A Risk Assessment of Northwest Christchurch Water Supply:

Systematic Review

of Lead Contaminants

A dissertation submitted in fulfilment of the requirements for the degree of

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Abbreviations

<	Less than
>	Greater than
>=	Greater or equal to
µg	Microgram
µg/ day	Microgram per day
µg/ dL	Microgram per decilitre
µg/ kg	Microgram per kilogram
µg/ L	Microgram per litre
µg/ m^3	Microgram per meter cubed
µm	Micrometer
µmol	Micromole
µmol/ L	Micromole per litre
BLL	Blood lead level
CCC	Christchurch City Council
CHI	Consumer health informatics
dL	Decilitre
DWSNZ	Drinking Water Standards for New Zealand
ECan	Environment Canterbury/ Canterbury Regional Council
EPA	United States Environmental Protection Agency
ESR	New Zealand Institute of Environmental Science and Research
FAO	United Nations Food and Agriculture Organization
g	Gram
GAC	Granular activated carbon
Health KM	Health knowledge management

ICT	Information Communication Technology
IQ	Intelligence Quotient
JECFA	Joint FAO/WHO Expert Committee on Food Additives
kg	Kilogram
kPa	Kilopascal
L	Litre
m^2	Meter squared
MAV	Maximum acceptable value
mg	Milligram
mg/ kg	Milligram per kilogram
mg/ L	Milligram per litre
mL	Millilitre
mm	Millimetre
MoH	New Zealand Ministry of Health
mol	Substance concentration/ molarity
NW	Northwest
PAC	Powdered activated carbon
Pb	Lead
PbB	Blood lead
pH	Potential of hydrogen
PTWI	Provisional tolerable weekly intake
PVC	Polyvinyl Chloride
URL	uniform resource locator
WHO	World Health Organization

Abstract

Lead (Pb) is a known toxicant that affects young children. It is believed that old water reticulation systems are prone to lead leaching from the walls of lead pipes and fixtures where water is conveyed to households. Many households in Christchurch city particularly in the Northwestern and Central parts of the city contain old water reticulation systems thereby, putting children at considerable health risks. The purpose of this dissertation is to identify the hazards of lead exposure that comes from old water reticulation system of Northwest (NW) Christchurch water supply to households, characterize the health risks due to such contamination and, finally, to suggest possible ways to minimize the hazards. This is accomplished by conducting a systematic review of literature on the exposure patterns of lead from reticulation systems and a literature review of the possible dose response patterns of health effects of lead contamination from old water reticulation systems on children. Thus, this dissertation involves a literature based risk assessment of lead contamination of drinking water supply in the Northwest Christchurch Zone and particularly, its effects on young children. The selection process of the research studies is based on whether they offer accurate and suitable information on the risk of adverse mental function in infants and young children due to environmental lead exposure; whether the studies have been peer reviewed by qualified scientists; whether the results are confirmed by other studies; and involves only human subjects. Future research may consider whether lead levels in drinking water are seasonal; whether these values are significant to health or, the possible role of the government in tightening product controls when monitoring the availability and health risk of high lead drinking water supply plumbing products available in the New Zealand market.

Chapter 1

Introduction

A search of available and reliable peer reviewed literature and databases was undertaken with a set of well defined search criteria and keywords to answer the following 3 questions:

1) What is the risk of lead leaching out from an old water supply reticulation system in a city and how much lead is usually present in the different water samples collected in Christchurch?

2) What is the health impact on children between 0—15 years of age who are exposed to lead in reticulated drinking water and from other environmental lead sources?

3) What steps may be taken and what evidence based public advisory work may be used to mitigate this problem?

A total of 6 databases were searched including Scopus, PubMed and ProQuest. A publication was selected if the objective of the publication was to investigate either the role of different types of water supply and their effects on lead content or, in the case of dose response study, if the objective of the study was to identify the risks of lead related diseases in children who were exposed to lead through sources that include drinking water. English language studies that belong to observational study designs were included in this review. However, studies on animals or human tissue-based wet laboratory studies were not selected for this review. In addition, all studies that were not written in the

English language or, were in letter form or other non-standardized and non-peer-reviewed publications were not considered. The results of the different studies were considered in totality of their findings since these studies were likely to be considerably heterogeneous, therefore a formal pooling of statistical data from each study was not attempted.

The key results from the literature review were the following: First, the sources and pathways of environmental lead are complex and their contribution varies from place to place. Second, the sources and pathways of environmental lead contamination differ between adults and children such as lead vapours via occupational exposure and soil lead via pica behaviour respectively. Third, the level of susceptibility to adverse health effects is greater in children aged 0—15 compared to adults due to the greater dose-response impact on their smaller bodyweight. Fourth, lead in drinking water is a common problem in older households that are dependent on factors such the presence of high lead plumbing materials. Fifth, the potential of hydrogen (pH) quality of Northwest Christchurch public water supply has improved to reduce corrosion concerns. Finally, lead from domestic drinking water systems can be successfully managed by homeowners exercising prudence and greater public access to information to proven remedial action.

1.1 Overview

1.1.1 The Issue: Health risk from water pipe corrosion contaminants

Water in New Zealand is generally "soft" meaning it is slightly acidic (Treloar, 1996) on the potential of hydrogen scale. This is characterized by corrosive properties. The potential of hydrogen of water varies throughout Christchurch. The Christchurch-West Melton Groundwater Quality review of data between January 1986 and March 2002 showed the water potential of hydrogen is lower (hence more acidic) from shallower aquifers and unconfined groundwater

zones (Environment Canterbury). Unusually higher levels of potential of hydrogen in a typically low potential of hydrogen zone may indicate nearby or localized contaminants seeping into groundwater. Over pumping of coastal zone aquifers may result in sea-water intrusion causing higher potential of hydrogen measurements, making it more alkaline (Aitchison-Earl, 2002).

The study showed that poor wellhead protection was the presumed cause for direct lead pollution from leaded land contaminants leaking into the Springton and Aquifer 1, Christchurch-West Melton groundwater. The Maximum Acceptable Value (MAV) for lead in New Zealand potable water is set at $>= 0.01$ mg/ L. These lead levels were recorded at 0.021 mg/ L and 0.015 mg/ L respectively. It should be noted that Christchurch groundwater itself is not chemically high in lead content. In terms of water potential of hydrogen values, some deeper aquifers may even have potential of hydrogen values greater than 8.5. Corrosion in household plumbing occurs through chemical reaction with water. This results in the dissolution of metallic elements including lead, nickel, antimony, cadmium, copper and zinc (Aitchison-Earl, 2002).

A fundamental requirement for good health is access to uncontaminated water supply. Two vital assumptions about the health impacts of water contamination are:

1) The likelihood of wide population exposure, and
2) The likelihood of adverse health outcomes from small changes to contaminant levels.

Australian studies have shown that widespread use of pesticides and chemicals in agricultural activities have contributed to serious algal bloom in the Darling River. The contamination affects large Australian populations (around 50 % of water requirements) as the river system eventually joins with the River Murray (McKay & Moeller). The report has warned against underestimating

a small contaminated water source as it can easily spread to cause extensive adverse health outcomes.

This study focuses on old drinking water reticulation systems. "Old" homes, defined here as those constructed prior to 1944, are believed to be made of outdated plumbing materials and therefore pose a possible health risk from lead contamination (Ministry of Health, 2005; Shearer, 1974). Lead toxicity cases have been recorded in Christchurch via exposure to dust from weather-flaked or sandblasted surfaces from old wooden homes with leaded paintwork. Both adults and children are exposed to aerosol lead through leaded dust inhalation; while young children are possibly exposed to an extra pathway where pica behaviour is involved through leaded soil ingestion when leaded paint flakes or dust settle onto nearby soil (Scott, 1983). In addition, both adults and children may also be exposed to lead from water supply if they happen to live in houses that are supplied by old reticulation system. Water lead exposure can initiate early on in life during the time of bottle feeding, or even as part of foetomaternal chemical transfer during pregnancy, when lead dissolution occur in household drinking water through leaded plumbing materials and fixtures such as brass taps. The current maximum allowable value of lead in New Zealand drinking water is in line with the World Health Organization (WHO) 1993 guidelines, as it is set similarly at 0.01 mg /L (World Health Organization D; Ministry of Health, 2007).

Plumbing materials and practices have evolved over the years. Nowadays, New Zealand's household plumbing regulations disallow the use of lead pipes for supply of drinking water (Shearer, 1974). In addition, the New Zealand Ministry of Health (MoH) recommends flushing of 1-2 cups of drinking tap water as a measure to reduce more than half the concentration of lead found in first drawn samples. In spite of this, old cast iron pipes are still used in some parts of the Northwest Christchurch Zone locations, as remnants of past installations (Christchurch City

Council, 2006). They have lead based joints that can potentially contribute to additional water lead exposure.

In Christchurch, groundwater is accepted as high in quality and does not involve filtering or other forms of treatment as it naturally sifts through the Canterbury Plains substrate that comprises of mostly gravel and sand layers (Christchurch City Council, 2004). Sourced from five aquifers, the overall 'Ba' grading of the Christchurch City public water supply (Drinking Water for New Zealand A) is the highest achievable grade without any chemical treatment (Drinking Water for New Zealand). Sourced from three aquifers, the overall 'Da' grading of Northwest Christchurch public water supply (Drinking Water for New Zealand B) was due to the use of a shallow unconfined aquifer source that is more vulnerable to groundwater contamination through surface activity seepage (Drinking Water for New Zealand). See Tables 1 & 2 for more information.

Table 1: Explanation of Source and Treatment Plant Grading System of water supply in Christchurch

Grade	Description
A1	Completely satisfactory, negligible level of risk, demonstrably high quality
A	Completely satisfactory, extremely low level of risk
B	Satisfactory, very low level of risk
C	Marginally satisfactory, moderately low level of risk.
D	Unsatisfactory level of risk
E	Unacceptable level of risk
U	Not yet graded. (Not yet required if less than 500 people)

Source: Drinking Water for New Zealand

However, for both water supply zones, the water quality was assessed on the basis of compliance with the year 2004 *E. coli* (*Escherichia coli*: from faecal matter) and protozoa (*Cryptosporidium* and *Giardia*) tests. These measures however did not take into account the issue of domestic water supply dissolution of inorganic metals including that of lead.

Table 2: Explanation of Distribution Zone Grading System of water supply in Christchurch

Grade	Description
a1	Completely satisfactory, negligible level of risk, demonstrably high quality
a	Completely satisfactory, extremely low level of risk
b	Satisfactory, very low level of risk
c	Marginally satisfactory, moderately low level of risk.
d	Unsatisfactory level of risk
e	Unacceptable level of risk
u	Not yet graded. (Not yet required if less than 500 people)

Source: Drinking Water for New Zealand

Lead in drinking water has become the greatest controllable source of lead exposure in the United States of America since the successful control of atmospheric lead (Levin, Schock and Marcus, 1989). Lead contamination of drinking water is often due to the dissolution of the domestic plumbing system. Some metal pipes, solders, fittings or, domestic service connections can contain high levels of lead. Even polyvinyl chloride (PVC) pipes are responsible for the dissolution of lead compounds in the domestic water supply. Factors that determine the level of water lead contamination through the dissolution domestic plumbing system include the value of potential of hydrogen, temperature, and standing time, besides the presence of chloride and dissolved oxygen, and with acidic water being the most corrosive (Quinn and Sherlock, 1990, cited in World Health Organization, 2003).

1.1.2 Health effects of environmental exposure to lead in children

Human lead sources and pathways include the inhalation of atmospheric lead particulates through the lungs from pulmonary action; ingestion of lead contaminated food through the gastrointestinal tract from dietary intake; and lead absorption through skin contact. However, skin lead absorption

of inorganic lead is of least concern (The Royal Society of Chemistry, 1982, cited in Thornton, 1984). A diagram of the exogenous and endogenous lead sources and pathways is in Figure 1.

Figure 1: **Exogenous and endogenous lead pathways**
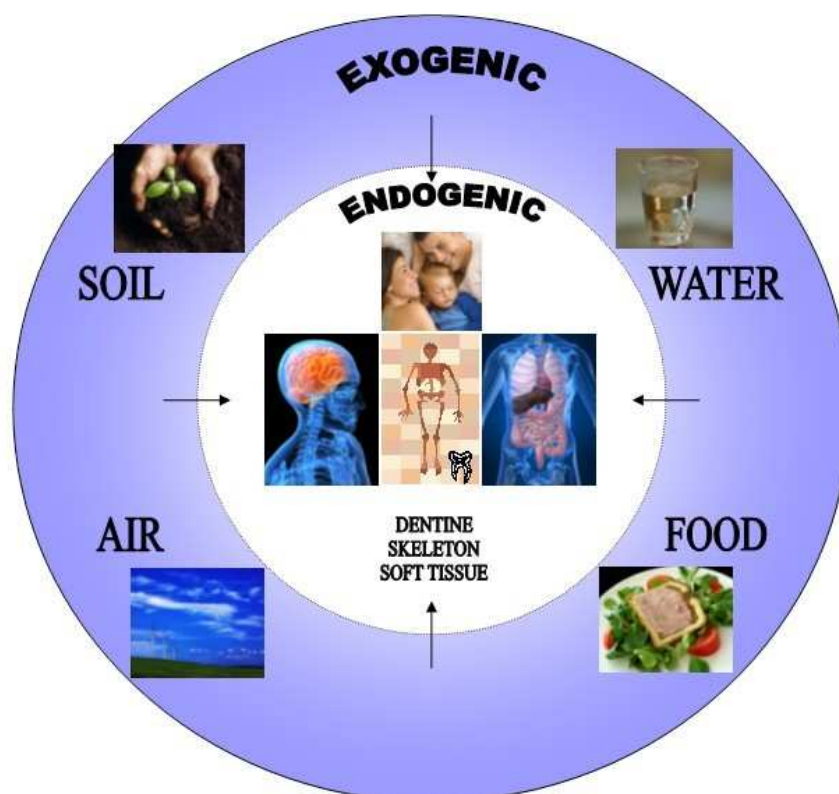
Although the rate of lead uptake within the gut can vary among individuals, it is recognized that the absorption rates are 3 to 6 times greater in children compared to adults (Karhausen, 1972; and Alexander at al., 1973, cited in Thornton, 1984). Furthermore, lead uptake in drinking water may be 6 to 20 times greater when taken on its own compared to when taken with food (The Royal Society of Chemistry, 1982, cited in Thornton, 1984). Therefore in terms of dose response association, infants and toddlers should be more susceptible to lead toxicity as drinking water is the base of their dietary intake, from baby food preparation and baby formula. Up to 90 % of the weight of an infant's diet can be attributed to household tap water when bottle-fed (Millstone, 1997). However, dwelling in newly constructed homes does not exempt the risk of lead poisoning

in children. The use of soldered connections in conjunction with copper piping can cause enough dissolution of lead to cause lead poisoning in children, having been recorded at approximately 210-390 μg/ L (Cosgrove, 1989, cited in World Health Organization, 2003).

Lead exposure *in utero* (prenatal) may interrupt early mental growth. However, it is suggested that presence of confounding factors such as low birthweight can also potentially contribute to the interference of early mental development (World Health Organization, 2003) The symptoms and health effects of lead poisoning are numerous and varied, affecting vast areas of the human body; and where it is possible to cause critical emergency symptoms with just one high lead dose (MedlinePlus, 2009). Chronic environmental exposure to lead may result in lead induced symptoms and chronic health effects in young children. Blood lead levels (BLL) measuring less than 10 μg/ dL can still have adverse effects on the neurological function of children. Lead is continuously negatively associated with Intelligence Quotient (IQ) for children in elementary school and younger, delaying the neurodevelopment of children (Binns et al., 2007). Besides examining the risk of water lead contamination in Northwest Christchurch water supply, the recognition of the physical, mental, and social health implications of environmental lead on young children is also the objective of this dissertation. A list of lead induced symptoms and complications is in Table 3, while a description of chronic health effects from chronic lead exposure is in Table 4.

1.2 Objectives

This dissertation addresses the following objectives:

1) Hazard identification: identify the health hazards due to environmental lead, including lead dissolution in households with older reticulation system

2) Risk characterization: characterize the risk of environmental exposure to lead and develop a conceptual service model based on effect measure and possible exposure levels and,

3) Risk mitigation: based on the risk characterization, outline what steps might be appropriate to limit the lead toxicity problem due to older reticulation system in Northwest Christchurch households.

Table 3: List of lead induced symptoms and complications

Definition	Conditions
Lead induced symptoms (Acute and Chronic)	• Nausea • Vomiting • Slurred speech • Stomach pain and cramping • Body shock • Coma • Ataxia • Tremors • Metallic taste • Low appetite and energy • Blue line on gum margins • Chronic nephritis • Nephrotic syndrome • Saturnine gout • Constipation • Encephalopathy • Muscle aches • Headaches • Irritability • Delirium • Difficulty sleeping • Aggressive behaviour • Arterial hypertension • Peripheral vasoconstriction • Reduced sensations • Leg pain and cramping • Radial nerve palsy (wrist drop) • Loss of past developmental skills in small children
Lead induced complications	• Problems with behaviour or attention • Failure in school studies • Kidney damage • Anaemia • Reduced IQ (neurological and cognitive function) • Reproductive dysfunction and preterm delivery

Source: MedlinePlus, 2009
                    International Programme on Chemical Safety INCHEM

Table 4: Chronic health effects in children resulting from chronic exposure to lead

Condition	Description
Reduced IQ	The chronic health effects of lead exposure become evident with time. These appear as developmental delays from impaired cognitive, behavioural, and motor abilities. Children can experience learning regression and refuse to play in cases of chronic neurological impairment. They may develop slurred speech, a state of stupor, ataxia or convulsions. * †
Encephalopathy and mortality	Fatal outcomes from lead encephalopathy have been recorded to be as high as 25 % of cases. Survivors from lead encephalopathy experience increased intracranial pressure, and often develop impaired mental abilities, seizures, cerebral palsy, muscular dystonia, or optical atrophy. †
Anaemia	Chronic lead toxicity can result in the inhibition of haem synthesis and drop of life span in erythrocytes (red blood cells), resulting in hypochromic microcytic anaemia. †

Source: * Binns, Campbell and Brown, 2007.
            † International Programme on Chemical Safety INCHEM

Chapter 2

Methodology

2.1 Overview

This dissertation reviews the possibility of lead poisoning through various sources and pathways, and the health effects associated with them; however, with greater attention on the possibility of water lead contamination in the Northwest Christchurch zone as a result of lead dissolution in old water reticulation systems. The first step was to conduct a background research to address the effects of lead on humans, followed by steps on lead hazard identification; hazard characterization; and risk mitigation. Based on this systematic literature review, we have attempted to develop a conceptual service model that might mitigate this potential public health issue. The essential steps of the research process are presented in Figure 2.

2.1.1 Development of the background information

In the first phase of the review, a background knowledgebase of international and local scale involving the study of lead sources and pathways and their effects on the human body was developed through literature searches. The detrimental effects of the many lead sources and pathways on the health of young children were discussed in particular. Moreover, efforts were made to attain detailed background information on Christchurch public water supply; and in

particular background information for Northwest Christchurch zone, having had access to exclusive information via communication with research professionals and city council officials.

Figure 2: **The steps of the dissertation research process**

Background Research: An introduction and literature review of lead sources and pathways and its effects on humans on an international, national and Christchurch scale is conducted. Focusing in particular on the public water supply in the Northwest Christchurch zone; its health effects in infants and young children; brief description of mental developmental effects; intelligence quotient (IQ) tests; mention of recommended effective abatement action to mitigate lead risk.	**Health Risk Review and Discussion:** to appraise the health risk and potential negative effects of lead exposure through various environmental lead sources and pathways on the mental development of infants and young children; and in relation to Northwest Christchurch drinking water, in reference to the California Environmental Protection Agency (EPA) environmental health hazard assessment evidence guidelines.	**Enabling powers of effective communication:** Review the benefits and trend of using web-based (e.g.- wikis, blogs, cellphone-web integration information communication technology (ICT), etc.) and traditional non web-based (e.g.- public dialogue, talks, brochures etc.) platforms in risk communication for improved information dissemination &collaboration.

Enable Informed Decision Making: improve management practice.

2.1.2 Environmental health risk assessment processes

A systematic review of relevant literature was undertaken using the Californian state Environmental Protection Agency (EPA) environmental health hazard assessment evidence guidelines (US EPA, 1986).

2.2 Steps of systematic review

The publications were often accessed via the internet through the web-based Yahoo!, and Google Scholar search engines; web-based PubMed, Scopus, ProQuest, ScienceDirect and Canterbury University library databases. To answer these three questions, a search of the available peer reviewed

and reliable literature was undertaken with a set of defined search criteria and keywords. In short, publications were chosen for review if the risk for lead exposure and lead poisoning effects on young children were discussed and examined.

2.2.1 Research question

In line with the topic of this dissertation study, this review specifically answers the following questions:

1) What is the extent of exposure to inorganic lead in the household water supply system as carried by old reticulation system and other possible sources?

2) What are the different health outcomes of environmental exposure to inorganic lead through drinking water as opposed to other sources of environmental exposure to lead on children aged 15 years and younger?

3) Based on the available evidence, what are some advisable mitigation activities to reduce the harm; and a consideration of what has already been done or steps being taken by the Christchurch City Council authorities?

In collecting background knowledge for this study, sources and pathways of potential lead contaminants in the Northwest Christchurch water supply networks were investigated. In addition, the effectiveness of activated carbon water purification systems in the management of lead in drinking water, as well as the benefits of greater information sharing between web-based and non web-based platforms in improving public risk communication and management practices, were briefly explored.

2.2.2 Search strategy

Internet and library databases were among the search engines and databases used to locate relevant literature. Boolean Logic (AND/OR/NOT) (Strickland & Henderson, 2009) was the primary technique used to conduct the searches.

Search terms used include key words and terminology such as '*plumbosolvency*', 'lead', 'water supply', 'health', 'activated carbon', 'corrosion', 'filtration', 'water treatment'. The complete list of search terms can be found in Table 5.

Table 5: Search terms used to identify the sources of environmental inorganic lead poisoning and their health effects on children

List of search terms used in conducting the literature database searches	
Christchurch	Drinking water
New Zealand	Water supply
Blood	Groundwater
Lead	Household
Pb	Domestic
Air	Plumbosolvency
Soil	Neurotoxicity
Food	Pica
Water	Behaviour
Infant	Child
Bottle	Urban
Rural	Mental
Developmental	Health
Pregnant	Breast milk
Activated carbon	Intelligence quotient
Filtration	IQ
Learning	Paint
Urban	Contamination
Rural	Pollution
Inorganic	Christchurch City Council
Surveillance	Ministry of Health
Poisoning	World Health Organization
Death	Reticulation
Consumer health informatics	Health knowledge management
CHI	Health KM
Web 2.0	

2.2.3 Retrieval of the publications

A publication was included for review if the focus of the study involved either the investigation of environmental lead sources; the origin of lead in drinking water supplies; estimation of dose response or, analysis of the association between environmental exposure to inorganic lead and the presence of specific neurological deficits in children aged between 0-15 years.

A study or publication was excluded from the scope of this review if it did not meet any of the above criteria or if it was based on animal subjects or, tissue-based wet laboratory assessments of lead toxicity.

The retrieval of publications for review essentially involves two stages. In the beginning, only titles and abstracts were analyzed to include or exclude a study from the scope of this review. Once a study was selected for further review, full texts were obtained for review, and the study critically appraised using the conditions described above.

Chapter 3

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Results and literature review

Table 6 shows a summary of the common plumbing materials used in New Zealand domestic plumbing (Shearer, 1974), along with a list of potential adverse outcomes from acquiring dangerous levels of body burden from these elements. There are no detailed records to confirm the exact type of domestic plumbing materials used in the old Northwest Christchurch homes, therefore it should not be taken as a direct representation of the actual domestic water supply plumbing materials used.

3.1 Summary of the background information

The lead exposure pathways are many and varied. For example, depending on wind strength and its dominant trajectory, windblown aerosol lead from leaded petrol vehicle emissions would tend to travel significant distances and contribute environmental lead by settling on nearby plant, soil and surface water sources. The danger therefore may be from aerosol lead particles that are directly inhaled through breathing, or settle and contribute to the lead contamination of garden soil where children play; crop in agricultural land; or water in poorly protected storage tanks, evident as air; soil; food; and dust as water lead contaminants through its different stages. Owing to its specific characteristics, absorption via skin contact was the least likely contamination pathway compared to inhalation or ingestion. In infants and young children, the obvious source of lead exposure would

have been through maternal breast milk; infant food and formula (lead tainted product or lead tainted

drinking water); mouthing of leaded toys; pica behaviour on lead contaminated soil; as well as poor

hygiene behaviour with hand washing practices.

Table 6: Health hazards at concentrations exceeding MAV from exposure to chemical components found in common New Zealand plumbing materials

Materials	MAV/ Guideline value	Health hazards at concentrations exceeding MAV
Metals Aluminium	Not established □	Neurotoxicity (behavioural impairment). ■
Copper	2 mg/ L □	Gastrointestinal problems; developmental problems. High risk for people with Wilson's disease ■
Iron	Not established □	Haemorrhagic necrosis, sloughing of stomach mucosa and submucosa. High risk for people with Haemochromatosis ■
Tin	Not established □	Gastrointestinal problems (vomiting; diarrhea). ‡
Zinc	Not established □	Gastrointestinal problems; fever. ■
Lead	0.01 mg/ L □	Lung cancer; Neuromotor problems; Developmental problems. High risk to pregnant women and young children. †
Alloys (example) Brass	-- □	Release of lead (Lead toxicity) compounds and other metals. ■
Plastics (example) P.V.C.	0.0003 mg/ L □	Vinyl chloride residue and release of Organotin. Multisystem toxicants. *

Source:
* Baue, 2001
† Millstone, 1997
□ World Health Organization B
‡ World Health Organization C
■ World Health Organization D

1) What may be the extent of exposure to inorganic lead in the household water supply system as carried by old public reticulation system and other possible sources?

The level of lead exposure in an indoor domestic environment is usually magnified on residents of

older homes. In addition, young children and pregnant women (child in the womb) are often at higher

risk of being poisoned. According to the Water & Sanitary Services Assessment 2005 (Christchurch City Council, 2005) publication, some water supplies in the northwest Christchurch City have received water treatment in terms of potential of hydrogen adjustment via caustic soda chemical treatment. However, only an estimated 20–30 % of the Northwest Christchurch Zone residents were affected. Water quality has since improved in the Northwest Christchurch water supply where the value of potential of hydrogen has increased through water mixing (Murugesh, 2009). Therefore water is now less corrosive and has less potential to cause adverse health effects. See Table 7 for more information.

Table 7: Key background information about exposure to inorganic lead in domestic water supply

Author, year	Resource	Summary information
WHO, 2003	Web-based publication	Lead in drinking water is the most controllable source of lead contamination since aerosol lead in the 1970s and 80s.
Millstone, 1997	Book	IQ tests have to be interpreted with care as there is always a measurement error involved and it is difficult, if not impossible to test all aspects of intelligence.
Murugesh, 2009	Personal Communication	Concerning public water supply lead hazards, the water pH at two water pumping stations (Burnside and Farrington) in the Northwest Christchurch zone were low (acidic) in the past due to use of shallower unconfined aquifers. After mixing with deeper well water, pH levels have improved to reduce the effects of corrosion on the public water supply reticulation system.
CCC, 2005	Web-based publication	Concerning domestic water supply hazards, Leaded plumbing solders and fixtures from domestic plumbing systems (within the homeowner's boundary) are the most probable cause of contamination.

Source: Christchurch City Council, 2005
Millstone, 1997
Murugesh, 2009
World Health Organization, 2003

2) What may be the different health outcomes of environmental exposure to inorganic lead through drinking water as opposed to other sources of environmental exposure to lead on children aged 15 years and younger?

For instance, these involve body lead burden measurements of children as well as pregnant mothers as lead is known to transfer from the mother to the foetus during pregnancy across the placental barrier, and through breastfeeding. In terms of maternal inorganic lead exposure, this highlights the significance of ensuring maternal consumption of inorganic lead through drinking water is minimized even while the foetus is *in utero*. See Table 8 for more information.

3) What may be some advisable mitigation activities to reduce the harm and a consideration of what has already been done or steps being taken by the Christchurch City Council authorities?

The publication of Christchurch City Council reports such as the Water & Sanitary Services Assessment (Christchurch City Council, 2005; Ministry of Health, 2005) helps to reduce harm with proven guidelines. The renewal of water reticulation mains in Christchurch city has also meant that old cast iron pipes were being replaced. The Mains Renewal Strategy as part of the Lifecycle Management Plan ensured that the public water reticulation service remains in good operation, and is being maintained, repaired or renewed when needed (Christchurch City Council, 2006). (See Table 9 for more information)

Table 8: Comparison of water supply lead and other lead health hazards affecting children 15 years and younger

Lead source	Main hazard route
Water lead	Ingestion pathway through drinking lead contaminated water. It can be found in drinking water through the dissolution of leaded plumbing components. For instance, this can occur when bottle-fed infants are given water from lead contaminated domestic water supplies. An example where exposure risk is high is when chemical factors in drinking water promote lead dissolution of water reticulation systems. Factors such as acidic water; high temperatures; and prolonged standing time in pipeworks can all encourage *plumbosolvency*. □ †
Food lead	Ingestion pathway through eating lead contaminated food. Often lead traces may be found in food itself, and lead levels often increase after lead contaminated potable water is used in cooking; lead-glazed containers or lead-soldered tins are used in the storage of foods. Like water lead levels and the effect of acidic water on lead dissolution, food lead levels increase when in contact with leaded materials. Infant body lead load has also been found to reflect maternal body lead levels through breast feeding in humans. □ †
Soil lead	Ingestion pathway through eating lead contaminated soil particles. Children may be exposed to high lead levels from playing in the garden where they may ingest chipped leaded external house paint or lead contaminated garden fertilizer from pica behaviour or by accident through poor hygiene practices such as eating before washing hands. ‡
Air lead (or Dust lead)	Ingestion or inhalation pathways through eating or breathing in lead contaminated dust particles. Examples where exposure risks are high are where children are exposed to dust from deteriorating old leaded house paint; where occupationally lead-exposed parents bring lead dust indoors from work; where children are exposed to vehicle and industrial emissions; and where children are exposed to lead fumes from proximity to cigarette smokers and adult hobbies involving use of leaded solder and components. * †

Source: *   California Environmental Protection Agency , 2001.
          □   Gulson et al., 1999.
          †   World Health Organization, 2003.
          ‡   Millstone, 1997.

Table 9: Steps taken by the CCC and MoH to mitigate public health concern for lead toxicity in the NW Christchurch public and domestic water supply

Author, Year	Description of the source	Key findings
CCC, 2006	Report	Old cast iron pipes have been replaced over the last decade and it is projected to continue with more replacement work over the coming years as part of their long term reticulation lifecycle management plan. Less acidic waters from water mixing also inhibits lead dissolution.
CCC, 2005	Report	Information on water quality, source and guidelines are provided in this report, specifically on the quality and management of Christchurch drinking water.
MoH, 2005	Report	A breakdown of nationwide water supply management guidelines. It includes provides a comprehensive record on guidelines governing both rural and urban populations, and covers both private and urban water supply users.
MoH, 2007	Report	The publication addresses the adverse effects of lead contamination and health problems in lead exposed persons, as well as providing proper management guidelines

Source: Christchurch City Council, 2006
                Christchurch City Council, 2005
                Ministry of Health, 2005
                Ministry of Health, 2007

3.2 Lead screening

3.2.1 Public health lead surveillance

There have been ongoing lead screening programmes in New Zealand, where national Public Health Surveillance data and information are collated, analyzed and the results presented in report publications. The Annual New Zealand Notifiable Disease Report 2008 (Environmental Science and Research, 2009) stated that 315 lead absorption cases were notified in year 2008, which is a significant increase from the 78 lead absorption cases notified in year 2007. This was 7.4 per 100

000 population and 1.8 per 100 000 population, respectively. However, upon closer inspection of the 315 cases, children aged < 15 years accounted for only 13 of the cases, while the rest were adults aged >= 15 years. A study of the lead absorption notifications in children and adults between years 1997-2008 showed that the highest recorded number of notifications in children was 25 cases in year 1999, while the lowest recorded number of notifications in children was 6 cases in years 2004, 2005 and 2007 (Environmental Science and Research, 2009).

3.2.1.1 Most common lead risk factor in children

Importantly in lead absorption for children, the most common risk factor for children was from regularly visiting or dwelling in a building constructed before 1970 that had deteriorating house paint or had undergone building alterations or renovations. This was consistent with the findings in previous years.

3.2.1.2 Most common lead risk factor in adults

On the other hand, for adults, the most common risk factor was from lead-exposure high-risk occupation. This was different from what was recorded in previous years (Environmental Science and Research, 2009).

Although the number of reports on notified cases in adults have increased significantly, perhaps it is possible to theorize that it is due to greater public vigilance. More adult individuals have gone for lead tests, and hence, a proportionately higher number of cases have been notified as opposed to the sudden influx of lead exposure cases among adults in New Zealand society. Nevertheless, the report did point to a cluster of 100 individuals who were indeed occupationally lead-exposed from a common task of paint removal works from the Auckland Harbour Bridge—contributing to a sudden lead poisoning increase. As with many other research studies, it is important to also note that often some study participants for

unknown reason are unable to provide information that are essential to the study, thereby, complicating the reliability of the end results.

For this study, there was no mention of exposure to water lead sources in the Public Surveillance Report.

3.3 Introduction to lead

3.3.1 Lead properties

In terms of the physicochemical properties of lead, inorganic lead has a melting point of 327.4 Centigrade. At 13 mg/ kg, lead is one of the most widespread heavy elements that comprise the earth's crust. Examples of stable lead isotopes that occur in nature are ^{208}Pb ^{206}Pb ^{207}Pb ^{204}Pb (World Health Organization, 2003). Lead nitrate, chlorate and chloride are water-soluble. Other lead salts have poor water solubility although many will dissolve with acids (International Programme on Chemical Safety INCHEM). Lead vapours form at 550-600 Centigrade. Occupational lead exposure can often be due to these lead vapours as fumes and mists in the work environment. Lead will be attacked/ corroded by pure water or weak organic acids with the presence of oxygen, as lead reacts strongly with oxidizing materials (International Programme on Chemical Safety INCHEM).

3.3.2 Lead use

3.3.2.1 Lead use in the human body

Lead serves no useful purpose in the body (Ministry of Health, 2007) and therefore, is undesirable and unsafe from the human health point of view.

3.3.2.2 Lead use in the manufacturing industry

Lead is used in the production of various things. It can also be present in alloys such as solders and brass. Some of the key uses of lead in the manufacturing industry include the use for production of leaded items such as:

- Lead acid batteries
- Alloys
- Solder

- Glazes
- Paint pigments

(Ministry of Health, 2007; World Health Organization D).

3.3.2.2.1 Lead use in petrol

The once extensive use of tetraethyl and tetramethyl lead as petrol anti knock compounds has greatly dwindled on a global scale. As of 2003, although it is reportedly still used in Eastern Europe and various developing countries, North America —being one of the past frequent users and contributors to atmospheric lead— is reportedly currently close to completely ending its use (World Health Organization, 2003).

3.4 Water Chemistry

3.4.1 Acidic water condition

Apart from being able to dissolve lead, acidic waters are able to corrode other metals. It becomes more acidic and aggressive when exposed to peat and decaying vegetation. Even rain water takes on a more aggressive reaction to certain compounds in the air. In acidic water conditions where potential of hydrogen values fall below 8, the decline in equilibrium of carbonate level occurs.

However, water high in alkalinity and air content is also potentially *plumbosolvent* (Christchurch City Council, 2005).

3.4.1.1 Acidic water effects on lead

Lead solubility and dissolution heightens as a result of the acidic water environment.

3.4.1.2 Pipework replacement & chemical dosing

During pipework replacement, chemical dosing of water supply is sometimes undertaken by adding orthophosphate to heighten potential of hydrogen levels to the ideal 8.0-8.5 (World Health Organization A).

3.4.1.3 Galvanic corrosion

Galvanic corrosion occurs when the rate of lead dissolution is not restricted by corrosion product solubility is, instead, influenced by chloride concentration thereby, accelerating the *plumbosolvent* nature of lead when it merges with copper (World Health Organization A). Hence, in acidic water conditions as in New Zealand, it is also possible to manage galvanic corrosion effects through the alteration of the potential of hydrogen levels and concurrent chemical treatment of drinking water with zinc and orthophosphate dosing.

3.5 Leaded paint in New Zealand

3.5.1 History of leaded paint hazards in New Zealand

Although controlling lead exposure due to water contamination as a result of old reticulation system is the theme of this research study, it is imperative to also acknowledge the history of

leaded paints in use in New Zealand. It is clear from research that the use and hazards of leaded paints in New Zealand was more extensive, and had been documented as posing a much greater risk to young children as a source of lead exposure and contributor to body lead burden (Ministry of Health, 2007). However, this review topic was chosen in the interest of academic study and to add to the limited number of water lead studies conducted in Christchurch.

3.5.1.1 Policy on permissible paint lead level

There is a policy by the Australian Uniform Paint Standard that New Zealand follows. In the Hazardous Substances and New Organisms Act 1996, under the Appendix 1 of the Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP) No. 20, the manufacture, supply, sale or use of paints of permissible level is set at < 0.1 % and 0.2 %. The percentage is based on the non-volatile paint content. Also, unless the manufacture, sell, supply or use of paint on children's toys complies with coating material conditions as stated in Part 3 of the Australian Standard 1647 for Children's Toys, it is banned in New Zealand (Ministry of Health, 2008).

3.6 Lead exposure

3.6.1 Susceptibility to lead poisoning

Young children are most susceptible to adverse effects from lead exposure. Young children and those *in utero* in pregnant women often succumb to greater danger from lead exposure compared to adults, as the degree of risk is dependent on relative bodyweight (Brown, Lawler and Smith, 1995; University of Colorado, 2008). In children, acute toxicity can often happen through ingestion of leaded paint flakes from pica behaviour (International Programme on Chemical

Safety INCHEM).For the purpose of this study, observations will focus on Northwest Christchurch zone infants, young children and pregnant women.

3.6.2 Lead contamination sources & pathways

3.6.2.1 Lead Sources

The most common reason for high body lead load is due to anthropogenic (human generated) lead sources. These sources commonly reach human level through these forms: air, food, drink, soil and water. As lead exposure can occur through a plethora of complex pathways, it is important to be aware of ways to avoid excessive exposure, particularly among susceptible populations.

3.6.2.1.1 Air lead

Atmospheric/ Air lead pollution can occur through various industry processes. A high risk of lead poisoning from exposure to lead compounds often occurs in occupationally exposed persons through work such as the smelting and refining of lead, steel welding, spray coating, battery manufacturing, building paint removal, plumbing and, burning of oil and coal. About 20 % of atmospheric lead remains airborne, and is dispersed far and wide. However, air lead concentrations will vary from location to location. Air lead concentrations in large urban cities can vary by 2-4 $\mu g/\ m^3$ whereas, in rural and suburban areas it can vary by 0.2 $\mu g/\ m^3$ or less (WHO, 1972; WHO, 1977; ACGIH, 1986; Budavari, 1989, cited in International Programme on Chemical Safety INCHEM; Ministry of Health, 2007). Air lead intake occurs through aerosol or airborne lead dust intake. Several factors can determine the level of atmospheric lead contamination. This includes the proximity to inhaled air lead sources such as road traffic dust. However, air lead levels have reduced drastically over the past decades with the introduction and

enforcement of atmospheric lead emission legislation and lead use in fuels (Levin, Schock, and Marcus, 1989).

Also, adult family members may expose others to lead dust when their occupation or hobby involves the use of high lead materials. Lead dust may be brought home by workers engaged in activities where lead dust may have deposited on the clothes. Due to poor hygiene and workplace health safety practices, workers may not change clothes or take a shower before returning home. Other possible contributors to household lead can be from lead dust where old leaded household paints deteriorate and chip. This is a hazard that applies globally.

The following are examples of the aforementioned air lead sources and pathways (Millstone, 1997; Ministry of Health, 2007):

- Leaded petrol emissions

- Leaded industry air emissions such as battery manufacturing

- Spray-paint or solder vapours from occupations or hobbies

3.6.2.1.2 Food lead

Significant levels of lead may be found in food, particularly when lead contaminated water, or leaded utensils and kitchenware are used. For instance, leaded glazed ceramics used for cooking and food storage purposes are especially hazardous when in contact with acidic foods. Lead soldered cans, although its use has declined in the food processing industry, are also a cause for food lead contamination. In many cases, it has been resolved by the use of lead-free solders (Quinn and Sherlock, 1990; and Galal-Gorchev 1991, cited in World Health Organization, 2003). However, the question

remains whether businesses would follow a country's set regulation controls. Other contexts for food lead concern include the following:

- Cross-contamination during food manufacture
- Mouthing of toys with leaded paint in infants (behavioural)

3.6.2.1.3 Water lead

It is reported that the most prevalent and near universal source of lead in drinking water distribution systems can be traced back to plumbing solder and fixtures (World Health Organization, 2003). Lead contamination of drinking water, even in storage tanks, can often also be attributed to the dissolution of leaded metal pipes or service connections in domestic plumbing systems. Nevertheless, even polyvinyl chloride (PVC) pipes are responsible for the dissolution of lead compounds in the domestic water supply. Factors that determine the degree of corrosion and concentration of water lead contaminants include the pH (power/ potential of hydrogen), temperature, standing time and, apart from the presence of chloride and dissolved oxygen, with acidic water being the most corrosive (Quinn and Sherlock, 1990; and Schock, 1990, cited in World Health Organization, 2003). Since the successful control of atmospheric lead levels, international research and the resultant deeper understanding of lead management has made lead in drinking water become the most controllable source of lead exposure in the United States of America (Levin, Schock, and Marcus, 1989). Other contexts for water lead concern include the following:

- Old leaded crystal decanters used in storing drinking spirits
- Leaching from new leaded domestic plumbing, prior to the development of a protective layer against corrosion

3.6.2.1.4 Soil lead

Apart from lead contaminating drinking water sources, young children are inclined to be exposed to lead of various concentrations in soil and settled household dust (US EPA, 1986; Clausing, Brunekreef and van Wijnen, 1987, cited in World Health Organization, 2003*). Lead concentrations from these sources are essentially constant without proper abatement action.

A Christchurch New Zealand study by Shellshear, Jordan & Shannon (1975) on soil lead as a potential health hazard for children showed that elevated body lead burden was also a problem in Christchurch children. A high level of soil lead concentration was found to be associated with older painted buildings. Pica behaviour through ingestion of lead contaminated garden soil from leaded external house paint dust or flakes were found to be high predictors for elevated blood lead concentrations in young children. This was particularly true in dilapidated housing conditions in poorer areas where the majority of lead poisoning cases occur. Another context for soil lead concern includes:

- Pica behaviour of lead contaminated garden soil from garden fertilizer

3.6.2.2 Lead pathways

Human lead exposure pathways include the inhalation of lead particulates through the lungs (pulmonary intake); ingestion (dietary intake) through the gastrointestinal tract; and absorption through the skin, in the case of exposure to organic lead compounds that were added to fuel. However, skin (dermal) lead absorption of inorganic lead is of the least concern (The Royal Society of Chemistry, 1982, cited in Thornton, 1984).

3.6.2.2.1 Occupational lead exposure

Breathing in of lead fumes and fine lead particulates are the main route of occupational and general environmental lead absorption (International Programme on Chemical Safety INCHEM).

3.6.2.2.2 Non occupational lead exposure

A high risk of lead poisoning can often occur in non-occupationally exposed persons through food and water ingestion (International Programme on Chemical Safety INCHEM).

3.6.2.2.3 Ingested lead compounds

Infants and young children are often at risk of lead ingestion. This is arguably the most challenging pathway. Ingested lead compounds can be in the form of leaded soil, dust or, paint flaked from internal or external house paint. This can easily occur through domestic (indoor) sources of lead exposure in children such as eating with unwashed hands after playing in lead exposed environments, or mouthing of objects with leaded paintwork (MedlinePlus, 2009). Pica, mouthing of objects and, poor hygiene are behaviours in daily activities that can potentially contribute to high body lead load in both infants and young children. Likewise, use of the aforementioned leaded earth-glazed pottery may also contribute to adult ingestion of lead compounds (Ministry of Health, 2007). Even so, risks that involve behaviours can be avoided or stopped such as when adult caregivers are aware of these behaviours and are educated to actively discourage pica behaviour as cautionary or intervention measures or, when young children naturally grow out of pica behaviour on their own.

3.6.2.2.4 Inhaled lead compounds

Apart from lead ingestion from daily activities, small amounts of lead can also be inhaled by infants and young children (MedlinePlus, 2009). As mentioned above, inhaled lead compounds can be in the form of lead fumes such as from steel welding; spray coating; or burning of coal in occupationally lead exposure persons. Without proper ducting, hobby soldering in homes can also contribute to dangerous levels of body lead load.

3.7 Lead uptake

3.7.1 Lead uptake contingency

Lead uptake is also dependent on the nutritional status of the person. Intake of phosphate, calcium, iron and zinc levels appear to affect the distribution and absorption levels of lead in the body. High intake of phosphate causes lead to be stored in bones. Conversely low intake of phosphate causes to lead to redistribute from bones into soft tissues (Ellenhorn, 1988; Gilman, 1990; Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM). Also, lead absorption is heightened with lowered calcium and zinc levels while iron appears to encourage lead absorption. Different lead components are also absorbed more rapidly and completely (Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM).

3.7.2 Lead accumulation

Lead accumulates in the body. There are primarily three clinical scenarios from inorganic lead poisoning. These are: i) acute poisoning, ii) chronic poisoning and, iii) asymptomatic poisoning, as occurs during childhood and early stages of poisoning (International Programme on Chemical Safety INCHEM).

3.7.3 Toxic kinetics of lead

3.7.3.1 Toxic kinetics of ingested lead

Reports on the kinetics (biochemical reaction) of lead though the ingestion route has shown the following: The adult human gastrointestinal tract is estimated as only absorbing up to 5-15 % of ingested lead, while the remaining unabsorbed lead components are eliminated through faeces. However, it is important to note that actual absorption may also increase up to 45 % under fasting conditions (Putnam, 1986, cited in International Programme on Chemical Safety INCHEM), and up to 53 % for young children and infants (WHO, 1977, cited in International Programme on Chemical Safety INCHEM). Therefore, when determining ingested lead absorption rates, it is implicit to also consider the effects of age and diet behaviours.

3.7.3.2 Toxic kinetics of inhaled lead

Whereas reports on the kinetics of lead through the inhalation route showed that: The absorption of lead particles that reach the respiratory tract is estimated at 50-70 % and should therefore be regarded as a significant route of entry. However, the absorption rate is still dependent on the concentration, ventilation rate and size (under 1 µm) of the particles (Putnam, 1986; and Budavari, 1989; and Gilman, 1990, cited in International Programme on Chemical Safety INCHEM). The bones comprise of approximately 95 % of body lead load. Lead concentrations in erythrocytes exceed lead concentrations in blood plasma by 16 times (WHO, 1977, cited in International Programme on Chemical Safety INCHEM).

3.7.4 Lead deposition

3.7.4.1 Blood lead deposits

Blood lead deposits remain in teeth (dentine) and bones (skeletal system) for long periods and are indicators of cumulative past exposures (US EPA, 1986). These can then become slow release, endogenic (internal) sources of body lead. Blood lead deposits can also affect the function of soft tissue including muscle and peripheral nerves, and organs such as the kidney and brain. Blood lead measurements are commonly used to indicate internal body lead uptake and are often in equilibrium with soft tissue lead stores.

3.7.5 Measuring body lead load

3.7.5.1 Blood lead load vs. total body lead load

When measuring body lead load, a danger exists where high blood lead concentrations can temporarily obscure hazardous levels of internal lead stores. Although blood lead levels are an indicator of recent lead exposure, it does not reflect on the total body lead burden. Nevertheless, decline in blood lead levels are relatively rapid compared to stored body lead concentrations. Blood lead levels decline to reflect reduced exogenic (external/ environmental) lead levels. While it is clear that blood lead levels show a causal link between likely exposure and effect components, there is still uncertainty surrounding the exact dose of lead necessary for adverse effects to occur (WHO, 1977, cited in International Programme on Chemical Safety INCHEM).

3.7.5.1.1 Maternal and infant blood lead concentrations

Due to the poor placental barrier against lead, newborn blood lead concentrations are found to be similar to maternal levels (Moore, 1983 cited in Thornton 1984). As a result, the neurological development of infants and young children may be adversely affected (MedlinePlus, 2009).

3.7.5.1.2 Venous vs. capillary blood lead sampling

Since the year 2007 amendment of the New Zealand Health Act 1956, a venous blood lead sample of $\geq$ 0.48 µmol/ L concentration was applied across all ages and established as a requirement for the official announcement of lead poisoning. Also, venous blood lead values were used to determine action instead of capillary blood (finger prick) values (Ministry of Health, 2007).

3.7.5.2 Highest lead concentration

The highest lead concentration appears to centre in the aorta in the human circulatory system.

3.7.5.3 Lowest lead concentration

Lower lead levels are found in various other parts involving different organ systems such as the kidney, liver, brain, heart and muscle (Schroeder and Tipton, 1968; and Barry and Mossman 1970, cited in Thornton, 1984) in the urinary, digestive, central nervous, circulatory and muscular systems respectively.

3.7.6 Lead storage

3.7.6.1 Skeletal stores

In a context of steady equilibrium, different concentrations of lead are found in different parts of the body, with the majority at approximately 90 % comprised of lead in skeletal stores (Waldron and Stofen, 1974, cited in Thornton, 1984).

3.8 Lead poisoning

3.8.1 Lead poisoning

Both chronic low dose exposure of lead and acute high dose exposure of lead can cause problems to various human bodily organ systems. The main lead health hazards are from exposure to lead through inhalation and ingestion routes via air, water, food and soil sources.

3.8.1.1 Lead poisoning symptoms

The symptoms of lead poisoning are numerous and varied, affecting vast areas of the human body and causing critical emergency symptoms. Nevertheless, lead poisoning is more often due to the gradual increase of body lead burden from cumulative lead exposures. Symptoms can remain undetected until prompted by the gradual health decline that increases with blood lead concentration (MedlinePlus, 2009). Therefore the symptoms and severity of lead poisoning is reliant on a dose response outcome.

Lead induced symptoms may include (MedlinePlus, 2009):

- Stomach pain and cramping
- Low appetite and energy
- Aggressive behaviour
- Constipation
- Headaches

- Irritability
- Difficulty sleeping
- Reduced sensations
- Loss of past developmental skills in small children

3.8.1.2 Lead poisoning complications

Lead target organs primarily involve the renal and central nervous systems (International Programme on Chemical Safety INCHEM). In addition, lead poisoning can cause damage to the reproductive system; peripheral nervous system; gastrointestinal structures; and cause haematological effects by impeding the haem (blood) biosynthetic pathway (Putnam, 1986; and Sax, 1989; and ATSDR, 1990, cited in International Programme on Chemical Safety INCHEM). Chronic poisoning most often affects young children and adults occupationally exposed to lead (International Programme on Chemical Safety INCHEM).

Lead induced complications in children may include (MedlinePlus, 2009; International Programme on Chemical Safety INCHEM):

- Failure in school studies
- Kidney damage
- Reduced IQ
- Anaemia
- Problems with behaviour or attention

3.8.1.2.1 Fertility problems

3.8.1.2.1.1 Reproductive dysfunction & preterm delivery

There have been reports of reproductive dysfunction in both males and females. Blood lead levels of 40-50 μg/ dL have also been linked with male gonadal dysfunction, causing lowered sperm count (Lancranjan, 1975; and Wildt, Eliasson and Berlin, 1983; and Cullen, Kayne, and Robins 1984; and Assennato et al., 1986, cited in World Health Organization, 2003). In addition, a study on pregnant women exposed to lead showed an increased risk of preterm delivery. According to a study (McMichael AJ et al., 1986, cited in World Health Organization, 2003), the relative risk of preterm delivery among pregnant women with blood lead levels exceeding 14 μg/ dL was four times greater than those recorded with blood lead levels of 8 μg/ dL or less.

3.8.1.2.2 Fatal poisoning

3.8.1.2.2.1 Fatal adult poisoning

According to Gosselin, 1984 (citing IPCS INCHEM) in lead toxicity for adults, exposure to lead acetate and lead carbonate in doses beyond 30 g would cause fatal poisoning, whereas actual 500 mg of absorbed lead is the estimated lethal dose. Absorption of lead beyond 0.5 mg/ day would cause lead to accumulate in the body, causing lead toxicity (Noji and Kelen, 1989, cited in International Programme on Chemical Safety INCHEM).

3.8.1.2.2.2 Fatal child poisoning

On the other hand, in lead toxicity for children, blood lead levels exceeding 1250 µg/L have been attributed to the fatal poisoning of children. At 100 µg/ L in blood lead level, causing a diminishing IQ score in children, was the lowest observed adverse effect level (LOAEL) to have caused developmental toxicity in children (Sax, 1989; and ATSDR, 1990, cited in International Programme on Chemical Safety INCHEM).

3.8.1.3 Acute poisoning symptoms

For acute symptomatic poisoning, the main lead induced clinical symptoms and prognosis includes: gastrointestinal effects such as colic and vomiting. This may also be followed by shock, leg cramps, pain and paraesthesia, anaemia and, renal dysfunction. In fatal cases, death can be swift and occur within hours 24-48 hours following a bout of depression and coma (International Programme on Chemical Safety INCHEM).

3.8.1.4 Chronic poisoning symptoms

For chronic symptomatic poisoning, the main lead induced clinical symptoms and prognosis includes: gastrointestinal effects such as colic, nausea and vomiting, anaemia, metallic taste, visible blue line on gum margins, anorexia (or decreased appetite), peripheral neuropathy causing radial nerve palsy (wrist drop), convulsions and encephalopathy, headache, hypertension, fatigue, sleep disturbance, muscle aches, saturnine gout (blood uric acid buildup due to lead poisoning causing inhibited urate excretion from waste products), nephropathy (kidney damage causing protein to leak from blood to urine), and chronic nephritis (kidney damage causing both protein and red blood cells to leak from blood to urine) (ILO, 1983; and Gosselin, 1984; and Ellenhorn, 1988; and Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM).

The major clinical symptoms can be deduced into three types. These are the gastrointestinal; neuromuscular; and cerebral types. The latter, can manifest as behavioural, cognitive and neurological deficits in developmental syndrome, and is often associated with encephalopathy in children. Deaths are due to the compounded factors and effects of lead poisoning (Ellenhorn, 1988; and Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM).

3.8.1.5 Asymptomatic poisoning in childhood

For asymptomatic poisoning in childhood, the prognosis includes: a delayed manifestation of symptoms even though blood lead levels may be elevated following lead exposure. The gradual appearance of anaemia is common. Suitable medical treatments such as chelation therapy are then recommended (Prerovska, 1974; and Gilman, 1990; and Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM).

3.9 Lead loss

3.9.1 Half life of lead

It is very difficult to estimate the biological half-life of lead (WHO, 1977, cited in International Programme on Chemical Safety INCHEM). The half life of lead is estimated to be 35 days in erythrocytes (red blood cells); 40 days in soft tissues; and 20-30 years in bone. It is estimated that 6 months would be required to reach a balanced state for the half-life in blood (Ellenhorn, 1988; and Garrettson, 1990, cited in International Programme on Chemical Safety INCHEM). Although it is estimated that 76 % of daily lead losses can be accounted for by urinary excretion; 16 % by gastrointestinal waste secretions; and 8 % in other routes such as nails, hair and sweat, the rate of

lead excretion remains low (WHO, 1977; and Ellenhorn, 1988, cited in International Programme on Chemical Safety INCHEM).

3.9.2 Lead loss via excretion

Body lead is excreted via faeces and urine (Thornton SJ 1984), and to a lesser extent through sweat and breast milk (Waldron and Stofen, 1974, cited in Thornton, 1984). Elimination via kidney excretion is the main route of body lead removal (Moore, 1983 cited in Thornton 1984), where blood lead is mostly filtered in the kidneys and expelled through urine.

3.9.2.1 Rate of recontamination

Therefore, the length of time required for the elimination of internal body lead burden is dependent on the estimated half time decline of skeletal lead stores of around a period of 2 years, as skeletal lead stores have a low response to body equilibrium (Black, 1962, cited in Thornton, 1984). Consequently contributing to the gradual recontamination of the human body via endogenic lead sources, that impedes the quick removal of body lead burden (Thornton, 1984).

3.10 Risk discrepancy

3.10.1 Risk discrepancy between adults and young children

The risk discrepancy between adults and infants or young children has long been acknowledged in terms of tolerable levels of body lead concentrations and their negative health effects. It is estimated that the greatest contributors of total daily lead intake at > 80 % are from food, soil (dirt) and dust pathways. The contribution of soil and dust to total lead intake varies with age as evidenced by a peak at around age 2 (Van Wijnen, Clausing and Brunekreef, 1990, cited in World

Health Organization, 2003). Whereas, a comparison between adults and young children on exposure to water lead showed the following: Presuming that lead content in drinking water accounts for 5 µg/ L, a calculated scale of total daily lead intake can amount from 3.8 µg/ day to 10 µg/ day in infants and adults respectively (World Health Organization, 2003). Nevertheless, while the proportion of total daily lead intake for children and adults from drinking water may seem negligible, it constitutes a major source of water-borne lead exposure in bottle-fed infants that subsist primarily on a diet of infant formula. In addition, provided the mother has a safe standard body lead load and has been avoiding exposure to high lead sources, the prolongation on newborn and infant maternal breastfeeding can have a delaying effect on their exposure to potentially high levels of lead contaminants from other forms of diet, such as those found in some baby formula and food products themselves (Gulson et al., 1999).

3.10.1.1 Lead dose response effect

Those who have dwelt *in situ* for generations with existing lead pipes, or have recently installed lead soldered pipeworks in the transportation of drinking water, are exposed to lead dissolution in the domestic plumbing system that can contaminate drinking water with hazardous lead levels. Chronic exposure of a lead source, even in relatively small doses, poses a direct risk of lead poisoning that can occur in increments, such as in drinking water with lead content leached from plumbing solders or fixtures (Levin, Schock, Marcus, 1989, cited in World Health Organization, 2003).

The Joint United Nations Food and Agriculture Organization and World Health Organization (FAO/ WHO) and the Expert Committee on Food Additives (JECFA B) organization determined 25 µg/ kg for lead content per kilogram of bodyweight in its intended 1986 provisional tolerable weekly intake (PTWI) guideline values. This effectively translates to an infant or child intake of 3.5 µg/ kg each day (JECFA B). Furthermore, it highlights the

importance of monitoring the long term cumulative risks and effects of lead exposure. According to several study outcomes (Ziegler et al., 1978; and Ryu et al., 1983, cited in World Health Organization, 2003) that were again verified by the Joint United Nations Food and Agriculture Organization and World Health Organization Expert Committee on Food Additives organization in 1993 (JECFA A), the provisional tolerable weekly intake was derived from infant metabolic studies where a reported daily intake value of ≥ 5 μg/ kg would cause lead retention, while a reported average daily intake of 3-4 μg/ kg would neither raise blood lead levels nor body lead burden.

3.10.1.2 Toxic kinetics comparison of adults and children:

In terms of dose response effect, children are more susceptible to lead uptake via gastrointestinal absorption. Although the rate of lead uptake within the gut can vary among individuals, it is recognized that the absorption rates are 3 to 6 times greater in children compared to adults (Karhausen, 1972; and Alexander at al., 1973, cited in Thornton, 1984). The gastrointestinal absorption of lead is dependent on factors such as the solubility of lead; whether food intake is involved and, the variation among adults and children. For instance, lead uptake in drinking water may be 6 to 20 times greater when taken on its own compared to when taken with food (The Royal Society of Chemistry, 1982, cited in Thornton, 1984). Hence, dose response is a key aspect to consider in the risk assessment and understanding of body lead burden effects.

3.11 Health risk assessment

3.11.1 Human health risk review

A quantitative human health risk assessment process is used to estimate the nature and likelihood of adverse health effects in humans whether now or in the future, when possibly exposed to health contaminants. In response to lead poisoning concerns, government authorities in the United States of America have mobilized large-scale, comprehensive risk assessment studies of the public population (Millstone, 1997). Their aim was to essentially identify and understand the source of lead hazards; characterize the hazards; and to recommend reasonable abatement action. For instance, the health risk assessment would enquire:

- What types of health problems are caused by environmental stressors such as chemicals?

- What is the chance of developing health problems with different levels of exposure?

- What is the level of safe exposure (if any)?

- What are people exposed to and at what level and duration of exposure?

- Are some people more susceptible than others due to a range of factors such as genetics, age or pre-existing health conditions?

- Are some people more exposed to environmental stressors than others due to a range of factors such as hobby, occupational or food exposure?

Answers to these similar queries help decision makers to understand the possible human health risks, whether they are public officials in council authorities or parents in the community.

The dissolution of heavy metals from old household reticulation systems and the adverse health effects can be analyzed by conducting a structured health risk review. The source of lead contaminants is first recognized through a process of hazard identification, followed by a depiction of possible harm through risk characterization. The following was conducted: **i)** Hazard

identification: An analysis of water source and the identification of potential lead contaminants; followed by **ii)** Risk characterization**:** An indication of potential lead harms; and **iii)** An exploration of the management strategies: A brief analysis of how both city council authorities and the public react to potential harms and, the role of risk communication on how knowledge of water abatement processes can promote informed decision making to improve water quality.

There are two main components to a health risk review— hazard identification and risk characterization. A further breakdown of the risk review would show that it involves a 4-step action plan. The four steps are as follows: i) Hazard identification, ii) Exposure assessment, iii) Dose response assessment and, iv) Risk characterization. In hazard identification, the origins of contaminants are identified and specified. In exposure assessment, the amount, duration and pattern of exposure are indicated. In dose response assessment, the amount of exposure and health effects is indicated. In risk characterization, the possible harms are indicated.

3.11.1.1 Step 1: Hazard Identification

During the hazard identification phase, the contaminant source is identified and specified, and types of health complications from lead exposure recorded (California Environmental Protection Agency, 2001). Environmental lead sources and pathways including the potential for water lead contamination in the Northwest Christchurch water supply systems is identified and analyzed. In order to identify whether lead poisoning has occurred, the diagnosis of lead poisoning can be determined through conducting a detailed study of lead exposure history; undergoing blood, urine or hair sample laboratory tests; or observing for lead induced clinical symptoms (International Programme on Chemical Safety INCHEM). The amount and duration of lead exposure determine the type of poisoning effect. Acute exposure to high lead concentrations would show rapid noticeable side effects. Chronic exposure to low lead concentrations would typically produce little noticeable effect although

it may have a potential for gradual health impact. It is essential that the chosen publications are able to grant information that are both timely and accurate in the assessment of lead contaminants (California Environmental Protection Agency, 2001). When considering adult worker lead load, it is worth noting that occupational studies are influenced by uncertainties such as whether the amount and duration of exposure is stable (California Environmental Protection Agency, 2001). Quantitative human health risk assessments allow for controlled experimentation although it is conditional on ethical and legal constraints. Also, the toxicokinetics of lead often allow for only immediate exposure measurements such as with blood lead concentration, where blood lead levels may not be an accurate representation of total body lead load when taking into consideration stored lead from long term cumulative exposures.

3.11.1.2 Step 2: Exposure Assessment

The duration of lead exposure; amount or concentration of contaminant exposure; whether exposure was constant or sporadic; and the various lead exposure pathways are examined (California Environmental Protection Agency, 2001). Lead uptake may consist of oral ingestion through food, drink or soil; lung inhalation through aerosol particulate or, absorption through skin contact. In order to conduct an exposure assessment, certain assumptions are often required. For example, an estimation of the amount of time spent outdoors in heavy traffic areas when lead levels are considered to be at its highest may be required when assessing aerosol lead exposure. As this study is primarily concerned with body lead burden from drinking water, an estimation of the pattern of water consumption for the Christchurch population would also be required in the exposure assessment. It would estimate the contact time of leaded plumbing materials with drinking water; whether exposure to high lead levels in drinking water is a constant or sporadic occurrence; and analyze the different possible routes of lead exposure. The amount, duration and pattern of

lead exposure can vary. For instance, the amount of lead detected in drinking water can vary from house to house due to different plumbing materials used in domestic water supplies, and from location to location due to different water chemistry and geomorphology. Duration of exposure can be in short term or long term exposures via cumulative lead concentrations and, pattern of exposures can be whether water with high lead concentrations are typically or occasionally consumed without flushing after long periods of stagnation. However, direct monitoring studies are often long and costly processes with outcomes that are often restricted to a few places, even though the data is of high quality. Conversely, the use of computer modelling studies would provide quick mathematical estimates to show the rate and direction of environmental lead exposure (California Environmental Protection Agency, 2001). Rational assumptions would be required in making estimates of human exposure to lead from drinking water.

3.11.1.3 Step 3: Dose-Response Assessment

In a dose-response assessment, information from the hazard identification stage is used to evaluate the negative effects of measured body lead burden on the mental function of infants and young children. The intensity and inclination toward harmful mental effects has shown to be correlated with different degrees of lead exposure(California Environmental Protection Agency, 2001). As there has been no proof of any beneficial function of lead to the human body and it has been shown to be cumulative in nature, even small degrees of lead exposure in low doses over an extended period of time would have amounted to high risk of body lead poisoning, characterized by a lowered rate of emission compared to the rate of lead uptake. Also, a single sufficiently high lead dose would easily result in lead poisoning. Identification of the susceptible infant and young children population subgroup, as well as the quality of studies used is considered. Safe levels of exposure for adults may not be safe for children, depending on the amount of lead concentration. Also, lead poisoning from acute high dose

exposures and cumulative small dose exposures can present different symptoms. The latter is often harder to detect in terms of presence of physical symptoms. Assuming body lead burden (often blood lead measurement) is correlated with childhood mental function, an increase in lead exposure would result in greater neurological harm, hence expresses itself through lowered mental function scores such as intelligence quotient measurements. A dose-response assessment also allows for the evaluation of lead exposure levels that are only characterized by low level harm to health. Therefore, it is important that the studies used are of a reliable standard.

3.11.1.4 Step 4: Risk Characterization

An evaluation of harm in the lead exposed population is conducted in the final step of risk characterization via information gathered from the first three risk assessment steps which comprise of hazard identification; exposure assessment; and dose-response assessment (California Environmental Protection Agency, 2001). It is important to note that the actual amount of lead contaminants found in drinking water can vary amongst households, and the amount of drinking water consumed per day per person is subjective to the individuals concerned. Hence, calculations for hypothesized risks are often reliant on general estimates that may have caused exaggerated outcomes. Also, the risk of lead harms are often compounded by factors such as diet behaviours and lifestyle choices where good nutrition has a protective effect against lead harms while smoking increased the risk of lead harms (California Environmental Protection Agency, 2001). Lead effects on intelligence quotient are dangerous in young children. It is irreversible, although abatement works may have stopped the source of lead danger. The harm is already done when lead poisoning occurs, when the rate of lead excretion via faeces and urine expelled, cannot keep up with the level of lead exposed to the body. As mentioned above, small doses can still be more dangerous to children due to their smaller body size. However exposure levels that exceed the allocated

reference value does not essentially equate to adverse health outcomes for all lead exposed population involved, although the risk of developing poisonous adverse health effects would increase together with dose accretion. Nonetheless, it serves to remind us of the vulnerability of the infant and young children subgroup to lead harms, and that further examination is required where exposures exceed the health reference value. However, it is important to also note that the nature of intelligence quotient tests makes it difficult for us to ascertain the harmful effects of lead on the neurological function of younger children.

3.11.2 Qualitative health risk assessment

The qualitative health risk assessment of this study shows that prospective study outcomes of lead exposure on the neurological health of infants and young children have been contradictory (World Health Organization, 2003). These study results failed to define the correlation of starting age of exposure and age range of greatest risk— where infants and children are most susceptible to the detrimental neurological effects of lead exposure. While it is reported that lead exposure *in utero* (prenatal) may interrupt early mental growth, it is suggested that the presence of confounding factors such as birthweight can also contribute to the interference of early mental development. In addition, the tests conducted offered no evidence to prove that these early effects persist to 4 years of age (World Health Organization, 2003).

3.11.3 Mitigation

Therefore as part of proper water management process, a prudent stance should be deemed the best approach as part of the mitigation effort. Other studies, yet to be verified, have indicated that the often greater incidence of lead exposure at the 1 to 3-year-old age group may imply a negative correlation between this age range and mental development (World Health Organization, 2003). Therefore it would seem that a prudent preventative measure is the best approach.

3.11.3.1 Management of lead in water

Effective mitigation of water lead concerns is costly and time consuming. Practicable actions are advised and may be sufficient in controlling lead content in the drinking water supply. As the source of lead in drinking water can often be traced back to the domestic water supply system, major abatement action can involve the removal of leaded plumbing materials such as pipes and fittings or, corrosion control via chemical dosing of the water supply. Other practicable actions such as water supply flushing are encouraged to diminish water lead exposure (World Health Organization, 2003).

3.12 determining the source

It is often difficult to identify the exact lead source that contributed to body lead load. The reason being lead sources are often interlinked. Frequently, numerous possible confounding factors exist. Hence, as part of quality assurance measures, it is important to identify these confounding factors and where possible, to eliminate them. For instance, an essential point to consider when reading old lead research studies is to question whether the results were affected by accidental cross contamination. Check for the development or adherence to proper quality assurance procedures during the preparation, collection and analysis of the samples, be it on soil, dust, food, blood or water lead concentration. During data comparison, question also the reliability of results from older studies. Older research methods may for instance lack the advantage of today's modern instrument processing power and detection sensitivity to allow for accurate estimates and analysis of lead exposure data.

3.13 Lead in drinking water

The guideline value for lead in drinking water is the maximum acceptable value (MAV) of 0.01 mg/ L, with the presumption that half of the 0.75 L drinking water consumed per day is received through

bottle-feeding for an infant of 5 kg in bodyweight. Being among the most susceptible subgroups in society, young infants would greatly benefit from the protective effect of this guideline value (World Health Organization, 2003).

3.13.1 Cause for lead dissolution

3.13.1.1 Lead dissolution factors

As mentioned above, the concentration of dissolved lead in drinking water is correlated with factors such as potential of hydrogen value, stagnation time, temperature and, water hardness – with high mineral content such as calcium elements (Quinn and Sherlock, 1990; and Schock, 1990, cited in World Health Organization, 2003).

3.13.2 Concern for lead dissolution at schools

In line with the concern for lead exposure and its adverse health effects on young children, it is only natural to be concerned with where lead contamination of drinking water may occur. For instance, lead in school water supply. Settling of atmospheric lead dust on drinking water when the school is in close proximity to areas of heavy motorway traffic or leaded industrial air emissions via an uncovered or poorly protected rainwater storage system or lake can lead to water lead contamination. However, a study of lead dissolution in a New Zealand school found no significant correlation between industrial or traffic (vehicular) air pollution on the concentration of lead in the drinking water supply. Instead, lead in school drinking water was attributed to either the direct dissolution of lead-containing components in the water reticulation or water storage system, or both (Ministry of Health, 2007).

3.13.2.1 Drinking fountains

Lead levels were often highest when collected from drinking fountains. This can be attributed to the longer extent of reticulation involved in the supply of drinking fountains (Ministry of Health, 2007). Therefore, apart from exposure to school-aged children, this water lead hazard may also extend to users of both park and workplace drinking fountains.

3.13.3 Lead hazards from plumbing components

3.13.3.1 Old lead pipes, leaded solders and fixtures

Lead pipes have been described as an indefinite source of leached lead contaminants whereas, leaded solders and plumbing fixtures such as brass taps, tend to decrease with time (Levin, Schock, and Marcus, 1989). The use of soldered connections in conjunction with copper piping can cause enough dissolution of lead— having recorded at approximately 210-390 µg/ L— to cause lead poisoning in children (Cosgrove et al., 1989, cited in World Health Organization, 2003).

3.13.3.2 New leaded solders

Despite greater attention on categorizing old water reticulation systems as potential health hazards, research has also described the practice of using high lead content solders in newly soldered water supply pipeworks as a source of lead contamination that can be present for several years (Millstone, 1997). Therefore, dwelling in newly constructed homes with new plumbing will not exempt the risk of high body lead load or lead poisoning in children. This problem could therefore extend to also involve recent repairs in old homes or installations in new homes. In response to such concerns, some governments have banned the use of lead solders in water supplies (US EPA, 1993). Nevertheless, there is no guarantee that the ban is always observed. Installers may or may not be aware of the lead content of solders or fittings

used. Therefore, as with leaded paint in New Zealand, perhaps stricter guidelines for the manufacture, sell, supply or use of lead solders for potable water plumbing should be enforced. For the purpose of this study however, the main focus is on old reticulation systems. The issue of lead corrosion was mentioned in the Drinking Water Standards for New Zealand 2005 (Ministry of Health, 2005) document and was defined as '*plumbosolvency*'. Its guidelines concern both public and private water supplies.

3.14 Lead management

3.14.1 A 'Healthy City'

The New Zealand government authorities are constantly working to promote safe awareness guidelines and introduce local water bylaw legislations when producing public reports. For instance, the Christchurch City Council is committed to safeguarding public health and practicing sustainable economic development. This is typical of risk communication action. The Draft Water Supply Strategy 2008 document (Christchurch City Council, 2008) was produced by the Christchurch City Council in conjunction with the Healthy Environment Programme, where a 'Healthy City' was listed as a goal for community outcomes (Christchurch City Council, 2008). Public opinion was gauged through consultation with the public population, and national guidelines and regulations (Ministry of Health 2005) developed with the cooperation of various relevant national, regional, and district level bodies.

3.14.2 Management of lead risk in the body

3.14.2.1 Poisoning management principle

In order to manage lead induced poisoning, it is imperative to seek appropriate medical care through professional symptomatic treatments. It is also important that persons experiencing chronic lead poisoning be removed from further exposure to the lead source (International Programme on Chemical Safety INCHEM).

3.14.2.2 Bodyweight effects on maximum acceptable value guidelines

It should also be noted that while the guideline for lead maximum acceptable value is based on 60 kg bodyweight in the World Health Organization (WHO), the value is based on a 70 kg bodyweight in the Drinking Water Standards for New Zealand document (Christchurch City Council, 2005). This may or may not be a significant problem when comparing data with overseas studies

3.14.3 Management of lead risk in the water

3.14.3.1 Local water chemistry & effects on plumbing

Each person in New Zealand is estimated to use an average of 250 L of clean potable water each day (New Zealand Water and Wastes Association, 2004). Yet only 1 % of that volume is used for drinking each day (Christchurch City Council and Boffa Miskell Ltd, 2005). Water in New Zealand is generally "soft" (acidic), and results in dissolution of several metallic elements including lead, nickel, antimony, cadmium (Ministry of Health, 2005), copper and zinc (Shearer, 1974). This accentuates the fact that water chemistry can vary quite markedly from one location to the next, reflecting the geomorphology of the area. In addition, old homes often reflect outdated plumbing materials and plumbing regulations (Millstone, 1997;

Treloar, 1996). Hence, it is essential to understand the water chemistry of Northwest Christchurch in order to comprehend its effects on the plumbing materials of the water supply systems.

3.14.3.2 Possible lead sources in Northwest Christchurch drinking water

Past New Zealand studies and public records were analyzed in an effort to trace back the materials used in Christchurch public water supply and in doing so, determine whether lead dissolution in the domestic or public reticulation system is the most probable cause of lead contamination in Christchurch drinking water. However, the limited number of Christchurch studies dating prior to the 1990s may be a consequence of the low awareness of potential lead harms in water reticulation systems. It may have also been an indication that past studies disregarded the correlation between the dissolution of leaded plumbing materials with body lead load, in light of more visible sources of lead contamination, for instance, the effect of leaded petrol (vehicle emissions) on body lead load from breathing in aerosol lead in high traffic areas or, the effect of ingesting chipped leaded house paint on body lead load. However, in retrospect, there has been no observable report of lead poisoning linked to the Christchurch public water supply. As part of the lead mitigation process in this study, the potential origins of water lead dissolution in the Northwest Christchurch zone were traced in the public drinking water supply from its starting point of water abstraction sites to its termination point of domestic drinking water taps.

Figure 3: Outline of Northwest Christchurch zone public water supply.

3.14.3.3 Lead pipes

The last known use of lead pipes in Christchurch public water supply was estimated to be in the 1920s (Murugesh, 2009). Owing to the high risk of lead contamination, it is advised that lead pipework is replaced in old homes where it is feasible (World Health Organization A).

3.14.3.4 Northwest Christchurch cast iron pipes

The cast iron pipes in Northwest Christchurch are remnants of past installations. According to the Drinking Water Standards for New Zealand document, its water quality poses an unacceptable level of health risk. This is due in part to the role of low water potential of hydrogen value that promotes corrosion and rust production in the old cast iron pipes (Christchurch City Council, 2005). In addition, use of lead joints in these cast iron pipes may also be a cause for water lead concern. This concern is further analyzed in this review.

3.14.3.5 Lead risk communication

According to the Drinking Water Standards for New Zealand 2005 document, potable water in New Zealand is to be assumed as *plumbosolvent* due to its generally soft property in

agreement with the chemical compliance criteria (Ministry of Health, 2005). However, water supply authorities that lack proof of the *plumbosolvent* nature of the water are required to publish a Ministry of Health warning. 1) It is to advise: a) the hazard of accumulated metals including lead after lying dormant for long periods of time in the reticulation system, due to the mildly corrosive effects of the water on plumbing systems— if the population supplied number greater than 1000 people; b) a minimum of 500 mL water be flushed from taps prior to use for drinking in order to clear corrosion contaminants, particularly after lying dormant overnight in the plumbing system; and, 2) This information is published to consumers at a minimum of twice annually, and, to be sent out to customers together with the water supply invoice or rate demand (Ministry of Health, 2005).

3.14.3.6 Private management and ownership of water supply

While a considerable number of water supplies are owned publicly by a local water authority, the majority of small water supplies in small communities that often number less than 500 people are under private management and ownership (Ministry of Health, 2005). Therefore, these smaller communities would be in greater need for improved access to information on current water management practices and risk communication.

3.14.3.6.1 Management of rural and urban fringe water supply

The use of surface water as a main source of potable water often occur among privately owned or managed water supply users in smaller and more rural communities in the Canterbury region. These are often farming and agricultural communities. Direct stream contamination from the occasional poorly contained land activity such as from surface runoff during heavy rainfall from agricultural fertilizer and animal effluent (Banks Peninsula District Council, 1998), decaying plant debris, or municipal sewage or septic tank leakage (Ministry of Health, 2005) will increase water-borne nitrate and microbial

levels among other pollutants. This increases the risk of contamination in general if the supply owner is inexperienced or lacks the knowledge of proper water management practices.

Management of these additional agricultural contaminants will require proper action, such as careful riparian planting to act as buffer zones between farming plains and streams, in accordance to set farm waterway management strategies as recommended by the Environment Canterbury (ECan) to help safeguard surface water sources. Although rainfall seepage means that some land contaminants are also absorbed downwards toward groundwater stores, shrub vegetation and tree roots will help to absorb nutrients in the groundwater while also helping to filter out surface runoff contaminants before reaching the waterways (Environment Canterbury, 2005). According to the Drinking Water Standards for New Zealand 2005 (Ministry of Health, 2005) guidelines, a 50 mg/ L maximum acceptable value of nitrates has been set to apply to short term exposures to guard against *methaemoglobinaemia* in bottle-fed infants. Therefore, rural and urban fringe surface water sources are easily rendered unsafe for consumption by anthropogenic agricultural pollutants; and, unlike urban Christchurch groundwater supply, would often need pre treatment to remove these contaminants.

When well (bore) water is contaminated, it is usually through the following pathways: animal faeces; rainfall washing pollutants into the well; pesticides back-siphoned from chemical mixing tanks; and nearby rubbish contaminating well water. Proper knowledge of management solutions, for instance, the installation of a securely protected well-head could have eliminated many of the contamination risks (Environment Canterbury, 2003). Awareness of current regulations guarding groundwater safety would advise individuals to protect well water against direct groundwater contamination by surface or climatic

changes; and that it is necessary to have well heads judged satisfactory by Ministry of Health (MoH) qualified personnel for health protection purposes (Ministry of Health, 2005).

3.14.3.7 Public management and ownership of water supply

Today, the potable water supply of the urban Christchurch City population is acquired by way of public water supply abstraction from water pumping stations that are dotted throughout the city, and pumped from groundwater gravel aquifers (artesian basin) that extend beneath the Canterbury Plains (Christchurch City Council, 2005). This groundwater system is also known as the Christchurch-West Melton aquifer system. The main source of groundwater for the Christchurch City area is the Waimakariri River that contributes up to 60 % of the water supply via seepage. This is followed by 35 % from rainfall over the lower plains where aquifers are mostly unconfined, and the final 5 % from the Paparua stock water race system (Christchurch City Council, 2008).

3.14.3.7.1 Management of lead risk in Northwest Christchurch public water supply

The issue of lead toxicity has had both local and international attention (Millstone, 1997; Ministry of Health, 2005). It is commonly accepted that old household drinking water reticulation systems are a possible health risk, particularly true of pre-1944 homes where a British study in the 1980s found between 15-20 % of these homes supplying drinking water with lead concentrations above 50µg/ L, compared to 5 % post-1944 (Millstone, 1997). Today, household plumbing regulations have evolved to exclude use of lead pipes for supply of drinking water (Blankenbaker, 1997). Chemical treatment (adding lime/ caustic soda/ orthophosphate) of drinking water supplies have been used to impede the corrosive, *plumbosolvent* nature of drinking water (Millstone, 1997).

In Christchurch, the pump station pipework is usually made of steel. The Northwest Christchurch water supply zone is shown on the water supply overview map highlighted in pale blue on Figure 4. The red dots show the water pump stations involved in the supply of potable drinking water. The 13 water pump stations are as follows:

- Wrights
- Auburn
- Withells
- Crosby
- Avonhead

- Jeffreys
- Burnside
- Farrington
- Grampian
- Harewood

- Redwood
- Thompsons
- Belfast

The water mains of the Northwest Christchurch zone public water supply system consist of pipes that are >= 100 mm in diameter while submains consist of pipes that are < 100 mm in diameter. A June 2004 valuation of water mains materials showed that 10 % of lead jointed cast iron pipes are still being used in the Christchurch public water supply. These were installed throughout the 1910s-1960s. Some Northwest Christchurch cast iron pipes date back to 1965. The majority of these cast pipes run relatively short distances in sections that belong to these roads:

- Rudleigh Avenue
- Langdons Road
- Sawyers Arms Road
- Sonia Place

- Tiora Place
- Riccarton Road – Auburn Avenue
- Cunliffe Road – Farquhars Road (across)

See Figure 5—9 for more information. The level of lead dissolution from lead joints will diminish over time, although the use of lead pipes in the supply of drinking water would remain a great concern as lead dissolution appears to occur indefinitely. Therefore, it is encouraging to know that any potential harm from the dissolution of lead joints in the

Northwest Christchurch public water supply will have declined greatly; and that no further installation of lead pipes has occurred in the past few decades to cause concern.

3.14.3.7.1.1 Past works

3.14.3.7.1.1.1 Chemical treatment of water supply

In the past, areas of the Northwest Christchurch zone supplied by the Burnside and Farrington pumping stations had received chemical treatment to adjust its potential of hydrogen value. This was done in accordance with the Drinking Water Standards for New Zealand (DWSNZ) year 2000 publication recommendations to deter corrosion. These water pumping stations supplied a total area of 20-30 % of the public water reticulation system in the Northwest Christchurch zone (Christchurch City Council, 2005).

3.14.3.7.1.1.2 Long term renewal plan

The Christchurch City Council has been replacing cast iron pipes throughout Christchurch city since the late 1990s as part of the headworks lifecycle management plan, due in part as a response to solve water supply corrosion complaints by the Christchurch public population (Christchurch city council, 2006). The majority of cast iron mains are within the Central and Riccarton pressure zones.

3.14.3.7.1.2 Present works

3.14.3.7.1.2.1 Mixing of water supplies

While both the Burnside and Farrington pumping stations have previously received chemical treatment of their water supplies (Christchurch City Council, 2005), at present, chemical treatment of water supplies in the Northwest Christchurch zone have been discontinued. Instead, deeper wells have been drilled at those sites to abstract groundwater with higher potential of hydrogen values that are used to mix with shallower groundwater to improve, and in this case to increase, the level of potential of hydrogen in the water supply (Murugesh, 2009). According to the Christchurch City Council (CCC) water quality records, the Northwest Christchurch water quality has improved, and the level of water potential hydrogen has increased (Murugesh, 2009).This renders the water less corrosive and therefore less likely to be a health threat.

3.14.3.7.1.2.1.1 Response to chlorination survey

The public water supply in Christchurch city is non-fluoridated and non-chlorinated. A survey conducted by the Opinions Market Research Limited in the year 2000, found that 84 % of respondents were against the suggestion to chlorinate the Christchurch water supply, even though an estimated 67 % of New Zealand population is supplied with chlorinated water (Christchurch City Council, 2005). The high percentage of respondents that voted against chlorination of the Christchurch water supply may be an indication of a wider general public opinion against unnecessary chemical treatment of water supply. Therefore, it may also be viable to suggest that the current practice of water mixing by the Christchurch City Council water supply

authority reflect their continual bid to improve water supply service and are attentive to community opinions. This study appears to embody the Christchurch population's reluctance to have their natural artesian source altered with the introduction of chemicals such as chlorine since Christchurch groundwater is already largely high in quality and safe to drink.

3.14.3.7.1.2.2 Long term renewal plan

The work of replacing cast iron pipes is ongoing. It is estimated that cast iron pipes will be fully replaced in a few more years as part of the Christchurch City Council reticulation lifecycle management plan.

3.14.3.7.1.3 Future works

3.14.3.7.1.3.1 Condition age and useful life

Christchurch City Council authorities are conscious of the effects of local water chemistry in the public water reticulation system. Due to condition age and useful life factors, some cast iron pipes can deteriorate and fail to perform properly with the development of leaky inelastic lead joints which may lead to pitting and pinholing of steel and galvanized submains. Oxide build-up can cause network blockages and loss of water flow (Christchurch City Council, 2006). However with proper management of pump stations, network losses can be handled. Reports have generally shown no significant deterioration in terms of water supply performance. Problems such as rusting; water discolouration and network blockages are still seen as minor problems that are solvable with public water supply flushing or scouring (Christchurch City Council, 2006). The fact that the remaining cast iron pipes in the Northwest Christchurch zone installed

from the 1960s onwards (Murugesh, 2009) are gradually being replaced as part of the reticulation lifecycle management plan, should solve this concern.

17.3.7.1.3.2 Long term renewal plan

Continual repair, maintenance and renewal work where needed.

WATER SUPPLY OVERVIEW MAP

Insert 'A'

See insert 'A'

NORTH

For location of hill pressure zones
see file "UP000215a.gws" and
layout "PressureZones-Hill"

Figure 4: Boundary of Northwest Christchurch zone and thirteen water pumping stations.

Source: Christchurch City Council (Murugesh, 2009). CI Pipes in NW Zone.doc Retrieved 2009.
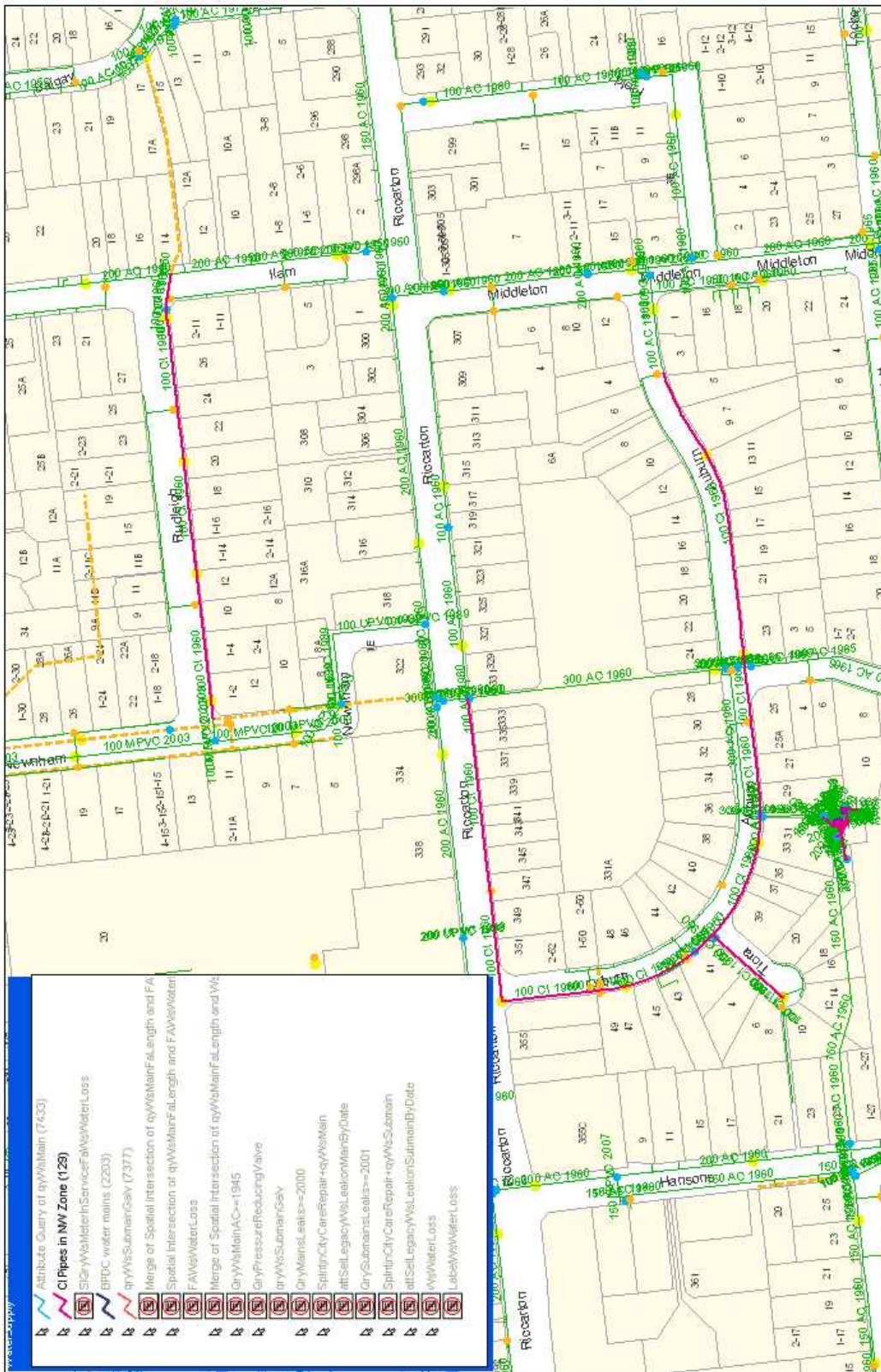
Figure 5: Cast iron pipes in Northwest Christchurch Zone— Rudleigh Avenue, Tiora Place and Riccarton Road-Auburn Avenue.

Source: Christchurch City Council B (Murugesh, 2009). UP000215AFlatZone.jpg. Retrieved 2009

Figure 6: Cast iron pipes in Northwest Christchurch Zone— Langdons Road.

Source: Christchurch City Council B (Murugesh, 2009). UP000215AFlatZone.jpg. Retrieved 2009.

Figure 7: Cast iron pipes in Northwest Christchurch Zone— Sawyers Arms Road.

Source: Christchurch City Council B (Murugesh, 2009). UP000215AFlatZone.jpg. Retrieved 2009.

Figure 8: Cast iron pipes in Northwest Christchurch Zone—Sonia Place.

Source: Christchurch City Council B (Murugesh, 2009). UP000215AFlatZone.jpg. Retrieved 2009
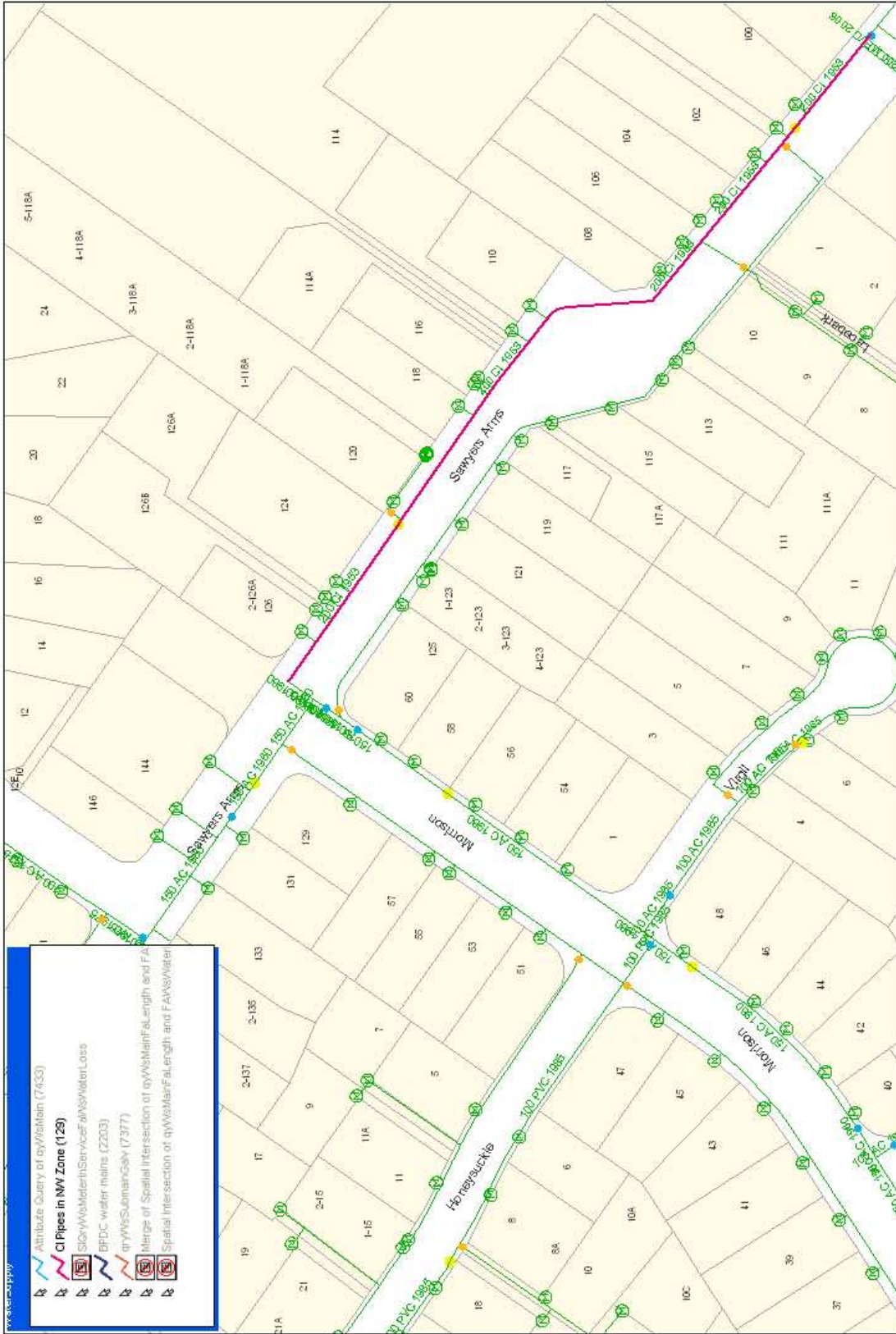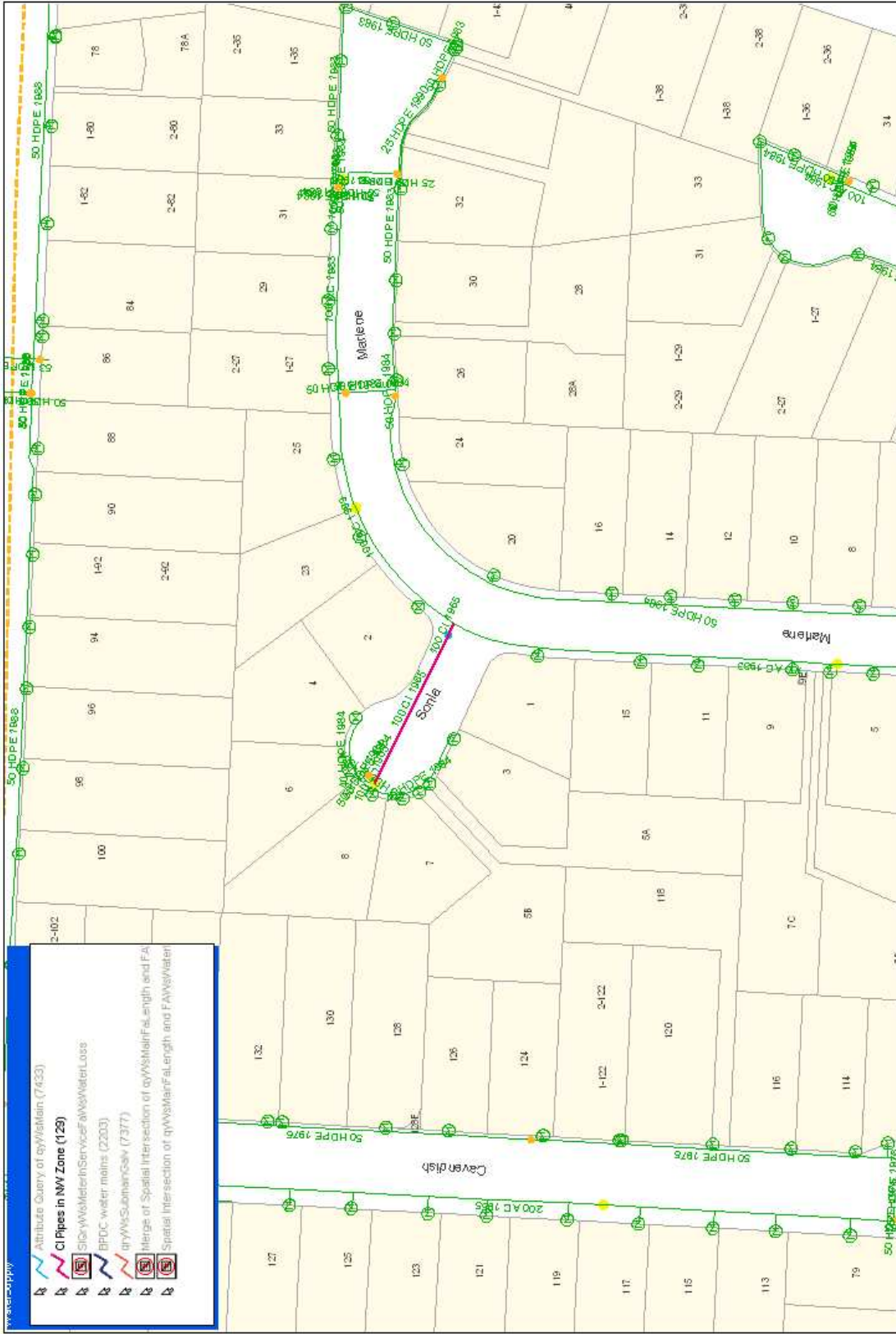
Figure 9: **Cast iron pipes in Northwest Christchurch Zone— Cunliffe Road-Farquhars Road (across).**

Source: Christchurch City Council B (Murugesh, 2009). UP0000215AFlatZone.jpg. Retrieved 2009

Chapter 4

Discussions

Electronic searches for the noun term 'lead' (Pb) are often mistaken for the verb 'lead' or a spelling component of other words, thereby often ending up with futile web-based platform searches before the chemical symbol —'Pb'— became the preferred search term. That action drastically narrowed down the scope of searches to more relevant literature only. This points to the importance of knowing specialized terms in the area of topics being researched, such as the use of the terms '*plumbosolvency*' and 'dissolution' as used here in this study. For instance, at the PubMed database, 'Pb + learning' was entered in the search field which subsequently produced 265 results. However, only a few were appropriate for this study after applying other relevant search criteria. This was due to parameters such as the need for the lead contaminant to be of inorganic form and derived from anthropogenic activity that exist in its various environmental lead forms (air, water, soil, food) and pathways; where animal study subjects were omitted in favour of human studies; and treatment applications were for drinking water rather than waste water treatment.

Lead poisoning is characterized by lower rates of lead excretion through the gastro-intestinal tract compared to the rate of lead intake.

Lead maximum acceptable values provide a health reference value, where exposures below the allocated maximum acceptable value is generally safe from adverse health outcomes, while outcomes that exceed the allocated reference value did not necessarily equate to adverse health outcomes for all the lead exposed population involved; even though the risk of developing toxic adverse health outcomes does increase with dose. It also served to reveal the vulnerability of the infant and young children subgroup to lower levels of lead harms due to the proportion of exposure to their small size; and that further examination was required where exposures exceeded the health reference value.

In the case of lead contamination in Northwest Christchurch water supply, it is imperative to understand that lead contamination sources and pathways are complex and may sometimes intersect, such as concurrent exposure to soil lead and water lead, from pica behaviour and from drinking water respectively; and where at first glance it is unclear whether the main contributor to body lead load is the result of one source over the other. Behavioural problems; learning disabilities; and deaths have all been linked to excess blood lead levels in children (Millstone, 1997). Alloys such as brass fittings that contain high lead concentrations can also add to body lead burden (World Health Organization D). However, even polyvinyl chloride (PVC) pipes have been reported as releasing immunotoxic Organotin, although it is often believed as harmless (Baue, 2001).

The extent of lead exposure through outdated water reticulation system can have important health risks. A comparison of lead exposure between leaded fittings and lead pipes showed that dissolution of lead pipes occur indefinitely but leaded fittings may develop a protective coating that lessen the amount of lead leached over time. However, lead levels may remain high for leaded fittings if: i) water velocity is high, and, ii) levels of dissolved or trapped air are high, caused by insufficient time to establish a protective layer against lead dissolution (World Health Organization A).

Records for individual water supply networks within the homeowner's property boundary are scarce and incomplete compared to records for Christchurch public water supply networks. An example of the detailed records for Christchurch public water supply networks is the reported use of cast iron pipes together with lead joints in the Northwest Christchurch Zone (Christchurch City Council, 2006).

The actual amount of lead contaminants found in drinking water can vary between households, and the amount of drinking water consumed per day per person is subjective to the individuals concerned. However, bottle-fed infants would consume a higher proportion of tap water therefore potentially exposing them to high levels of lead from old domestic plumbing without proper remedial action. Also, the risk of lead harms are often compounded by factors such as diet behaviours and lifestyle choices where good nutrition has a protective effect against lead harms while maternal smoking could increase the risk of lead harms.

Apart from the dissolution of lead from old water reticulation systems, mouthing of toys with leaded paint can also contribute to body lead burden in infants and young children. Observational studies can produce high quality data, however the procedures are often time-consuming and costly, and possibly with outcomes that are applicable to only a few places. Conversely, the use of computer modelling studies can provide quick mathematical estimates to show the rate and direction of environmental lead exposure.

For the exposure assessment, the following conditions were taken into account: (1) the duration of lead exposure; (2) the amount or concentration of contaminant exposure; (3) whether exposure was constant or sporadic; and (4) the various lead exposure pathways were examined. Lead uptake may consist of oral ingestion through food and drink; lung inhalation through aerosol particulate or, absorption through skin contact. As this study was primarily concerned with body lead burden from

drinking water, the pattern of water consumption for the average Christchurch population, infants and young children were also estimated and considered in the risk review.

4.1 Limitations

The limitations of this study approach: The topic was too narrow, with limited numbers of Christchurch drinking water studies to allow a full study of the lead contamination situation from old Christchurch water reticulation systems. The use of animal studies for neurological function and intelligence/ learning ability tests are often inevitable as they cover a large proportion of available studies and are favoured by some researchers as they offered direct experimental manipulation of dose-response effects in facilitating risk characterization.

4.2 Future plans

Future studies may perhaps look at the possibility of finding seasonal lead concentration changes and whether these are significant to health, or perhaps the next step is to conduct a quantitative study to monitor the actual potential and level of lead dissolution in domestic water reticulation systems by water sampling and laboratory testing of Christchurch households between pre-1945 homes and present day homes. Although the potential for water lead contamination and level of lead dissolution varies from place to place depending on water chemistry, the science behind the process is the same everywhere, hence its applicability to most situations.

With more studies such as this review that exist to explain and add to our wealth of understanding the characteristics and effects of environmental lead on the human body, the more can be done to safeguard public health by improving lead contamination management practices; as well as preventing unnecessary lead contamination. In terms of small lead abatement action and the possible

role of government intervention, perhaps the regulations for imports controls can be tightened to ensure better safety of plumbing products in New Zealand, where only lead-safe parts and materials are used for the manufacture, selling or buying of plumbing goods such as brass taps. This will help to actively reduce the number of potentially harmful plumbing products being sold and used by the New Zealand public.

Chapter 5

Discussion on ways to improve lead management

5.1 Lead detection in domestic water supply

The most reliable results can be obtained by having individual homeowners collect first flush samples of their drinking tap water to undergo professional laboratory testing at a Ministry of Health accredited laboratory. This primary step of water lead management will determine whether further action is required, and whether there is any need for health concern.

5.2 Importance of this qualitative review study

5.2.1 Importance of this qualitative health risk assessment

While tests conducted by water supply authorities indicate water quality from the source to the owner's property boundary (Christchurch City Council), they do not indicate the level of contaminants that a person in the household is exposed to by way of the domestic water reticulation system.

5.3 Suggestion for systematic tap water testing

5.3.1 Hazard surveillance programme

Although this review study is predominantly a qualitative research work that will result in some helpful insight into the lead risk management of Christchurch water supply, it is unable to offer concrete figures to prove or argue a point that inferential statistics would otherwise provide. The benefit of conducting quantitative research is its ability to essentially draw general conclusions. For example, in this case, water lead concentration of water samples taken from leaded brass taps in old domestic reticulation systems.

5.3.1.1 Possible steps

With a quantitative risk assessment, these concrete steps could have been made:

1) A systematic analysis of water samples taken annually to gauge the level of lead content in the water supply.

2) Investigate as part of a hazard surveillance programme or the national public health surveillance such as the Annual New Zealand Notifiable Disease Report, into houses considered as being at risk from lead contamination due to old water reticulation system and a high probability of lead exposure.

3) Should lead levels in the water samples go beyond the maximum acceptable value, regular measurements of blood lead levels in children and infants could be conducted.

5.4 Lead abatement work

5.4.1 Domestic water supply lead abatement work

5.4.1.1 Supply flushing

Vital factors such as the period of stagnation in reticulation systems and the extent of water supply flushing practiced by individuals in the general population can vary greatly, rendering lead levels highly variable. Hence these water lead estimates will have a wide margin of error and should be interpreted with caution (Levin, Schock, and Marcus, 1989).

5.4.1.1.1 Manual supply flushing

The endorsed practicable remedial action include flushing out and discarding the first approximate 500 mL of drinking tap water in the morning, to discard lead dissolution products that have been left sitting overnight in pipeworks in contact with lead solder and leaded fixtures. Water lead concentrations were found to be considerably higher in first flush samples compared to successive samples when collected at their termination point such as from sink faucets, where this is likely indicative of lead leaching from the reticulation system as opposed to leaded rainwater storage system components. The leaded components may comprise of lead-head nails, lead solder or flashings.

5.4.1.1.2 Automatic-flushing solenoid valves

Like manual supply flushing, automatic-flushing solenoid valves are set at timed intervals to flush out and discard contaminated drinking tap water.

5.4.1.1.2.1 Supply flushing efficiency and effectiveness

Supply flushing can be a simplistic, rapid and cost effective approach to lead abatement action of water supply lead contaminants. Nevertheless, there may be hidden ongoing costs involved in the use of automatic-flushing solenoid valves, where repair services may be required. There is also a propensity for water wastage from the practice of supply flushing.

5.4.1.2 Carbon filters

Powdered and granular activated carbon (PAC; GAC) have been used in the adsorptive removal of lead from water (Li and Wang 2009; Gulson et al., 1997). Activated carbon is the product of control-thermalized carbonaceous matter such as wood; coconut shells; coal or peat, where the resulting material develops high adsorptive qualities to contaminants with its porous surface and estimated 500- 1500 m^2/ g wide surface area (World Health Organization A). Lead is among the various contaminants removed in this method, together with the removal of total organic carbon, cyanobacterial pollutants as well as, odour and taste compounds. Note that like other filters, maintenance is involved. A replacement is needed following the exhaustion of activated carbon adsorption capacity (World Health Organization A).

5.4.1.2.1 Adsorption efficiency and effectiveness

Powdered activated carbon dosing is in slurry form while granulated activated carbon treatment is via fixed-bed adsorption. The affinity of contaminants will differ with the type of activated carbon used. The latter is characterized by greater efficiency and effective carbon use for each volume of water treated (World Health Organization A). Contact time with water, and carbon use capacity will determine the useful life of granulated activated carbon beds. The capacity for particular organic compounds will

differ with the type of granulated activated carbon used, which in turn will affect its useful life (World Health Organization A). In order for lead to be adsorbed, several conditions are necessary. The source of water and presence of organic compounds are cause for a major decline in the adsorptive capability of carbon. The chemical adsorbed would also have low solubility and high octanol/ water partition coefficient ($logK_{ow}$) (World Health Organization A). The replacement of the affected reticulation system is a costly remedial action. There will invariably be hidden ongoing costs involved: Activated carbon filters, like the majority of other filtration products will need the regular change of filter stores.

Therefore, it helps to have the domestic water supply first flush water sample laboratory tested before deciding on adopting these recommended practices. It may help to prevent the unnecessary wastage of time, costs and water. Nevertheless, some may decide to adopt these recommended practices as a precautionary measure thereby, practicing prudence to safeguard their family health.

The benefit of risk communication is evident. Knowledge and proper water management information such as the ones mentioned above, adds to the wealth of public consumer information, and provides the public population with the opportunity to make informed decisions whether as individuals or choices made on behalf of their family. In addition, where the issue of high costs and affordability is involved, this may even extend to impacting major life decisions such as whether to purchase and stay in an old home with a leaded water reticulation system, especially among young families where young children or pregnant women are involved.

5.5 Improving risk communication

In order to identify and mitigate the potential hazards of lead exposure that come from old public water reticulation system of Northwest Christchurch and old domestic water supplies, it would also entail improving risk communication. The review of lead studies highlights the importance of communication between the authorities and the public population. Efficient and effective risk communication benefits both public and private water supply users.

5.5.1 Web-based platforms

5.5.1.1 Health Knowledge Management and Consumer Health Informatics

In understanding the web-based communication phenomenon, observe the benefits from the perspective of the 'consumer health informatics' (CHI) (Eysenbach, 2000) and 'health knowledge management' (Health KM) (The George Washington University) concepts. In consumer health informatics, public demand for more information will advance efforts for improved public health risk management practices. In health knowledge management, information communication technology (ICT) tools can improve the management of information by enhancing public access to knowledge and services. Perhaps the growing e-Health patient-physician relationship trends (Weinberg et al., 2000) are good predictors of the potential of information communication technology related services in public health lead risk communication. Information communication technology tools can help to spread lead risk information efficiently to a wide audience, and foster pro-activity in individuals by promoting individual management of domestic reticulation systems.

5.5.1.2 Web 2.0

As with the Web 2.0 concept (O'Reilly, 2005), the Northwest Christchurch public population can make use of the power of online applications such as blogs and cellphone-web

integrations, to share the latest information in drinking water management practices. There is opportunity to make full use of these tools to provide ample quality information with minimal time and travel costs.
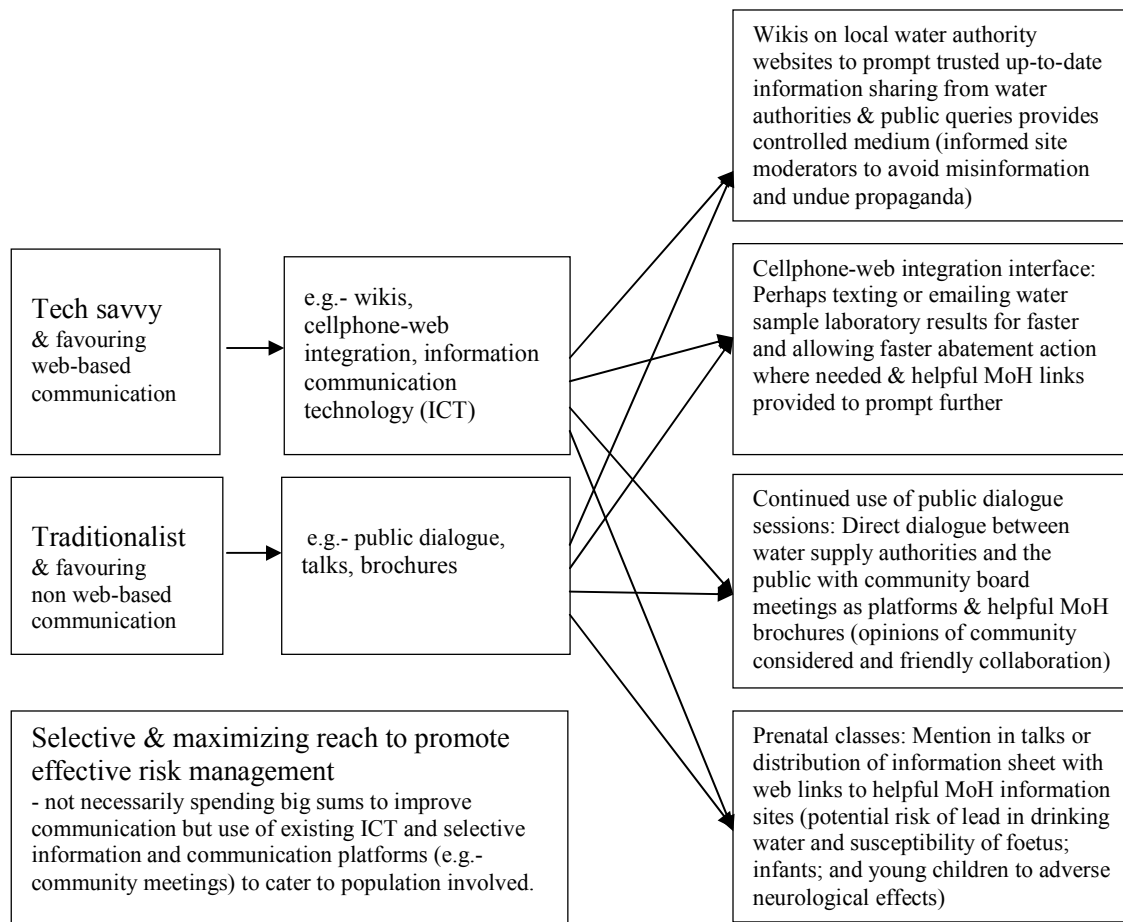
5.5.2 Non web-based platforms

At present, non web-based paper educational materials such as information brochures and leaflets are still crucial and beneficial to risk communication efforts. Also, the use of both web-based and non web-based platforms have already crossed paths, for instance the presentation of useful information in paper form may also conveniently point to web-based platforms such as the inclusion of website uniform resource locator (URL/ address) links for further reading of related information. Conversely, web-based tools may also conveniently point to non web-based information such as the announcement of public talks or where tangible copies of the searched document may be located in its full paper form, and may be post delivered when requested. Hence, non web-based platforms have the potential to reach a wide audience, too.

In addition, smaller rural communities that may already be disadvantaged in terms of questionable water supply quality and access to monitoring services, may encounter problems with the reality of accessing information communication technology services itself. Perhaps the telecommunication reception may be restricted; the travel time and costs involved to access information and services too high, or level of proficiency in computer literacy particularly among the elderly may be an issue. Even so, the information communication technology approach should not be abandoned, as its advantages will far outweigh its disadvantages over time with the projected increasing trends of its use and acceptance over time. For now, perhaps the current situation of a combination of both paper and electronic platforms is necessary.

5.5.3 Potential of web-based and non web-based platforms

Fully utilize both web-based and non web-based platforms that can maximize the potential of reaching and communicating with target communities. A diagram of the proposed plan is shown in Figure 10.

Figure 10: The proposed plan

The current mix of providing both paper and electronic educational materials, interlink between web-based and non web-based platforms, and the option to meet with public authorities for dialogue, ensures wide population coverage. This provides the opportunity to better inform and educate the public community. It reaches an audience of both technology-savvy and traditionalist individuals and assists them with informed decision making by promoting improved and effective

water quality management and lead risk management practices. Although statistics may indicate a general increase in the use of web-based technology over time (Weinberg et al., 2000), there is still a need to provide information to those unable to access web-based information. Perhaps there may be a major shift towards web-based platforms in the future, although changes to improve services should reflect what is appropriate for the times, and the current situation seems to favour a mixture of both approaches for effective and efficient risk communication.

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