

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**A comparison of the microbiological quality of
drinking-water of urban and semi-urban dwellings in
the Richmond district of New Zealand**

A thesis presented in partial fulfilment of the requirements for the degree
of
Master of Environmental Health Science
at
Massey University, Wellington, New Zealand

Lucy Thompson

2013

Abstract

This study aimed to determine if residents of Richmond, Nelson, with an on-demand, mains pressure, and metered drinking-water supply had the same microbiological drinking-water quality at the kitchen tap as dwellings with a restricted, low-flow supply. Both dwelling types were supplied with water from the same untreated, reticulated water supply scheme. The results from this study provide information for both consumers and the supplier regarding the microbiological quality of drinking-water supplied at the kitchen tap.

A cross-sectional, interviewer administered survey of 50 dwellings with a metered supply and 61 dwellings with a restrictor supply was conducted during May-July 2012. Microbiological water quality of each dwelling was ascertained by testing water samples from the kitchen tap for the presence of indicator organisms, using the Colilert®-18 method.

When total coliforms were used as an indicator, metered dwellings did not have the same water quality as restrictor-only dwellings ($p < 0.0005$): more restrictor-only dwellings were contaminated than metered dwellings. Drinking-water at the kitchen tap for 84% of metered dwellings and 48% of restrictor-only dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of < 1 total coliform per 100 ml. When *E.coli* was used as an indicator, metered dwellings were found to have the same water quality as restrictor-only dwellings ($p = 0.242$). Drinking-water for all metered dwellings and 94% of restrictor-only dwellings complied with the microbiological criteria set in the DWSNZ 2005 (Revised 2008) of < 1 *E.coli* per 100 ml. Supplementing the reticulated water supply with water from another source was undertaken by 18% of participants with a restrictor supply and it appeared to cause a reduction in the microbiological quality of drinking-water.

The results for *E.coli* have demonstrated that it is possible to provide a potable supply of drinking-water from an untreated, reticulated supply to dwellings with either a metered or a restrictor-only supply. The total coliform results indicated that there might be issues with the use of restrictor drinking-water supplies, in particular the use of private water storage systems. Owners of restrictor supplies need to be provided with more information on the set-up, design, and maintenance of these water storage systems.

Acknowledgements

I would like to thank my supervisors, Stan Abbott and Dr. Barry Palmer, for their invaluable guidance and assistance with this research project. An extra big thank you also goes to Stan for organising all of the laboratory equipment, for responding to all of my queries, and for being so enthusiastic about this project.

Thanks also go to the following people:

- Dr. Gillian Bullock, Water Scientist, MWH New Zealand Ltd, for providing me with information about the Richmond water supply and for taking the time to answer all my questions
- Dr. John Heath, Senior tutor in Health sciences, Massey University, for his assistance with the statistics in this project
- Jim Graham, Principal Environmental Scientist, Opus International Consultants Ltd, for explaining parts of the legislation and Standards relating to water supplies that I didn't understand
- Dr. Linda Liddicoat, Research Consultant, for help with using SPSS
- Evan Mackenzie, Drinking Water Assessor, Nelson Marlborough District Health Board, for providing background information on the Richmond water supply.
- Jeff Cuthbertson, Utilities Asset Manager, for ensuring that all the resources that I needed from the Tasman District Council were made available to me
- All of the participants who took part in this study. Thank you for taking the time to answer my questions and for making me so welcome in your homes.

Lastly, I would like to acknowledge my husband and children for the understanding, love, and support that they have given me whilst I have worked on this thesis. I could not have completed this thesis without your help.

Table of Contents

Abstract	i
Acknowledgements	ii
Table of Contents	iii
List of Figures	ix
List of Tables	xi
1 Introduction	1
2 Background	4
2.1 The Tasman District	4
2.2 Richmond urban water scheme	4
2.2.1 Source	4
2.2.2 Distribution	7
2.2.3 Maintenance	7
2.2.4 Metered and restrictor supplies	7
2.3 Grading and compliance of the Richmond supply 2001-2011	10
2.4 Current compliance status and grading of the Richmond supply	12
2.4.1 Compliance with the Health Act 1956	12
2.4.2 Bacterial compliance with the DWSNZ 2005 (Revised 2008) for water leaving the treatment plant	13
2.4.3 Bacterial compliance with the DWSNZ 2005 (Revised 2008) for water in the distribution zone	14
2.4.4 Protozoal compliance with the DWSNZ 2005 (Revised 2008)	14
2.4.5 Chemical compliance with the DWSNZ 2005 (Revised 2008)	15
2.4.6 Grading of the Richmond supply	16
2.5 Future plans for the Richmond water supply	16
3 Literature Review	17
3.1 Reticulated drinking-water supplies	17
3.1.1 Source water	17
3.1.2 Treatment	18
3.1.3 Distribution	20
3.2 Framework for provision of potable water in New Zealand	20
3.2.1 Multiple barrier approach	20
3.2.2 Legislation	23

3.2.3	Drinking-water Standards for New Zealand 2005 (Revised 2008)	23
3.2.4	Drinking-water quality in New Zealand	24
3.2.5	Microbiological water testing	24
3.2.6	Public health grading	25
3.2.7	Annual Report on Drinking-water Quality	25
3.3	Restrictor drinking-water supplies	25
3.3.1	Legislation	26
3.3.2	Advantages	26
3.3.3	Disadvantages	26
3.4	Waterborne disease	28
3.4.1	Causes and effects	28
3.4.2	Endemic waterborne disease in New Zealand	28
3.4.3	Epidemic waterborne disease in New Zealand	29
3.4.4	Waterborne outbreaks worldwide	33
3.4.5	Reticulated supplies and waterborne outbreaks of disease	33
3.5	Water testing	35
3.5.1	Advantages	35
3.5.2	Disadvantages	35
3.5.3	Indicator organisms	36
3.5.4	Restrictor supplies	38
3.6	Water treatment devices	38
3.7	Consumers' knowledge and perceptions	40
3.7.1	Knowledge of water quality	40
3.7.2	Perceptions of water quality	40
3.8	Conclusion	41
4	Research hypothesis, aim, and objectives	42
4.1	Hypothesis	42
4.2	Aim	42
4.3	Objectives	42
5	Methodology	44
5.1	Researcher's worldview	44
5.2	Justification for methods employed	44

5.2.1	Cross-sectional survey	44
5.2.2	Population	44
5.2.3	Sampling	45
5.2.4	Use of questionnaire	46
5.2.5	Use of an interviewer	46
5.2.6	Laboratory facilities	47
5.2.7	Colilert®-18 method	47
5.2.8	Pilot study	48
5.2.9	Ethical considerations	48
5.2.10	Reliability	48
5.2.11	Validity	49
6	Sampling and data analysis	50
6.1	Population	50
6.2	Sampling	50
6.3	Interview procedure	51
6.4	Water sampling	52
6.4.1	Analysis of samples	52
6.5	Communication of results	54
6.6	Data analysis	55
7	Results	56
7.1	Response rates	56
7.2	Demographics	56
7.2.1	Details of participants	56
7.2.2	Details of dwellings	59
7.3	Water usage	60
7.4	Microbiological water test results	61
7.4.1	Total coliform results	61
7.4.2	<i>E.coli</i> results	62
7.4.3	Compliance with the DWSNZ 2005 (Revised 2008)	63
7.5	Water treatment devices	64
7.5.1	Number and type of water treatment devices utilised	64
7.5.2	Reasons given for installation of water treatment devices	64
7.5.3	Effectiveness of water treatment devices	65

7.6	Water testing behaviour	68
7.6.1	Reasons for having water tested	68
7.6.2	Reasons for not having water tested	71
7.7	Perceptions of quality of drinking-water	72
7.7.1	Perception of taste	72
7.7.2	Perception of odour	73
7.7.3	Perception of colour	74
7.7.4	Perception of safety	75
7.7.5	Perception of value for money	76
7.8	Knowledge of the Richmond urban water supply	77
7.8.1	Knowledge of treatment status	77
7.8.2	Knowledge of public health grading	77
7.8.3	Access to information sources	78
7.9	Water storage systems	78
7.9.1	Number and type of tanks	78
7.9.2	Tank size	80
7.9.3	Tank age	80
7.9.4	Location of water storage tanks	81
7.9.5	Tank accessories	81
7.10	Frequency of maintenance of water treatment systems	82
7.10.1	Frequency of maintenance of household water treatment devices	82
7.10.2	Frequency of tank inspection	82
7.10.3	Frequency of tank cleaning	83
7.11	Restrictor-supplemented supplies	84
7.11.1	Total coliform and <i>E.coli</i> results	84
7.11.2	Compliance with DWSNZ 2005 (Revised 2008)	84
8	Discussion	85
8.1	Water quality	85
8.1.1	Total coliform results	85
8.1.2	<i>E.coli</i> results	88
8.2	Indicator organisms	90
8.3	Supplementary supplies	91

8.4	Water usage	92
8.5	Water treatment devices	92
8.6	Water testing behaviour	94
8.7	Perceptions of water quality	95
8.8	Water storage systems	96
8.9	Maintenance of treatment and water storage systems	98
8.10	Knowledge of water supply	99
8.11	Survey response rates	100
8.12	Demographic data	100
8.13	Limitations to the study	102
8.14	Future studies	103
9	Conclusion	104
10	References	107
Appendix A.	Strength of association for outbreaks of waterborne disease	128
Appendix B.	Questionnaire	129
Appendix C.	Laboratory	142
Appendix D.	Dual water sampling	143
Appendix E.	Information sheet for participants	145
Appendix F.	Participant consent form	146
Appendix G.	Visit log	147
Appendix H.	Result reporting letters	148
Appendix I.	Justification for microbiological reporting categories	151
Appendix J.	Statistical information for dwellings with a metered or a restrictor-only water supply	153
J.1	Analyses performed	153
J.2	Response rates	153
J.3	Water storage	153
Appendix K.	Tables of data for metered and restrictor-only dwellings	154
Appendix L.	Results and discussion for restrictor-supplemented supplies	166
L.1	Demographic details	166
L.2	Type of supplementary supply	166

L.3	Water usage	166
L.4	Microbiological water test results	167
L.4.1	Total coliform and <i>E.coli</i> results	167
L.4.2	Compliance with DWSNZ 2005 (Revised 2008)	167
L.5	Water treatment devices installed	167
L.5.1	Number and type of water treatment devices installed	167
L.5.2	Reason for installation of water treatment device	167
L.5.3	Effectiveness of water treatment devices	169
L.6	Water testing behaviour	169
L.6.1	Reasons for and frequency of water testing	169
L.6.2	Reasons for water testing	170
L.7	Participants' perceptions of drinking-water quality	170
L.7.1	Perception of taste, odour, and colour	170
L.7.2	Perception of safety and value for money	171
L.8	Knowledge of the Richmond urban water supply	172
L.9	Water storage systems	172
L.10	Maintenance of water supply systems	174
L.11	Restrictor supplies supplemented with rainwater	175
L.12	Restrictor supply supplemented with spring water	177
L.13	Restrictor supply supplemented with well water	177
Appendix M.	Tables of data for restrictor-supplemented dwellings ...	179

List of Figures

Figure 1.	Schematic of Richmond water supply	5
Figure 2.	Richmond water scheme with monitoring detail	6
Figure 3.	Map of Richmond supply	9
Figure 4.	Diagram of a conventional treatment system	19
Figure 5.	Diagram showing elements of the multiple barrier principle	22
Figure 6.	Quanti-Tray® control cultures after incubation	54
Figure 7.	Participants' age for participants with a metered or a restrictor-only water supply	57
Figure 8.	Occupation of participants with a metered or a restrictor-only water supply	58
Figure 9.	Number of people living at each dwelling with a metered or a restrictor-only water supply	59
Figure 10.	Number of bedrooms for dwellings with a metered or a restrictor-only water supply	60
Figure 11.	Number of total coliforms per 100 ml for dwellings with a metered or a restrictor-only water supply	61
Figure 12.	Number of <i>E.coli</i> per 100 ml for dwellings with a metered or a restrictor-only water supply	62
Figure 13.	Microbiological results for dwelling R30 showing the effectiveness of the filtration system fitted at this dwelling	68
Figure 14.	Reasons given by participants with a metered or a restrictor-only water supply for not having their water tested	71
Figure 15.	Perception of taste of drinking-water for participants with a metered or a restrictor-only water supply	72
Figure 16.	Perception of odour of drinking-water for participants with a metered or a restrictor-only water supply	73
Figure 17.	Perception of colour of drinking-water for participants with a metered or a restrictor-only water supply	74
Figure 18.	Perception of safety of drinking-water for participants with a metered or a restrictor-only water supply	75
Figure 19.	Perception of value for money of drinking-water for participants with a metered or a restrictor-only water supply	76

Figure 20.	Participants' knowledge of the treatment status of the Richmond water supply	77
Figure 21.	Number of water tanks per dwelling for dwellings with a restrictor-only water supply	79
Figure 22.	Tank sizes for all water storage tanks owned by participants with a restrictor-only water supply	80
Figure 23.	Age of all water storage tanks for dwellings with a restrictor-only water supply	81
Figure 24.	Frequency of inspection of water storage tanks owned by participants with a restrictor-only water supply	82
Figure 25.	A cracked water storage tank	87
Figure 26.	Polyethylene water storage tank in good condition with tank lid firmly in place	97
Figure L1.	Perception of taste, odour, and colour of drinking-water for participants with a restrictor-supplemented water supply	170
Figure L2.	Perception of safety and value for money of drinking-water for participants with a restrictor-supplemented water supply	171
Figure L3.	Capacities of water storage tanks owned by participants with a restrictor-supplemented water supply	173
Figure L4.	Frequency of water storage tank inspection by participants with a restrictor-supplemented water supply	175

List of Tables

Table 1.	Public health grading for the Richmond supply 2001-2011	11
Table 2.	Waterborne outbreaks in New Zealand from 1984-2012	30
Table 3.	Number of metered and restrictor-only dwellings compliant with microbiological criteria set in the DWSNZ 2005 (Revised 2008)	63
Table 4.	Type of water treatment devices installed by participants	64
Table 5.	Maintenance undertaken and effectiveness of water treatment devices installed	66
Table 6.	Previous water testing results and current water test results for participants who have had their water tested previously	69
Table 7.	Participants' knowledge of the Richmond supply grading	78
Table 8.	Total coliform counts for polyethylene and concrete water storage tanks for dwellings with one water storage tank	79
Table 9.	Water quality of restrictor-supplemented dwellings	84
Table D1.	Results of dual microbiological testing with the Cawthron Institute	144
Table K1.	Age in years for participants with a metered or a restrictor- only water supply	154
Table K2.	Ethnicity of participants with a metered or a restrictor-only water supply	154
Table K3.	Occupation of participants with a metered or a restrictor-only water supply	155
Table K4.	Length of time lived at dwelling for participants with a metered or a restrictor-only water supply	155
Table K5.	Dwelling ownership for participants with a metered or a restrictor-only water supply	156
Table K6.	Land area for participants with a metered or a restrictor-only water supply	156
Table K7.	Number of persons living at each dwelling for dwellings with a metered or a restrictor-only water supply	157
Table K8.	Number of bedrooms for dwellings with a metered or a restrictor-only water supply	157

Table K9.	Microbiological results for dwellings with a metered water supply	158
Table K10.	Microbiological results for dwellings with a restrictor-only water supply	159
Table K11.	Reasons for not having water testing done for participants with a metered or a restrictor-only water supply	160
Table K12.	Perception of taste of drinking-water for participants with a metered or a restrictor-only water supply	160
Table K13.	Perception of odour of drinking-water for participants with a metered or a restrictor-only water supply	161
Table K14.	Perception of colour of drinking-water for participants with a metered or a restrictor-only water supply	161
Table K15.	Perception of safety of drinking-water for participants with a metered or a restrictor-only water supply	162
Table K16.	Perception of value for money of drinking-water for participants with a metered or a restrictor-only water supply ...	162
Table K17.	Knowledge of the treatment status of the Richmond water supply for participants with a metered or a restrictor-only water supply	163
Table K18.	Number of water storage tanks owned by each participant with a restrictor-only water supply	163
Table K19.	Capacity of each tank owned by participants with a restrictor-only water supply	164
Table K20.	Total water storage capacity of tanks owned by participants with a restrictor-only water supply	164
Table K21.	Age of each tank owned by participants with a restrictor-only water supply	164
Table K22.	Frequency of tank inspection by participants with a restrictor-only water supply	165
Table L1.	Type of treatment device and results of water testing for dwellings with a restrictor-supplemented supply	168

Table L2.	Frequency of presence of birds and animals on the roof of dwellings with a restrictor supply supplemented with roof-collected rainwater	176
Table M1.	Perceptions of participants with a restrictor-supplemented drinking-water supply	179
Table M2.	Capacities of water storage tanks owned by participants with restrictor-supplemented water supplies	179
Table M3.	Frequency of inspection of water storage tanks owned by participants with a restrictor-supplemented water supply	180