The York report also reported dental decay rates increased when water fluoridation was stopped. The fluoride levels were <0.7 ppm in the control group and 0.7–1.2 ppm in the exposure group. In most cases the control group had levels below 0.2 ppm and the control group had levels close to 1ppm. These approximate levels match the NZ setting.

Below, we discuss the results of the York report as measured by either percent caries-free or dmft/DMFT.

Results measured by percent caries-free

The reported reduction of percent caries-free from water fluoridation by each of the studies ranged from -5.0 to 64 percent, with a median of 14.6 percent. The median result of 14.6 percent, rounded to 15 percent, is often quoted as the benefit of water fluoridation.

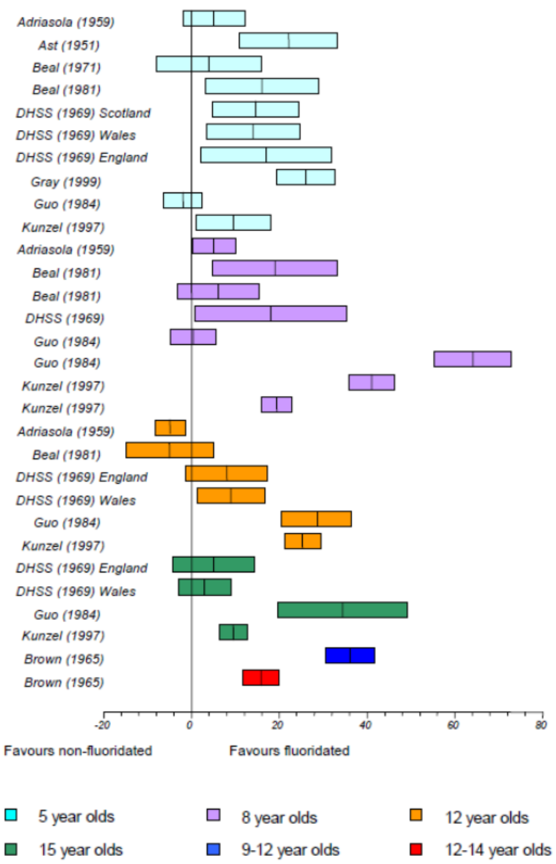
The York report did not report percent caries-free values for fluoridated and non-fluoridated areas; just the difference. We have calculated the percent caries-free for fluoridated and non-fluoridated areas by taking the mean of the reported rates for each of the studies (as listed in Appendix F of the York report). We calculate the percent caries-free to be 15 percent without water fluoridation and 30 percent with water fluoridation.

In the 26 studies identified in the York report, there were 30 analyses of the benefits of water fluoridation measured using percent caries-free. The analyses are summarised in Figure 5 below. There was a statistically significant change with a greater proportion of caries-free children in the fluoridated area in 19 analyses. One analysis found a statistically significant greater decrease in the proportion of caries-free children exposed to fluoridated water compared with those exposed to non-fluoridated water. The remaining 10 analyses were unable to detect a statistically significant difference.

The York report estimated a median of 6 people need to receive fluoridated water for one extra person to be caries-free; i.e. the number needed to treat is 6. The interquartile range of study numbers needed to treat to avoid one bad outcome is 4 to 9.

In the figure below, the vertical line, at 0, is the 'no effect' line for measures of difference. Studies are indicated with a rectangle showing the 95 percent confidence intervals around the mean. If the rectangle crosses the 'no effect' line the difference is not statistically significant. If the rectangle is entirely to the right of the line the difference is statistically significant and fluoridation is associated with an increase in the proportion of children who are caries-free. If the rectangle is entirely to the left of the line the difference is statistically significant and fluoridation is associated with a decrease in the proportion of children who are caries-free.

Figure 5 Increase in proportion (%) of caries-free children in fluoridated compared to non-fluoridated areas (mean difference and 95 percent CI)



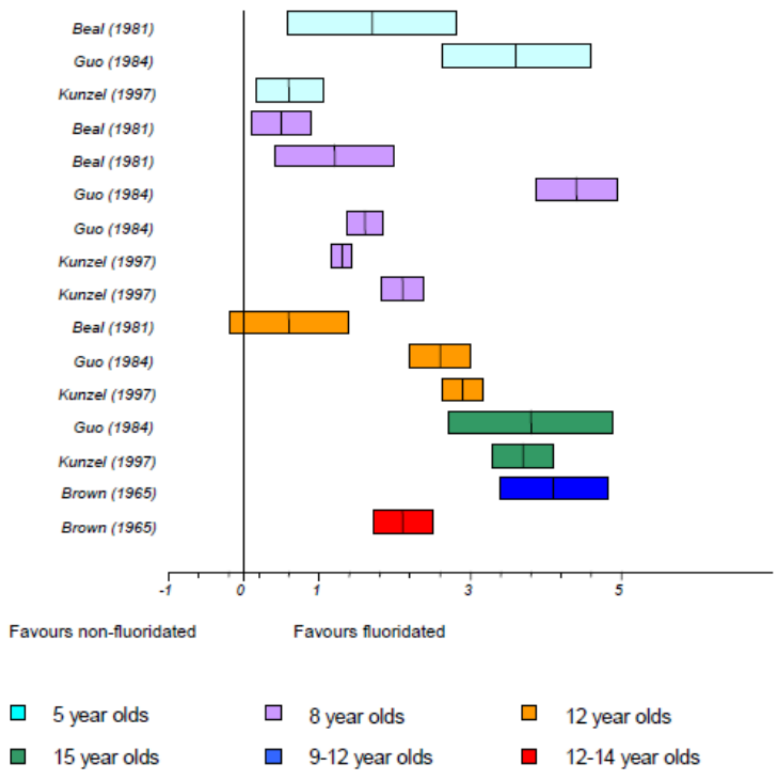
Source: University of York (2000) page 12.[28]

Results measured by dmft/DMFT

Fifteen analyses found a statistically significant greater mean reduction in dmft/DMFT scores in the fluoridated areas than in the non-fluoridated areas. One analysis found a non-statistically significant reduction. The range of mean reduction in dmft/DMFT score was from 0.5 to 4.4, with a median of 2.25 teeth.

The results of the different analyses from the studies that include dmft/DMFT as a measure are summarised in the figure below.

Figure 6 Change in dmft/DMFT Score (mean difference and 95 percent CI)



Source: University of York (2000) page 12.[28]

3.4 Evidence of 20 to 30 percent reduction in dental decay in adults

3.4.1 First systematic review to report that water fluoridation is effective in adults

The first systematic review to report that water fluoridation is effective in adults was a meta-analysis published in 2007 by Griffin et al.[29] Griffin et al report that adults living in areas with water fluoridation had 27 percent less dental decay. The most robust estimate of water fluoridation we understand to be applicable to the New Zealand population is the results of the Australian National Survey of Adult Oral Health (NSAOH) which were published in 2013.[30] The reported results were a 21 percent reduction in dental decay for those aged 18 to 44 years and a 30 percent reduction for those aged 45+. This evidence is summarised in Table 2 below and is further discussed in the following sub-sections.

Table 2 Summary of key evidence for benefits of water fluoridation in adults

Study (year of publication)	Population	Study type	Reduction in dental decay
Australian National Survey of Adult Oral Health (NSAOH) (2013)	3,779 Australian adults surveyed between 2004 and 2006	Cross-sectional and controlled for duration of exposure to water fluoridation	21% in those aged 15 to 44[a] 30% in those aged 45+[a]
Griffin et al (2007)	2,530 participants from 5 studies published between 1990 and 1992	Meta-analysis of cross-sectional studies	27%[b]
Cochrane (2015)[17]	10 studies with 78,764 participants	Meta-analysis of before-and-after studies Prospective studies	26%[c]

[a] NSAOH: Reported as the reductions in DF-Surfaces (missing was excluded).

[b] Griffin et al reported 'the prevented fraction for water fluoridation was 27%'; this was based on differences in DMFS.

[c] Cochrane reported on reduction in DMFT.

The Griffin et al report included two sets of results: one included nine studies and the other was restricted to the five studies (with a total of 2,530 participants) where heterogeneity was not an issue. We have focused on the results where heterogeneity was not an issue. The studies included were published between 1990 and 1992. All of the studies were cross-sectional, i.e. measuring the difference between groups with and without exposure to water fluoride at a point in time.

The five studies included in the second set of results in the meta-analysis are summarised in Table 3 below.

Table 3 Studies included in the meta-analysis for adults[29]

Authors/study	Type and number of subjects	Location; mean age in years (age range)	Fluoridation levels
Grembowski et al, 1992	Cross-sectional; 595	Washington; 30.6 (20 to 34)	NR
Morgan et al, 1992	Cross-sectional; 104	Australia; NR (20 to 24)	NR
Stamm et al, 1990	Cross-sectional; 967	Canada; 41.5 (18 to 60+)	1.6 ppm vs. 0.2 ppm
Thomas and Kassab, 1992	Cross-sectional; 649	Great Britain; NR (20 to 32)	0.9 ppm vs. NR
Wiktorsson et al, 1992	Cross-sectional; 496	Sweden; NR (30 to 40)	1 ppm vs. 0.3[a]

NR= Not reported.

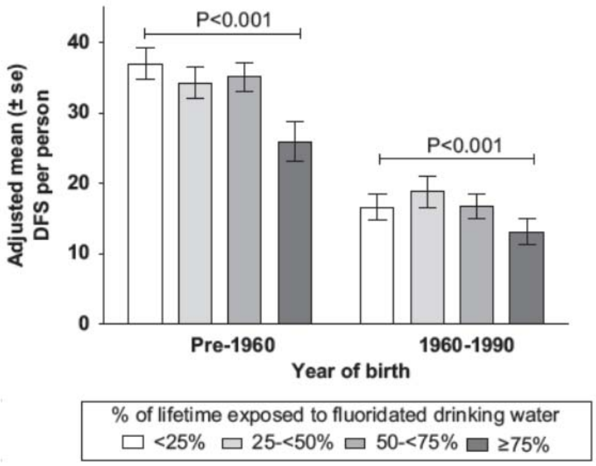
[a] Griffin et al reported the fluoridation levels from the Wiktorsson et al 1992 study as not reported. However, the original publication did include the fluoridation levels.

3.4.2 Australian National Survey of Adult Oral Health (NSAOH)

The Australian 2004–2006 National Survey of Adult Oral Health (NSAOH) examined 5,505 people selected from all eight states and territories. People aged ≥ 15 years were selected at random. Moreover, the NSAOH also collected information about participants' residential history. Information was collected for 3,779 participants and was used to inform the estimate of the benefits of lifetime exposure to water fluoridation.

Participants were grouped by the amount of time spent living in areas with water fluoridation. The groups included <25 percent, 25 to <50 percent, 50 to <75 percent and ≥75 percent of lifetime exposure to water fluoridation. The number of tooth surfaces affected by dental decay by these groups is shown in Figure 7 below. The results were reported by those aged 45+ (born pre-1960) and 15 to 44 (born from 1960 to 1990).

Figure 7 Number of tooth surfaces with untreated decay or fillings: By duration of exposure to water fluoridation and age group



Source: Slade et al 2013[30]

The authors estimate the impact of water fluoridation using both the DMFT and DF-Surfaces. The DF-Surfaces measure is different to standard measures of tooth surfaces affected by dental decay as it excludes missing teeth. The estimated impact of water fluoridation was 10 percent and 11 percent fewer DMFT in the 15 to 44 and 45+ age groups. The estimated impact on DF-Surfaces was 21 percent and 30 percent respectively. These results are summarised in Table 4 below.

We understand the results based on DF-Surfaces provide a better estimate of the benefits of water fluoridation. This is because the measure takes into account instances where the severity of the untreated decay (per tooth) or filling is reduced, but the tooth still has some decay. However, there is a question about the generalisability of the estimate to the impact on missing teeth; expert advice we received is that the reduction will likely apply to missing teeth.

Table 4 Estimated benefits of water fluoridation, NSAOH

Measure	Age group	Reduction from water fluoridation
DMFT	15 to 44	10 percent 1.14 teeth
	45+	11 percent 2.58 teeth
DF-Surfaces	15 to 44	21 percent 3.44 surfaces
	45+	30 percent 11.10 surfaces

Source: Results reported by Slade et al;[30] table produced by Sapere.

The estimates of dental decay were adjusted for fluoridation exposure, age, region of state, sex, country of birth, reason for dental visits, tooth-bushing frequency, annual income and highest level of education.

We believe the results of this study provide a credible estimate of the impact in the New Zealand adult population because:

- The study was well conducted and adjusted for lifetime exposure to water fluoridation;
- The results controlled for a number of confounders;
- The levels of fluoride in the Australian water supplies are similar to those used in New Zealand;
- The level of dental decay in the population is similar to that in the New Zealand population;
- The study includes all ages, which makes it applicable to the entire NZ adult population; and
- The estimate is based on relatively recent observations.

4. Cost of water fluoridation

We set out in this section the costs of fluoridating water, the data sources we use and any assumptions underpinning the estimates. The Health Act 1956 as amended by the Health (Drinking Water) Amendment 2007 Act sets out different sizes of water supplies as follows:

- Neighbourhood: serving up to 100 people;
- Small: serving 101–500 people;
- Minor: serving 501–5,000 people;
- Medium: serving 5,001–10,000 people; or
- Large: serving more than 10,000 people.

We provide costs for each of those plant sizes.

4.1 Two primary data-sets

We make use of two data-sets – one provides engineering-based costs and the other provides data on plants and water supply.

4.1.1 Costs of fluoridation based on engineering estimates

The Ministry of Health (MoH) commissioned CH2M Beca Ltd (Beca)[31] to estimate the costs of water fluoridation. The costs were estimated for neighbourhood through to medium-sized plants. These costs were based on new capital replacement costs and Beca also included estimates of operating and fluoridation costs.

In addition to the cost estimates in the Beca report, we collected cost information from nine district councils. We have used the costs provided to us by councils in the sensitivity analysis. See Appendix 1 for further details regarding the costs supplied to us by district councils.

4.1.2 ESR water supply data

Water supply data held by ESR records data by community and water plant (the supply end). Water plants can serve a number of communities and communities can be served by a number of water supplies. In many cases a community may be supplied with water from more than one plant. It may be that there is a primary plant and an emergency or secondary plant, or that different parts of a community are supplied by different plants. Some big water plants serve multiple communities and even multiple district councils. For example, Te Marua water plant supplies parts of Wellington, Porirua, Lower Hutt and Upper Hutt. Attribution of cost to district councils can, therefore, be difficult. This creates a complicated data-set needing to be disentangled.

4.2 A number of important assumptions

We make a number of important assumptions:

- Beca provided the capital cost of water fluoridation plant as a range reflecting different existing configurations. For example, the range of capital costs for a medium-sized plant is reported to be $145,000 to $260,000. We have used a point estimate of $202,500. For the annual ongoing costs, we used Beca's estimates of operator and maintenance costs.
- Beca does not provide a cost estimate for large plants,[vi] i.e. plants supplying over 10,000 people. We have used council costs supplied to us, resulting in an estimate of $347,004 capital purchase cost.
  - On operating cost and cost of fluoridation, we assume the costs would be the same for large and medium-sized plants, differing only by volume of water (i.e. given larger plants tend to have higher water usage, the resulting cost of fluoride chemical would be higher). We have used the estimates in the Beca report for medium-sized plants as an estimate of the costs for large plants.
- We assume the lowest cost combination of capital and fluoride type for each plant. However, we are aware that some councils do not take this approach, usually for operating reasons. For instance, councils may decide to use the same type of fluoride across all their plants to simplify stockholding and minimise monitoring costs. Further, our cost estimates assume fluoridation at each of the water treatment plants; but in some cases water from multiple plants is piped to a single point and fluoridated.
- Water supply data are recorded in cubic metres per day (m^3/day; a cubic metre is 1,000 litres). Many plants have this information recorded and those plants with data tend to be larger plants. Where this information is not provided, we calculate an estimated amount of water by applying the water usage per person from where data are available. This average measure will be a reasonable proxy for usage in most situations, but will be a poor proxy when a plant is not the primary supply for the community (or zone) as would be the case with emergency-only plant.
- The chemical cost of fluoride is made up of the average amount of water used for each water plant and the price of fluoride. The price of fluoride differs by the type of fluoride used. The type of fluoride used is determined by the size of the water treatment plant.

4.3 Fluoride type

Fluoridation of water supplies can be achieved through treatment by several chemicals:

- Sodium fluoride (NaF);
- Fluorosilicic acid (FSA);[vii] and
- Sodium fluorosilicate.[viii]

[vi] Beca provided estimates for fluoridating four large water supplies; the water treatment plants that made up the four supplies varied in size.

[vii] Also referred to as hexafluorosilicic, hexafluosilicic, hydrofluosilicic (HFA), and silicofluoric acid.

The chemical compounds generally require chemical-specific equipment to feed the fluoride into the water supply at the correct levels. The costs of set-up, maintenance and supply differ according to which chemical is to be used in the fluoridation process. The three types of fluoridation processing systems that are currently in use, or could possibly be used, in New Zealand are:

- A powder feed system which is able to process sodium fluorosilicate or sodium fluoride;
- A slurry system which processes sodium fluorosilicate or sodium fluoride; and
- A liquid-based system which processes fluorosilicic acid (HFA).

The decision of which fluoridation set-up to use usually involves a comprehensive evaluation of the various technologies available at the site and the associated financial costs and benefits, including consideration of capital set-up costs; ongoing maintenance and operation costs; fluoride supply costs; and reliability. Generally smaller plants have a higher chemical cost and simpler feed systems and larger plants have a lower per unit cost of fluoride but a higher capital cost.

We calculate the cost of fluoride per unit of water used (m^3/day). The calculation is based on figures in the Beca report. The annual cost of fluoride per m^3/day is calculated as the annual cost divided by the average water flow (m^3/day). For example, the reported annual cost of fluoride chemical for a medium-sized plant is $4,300 and the corresponding average water flow is 3,450 m^3/day, with an annual cost of fluoride of $1.25 per m^3/day.

4.4 Summary of costs

The cost of fluoridating water supplies is made up of capital, maintenance and fluoride costs. The cost structure differs by plant size, with small plants having higher capital costs relative to supply volume and using a more expensive chemical.

Capital and operating costs change with the number of plants servicing any one population; i.e. a high number of treatment plants increases the average cost. The contribution of the capital and operating costs differs greatly depending on the size of the plant; capital and operating costs account for:

- Approximately half the total cost for a large plant;
- Up to 99 percent of the total costs for neighbourhood-sized plant plants.

We incorporate the water usage for each water treatment plant when estimating the costs. The costs used in the cost model are summarised in Table 5 below. Using these costs, the 20-year cost (undiscounted) of a medium-sized plant with water flow of 3,450 m^3/day is $466,500. This cost is made up of:

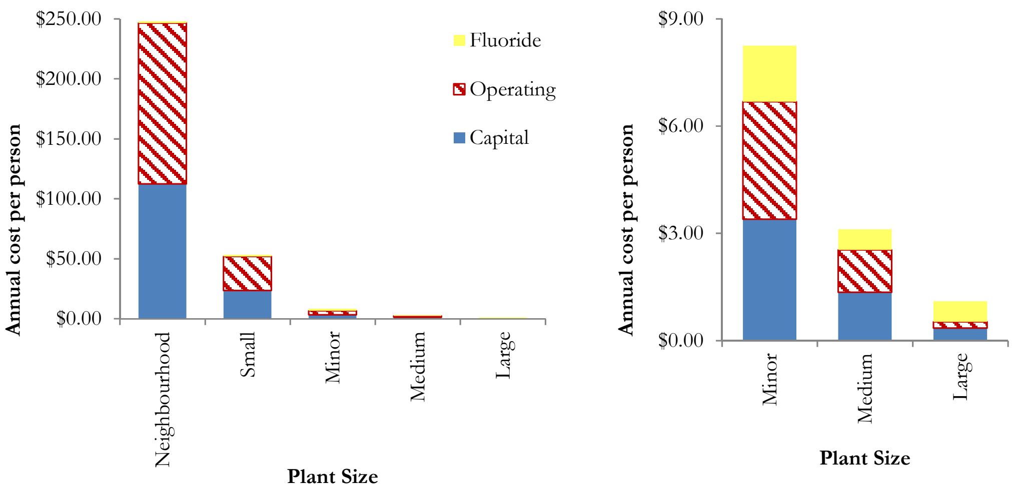
- $202,500 in capital costs;
- $178,000 in operating costs; and
- $86,000 in fluoride.

[viii] Also referred to as sodium silicofluoride (SSF).

Table 5 Estimated cost of water fluoridation, by plant size

Plant size	Population	Fluoride chemical	Total capital set-up costs	Annual operating costs	Annual fluoride supply cost per m^3/day
Neighbourhood	<100	Sodium fluoride (NaF)	$112,500	$6,700	$3.57
Small	101–500		$117,500	$7,100	$3.46
Minor	501–5,000		$170,000	$8,200	$3.41
Medium	5,001–10,000	Fluorosilicic acid (FSA)	$202,500	$8,900	$1.25
Large	10,001+		$347,004	$8,900	$1.25

Figure 8 Breakdown of fluoridation costs by size* of water plant (note the graph on the left has five plant classifications and the graph on the right is an expansion of the three larger plant sizes)



* *Population sizes used in figure are: Neighbourhood 50; Small 250; Minor 2,500; Medium 7,500; Large 50,000. Water usage estimated to be 0.46 m^3/day per person.*

For one supply, there might be more than one treatment plant and possibly as many as ten. Therefore, we have applied size definitions to the water treatment plant rather than at the supply level for the purpose of estimating costs.

5. Fluoridation proves to be highly cost-effective

In the model, we address the costs borne by public funders (health and local governments) and, also, those incurred by individuals (in terms of private provision of dental treatment). The expected life of the capital investment in water plants is 20 years; therefore, 20 years is the time horizon for the analysis.

As with all economic analyses, we discount future benefits back to today's dollars. A discount rate of 3.5 percent p.a. is applied to benefits and costs. 3.5 percent is the standard discount rate applied by PHARMAC[32] in economic analysis, and facilitates comparability of results for this analysis with analyses for other health interventions. The discount rate is a 'real' rate of return. We also test the result at 8 percent per annum based on Treasury guidance.[33]

5.1 Method for estimating the number of teeth and tooth surfaces affected by dental decay

This section sets out the methods used to estimate the reduction in tooth surfaces and teeth affected by dental decay, as a result of water fluoridation in the New Zealand population. The following steps were used:

- Step 1: Select Relative Risk Reductions (RRRs).
- Step 2: Estimate amount of dental decay experience with and without water fluoridation, including annual rate of decay by age groups – this incorporates the RRRs from step 1.
- Step 3: Estimate the impact by outcomes of decay experience: untreated decay, missing and filled tooth surfaces.
- Step 4: Approximate annual rate of decay experience with and without fluoridation.
- Step 5: Estimate the population rate of decay experience with and without fluoridation, over the 20-year period of the model.

Step 1: Select Relative Risk Reductions (RRR)

We applied separate RRRs for children, adults aged 18 to 44 and adults aged 45+; the values used are a 40 percent reduction for children, 21 percent reduction for adults aged 18 to 44 and a 30 percent reduction for adults aged 45+. We have discussed these relative reductions in previous chapters. The 40 percent reduction in children is based on the results of the NZOHS. The reduction in adults is based on the findings of the Australian National Survey of Adult Oral Health (NSAOH). The estimated impact of water fluoridation was reported as a 21 percent and 30 percent reduction in DF-Surfaces in the 15 to 44 and 45+ age group cohorts respectively.

Step 2: Estimated amount of dental decay experience with and without water fluoridation using selected RRRs

We use the NZOHS to help inform our estimate of dental decay experience with and without water fluoridation. The NZOHS reports the amount of decay experienced by age bands (mostly 10-year age bands). We assume the reported amount of decay experienced is halfway between the amount of dental decay with and without water fluoridation. We assume this because approximately half of New Zealanders currently live in areas with water fluoridation. We note this method will likely result in a small overestimation of time exposed to fluoridated water supply, and hence underestimates decay experience, as many New Zealanders currently with fluoridated water spent a significant amount of their life without fluoridated water. For example, we assume that 18 to 44 year olds living in areas without fluoridation have a 10.5 percent higher amount of tooth surfaces with decay compared to the average amount of decay reported in NZOHS. This estimated decay will be a slight overestimation as the non-fluoride group will be closer to the national average.

We apply the relative risk reductions to the rates of decay reported by the NZOHS. For example, for New Zealanders aged 45 to 54 and without water fluoridation, we take the DMFS score as reported by NZOHS (50 DMFS), and apply the RRR of 0.30 (i.e. 30 percent reduction). This results in estimated amounts of decay of 59 DMFS and 41 DMFS for those without/with lifetime exposure to water fluoridation respectively.

The table below reports our estimates of dental decay with and without water fluoridation by age group, alongside the values reported in the NZOHS.

Table 6 Estimated dental decay experience by age group, with and without water fluoridation (measured by dmfs/DMFS)

Age group	With and without fluoridation NZOHS[3]	Without fluoridation (our estimate)[4]	With fluoridation (our estimate)[4]
2–4[1]	1.8	2.3	1.4
5–11[1]	3.5	4.4	2.6
12–17[2]	2.7	3.4	2.0
18–24[2]	6.3	7.0	5.6
25–34[2]	13.0	14.5	11.5
35–44[2]	21.0	23.5	18.5
45–54[2]	50.0	58.8	41.2
55–64[2]	65.0	76.5	53.5
65–74[2]	74.0	87.1	60.9
75+[2]	75.0	88.2	61.8

[1] Ages 2–11: Decay measured by dmfs, i.e. primary tooth surfaces.

[2] Ages 12+: Decay measured by DMFS, i.e. permanent tooth surfaces.

[3] As reported in the New Zealand Oral Health Survey[7] (Appendix B).

[4] Estimated by Sapere.

Source: NZOHS[7] and Sapere estimates.

Step 3: Estimate the impact by decay experience outcomes: untreated decay, missing and filled tooth surfaces

We break down the estimate of decay experience to untreated decay and missing or filled surfaces to apply the cost of treatment (and estimate the avoided treatment costs). We do this by applying the methods above to the three types of decay severity outcomes as reported in the NZOHS. We assume that water fluoridation has the same relative effect on each of the three outcomes of decay.

Table 7 Our estimate of dental decay experience at surface level by age group, split by untreated decay, missing and filled tooth surfaces

Age group	Untreated decay		Missing		Filled	
	W/O	With	W/O	With	W/O	With
2–4	0.6	0.4	0.1	0.1	1.5	0.9
5–11	0.6	0.4	0.4	0.2	3.4	2.0
12–17	0.4	0.2	0	0	3.1	1.9
18–24	1.0	0.8	1.0	0.8	5.0	4.0
25–34	2.2	1.8	3.1	2.5	10.2	8.0
35–44	1.5	1.1	5.6	4.4	15.6	12.4
45–54	1.5	1.1	21.2	14.8	36.5	25.5
55–64	1.3	0.9	27.1	18.9	48.2	33.8
65–74	0.9	0.7	42.4	29.6	43.5	30.5
75+	0.9	0.7	48.2	33.8	38.8	27.2

W/O = Without water fluoridation.
With = With water fluoridation.

Source: Sapere estimate.

Step 4: Approximate annual rate of decay experience with and without fluoridation

We estimate the annual rate of decay experience as follows:

- We approximate the annual rate of decay experience by calculating the annual rate of decay experience between each age band, assuming no period or cohort effects. This approach is the same method used in other cost-effectiveness analyses.[46, 47] For example, we estimate the average number of filled tooth surfaces for a 45 to 54 year old with exposure to water fluoridation to be 25.5, which is 13.1 (25.5 to 12.4) more filled surfaces than a 35 to 44 year old. Therefore, we estimate the annual rate of filled surfaces for those aged 45 to 54 with exposure to water fluoridation to be 1.32 (13.1 filled surfaces over 10 years). In cases where there is a drop in a measure of decay as the age group increases, we assume an annual rate of zero increase. In some cases, teeth that have previously had untreated decay or a filling will become missing. This issue is across all age groups and is more common in older people.
- We have assumed all the decay seen in the permanent teeth of 12 to 17 year olds happens during that age band, in order to simplify the calculations. This simplification will likely slightly underestimate decay in the 5 to 11 age group and slightly overestimate decay in the 12 to 17 age group.

- We estimate an average of 11 years age difference between the 75+ age group and the 65 to 74 age group, assuming the average 75 year old lives until 81 years old (based on Statistics New Zealand life tables).

Table 8 Estimated annual rate of dental decay experience at surface level with and without fluoridation

Age group	Untreated decay		Missing		Filled	
	W/O	With	W/O	With	W/O	With
2–4	0.2	0.1	0.0	0.0	0.5	0.3
5–11	0.1	0.1	0.1	0.0	0.7	0.4
12–17	0.1	0.0	0.0	0.0	0.4	0.3
18–24	0.1	0.1	0.2	0.1	0.3	0.3
25–34	0.1	0.1	0.2	0.2	0.6	0.5
35–44	0.0	0.0	0.2	0.2	0.5	0.4
45–54	0.0	0.0	1.6	1.0	2.1	1.3
55–64	0.0	0.0	0.6	0.4	1.2	0.8
65–74	0.0	0.0	1.5	1.1	0.0	0.0
75+	0.0	0.0	0.5	0.4	0.0	0.0

Source: Sapere estimate.

Step 5 Estimate the population rate of dental decay experience with and without fluoridation, over the 20-year period of the model

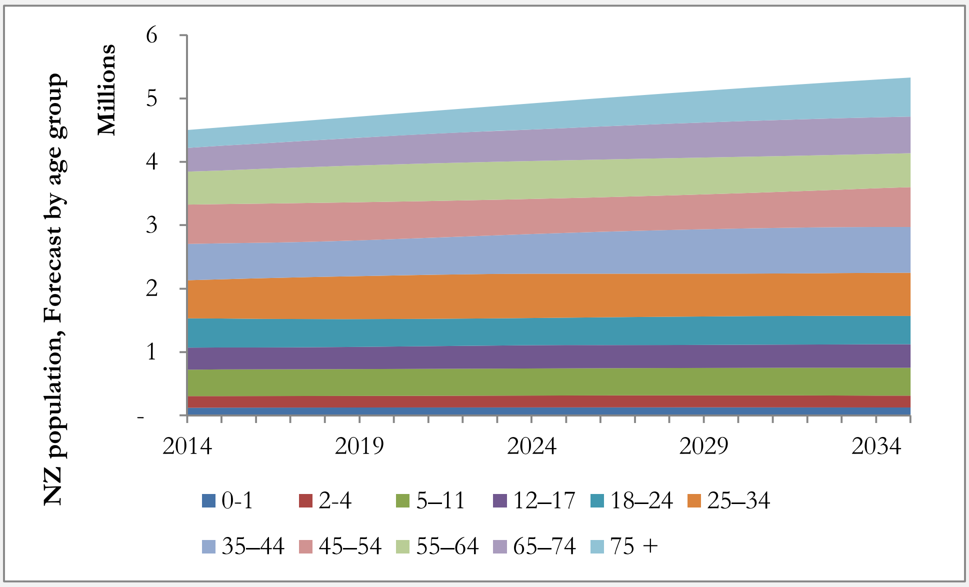
We apply the Statistics New Zealand population estimates to the annual probabilities from Step 4 above; resulting in an estimate of the number of tooth surfaces with untreated decay, missing, or with a filling. We perform this calculation with and without water fluoridation, for a 20-year horizon, this being the economic life of a water plant (2016–2035).

We used the Statistics New Zealand 2011 base 50th percentile population projection. We applied the rates to the population in residences with public water supply, i.e. 85 percent of the population. The rates of dental decay experience were applied to those who have teeth (i.e. excludes edentulism). The prevalence of complete loss of teeth per age group used in our analysis is taken from the NZOHS.[7]

Population growth is based on Statistics New Zealand population forecast:

Currently, public water treatment plants serving populations over 500 provide drinking water to an estimated 3.8 million (approximately 85 percent) New Zealanders. We assume that the rate of population growth will be the same for areas with a public water supply, as for those without. Our estimate of population growth and age group splits are based on forecasts published by Statistics New Zealand. Statistics New Zealand estimates that the New Zealand population will be 5.3 million in 2035 and, consequently, we estimate that 4.5 million will be serviced by public water supplies, resulting in an average of 4.2 million people on public water supply over the next twenty years.

Figure 9 Population by age group, forecast over the next 20 years



Source: Data from Statistics New Zealand; graph created by Sapere.

Table 9 Estimated number of tooth surfaces affected by decay over 20 years, with and without water fluoridation

Disease experience	Number of tooth surfaces affected over 20 years (undiscounted)		
	W/O	With	Reduction from water fluoridation
Decayed (untreated) surfaces	2,963,000	2,116,000	-847,000
Missing surfaces‡	40,463,000	28,260,000	-12,203,000
Filled surfaces	50,591,000	34,998,000	-15,592,000
Decayed, missing or filled surfaces*	94,017,000	65,375,000	-28,642,000

‡ Each missing tooth is counted as three surfaces.

*The total will include some cases where one tooth surface is affected more than once: each tooth surface could be untreated, filled, then missing.

Source: Sapere estimate.

We apply the ratio of surfaces affected per tooth, as implied by the reported dmfs/DMFS and dmft/DMFT scores in the NZOHS in order to estimate the number of teeth affected by decay. The results are shown in Table 10 below. As noted before, the relative reduction in the measures of untreated decay and fillings for teeth is lower than for tooth surfaces.

Table 10 Estimated number of teeth affected by decay over 20 years, with and without water fluoridation

Disease experience	Number of teeth effected over 20 years (undiscounted)		
	W/O	With	Reduction from water fluoridation
Decayed (untreated) teeth	1,961,000	1,502,000	-459,000
Missing teeth	13,488,000	9,420,000	-4,068,000
Filled teeth	20,374,000	17,014,000	-3,361,000
Decayed, missing or filled teeth*	35,823,000	27,936,000	-7,887,000

*The total will include some cases were one tooth is affected more than once as each tooth could be untreated, filled, then missing.
Source: Sapere estimate.

5.2 Averted cost assumptions

Our key assumptions regarding averted costs are set out in this section, other than estimates of reductions in dental decay which are discussed in previous chapters.

There are a number of cost off-sets due to the reduction in dental decay and we set out below our assumptions and sources of data.

Replacement of fillings is based on observed norms

The frequency with which a filling has to be replaced depends largely on the type of filling. Amalgams (silver fillings) are more durable and have to be replaced less frequently. Composites (tooth-coloured fillings) are less durable, but look nicer, and have to be replaced more frequently. Amalgam fillings typically last 13 years and composite fillings last 5 years.[34] At the Dunedin Faculty of Dentistry General Dental Practice clinic, during 2009, the split of composite and amalgam fillings was 62 percent and 38 percent respectively. We have used these rates in our analysis. This split of type of filling results in an estimated average cost of an adult filling of $247 and average time for replacement of 7.9 years.

Cost for adults measured by New Zealand Dental Association's fee survey

The New Zealand Dental Association conducted a fee survey of dental practices from across New Zealand.[35] The number of replies varied by procedure. For most procedures there were at least 300 replies. The reported costs are as at February 2013.

We used the following average costs reported in the survey:

- Single extraction using local anaesthetic – $200.
- Composite filling (class II) – $219.
- Composite, multi-surfaced – $282.
- Amalgam filling, one surface – $143.
- Amalgam filling, two surfaces – $189.

We apply the cost of a single extraction using local anaesthetic for each missing tooth, i.e. $200. For the cost of an avoided filling we used a weighted average of the multi-surfaced composite and two-sided amalgam surface filling costs, as stated above, which results in an average cost of $247 per filled tooth.

We estimate a saving of $90 where water fluoridation is estimated to reduce the number of filled surfaces but not avoid a filling. This estimate is based on the difference in costs of single and multi-surfaced filling, and is based on the same ratio of composite and amalgam as above.

We note there is significant variation in some of the costs reported by dental practices. For example, the cost of a multi-surfaced composite filling has a reported 25th percentile cost of $220 and a 75th percentile cost of $330. That is, half of the surveyed practices had costs in this range, while the rest of the practices had lower or higher costs (the ranges were not reported). Further, the average costs by region vary significantly. We have assumed an average estimate as the point estimate for our calculation.

Costs for children are based on government funding

Basic oral health care is publicly funded by the government for children and adolescents. Our estimate of averted dental costs in this under-18 age group is the averted cost of funding that service. Dentists are paid for a package of oral health services they provide to children in New Zealand. The package consists of:

- A consultation, including examination and diagnosis, prophylaxis, advice on dental care and any special tests and bitewing radiographs considered necessary. This includes both regular consultations as necessary and any necessary emergency consultations in normal hours;
- All necessary one-surface restorations in posterior teeth (molars and premolars);
- Periodical X-rays where required;
- Fissure sealants where required;
- Further preventive treatments (e.g. topical fluoride applications) where required; and
- Chair-side education on oral health care.

The treatment of basic fillings and extractions is covered as 'fee-for-service' items which are additional to the package described above. These items are listed on a pre-approved basis and do not require prior approval from the District Health Board.[36]

We used the following fees for service included in the agreement:

- Single extraction using local anaesthetic – $58.03.
- Simple non-metallic restoration in anterior teeth – $74.36.

- More than one surface non-metallic restoration – $99.99.
- One surface restoration in posterior teeth – $62.56.
- Two surface restorations in posterior teeth–$82.05.

We applied the cost of a single extraction using local anaesthetic for each missing tooth, i.e. $58.03.

For the cost of an avoided filling, we used a weighted average of four types of restorations listed above, resulting in an average cost of $84. We used the same ratio of composite (i.e. non-metallic) for adults and we assumed that 40 percent were single-surface fillings and 60 percent were multi-surface fillings (this is based on New Zealand children having an average of 1.6 surfaces affected by each filling).

Costs are likely conservative

We have assumed basic treatment costs for the missing and filled outcomes of dental decay; we used the cost of a simple extraction (for missing teeth) and a filling. This is conservative as more expensive treatments such as dental crowns, dental bridges, endodontic treatment and implants may be avoided. We have used this method of assuming averted basic treatment costs as it is defensible in terms of not overestimating the cost reductions and is the method used in other analyses.

5.2.1 Estimated reduction in hospitalisation

We identified two publications reporting the impact of water fluoridation on hospitalisations for young children. The results were:

- 11 per 1,000 children (under 6 years) from fluoridated Dunedin were treated under general anaesthetic; approximately 42 per 1,000 children from nearby non-fluoridated Mosgiel and Outram required such treatment – i.e. 73 percent reduction.[21]
- In England, for children aged 1–4 the rate of hospital admission in non-fluoridated areas was 4 per 1,000 person years at risk compared to 2.2 per 1,000 in fluoridated areas – i.e. 48 percent reduction.[37]

For our analyses we assumed that children aged 0 to 4 exposed to water fluoridation will have a 48 percent reduction in hospitalisation for treatment of dental decay. The estimate is based on the results of the much larger English study.

We estimate that in the year ending June 2012 there were 2,918 admissions for children aged 0 to 4 requiring treatment for dental decay. The expected cost of these admissions is estimated at $5.6 million. Our estimate is based on the hospital admission data recorded in the National Minimum Dataset[38] where the primary diagnosis is related to dental decay. We identified dental decay using ICD 10 codes; we used the following ICD 10 codes – K02 (dental caries) and K04 (diseases of pulp and periapical tissues) – and the number of discharges matches values published on the Ministry of Health website.[39]

On hospitalisations, we use a similar method to that used to estimate the amount of dental decay with and without water fluoridation:

- We assume the number of reported hospitalisations is half way between the amount with and without water fluoridation. We assume this because approximately half of New Zealanders currently live in areas with water fluoridation.

- We then apply the relative risk reduction (48 percent) to the reported amount of hospitalisation (2,918); which results in an estimate of 2,000 and 3,800 hospitalisations for 0 to 4 year olds, with and without water fluoridation respectively.

Table 11 Estimated annual impact of water fluoridation on hospitalisation to treat dental decay in children aged 0 to 4

	Without fluoridation	With fluoridation	Difference
Admissions	3,800	2,000	1,800
Costs	\$7.4m	\$3.8m	\$3.6m

5.3 Net savings over 20 years from fluoridating populations over 500

Our estimates suggest a surprisingly large gain from fluoridation in costs avoided. We set out our estimates of net cost in this section.

The cost of fluoridating water differs largely because of the size of the plant. The net cost of water fluoridation reduces as the plant size increases, assuming the per-person benefits of fluoridation are the same for areas supplied by neighbourhood through to large water plants. The table below sets out costs. Cost offsets are over 20 years and are discounted at 3.5 percent p.a. The break-even on costs avoided would appear to be reached by 'minor' plants supplying a population greater than 500.

For neighbourhood and small plants the cost of water fluoridation is greater than the estimated cost offsets from reduced dental costs. For minor through to large plants, the cost offsets are greater than the cost of fluoridation, resulting in a net cost saving. For a large plant supplying 50,000 people, the cost offsets are over 20 times the cost of fluoridation; that is, for every dollar invested there is a return of 20 dollars. We note costs are borne by councils and benefits accrue largely to those suffering dental decay.

Table 12 Cost of water fluoridation by plant size: 20 year costs (discounted)

Plant size	Population used for estimate	Fluoridation cost*	Dental care cost savings*	Net cost (a negative is a net saving)
Neighbourhood	50	$212,000	$19,000	$193,000
Small	250	$228,000	$94,000	$134,000
Minor	2,500	$348,000	$939,000	-$591,000
Medium	7,500	$397,000	$2,818,000	-$2,421,000
Large	50,000	$900,000	$18,785,000	-$17,885,000

* Over 20 years, discounted at a rate of 3.5 percent p.a.

5.4 A net saving of $1.4 billion

We estimate the net saving over 20 years to be $1,401 million. This estimate is made up of a cost of fluoridation of $177 million and cost offsets of $1,578 million from reduced dental decay. The net saving is based on providing water fluoridation to plants supplying populations over 500. This is a very favourable result, a net saving with improved health outcomes. Most health interventions require a net increase in spending in order to achieve improved health outcomes.

Our estimate of avoided dental treatment is as follows:

- 459,000 teeth with untreated decay;
- 4,068,000 extractions (i.e. missing teeth); and
- 3,361,000 fillings.

We estimate a total of 4.2 million people will live in areas with public water supplies over the next 20 years and therefore can potentially benefit from fluoridating public water supplies. This is based on 3.8 million people currently on public water supply, growing to 4.5 million in 20 years, resulting in an average of 4.2 million. Growth is based on population growth estimates produced by Statistics New Zealand. The level of fluoride is estimated to be approximately 0.2 ppm without fluoridation (naturally occurring levels) and 0.7 to 1.0 ppm with fluoridation.

Table 13 Cost of water fluoridation compared to no water fluoridation: 20-year time horizon, providing water fluoridation to plants supplying populations over 500

Intervention	Fluoridation costs*	Dental care costs*	Net cost
No water fluoridation	$0m	$7,725m	$7,725m
Water fluoridation	$177m	$6,147m	$6,324m
Net	**$177m**	**-$1,578m**	**-$1,401m**

* Over 20 years, discounted at a rate of 3.5 percent p.a.

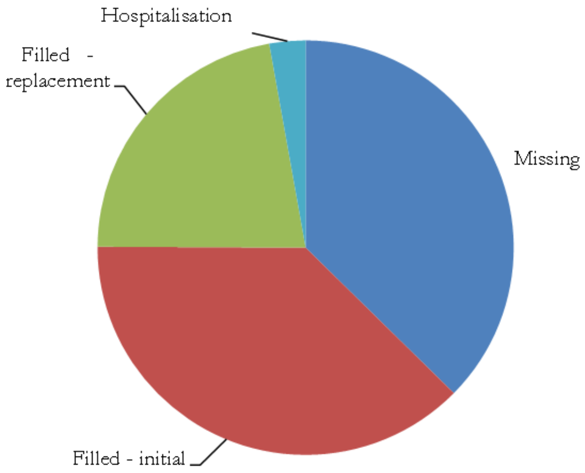
5.4.1 Benefits for the average person

We estimate the average reduction in tooth decay from water fluoridation per person over 20 years is:

- 0.1 teeth with untreated decay (NNT 9).
- 1.0 missing tooth (NNT 1).
- 0.8 teeth with fillings (NNT 1.2).
- 1.9 in dmft/DMFT (i.e. all three of the above) (NNT 0.5).

There are cost savings from reduced need for dental care due to water fluoridation; over 20 years these are expected to be $376 per person, including cost savings from fillings (including replacements), missing teeth and childhood hospitalisations. The majority of these costs are from avoided fillings and future replacement fillings. The breakdown of cost savings is shown in the figure below.

Figure 10 Breakdown of cost offsets



5.4.2 Breakdown of national cost split by stakeholder

The costs of water fluoridation are incurred by local government (with a small proportion subsidised by the Ministry of Health). The majority of the savings come from reduced private expenditure due to adults needing less dental care to treat their decay. The costs by stakeholder are summarised in the table below.

Table 14 Net costs by provider: 20-year time horizon

Stakeholder	Cost*	Saving*	Net cost
Health budget		-$149m	-$149m
Local government	$177m		$177m
Private		-$1,428m	-$1,428m
Total	$177m	-$1,578m	-$1,401m

* Over 20 years, discounted at a rate of 3.5 percent p.a.

5.4.3 Costs by current fluoridation status

The estimated net saving from fluoridation at the plants (plants supplying population over 500) currently fluoridated is estimated to be $758 million, taking into account the $32 million cost of fluoridation and $790 million in dental care offsets. This statistic represents approximately half the New Zealand population.[ix] The cost per person in these areas is relatively low, predominantly due to plants with very large water supplies (i.e. Auckland and Wellington).

The net savings of extending water fluoridation to those areas that do not currently have fluoridation are estimated to be $644 million, taking into account the $144 million cost of fluoridation and $789 million in dental care offsets.

The average cost of water fluoridation is estimated to be over four times higher in areas that do not currently have fluoridated water. This is because the areas that do not currently fluoridate their water tend to have smaller water treatment plants. The cost offsets are estimated to be the same for areas currently with and without fluoridated water: $789 to 790 million saved.

Table 15 Costs by current fluoridation status

Comparator	Intervention	Fluoridation cost*	Dental care cost*	Net cost
No fluoride	Current fluoride	$32m	-$790m	-$758m
Current fluoride	All fluoride	$144m	-$788m	-$644m
No fluoride	All fluoride	$177m	-$1,578m	-$1,401m

* Over 20 years, discounted at a rate of 3.5 percent p.a.

5.4.4 Similar results to published estimates

There are numerous reports of water fluoridation being cost-saving, [1,44,45,46,47] although for small populations water fluoridation is estimated by some to be a net cost.

In order to be able to compare our results with published results, we have compared the annual net cost savings per person of water fluoridation (undiscounted). This allows comparison of results when the time horizon, discount rate and population size differ. Our annual estimated cost saving per person for New Zealand is $24.

There is a large range in the net savings per patient in the published cost-effectiveness analyses. In the analyses we reviewed, the net savings ranged up to $22 per person per year. It is not surprising the published results report a smaller benefit than we do as they underestimate the benefits from water fluoridation by including conservative assumptions. The analyses we reviewed:

- Assume a low benefit from water fluoridation;

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ix Note that costs of dental care and QALY are based on populations approximated by water volumes by plant. The volume of water is split about half between fluoride and non-fluoride areas. Split of population with fluoride water is 56% fluoride and 44% without.

- Tend to exclude the benefits to adults (which contribute 90 percent of the savings in our estimate); and
- Tend to limit the savings in dental care to initial fillings.

The lower end of benefit shown in the published estimates is an outlier and is from a study based on population size of under 1,000 and limits the estimated benefit of fluoridation to a 15 percent reduction in dental decay for children; in this case the reported result was a net annual cost of $26 per person.[44] The rest of the published results are a net saving.

Further details of the published cost-effectiveness analyses we reviewed are Appendix 2.

5.5 Sensitivity analysis shows discount rate and the efficacy and cost of fluoridation are most important

The sensitivity analysis results show that the model is most sensitive to the assumptions regarding the discount rate, the efficacy of water fluoridation and costs of treating dental decay. In all scenarios, water fluoridation was cost-saving.

The discount rate was varied between 0 percent and 8 percent. Using a lower discount rate of 0 percent results in more net savings, $2,035 million. Using a higher discount rate of 8 percent results in lower net savings, $927 million. This is expected due to the capital costs being upfront (where capital is not already in place) and benefits accruing over 20 years.

The efficacy of water fluoridation was varied by -23 percent and +23 percent; this was based on one standard deviation of the estimated impact of water fluoridation in adults.[x] This resulted in a range of net savings of $1,002 million to $1,836 million.

Councils report lower costs than Beca partly because past capital costs have been lower than current replacement costs. If the costs of fluoridation are based on figures provided to us by councils instead of using the Beca cost estimates, then the resulting net saving is $1,457 million.

[x] The standard deviation was calculated by Sapere, based on values reported by Slade et al for the DFS measure. We calculated the standard deviation to be 27 percent for those aged under 45 and 20 percent for those aged 45+; our estimate of 23 percent was based on a weighted average using population weights.

Table 16 One-way sensitivity analysis: Water fluoridation for New Zealand water supplies serving populations over 500

Variable	Base case	Updated	Net cost*
Base Case			**-$1,401m**
Efficacy of fluoridation			
Average risk reduction decay	24%	19%	-$1,002m
		30%	-$1,836m
Cost of fluoridation			
Plant capital costs	100%	50%	-$1,444m
		200%	-$1,317m
Plant maintenance costs	100%	50%	-$1,427m
		200%	-$1,350m
Cost of fluoride	100%	50%	-$1,422m
		200%	-$1,361m
Cost offsets			
Cost of a filling†	$220	$176	-$1,213m
		$264	-$1,589m
Proportion of fillings that are composite	62%	40%	-$1,196m
		70%	-$1,458m
Cost of an extraction†	$177	$141	-$1,284m
		$212	-$1,519m
Discount rate			
Discount rate	3.5%	0.0%	-$2,035m
		8.0%	-$927m

* Over 20 years, discounted at a rate of 3.5 percent p.a.

† Average (weighted) cost for adults and children.

6. Quality of life benefits are significant

We seek to assess the health benefits of water fluoridation by estimating the quality adjusted life years (QALYs) gained. A particular benefit of QALY analysis is that it allows easier comparison with other health initiatives, such as pharmaceutical investments, screening (e.g. bowel screening), and other possible expenditures.

6.1 QALYs reported separately to costs

The common approach to reporting QALYs is to report an incremental cost-effectiveness ratio, which is the net additional cost divided by the net additional QALYs. We have chosen to report the QALYs separately to the costs, as water fluoridation is cost-saving for minor, medium and large plants, which means there is no incremental cost per QALY.

6.2 QALY gains are material

We estimate provision of fluoridated water to all of New Zealand's reticulated water supplies over 20 years would result in between 8,800 and 13,700 QALYs gained. At an individual level, the average health benefit per person due to a reduction in dental decay is expected to be between 0.002 and 0.003 QALYs (discounted, i.e. approximately equivalent to an additional 1 to 1.5 days of life at full quality of life).

These QALY gains are material and are in addition to the cost savings we identify. For each million dollars invested, we estimate 50 to 78 QALYs gained and $9 million in savings. This is in stark contrast to pharmaceuticals, where there is a net cost to funding new medicines[40] and for each million dollars invested (including cost offsets) the average return is estimated to be at least 27 QALYs.[xi]

The following sections highlight the scarcity of available information for use in QALY estimates and detail our method of estimating the QALY gains.

6.3 Common dental measures of Quality of Life cannot inform QALY gains

We have identified numerous studies estimating how Quality of Life (QoL) is affected by dental decay; however, these tend to be measures of QoL that cannot directly be used to estimate QALYs. A common tool used in dental health is an index known as the Oral Health Impact Profile-14 (OHIP-14). OHIP-14 measures patient discontent from pain, dry mouth

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[xi] Based on the average cost-effectiveness of medicines funded by PHARMAC in the year ending June 2014. Result reported as 'Funded proposals provided a minimum weighted average of 27 QALYs per million dollars spent'.

and chewing problems, but does not capture the trade-off between improved QoL and improved life expectancy. Therefore, OHIP-14 cannot be used to estimate the utility values in QALY estimates.

Formulae have been derived allowing conversion of OHIP-14 results to QoL values[41] and, despite limitations, these could be used to generate QoL values (which in turn could inform QALY estimates). However, we have not identified estimates of the impact of water fluoridation on measures such as OHIP-14, so we are unable to use these formulae.

6.3.1 We identified two studies with DALY measures

We have identified two cost-effectiveness analyses for water fluoridation (both Australian) that quantify the impacts in terms of disability adjusted life years (DALYs) (Cobiac and Vos 2012[44] and Ciketic et al 2010[42]). DALYs are similar to QALYs. The methods used in both studies are replicates of 'The burden of disease and injury in Australia 2003'.[43] The authors assumed a disability weight of 0.057 for a period of time for each tooth affected by symptomatic decay, with 32.4 percent of tooth decay being symptomatic. Ciketic et al applied a disutility of 0.0057 for 28 days in children and 55 days in adults.[42] It is unclear what duration was applied by Cobiac and Vos. There are weaknesses to this approach:

- The accumulation of dental decay is assumed to be the irrespective of the amount of existing decay, i.e. the impact of going from one to two fillings is assumed to be the same as going from ten to eleven fillings; and
- Untreated decay is not accounted for.

6.3.2 Health states used follow from the NZOHS

Our approach is similar to the standard method of estimating QALYs in cost-utility analyses (CUAs); we assign differing QoL values to different health states. The QALY gains are measured by assigning different quality of life scores to those with low, moderate and high amounts of dental decay. We estimate the proportion of people in each of these groups based on their water fluoridation status and age group. We base the definitions of decay on dmft/DMFT scores. The dmft/DMFT scores included in each of the health states were: low decay 0–2 DMFT, moderate decay 3–11 DMFT, high decay 12+ DMFT. We have also included edentulism (i.e. no teeth). The QoL values used in our model are summarised in the table below. A QoL value of 1 represents full quality of life and a QoL value of zero is equivalent to being dead. The inference of using a QoL value of 0.997 for the high decay group is that, on average, people would be willing to give up one day each year in order to be restored to full QoL.

In undertaking this calculation, we expect the average effect of dental decay will be relatively small. We take into account the following:

- Some dental decay will be asymptomatic (i.e. no effect on day to day life);
- There will be some periods of high pain and anxiety (i.e. prior to and during dental treatment); and
- People will have differential timing and quality of dental care.

The New Zealand Burden of Disease Study was the best published estimate of QoL and test approximation of QALYs that we identified. We use quality of life (QoL) values that result in a similar QALY loss from dental decay as the DALY loss reported in that study.

6.3.3 Judgement used to apportion QoL to different health states

The spread of the QoL values across the different health states is based on our own judgement and informed by the health state definitions in the table below.

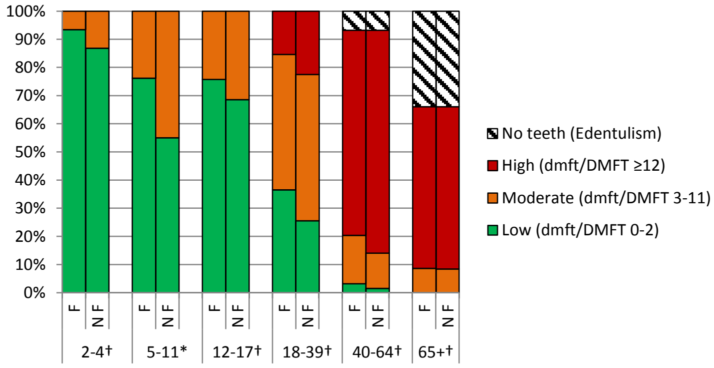
Table 17 Quality of life values for different health states

Health state	Definition	Health-related QoL score
Low level of decay (DMFT 0–2)	People have an average of 0.7 teeth affected by decay, with 80 percent treated (mostly with fillings) and the remaining untreated. The untreated decay is relatively minor and is unlikely to be symptomatic (i.e. the person is unlikely to be aware of decay).	1
Moderate level of decay (DMFT 3–11)	People have on average 7 teeth affected by decay, with an average of 1 tooth untreated.	0.999
High level of decay (DMFT 12+)	People have an average of 21 teeth affected by decay, with 60% of decayed teeth having fillings, and 37% missing and the remainder untreated. The average number of teeth with untreated decay is 1 (same as for the moderate group).	0.997
Edentulism (no teeth)*	Assumed to have the same quality of life as people with a high level of decay.	0.997

* Same proportion of people with and without fluoridation, i.e. no impact on results.

The proportion of people in each health state is shown in the chart below. These proportions are based on information collected in the NZOHS provided to us by the Ministry of Health; the data has been adjusted for age, sex, ethnic group and deprivation.

Figure 11 Proportion of people in dental decay groups: By age and fluoridation status



Source: Data supplied by Ministry of Health; graph produced by Sapere.

*Differences for age 5–11 are statistically significant (95 percent Confidence).

† Differences by fluoridation status are not statistically significant by age group.

6.3.4 QALY gains from water fluoridation are likely under-estimated

The NZOHS likely underestimates the benefits of water fluoridation for adults, as the survey does not account for duration of exposure to water fluoridation. Fluoridation status was based on the fluoridation status of where the participant lived at the time of the survey. The QALY gains are much greater if based on the Australian National Survey of Adult Oral Health (NSAOH),[30] which adjusted for lifetime exposure to water fluoridation; the NSAOH reported a 75 percent greater reduction in decay in the adult population (as measured by DMFT) than did the NZOHS.

6.3.5 Small but important QALY gains for individuals

The quality adjusted life year (QALY) is a measure of the quality of life (QoL) over time. QALYs also take into account changes in QoL over time. In order to estimate the QALY gain from water fluoridation, we:

- Multiplied the difference in proportion of people in health states;
- Forecast age distribution of New Zealanders; and
- Applied the QoL values.

The resulting QALY gain from water fluoridation per person is 0.003 per person over 20 years of exposure (undiscounted); i.e. 0.035 QALYs lost from dental decay without water fluoridation and 0.032 QALYs lost with water fluoridation. These gains are small but important and, when considered across the whole of the population, are material. Moreover, the averaging of the statistic hides those suffering from chronic pain from untreated dental decay.

6.4 Result consistent with other studies

We validated our result against other published estimates. Our estimate of QALY gain per person from water fluoridation is smaller than that inferred by the other published estimate we identified, 0.00014 compared to 0.00041. Half of the difference is attributable to our conservative estimate of benefit. We assumed an 8 percent reduction (based on NZOHS) in the severity of dental decay where the other published report assumed a 15 percent reduction. The rest of the difference is due to a difference in methodology. Our estimate of the QALYs lost from dental decay is similar to another New Zealand-specific estimate. Specifically, our comparison is as follows:

- We compared our result with the two identified CUAs. Cobiac and Vos[44] report the number of DALYs avoided from water fluoridation to be 3,700. From this statistic, we calculate the annualised per person DALY reduction, taking into account discount rate, duration of the model and the size of the population assumed to benefit (i.e. those under 16). The annual DALYs averted from water fluoridation worked out to be 0.00041 per person per year. The second study did not provide us with enough information to compare.
- The QALY loss per person from dental decay in our model is very similar to that implied in the New Zealand burden of disease, 0.00174 compared with 0.00182.
- In our model we estimated that the QALY loss from dental decay per person per year in New Zealand is 0.00174. Using the NZOHS data, which include an 8 percent reduction in dental decay, the QALY gain from providing water fluoridation is estimated be on average 0.00014 per person per year.

Table 18 Comparison of QALY estimates

Estimate	Annual impact per person, measured by QALYs/DALYs
QALY loss from dental decay	
Model: QALY loss from dental decay, without fluoridation	0.00174
NZ Burden of Disease Study[10]	0.00182
Gains from water fluoridation	
Model: QALY gain from water fluoridation	0.00014
Cobiac & Voss[44] CUA Reduction in DALY from water fluoridation, in the under 16 population	0.00041

6.4.1 Recalculated benefit based on published method suggests our estimate is very conservative

We applied the method of calculating DALYs in the identified publications (Cobiac and Vos 2012,[44] Ciketic et al 2010[42] and the Australian burden of disease and injury study[43]). Using this method, we calculate an estimated 13,700 DALYs averted over 20 years when discounted at 3.5 percent. This DALY calculation is 56 percent higher than our estimate of QALYs gained, largely because of the increased benefit identified in the NSAOH.

The method we use in this recalculation is as follows:

- Estimate the reduction in the number of teeth affected by decay (as reported in Table 10) for children and adults.
- Estimate the DALY loss per tooth affected, 0.0014 for children and 0.0028 for adults, based on:
  - 32.4 percent of teeth affected by decay being symptomatic;
  - Disutility weight (i.e. reduction in QoL) of 0.057;
  - Duration of impact of 28 days (0.08 years) for children and 55 days (0.15 years) for adults.
- Discount at 3.5 percent.

6.5 QALY gains for smaller water treatment plants are not material enough

We have shown water fluoridation is cost-saving for water treatment plants serving populations over 500. There is a net cost for populations 500 and under. We have measured the value in terms of the amount needing to be spent to gain a quality adjusted life year (QALY). This cost per QALY is $1,842,000 and $256,000 for neighbourhood and small plants respectively. We do not consider it cost-effective to fluoridate water treatment plants with a population under 500, based on these costs per QALY.

The cost-effectiveness results by water treatment plant are summarised in the table below.

Table 19 Cost of water fluoridation by plant size: 20-year costs (discounted)

Plant size	Population used for estimate	Net cost	QALYs gained	Cost per QALY
Neighbourhood	50	$193,000	0.1	$1,842,000
Small	250	$134,000	0.5	$256,000
Minor	2,500	-$591,000	5.2	Cost Saving
Medium	7,500	-$2,421,000	15.7	Cost Saving
Large	50,000	-$17,885,000	104.8	Cost Saving

7. Disparities likely to be reduced

Equally important to the overall efficiency of health interventions are their distributional effects. There is strong evidence that water fluoridation reduces dental decay regardless of ethnicity, socioeconomic status and age. We expect that the relative impact of water fluoridation is the same across ethnic groups and deprivation. Because of the increased amount of dental decay in Maori and those who are most deprived, we expect these groups to have a greater absolute benefit from water fluoridation.

In this section, we first highlight the disparities of dental decay in New Zealand, then look at the effect water fluoridation has on them.

7.1 Disparities between Maori and non-Maori are clear

In New Zealand there are disparities in oral heath between Maori and non-Maori, with Maori having more severe dental decay. Those living in areas of high deprivation have poorer dental outcomes, although the difference in dental outcomes is more pronounced between Maori and non-Maori.

The difference in outcomes for Maori and non-Maori reported in the NZOHS have been adjusted for age, gender and deprivation,[7] and can be summarised as follows:

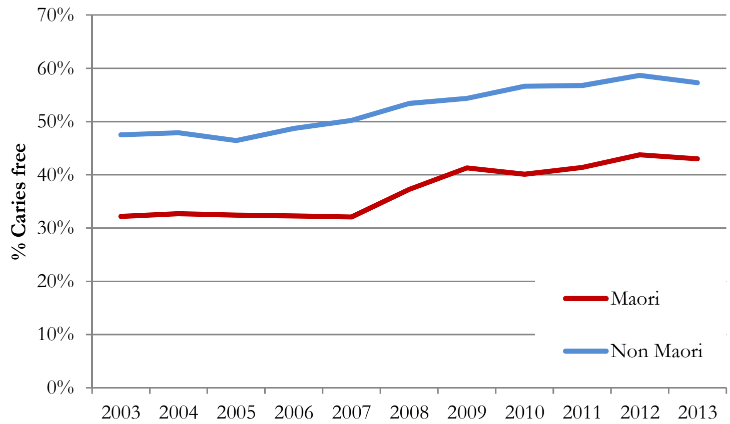
- **Maori adults:**
  - 10 percent more teeth affected by dental decay (1.9 additional teeth), as measured by DMFT.
- **Maori children:**
  - 50 percent more primary teeth (0.7 teeth) affected by dental decay, as measured by dmft.
  - 80 percent more permanent teeth (0.8 teeth) affected by dental decay, as measured by DMFT.
  - 30 percent less likely to be caries-free, 14 percent absolute difference in percent caries-free.

Other measures in the NZOHS also show Maori to have poorer outcomes. These include worse performance on measures such as tooth loss (edentulism), number of sound teeth and untreated decay.

The Community Oral Health Service (COHS)[22] time series data also show a negative difference between Maori and non-Maori. This difference is shown when dental decay is measured by both percent caries-free and dmft/DMFT. Unlike the NZOHS data reported above, the COHS data-set has not been adjusted for potential biases such as deprivation and gender, which limits its reliability. The chart below shows Maori children are less likely to be caries-free than non-Maori. In 2013, 43 percent of Maori were reported to be caries-free, compared to 57 percent for non-Maori. The size of the difference between Maori and non-

Maori has been constant over the last decade, despite improvements in dental health outcomes of both groups.

Figure 12 Percent caries-free for 12 year olds across New Zealand, comparing Maori and non-Maori*



Source: Ministry of Health Data; analysis by Sapere.
*The pattern and relative effect are similar for 5 year olds.

7.1.1 New Zealanders living in deprived neighbourhoods have poorer oral health

The NZOHS[7] compared the dental health outcome of those living in the most and least deprived neighbourhoods. It reported that:

- The differences in percent caries-free and DMFT were not statistically significant. The reported differences were less than seen for Maori and non-Maori.
- Other measures, such as proportion of people with remaining natural teeth (edentulism), showed a statistically significant result. Again, those in most deprived areas had poorer oral health outcomes.

7.2 Expected reduction in disparities

We base our view on reduction in disparities on the following:

- The Community Oral Health Service (COHS) records show that the reduction in dental decay for those attending a school with water fluoridation is greater for Maori than non-Maori. This is in both absolute and relative terms.[22]
- A study of Wellington and Christchurch children reported Maori and those who are most deprived had greater absolute reductions from water fluoridation, although the relative effect was similar for all groups.[20]
- The York report found mixed results for the absolute and relative impacts of water fluoridation when comparing those living in areas of different levels of deprivation.[28]
- The 2014 Public Health Report found that children living in the most deprived areas had the greatest benefits from water fluoridation.[37]

We identified one New Zealand study that reported the impact of water fluoridation for different populations, i.e. estimated the impact by Maori and non-Maori and by deprivation.[20] The study compared the outcomes of 5 and 12 year olds in Wellington and Christchurch, and reported that Maori children and those living in areas of higher deprivation have more severe dental decay. The authors reported reduction in decay from water fluoridation was greater for Maori children in absolute terms; however, the relative effect was similar. The results of the 5 year olds showed a greater absolute reduction in dental decay from water fluoridation for those living in the most deprived areas, but a similar (slightly lower) relative reduction. The reduction for 12 years was similar for those living in areas with differing levels of deprivation.

Given the difference in reported effects, we expect the relative impact of water fluoridation is the same across ethnic groups and socioeconomic class; because of the increased amount of dental decay in Maori and those who are most deprived, we expect these groups to have a greater absolute benefit from water fluoridation. For example, Maori children have 80 percent more permanent teeth affected by dental decay. Therefore, we expect the absolute gain for Maori children to be 80 percent greater. This gain translates to an estimated gain of 0.9 fewer permanent teeth affected by decay, compared with 0.5 in non-Maori. These estimates are summarised below.

Table 20 Estimated benefits of water fluoridation by Maori and non-Maori: In children's permanent teeth

Ethnic group	Number of children's teeth affected by decay (DMFT)*		
	Without fluoridation	With fluoridation	Difference
Maori	2.3	1.4	0.9
non- Maori	1.3	0.8	0.5

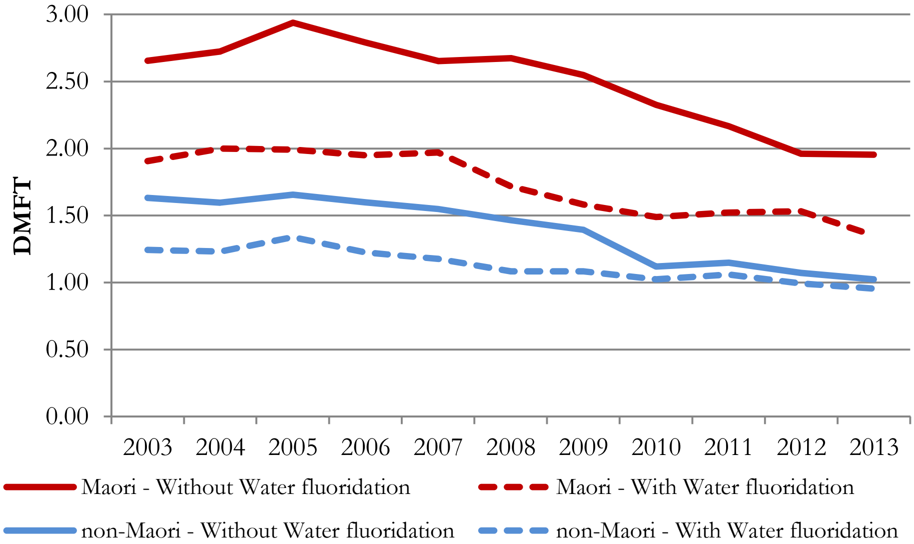
*These estimates are based on an average DMFT rate of 1.2 and Maori having 1.8 times more decay, as reported in NZOHS. We assumed that Maori account for 23 percent of this population, as estimated by Statistics New Zealand.

7.2.1 Material reductions in disparities for Maori and non-Maori

The key source of information identified for the reduction of disparities between Maori and non-Maori is the COHS data. The COHS data show the difference between the severity in dental decay between Maori and non-Maori is smaller for those children attending a school with fluoridated water, versus without. The relative effect of water fluoridation was similar across ethnic groups in 2003 (2003 is the first year in the data-set that includes ethnicity information), with approximately 30 percent less dental decay in areas with water fluoridation in 2003. However, given higher decay rates in Maori, the absolute benefit is greater; in 2003 the difference in DMFT score was 0.7 for Maori, compared with 0.4 for non-Maori.

Over the last decade the difference in the severity of dental decay between children attending schools with and without water fluoridation has changed materially. For non-Maori, the gap in dental outcomes for children attending schools with and without fluoridated water has closed considerably. For Maori, children attending schools with fluoridated water continued to have less severe dental decay. This change can be seen in the chart below.

Figure 13 DMFT score for 12 year olds across New Zealand, comparing those attending schools with and without water fluoridation and Maori with non-Maori*



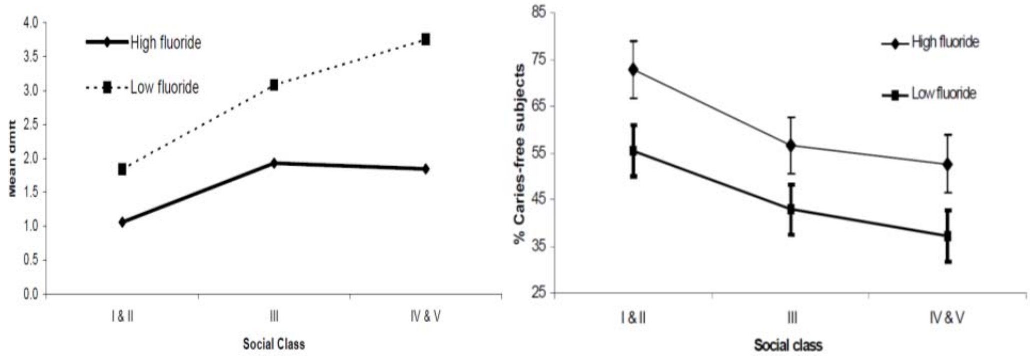
*The pattern and relative effect are similar for 5 year olds, when measuring primary teeth (dmft). The pattern is also similar when comparing percent caries-free.
Source: Ministry of Health Data; analysis by Sapere.

7.2.2 International evidence for reduced disparity is less clear

The York report was identified as the key meta-analysis for the evidence for water fluoridation (as discussed in section 3.3.3). One of the questions the analysis sought to answer was 'Does water fluoridation result in a reduction of caries across social groups and between geographical locations, bringing equity?' The authors of the York report suggest caution in interpreting the results for reductions in disparities due to the small quantity of studies, differences between studies and the studies' low quality rating.[28]

Based on 15 studies, the York report found that water fluoridation appears to have an impact on reducing the differences in the severity of dental decay between areas of deprivation for children aged 5 years old. The chart below presents the dmft score for children aged 5 years old in different areas of deprivation (reported as differences in social class – left hand chart). As can be observed, the difference of dmft score in the area of low deprivation (social classes I & II) is much lower than the difference in dmft score in the areas of high deprivation (social classes IV and V). The difference in dmft score for low deprivation is 0.7, while for high deprivation it is 2. This implies that fluoridated water provides greater benefits in dental decay outcomes for children in poorer environments than for those children in higher social classes. However, when severity of dental decay was measured using the percent caries-free measure, the absolute benefit of fluoridated water was the same across all social classes; i.e. there was no evidence that water fluoridation reduced disparities (this implies a lower relative reduction in those living in areas of higher deprivation).[28]

Figure 14 dmft score (left) and percent caries-free (right) by social class: For children aged 5 years old



Source: York meta-analysis.[28]

Appendix 1 Cost of fluoridation supplied by district councils, used in sensitivity analysis

In the base case we have used the costs of fluoridation estimates reported by Beca.[31] In this section, we summarise the costs supplied to us by district councils; these costs are used in the sensitivity analysis.

The purchase costs of capital that have been reported by councils are on average approximately half the capital costs estimated by Beca. The key reasons that the councils' reported capital costs are lower:

- Recent changes in the code of practice that regulates treatment of water supplies result in the need for more intensive monitoring; this leads to high capital costs.
- The capital costs that we have derived from council experience may be lower than the total cost incurred. This may occur when costs are incurred following the initial installation; we are aware of at least one district council that had this issue for a number of their plants. If the costs of capital are higher than our estimates, it will only have a very small impact on the overall result.

A summary of the cost of fluoridation based on information provided to us by district councils is provided in Table 1 below. We don't have council information on costs of neighbourhood and small-sized water treatment plants, so we assume the cost is the same as for minor plants. We have very limited information on annual operating costs and fluoride costs for medium-sized plants, so we assume these costs would be the same as for large plants, varying by water volume.

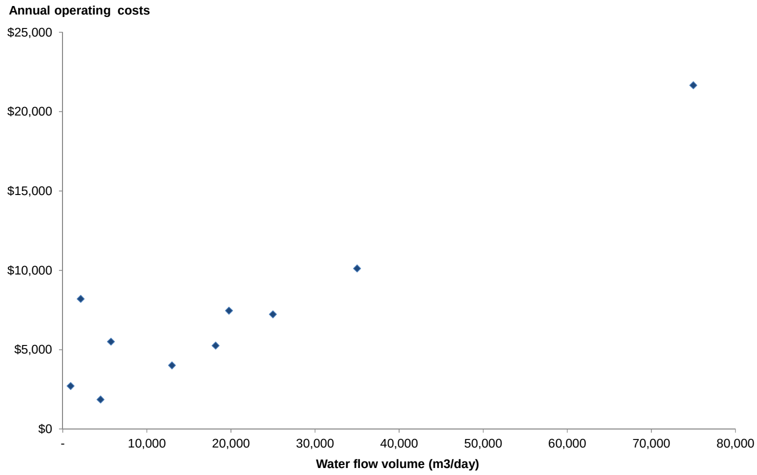
Table 21 Estimated cost of water fluoridation, by plant size

Plant size	Population	Fluoride chemical	Total capital set-up costs	Annual operating costs	Annual fluoride supply cost per m³/day
Neighbourhood	<100	Mix of different chemicals used	$36,923	$5,448	4.01
Small	101 - 500		$36,923	$5,448	4.01
Minor	501 – 5,000		$36,923	$5,448	4.01
Medium	5,001–10,000		$61,034	$8,742	1.06
Large	10,001+		$347,004	$8,742	1.06

Operating cost data are sufficient for this analysis but may be slightly overstated

We found limited information regarding the operating costs of fluoridation. Most district councils pay a lump sum amount to contractors for all operational services on their water plants (maintenance, repairs, labour, etc.) and are not able to estimate the portion relating to water fluoridation. Consequently, we are not able to clearly isolate the incremental operating costs of adding fluoridation systems from general plant operations. So where operating cost estimates have been provided, we note that these values could be slightly overstated. On the other hand, other councils were able to provide us with an annual cost estimate based on what they have observed over the years. The cost information was gathered from a wide range (small to large) of councils. Below is a chart of all the operating cost values that we obtained, and the corresponding amount of water processed by each plant.

Figure 15 Annual operating costs by plant size (m³/day) for NZ district councils (where data were available)

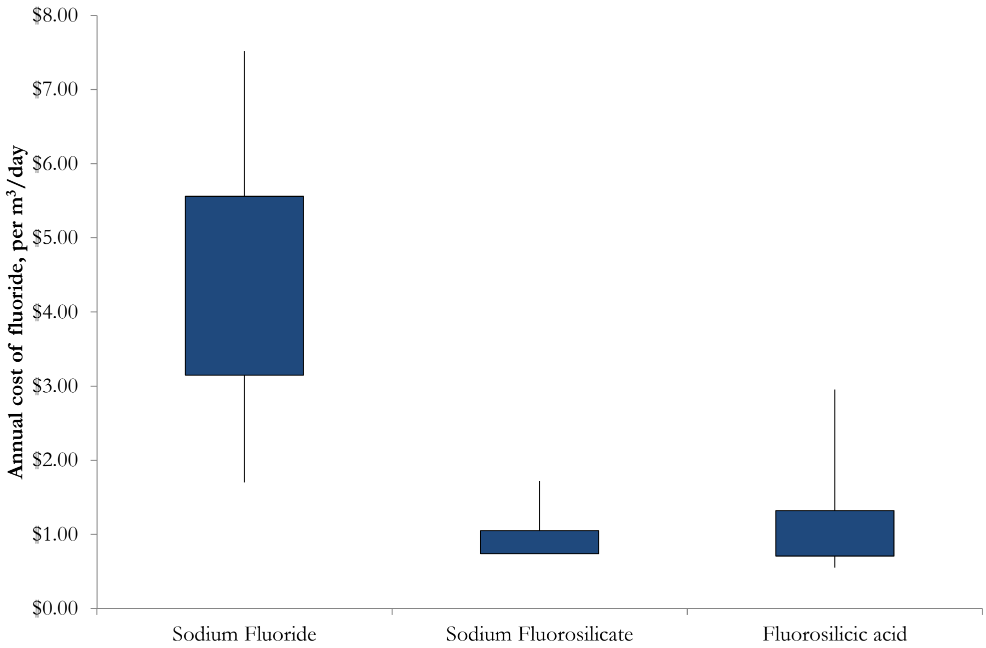


Source: Cost data supplied by district councils, volume data supplied by ESR, graph by Sapere

Cost of fluoride chemical

Our estimates of fluoride include the chemical cost and (where possible) costs of procurement such as delivery, handling, etc. We set out the range of fluoride cost estimates obtained from district councils in the chart below. We observe low variability in fluoride costs across different types of fluoride, besides sodium fluoride. On the other hand, there is a wide cost range for sodium fluoride, largely due to high procurement costs for smaller water plants with more variable water supply volumes.

Figure 16 Range of cost of fluoride chemical: By type of fluoride for councils in NZ



Source: Cost data supplied by district councils; graph produced by Sapere

7.2.3 Council figures used to derive our cost estimates

In Table 22 below, we present a summary of the cost values supplied by district councils which form the basis of our estimates for the cost of water fluoridation. We contacted a number of district councils and received costing information for the nine councils listed in the table below. This costing information is for 17 water treatment plants. The majority of the information came from correspondence with district councils. The Ministry of Health provided a number of the capital costs estimates, which were derived from capital funding applications. We could only use costing information where the costs could be attributed to individual water treatment plants. In order to derive our estimates in Table 21, we grouped the costs by water treatment plants by size and used the averages.

Table 22 Reported costs by district councils

Provider/source	Region	Chemical used	Water flow (m^3/day)	Total capital cost	Annual operating cost	Annual fluoride cost
Greater Wellington District Council	Gear Island	Fluorosilicic acid	18,190	$260,438	$5,253	$30,000
	Waterloo	Sodium fluorosilicate	35,000	$417,869	$10,108	$25,926
	Te Marua	Sodium fluorosilicate	75,000	$216,000	$21,659	$55,556
	Wainuiomata	Sodium fluorosilicate	25,000	$805,714	$7,220	$18,519
Dunedin City Council	Mt Grand	Sodium fluorosilicate	19,778		$7,451	$16,752
	Dunedin	Sodium fluorosilicate	9,385			$10,415
Stratford District Council	Stratford	Sodium fluorosilicate	4,500	$38,400	$1,850	$4,460
	Stratford	Fluorosilicic acid	4,500	$52,300		
Clutha District Council	Balclutha	Sodium fluoride	2,136		$8,196	$6,804
	Milton	Sodium fluoride	543			$4,082
	Tapanui	Sodium fluoride	480			$1,512
	Kaitangata	Sodium fluoride	888			$1,512
	Milton, Tapanui, Kaitangata	Sodium fluoride	1,911	$83,081		
South Waikato District Council	Billah Street	Fluorosilicic acid	5,732		$5,500	$4,500
Ashburton District Council	Methven	Sodium fluoride	950	$40,145	$2,700	$5,283
Kapiti Coast District Council	Waikanae	Sodium fuorosilicate	7,696			$13,213
South Taranaki District Council	Hawera	Fluorosilicic acid	6,200	$55,125		
Masterton District Council	Kaituna	Fluorosilicic acid	13,000	$35,000	$4,000	$9,530

Appendix 2 Previous cost-effectiveness studies are not definitive

We summarise the findings from the cost-effectiveness studies as follows:

- The cost-effectiveness studies identified by us reported water fluoridation to be cost-saving for all or some population groups. Some analyses reported water fluoridation to be a net cost for small populations. All studies assumed a benefit in terms of reduced dental decay.
- All studies reported the costs of water fluoridation and the savings from reduced dental treatments. Some studies also estimated benefits of reduced time off work from dental decay; these studies reported greater savings from water fluoridation.
- Two studies quantified the health benefits and used disability adjusted life years (DALYs)[xii] averted (Cobiac & Voss 2012[44] and Ciketic et al 2010[42]). This is similar to the measure quality adjusted life years (QALYs) gained, as used in the analysis described in this report.

From these studies, we draw two general conclusions:

- The cost of water fluoridation in New Zealand is likely to be greater than in the majority of studies reported in the table below. This is because there are many small water treatment plants in New Zealand, and these have a much higher cost per person.
- The benefits of fluoridated water in the reports vary substantially. Some restrict benefits to children while others apply benefits to the entire population. Many of the studies do not provide much discussion on the evidence, particularly regarding the applicability to their populations. The York report is often cited but the evidence base may not align with the application in the cost-effectiveness study. For example, one study applies the benefits observed in children to the entire population (Kroon and van Wyk 2012).[47] Another study applies the reported absolute risk reduction as a relative risk reduction (Cobiac and Vos 2012).[44]

One cost-effectiveness study looking at New Zealand was identified.[1] This study provided different scenarios of cost-effectiveness based on population size. The study is not of sufficient quality to inform the current debate for a number of reasons, including:

- The benefits of water fluoridation in children were based on a comparison of decay rates for children in two cities, one with (Wellington) and one without (Christchurch) water fluoridation. This approach is open to bias as there are a number of factors that could influence differences in dental decay.
- There was limited evidence of benefits for water fluoridation in adults at the time of the analysis (1999), so the analysis restricted benefits to children in the base case.

[xii] A DALY is a measure of both life years lost and years lived with a disability, with more debilitating diseases creating a greater DALY loss.

- The same costs structure was assumed regardless of plant size. No information on the number and size of water plants in New Zealand was provided.
- National estimates of the benefits and costs were not provided.

A summary of the identified cost-effectiveness studies is included in Table 23 below. The costs have been separated out to show:

- Cost of fluoridation, limited to the direct costs;
- Net cost, i.e. taking into account savings from reduced dental decay such as fewer dental procedures and less time off work.

The costs have been separated out as there is a large variation in the difference in both the cost of water fluoridation and the cost savings. The variation in the cost savings is due to the different assumptions about the magnitude of the benefits of water fluoridation and the scope of cost savings included.

Table 23 Summary of cost-effectiveness studies

Source	Costs (annual per person)	Modelled benefits	Relevance to New Zealand
Cobiac & Vos (2012)[44] Cost-effectiveness of extending the coverage of water supply fluoridation for the prevention of dental decay in Australia.	Cost of fluoridation[1] Pop >1000: $0.27 Pop <1000: $27 Net cost[1] Pop >1000: -$1.7 Pop <1000: $26.6	15% relative risk reduction in percent caries-free for under 16 year olds (based on York report 2000). 0.0001 DALY averted per person p.a. (includes adults).	This highlights that population size creates a large variation in cost of fluoridation. They found the cost of extending water fluoridation to rural areas is 100 times higher than urban.
Campain et al. (2010)[45] Evaluates the decline in dental decay over time, and the effect on the cost-effectiveness of fluoridation schemes.	Cost of fluoridation[1] $0.27 Net cost[1] 1970s: $57 1980: $28 1990s: $19	Relative risk reduction 1970s: 50% 1980: 30% 1990s: 25% No QALY estimates.	The cost offsets are optimistic as they assume savings from increased productivity.

Source	Costs (annual per person)	Modelled benefits	Relevance to New Zealand
Griffin et al. (2001)[46] Assessment of the cost-effectiveness of water fluoridation given prevalence of fluoride from other sources.	Cost of fluoridation[2] $0.54 to $3.46 Net cost -$19 to -$22 Population <5,000–>20,000	A reduction of 1.16 caries per year, as measured by tooth surfaces. (Various data sources.) No QALY estimates.	The cost offsets are less relevant as they are optimistic by assuming savings from increased productivity.
Kroon & van Wyk (2012).[47] The paper evaluates the cost-effectiveness of providing water fluoridation in South Africa across different communities.	Cost of fluoridation[2] (Size of plant: Cost) <100 ML per day: $0.35 100–700 ML per day: $0.40 >700 ML per day: $0.47 Net cost <100 ML per day: -$1.5 100–700 ML per day: -$1.6 >700 ML per day: -$1.8	15% reduction in decay, all age groups (based on York report 2000). No QALY estimates.	This shows that smaller water supplies have a higher cost per person of water fluoridation. However, NZ water supplies are a lot smaller and are associated with higher costs per person.
Wright et al. (2001)[1] Cost-effectiveness of fluoridation water supplies in New Zealand.	Cost of fluoridation $0.2–$9.7 Population 1,000–300,000 Net cost -$1.1 to -$10.6 Population 1,000–300,000	40–60% reduction in restorations for children. 17% increase in extractions of primary teeth. (Based on a comparison of Wellington and Christchurch.) No benefit to adults (base case). No QALY estimates.	This is of limited relevance due to the relatively low-quality evidence used for benefits of water fluoridation.

[1] Costs translated to NZD using an exchange rate of 0.95, original values reported in AUD.

[2] Costs translated to NZD using an exchange rate of 0.85, original values reported in USD.

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