Community Water Fluoridation (CWF) is the adjustment of fluoride concentration in community drinking water to a level that confers optimal protection from dental caries (Truman et al 2002). It is supported by many authorities as the single most effective public health measure for reducing dental caries (DHS 2007). It has consistently been shown to be effective in reducing the prevalence and severity of dental caries in populations following its introduction (NHMRC 1999). The most dramatic reductions (50-60%) were demonstrated in the earlier studies although more recent research has still shown reductions of between 30 and 50% (Truman et al 2002). Despite the strong scientific evidence for its beneficial effects and safety the issue of the appropriateness of CWF is often the focus of public debate. Proponents argue that it reduces dental caries, is safe and cost effective, and that it provides significant benefits to all social classes (Slade et al 1995; Slade et a 1996; Spencer et al 1996). Opponents question its efficacy and safety and argue that its addition to community water supplies is unethical mass medication (Colquhoun 1990; Diesendorf 1986; Diesendorf et al 1997).

More recently, however, there have been important questions raised regarding the continuing benefit of CWF over and above that produced by the widespread use of other sources of fluoride (toothpaste, mouth rinses, varnish and other professionally applied fluorides). Generally, dental caries has declined steeply in the last thirty years and many have observed that dental caries has also reduced in parts of Australia and other countries where there has never been CWF or where it has ceased. It has been suggested that because of the current low population levels of dental caries and the increase in alternate sources of fluoride, CWF no longer offers the benefits it may have in the past. Given this notion, together with the concerns of a minority subgroup of the population regarding the safety of CWF, it is valuable to examine current evidence to answer the question: Is there still a role for CWF in Australia?

This paper will firstly examine the history of water fluoridation and its mechanisms of action. Secondly, trends in dental decay experience over the last three decades with particular emphasis on social and geographical inequities in Australia will be described. We also review the current state of scientific evidence for the benefits of CWF including the contribution it makes to the reduction of oral health inequalities. In light of this we will provide a response to the question posed above.

**History of CWF**

Fluorine is considered a trace element and ranks thirteenth in terms of abundance of elements in the earth’s crust (NHMRC 1999). Fluorine
Mechanisms of Action

Fluorinated water provides protection in two ways: pre- and post tooth eruption. Systemic ingestion during development of the teeth (pre-eruption) allows fluoride to be incorporated into the developing dental tissues, especially enamel, making them more resistant to demineralisation. Topical contact with erupted teeth (post-eruption) enhances the replacement of minerals on the surface of the teeth again making them more resistant to dental caries. Dietary substrates, especially sugars, allow oral bacteria to produce acids which encourage the demineralisation of minerals from the enamel surface. Fluoride, should it be available in the oral cavity, assists in the remineralisation of the tooth surface thus preventing a net loss of minerals which over time would lead to breakdown or cavitation of the enamel surface (Pitts 2001). Contemporary evidence now supports the theory that frequent exposure to low concentration topical fluoride provides greater benefits than systemic ingestion. For this reason water and toothpaste fluoridation are now strongly supported and systemic supplements (which have little topical effect unless chewed or held in the mouth before swallowing), such as tablets and drops, are only recommended for those individuals considered at high risk. This idea was reinforced in the recent guidelines for the use of fluorides in Australia resulting from the Australian Research Centre for Population Oral Health (ARCPOH) Workshop on the Use of Fluorides in Australia (ARCPOH 2007).

Socio-demographic Differences in Water Consumption

Access to water from reticulated supplies is of course required in order to gain benefits from CWF. Geographical location can affect this access with many rural and remote dwellings relying on rain, bore or other sources of water. Furthermore it is important to consider that just over half of children living in rural Victoria do not use reticulated water as their usual source of drinking water (DHS 2007a). Alternate sources of fluoride exposure need to be considered for these groups to ensure equity in access to dental caries risk protection for the entire population.

In addition, residing in areas with CWF does not guarantee exposure will occur through drinking tap water. Recent climate change and a longstanding drought in Australia may also have had some impact on water use as water taste and quality may be affected although there is little substantive evidence available to support this idea.

Australia is also a culturally diverse society with new arrivals settling here for many reasons such as employment and education, marriage and family and even fleeing from war and persecution. These groups may also have higher existing dental caries experience and ongoing risk (Chaffin et al 2003; Nurko et al 1998) making them a group that would benefit from exposure to CWF. Migrants and refugees have often come from countries where community water has been unsafe to drink and are not aware that Australia's community water supply is purified and safe for consumption.

Fluoridation in Australia

CWF in Australia began with the fluoridation of the public drinking water in Beaconsfield Tasmania. Hobart and the ACT became the first capital cities to fluoridate in 1964. Two years later Sydney and Perth introduced CWF with Adelaide and Darwin following in 1971 and 1972 respectively. By 1977 all capital cities with the exception of Brisbane had successfully introduced fluoridation (see figure one). Queensland is striking in its low level of water fluoridation (see figure below) with the majority of the state's population (approx 95%) not receiving optimally fluoridated drinking water (Akers et al 2005).
COMMUNITY WATER FLUORIDATION: IS IT STILL WORTHWHILE?

The case of Queensland is of interest. Queensland has the poorest dental health in terms of dental caries despite spending more per annum on publicly funded dental services than any other state. The Queensland government funds 30% of dental services compared to a state average across Australia of 17% (AIHW 2004). Despite the potential benefits of CWF successive governments have failed to introduce this public health measure. Akers, Porter & Rae (2005) have examined the reasons for Queensland’s failure to implement CWF in the face of trends in all other states and territories. They reject a cultural hypothesis of Queensland’s “difference” instead pointing to the nature of state legislation governing fluoridation. This legislation has prevented the introduction of CWF even when political will to do so has been strong. Their analysis showed that all other States and Territories allow for centralised executive decisions to fluoridate and also discourage the use of public referenda on the issue. Other common features were the use of an indemnified advisory committee or government officer and the provision of financial support to local or water authorities for the setup costs.

Since the 1980s there has been relatively little new activity in the introduction of CWF in Australia although several communities (mostly in Queensland) have ceased their fluoridation programs (Akers et al 2005). Since 2004 however there has been some activity in the states of New South Wales and Victoria. In the period 2004-2007, twenty-one New South Wales communities have been gazetted to fluoridate. Currently New South Wales has 90% population coverage for CWF but with the fluoridation of Gosford (population ~ 165,000) in 2008 will achieve coverage of 96% (Shanti Sivaneswaran, personal communication). The Victorian State Government has recently instigated a program of CWF in non-fluoridated rural and regional areas. The government has directed water authorities to fluoridate water supplies following a period of community information and discussion.

Dental Caries Trends in Australia

The prevalence of dental caries has reduced dramatically in Australia and many other developed countries in the last three decades. Prior to the 1970s dental caries affected most of the population of Australia. In 1977 90% of 12 year old children had experienced some dental caries (NHMRC 1999). This had dropped to 42.5% in 1994 and 35.5% in 1999 (Armfield et al 2003; Davies and Spencer 1997). Over the same period there was a reduction in the mean number of teeth affected by dental caries as measured by the number of decayed, missing and filled permanent teeth (DMFT) for 12 year olds from 4.79 in 1977 to 1.9 in 1994 and 0.83 in 1999 (Armfield et al 2003; Davies and Spencer 1997). The most recent data available for Australian 12 year olds shows a slight increase to 40.3% with some caries experience with an average DMFT of 0.95 (Armfield et al 2006b). In deciduous (primary) teeth a similar, although less dramatic trend has been observed.

Despite these overall improvements dental caries remains the second most costly diet-related disease in Australia, comparable to diabetes and heart disease in terms of economic impact (AHMAC 2001). In the year 2002-2003 4.3 billion dollars was spent on dental services which represents 6.2% of total health expenditure (AIHW 2006). As only half of the population regularly attend dental services the cost of care, should actual need be expressed as demand, would be significantly greater. In addition dental caries has significant effects on quality of life and social functioning in all age groups including young children and the elderly.

Another recent trend has been the increasing polarisation of disease (Armfield et al 2006a). The majority of dental caries is now concentrated in fewer people, with disadvantaged and marginalised groups suffering a disproportionate burden of disease. These groups have fewer resources for attaining and maintaining good dental health such as accessible and secure dental care and the capacity to purchase oral health care products such as fluoridated toothpastes, mouth rinses and supplements. As a result a significant majority of Australians suffer pain, disfigurement and reduced oral function as a result of untreated dental caries. In Victoria, and in most other States and Territories, children from lower socioeconomic family backgrounds and those living in rural and regional areas are significantly more likely to have dental decay and experience more of it. Children living in metropolitan Melbourne have half the dental caries in their primary dentition (as measured by dmft) than children in rural and regional areas (Armfield and Slade 2006). In addition rural children under the age of nine years are three times more likely, and those of preschool age four times more likely, to be admitted for dental treatment under a general anaesthetic than metropolitan children (DHS 2004). The reasons for these apparent inequalities in oral health are likely to be complex but probably include issues of access to dental services and the reduced likelihood of optimal exposure to fluoride.

Current inequalities in the burden of poor oral health and dental caries in Australia are also reflected in an unequal burden of costs to individuals and families. The States and Territories provide public dental health services, targeted at more socially and economically disadvantaged groups. However, average waiting times in Victoria of 22-23 months for non-urgent care suggests that access to these public services is highly limited. Dental health care in Australia remains an area of predominantly private practice and individual payment, either directly out of pocket (68%) or indirectly via private health insurance (15%) with only 17% through government funds (AIHW 2004). The cost of dental care therefore dissuades many Australian families from accessing preventative dental care or even from seeking help for oral health problems when they occur (Spencer and Harford 2007).

There is also now some concern that at a population level the trend in caries reduction has halted or may be reversing (Armfield et al 2003). The reasons for this are not yet known however the recent increase in the use of low fluoride toothpastes in non-fluoridated
Evidence for Positive Effects of CWF


Evidence for Effects on Dental Caries

All three reviews examined the reported effects of CWF on dental caries experience. The purpose of the Australian review was to collect and assess the scientific evidence from the previous nine years (time since the last review) in relation to the effects on health of CWF and fluoride from other sources to allow the NHMRC Health Advisory Committee to make appropriate recommendations (NHMRC 1999). This review concluded that there were significant benefits in preventing caries in both deciduous (primary) and permanent teeth. Although the protective effects were greater in deciduous teeth than permanent teeth there was evidence that CWF benefited adults as well as children. Furthermore the included studies showed an increase in caries experience in communities that had ceased water fluoridation.

The York Review, completed and published in 2000, included 214 studies and addressed five questions regarding the effects (positive and negative, clinical and social) of water fluoridation (McDonagh et al 2000). The extensive search which included 25 databases, hand searching and no language exclusions, found no randomised controlled trials of water fluoridation. Like many public health initiatives, the nature of water fluoridation where water is supplied to whole population via a centralised water reticulation system makes randomisation at an individual or household level impossible. After applying inclusion/exclusion criteria (all cross sectional studies were excluded), 26 studies remained all of which the authors considered of moderate quality. They concluded that the best available evidence suggests that CWF is effective in reducing the prevalence of dental caries. Despite the limited number of studies included, CWF was found to affect both the proportion of children who are caries free and the total dental caries experienced as measured using dmft/DMFT score. Their meta-analysis found a median difference (increase) in the proportion of children caries free of 14.5% (interquartile range 5.05, 21%) when comparing fluoridated with non-fluoridated groups. The median change (decrease) in dmft/DMFT in fluoridated groups was 2.25 teeth (interquartile range 1.28, 3.63 teeth). In terms of numbers needed to treat (NNT) it was estimated that six people would need to receive CWF for one extra person to be caries-free. Furthermore this review attempted to estimate the beneficial effects of CWF over and above that offered by alternate sources of fluoride eg toothpastes. Studies prior to 1974 were excluded (date that fluoride containing toothpastes became commercially widely available) leaving nine studies of moderate quality. Despite the limitations of the available evidence the authors concluded that there was sufficient evidence that CWF did offer additional benefits in spite of the population wide exposure to other sources of fluoride (McDonagh et al 2000).

The later systematic review conducted in the United States and published in 2002 evaluated the evidence for the effectiveness of starting or stopping CWF in reducing dental caries prevalence, the applicability of these findings in various settings, the costs and the economic value of CWF programs (Truman et al 2002). This review included 21 primary studies addressing the first two questions and 27 for the economic analysis. The included studies varied in design, analysis, levels of fluoride concentration and measures of dental decay. In order to assess the strength and consistency of evidence the authors grouped the studies according to study design and direction of change in dental caries. The first group of studies had a before and after design with concurrent comparison groups and included studies that either assessed the effects of starting/continuing CWF or stopping CWF. The second group included post exposure only measurements of difference in caries with concurrent comparisons for both starting and stopping CWF. Although the data from the two groups could not be combined the review concluded that CWF reduced dental caries by 30-50% when compared with what could be expected in a population without CWF. Overall stopping CWF was associated with a 17% increase in dental caries over a 6-10 year follow up period (Truman et al 2002).

Evidence for Effects on Reducing Social Inequalities

CWF is reported to have beneficial effects on the oral health of all social classes. It therefore has the potential to reduce dental health inequities related to social disadvantage (Gabardo et al 2007). The York Review considered the question: Does water fluoridation result in a reduction of caries across social groups and between geographical locations, bringing equity? The search found no studies of good quality addressing this question. Despite this they considered the importance of this question was high and therefore they considered 15 studies they rated as level C evidence (lowest quality of evidence, high risk of bias). These studies collectively indicated some evidence that CWF reduced inequalities in dental health across social groups in six and twelve year old children using measures of severity ie dmft/DMFT. The same effect was not identified when using the prevalence measure of the proportion of caries free children. No effects were observed with any of the measures in other age groups (McDonagh et al 2000).
Evidence for Negative Effects of CWF

The negative effects of fluoride ingestion have received considerable attention since the commencement of planned CWF programs in the 1950s. The negative effects investigated are predominately fluorosis, bone disorders and cancer although other conditions such as Down's syndrome and autism have been associated with CWF. Two of the three reviews (McDonagh et al 2000; NHMRC 1999) included a careful consideration of the quality and strength of evidence for these proposed negative effects. The 2002 review (Truman et al 2002) included only a brief appendix summarising the findings of the York Review.

The York Review (McDonagh et al 2000) included studies which compared the incidence of any possible adverse effect between populations with fluoridated water (natural or adjusted) and communities without CWF. This review found more studies on fluorosis, bone fracture and cancer than any other outcome.

Fluorosis

Enamel fluorosis is a condition that affects the mineralisation of enamel as it is laid down prior to eruption into the mouth therefore it does not affect tooth enamel once the teeth have completed crown formation. It results in varying degrees of hypo-mineralisation and its clinical presentation ranges from barely noticeable white striations to darkly stained and pitted enamel (Riordan 1999). The threshold dose at which fluoride produces enamel fluorosis is not precisely known but is thought to be approximately 0.1 mg per kg of body weight (Riordan 1999). The concentration of fluoride currently recommended for CWF of 0.7 - 1 ppm is based on the observations from the earlier studies that demonstrated a caries reduction of up to 60% and a fluorosis prevalence of about 10% (NHMRC 1999).

The NHMRC (1999) review included studies published between 1991 and 1998 including three Australian studies. The primary studies were mostly cross sectional in design relying on parent recall of fluoride exposure for periods of many years. This review concluded that the prevalence of enamel fluorosis had risen across the 1990s and recommended the reduction of fluoride supplements and the use of lower concentration fluoride toothpaste in young children living in areas with CWF. The three Australian studies found significant relationships with CWF although the majority of fluorosis detected was of the very mild (barely discernable) type. Recent surveys have shown a reduction in fluorosis following modification of fluoride supplementation (Riordan 2002).

The York Review (McDonagh et al 2000) included 88 studies which assessed the relationship between CWF and fluorosis. Only one study used a baseline survey at the time of introduction of CWF and only four studies used prospective design. The majority (82%) of studies failed to use blind assessment and over half (57%) did not account for confounding factors such as the concurrent use of other fluoride products. As a result all but one study were rated as evidence level C (lowest quality of evidence, high risk of bias).

Another potential problem impacting the interpretation of the results of the studies was the fact that the analyses used by most studies was based on the prevalence of ‘fluorosed’ people which effectively reduces multiple criteria based on severity into a dichotomous variable of no fluorosis versus any fluorosis. This ignores the observation made by Bowen (2002) that the majority of cases of fluorosis are of the very mild to mild type and a ‘minor cosmetic defect that should not be cause for alarm’ (Bowen 2002 p1405). It also fails to provide an indication of the severity or the clinical relevance of the fluorosis (NHMRC 1999). For this reason the authors of the York Review also used a second method of determining the proportion with fluorosis within studies included in their review (McDonagh et al 2000). Their method describes the proportion of individuals having dental fluorosis that may cause aesthetic concern given that much of the fluorosis is of the mild to very mild form. When assessing the prevalence of fluorosis using any fluorosis the estimate was 48% (95% CI 40, 57) with water at 1 ppm. However when using only fluorosis of aesthetic concern the prevalence at this water level fell to 12.5 % (95% CI 7.0, 21.5).

Recently Do and Spencer (2007a) reported a decline in dental fluorosis prevalence and severity in South Australian children in the decade since the early 1990s when policy recommendations were made to control exposure to discretionary fluorides in children. They found a reduction in prevalence from 45% in 1992/93 to 26% in 2002/03. The prevalence reduced by half in non-fluoridated areas and by one third in fluoridated areas (Spencer and Do 2007).

There is no available data on the costs of dental fluorosis relating to the negative aesthetic impact or in terms of treatment required to address its negative aesthetic or clinical effects. Interestingly one very recent Australian research indicates that children and parents rated teeth with mild fluorosis as more attractive (Do and Spencer 2007b).

Other Effects

Bone mineral density (BMD) and fractures and their association with CWF has been studied. Fluoride is deposited in bones increasing their density particularly in the axial skeleton. In high levels however the bone is not synthesised normally and becomes structurally weak and perhaps more prone to fracture. The NHMRC review included 16 studies which had been published between 1990-1999 (NHMRC 1999). The collective evidence for fracture of bones was equivocal and subject to high levels of confounders and variable sensitivity in diagnosing fractures. They concluded that there was variable effect of CWF on BMD and hip fracture however the stronger studies suggested protective effects. For other fractures the effect was also variable. They concluded that there was no consistent evidence for either a risk or protective effect with relation to bone fracture. These
findings were confirmed in the York Review which included 29 studies on bone development and fracture all of which were rated as C level evidence. The meta-analysis also concluded that the available evidence suggested no association between bone fracture and CWF (McDonagh et al 2000).

Cancer is the other condition which has been subject to research in this area. The York Review included 26 studies on tumours and cancers 18 of which were C level evidence. The NHMRC review included six studies. Both reviews found no clear association between CWF and cancer incidence or mortality (McDonagh et al 2000; NHMRC 1999).

Evidence for Economic Benefits

One of the major benefits claimed of CWF is its cost effectiveness. Despite this only one of the three systematic reviews included a review of cost-effectiveness (Truman et al 2002). Truman and co-workers included nine primary cost or cost-effectiveness studies in their systematic review, seven of which included an estimate of the cost of community water fluoridation. The authors observe that although the delivery systems vary considerably, variation in the program cost per person is largely explained by economies of scale (i.e. the larger the population served, the smaller the cost per person of initiating and/or maintaining a fluoridated water supply). The estimated fluoridation cost per person in this review ranged from a US $2.70 for systems serving less than 5000 people to $0.40 per year for populations greater than 20,000. In all studies, community water fluoridation was a cost-saving (i.e., 'win-win') intervention, as the cost of providing a fluoridated water supply was less than the costs savings that flow on from the outcome of reduced caries in the form of reduced use of dental services and associated reductions in productivity at, or time off, work and school. These findings have been repeated in a more recent study of the cost-effectiveness of CWF in New Zealand, where CWF was found to be cost-saving for any population greater than 1000 people (Wright et al 2001). Based on these findings, CWF has been associated with an estimated saving over the last 25 years of $1 billion dollars in averted dental treatment costs and lost productivity in Victoria (DHS 2007b).

However, the assessment of community water fluoridation as a 'win-win' intervention comes from studies that include only positive outcomes of fluoridation (reduced dental caries) and a narrow assessment of costs. A complete economic evaluation would seek to identify and value all relevant costs and consequences that emerge from community water fluoridation, including negative dental outcomes (fluorosis) as well as the more generic negative outcomes of public health programs associated with perceived violations of freedom and choice (Shackley and Dixon 2000). To date, only one study has attempted to assess community values for water fluoridation and this found a distinct grouping of community values: the largest group held positive values for fluoridation, linked mainly to expected dental health benefits; a second group had no strong preference either way; and a minority held positive values for maintaining a non-fluoridated water supply, due to desires to maintain freedom of choice and a natural water supply (Shackley and Dixon 2000). A complete economic assessment of CWF would also need to assess the impact of fluoridation on costs of household

Figure one: Extent of CWF in 2006
Source: www.arcpoh.adelaide.edu.au/dperu/fluoride/atlas.html
water consumption from all sources, as households may alter their purchase of toothpastes and bottled water in response to a change in water supply fluoridation.

None of the existing economic studies of community water fluoridation have included an assessment of the impact of CWF on socio-economic inequalities. If the provision of CWF were to reduce both oral health inequalities and their associated economic burden on individuals and families, this could be seen as an additional aspect of benefit to be included in a future comprehensive evaluation.

**Discussion**

Contemporary evidence suggests that water CWF is a safe and effective strategy for reducing dental caries risk at a population level. CWF appears to offer significant reductions in dental caries prevalence and severity. This in turn offers significant cost savings in terms of averted dental treatment. It would also be reasonable to assume that the reduction in disease experience would serve to reduce the other costs associated with dental morbidity such as work/school time lost, reduced economic productivity and the costs to families and individuals in terms of travel and inconvenience. However the true cost effectiveness of CWF in Australia can only be determined when all costs and consequences (including negative effects) associated with water fluoridation are captured and quantified. There is therefore a need to include a comprehensive economic evaluation in any future work evaluating the effects of CWF.

The current available evidence also suggests that CWF continues to offer benefits over and above those afforded by alternate sources of fluoride such as toothpaste and supplements. There is also some evidence that fluoridation of water supplies reduces social inequalities in dental disease experience, however, further research is required to provide better evidence for this claim. As CWF is more likely to occur in metropolitan areas, a lack of access is biased towards lower socio-economically positioned groups. At this stage it is unclear what the effects of this are however the extension of CWF into rural and other areas of disadvantage would likely contribute to a reduction in oral health inequalities (Spencer 2004). This also requires evaluation using prospective, well-designed studies.

In the Australian context, recent drought and other economic and social changes may have an impact on water consumption patterns which could affect the reach and relative impact of CWF. Complementary work is required to identify alternate methods for exposure to fluoride for communities or groups who can not, or chose not to use reticulated water systems. This is particularly important given the risk of widening inequalities if non-users are disadvantaged groups.

In conclusion the answer to the question 'is CWF still worthwhile?' appears to be 'Yes'. The current evidence base supports continuing fluoridation of public drinking water and the extension of CWF to communities who currently do not enjoy its benefits. However given the limitations of past and current research findings, CWF should continue to be monitored and new work should be undertaken to enhance the evidence base particularly in the area of economic and social benefits to determine its continued worth in contemporary Australia.

**References**


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