

Finding the optimum: Fluoridation of potable water in South Africa[#]

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Abstract

Since the South African Department of Health has tabled legislation to make fluoridation of public water supplies mandatory, the issue of whether fluoride is beneficial or harmful has, once again, become controversial in South Africa. We reviewed the literature, the experiences of fluoridation in overseas countries and the latest WHO recommendations, and have found that fluoride is desirable at certain levels, and undesirable above these. The following recommendations are made for optimum fluoride levels in South Africa's potable water:

- The decision to fluoridate a public water supply must be a community decision taken after public consultation. However, it can only be reached when the public is properly informed about the issue.
- Optimum levels of fluoride for human health range from 0.4 to 0.7 mg F/l, depending on the maximum mean annual temperature. *The maximum level of 0.7 mg F/l should not be exceeded.*
- Accordingly, it is recommended that in areas where natural fluoride concentrations in the drinking water exceed 0.7 mg F/l steps be taken to *defluoridate* the water.
- As an interim measure, a scale of temperature-adjusted optimum fluoride levels should be adopted in South Africa, rather than a single level covering the wide-ranging ambient temperatures (and corresponding consumption rates of drinking water) in the country. A sliding scale would mean that the community within a water supply region can determine its own fluoride consumption within the optimum range.
- Fluoridation should be considered only a short-term measure, until economic conditions are such that all South Africans have access to proper dental health care.

The duration of fluoridation of a community water supply, and the level of fluoridation (within the optimum range of fluoride levels) should both be considered a community decision. However, defluoridation should be a permanent necessity in those areas where the drinking water exceeds levels of 0.7 mg F/l.

Introduction

Water fluoridation has been defined as the deliberate adjustment (either by increasing or decreasing) of the fluoride levels of a water supply so that the greatest protection against dental caries is produced with the least risk of dental fluorosis (Pontius, 1991). However, this definition is confusing, since fluoridation is generally understood by the public as only the addition of fluoride to drinking water supplies. Therefore, for the purposes of clarity in this paper, "fluoridation" will refer specifically to the addition of fluoride while "defluoridation" will refer to the removal of fluoride from drinking water supplies. "Fluoride management" means both fluoridation and defluoridation.

The issue of whether, and at what levels, to manage fluoride in South Africa's public water supplies is a contentious one which has recently resurfaced because the Department of Health has tabled legislation to introduce compulsory fluoridation of public water supplies. However, consideration should also be given to the removal of fluoride in certain regions. This paper is a discussion of fluoride- and fluoridation-related research with particular reference to the legislation currently tabled in South

Africa. Recommendations are proposed for optimum fluoride levels for South Africa's potable water.

Individuals are demanding health care as a right, and therefore effective public health systems need to be improved to prevent illness and dental decay with its associated pain (Hartshorne and Carstens, 1990). Dental decay is the commonest disease affecting mankind and produces a permanent breakdown of tooth substance (Cleaton-Jones, 1979). It is caused when bacteria on the surface of teeth ferment carbohydrates to produce acids which then destroy the hard, calcified tooth tissue. Fluoride interferes with the metabolism of bacteria, inhibits the production of acid by decay-causing bacteria (Cleaton-Jones, 1979; Pontius, 1993) and results in a change in the population of bacteria in dental plaque (Cleaton-Jones, 1979).

In the 1930s and 1940s, studies in the United States found that *natural* levels of 1 mg fluoride per liter (mg F/l) reduced the incidence of dental caries by approximately 50% (Underwood, 1977; WHO, 1994). Life-time consumption of fluorides, whether taken systemically or used topically, significantly reduces the incidence of dental caries (Hargreaves, 1990; Murray et al., 1991). Fluoride is essential to the development of resistance to caries and these benefits are lifelong. It reduces the susceptibility of teeth to caries by stabilising the apatite crystal of the dental enamel, making it more acid-resistant and results in remineralisation of the enamel (Cleaton-Jones, 1979; Pontius, 1993). Fluoride is essential from birth until the permanent teeth have been formed as it is incorporated into the tooth enamel which is formed before the teeth erupt.

[#] The views expressed in this paper are not necessarily those of Rand Water, the Institute for Water Research or Rhodes University.

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Water fluoridation is a form of mass medication or diet supplementation, where fluoride is added to the public water supplies so that all water consumers are treated, irrespective of individual age, state of health or needs. Fluoride was declared an essential element in the recommended daily dietary allowance by the United States National Academy of Science's National Research Council (NRC) in 1980, particularly because of its beneficial effects on dental health (Hargreaves, 1990). Murray et al. (1991) concluded that the 50 to 60% reduction of caries in permanent teeth is due to the fluoridation of public water supplies. The difference in the incidence of caries between fluoridated and non-fluoridated areas, even taking into account the use of fluoride toothpastes and mouth rinses, remains significant (Hargreaves, 1990) and continued fluoridation of public water supplies is widely recommended. A case study in Scotland where fluoridation was stopped showed a significant increase in the incidence of caries, and a 115% increase in the cost of restorative dental work (Attwood and Blinkhorn, 1988).

After an intensive investigation, the US NRC concluded that the decision whether or not to fluoridate the water should be a community decision (Pontius, 1993). South Africa will be introducing similar legislation. Although it is important to reach a community decision via "reasonable consensus", the definition of "community" and at what point reasonable consensus is reached is hazy and inconclusive (Chikte and Josie-Perez, 1995). A recent survey revealed a lack of knowledge regarding fluoride and the issue of water fluoridation (Chikte and Josie-Perez, 1995). Any public decision-making will therefore have to include a major education drive regarding the issues at hand.

Background issues

The issues in the fluoride debate can be grouped into three broad categories. These are environmental issues (non-human health), human health (including dental health) and ethical, moral and sociopolitical issues. These will be discussed in turn.

Environmental issues

Low concentrations of fluoride in water may be toxic to several organisms living in the water, but the processes of water use, dilution of sewage by rain and groundwater, fluoride removal during secondary sewage treatment, and the flow dynamics of the effluent outfall may eliminate the fluoride-related effects in the environment (Osterman, 1990). A mass balance model for Montreal showed that fluoride-level changes in the water system were minimal and were usually within natural limits; they remained below toxic levels and recommended levels (Osterman, 1990).

Five species of benthic insect larvae showed acute toxic responses to fluoride at levels exceeding 18.8 mg F/l (Camargo and Tarazona, 1990). However, no chronic tests were done. Fluoride toxicity in *Daphnia magna* is temperature-related, with an increase in temperature resulting in increased susceptibility to fluoride (Fieser et al., 1986). Reaction to fluoride by aquatic animals has been examined in several species of fish. Fish exposed to poisonous levels of sodium fluoride become apathetic, lose weight, have periods of violent movement, wander aimlessly, lose equilibrium and die (WHO, 1984). Studies have shown that the effects of fluoride on aquatic animals are influenced by factors such as size, density of fish per volume of aquarium, water temperature and other water quality variables. The levels of fluoride which are toxic to freshwater fish (rainbow trout) can be as low as 4 mg F/l (WHO, 1984).

Plants take up fluoride mainly through gaseous transfer and particulate deposits, and some through their roots. Fluoridation is not perceived to be a major agricultural issue as very little fluoride is taken up from the soil by plants; fluoride uptake by plant roots depends on the soil type (Ginster and Fey, 1995). Generally, little or no injury will occur when the most sensitive species are exposed to a fluoride level of about 0.2 mg F/l (Ginster and Fey, 1995). Some species (especially the tea family) even accumulate high fluoride levels in their leaves. The toxic effects of fluorides on plants include chlorosis, peripheral necrosis, leaf distortion, and malformation or abnormal fruit development (WHO, 1984). Reduced plant yields resulted when plants were irrigated with water containing 40 mg F/l (Ginster and Fey, 1995). The accumulation effects of fluoride in the soil are unknown, especially in areas with existing high fluoride concentrations.

Increase of corrosivity of potable water as result of addition of fluoride to potable water with fluorosilicic acid or sodium fluorosilicate is negligible in most systems (Reeves, 1994). Corrosion of water lines is primarily related to dissolved oxygen concentration, pH, water temperature, alkalinity, hardness, salt concentration, hydrogen sulphide and the presence of certain bacteria (Reeves, 1994) and is unrelated to fluoride, especially at concentrations near optimum levels for drinking water.

Therefore, the environmental effects of concentrations of fluoride of less than 1 mg F/l appear to be largely undetermined or negligible. However, further investigation of the effects of low levels of fluoride on the environment is recommended.

Human health issues

Fluoride is associated with bones and teeth within 24 h of ingestion: that which is not retained is usually eliminated via the kidneys (Pontius, 1993). Various factors affect the retention of fluoride in the body, such as diet and metabolism (Underwood, 1977) and age (Pontius, 1992). Required levels of fluoride are estimated to be approximately 0.1 to 0.5 mg F/d for children less than 6 months old, while for adults, the range is 1.5 to 4.0 mg F/d (Hargreaves, 1990). However, neither diet nor fluoride (through fluoridation) by themselves will eradicate dental disease; both proper diet and fluoridation are essential for optimum dental health (Wulf et al., 1988; Rudolph et al., 1995).

Too much fluoride during early childhood can lead to dental fluorosis as a result of the enamel failing to crystallise properly. Increased fluoride levels lead to increased levels of dental mottling (Pontius, 1993). During periods of high intake, fluoride is stored in the bones. These elevated levels of fluoride may extend the period of fluoride influence particularly on dental fluorosis (Ishii and Nakagaki, 1986). Mottling of teeth can begin at levels of 0.7 to 0.9 mg F/l, but there is no indication of how long these levels need to be sustained before the mottling begins (Murray et al., 1991). Mild dental fluorosis is evidenced by a small percentage of the population at 1.0 mg F/l and the rate of severity of dental fluorosis increases rapidly at levels above 1.0 mg F/l (Reeves, 1994), while skeletal fluorosis results from fluoride intake of > 20 mg F/d for 20 years or more (which is the same as 10 mg F/l at 2 l per day). A study in Japan (Yamauchi et al., 1986) showed that fluoride levels of 3 mg F/l (as result of pollution) reduced the incidence of caries but increased the incidence of dental fluorosis.

The effect of fluoride on bone fractures and skeletal strength is inconclusive and further testing is recommended; skeletal fluorosis may become a problem with high fluoride intake (10 to 20 mg F/l) for extended periods of time (10 to 20 years). There is

no evidence for the reduction of osteoporosis and related bone fractures by increased levels of fluoride (Pontius, 1991).

Dental fluorosis is considered a cosmetic effect and not an adverse health effect, by the United States Environmental Protection Agency (USEPA) (Pontius, 1993). However, in the North West Province (South Africa), dental fluorosis has resulted in cases of psychological trauma, particularly amongst adolescents. Many of the local inhabitants in areas where fluoride levels in drinking water exceed 3 mg F/l are demanding that their teeth be extracted and replaced with dentures (Mothusi, 1995; Rudolph et al., 1995).

Undernourished, diseased and old people are not able to tolerate fluoride in the same manner as healthy, young persons (Yiamouyiannis, 1986). In industrialised countries, 98% of the population that consults medical doctors suffer from ailments such as dizziness, headaches, general pains, nausea, nervousness, etc. - symptoms which are difficult to ascribe to any particular disease (Moolenburgh, 1979). In a study conducted in the Netherlands, a strong correlation was drawn between fluoridation levels of 1.0 mg F/l and the symptoms displayed by patients (Moolenburgh, 1979). These symptoms are thought to be indicative of low-grade chronic poisoning (Moolenburgh, 1979). The study concluded that between 1 and 5% of patients reacted adversely to fluoride in drinking water. However, contrary to these claims, two studies (Cleaton-Jones, 1979; Lang and Clarke, 1982) found no such effects.

Symptoms of acute fluoride toxicity as a result of ingestion include nausea and vomiting with burning cramp-like abdominal pains, diarrhea, excessive salivation and tearing, mucous discharges from the nose and mouth, headache and general weakness. The probable acute toxic dose has been estimated to be approximately 4 mg F/kg for a young child, 15 mg F/kg for an older child and approximately 32 mg F/kg for an adult (Anon, 1993). If the dose becomes lethal, spasms, convulsions, weakened pulse, disorientation and unconsciousness result (Yiamouyiannis, 1986; Anon, 1993). Further symptoms include faintness, shallow breathing, unusual excitement, weakness, constipation, loss of appetite, pain and aching of bones, rash, sores in the mouth and lips, stiffness, loss of weight, discoloration of teeth, allergic reactions, and behavioural and neurological symptoms (Yiamouyiannis, 1986). Death has resulted following the application of fluoride treatment by dental hygienists (Yiamouyiannis, 1986).

Levels of fluoride in drinking water of 1 to 5 mg F/l have been used in laboratory animals such as primates, rats and mice, to induce symptoms such as kidney damage and interference with kidney enzymes, depressed thyroid activity, autoimmune responses and interference with the normal immune system functioning (Yiamouyiannis, 1986). Gastrointestinal symptoms can be a result of the toxic effects of the fluoride on the natural stomach fauna (Yiamouyiannis, 1986). Chronic high levels of fluoride (7.2 to 10.7 mg F/l fluoride consumed for 20 to 35 years) resulted in the inhibition of glycolysis in the red blood cells by 70% (Saralakumari and Ramakrishna Rao, 1991). In India, fluoride-related bone and tooth disorders have been found in people who drink levels of 0.7 to 2.5 mg F/l in the drinking water, although this is associated with a poor diet (Yiamouyiannis, 1986). Fluoride has caused mutations and chromosome changes in various animals cells, but the amounts of fluoride required are approximately 100 times the normal levels of plasma fluoride (Pontius, 1991).

However, there is no evidence to support claims that fluoride weakens the immune system, reduces collagen, increases the risk

of diabetes, results in genetic damage, increases risk of cancer, or is associated with kidney diseases and hypothyroidism (Wulf et al., 1988). No association could be found between increased levels of fluoride in the water and the occurrence of cancer in the bone or osteosarcoma incidence (Mahoney et al., 1991). Low levels of fluoride have not been shown to be associated with birth defects, or gastrointestinal, urogenital and respiratory problems (Pontius, 1991). No evidence exists that fluoride elicits allergic or intolerant responses at doses of 1.0 mg F/l; fluoride intake could not be linked to incidence of mongolism; fluoride does not harm the kidneys at these doses, nor does it have any effect on patients undergoing dialysis (Cleaton-Jones, 1979; Lang and Clarke, 1981). The link between fluoride and various diseases was examined by the US NRC (Pontius, 1993): there is no conclusive or credible link between increased fluoride in potable water and increased cancer risk; long-term exposure to fluoride levels of up to 8 mg F/l did not lead to increased kidney toxicity; gastrointestinal problems are not associated with the levels of fluoride recommended by the USEPA (0.7 to 1.2 mg F/l); current recommended optimum levels of fluoride do not have an effect on human reproduction (in animals, fluoride levels of 100 mg F/l or higher lead to reproductive effects).

The range of fluoride levels that is beneficial to human health is a narrow one (White, 1988). The reasons for not fluoridating the water supply are based on the fact that an excess of fluoride is poisonous. This makes the control of fluoridation supplementation levels critical, as fluoride is an acute as well as a chronic poison (Yiamouyiannis, 1986). The use of literature by anti-fluoridation campaigners was examined by Wulf et al. (1988) who concluded that scientific literature was abused to suit the cause, and that non-scientific literature is used to support anti-fluoride claims and accusations.

Ethical, moral and socio-political issues

The issue of fluoridation of drinking water supplies has been a public debate since the 1950s, particularly with the public's increasing awareness of environmental issues and food additives (Lang and Clarke, 1981). Issues such as the right of the government to prescribe mass medication, the lack of choice (since all toothpastes are already fluoridated), incomplete understanding of the complex interactions of tooth decay, the difficulty of working out the requirements of individuals because of different diets and use of toothpastes, the opinion that only the 0 to 10-year-old age group requires fluoride, and the movement of people to and from areas with different levels of fluoride (making it difficult to establish previous exposure to fluoride) have all been cited as reasons for not fluoridating drinking water supplies.

A study in New Zealand showed that in fluoridated areas there was no significant difference in the incidence of tooth decay with regard to socio-economic status, while in non-fluoridated areas, individuals from lower socio-economic groups had significantly higher levels of tooth decay than those from higher socio-economic groups (Wellington Regional Council, 1993). Alternative sources of fluoride such as fluoride tablets, drops, toothpastes and application by dentists are not likely to be used by the population that the fluoridation is generally aimed at (Wellington Regional Council, 1993). Fluoride management thus serves to protect the socially disadvantaged and the young (Wellington Regional Council, 1993). This protection of the socially disadvantaged and the young was deemed to outweigh the loss of individual rights and freedom regarding fluoridation (Wellington Regional Council, 1993).

In the United States, fluoridation has been upheld in supreme courts in more than a dozen states, and has withstood challenges in more than 25 states against arguments that fluoridation is an illegal invasion of privacy and individual rights and unconstitutional (Reeves, 1994).

Fluoride has received negative publicity from anti-fluoridation campaigns and public debates, and through lack of professional opposition to attempts to prevent fluoridation of public water supplies (Hartshorne and Carstens, 1990). The anti-fluoride campaign is based on human rights, freedom of choice, environmental pollution, scepticism about the public health systems and scepticism about the safety of water fluoridation (Hartshorne and Carstens, 1990), issues that have been shown to have limited scientific support or social priority. Opposition to fluoridation is therefore a major concern for only a few individuals and it appears to have a low profile with the community at large (Wellington Regional Council Report, 1993). The anti-fluoridation reasoning is often an emotional one with fluoride issues frequently being taken out of context (Lang and Clarke, 1981; Wellington Regional Council Report, 1993; Wulf et al., 1988).

Alternative forms of fluoridation

The preventative action of fluoride has been deemed by the US Surgeon General to be the most cost-effective public health measure for preventing tooth decay (Cleaton-Jones, 1979). The method of introducing fluoride into teeth does not matter since they are all effective in reducing the prevalence, incidence and severity of dental caries (Cleaton-Jones, 1979) and the benefits of fluoride are not restricted to childhood.

Alternatives to water fluoridation such as fluoridated salt and milk are not practical because of inherent problems with the products themselves rather than with the fluoride (Hargreaves, 1990). It may not be practical to fluoridate salt as a result of the drive to reduce salt intake because of its role in hypertension and cardiac disease (Hargreaves, 1990). Similarly, fluoridating milk supplies may be impractical because of the relatively high incidence of lactose intolerance. Fluoride supplementation of flour and sugar is being considered by some researchers, but evidence is incomplete (Hargreaves, 1990).

Dietary supplementation is recommended, but with extreme caution. Temporary peak values of increased plasma fluoride levels, such as those obtained from tablet and drop ingestion, are more likely to lead to fluorosis than consistently elevated levels obtained from drinking fluoridated water (Hammer, 1986; Murray et al., 1991). Systemic fluoride uptake offers better protection against dental caries since the fluoride levels in the saliva increase and this affords longer-lasting protection against dental caries (Chikte, 1995).

Levels of 0.25 to 1.0 mg F/1 per day taken in the form of fluoride tablets or drops are reported to significantly reduce the incidence of dental caries but there is no strong dose-dependent response to reduction of caries and the intake of fluoride (Cleaton-Jones, 1979). Fluoride tablets are Schedule 2 drugs and can be bought readily in South Africa. Fluoride drops and tablets are most effective in reducing caries when they are taken from birth and even prenatally, rather than starting when the child is older, for both deciduous and permanent teeth (Murray et al., 1991). However, fluoride supplementation via tablets and drops (under the control of the individual) should be discouraged, since taking these supplements incorrectly is more likely to be harmful, because they then either do not deliver any protection or result in

dental fluorosis (Hargreaves, 1990).

Fluoride uptake from mouth rinses is restricted to the outermost layers of the enamel in deciduous teeth while fluoride uptake from ingested fluoride result in elevated fluoride levels deep into the enamel (Iijima and Katayama, 1986). Levels of fluoride in the enamel were significantly higher in children who had access to natural fluoride of levels from 1.0 to 3.2 mg F/1 than those children who rinsed with fluoride mouth rinse (Iijima and Katayama, 1986). Mouth rinses are only effective when used with a fluoride toothpaste and the effect of the fluoride is lost when mouth rinsing is stopped (Murray et al., 1991).

Fluorides in toothpastes as a source of fluoride is not recommended for children under six years of age because they tend to swallow the paste (WHO, 1994). The majority of toothpastes, even those specifically for children, have fluoride supplements of 1 mg F/g.

In developing countries, the best approach to fluoride supplementation is to fluoridate the water (Hargreaves, 1990). The US Department of Health and Human Services has concluded that water fluoridation decreases the incidence of caries, and that although caries can be prevented by fluoridated toothpaste, mouth rinses, treatments and diet supplements, it is more cost-effective to fluoridate the water (Cleaton-Jones, 1979; Pontius, 1991). The cost-effectiveness of topical applications, such as fluoride toothpastes and community fluoride rinse projects, should be considered in developing countries if alternatives to water fluoridation are being considered (Hargreaves, 1990). A further alternative, albeit expensive, may be to fluoridate only the school water supplies (Hargreaves, 1990).

The incidence of dental caries in industrialised countries is decreasing, largely because of ready access to fluoride products such as fluoridated toothpastes, drops and tablets, while dental caries is increasing in South Africa (Chikte, 1995). South Africa is in a situation where some of the population has access to fluoride products, while a large proportion of the population does not. It is these developing communities, with changing diets and habits, that water fluoridation seeks to protect against dental caries.

World trends of fluoridation

Determination of appropriate levels of fluoride in drinking water is important if fluoride management is to be an effective means of reducing the incidence of caries, either by adding or by removing fluoride (WHO, 1994). The recommended optimum concentration of fluoride levels in the drinking water is based on annual average air temperature (Hammer, 1986), although it has now become apparent that the temperature guidelines were not appropriate for use in tropical and subtropical climates because of the higher incidence of fluorosis there (WHO, 1994). The latest guidelines from the WHO (1994) view 1.0 mg F/1 as the absolute upper limit even in cold climates while a lower limit of 0.5 mg F/1 is recommended for warm climates such as Hong Kong and the Gulf States.

Extent of fluoridation

It is estimated that about 210 m. people throughout the world drink artificially fluoridated water and that a further 103 m. drink water whose natural fluoride level is high enough to provide a significant degree of protection against tooth decay (WHO, 1994; Public Health Alliance, 1994). Fluoridation occurs in 39 countries, both First and Third World (Murray et al., 1991; Wellington

Regional Council, 1993; Chikte and Josie-Perez, 1995). Some countries need not fluoridate their drinking water since they have naturally high levels of fluoride in their water. Countries such as India (Banerjee, 1986; Yiamouyiannis, 1986), Japan (Iijima and Katayama, 1986; Muramoto et al., 1990), Thailand (Phantumvanit et al., 1986), China (Chen et al., 1993), Sri Lanka (Dharmagunawardhane and Dissanayake, 1993) and some countries in Africa, such as those countries along the Rift Valley (WHO, 1994), have naturally high levels of fluoride in their drinking water. Approximately 5.5% of the world's population is drinking water with an optimal fluoride concentration. There is a general increasing trend in the extent of fluoridation.

Those countries not fluoridating yet or those who have ceased to fluoridate may not be doing so either because of the costs involved or because of public pressure and an unwillingness to remain in or become involved in the fluoridation debate (Chikte and Josie-Perez, 1995). China has ceased water fluoridation because the water supply is not bulk, but supplied by community wells; it is difficult to control the fluoride levels on all individual wells (Chikte and Josie-Perez, 1995). Countries such as the Netherlands, Belgium, Switzerland, Germany and Portugal have now banned fluoridation of drinking water (Public Health Alliance, 1994) but the populations in these countries have ready access to fluoride-containing products. Britain is slow to introduce water fluoridation because the waterboards are now privatised and they are afraid of legal ramifications if they do fluoridate their water supplies (Matthews, 1995).

Conclusions and recommendations

The fluoridation debate has raged internationally and nationally for many decades. However, fluoridation is not viewed as a scientific controversy since there is much literature and scientific evidence supporting the effects and efficacy of fluorides in drinking water (Wulf et al., 1988). The debate appears to be centered on personal preferences and to be sustained by a minority of "experts" who are able to play on the fears of others.

Why fluoridate in South Africa?

Tooth decay is one of the most common health problems in South Africa and leads to loss of working and schooling days as a result of pain and suffering. Caries affects 90 to 93 % of the South African population (Van Wyk, 1995). Oral health in the disadvantaged community is "in a sad state of affairs", and in particular the dental services available to these communities are such that children get to see an oral health worker only once every 5 years (Carstens, 1995). Oral hygiene problems generally arise when there is a move from rural to urban areas with a marked increase in dental lesions as a result of the change to a more Western diet of refined carbohydrates (Rudolph et al., 1995). Fluoride is a proven preventative measure, and may reduce tooth decay by 50% within 2 years, thereby significantly reducing the number of working days lost. In South Africa, fluoridation of public water supply is aimed largely at the developing community; fluoride levels of 0.3 to 0.4 mg F/l will be able to reduce the incidence of caries by 56% (Carstens, 1995).

The low costs of adding fluoride to water, the fact that 80% of the people in South Africa are dependent on the state, and the high incidence of caries (particularly amongst developing communities) makes it a moral issue to regulate fluoride levels in drinking water (Carstens, 1995). The effects on the labour force make it an economic issue too.

Natural levels of fluoride in South Africa's drinking water

Concentrations of fluoride in South African surface waters are generally below 0.5 mg F/l. Dams and rivers show similar levels of fluoride, while borehole water has significantly higher levels of fluoride than other sources of drinking water (Grobler and Dreyer, 1988). South Africa has some of the highest recorded fluoride levels (20 to 40 mg F/l) in groundwater (Underwood, 1977; WHO, 1984). The range of fluoride levels in South African drinking waters varies across the country between <0.05 to 13 mg F/l (Grobler and Dreyer, 1988; Mothusi, 1995). Variations within a water supply occur frequently, and these variations can be attributed to wet and dry seasons (Grobler and Dreyer, 1988). South Africa uses river, dam and borehole water as source waters and sometimes the variation in the fluoride levels can be attributed to different ratios of mixing of the various water sources (Grobler and Dreyer, 1988). This variation and the subsequent fluctuations in the natural fluoride level must be taken into account when making decisions about optimal levels of fluoride management.

Optimum fluoride levels for South Africa

The recommended daily dosage for water fluoride management is currently determined by annual mean temperature levels and is independent of dietary intake of fluoride (WHO, 1984; WHO, 1994). The WHO (1984) originally recommended a range of 0.7 to 1.2 mg F/l, based on the daily consumption of 2 l of water at an average temperature of 16°C (temperate climates). This recommended optimum concentration of fluoride in drinking water is based on the annual average of the maximum daily air temperature over a minimum of 5 years and is calculated as:

$$C_{\text{opt}} = \frac{0.34}{(0.16 + 0.011T)}$$

where:

C_{opt} is the optimum fluoride concentration (mg F/l) and
 T is the annual average maximum daily air temperature in °C (Hammer, 1986; WHO, 1984).

If the only source of fluoride is water, then water with the WHO recommended optimum levels of fluoride results in mild fluorosis in about 10% of the population and almost no cases of moderate or severe fluorosis (Pontius, 1993). However, fluoride intake from toothpastes and mouth rinses can equal or exceed fluoride intake from other sources (Pontius, 1993). As levels of fluoride are increased, the risk of dental fluorosis increases more rapidly than the decrease in dental decay. This illustrates the need for careful control and choosing of optimum levels of fluoride (Hargreaves, 1990). The formative stages of enamel development are sensitive to fluoride and care must be taken not to over-fluoridate during these times as fluorosis is irreversible; fluoride levels can be increased after these formative stages to increase the fluoride levels in the outer layers of enamel to protect the teeth.

The WHO (1984) formula for optimum levels of fluoride has been found to be inappropriate in tropical and subtropical areas due to their higher ambient temperatures and associated increase in water consumption (WHO, 1994). In tropical and subtropical areas, the level of fluoride in the drinking water should be restricted to 0.5 to 0.7 mg F/l, because of the anticipated increase in water consumption (Hargreaves, 1990). An epidemiological

study in the Free State Goldfields (South Africa) revealed that 0.45 to 0.65 mg F/l was an optimum range for reduced incidence of caries with minimum risk of dental fluorosis (Du Plessis, 1995). An optimum level of fluoride of 0.5 mg F/l in South Africa in drinking water was supported by a study (in South Africa) by Rudolph et al. (1995). It is better to adopt a conservative level as one's optimum because some of the population has access to fluoridated dental products and fluoride supplements and these population groups then have a greater risk of developing dental fluorosis if the water fluoride levels exceed 0.7 mg F/l (Du Plessis, 1995). Thus, in South Africa's hotter ambient environment, it is recommended that optimum fluoride levels ranging from 0.4 to 0.7 mg F/l should be introduced. An optimum level of 0.5 mg F/l is likely to ensure the greatest protection against dental caries with the least risk of dental fluorosis or other health risks. The WHO (1994) maximum level guideline of 0.7 mg F/l should be adopted to protect against possible dental fluorosis.

Fluoride management in South Africa

Three issues need to be highlighted here.

- The level of fluoridation can be determined by public decision-making within a region, within the sliding scale guidelines of 0.4 to 0.7 mg F/l. This will mean that the levels of fluoride adjustment will vary from region to region. This sliding scale is based on the varying ambient temperatures across South Africa's water supply regions. A region is defined as a water supply area (e.g. an area supplied by a water board) and the fluoride levels can be managed according to the maximum mean annual temperature within that supply area and also taking into account the seasonal variation in fluoride levels. Continuous on-line monitoring must take place to ensure that the optimum fluoride level is not exceeded. This sliding scale can then also take into account consumer consensus and catchment sensitivity as determined by the Director-General of Water Affairs and Forestry. Risk assessments of the environmental effect of fluoride management on catchments will have to be considered.
- Since it is recommended that the fluoride concentration of drinking water should not exceed a maximum of 0.7 mg F/l, where fluoride levels are higher than the recommended level, pressure should be put on the government and local authorities to either **defluoridate** or to provide alternative water supplies (Hargreaves, 1990).
- Finally, fluoridation should be seen as an interim measure, introduced as a short-term answer to the existing crisis in the dental health care system in South Africa. With improved socio-economic conditions and improved access to dental health care, fluoridation can be phased out. However, defluoridation is a permanent measure, unless alternative water supplies with lower fluoride levels are provided.

To illustrate these management recommendations, consider Cape Town (which has a fluoride level of <0.05 mg F/l), Durban (which has natural fluoride levels of approximately 0.05 mg F/l) and the North West Province (where drinking water is supplied by borehole water with fluoride levels up to 13 mg F/l) (Grobler and Dreyer, 1988; Mothusi, 1995). North West Province will need to defluoridate the drinking water, or find an alternative water supply, because the fluoride level exceeds the recommended optimal level, while other provinces and towns will need to (consultatively) fluoridate. Should they decide to fluoridate,

Cape Town may decide on a higher fluoride level than Durban because Cape Town has a lower annual average maximum temperature than Durban.

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