ESTIMATED DIETARY FLUORIDE INTAKE FOR NEW ZEALANDERS

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by

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

A desktop study was undertaken to estimate dietary fluoride intakes for a range of age and gender sub-populations based on New Zealand data. The aim of this study was to identify for further investigation any groups at risk of high exposure to fluoride. In addition the fluoride content of infant and toddler formula products available in New Zealand was analysed to inform intake estimates including these products.

Key sources of food consumption data included the 1997 National Nutrition Survey, the 2002 Children's Nutrition Survey and the 2003/04 New Zealand Total Diet Survey (NZTDS), while data on the fluoride content of foods was mainly from the 1987/88 and 1990/91 NZTDSs. For each sub-population, two separate dietary intake estimates were made – one based on an unfluoridated water supply (fluoride concentration of 0.1 mg/L), and the other based on a water supply fluoridated to a concentration of 1.0 mg/L. For exclusively formula-fed infants a further scenario (water fluoridated at 0.7 mg/L) was also examined.

Mean and 95th percentile estimations of dietary fluoride intake were well below the upper level of intake (UL) when intakes were calculated on the basis of an unfluoridated water supply for all age and gender groups. The corresponding estimated dietary intakes, calculated on the basis of fluoridated water supply containing the maximum recommended fluoride concentration were also below the UL, with the exception of estimates for a fully formula-fed infant. The estimates for a fully formula-fed infant exceeded the UL approximately one-third of the time for formula prepared with water at 0.7 mg fluoride/L and greater than 90% of the time for formula prepared with water at 1.0 mg fluoride/L. However, it should be noted that the current fluoride exposure estimates for formula-fed infants are based on scenarios consistent with regulatory guidelines, rather than on actual water fluoride concentrations and observed infant feeding practices. Similar research recently undertaken by Food Standards Australia New Zealand has also concluded that a proportion of children up to 8 years could exceed the UL when fluoridated water (0.6 - 1.0 mg/L), from any source, is consumed. The use of fluoride-containing toothpastes will provide an additional contribution to total fluoride exposure.

It should be noted that for many of the population groups considered, mean fluoride intakes were significantly below the adequate intake (AI) level for caries protection. In most cases, the additional fluoride contribution from toothpaste would be insufficient to bring the total fluoride exposure to a level above the AI.

Mean levels of dietary fluoride intake were generally consistent with similar estimates made overseas. This is not surprising, as the average fluoride levels of most foods fall within a fairly narrow range of concentrations. Overall, intake of fluoride will be driven by consumption of dietary staples (bread, potatoes), beverages (particularly tea, soft drinks and beer) and the fluoride status of local drinking-water.

At all ages, dietary fluoride intake tends to be dominated by the contribution from liquid foods or foods prepared with addition of water in the home. Dietary staples, such as bread and potatoes, also contribute consistently due to the quantities consumed. Three distinct patterns were noted within the general contribution of liquid foods (beverages) to dietary fluoride intake:

- For children the beverage fluoride contribution was dominated by water, or infant formula prepared with water.

- During adolescent years the contribution to dietary fluoride intake from carbonated beverages becomes more significant and tea emerges as a contributor.
- During adulthood the contributions of tea and beer to dietary fluoride intake increase relative to adolescent years, while the relative contributions of carbonated beverages and water decrease.

As with many environmental exposures, the very young appear to be the group at greatest risk of exceeding the UL. Their dependence on a narrow range of foods, particularly foods made up with the addition of potentially fluoridated water, means that the infant diet will always be a balancing act between fluoride insufficiency and fluoride excess. However, the Food Standards Australia New Zealand assessment identified that, although UL values were based upon the best available information at the time, the rarity of moderate dental fluorosis in the Australia or New Zealand populations indicates that current exceedances do not constitute a safety concern, and indicates that the UL may need to be reviewed. The introduction of fluoride-containing toothpastes for cleaning erupting teeth will further add to the delicacy of this balancing act.

GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

24HDR	24-hour dietary recall
AI	Adequate intake. The average daily nutrient intake level based on observed or experimentally-determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate.
ATSDR	Agency for Toxic Substance and Disease Registry
CNS02	2002 National Children's Nutrition Survey (New Zealand)
EER	Estimated Energy Requirements
ESR	Institute of Environmental Science and Research Ltd
FAO	Food and Agriculture Organization.
FSANZ	Food Standards Australia New Zealand
IRIS	Integrated Risk Information System
MRC	Medical Research Council (United Kingdom)
MRL	Minimal risk level
NHMRC	National Health and Medical Research Council (Australia)
NNS97	1997 National Nutrition Survey (New Zealand)
NRC	National Research Council (United States)
NZDep1996	New Zealand Index of Deprivation 1996 (Salmond *et al.*, 1998). Provides a deprivation score (1 to 10) for geographical units within New Zealand, based on nine census variables that reflect aspects of material and social deprivation. For the NNS97 the Index of Deprivation was expressed in quartiles (I to IV), rather than deciles.
NZDep2001	New Zealand Index of Deprivation 2001 (Salmond and Crampton, 2002). Provides a deprivation score (1 to 10) for geographical units within New Zealand, based on nine census variables that reflect aspects of material and social deprivation
NZFSA	New Zealand Food Safety Authority
NZTDS	New Zealand Total Diet Survey
PHC	Public Health Commission

RfD	Oral reference dose
UL	Upper level of intake. The highest average daily nutrient intake level likely to pose no adverse health effects to almost all individuals in the general population. As intake increases above the UL, the potential risk of adverse effects increases.
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WHO	World Health Organization.

1 INTRODUCTION

Fluoride is a naturally occurring element found in water, air, soil and food (World Health Organization, 2002). Fluoride is added to some drinking-water supplies in New Zealand and overseas as a protective measure against tooth decay (Medical Research Council, 2002; National Research Council, 1993; Public Health Commission, 1994). Fluoride prevents tooth decay by strengthening the tooth surface and inhibiting growth of cariogenic bacteria. It also assists in repairing the early stages of tooth decay (Featherstone, 2000).

Periodic assessments of fluoride intake from all sources are necessary as fluoride exposures above optimal levels can have negative health outcomes (Medical Research Council, 2002; National Research Council, 2006; World Health Organization, 2002), while low fluoride exposure may result in failure to achieve the benefits of fluoride exposure. Fluoride concentrations in drinking-water in New Zealand are monitored by the water suppliers to ensure compliance with the New Zealand Drinking Water Standards. Fluoride exposure from the diet can vary according to geographical location, age group and dietary habits. Changes in dietary habits over time can increase or decrease fluoride intakes (National Health and Medical Research Council, 1991). Estimates of dietary fluoride intake by New Zealanders were carried out as part of the 1987/88 and 1990/91 New Zealand Total Diet Surveys (NZTDS) (Hannah *et al.*, 1995; Institute of Environmental Science and Research/Ministry of Health, 1994).

1.1 Sources of Fluoride Exposure

The main sources of fluoride exposure for the general population are fluoridated drinking-water, diet and toothpaste (Agency for Toxic Substances & Disease Registry, 2003; National Research Council, 2006). Other potential sources of fluoride exposure include industrial emissions, e.g. from phosphate fertiliser plants, aluminium plants and coal-fired power plants (Agency for Toxic Substances & Disease Registry, 2003; National Research Council, 2006), occupational exposure and therapeutic treatment (Agency for Toxic Substances & Disease Registry, 2003; Medical Research Council, 2002).

1.1.1 Drinking-water

The Ministry of Health recommends that the concentration of fluoride in fluoridated water supplies should be between 0.7–1.0 mg/L (Ministry of Health, 2005). In 2006, an estimated 2.2 million people received drinking-water from a fluoridated water supply and for 99.7% of this population, the fluoride concentration in drinking-water complied with the maximum acceptable value for fluoride of 1.5 mg/L (Ministry of Health, 2009). In unfluoridated supplies, fluoride concentrations in drinking-water range from < 0.1–1.8 mg/L, with a median concentration of < 0.1 mg/L (Ministry of Health, 2005).

1.1.2 Diet

Diet is the second largest source of fluoride exposure after drinking water for the US population (National Research Council, 2006). Fluoride is a naturally occurring element and all food items contain fluoride though generally at low levels (World Health Organization, 2002). Factors that contribute to the fluoride concentration of food include the location where the food was grown and the use of fluoride containing fertilisers and pesticides (Agency for Toxic Substances & Disease Registry, 2003). The fluoride level of water used to prepare or process food also contributes to the fluoride concentration of a particular food (World Health Organization, 2002). Food items known to be high in fluoride include tea and fish (Agency for Toxic Substances & Disease Registry, 2003; World Health Organization, 2002). Infant formulae have also been reported to contain high levels of fluoride (National Health and Medical Research Council, 2006). Fluoride intake from dietary sources is generally higher in areas with fluoridated water supplies or where there are naturally occurring elevated concentrations of fluoride in drinking-water (Ophaug *et al.*, 1985; World Health Organization, 2002).

Foods and beverages contain both free and bound forms of fluoride, with bioavailability being roughly related to the proportion of fluoride in the free form. A large proportion (75–90%) of fluoride ingested is absorbed from the gastrointestinal tract (National Research Council, 1993). Ekstrand *et al.* (1994) measured the absorption of fluoride from food by infants (aged 79–422 days) using metabolic balance studies – the mean absorption of fluoride was 90%. While several components of foods (calcium, particularly in association with dairy products, magnesium, chloride, iron and zinc) inhibit the absorption of fluoride in rats, the inhibition has generally been at concentrations far in excess of those encountered in a normal human diet (Cressey, 1996).

1.1.3 Toothpaste

Dental products including fluoridated toothpaste and mouthwashes, topical applications of fluoride, and fluoride supplements also contribute to the total fluoride exposure (Agency for Toxic Substances & Disease Registry, 2003; World Health Organization, 2002). The Ministry of Health no longer recommends the use of fluoride tablets in unfluoridated areas as a public health measure. Instead, fluoride tablets are considered to be a personal health measure for at-risk individuals and they should only be prescribed by dental professionals (Ministry of Health, 2004).

In 1998, 96% of toothpaste sold in New Zealand contained fluoride (Ministry of Health, 1999). Fluoridated toothpastes available in New Zealand generally contain 1000 mg/kg fluoride (Public Health Commission, 1995). Toothpastes with a lower fluoride content of 400 mg/kg are also available in New Zealand (Public Health Commission, 1995) and are promoted by the manufacturers for use by children up to the age of 6 years. The Ministry of Health recommends that all age groups use fluoridated toothpaste with a fluoride concentration of 1000 mg/kg and the recommended usage of toothpaste is a smear of toothpaste on the brush for children under 6 years of age and a pea-sized amount of toothpaste for children aged 6 years and older (Ministry of Health, 2004). Fluoride exposure from toothpaste has been identified in several studies as an important source of fluoride intake, particularly if swallowed (Agency for Toxic Substances & Disease Registry, 2003; Erdal and Buchanan, 2005; National Research Council, 1993; Pessan *et al.*, 2003). Young children have poorer control over swallowing and are more likely to swallow toothpaste during toothbrushing (Agency for Toxic Substances & Disease Registry, 2003; National Research Council, 1993).

1.1.4 Soil ingestion

Soil ingestion is another potential source of fluoride exposure as fluoride is naturally present in soil. Sources of additional fluoride in soil include industrial emissions, volcanic eruptions and application of phosphate fertilisers (Agency for Toxic Substances & Disease Registry, 2003). Loganathan *et al*. (2001) measured fluoride concentrations from 106–454 mg/kg in New Zealand pasture soils and fluoride concentrations in three datasets ranged from 22–540 mg/kg for New Zealand soils (Cronin *et al*., 2000). Using the default exposure value for soil ingestion by children for New Zealand soils of 100 mg per day (MfE/MoH, 1997) and the highest reported soil concentration for New Zealand soils, the daily intake from soil for a child would be 0.05 mg of fluoride. US estimates for exposures to fluoride from soil for children aged 1–12 years are in the range 0.04–0.16 mg per day (United States Environmental Protection Agency, 2004) and 0.04–0.17 mg per day for 3–5 year old children (Erdal and Buchanan, 2005).

1.2 Health Effects of High Fluoride Intakes

Exposure to elevated levels of fluoride can cause fluorosis of teeth and bones (World Health Organization, 2002) and has been shown in some studies to cause an increase in bone fractures in elderly people (as reviewed in ATSDR, 2003). Consuming elevated concentrations of fluoride during tooth development can cause dental fluorosis (between the ages of 1–8 years) (Agency for Toxic Substances & Disease Registry, 2003). A dose-response relationship exists between fluoride intake during tooth development and severity of fluorosis (National Research Council, 1993; World Health Organization, 2002), with the duration of exposure also being important (Agency for Toxic Substances & Disease Registry, 2003; Aoba and Fejerskov, 2002). Dental fluorosis ranges from mild cosmetic defects in the enamel (diffuse or demarcated opacities), to more severe pitting, discolouration and brittleness (hypoplasia) (National Research Council, 1993).

The most recent study of enamel defects in New Zealand children found that the rates of diffuse opacities for children who had only lived continuously in a fluoridated area until age four years were higher than those who had no or non-continuous exposure to a fluoridated water supply (Mackay and Thomson, 2005). Rates of hypoplastic defects were equivalent between the two groups, while rates of dental caries were approximately halved in those with continuous exposure to fluoridated water. The authors concluded that the rates of diffuse opacities had not increased compared to earlier studies.

These findings are consistent with a recent nutrition risk assessment carried out by Food Standards Australia New Zealand (FSANZ) that concluded that, while mild and very mild dental fluorosis was not uncommon in Australian and New Zealand children, moderate dental fluorosis is rarely seen (Food Standards Australia New Zealand, 2009). The prevalence of mild and very mild dental fluorosis is usually higher is regions with fluoridated water supplied than in regions with unfluoridated water supplies. However, mild and very mild dental fluorosis are not considered to be a health concern.

Comprehensive reviews of the health effects associated with fluoride intake have been prepared by the National Research Council (National Research Council, 1993;2006), the US Agency for Toxic Substances and Disease Registry (Agency for Toxic Substances & Disease Registry, 2003), the World Health Organization (World Health Organization, 2002) and the United Kingdom Medical Research Council (Medical Research Council, 2002).

1.3 Study Outline

Previous estimates of dietary fluoride exposure for New Zealand are now somewhat dated, only considered average dietary exposures, and did not consider additional exposure to fluoride from toothpaste or the impact of a fluoridated water supply (Hannah *et al.*, 1995; Institute of Environmental Science and Research/Ministry of Health, 1994). The approach taken in this report of combining food consumption information from the 1997 National Nutrition Survey (NNS97), the 2002 National Children's Nutrition Survey (CNS02) and the 2003/04 NZTDS with fluoride concentration data from earlier NZTDSs (1987/88 and 1990/91), enables the identification of groups that are potentially at risk from elevated fluoride exposure and the food items contributing to any elevated exposures.

A desktop study was undertaken to estimate dietary fluoride intakes based on New Zealand data to identify any groups that are at risk of high exposure to fluoride that might require further investigation. The estimated daily intakes were compared with the adequate intake (AI) and upper level of intake (UL) levels for fluoride published by the New Zealand Ministry of Health and the Australian National Health and Medical Research Council of Australia (National Health and Medical Research Council, 2006).

In addition, analyses were carried out of the fluoride content of infant formula products available on the New Zealand market in 2008, to determine if these had changed since a previous survey and to provide information for estimating the dietary fluoride intake of fully formula-fed infants.

2 MATERIALS AND METHODS

Dietary intake assessment involves combining information about the concentration of the component of interest in foods and beverages with information about the amounts of foods consumed.

2.1 Fluoride Concentrations in Foods

2.1.1 <u>Desktop study</u>

Several sources of information on the fluoride content of foods, in general, and New Zealand food, in particular, were considered:

- 1987/88 New Zealand Total Diet Survey (NZTDS) (Institute of Environmental Science and Research/Ministry of Health, 1994). Fluoride contents of 105 foods, prepared ready for consumption, were determined. Foods were prepared using distilled water.
- 1990/91 New Zealand Total Diet Survey (Hannah *et al.*, 1995). Fluoride contents of 107 foods, prepared ready for consumption, were determined. Foods were prepared using distilled water. Foods analysed were largely the same as those analysed in the 1987/88 NZTDS.
- 1996/97 Assessment of selected pesticides and the elements cadmium, lead, tin, iodine and fluoride in infant formulae and weaning foods (Vannoort and Cressey, 1997). The fluoride contents of 25 milk- and soy- based infant formulae and 30 weaning foods were determined, including cereal-based-, vegetable-based-, and meat/vegetable-based- savoury foods and desserts.
- 1985 Australian Market Basket Survey. Fluoride contents of 58 foods, prepared ready for consumption, were determined (National Health and Medical Research Council, 1987).
- United States National Fluoride Database of Selected Beverages and Foods - Release 2 (United States Department of Agriculture, 2005).

To estimate the fluoride concentrations of foods, results from the two NZTDSs (Hannah *et al.*, 1995; Institute of Environmental Science and Research/Ministry of Health, 1994) were compared. When these results were in good agreement, the two results were averaged and the average used for further analysis. An arbitrary test for ‘good agreement’ was defined as a relative standard deviation of less than 50%. Where the results from the two NZTDSs were not in good agreement, data from Australia (National Health and Medical Research Council, 1987) and the United States (United States Department of Agriculture, 2005) were considered to suggest which of the NZTDS results was likely to be more reliable. Results from these various sources are compared in Appendix 1 and the values used for further analysis are indicated. Some general observations can be made:

- There was generally good agreement between the New Zealand, Australian and US data for equivalent meat and dairy products.
- The elevated fluoride content reported for eggs in the 1990/91 NZTDS is inconsistent with results from any of the other sources.
- The 1990/91 NZTDS reported considerably higher fluoride levels in fats and oils than the other studies.

- Results for fruit and fruit products show very good agreement between all studies considered. The only exception is raisins in which the US fluoride result is much higher than the result from either NZTDS.
- Fluoride values for some cereal (grain)-based foods were much higher in the 1990/91 NZTDS than other sources of information, which in general show good agreement with one another. In a number of cases, the 1990/91 NZTDS result, normally the mean from 15 or more samples of the food, is greater than the highest reported US value obtained from testing a large number of examples of that food from throughout the US.
- There are major differences between the results from the two Total Diet Surveys and between these and the US results from equivalent foods when the prepared foods include added tap water. One of the biggest differences is for coffee, which had a very low fluoride content in the 1990/91 NZTDS (0.01 mg/kg). It is likely that these differences are due to the use of distilled water in preparing these foods for the NZTDS.
- The NZTDS results for sugar are surprisingly high, 1.17 mg/kg in the 1987/88 NZTDS and 0.34 mg/kg in the 1990/91 NZTDS. Both US and Australian data suggest that sugar contains negligible fluoride in those countries. It is possible that the high New Zealand values reflect a true difference in the refining or source of sugar in New Zealand.
- Results for some vegetables and vegetable products show wide variability between the two NZTDSs and between New Zealand and overseas fluoride levels.

The NZTDS methodology uses distilled water for the preparation of all foods. The Ministry of Health recommends that the concentration of fluoride in fluoridated water supplies should be between 0.7–1.0 mg/L. Naturally occurring concentrations of fluoride in New Zealand drinking-water distribution zones measured as part of the P2 Chemical Determinand Identification Programme, ranged from not detected–1.8 mg/L, with a median value of not detected (detection limit = 0.1 mg/L) (Ministry of Health, 2005).

For the purpose of the current study all foods that would be prepared by addition of water in the home had their fluoride contents recalculated based on scenarios of either average New Zealand tap water (fluoride concentration = 0.1 mg/L), or fluoridated tap water (fluoride concentration = 1.0 mg/L). Further details of the calculations to correct for the fluoride content of water are included in Appendix 1. While it is possible that vegetables boiled in fluoridated water may take up fluoride, no robust information on this could be found and the fluoride content of vegetables was not adjusted for fluoride acquired during cooking under the scenarios outlined above.

2.1.2 Analysis of infant and toddler formula products

Infant and toddler formula products available on the New Zealand market were sampled and analysed for fluoride. Data for infant formulae (starter formulae) were used to estimate the dietary fluoride intake for exclusively formula-fed infants (0-6 months). Data on the fluoride content of follow-on and toddler formulae were included in the total diet estimations of fluoride intake for infants 6-12 months and toddler 1-3 years respectively.

2.1.2.1 Infant and toddler formula products

As the infant formula products are nationally distributed, all infant formula products were purchased from supermarkets in Christchurch. Infant formulae containers were shaken to mix contents. All formulae were made up according to manufacturers' instructions using deionised water. Four formulae with the highest fluoride concentrations were also prepared with water containing 0.7 mg F/L and water containing 1.0 mg F/L.

Infant formula products can be classified in a number of ways. For the purpose of the current study, formulae were primarily classified by the life stage that they are formulated for. The main categories are:

- Starter, for feeding from birth (IF, infant formula)
- Follow-on, for feeding from 6 months of age (FO, follow-on formula)
- Toddler, for feeding from age 1 to 3 years (T, toddler formula)

Of the 32 products analysed in the current study 19 were infant formula, 8 follow-on formula and 5 toddler formula. Of the 32 products, 19 products were manufactured in New Zealand, although one soy-based product manufactured in New Zealand was blended from imported ingredients. The remaining 13 products were manufactured in Ireland (8) or France (5).

2.1.2.2 Fluoride analytical methods

All samples were analysed for total fluoride by the Fluoride Laboratory, University of Iowa College of Dentistry, Iowa City, Iowa, USA. Samples were analysed using a modification (Van Winkle *et al.*, 1995) of the microdiffusion method of Taves (1968). The limit of detection for the method is 0.02 mg/L.

A certified reference material, SR17 267a, Fluoride in Freeze-Dried Urine (The National Institute of Standards and Technology Gaithersberg, MD) with a designated fluoride content of 0.55 (± 0.03) mg/kg, was analysed to demonstrate method accuracy at the low fluoride levels encountered in infant formula products.

2.2 Food Consumption Information

Three approaches were used to provide information on the food consumption patterns of New Zealanders

2.2.1 Exclusively formula-fed infants (0–6 months of age)

Formula consumption information was derived using an approach similar to that of Vannoort and Cressey (1997) and adapted by Cressey (2008). This approach assumes that infants are receiving their estimated energy requirements (EER) and that infant formulae are the sole source of nutrition.

The estimated energy requirements (EER) for infants are made up of two components:

- Total energy expenditure (TEE), including energy required for basal metabolism, thermoregulation, physical activity and the thermic effect of feeding (Butte, 2005).

- Energy deposition (ED) or the energy cost of growth (ECG). This is, in turn, dependent on the weight gain or weight velocity (g/day) and the energy cost of tissue deposition (kJ/g) (Butte, 2005).

Butte (2005) published combined estimates and also separate estimates for TEE for breast-fed and formula-fed infants. TEE for formula-fed infants can be calculated as:

$$\text{TEE (kJ/day)} = 346 \times \text{body weight (kg)} - 122$$

For the current study, EER was modelled stochastically to allow inclusion of the variability that would be expected in an infant population. Simulation modelling was carried out using the Excel add-in, @Risk (Palisades Corporation). Data from Kuczmarski *et al*. (2000) was used to develop distributions for body weight at 1, 2, 3, 4, 5 and 6 months for males and females.

Two alternative approaches were used to calculate energy deposition:

- ED/ECG was represented by point values, as outlined in the Nutrient Reference Values for Australia and New Zealand (National Health and Medical Research Council, 2006), with a value of 730 kJ/day for 0-3 month olds and 230 kJ/day for 4-6 month olds.
- Weight gain for a one-month period (g/day) distributions were constructed using data from a WHO evaluation (WHO Working Group on Infant Growth, 1994) and combined with energy cost of tissue deposition figures (kJ/g) for 1, 2, 3, 4, 5 and 6 month old males and females (Butte, 2005).

These two approaches give very similar average results, but the second approach allows variability in individual infant growth rates to be included in the model.

Table 1 summarises the EERs for infants aged 1–6 months (National Health and Medical Research Council, 2006), the EERs for formula-fed infants (Butte, 2005) and the EERs from the current model, calculated by the semi- or fully-stochastic approach.

Table 1: Reference body weights and estimated energy requirements for infants aged 1–6 months

Age (months)	Reference Body weight (kg)		Estimated Energy Requirements (EER) for Infants 1-6 months (kJ/day)							
			All[1]		Formula-fed[2]		Formula-Fed (semi-stochastic)*[,3]		Formula-Fed (fully stochastic)*[,4]	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
1	4.4	4.2	2000	1800	2150	2000	2130 (1703-2557)	2061 (1679-2443)	2245 (1645-2847)	2066 (1535-2590)
2	5.3	4.9	2400	2100	2550	2250	2442 (1967-2916)	2303 (1875-2731)	2457 (1814-3086)	2223 (1672-2773)
3	6.0	5.5	2400	2200	2550	2350	2684 (2164-3203)	2511 (2042-2980)	2522 (1898-3146)	2301 (1743-2863)
4	6.7	6.1	2400	2200	2450	2300	2426 (1863-2989)	2218 (1713-2724)	2625 (1997-3255)	2421 (1849-2993)
5	7.3	6.7	2500	2300	2600	2450	2634 (2036-3232)	2426 (1888-2965)	2734 (2089-3387)	2544 (1951-3133)
6	7.9	7.2	2700	2500	2800	2600	2841 (2211-3472)	2599 (2060-3138)	2836 (2174-3496)	2613 (2042-3191)

* Figures in brackets are 95th percentile confidence intervals

1 Mean Estimated Energy Requirements – all infants (NHMRC, 2006)

2 Mean Estimated Energy Requirements – Formula-fed infants (Butte *et al*., 2005), estimates have been recalculated to match body weights and rounded up to the nearest 50 kJ/day

3 Calculated, using distributions for body weight to calculate total energy expenditure and using fixed values for energy deposition (730 kJ/day for 0 - 3 months and 230 kJ/day for 4 - 6 months)

4 Calculated, using distributions for body weight and for weight gain (see text for further details)

2.2.2 Population sub-groups (6–12 month old infants, 1–3 year old toddlers, 4–6 year old children, 11–14 year old children, 19–24 year old males and adults 25 years of age and over)

This food consumption information was taken from the 2003/04 NZTDS (Brinsdon, 2004; Vannoort and Thomson, 2006). The NZTDS uses a simulated typical diet for each of the above age groups. The main data sources were the 1997 National Nutrition Survey (NNS97) conducted for New Zealanders 15 years of age and older (Russell *et al.*, 1999), the 2002 National Children's Nutrition Survey (CNS02) for children 5–14 years of age (Ministry of Health, 2003) and recent surveys of young children (Soh *et al.*, 2002; Wall, 2004). Industry groups were contacted to confirm selected changes in consumption patterns. The simulated diets were created to resemble an average consumer in each of the selected groups and included all appropriate foods from the food list (i.e. children's diets do not contain alcohol).

2.2.3 New Zealand population aged 5 years and older.

Actual food consumption information is available from the NNS97 conducted for New Zealanders 15 years of age and older (Russell *et al.*, 1999) and the CNS02 for children 5–14 years of age (Ministry of Health, 2003). These surveys include 24-hour dietary recall information (24HDR) for almost 8000 New Zealanders (4636 in the NNS97 and 3275 in the CNS02). These individual records allow a dietary modelling approach to be carried out (see section 2.3.3).

2.3 Estimation of Dietary Intake of Fluoride

Dietary intake estimates were made for a range of New Zealand age and gender sub-populations. In each case, two separate dietary intake estimates were made - one based on an unfluoridated water supply (fluoride concentration of 0.1 mg/L), and the other based on a water supply fluoridated to a level of 1.0 mg/L.

2.3.1 Exclusively formula-fed infants (0-6 months)

The declared energy density and measured fluoride concentration of infant formulae included in the current study were modelled as continuous distribution using the Bestfit function of @Risk. The distributions were truncated so that energy density and fluoride values could not fall outside the range observed in the current study.

At each model iteration the model:

- Assigned a gender to the infant, based on a binomial distribution with number of trials equal to one and the probability equal to the proportion of males among live births in 2006 (http://www.stats.govt.nz/analytical-reports/dem-trends-07/default.htm),
- Assigned an age (in months) using a uniform discrete distribution to give ages of 1, 2, 3, 4, 5 or 6 months,
- Assigned a body weight and growth rate from the distributions for that age-gender group,
- Calculated an EER based on the assigned gender, age, body weight and growth rate.
- Assigned a value from the distribution for the energy density of the infant formula and calculated the volume of infant formula fed per day.

- Assigned a value from the distribution for the fluoride concentration of the infant formula and calculated the estimated daily fluoride intake for the iteration.

The model was run for 20,000 iterations

2.3.2 General population – total diet approach

The total diet approach to calculating dietary intakes of food components was carried out according to Vannoort and Thomson (2006). This involves combination of average fluoride concentrations for foods with amounts of the foods consumed, as specified in typical simulated diets (Brinsdon, 2004). The total diet approach, utilising simulated diets, is a cost effective and relatively simple means of estimating the mean dietary intake of populations to chemicals in foods. Total diet surveys have been performed in New Zealand since 1974 (Dick *et al.*, 1978a; Dick *et al.*, 1978b) and are performed in a number of overseas countries (for a summary, see Vannoort and Thomson, 2006), providing opportunities to compare estimates of dietary intake across time and between countries. Although, variations within the methodology mean these comparison must always be conducted with some caution. The total diet approach is limited in its ability to examine the variability in dietary intake within a population. The limited range of foods included in the simulated diets (typically 60-150) means that, in some cases, significant source of dietary exposure may be overlooked.

As the food list for the NZTDS has expanded with each successive study there were foods in the 2003/04 NZTDS that were not included in the 1987/88 or the 1990/91 NZTDSs and, therefore, no New Zealand fluoride concentration data were available for these foods. Fluoride values were assigned to these extra foods by a matching or mapping process, where the extra food in the 2003/2004 NZTDS is matched to a similar food in the 1987/88 or 1990/91 NZTDSs. See Appendix 2 for details of mappings used.

2.3.3 General population – dietary modelling approach

Estimates of dietary intake of fluoride were made by combining typical levels of fluoride determined in foods (see section 2.1) with 24HDR information from the CNS02 or the NNS97 (see section 2.2) using Microsoft FoxPro. This was carried out by linking three database files:

- 24HDR unit records, including CNS02/NNS97 food descriptors,
- A mapping file containing the relationship between CNS02/NNS97 food descriptors and descriptors for foods for which fluoride concentration data were available, and
- A file listing food descriptors and mean fluoride concentrations for those foods.

The mean amount of fluoride in each food type was multiplied by the amount of food consumed, derived from the CNS02/NNS97, and summed over all foods assessed to estimate the dietary exposure to fluoride from the diet for each individual surveyed in the CNS02/NNS97. This allowed an individual estimate of dietary intake of fluoride to be determined for each of the respondents to the 24HDR questionnaire.

Weighted arithmetic mean intake values were calculated and 95th percentile intake values were taken from the ordered list of all intake estimates using Microsoft Excel. The weightings are used to adjust the demographic profile of the survey population to that of the New Zealand population. A 95th percentile consumer is often used to represent a 'high' or 'extreme' consumer. While it is tempting to consider maximum intake values, these will often represent atypical consumer or even questionable data in the 24HDR dataset.

This dietary modelling approach is used extensively by FSANZ in their estimations of dietary exposure to chemicals. For a fuller discussion see: http://www.foodstandards.gov.au/newsroom/factsheets/factsheets2000/dietaryexposureasses254.cfm

The dietary modelling approach to estimating dietary intake has the advantage of allowing assessment of the variability in dietary intake within a population. However, the range of foods described in 24HDR records will be much broader than those for which chemical concentration data are available and the degree of food mapping for dietary modelling will typically be greater than for total diet approaches. It should also be noted that the 24HDR records represent a single day's food consumption for each individual and are not necessarily representative of the individual's habitual food intake.

2.3.3.1 Age-gender population groups evaluated

The complete set of dietary intake estimates was further sub-divided to provide information on sub-groupings defined by age and gender. These groups were selected to align as closely as possible to those used in the 2003/04 NZTDS (Vannoort and Thomson, 2006). A comparison between the two studies is given in Table 2.

Table 2: Population sub-groups used in the 2003/04 NZTDS and for dietary modelling in the current study

Dietary Modelling			2003/04 NZTDS	
Age/Gender	**Mean body weight* (kg)**	**Number of respondents**	**Group**	**Mean body weight (kg)**
			6–12 month old infant	9
			1–3 year old toddler	13
5–6 year old child	23.4	692	5–6 year old child	23
7–10 year old child	33.9	1425		
11–14 year old boy	53.7	567	11–14 year old boy	54
11–14 year old girl	54.6	576	11–14 year old girl	55
15–18 year old male	71.2	106		
15–18 year old female	61.4	134		
19–24 year old male	78.0	141	19–24 year old male	78
19–24 year old female	67.8	205		
25+ year old male	81.7	1648	25+ year old male	82
25+ year old female	69.5	2309	25+ year old female	70

* Weighted mean, using survey weights to align the sample set with the total population

2.3.3.2 Mapping

The 24HDR records included in the NNS97 and CNS02 contain a much wider range of foods than the food lists for the 1987/88 and 1990/91 NZTDSs. To utilise all the data in the nutrition surveys, a mapping process was carried out to match the foods from the 1987/88 and 1990/91 NZTDSs, for which fluoride concentration data are available, to food descriptors employed in the CNS02/NNS97. For example, the only leafy vegetable included in the 1987/88 and 1990/91 NZTDSs was lettuce, for the purpose of dietary modelling the fluoride concentration for lettuce was applied to all lettuce, lettuce-based salads and other leafy vegetables (e.g. spinach, silverbeet). See Appendix 2 for details of mappings used.

This type of mapping is commonly used in studies to estimate dietary intake, to match the range of foods for which food consumption information is available to the range of food for which chemical concentration information is available. While the mapping process inevitably introduces uncertainties, these are generally considered to be less than the uncertainties that would be introduced by ignoring the contribution to dietary intake due to a food, because of a lack of available concentration data. Mapping is a common process undertaken as part of the Australian Total Diet Survey and a more detailed discussion can be accessed by reference to reports from that study (Food Standards Australia New Zealand, 2003;2005). Where possible, the validity of the mapping process was checked by comparisons of concentration data for mapped foods in international studies.

2.3.3.3 Food contributions

The contribution of a particular food to total dietary fluoride intake was calculated from NNS97 or CNS02 data by summing the contributions to fluoride intake from the specific food, across all consumers in a particular age-gender group, and dividing by the total fluoride intake for that group. The resulting proportion was converted to a percentage by multiplying by 100. The total diet approach also allows the contribution of individual foods and groups of foods to total dietary intake to be determined (Vannoort and Thomson, 2006).

2.3.3.4 High fluoride diets

For the identified age groups within the NNS97 and CNS02 data sets, individuals with the highest dietary intakes of fluoride were identified. The average amounts of individual foods consumed by this subset were identified and compared to the average of the whole study population. Males and females were considered together for each age group and the 95th percentile level was used to define high fluoride diets.

2.4 Areas of Uncertainty in Estimated Dietary Intakes

The methodology outlined in the previous sections is designed to provide a realistic estimate of the actual dietary intake of the selected sub-populations of New Zealanders to fluoride. Such estimates will always contain areas of uncertainty, where the data employed may not match the true prevailing information. Areas of uncertainty include:

- Fluoride concentration of foods. Recent, robust data on the fluoride content of the New Zealand food supply are not available. Data from the two primary New Zealand data sources do not always present a consistent picture and in some cases the authors have made judgements as to the 'best' values to use.

- Mapping. Foods analysed in this survey were mapped to a wider range of foods, described in the CNS02 and NNS97. It is assumed that the mapped foods will have similar patterns of fluoride content to the analysed foods. International data were consulted to confirm the validity of mapping, where possible.
- Use of 24HDR records. The 24HDR records from the CNS02 and NNS97 are generally assumed to represent the typical diet for the individual respondent. This is unlikely, as each individual's diet will vary from day to day. While mean fluoride intakes are likely to represent the true New Zealand situation, high percentile values (95^{th} percentile) will be higher than the 95^{th} percentile from habitual diets.
- Lack of food consumption information for the New Zealand population less than five years of age. Simulated diets were developed for 6-12 month old infants and 1-3 year old toddlers, as part of the 2003/04 NZTDS (Vannoort and Thomson, 2006). However, the national nutrition surveys carried out in 1997 and 2002 only provide 24HDR records for the population five years and older.
- Effect of people consuming bottled water and/or filtered water (National Research Council, 2006).
- Fluoride concentration of drinking water in fluoridated supplies. While the fluoride concentrations of fluoridated supplies are monitored to ensure compliance with the New Zealand Drinking Water Standards (2005), the data for individual supplies have not been aggregated into a national dataset. In this report, as a conservative approach, fluoride intakes have been modelled using the maximum recommended fluoride concentration value of 1.0 mg/L.

2.5 Estimates of Fluoride Intake Due to Toothpaste Use

Infant and child intakes of fluoride from toothpaste were estimated for two toothpaste fluoride concentrations – 400 and 1000 mg/kg. Rates of actual toothpaste use for New Zealand children are not available. The Ministry of Health recommends that children under the age of 6 years use a smear of toothpaste and that for children over the age of 6 years, a pea-sized amount should be used (Ministry of Health, 2004). Equivalent weights of toothpaste to these recommended amounts were taken from a study in the UK in which mothers were asked to apply either a pea-sized amount or a smear of toothpaste. The mean amount of toothpaste applied for a smear was 0.22 g and 0.30 g for a pea-sized amount (Bentley *et al.*, 1997). These amounts of toothpaste are lower than the mean values measured in studies of actual toothpaste use by young children. For example, British children aged 30 months used a mean value of 0.36 g toothpaste (Bentley *et al.*, 1999). In a study of Irish and Dutch children, the mean amounts of toothpaste used were 0.35 g for children aged between 1.5–2.5 years and 0.44 g for children aged between 2.5–3.5 years (Van Loveren *et al.*, 2004).

In this study, it was assumed that infants under the age of 12 months ingested 80% of the dispensed toothpaste (Chowdhury *et al.*, 1990) and children over the age of 12 months retained in the mouth or swallowed 68% of the dispensed toothpaste. This figure of 68% was derived from a study of the tooth-brushing habits of Irish and Dutch children aged between 1.5–3.5 years which found that the mean amount of toothpaste recovered from children who spat but did not rinse after brushing, was 32% (Van Loveren *et al.*, 2004). A study from the UK reported a similar value of 72% for retained toothpaste for children aged 30 months (Bentley *et al.*, 1999). The current advice provided in New Zealand is that children should spit and not rinse after brushing. Frequency of tooth brushing was assumed to be twice per day as per the Ministry of Health's recommendation (Ministry of Health, 2004).

Literature information was used to derive a consensus estimate of fluoride intake from the use of fluoridated toothpastes for adolescents and adults (National Research Council, 1993;2006). For all age groups, the intake figure from toothpaste was compared to the intake from the diet and the implications of aggregate intake discussed.

2.6 Risk Characterisation

To characterise the level of risk associated with a particular level of fluoride intake, it is necessary to compare intake estimates to a benchmark level of intake. The recently released Nutrient Reference Values for Australia and New Zealand (National Health and Medical Research Council, 2006) give two reference levels of intake – adequate intake (AI) and upper level of intake (UL). The data in Table 3 have been taken from this report.

Table 3: Criteria, Adequate Intakes (AI) and Upper Levels of Intake (UL) for fluoride by life stage group*

Life Stage Group	Criterion	AI (mg/day)		UL (mg/day)
		Male	Female	
0– 6 months	Human milk content	0.01#	0.01#	0.7
7–12 months	Caries prevention	0.5	0.5	0.9
1–3 years	Caries prevention	0.7	0.7	1.3
4–8 years	Caries prevention	1	1	2.2
9–13 years	Caries prevention	2	2	10
14–18 years	Caries prevention	3	3	10
19–30 years	Caries prevention	4	3	10
31– 50 years	Caries prevention	4	3	10
51–70 years	Caries prevention	4	3	10
> 70 years	Caries prevention	4	3	10
Pregnancy				
14–18 years	Caries prevention	—	3	10
19–30 years	Caries prevention	—	3	10
31– 50 years	Caries prevention	—	3	10
Lactation				
14–18 years	Caries prevention	—	3	10
19–30 years	Caries prevention	—	3	10
31–50 years	Caries prevention	—	3	10

* NHMRC (2006)

the AI for the 0–6 month age group is based on the average consumption of breast milk (780 ml/day) and the average concentration of fluoride in the breast milk of mothers in areas with fluoridated water (0.013 mg/l)

FSANZ recently reviewed the derivation of the UL for fluoride and concluded that "the apparent discordance between the theoretical and actual intakes without an increase in the adverse clinical signs of moderate dental fluorosis suggests that the existing UL may need to be revised upwards" (Food Standards Australia New Zealand, 2009). However, in the absence of such a revision, the UL has been used in the current study as a benchmark level of risk.

The US Agency for Toxic Substance and Disease Registry (ATSDR) has derived a chronic duration oral Minimal Risk Level (MRL) for fluoride of 0.05 mg fluoride/kg body weight/day (Agency for Toxic Substances & Disease Registry, 2003). The MRL is "an estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects over a specified route and duration of exposure" (Agency for Toxic Substances & Disease Registry, 2003). The MRL for fluoride is based on the risk of bone fracture due to skeletal fluorosis (Li *et al.*, 2001). This MRL would equate to a daily fluoride intake of 3.5 mg/day for a 70 kg adult or 0.65 mg/day for a 13 kg toddler.

The US Environmental Protection Agency (EPA) has derived an oral reference dose (RfD) for fluoride of 0.06 mg/kg/day (IRIS, 1989). The RfD is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure of the human population to a potential hazard that is likely to be without risk of deleterious effects during a lifetime" (Agency for Toxic Substances & Disease Registry, 2003). The RfD is based on the risk of dental fluorosis in children (IRIS, 1989). This RfD would equate to a daily fluoride intake of 4.2 mg/day for a 70 kg adult or 0.78 mg/day for a 13 kg toddler. The MRL and the RfD, despite having slightly different values, have the same functional intent.

3 RESULTS AND DISCUSSION

3.1 Fluoride Concentrations in Infant and Toddler Formula Products

3.1.1 Analytical quality assurance

The Fluoride Laboratory of the University of Iowa College of Dentistry is an internationally regarded laboratory for fluoride analysis and was the provider of analyses for the US Department of Agriculture (USDA) National Fluoride Database (Cutrufelli *et al.*, 2005).

Analysis of a freeze-dried urine sample with a certified fluoride content of 0.55 ± 0.03 mg/kg (SRM 2671a, National Institute of Standards and Technology, Gaithersburg, Maryland) gave analytical results in the range 0.54-0.55 mg/kg. The coefficient of variation (relative standard deviation), determined from duplicate analyses, was 2.6%.

3.1.2 Concentrations of fluoride in infant and toddler formula products

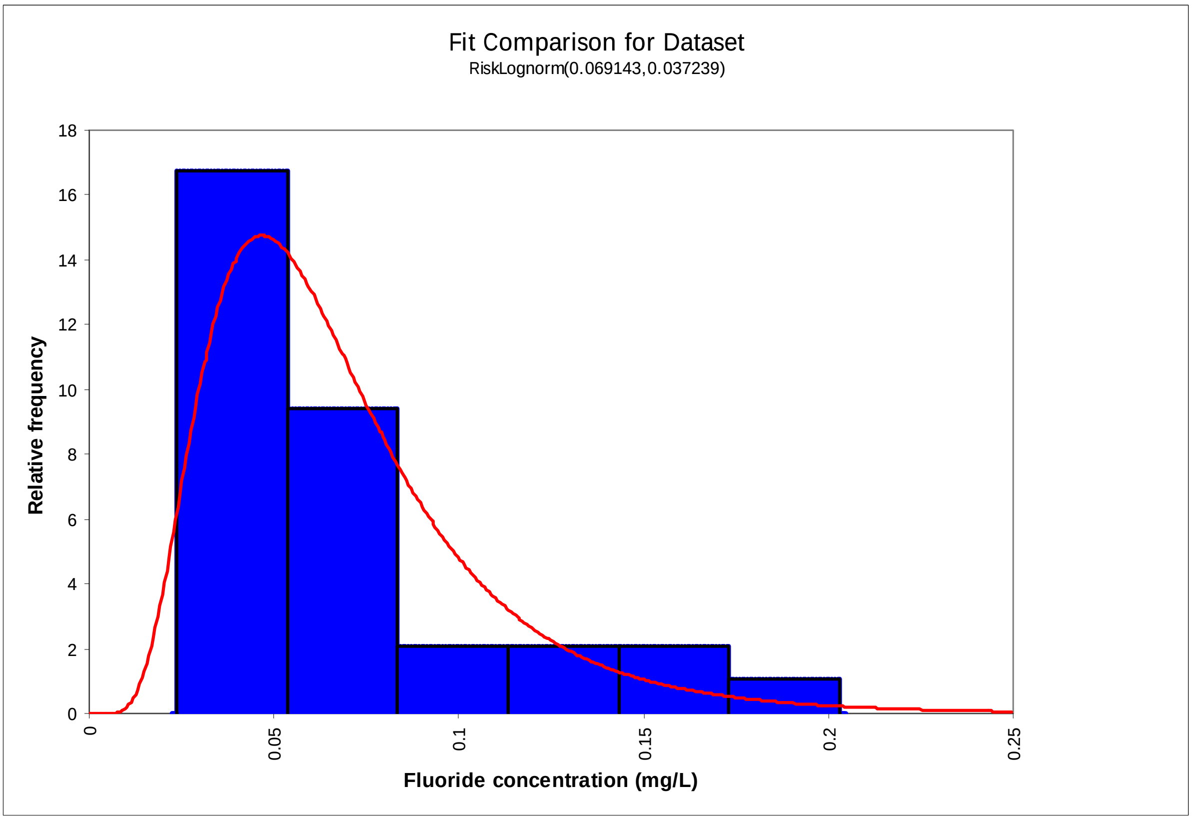
A summary of the fluoride content of prepared infant and toddler formula products included in this survey is given in Table 4. A full listing of analytical results for all products analysed is included in Appendix 3.

Table 4: Fluoride content of prepared infant and toddler formulae available in New Zealand

Product type	Mean fluoride concentration (mg/L)	Range of fluoride concentrations (mg/kg)
Infant formula	0.069	0.024-0.20
Follow-on formula	0.065	0.044-0.16
Toddler formula	0.081	0.039-0.13

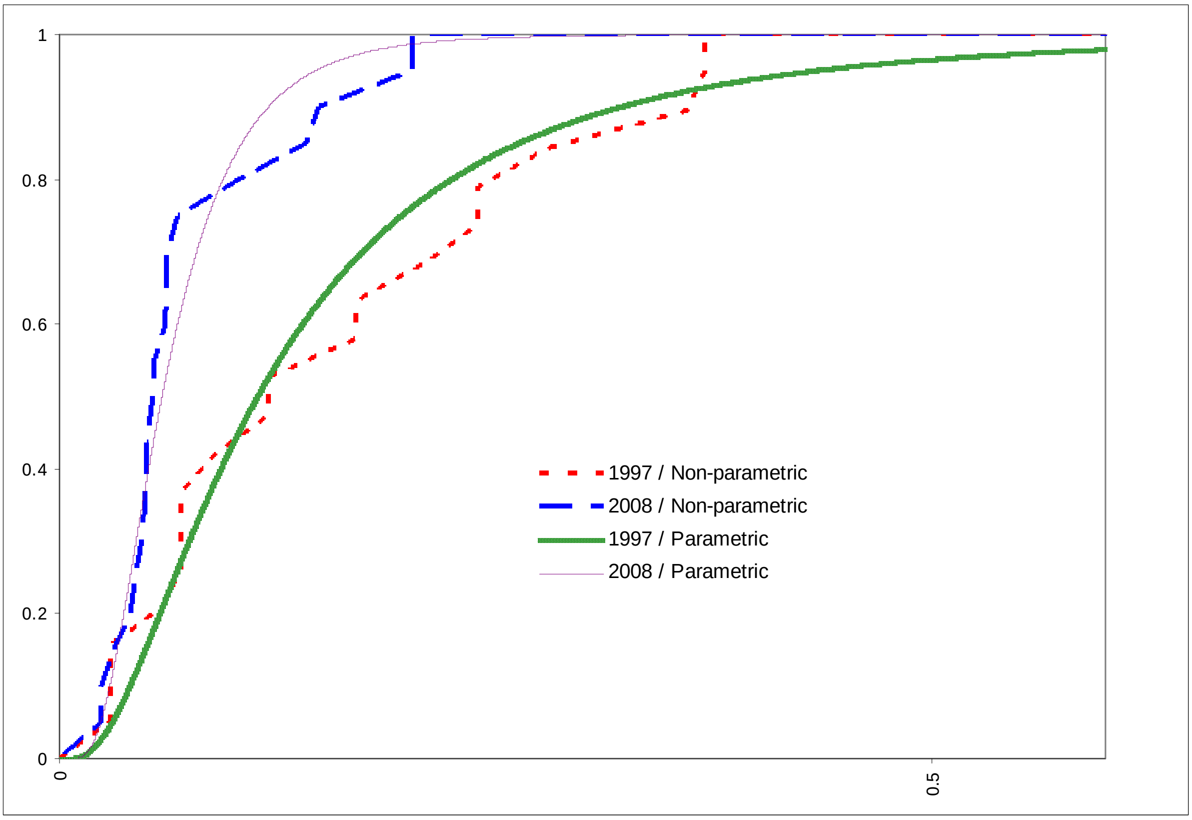
The concentrations of many components of foods have been observed to conform to a lognormal distribution (Sioen *et al.*, 2007). Figure 1 shows the fitting of a lognormal distribution to the observed fluoride concentrations in infant and toddler formula products. The fitted distribution for the complete data set (infant, follow-on and toddler formulae; lognormal (0.069,0.037)) is nearly identical to the fitted distribution for infant formulae alone (lognormal (0.068,0.041)).

Figure 1: **Histogram and best fit lognormal distribution for the fluoride concentration of prepared infant and toddler formulae available in New Zealand**



A previous New Zealand survey carried out in 1997 found a mean fluoride content for infant formulae of 0.15 mg/L and for follow-on formulae of 0.098 mg/L (Vannoort and Cressey, 1997). Toddler formulae are a relatively recent product on the New Zealand market and were not included in the 1997 survey. The full distributions of fluoride concentrations of infant formulae from the two New Zealand surveys were compared by fitting the data to a parametric (lognormal) distribution and to a non-parametric cumulative distribution. No comparison was carried out for follow-on formula, due to the small number of samples analysed, or for toddler formulae, as these were not included in the 1997 survey. Results are presented in Figure 2.

Figure 2: Comparison of cumulative probabilities for fluoride content of infant formulae between 1997 and current survey



The comparison demonstrates clear first-order stochastic dominance, with the fluoride concentration of infant formula sampled in 2008 lower than or equal to those sampled in 1997 at all probability levels. This provides clear evidence that the fluoride content of infant formulae available in New Zealand has decreased since 1997. This is consistent with anecdotal evidence from infant formula manufacturers, that they were making efforts to reduce the fluoride content of their products.

Fluoride contents of formulae from the current survey are generally similar to or lower than those reported for equivalent studies internationally. Table 5 summarises results from relevant comparative studies. Wherever possible data have been restricted to powdered infant formulae reconstituted with fluoride-free water according to manufacturers' instructions. Several studies were not included in this comparison, due to results being given only for the unreconstituted powder (Dabeka and McKenzie, 1987; Rahul *et al.*, 2003; Vlachou *et al.*, 1992) or because insufficient information was provided to determine summary parameters (Koparal *et al.*, 2000). Assuming that powdered infant formula is reconstituted at a rate of approximately 13 g of formula to 100 ml of finished formula, the results of Dabeka and McKenzie and Vlachou *et al*. appear to be consistent with other studies reported in Table 5.

Based on the data in Table 5, the fluoride content of infant formula products appears to be remarkably consistent between countries and across time. This is perhaps not surprising as infant formula products are a heavily internationalised food, with products from large manufacturers available in a wide range of countries. Given this observation, the approximate halving of the fluoride concentration of infant formula products available on the New Zealand market should be viewed as a significant development.

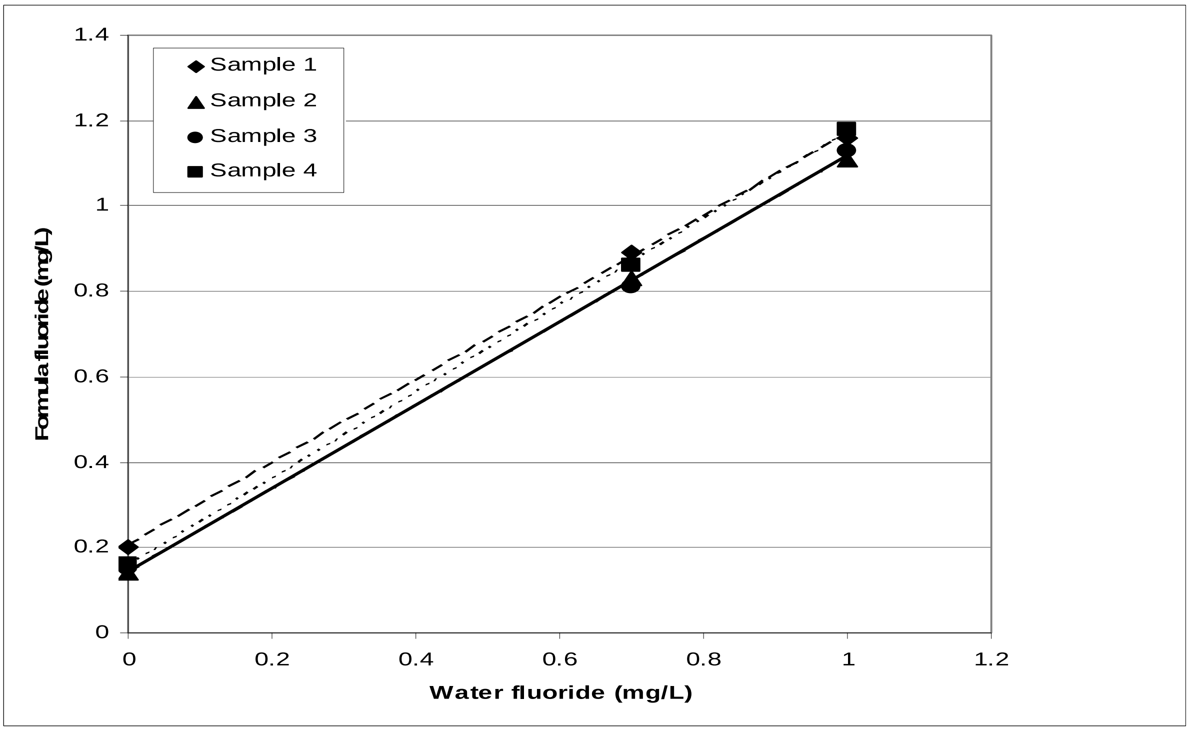
Table 5: Summary of results from international studies on the fluoride content of prepared infant formulae

Country	Number of samples	Fluoride concentration, Mean (range), mg/L	Reference
New Zealand (current study)	19	0.069 (0.024-0.20)	
New Zealand	18	0.15 (0.03-0.37)	(Vannoort and Cressey, 1997)
Australia		0.24 (0.03-0.53)	(Silva and Reynolds, 1996)
Brazil	10	0.14 (0.01-0.75)	(Buzalaf *et al.*, 2001)
Brazil	4	0.16 (0.08-0.21)	(Buzalaf *et al.*, 2004)
Brazil	7	0.15 (0.04-0.33)	(Pagliari *et al.*, 2006)
Japan	10	0.07 (0.04-0.12)	(Tomori *et al.*, 2004)
Turkey	5	0.10 (0.01-0.19)	(Atac *et al.*, 2001)
USA	29	0.12 (0.03-0.24)	(Johnson and Bawden, 1987)
USA	3	0.07 (0.06-0.10)	(McKnight-Hanes *et al.*, 1988)
USA	17	0.14 (0.05-0.28)	(Van Winkle *et al.*, 1995)

3.1.3 Impact of water fluoride on formula fluoride concentration

The four infant formula products with the highest fluoride concentrations when reconstituted with deionised water were reanalysed after reconstitution with water at 0.7 and 1.0 mg/L fluoride concentrations. Results for the measured fluoride concentration of these four formulae at water fluoride concentrations of 0.0, 0.7 and 1.0 mg/L are summarised graphically in Figure 3. Regression lines for formula fluoride against water fluoride are all highly linear ($R^2 > 0.999$) with slopes close to unity (0.96-1.02). This indicates that little or no irreversible binding of fluoride to the infant formula substrate is occurring and formula fluoride is a linear function of water fluoride.

Figure 3: Comparison of prepared infant formula fluoride content at three make-up water fluoride concentrations



3.2 Dietary Fluoride Intake - Infants (Breast-fed)

The Nutrient Reference Values for Australia and New Zealand (National Research Council, 2006) estimated a fluoride intake for breast-fed infants based on an average consumption of breastmilk of 0.78 L/day for the period 0-6 months and an average fluoride concentration in breastmilk of 0.013 mg/L (Dabeka *et al.*, 1986). This equates to an average daily fluoride intake of 0.01 mg/day.

Chowdhury *et al*. (1990) reported even lower fluoride contents for New Zealand breastmilk samples, in the range 0.001-0.005 mg/L. No significant difference was found between the fluoride content of breastmilk of women living in communities with fluoridated water supplies and those in communities with unfluoridated supplies.

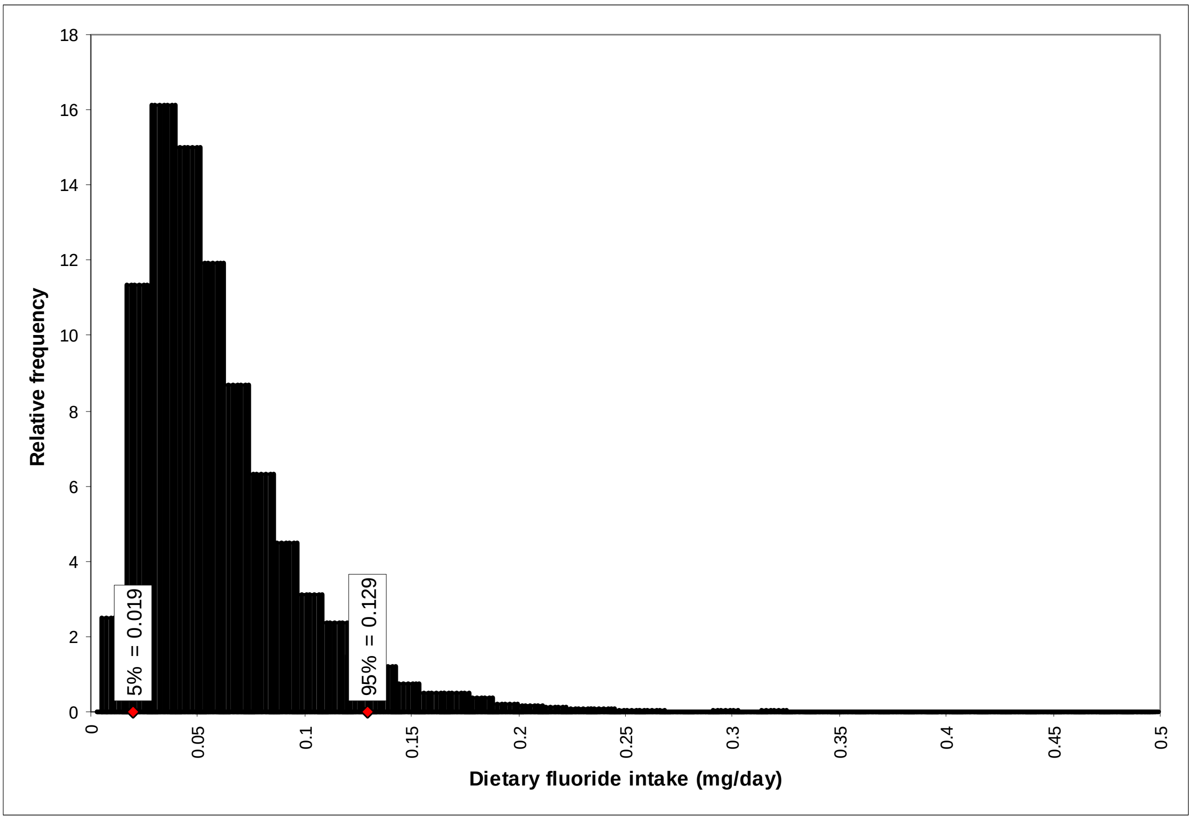
More recent studies on the fluoride content of breastmilk in quite diverse countries have shown similar average levels of fluoride (Kenya, 0.033 mg/L, Thailand, 0.017 mg/L, Turkey, 0.019 mg/L) (Chuckpaiwong *et al.*, 2000; Koparal *et al.*, 2000; Opinya *et al.*, 1991). It should be noted that the higher breastmilk fluoride levels reported in Kenya were from a region with very high water fluoride (9 mg/L).

3.3 Dietary Fluoride Intake - Infants (Exclusively Formula-fed)

A large percentage of New Zealand infants are likely to be fully formula-fed. In 2003, 9% of infants were formula fed by two weeks of age (Ministry of Health, 2008). Figures from 2005 showed that by six weeks 18% of infants are formula fed and at three months this figure has risen to 29%, with 40% formula fed at six months (Ministry of Health, 2008). The fluoride intakes of exclusively formula-fed infants were estimated as outlined in Section 2.3.1.

Figure 4 shows the results of the Monte Carlo simulation to estimate the dietary fluoride intake for infants 0-6 months consuming only infant formula prepared with fluoride-free water. The mean estimated dietary fluoride intake was 0.059 mg/day (5th - 95th percentiles 0.019-0.129 mg/day). When expressed on a body weight basis the mean estimated dietary fluoride intake is 0.010 mg/kg body weight/day (5th – 95th percentiles 0.003-0.023).

Figure 4: Dietary fluoride intake for fully formula-fed infants (1-6 months). Formula prepared with fluoride-free water



The Nutrient Reference Values for Australia and New Zealand recommend an adequate intake (AI) for infants 0-6 months of 0.01 mg/day and upper level of intake (UL) of 0.7 mg/day (National Research Council, 2006). The results of the current simulation modelling suggest that dietary fluoride intakes for fully formula-fed infants will fall within this range (0.01-0.7 mg/day) on greater than 99% of occasions. Of the 20000 iteration none simulated an intake of greater than 0.7 mg/day and less than 0.3% of iterations were less than 0.01 mg/day.

The formula feeding rates used in the calculations carried out to produce Figure 4 represent mean fluid intakes ranging from approximately 180 ml/kg body weight/day (5th – 95th percentiles 119-260 ml/kg) for a 1 month old infant to 130 ml/kg body weight/day (5th – 95th percentiles 90-175 mg/kg) for a 6 month old infant. Infants 0–6 months of age may typically consume 140–160 ml/kg body weight/day, with some consuming as much as 180 ml/kg body weight/day (Barbara Cormack, Auckland District Health Board, personal communication).

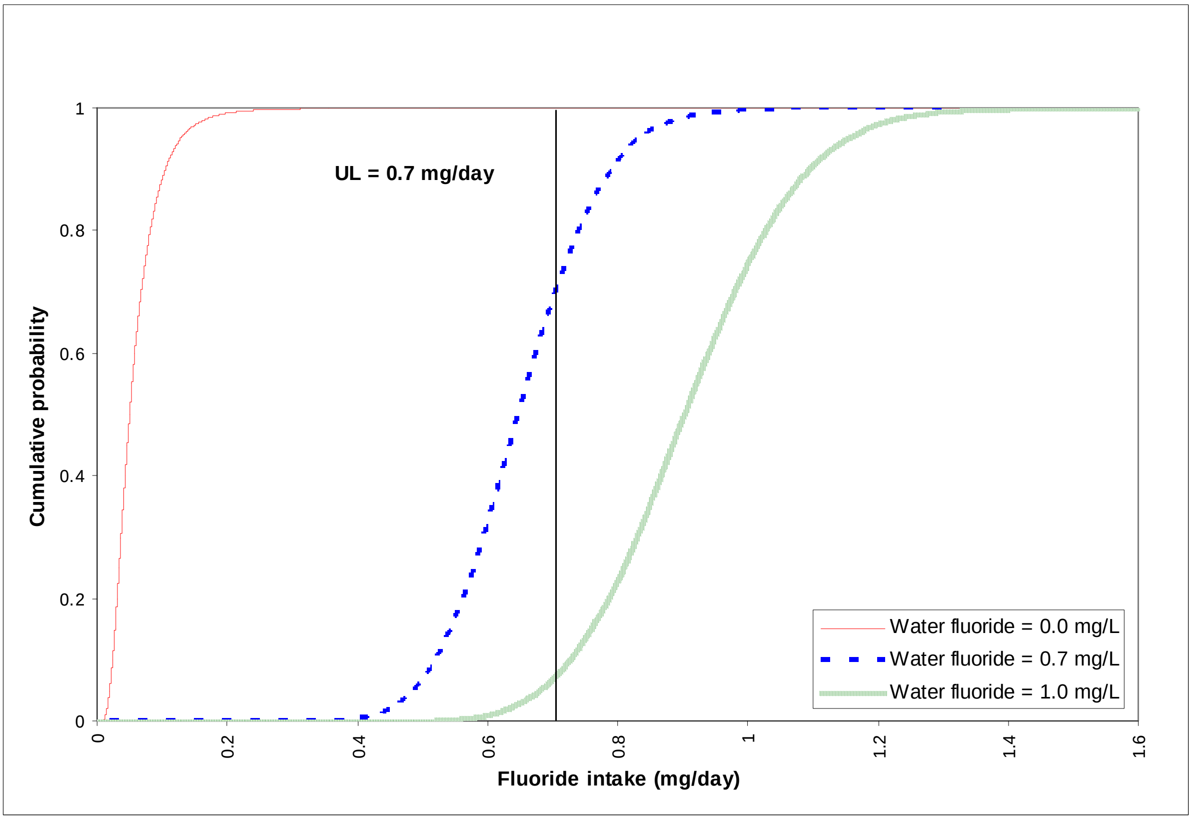
Consumption of formulae prepared with unfluoridated water results in estimated dietary intake of fluoride well below the UL for infants (0.7 mg/day). As a point of comparison

Chowdhury *et al*. (1990) estimated that the mean daily intake of fluoride of a breastfed infant would be 0.003 mg per day.

3.3.1 Dietary intake of fluoride – impact of water fluoride concentration

The Ministry of Health recommends fluoridation of drinking-water to concentrations in the range 0.7–1.0 mg/L (Ministry of Health, 2005). The simple linear relationship between water fluoride and formula fluoride was used to recalculate all formula fluoride concentrations on the basis of water fluoride concentrations of 0.7 and 1.0 mg/L. The mean slope of the regression lines for the four analysed infant formulae (0.982) was used for this recalculation. Recalculated fluoride concentrations were then fitted to lognormal distribution for use as inputs to the simulation model.

Figure 5: Cumulative probability of fluoride intake for fully formula-fed infants at varying water fluoride concentrations



Mean estimated fluoride intakes at the three water fluoride concentrations are 0.059, 0.66 and 0.91 mg/day at 0, 0.7 and 1.0 mg/L water fluoride concentrations respectively. While exceeding the UL is clearly an improbable event for infants consuming infant formula prepared with fluoride-free water, for formula prepared with water containing 0.7 mg/L fluoride simulation modelling suggests that the UL would be exceeded approximately 30% of the time, while at a water fluoride concentration of 1.0 mg/L the UL would be exceeded 93% of the time.

The mean estimates from the current study are slightly lower than recent estimates for a 3-month old exclusively formula fed infant derived by FSANZ (Food Standards Australia New Zealand, 2009). However, the FSANZ estimates used older data for the fluoride content of infant formulae (Silva and Reynolds, 1996), which gave significantly higher values than the current study. Given these difference, the mean estimated fluoride intake for a fully formula fed infant received formula prepared with water fluoridated at 1.0 mg/L was similar between the two studies (0.91 mg/day – current study, 1.0 mg/day – FSANZ).

Anderson *et al*. (2004) also used a stochastic approach to estimate the dietary exposure of formula-fed infants to fluoride. Based on an average prepared formula fluoride concentration of 0.84 mg/L, they estimated the dietary exposure during the first four months of life to be 0.132 mg/kg body weight/day (2^{nd} – 98^{th} percentiles 0.106-0.170). This is analogous to the scenario of formula prepared with water at 0.7 mg/L fluoride in our model. This scenario resulted in an average formula fluoride content of 0.76 mg/L and an average fluoride exposure for the first six months of life of 0.11 mg/kg body weight/day (5^{th} – 95^{th} percentiles 0.08-0.16). Despite significant differences in the modelling approaches used, the two studies give near identical estimates when differences in formula fluoride are accounted for. These similarities presumably reflect the dominant contribution of water fluoride concentration to dietary fluoride intake for exclusively formula-fed infants.

Levy *et al*. (1995) estimated fluoride intakes for 192 children at the ages of 6 weeks, 3 months, 6 months and 9 months, based on diet diaries. Fluoride intake from formula consumption decreased from a mean of 0.43 mg/day (range 1–1.24 mg/day) at 6 weeks to 0.32 mg/day (range 0–1.07 mg/day) at 9 months. Given that the fluoride content of the waters used to prepare the formulae ranged from 0.02–1.00 mg/L, these results are consistent with the results of the current study.

Ophaug *et al*. (1985) used a market basket approach to estimate the dietary intake of fluoride by 6 month old infants. Market baskets from cities with water supplies containing greater than 0.7 mg fluoride per litre gave an average dietary intake of 0.42 mg/day, while market baskets from cities with water supplies containing <0.3 mg fluoride per litre gave an average dietary intake of 0.23 mg/day. The approach of Ophaug *et al*. (1985) differed from the current approach in considering a diverse diet, rather than infant formula alone. An earlier study by the same authors produced similar results (Ophaug *et al.*, 1980a), with average dietary intakes of 0.35 and 0.54 mg fluoride per day for 6 month old infants from areas where water supplies contained low and high levels of fluoride, respectively.

3.4 Dietary Fluoride Intake - Children (< 10 years of age)

Table 6 summarises estimates of dietary intake of fluoride for New Zealand children, aged 1–10 years, based on total diet calculations and dietary modelling. There is excellent agreement between intake estimates based on the total diet approach and derived by dietary modelling.

Table 6: Estimated dietary intake of fluoride for New Zealand children, aged 1–10 years

Age	Guideline Levels (mg/day)		Mean estimated dietary fluoride intake (95th percentile[1]) (mg/day)			
			Total Diet		Dietary Modelling	
	AI[2]	UL[2]	Fluoridated water	Unfluoridated water	Fluoridated water	Unfluoridated water
6–12 month old infant	0.5	0.9	0.71	0.18		
1–3 year old toddler	0.7	1.3	0.57	0.25		
5–6 year old child	1	2.2	0.86	0.36	0.84 (1.74)	0.38 (0.73)
7–10 year old child	1–2	2.2–10			0.99 (1.80)	0.45 (0.82)

AI = Adequate Intake UL = Upper Level of Intake
1 95th percentile intakes are only available from the dietary modelling approach
2 NHMRC (2006)

All mean and 95th percentile estimates of dietary fluoride intake are within the ULs defined for the respective age groups in Table 3, irrespective of the approach (total diet or dietary modelling) used and the assumed fluoridation status of the water. However, in most cases the average dietary intake of fluoride does not meet the AI level for caries protection, even under scenarios of optimal water fluoridation.

There are a lack of nationally representative data on the diets of children younger than 5 years of age, as the CNS02 (Ministry of Health, 2003) did not include this age group. A market trend worth noting is the introduction of formulated supplementary foods for young children or "toddler milk" products onto the New Zealand market. These products are marketed as dietary supplements and substitutes for fresh cow's milk and are prepared from a dry powder. The total diet calculation for the 1–3 year age group presented in Table 6 is based on a simulated diet that includes approximately 260 g/day of milk. If all of this milk consumption was replaced by toddler milk formulations and assuming that toddler milk formulae contain similar levels of fluoride to other infant formulae, the estimated dietary fluoride intake for this age group would increase to 0.28 mg/day in unfluoridated areas and to 0.85 mg/day in areas with fluoridated water supplies, from 0.25 and 0.57 mg/day, respectively, which does not exceed the UL of 1.3 mg/day.

The Ministry of Health has described a milk consumption of up to 500 ml/day for 1–2 year old children as 'sufficient' for growth (Ministry of Health, 2008). If this volume of milk was consumed as toddler milk it would contribute 0.10 mg/day to dietary fluoride intake for an unfluoridated water supply, and 0.5 mg/day for a fluoridated water supply. If all other aspects of the simulated diet for a 1–3 year old toddler remained unchanged, the corresponding dietary fluoride intakes would be 0.35 mg/day for an unfluoridated water supply and 1.1 mg/day for a fluoridated water supply, which does not exceed the UL for this age group of 1.3 mg/day. It should be noted that the Ministry of Health does not recommend the use of toddler milk products.

The 1987/88 NZTDS estimated mean dietary fluoride intakes of 0.17 and 0.22 mg/day for a young child (1–3 years of age) and a child (4–6 years of age), respectively (Institute of Environmental Science and Research/Ministry of Health, 1994). The 1990/91 NZTDS estimated significantly higher mean dietary intakes for the same two population groups of 0.70 and 0.81 mg/day. Results from both NZTDSs were for foods prepared with distilled (fluoride-free) water, however, the later survey calculated fluoride intake from drinking-water based on a concentration of 0.9 mg/L. Water was not included as a food in the 1987/88 NZTDS.

FSANZ recently used the same approach as the current study to estimate the dietary fluoride intake of 6-12 month old New Zealand infants (Food Standards Australia New Zealand, 2009). Their estimates for an unfluoridated and optimally fluoridated water supply (0.4 and 0.9 mg/day, respectively) are higher than the estimates from the current study. However, the FSANZ estimate was derived using concentration data exclusively from the 1990/91 NZTDS, which were high for some foods (see Appendix 1).

Chowdhury *et al*. (1990) used a duplicate diet approach to estimate the dietary fluoride intake of 31 New Zealand children (aged 11–13 months) from areas with fluoridated water and 29 children from non-fluoridated areas. The mean fluoride intakes from food and drinks were 0.263 mg/day in the fluoridated area and 0.082 mg/day in the unfluoridated area. While the relative magnitudes of dietary intakes between fluoridated and unfluoridated areas are similar when the current study and Chowdhury *et al*. (1990) are compared, the estimates from the current study are approximately three-times higher.

Guha-Chowdhury *et al.* (1996) used a duplicate diet approach to examine the dietary fluoride intake of 66 New Zealand children (aged 3–4 years). The mean estimated dietary fluoride intakes were 0.36 mg/day in fluoridated areas and 0.15 mg/day in low fluoride areas. These estimates are closer to the estimates in Table 5 for a 1–3 year old toddler, but are still lower.

The estimated daily intakes of fluoride presented in Table 6 for New Zealand children are also consistent with international estimates of fluoride intake from diet (Table 7).

Table 7: International estimates of dietary exposure to fluoride for child populations

Country	Year	Population description	Details	Mean estimated dietary intake (mg/day)	Reference
Australia	1994	9 months 2 years	Representative diet (including milk and tea)	0.14 0.23	(National Health and Medical Research Council, 1999)
Australia	2009	9 months	Model diet Water fluoride = 0.1 mg/L Water fluoride = 0.6 mg/L Water fluoride = 1.0 mg/L	 0.4 1.0 1.3	(Food Standards Australia New Zealand, 2009)
Australia	2009	 2-3 years 4-8 years	Dietary modelling Water fluoride = 0.1 mg/L Water fluoride = 0.6 mg/L Water fluoride = 1.0 mg/L Water fluoride = 0.1 mg/L Water fluoride = 0.6 mg/L Water fluoride = 1.0 mg/L	 0.5 0.8 1.1 0.6 0.9 1.3	(Food Standards Australia New Zealand, 2009)
Brazil	2003	4–5 years 6–7 years 4–7 years	Duplicate diet study Water F 0.6–0.8 mg/L	0.44 0.38 0.40	(Pessan *et al.*, 2003)
Canada	1987	1–4 year old males and females 5–11 year old males and females	Comprehensive total diet study	0.35 0.53	(Dabeka and McKenzie, 1995)
Germany	NS	3–6 years	2-day duplicate diet approach	0.2	(Haftenberger *et al.*, 2001)
Hungary	NS	< 4 years	NS	0.44	(Schamshula *et al.*, 1988)
Iran	1995/1996	4 years	Three day dietary diary and analysis of food Water F 0.30–0.39 mg/L	0.39	(Zohouri and Rugg-Gunn, 2000)
Japan	2002	3 years 4 years 5 years	Duplicate diet study, 3 sampling periods over 1 year Water F < 0.16 mg/L	0.30 0.28 0.30	(Murakami *et al.*, 2002)
United States	1977–78	6 months	Estimated from market basket food collections, four regions of the USA	0.21–0.54	(Ophaug *et al.*, 1980a)
United States	1977–1982	6 months 2 years	Estimated from market basket food collections Water F < 0.3 mg/L	0.23 0.21	(Ophaug *et al.*, 1985)
United States	1977–1982	6 months 2 years	Estimated from market basket food collections Water F 0.3–0.7 mg/L	0.31 0.39	(Ophaug *et al.*, 1985)
United States	1977–1982	6 month 2 years	Estimated from market basket food collections Water F > 0.7 mg/L	0.42 0.62	(Ophaug *et al.*, 1985)

NS = Not Stated F = Fluoride

Ophaug *et al*. (1980b) used a market basket approach to estimate dietary fluoride intakes for 2 year old children in four regions of the United States. Mean intakes for the four regions were in the range 0.32–0.61 mg/day. These figures are very similar to the figures for unfluoridated and fluoridated water for the 1–3 year old toddlers in Table 6 (0.25 and 0.57

mg/day). The similarity in the figures from the two studies may reflect the similarity in the methods used to calculate the intakes. Estimates in Ophaug *et al*. (1985) are also similar to the estimates in the current study, with estimated mean fluoride intakes for 2 year old children of 0.62 mg/day for areas with a water fluoride concentration of greater than 0.7 mg/L, and of 0.21 mg/day for areas with a water fluoride concentration of less than 0.3 mg/L.

3.4.1 Additional exposure from toothpaste

Additional fluoride exposure from toothpaste was estimated using the Ministry of Health recommended amounts of toothpaste for each age group and for two toothpaste fluoride concentrations – 400 and 1000 mg/kg. The estimated daily fluoride intake from toothpaste is summarised for each age group in Table 8. While these estimated fluoride intakes from toothpaste were within the range previously reported (Table 9), children who use larger amounts of toothpaste and/or ingest toothpaste would have higher daily fluoride intakes from toothpaste.

Table 8: Estimates of daily fluoride intake (mg/day) from toothpaste for child populations

Age group	Toothpaste Fluoride Concentration (mg/kg)	
	400	**1000**
< 1 year	0.14	0.35
1–6 years	0.12	0.30
> 6 years	0.16	0.41

Table 9: Estimates of fluoride intake from toothpaste for child populations

Country	Population	Details	Toothpaste F concentration (mg/kg)	Estimated intake from toothpaste* (mg/day)	Reference
Germany	3–6 years	Analysis of toothpaste used	NS	0.27	(Haftenberger *et al.*, 2001)
Ireland	1.5–2.5 years	Analysis of toothpaste used	500 >1000	0.32 0.61	(Van Loveren *et al.*, 2004)
Ireland	2.5–3.5 years	Analysis of toothpaste used	500 >1000	0.39 0.89	(Van Loveren *et al.*, 2004)
New Zealand	11–13 months	Analysis of toothpaste used	NS	0.08–1.12	(Chowdhury *et al.*, 1990)
New Zealand	3–4 years	Analysis of toothpaste used	NS	0.23	(Guha-Chowdhury *et al.*, 1996)
Netherlands	1.5–2.5 years	Analysis of toothpaste used	250 500 >1000	0.17 0.25 0.50	(Van Loveren *et al.*, 2004)
Netherlands	2.5–3.5 years	Analysis of toothpaste used	250 500 >1000	0.16 0.41 0.52	(Van Loveren *et al.*, 2004)
United Kingdom	30 months	Analysis of toothpaste used	400 1450	0.14 0.85	(Bentley *et al.*, 1999)
United States	3 months 6 month 9 months	Mothers' estimates of amount of toothpaste used	NS	0.21 0.20 0.19	(Levy and Kiritsy, 1997)
United States	6–12 months 1–2 years	Typical daily intakes	NS	0.1 0.15	(National Research Council, 2006)

Country	Population	Details	Toothpaste F concentration (mg/kg)	Estimated intake from toothpaste* (mg/day)	Reference
	3–5 years 6–12 years			0.25 0.3	
United States	< 1 year 3–5 years 6–12 years	Literature values	NS	0-0.3 0.15–0.3 0.25–0.3	(United States Environmental Protection Agency, 2004)
United States	3–5 years	Estimated intake	1000	0.52 2.2 (Reasonable maximum exposure scenario)	(Erdal and Buchanan, 2005)

*Data adjusted for twice daily brushing as required and mean values reported unless otherwise stated.
NS = Not Stated F = Fluoride

Infants aged 6–12 months

As infants typically get their first teeth at 5–6 months of age (Ministry of Health, 2008), it is likely that a proportion of infants aged over 6 months will have their teeth brushed with toothpaste. Infants whose teeth are brushed using the recommended amount of toothpaste would receive an additional 0.14 mg and 0.35 mg of fluoride per day for the 400 and 1000 mg/kg fluoride toothpastes, respectively. These estimated intakes for New Zealand infants are within the range previously reported for studies in New Zealand and overseas (Table 9). For example, Chowdhury *et al*. (1990) estimated intakes of fluoride of 0.08 to greater than 1.12 mg/day from toothpaste for New Zealand infants (11–13 months old) with a mean value of 0.30 mg/day.

For infants aged 6–12 months with a fluoridated water supply, exposure from the diet would still be the main source of fluoride for this age group. In a fluoridated area using the higher strength toothpaste (1000 mg/kg) at the recommended application rate of a smear of toothpaste would raise the combined mean daily intake to just above the UL of 0.9 mg/day. In areas with an unfluoridated water supply, toothpaste would be a greater source of fluoride than the diet for this age group if the higher strength toothpaste were used. Using a 1000 mg/kg toothpaste would contribute 0.35 mg fluoride per day compared with 0.21 mg fluoride per day from the diet, and would raise the combined estimated mean fluoride intake above the AI for 6– month old infants.

Toddlers (1-3 years)

Toddlers aged 1–3 years using the recommended amount of 1000 mg/kg fluoride toothpaste would receive an estimated additional 0.30 mg/day of fluoride. Those using toothpaste with the lower fluoride concentration of 400 mg/kg would receive an additional 0.12 mg of fluoride per day. In an area with a fluoridated water supply, diet would contribute up to twice the amount of fluoride compared to toothpaste. In comparison, in an unfluoridated area, using 1000 mg/kg fluoride toothpaste would contribute more fluoride to the overall daily intake than diet. The estimated fluoride intakes are comparable to the results of an earlier study in New Zealand investigating toothpaste use for New Zealand children. Guha-Chowdhury *et al.* (1996) reported mean daily fluoride intakes from toothpaste of 0.37 mg/day for 3–4 year old children in New Zealand at the beginning of their study, and 0.23 mg/day, 12 months later.

The reduction in mean daily fluoride intakes over the study period was attributed to decreases in the amount of toothpaste used. The estimated fluoride intakes for New Zealand children from toothpaste presented in Table 8 are also comparable to those reported in overseas studies (Table 9).

Using the recommended amount of 1000 mg/kg fluoride toothpaste would raise the estimated mean daily intake for a toddler living in a fluoridated area to above the AI. Allowing for additional fluoride from toothpaste does not raise the estimated mean daily intake for toddlers to the AI level for the unfluoridated scenarios.

Children aged 5–6 years

For children aged 5–6 years, diet contributes more fluoride to the estimated daily intake than toothpaste. In fluoridated areas, the additional estimated fluoride exposure from the higher strength toothpaste raises the estimated mean daily intakes for both the total diet and dietary modelling scenarios above the AI. In comparison, for the unfluoridated scenarios, additional fluoride from toothpaste does not increase the mean estimated combined daily intakes to the AI.

Children aged 7–10 years

For children over the age of 6 years, using the recommended amount of toothpaste, exposure from toothpaste contributes less fluoride than the diet. Use of a child strength toothpaste (400 mg/kg) contributes an additional 0.16 mg of fluoride per day and toothpaste containing 1000 mg/kg fluoride contributes an additional 0.41 mg fluoride per day. In unfluoridated areas, the additional exposure from toothpaste is not sufficient to raise the estimated combined mean intakes to the AI. In fluoridated areas, the additional exposure from the recommended amount of 1000 mg/kg fluoride toothpaste would raise the combined intake for children aged 7–9 years to a level above the AI. The combined intake for children aged 10 years would be below the AI.

3.4.2 Foods contributing to dietary intake

Infants aged 6–12 months

For 6-12 month old infants and using a total diet approach, dietary intake of fluoride (unfluoridated water) comes mainly from infant formulae and specialised weaning foods (37%), grain products such as bread (17%), dairy products and beverages (12% each). If the infant was receiving water from a fluoridated supply then the contribution from infant formulae and weaning foods rises to 55%, while that from beverages rises to 27%.

Toddlers (1-3 years)

For 1–3 year old toddlers and using a total diet approach (unfluoridated water), water is the single greatest source of dietary fluoride (10.1%), followed by dietary staples such as bread, potatoes and dairy products. Under the scenario of a fluoridated water supply, beverages would contribute almost two-thirds (60%) of the dietary fluoride intake, with water as a beverage contributing 44% of total dietary fluoride.

Similar food items have previously been identified as contributing to the dietary intake of fluoride for Australian children. For example, dairy products, milk and grain and other cereal products were the main food sources of fluoride for 9 month old Australian infants and milk, potatoes, grain and other cereal products were the main food sources of fluoride for a 2 year old toddler (National Health and Medical Research Council, 1999).

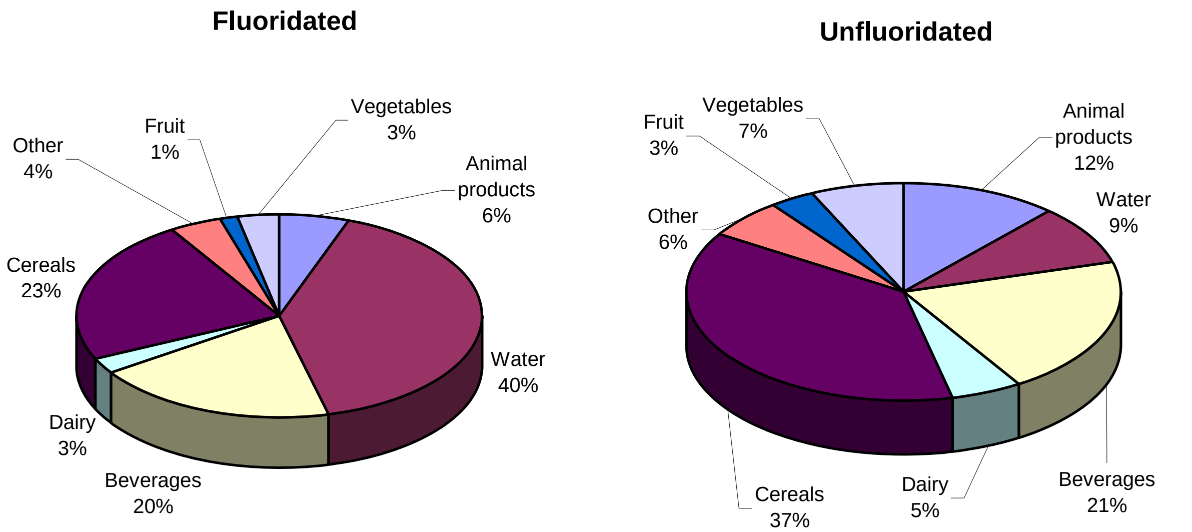
Children aged 5–6 years

The total diet approach shows an almost identical distribution of fluoride intake amongst foods for a 5–6 year old child as for a 1–3 year old child.

Children aged 7–10 years

Figure 6 shows the distribution of dietary fluoride intake amongst food groups for a 7–10 year old child, based on fluoridated and unfluoridated water supplies and using a dietary modelling approach.

Figure 6: Contribution of different food types to estimated dietary fluoride intake for 7–10 year old New Zealand children, dietary modeling approach



While the pattern of foods contributing to dietary intake is broadly similar to the younger age groups, some age-related trends are apparent. For example, the fact that beverages make up a similar percentage of intake under both the fluoridated and unfluoridated scenarios reflects the adoption of tea as a commonly consumed beverage, as tea prepared with unfluoridated water still contains significant concentrations of fluoride. Contributions from beverages such as fruit juices and soft drinks will be unaffected by the fluoridation status of the water supply. Also, for this age group dairy products are a decreasingly important contributor to fluoride intake, while bread and other cereal products are becoming increasingly important.

The pattern of beverages, including water, being the main sources of dietary intake of fluoride for children and infants is consistent with the results of previous exposure estimates for children and infants (Erdal and Buchanan, 2005; National Health and Medical Research Council, 1999).

3.4.3 High fluoride intake diets

The CNS02 diets were examined for children up to 10 years of age using a dietary modelling approach. Diets exceeding the 95th percentile of fluoride intake, based on an unfluoridated supply, were examined in greater detail. The high fluoride intake diets for this age group were characterised by a higher than average consumption of beef recipes such as stews and chow meins, chocolate-coated biscuits, cake, white bread, eggs, salmon, ham, fruit juices and powdered drinks, lollies, noodles, oranges, pasta, pies and pizzas, rice, soft drinks, and tea (10-times the average) when compared to diets with average levels of fluoride intake in the complete CNS02 dataset. The high fluoride intake group consumed less water as a beverage than the average of the CNS02 data set overall. It is likely that the elevated fluoride intakes observed for these individuals are due to these children being consumers of high volumes of food, rather than any particular pattern of consumption, although the high level of tea consumption (317 g/person/day compared to an average of 30 g/person/day overall) is worth noting.

The survey design of the CNS02 over-represented certain population groups and the 3275 respondents were made up of Maori (37%), Pacific Islanders (32%) and New Zealand European and other (30%). Of the respondents with high dietary fluoride intakes, 56% were Pacific Islanders, 26% were Maori and 18% were New Zealand Europeans or other. Approximately two-thirds of this group were classified as decile 9 or 10 on the 2001 New Zealand Index of Deprivation (Salmond and Crampton, 2002), compared to approximately 42% of the total survey group classified as decile 9 or 10. These trends are similar if the high fluoride diets are selected on the basis of a fluoridated water supply.

The UL was exceeded by less than 0.1% of respondents up to 10 years of age, based on an unfluoridated water supply, and by approximately 0.8% of respondents, based on the scenario of a fluoridated water supply, using dietary modelling.

3.5 Dietary Fluoride Intake - Adolescents (11–18 years of age)

Table 10 summarises estimates of dietary intake of fluoride for New Zealand adolescents, aged 11–18 years, based on total diet calculations and dietary modelling.

Table 10: Estimated dietary intake of fluoride for New Zealand adolescents, aged 11–18 years

Age/Gender	Guideline Levels (mg/day)		Mean estimated dietary fluoride intake (95th percentile[1]) (mg/day)			
			Total Diet		Dietary Modelling	
	AI[2]	UL[2]	Fluoridated water	Unfluoridated water	Fluoridated water	Unfluoridated water
11–14 year old male	2–3	10	1.00	0.50	1.26 (2.34)	0.61 (1.09)
11–14 year old female	2–3	10	0.90	0.43	1.03 (2.09)	0.49 (1.00)
15–18 year old male	3	10			1.89 (3.53)	0.86 (1.88)
15–18 year old female	3	10			1.68 (3.27)	0.73 (1.41)

AI = Adequate Intake UL = Upper Level of Intake

1 95th percentile intakes are only available from the dietary modelling approach

2 NHMRC (2006)

All mean and 95th percentile estimates of dietary fluoride intake are below the ULs defined for the respective age groups in Table 3. Only the 95th percentile estimates of dietary fluoride intake reach the AI level for the respective age groups with fluoridated water, but all remain below the AI for unfluoridated water supplies.

While dietary intake estimates vary between the total diet calculation approach and the dietary modelling approach, the two sets of results are of the same order-of-magnitude and show consistent patterns between fluoridated/unfluoridated water and between male/female consumers.

No intake estimates are available for these age groups from the 1987/88 or 1990/91 NZTDSs.

Table 11 summarises other international estimates of dietary exposure to fluoride for this age group.

Table 11: International estimates of dietary exposure to fluoride for adolescent populations

Country	Year	Population description	Details	Mean Estimated dietary intake (mg/day)	Reference
Australia	1994	12 year old male	Representative diet (including milk and tea)	0.67	(National Health and Medical Research Council, 1999)
Australia	2009		Dietary modeling		(Food Standards Australia New Zealand, 2009)
		9-13 years	Water fluoride = 0.1 mg/L	0.7	
			Water fluoride = 0.6 mg/L	1.2	
			Water fluoride = 1.0 mg/L	1.6	
		14-18 years	Water fluoride = 0.1 mg/L	1.0	
			Water fluoride = 0.6 mg/L	1.6	
			Water fluoride = 1.0 mg/L	2.1	
Canada	1987	12–19 year old male and female	Comprehensive total diet study	1.03	(Dabeka and McKenzie, 1995)
		12–19 year old male		0.91	
Hungary	NS	School children mean age 14 years	NS	1.49	(Schamshula *et al.*, 1988)
United States	1975	16–19 year old male	Estimate from market basket food collections, (4 regions of the USA)	0.91–1.72	(Singer *et al.*, 1980)

NS = Not Stated

3.5.1 Additional exposure from toothpaste

Allowing for an estimated daily intake of fluoride from toothpaste for adolescents of 0.3 mg per day (National Research Council, 1993;2006) does not raise the average daily intake of fluoride above the UL of 10 mg per day (Table 3) for any of the adolescent age groups. In fact, the mean intakes of fluoride from the diet and toothpaste combined are still below the AI levels for both the fluoridated and unfluoridated water exposure scenarios.

3.5.2 Foods contributing to dietary intake

Adolescents aged 11-14 years

For the 11–14 year old sub-groups (unfluoridated water, total diet approach), dietary fluoride intake is mainly from grain products (34% for males, 31% for females) and beverages (24% for males, 26% for females). In this age group meat and eggs, takeaway foods and vegetables are increasingly important sources of dietary fluoride when compared to the younger age groups. Within the beverage category, carbonated beverages and tea/coffee become more important, while water as a beverage is becoming less important for the 11–14 year old age group.

Water continues to be the most significant single food contributing to fluoride intake when diets are based on a fluoridated water supply (35% for males, 39% for females), with total beverages, including tea, accounting for 57% and 60% of dietary fluoride intake, respectively, for 11–14 year old males and females.

The relative importance of food groups is comparable to the results of the estimated fluoride intake for an Australian 12 year old boy (National Health and Medical Research Council, 1999). Food groups contributing more than 5% of the total daily fluoride intake included tea, beverages, potatoes, grain and cereal products, and meat, fish and poultry. Beverages, including tea, contributed 53% of the daily intake of fluoride overall.

Dietary modelling analysis of CNS02 data for the 11–14 year age group shows similar patterns of food contribution to dietary fluoride intake overall to results from the total diet approach, but shows considerably more variation between males and females. For 11–14 year old females, carbonated beverages and tea are much more significant contributors of fluoride to the unfluoridated diet (31% and 22%, respectively, of total dietary fluoride intake) than for 11–14 year old males (10% and 7%, respectively, of total dietary fluoride intake). For males, water as a beverage and bread are more significant contributors to fluoride intake than for the equivalent group of females.

Adolescents aged 15-18 years

The pattern of foods contributing to dietary fluoride intake for 15–18 year old males and females (dietary modelling) is qualitatively similar to the pattern described for 11–14 year old adolescents, with some minor differences:

- Little difference between males and females with respect to the contribution from water as a beverage and soft drinks, but females continue to derive a higher proportion of their fluoride intake from tea consumption.
- Cereal products, particularly bread, breakfast cereals and noodles continue to be significant fluoride sources for both males and females, but more so for males.
- Beer emerges as a source of dietary fluoride (4% for male, unfluoridated diet).

3.5.3 High fluoride intake diets

Adolescents aged 11-14 years

Using a dietary modelling approach, for the 11–14 year age group, diets with fluoride intakes above the 95th percentile, based on an unfluoridated water supply, were examined and the average amount of each food consumed was compared to the average for that age group overall. The high fluoride intake group was characterised by having higher consumption of a wide range of foods and this group probably represents consumers of high volumes of food in general. Foods of particular note consumed in greater quantities by this group include water, tea (mean 241 g/day compared to 45 g/day for all 11–14 year old respondents), soft drinks, fruit flavoured drinks, beef recipes, potatoes, bread and other cereal products.

The high fluoride intake group is more likely to be Pacific Islander and classified in the higher deciles according to the 2001 New Zealand Index of Deprivation (Salmond and Crampton, 2002) when compared to the composition of the 11–14 year survey group overall.

Adolescents aged 15-18 years

Diets with fluoride intakes above the 95th percentile, based on an unfluoridated water supply, were examined for the 15–18 year old adolescents (dietary modelling approach). High fluoride intake diets were characterised by high consumption of tea (average of 539 g/day compared to an average of 92 g/day for this age group overall), soft drinks, milk, fruit drinks, fish, bread and other cereal products and beer when compared to the average food consumption for this age group. The demographic profile of the high fluoride consumers appears to be similar to that of the age group overall.

For this age group none of the daily diet scenarios represented in the CNS02 and NNS97 resulted in an estimate of fluoride intake that exceeded the UL for either fluoridated or unfluoridated water supplies.

3.6 Dietary Fluoride Intake - Adults

Table 12 summarises estimates of dietary intake of fluoride for New Zealand adults, aged 19 years and over, based on total diet calculations and dietary modelling.

Table 12: Estimated dietary intake of fluoride for New Zealand adults, aged 19 years and over

Age/Gender	Guideline Levels (mg/day)		Mean estimated dietary fluoride intake (95th percentile[1]) (mg/day)			
			Total Diet		Dietary Modelling	
	AI[2]	UL[2]	Fluoridated water	Unfluoridated water	Fluoridated water	Unfluoridated water
19–24 year old male	4	10	1.37	0.80	2.25 (4.28)	0.98 (2.09)
19–24 year old female	3	10			2.03 (4.03)	0.88 (1.87)
25+ year old male	4	10	2.10	1.12	2.50 (4.60)	1.26 (2.52)
25+ year old female	3	10	2.07	0.98	2.35 (4.52)	1.04 (2.16)

AI = Adequate Intake UL = Upper Level of Intake
1 95th percentile intakes are only available from the dietary modelling approach
2 NHMRC (2006)

All mean and 95th percentile estimates of dietary fluoride intake are within the ULs defined for the age groups shown in Table 3. Interestingly, mean fluoride intakes are all lower than the AI for caries protection given in Table 3, irrespective of the fluoridation status of the water supply.

Dietary intake estimates are similar for both the total diet calculation and the dietary modelling approaches, when an unfluoridated water supply is assumed. Estimates based on a fluoridated water supply do not agree as well, but are of similar orders-of-magnitude.

Dietary fluoride intake estimates for the 19–24 year old male, and 25+ year old males and 25+ year old females, irrespective of estimation method and water fluoridation status, are significantly higher than estimates from the 1987/88 NZTDS (0.73, 0.61 and 0.50 mg/day, respectively), but generally lower than estimates from the 1990/91 NZTDS (3.0, 2.6 and 2.1 mg/day, respectively). This is not surprising as fluoride concentration data used in the current study are, in most cases, averages of concentration data from the 1987/88 and 1990/91 NZTDSs.

Table 13 summarises other international estimates of dietary exposure to fluoride.

Table 13: International estimates of dietary exposure to fluoride for adult populations

Country	Year	Population description	Details	Mean Estimated dietary intake (mg/day)	Reference
Australia	1994	Adult males	Representative diet (including milk and tea)	3.18	(National Health and Medical Research Council, 1999)
Australia	2009		Dietary modeling		(Food Standards Australia New Zealand, 2009)
		19-29 years	Water fluoride = 0.1 mg/L	1.0	
			Water fluoride = 0.6 mg/L	1.8	
			Water fluoride = 1.0 mg/L	2.4	
		30-49 years	Water fluoride = 0.1 mg/L	1.0	
			Water fluoride = 0.6 mg/L	1.8	
			Water fluoride = 1.0 mg/L	2.4	
		50-69 years	Water fluoride = 0.1 mg/L	0.9	
			Water fluoride = 0.6 mg/L	1.6	
			Water fluoride = 1.0 mg/L	2.1	
		70+ years	Water fluoride = 0.1 mg/L	0.8	
			Water fluoride = 0.6 mg/L	1.3	
			Water fluoride = 1.0 mg/L	1.8	
Canada	1986–1988	20–39 year old males	Total diet, water at 1 mg F/l	2.54	(Dabeka and McKenzie, 1995)
		20–39 year old females		2.17	
		40–65 year old males		3.03	
		40–65 year old females		2.62	
		65+ year old males		2.59	
		65+ year old females		2.41	
UK	1997	Population average	Total diet, water from collection sites (mixture of fluoridated and unfluoridated)	1.2	(Food Standards Agency, 2000)
		Adult consumer		0.94	
USA (Baltimore)	1970	16–19 year old males	Representative diet	0.8–0.9 (food only) 2.1–2.4 (food and water)	(San Filippo and Battistone, 1971)

NS = Not Stated F= Fluoride

3.6.1 Additional exposure from toothpaste

No New Zealand-specific data could be found on adult exposure to fluoride from toothpaste and other fluoride-containing dental products. Overseas estimates of fluoride intake from toothpaste for adults range from 0.1–0.3 mg per day (National Research Council, 1993;2006). Diet contributes 3–20-times more fluoride than toothpaste for adults, which is consistent with the other age groups. This additional exposure from toothpaste does not raise the mean daily fluoride intakes for adults in both fluoridated and unfluoridated areas to the AI level.

3.6.2 Foods contributing to dietary intake

Young adults aged 19-24 years

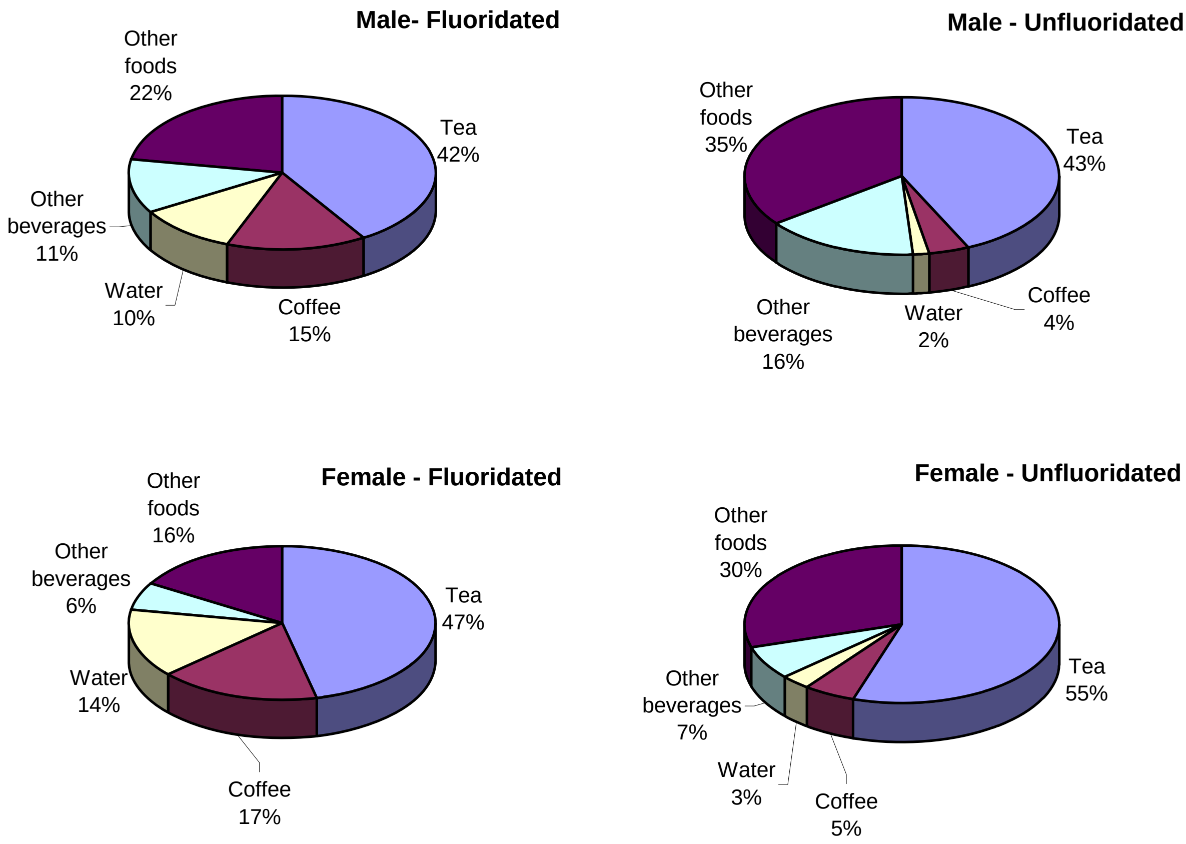
For 19–24 year old males (unfluoridated water, total diet approach), fluoride intake is mainly due to consumption of beverages (47%, including water (3%), beer (10%), carbonated beverages (11%) and tea (11%)) and grain products (17%). A fluoridated water scenario increases the proportion of dietary fluoride intake from beverages to approximately two-thirds of the daily intake. Dietary modelling reveals an almost identical pattern of food contributions to daily dietary fluoride intake, except the contribution from water is slightly higher (9%).

The pattern of foods contributing to the dietary fluoride intake of 19–24 year old females (unfluoridated water, dietary modelling approach) shows a greater contribution from tea consumption (28%) and a lesser contribution from carbonated beverages (9%) and beer (4%), than for males in the corresponding age group.

Adults aged 25 years and over

For adult males (25 years of age and over, unfluoridated water, total diet approach) the contribution of beverages to dietary fluoride intake is even more marked, with 65% of the daily intake from this source. Principal contributors are tea (43%), beer (8%), carbonated beverages (4%) and coffee (4%). Grain products contribute a further 14% to total intake. The fluoridated water scenario increases the total contribution from beverages to 78%. These trends are more marked for adult females, with 71% of dietary fluoride intake, under an unfluoridated water scenario, coming from beverages, with tea (55%), coffee (5%) and water (3%) predominating. Where the water supply is fluoridated, 84% of an adult female’s dietary intake of fluoride will be from beverages. The distribution of dietary fluoride intake amongst foods for adult males and females (total diet approach) is presented in a simplified form in Figure 7. The dietary modelling and total diet approaches closely resemble one another in terms of the pattern of foods contributing to daily dietary fluoride intake.

Figure 7: Contribution of different food types to estimated dietary fluoride intake for 25+ year old adults in New Zealand, Total Diet approach



An Australian estimate of dietary fluoride intake showed that beverages, tea and grain and cereal products were the foods contributing significantly to the daily intake of an adult male (National Health and Medical Research Council, 1999).

3.6.3 High fluoride intake diets

Young adults aged 19-24 years

Diets with fluoride intakes above the 95th percentile, based on an unfluoridated water supply (dietary modelling approach), were examined for the 19–24 year old age group (males and females combined), and the average amount of each food consumed was compared to the average for that age group overall. The high fluoride intake group was characterised by having higher consumption of a wide range of foods and this group probably represents consumers of high volumes of food in general. Foods of particular note consumed in greater quantities by the group with high fluoride intakes included beer (1106 g/day compared to an age group average of 198 g/day) and tea (792 g/day compared to an age group average of 162 g/day). The high fluoride intake group consumed lower average amounts of water (482 g/day compared to an age group average of 904 g/day).

The demographic composition of the high fluoride intake group is very similar to that of the 19–24 year old group in general.

Adults aged 25 years and over

A comparison of high fluoride intake diets and average fluoride intake diets for adults, who are 25 years of age or older, mirrors the pattern seen for the 19–24 year age group. Those with high fluoride intake diets consumed greater amounts of staples, indicating that they are probably consumers of high volumes of food in general. However, the most striking differences were in consumption of tea (1796 g/day compared to an age group average of 454 g/day) and beer (655 g/day compared to an age group average of 167 g/day).

The demographic profile of adults who have diets with high fluoride intakes is very similar to the adult profile in general. However, New Zealand Maori are over-represented (20% of high fluoride consumers compared to 10% in the NNS97 dataset overall), as are individuals classified in Deprivation Index IV (most deprived group, New Zealand 1996 Index of Deprivation; NZDep1996) (Salmond *et al.*, 1998) (44% compared to 33% in the dataset overall).

None of the adult daily dietary fluoride intake scenarios exceeded the UL when calculated on the basis of unfluoridated water. When fluoridated water was assumed, only 0.1% of daily diets exceed the UL of 10 mg/day.

4 RECOMMENDATIONS

- The Ministry of Health consider periodically collating data on the actual concentrations of fluoride in community water supplies, for the purpose of updating intake assessments.

- The potential for fully formula-fed infants to exceed the UL for fluoride should be further investigated.

- On-going monitoring of the literature in relation to fluoride toothpastes and very young children should also be done to regularly review the appropriate use of toothpaste for decreasing dental caries risk while minimising the risk of fluorosis development.

5 CONCLUSIONS

Dietary intakes of fluoride were estimated for a range of population sub-groups using three different techniques (formula-fed infant stochastic modelling, total diet and dietary modelling), and based on two scenarios of fluoridated and unfluoridated water. The study was undertaken to identify any groups at risk of high exposure to fluoride. Estimates of dietary fluoride intake were compared to adequate intakes (AI) and upper levels of intake (UL) adopted for New Zealand and Australia (National Health and Medical Research Council, 2006).

Mean and 95th percentile estimates of dietary fluoride intake were well below the UL when intakes were calculated on the basis of an unfluoridated water supply for all age groups. The corresponding estimated dietary fluoride intakes, calculated on the basis of an optimally fluoridated water supply were also below the UL, with the exception of estimates for a fully formula-fed infant.

For a fully formula-fed infant, aged 1 to 6 months, based on a stochastic model considering variability in infant body weights, growth rates, formula fluoride contents and energy densities, the estimates of dietary fluoride intake would exceed the UL approximately one-third of the time for water fluoridated at 0.7 mg/L. Estimates would exceed the UL greater than 90% of the time if formulae were prepared with water fluoridated at 1.0 mg/L. The current fluoride intake estimates for formula-fed infants are based on scenarios consistent with regulatory guidelines, rather than on observed actual water fluoride concentrations and infant feeding practices. Similar research recently undertaken by Food Standards Australia New Zealand has also concluded that a proportion of children up to 8 years could exceed the upper level of intake when fluoridated water (0.6 - 1.0 mg/L), from any source, is consumed. The use of fluoride-containing toothpastes will provide an additional contribution to daily total fluoride intake. Based on estimates in this study, an exclusively formula-fed infant consuming formula prepared with water fluoridated at 1.0 mg/L and using fluoride-containing toothpaste would have a greater than 99% probability of exceeding the UL.

The potential for formula feeding combined with optimal water fluoridation to result in elevated fluoride intakes was recognised during the development of the current NRVs for Australia and New Zealand (National Health and Medical Research Council, 2006). Specifically, it was noted that “Australian data have shown that prolonged consumption of infant formulas reconstituted with optimally-fluoridated water beyond 12 months of age could result in excessive amounts of fluoride being ingested during development of the enamel of the anterior permanent teeth and therefore may be a risk factor for fluorosis of these teeth” (National Health and Medical Research Council, 2006).

The American Dental Association (ADA) have recently recommended that, where liquid concentrate or powdered infant formula is the primary source of infant nutrition, infant formula can be prepared with fluoride-free or low fluoride water to reduce the risk of dental fluorosis (American Dental Association, 2006). The New Zealand Ministry of Health have considered this recommendation and concluded that the recommendation “cannot be used to argue against wider fluoridation of New Zealand drinking water” (Ministry of Health, 2006). This conclusion was based on the observed benefits of fluoridation for caries prevention and the lack of any observable increase in the prevalence of dental fluorosis over time.

A recent FSANZ assessment identified that the prevalence of mild and very mild dental fluorosis are usually higher in regions with fluoridated water supplied than in regions with unfluoridated water supplies in Australia and New Zealand. However, mild and very mild dental fluorosis are not considered to be a health concern. Although UL values were based upon the best available information at the time, the rarity of moderate dental fluorosis in the Australia or New Zealand populations indicates that current exceedances do not constitute a safety concern, and that the current information indicates that the UL will need to be reviewed.

Excluding formula-fed infants, all population groups mean fluoride estimates were below the AI level for caries protection and, in most cases the additional fluoride contribution from toothpaste would be insufficient to bring the total fluoride exposure above the AI.

Mean levels of dietary fluoride intake were consistent with similar estimates made overseas. This is not surprising, as the average fluoride levels of most foods fall within a fairly narrow range of concentrations, with most foods typically having fluoride contents in the range 0.1-1.0 mg/kg. Overall, intake of fluoride will be driven by consumption of dietary staples (bread, potatoes), beverages (particularly tea, soft drinks and beer) and the fluoride status of local drinking-water.

At all ages, dietary fluoride intake tends to be dominated by the contribution from liquid foods or foods prepared with addition of water in the home. Dietary staples, such as bread and potatoes, also contribute consistently due to the quantities consumed. Three distinct patterns were noted within the general contribution of liquid foods (beverages) to dietary fluoride intake:

- For children the beverage fluoride contribution was dominated by water or infant formula, prepared with water.
- During adolescent years the contribution to dietary fluoride intake from carbonated beverages becomes more significant and tea emerges as a contributor.
- During adulthood the contributions of tea and beer to dietary fluoride intake increase relative to adolescent, while the relative contributions of carbonated beverages and water decrease.

Diets of individuals with the highest intakes of fluoride were characterised by high levels of food consumption, but notably high consumption of tea, across all age groups, and beer, within the adult groups. While individual diet scenarios occasionally exceeded the UL, it should be stressed that the scenarios are based on an individual's recall of their diet in a single 24-hour period and may not represent habitual patterns of food consumption.

As with many environmental exposures, the very young appear to be the group at greatest risk of exceeding the UL. Their dependence on a narrow range of foods, particularly foods made up with the addition of potentially fluoridated water, means that the infant diet will always be a balancing act between fluoride insufficiency and fluoride excess. The introduction of fluoride-containing toothpastes for cleaning erupting teeth will further add to the delicacy of this balancing act.

The estimates of dietary fluoride intake made in the current study were based on the best available New Zealand food consumption and food fluoride concentration data. However, as with any data, these data have limitations that may impact on the intake estimates derived. Specifically:

- The age of fluoride concentration data. Food concentration data used in this study date from 1987/88 and 1990/91. The New Zealand food supply has become increasingly internationalised in the intervening years. It is uncertain what impact these changes may have had on the fluoride content of the food supply. Data on the fluoride content of infant formulae date from 1997. Many products have been reformulated since then and many products included in the original survey are no longer on the New Zealand market.
- The age of the food consumption data. The NNS97 data, used for adult dietary modelling and as a major input to the simulated diets used in the total diet approach, is now ten years old. The dietary habits of New Zealanders have changed during this period. It is not possible to say what impact dietary changes will have had on dietary fluoride intake.
- Use of single day 24HDR food consumption information. While mean intakes generated from these food consumption data are likely to be reliable, single day dietary recall records overstate the variability in habitual intake (Nusser *et al.*, 1996). Consequently, 95th percentile dietary intakes reported in the current study will be overestimates.
- Under-reporting of food consumption. It has long been recognised that respondents will tend to underestimate or under-report serving sizes in dietary recall studies. This has the potential to result in underestimation of mean and percentile dietary intakes. However, no systematic assessment of under-reporting in the New Zealand nutrition surveys was located and no assessment of the degree of underestimation was possible.

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APPENDIX 1 FLUORIDE VALUES ASSIGNED FOR FOODS

The following table gives fluoride concentration data from the 1987/88 and 1990/91 NZTDSs and, where available, corresponding data for the same or similar foods taken from the USDA fluoride database and/or the 1985 Australian Market Basket Survey. Where results from the two NZTDSs are in good agreement or where no other information is available, the two NZTDS values have been averaged to give a 'best estimate' fluoride concentration. If the two NZTDS values are not in good agreement with one another, but one is in good agreement with information from another source, then that NZTDS value has been selected as the best estimate.

For foods that are prepared by the addition of water, the NZTDS values represent preparation with distilled water containing no fluoride. In these cases the best estimate has been recalculated under two scenarios:

- Assuming addition of unfluoridated New Zealand water (fluoride content = 0.1 mg/L)
- Assuming addition of fluoridated New Zealand water (fluoride content = 1.0 mg/L)

In this calculation, it has been assumed that all the fluoride in the NZTDS value has been contributed by the food itself and none by the added distilled water. The fluoride level has been recalculated using the formula, $F_{inal} = F_{TDS} + F_{water} X \frac{Weight(water)}{Weight(food)}$

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Cereal Products								
Biscuit, chocolate			0.12	1.1			0.61	
Biscuit, plain	Cookies, without raisins, all		0.43	0.70	0.16		0.57	
Biscuit, crackers	Crackers, all		0.49	2.17	0.24		0.49#	
Bran flakes	Raisin bran	Unprocessed bran	0.66	1.01	0.65	0.3	0.84	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Bread, White	Bread, all (white and whole wheat)	White bread	0.49	0.75	0.39	0.4	0.62	
Bread, White Roll	Bread, all (white and whole wheat)		0.53	0.76	0.39		0.65	
Bread, Wholemeal	Bread, all (white and whole wheat)	Wholemeal bread	0.51	0.83	0.39	0.5	0.67	
Cake	Cake, all		0.21	0.41	0.22		0.31	
Cornflakes	Corn flakes	Cornflakes	0.52	1.75	0.17	0.3	0.52#	
Custard			0.10	0.10			0.20	1.07
Flour			0.54	1.1			0.82	
Instant Chocolate Pudding	Puddings, instant, prepared with whole milk		0.04	0.04	0.22		0.14	1.01
Macaroni	Macaroni and spaghetti, cooked		0.12	0.30	0.07		0.27	0.80
Muesli	Granola, with raisins		0.24	1.70	0.33		0.24#	
Noodles	Noodles, egg, cooked		0.13	0.32	0.06		0.29	0.82
Oats Rolled, Cooked	Oatmeal, cooked		0.12	0.09	0.72		0.19	0.94

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	**United States**	**Australia**	**1987/88 NZTDS**	**1990/91 NZTDS**	**USDA**	**1985 AMBS***	**'Best estimate' value**	
							Non-fluoridated	**Fluoridated**
Pastry, frozen, baked			0.36	0.70			0.53	
Rice	Rice, cooked	Rice, white	0.09	0.20	0.41	0.9	0.20	0.69
Weetbix	Wheat, ready-to-eat	Wholewheat breakfast biscuits	0.48	1.20	0.27	0.1	0.48#	
Dairy								
Butter	Butter	Butter	0.07	0.17	0.03	ND	0.12	
Cheese	Cheese, cheddar	Cheese	0.15	0.31	0.35	0.1	0.23	
Ice cream	Ice creams, vanilla	Ice cream	0.24	0.37	0.15	0.2	0.31	
Milk, Trim	Milk, skim		0.06	0.04	0.03		0.05	
Milk, Whole	Milk, 2%	Milk, full cream	0.05	0.03	0.03	ND	0.04	
Yoghurt	Yogurt, plain, low-fat		0.15	0.43	0.12		0.29	
Fats and Oils								
Margarine	Margarine	Margarine, table	0.05	0.49	0.05	ND	0.05#	
Oil, Soybean	Vegetable oil, corn	Blended oil	<0.05	0.34	0.01	ND	0.05#	
Animal Products								
Bacon	Bacon, cooked		0.35	0.37	0.22		0.36	
Beef, corned			0.35	1.1			0.73	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Beef, rump steak	Beef, cooked and raw		0.10	0.27	0.22		0.19	
Beef, steak mince	Beef, cooked and raw	Minced steak	0.20	0.28	0.22	0.45	0.24	
Beef, topside roast	Beef, cooked and raw		0.13	0.25	0.22		0.19	
Chicken	Chicken, cooked (includes fried and roasted)	Chicken	0.17	0.24	0.15	0.2	0.21	
Egg, poached	Egg, cooked	Eggs	0.12	0.62	0.05	ND	0.12#	
Egg, boiled	Egg, cooked	Eggs	0.10	0.48	0.05	ND	0.10#	
Fish, hoki/red cod	Fish, cooked		0.17	0.24	0.18		0.21	
Fish, Terakihi	Fish, cooked		0.16	0.54	0.18		0.16#	
Lamb, shoulder chops	Lamb chop, pan cooked with added fat	Lamb chops	0.28	0.45	0.32	0.25	0.37	
Lamb, leg roast			0.17	0.84			0.51	
Lamb, liver		Liver	0.07	0.10		0.1	0.09	
Luncheon sausage	Bologna		0.35	0.56	0.29		0.46	
Oysters, raw			0.77	0.80			0.79	
Pork Pieces	Pork, chop, baked	Pork chops	0.17	0.18	0.38	0.5	0.18	
Salmon, canned		Canned salmon	3.35	3.94		5.1	3.65	
Sausages	Sausage, pork		0.78	0.75	0.18		0.77	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Tuna, canned	Tuna, canned in oil, drained		0.64	0.56	0.31		0.60	
Vegetable Products								
Beans Sliced, Frozen, Boiled	Beans, mature, boiled	Beans	1.52	0.34	0.02	0.4	0.34#	
Beetroot, Canned	Beets, canned	Canned beetroot	0.09	0.01	0.26	ND	0.05	
Cabbage, Boiled	Cabbage, boiled	Cabbage	0.05	0.20	0.01	0.8	0.13	
Carrots, Boiled	Carrots, cooked	Carrots	0.05	0.01	0.47	0.5	0.03	
Cauliflower, Boiled	Cauliflower, boiled	Cauliflower	0.05	0.18	0.01	0.7	0.12	
Creamed Corn, Canned	Corn, cream style, canned		0.10	0.19	0.28		0.15	
Cream of mushroom soup, canned				0.44			0.47	0.69
Dried soup, other variety			0.21	0.08			0.24	1.04
Dried soup, tomato			0.08	0.18			0.22	1.06
Lettuce	Lettuce	Lettuce	0.32	0.40	0.05	ND	0.36	
Onion, Fried	Onion rings, breaded, fried, frozen, heated	Onions	0.06	0.06	0.55	0.3	0.06	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Oven Fries, Frozen Baked	Potatoes, mashed		0.10	0.57	0.39		0.34	
Peas, frozen, boiled	Peas, green (including cooked and canned)	Peas	0.08	0.12	0.29	0.45	0.10	
Potato Crisps	Potato chip		0.37	2.86	0.65		0.37#	
Potatoes, Baked	Potatoes, russet, baked	Potatoes	0.21	1.19	0.45	0.4	0.21#	
Potatoes, Boiled Peeled	Potatoes, boiled	Potatoes	0.09	0.26	0.49	0.4	0.18	
Pumpkin, boiled		Pumpkin	0.05	0.25		0.4	0.15	
Tomato, Fresh	Tomatoes, raw	Tomatoes	0.08	0.25	0.02	ND	0.17	
Tomato sauce, canned	Tomato Sauce, Canned		0.17	0.12	0.35		0.15	
Tomatoes in juice, canned	Tomatoes, canned		0.06	0.25	0.06		0.16	
Tomato soup canned	Soup, tomato, canned reconstituted, with milk		0.20	0.21	0.07		0.26	0.71
Fruit Products								
Apple	Apple, raw, with peel	Apples	0.09	0.06	0.03	ND	0.08	
Apricots, dried			0.13	0.17			0.15	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Banana	Bananas, raw	Bananas	0.06	0.06	0.02	ND	0.06	
Currants			0.13	0.17			0.15	
Dates			0.19	0.18			0.19	
Fruit juice, apple concentrate			<0.01	0.18			0.17	0.92
Fruit Juice Orange Concentrate	Orange, juice, frozen, concentrate		0.06	0.08	0.20		0.15	0.90
Fruit Juice, other	Fruit juice drink, blends (not cranberry), ready-to-drink	Orange juice	0.29	0.27	0.49	0.3	0.28	
Fruit Salad, Canned	Fruit cocktail, canned		0.07	0.01	0.09		0.06	
Kiwifruit			0.06	0.09			0.08	
Orange		Oranges	0.08	0.11		ND	0.10	
Peaches, canned	Peaches, canned	Peaches	0.10	0.04	0.07	ND	0.07	
Pears	Pears, raw	Pears	0.07	0.01	0.02	ND	0.04	
Pineapple, Canned	Pineapple, canned, juice pack	Canned pineapple	0.08	0.12	0.02	ND	0.10	
Raisins	Raisins		1.22	0.51	2.34		0.87	
Sultanas			0.31	0.27			0.29	
Spreads and Confectionery								

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Chocolate Plain	Candies, milk chocolate		0.09	0.10	0.05		0.10	
Confectionery	Candies, caramels		0.32	0.96	0.27		0.64	
Honey	Honey, bottled		0.11	0.02	0.07		0.07	
Jam	Jam, strawberry		0.10	0.05	0.19		0.08	
Marmalade			1.46	0.28			0.87	
Sugar white	Sugar, granulated	Sugar	1.17	0.31	0.01	ND	0.31#	
Yeast extract			2.11	1.65			1.88	
Alcoholic beverages								
Beer Draught	Alcoholic beverage, beer, regular	Beer	0.21	0.37	0.44	0.8	0.29	
Beer Lager	Alcoholic beverage, beer, light	Beer	0.20	0.11	0.45	0.8	0.16	
Wine Still, White	Alcoholic beverage, wine, white	Wine, white	0.15	0.16	2.02	0.4	0.16	
Wine, Still Red	Alcoholic beverage, wine, red	Wine, red	0.13	0.20	1.05	0.5	0.17	
Non-alcoholic beverages								

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Breakfast Powder Drink	Fruit flavoured drinks, prepared from powder		0.02	0.18	0.42		0.19	1.01
Chocolate Drink	Chocolate-flavour beverage, mix for milk, powder		0.08	0.13	0.05		0.21	1.08
Coffee Powder, Instant Infusion	Coffee, brewed	Coffee, dry weight basis	0.09	0.01	0.91	1.3	0.15	1.04
Cola Beverage	Carbonated, cola, fast food type, without ice		0.65	0.13	0.65		0.39	
Lemonade	Carbonated, orange soda		0.19	0.34	0.84		0.27	
Tea, Infusion	Tea, brewed, regular, all		0.35	1.75	3.73		1.15	2.04
Water	Waters, tap, all regions, all (includes municipal and well)		0.00	0.91	0.71		0.10	1.00
Mixed dishes								
Baked Beans, Canned	Beans, baked, canned, with pork		0.13	0.29	0.54		0.21	

Food name			Mean fluoride concentration (mg/kg)					
New Zealand	United States	Australia	1987/88 NZTDS	1990/91 NZTDS	USDA	1985 AMBS*	'Best estimate' value	
							Non-fluoridated	Fluoridated
Fish and chips		Fish, battered and fried	0.22	0.06		0.55	0.14	
Meat pie			0.21	0.41			0.31	
Spaghetti, Canned	Spaghetti, with sauce, no meat, canned		0.77	0.22	0.24		0.50	
Nut products								
Peanut butter	Peanut butter, creamy	Peanut butter	0.13	0.11	0.03	ND	0.12	
Peanuts, raw and roasted	Peanuts, dry roasted, salted	Peanuts	0.26	1.00	0.16	ND	0.26#	

ND = Not Detected, for 1985 AMBS the limit of detection was 0.1 mg/kg

* Values from the 1985 AMBS are median values, not mean values

Best estimate values taken from one NZTDS, rather than the mean of both. This was done where the results from the two NZTDSs were in poor agreement, but one result was in good agreement with fluoride concentration data from the other sources.

APPENDIX 2 FOOD MAPPINGS USED IN THE CURRENT STUDY

For both the Total Diet and Dietary Modelling approaches to estimating dietary intake of fluoride used in this study, food consumption information was available for foods for which no New Zealand fluoride concentration data were available. Omitting these foods from dietary intake calculations would lead to an inevitable underestimation of dietary intake. The alternative is to apply a 'best guess' fluoride concentration value to these foods. The 'best guess' value is usually taken from a related food, where there is a reasonable expectation that the fluoride concentrations will be similar. This process is known as mapping.

Total Diet Approach Mapping

The table below identifies food included in the 2003/2004 NZTDS for which no New Zealand fluoride concentration data are available and indicates the mapping process that has been carried out.

2003/2004 NZTDS food	Mapped to	Justification
Avocado	Kiwifuit	Same FAO food classification group (fruit, inedible peel). The fluoride concentration of kiwifruit used in this study is 0.08 mg/kg. The fluoride content of avocado determined in the US is 0.07 mg/kg
Capsicum	Tomato	Same FAO food classification group (fruiting vegetables). Capsicum and tomato both had the same fluoride concentration in the USDA database
Celery		No NZ data available for fluoride in stem vegetables. US concentration value (0.04 mg/kg) used
Chicken takeaway	Chicken	Major food ingredient
Chinese dish	Chicken	Purchased dishes were chicken and vegetables. Vegetables generally have low fluoride concentrations and the fluoride content of this dish is likely to be dominated by the chicken component
Cucumber		While data were available for another cucurbit vegetable (pumpkin), it was not possible to validate the mapping for fluoride content and the US concentration value for cucumber (0.01 mg/kg) was used
Grapes	Currants	Same FAO food classification group (small fruit).
Ham	Pork chops	Both pigmeat products
Mushroom		No NZ data available for fluoride in fungi. US concentration value (0.1 mg/kg) used
Melons		While data were available for another cucurbit (pumpkin), it was not possible to validate the mapping for fluoride content and the US concentration value for watermelon (0.01 mg/kg) was used
Mussels	Oysters	Both bivalve molluscs
Pizza		No NZ data available for fluoride in comparable food. US concentration value (0.31 mg/kg) used. This is consistent with a combination of grain products, cheese, tomato and meat products, based on NZ data.

Silverbeet	Lettuce	Same FAO food classification group (leafy vegetables)
Strawberries	Jam	Same FAO food classification group (berries and other small fruit)
Taro	Mean of beetroot, carrot and potato	Same FAO food classification group (root and tuber vegetables)

Dietary Modelling Approach Mapping

The list below identifies the major mapping groups used to match the foods from the 1990/91 NZTDS, for which fluoride data were available to the wider range of food descriptors used in the National Nutrition Surveys (CNS02 and NNS97). For two groups of vegetables; stem (e.g. artichoke, asparagus, celery, rhubarb) and cucurbit (e.g. melons and watermelons, cucumber, zucchini), it was considered that the NZTDS foods did not contain a suitable comparable food for mapping and the USDA database was used to provide suitable values for the fluoride content of these foods.

1990/1991 NZTDS food	Mapped to
Biscuit, chocolate	All chocolate and chocolate-coated biscuits
Biscuit, plain	All plain sweet and filled biscuits
Biscuits, savoury	All cracker biscuits and crispbreads
Bran flakes	Bran flakes and bran-based breakfast cereals
Bread, white	All white breads
Bread, white rolls	All white bread rolls
Bread, wholemeal	All wholemeal and mixed grain breads and bread rolls
Cake	All cakes and slices
Cornflakes	All corn- or rice-based breakfast cereals
Custard	All custards and custard-like dairy foods
Flour	All wheaten and other flours
Instant chocolate pudding	All instant puddings
Macaroni	All pasta and pasta-based dishes, except canned
Muesli	All toasted and untoasted mueslis
Noodles	All noodles and noodle-based dishes
Oats, rolled, cooked	All rolled oats (porridge)
Pastry, frozen, baked	All pastry
Rice	All rice types and rice-based recipes
Weetbix	All wheat-based breakfast cereals
Butter	Salted and unsalted butter
Cheese	All cheeses and cheese spreads
Ice cream	All ice cream and milk-based ice-blocks
Milk, trim	All low and reduced fat milks
Milk, standard	All standard and full fat milks
Yoghurt	Yoghurt and yoghurt-based ice-blocks
Margarine	All margarines and butter/margarine blends
Oil, soyabean	All vegetable oils
Bacon	All bacon and ham
Beef, corned	All corned beef/silverside and corned beef recipes
Beef, rump steak	All beef steak and beef steak recipes

Beef, steak mince	All beef mince and beef mince recipes
Beef, topside roast	All roasted beef
Chicken (No.6)	All chicken, chicken pieces and chicken recipes
Eggs, boiled and egg, poached (mean)	All eggs and egg recipes
Hoki	Hoki
Terakihi	All non-hoki, non-canned fish and fish recipes, except battered fish
Lamb leg roast	All lamb, hogget and mutton roasts
Lamb shoulder chops	All lamb, hogget and mutton chops and other cuts
Luncheon sausage	Luncheon meat
Oysters, raw	All shellfish and crustacea
Pork pieces	All pork
Salmon, canned	Salmon, canned
Sausages	All sausages, sausage meat, saveloys and frankfurters and recipes
Tuna, canned	Tuna, canned and other non-salmon canned fish
Beans, sliced, frozen	Green beans and green bean salads
Beetroot, canned	All beetroot, canned and non-canned
Cabbage, boiled	Cabbage, Brussels sprouts and coleslaw
Carrots, boiled	Carrots and carrot salad
Cauliflower, boiled	Cauliflower, broccoli and broccoflower
Creamed corn, canned	All canned and non-canned corn
Creamed mushroom soup, canned	All canned soups and other soups in liquid form
Dried soup, other variety	Dried soup, all non-tomato varieties
Dried soup, tomato	Dried soup, tomato
Lettuce	Lettuce, lettuce-based salads and other leafy vegetables (e.g. spinach, silverbeet)
Onion, fried	Onion and other bulb vegetables (e.g. garlic, leeks)
Oven fries, baked	All hot chips, wedges and hash browns
Peas, frozen	Peas and snowpeas
Potato, baked in skin and potato, boiled, peeled (mean)	All root and tuber vegetables, except beetroot and carrots
Potato crisps	All vegetable crisps
Pumpkin, boiled	Pumpkin, pumpkin salad and squash
Tomato, fresh	Tomato and tomato salad and other fruiting vegetables (e.g. capsicum, eggplant)
Tomato sauce, canned	All tomato and tomato-based sauces
Tomatoes in juice, canned	Tomatoes, canned
Apple	Apple, fresh and canned
Apricots	Apricots, fresh, canned and dried
Banana	Banana
Currants	Currants and other small fruit (e.g. grapes)
Dates	Dates and figs
Fruit juice, apple concentrate	All apple-based fruit juices
Fruit juice, orange concentrate	All orange-based fruit juices

Fruit juice, other	Fruit juices, other than apple or orange-based
Fruit salad, canned	All canned fruit not covered elsewhere
Kiwifruit	All fruit, inedible peel (e.g. papaya, mango, guava), except pineapple and banana
Orange	All citrus fruit
Peaches, canned	Peaches, nectarines, plums and cherries, fresh and canned
Pears	Pears, fresh and canned
Pineapple, canned	Pineapple, fresh and canned
Raisins	Raisins
Sultanas	Sultanas
Chocolate, plain	All chocolate and chocolate bars
Confectionery	All lollies and related confectionery
Honey	Honey
Jam	All jams and fruit jellies and fresh or canned berries
Marmalade	Marmalade
Sugar, white	All sugar
Yeast extract	All yeast extracts
Beer, draught and beer, lager (mean)	All beer
Wine, still red	Wine, red
Wine, still white	Wine, white (still and sparkling), fortified wines, ciders and spirits
Breakfast drink, powder	All powdered fruit-flavoured drinks
Chocolate drink	Chocolate drink
Coffee powder, instant infusion	All coffee
Cola beverage	All cola carbonated beverages
Cordial	All cordials and liquid fruit drinks
Lemonade	All non-cola carbonated beverages
Tea, infusion	All tea
Water	All tap and bottled water
Baked beans, canned	All canned beans
Fish and chips	All battered fish
Meat pie	All savoury pies
Spaghetti, canned	All canned pasta
Peanut butter	All nut butter and spreads
Peanuts, raw and roast/salt	All nuts and seeds, other than butters and spreads

APPENDIX 3 RESULTS OF ANALYSIS OF PREPARED INFANT AND TODDLER FORMULA PRODUCTS FOR FLUORIDE

Sample number	Product type	Country of manufacture	Preparation instructions	Energy label claim (kJ/100 ml)	Fluoride concentration (mg/L), prepared formula at water fluoride concentration		
					0.0 mg/L	0.7 mg/L	1.0 mg/L
1	IF	France	8.6g + 60ml water	271.6	0.068		
2	IF	France	9.2g + 60ml water	295.6	0.044		
3	IF	France	8.6g + 60ml water	280.5	0.062		
4	IF	France	8.6g + 60ml water	273.4	0.104		
5	IF	New Zealand	7.3g + 50ml water	290	0.054		
6	IF	New Zealand	7.3g + 50ml water	290	0.050		
7	IF	New Zealand	7.9g + 50ml water	278	0.203	0.89	1.16
8	IF	New Zealand	7.7g + 50ml water	295	0.062		
9	IF	New Zealand	7.5g + 50ml water	285	0.044		
10	IF	New Zealand	7.7g + 50ml water	285	0.051		
11	IF	New Zealand	8.3g + 50ml water	310	0.061		
12	IF	New Zealand	7.1g + 50ml water	280	0.142	0.83	1.11
13	IF	New Zealand	7.5g + 50ml water	290	0.149	0.82	1.13
14	IF	New Zealand	7.5g + 50ml water	290	0.041		
15	IF	Ireland	12.6g + 90ml water	278	0.024		
16	IF	Ireland	12.7g + 90ml water	281	0.025		
17	IF	Ireland	12.7g + 90ml water	281	0.031		
18	IF	Ireland	13.0g + 90ml water	281	0.055		
19	IF	Ireland	13.0g + 90ml water	280	0.048		
20	FO	France	8.6g + 60ml water	268.3	0.053		
21	FO	New Zealand	7.9g + 50ml water	282	0.053		
22	FO	New Zealand	7.9g + 50ml water	282	0.044		
23	FO	New Zealand	7.8g + 50ml water	280	0.058		
24	FO	New Zealand	7.8g + 50ml water	280	0.049		
25	FO	New Zealand	7.5g + 50ml water	290	0.160	0.86	1.18

Sample number	Product type	Country of manufacture	Preparation instructions	Energy label claim (kJ/100 ml)	Fluoride concentration (mg/L), prepared formula at water fluoride concentration		
					0.0 mg/L	**0.7 mg/L**	**1.0 mg/L**
26	FO	Ireland	13.0g + 90ml water	275	0.050		
27	FO	Ireland	13.0g + 90ml water	275	0.052		
28	T	New Zealand	9.0g + 50ml water	294	0.071		
29	T	New Zealand	9.0g + 50ml water	278	0.100		
30	T	New Zealand	9.0g + 50ml water	305	0.067		
31	T	New Zealand	9.7g + 50ml water	315	0.100		
32	T	Ireland	8.8g + 35ml water	421	0.039		

IF = infant formula FO = Follow-on formula T = Toddler formula