The Control of Disinfection By-Products in Water Treatment Plants and Distribution Systems

By

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Dissertation Declaration

This thesis has not previously been submitted to this, or any other college. With acknowledged exception, it is entirely my own work.

Kristina Lundy

Kristina Lundy

Acknowledgements

I wish to express my sincere gratitude to Ann-Marie Duddy, my project supervisor for her invaluable assistance throughout the duration of my project.

My thanks to all the caretakers of water treatment plants who participated in the survey, in Counties Mayo Galway, Leitrim and Roscommon.

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Abstract

The development of techniques to disinfect drinking water is seen as one of the major achievements of the nineteenth century. However, with the advancement and development of analytical techniques, substances formed from disinfection reactions are now a cause for public concern and have resulted in the development and application of alternative disinfection methods and technologies to control potentially harmful disinfection by-products.

Disinfection is critical to ensuring the safety of drinking water. It must not be compromised by efforts used to control disinfection by-products. The study details the current methods, which may be used for the control of disinfection by-products at water treatment plants and distribution systems and examines the effectiveness of their application.

This study highlights the disinfection practices currently carried out in participating water supply regions in Connaught, Ireland. It establishes that chlorination is the sole process used to adequately disinfect drinking water and is achieved through the application of chlorine. The use of alternative methods and disinfecting agents is not considered in the treatment of drinking water in public water treatment plants that participated in this study.

The study also reveals that proactive measures, which may be taken to control and limit the formation of disinfection by-products, are not considered in the Connaught region. It has been established that only reactive monitoring of substances such as bromate and total trihalomethanes is routinely undertaken by the majority of local authorities in the Connaught region.

It is apparent from the findings of this study that only basic water treatment processes are relied upon to control the formation of disinfection by-products at water treatment plants, while flushing is the principle method employed for the cleaning of water distribution pipes.

Contents

Title page i

Dissertation Declaration ii

Contents vi

List of Figures viii

List of Tables viii

List of Appendices x

1.0 Introduction 1

2.0 Literature review 5

2.1 Drinking Water Treatment Processes 5
2.2 Disinfection 10
2.2.1 Pathogens 10
2.2.2 The purpose of disinfection 12
2.2.3 Methods of Disinfection 13
2.2.4 Disinfection processes currently in use 14
2.2.5 Factors affecting disinfection 18
2.3 Disinfection By-products 19
2.3.1 Introduction 19
2.3.2 Trihalomethanes 21
2.3.3 Factors affecting the formation of THM's and other chlorination DBP's25
2.4 Trihalomethane Control Strategies 28
2.4.1 Source Water Quality Control 29
2.4.2 Natural Organic Matter Removal 31
2.4.3 Alternative Methods of Disinfection 32
2.4.4 Biofilm control strategies 36
2.4.5 Changing the point of disinfection in the distribution network 41
2.4.6 Increased monitoring 41

3.0 Methodology 43

3.1 Questionnaire development 43
3.2 Questionnaire design 45
3.3 Conducting the questionnaire 50
3.4 Analysis of results 50

4.0 Results 51

4.1 Unit processes carried out at drinking water treatment plants 53
4.2 Methods employed for the disinfection of drinking water 58
4.3 Substances used to achieve the chlorination of drinking water 59
4.4 The control of algae at water treatment plants 62
4.5 Total Organic Carbon monitoring 63
4.6 Bromide analysis 66
4.7 Methods employed for the cleaning of distribution lines 68
4.8 The frequency of cleaning of distribution lines 69
4.9 Issues dealt with in Action Plans of the Protection of Drinking Water 72

5.0 Discussion 76

6. 0 Conclusions 93

7.0 Recommendations 97

List of Figures

Figure 1: Typical water treatment processes, EPA, (1998). 5
Figure 2: The chemical structure of four trihalomethanes 22

List of Tables

Table 1: Unit processes carried out for the treatment drinking water 6
Table 2: Common Disinfection Techniques 13
Table 3: Current Disinfection Practices 15
Table 4: Summary of disinfection impacts 18
Table 5: Disinfection by-products formed from various disinfectants 20
Table 6: Summary of toxicological information of THM's 23
Table 7: THM guideline values 24
Table 8: Characteristics of the non-aggressive pipe cleaning methods 39

List of Result figures

Figure 4.1:	Percentage of completed questionnaires received from each region of Connaught.	52
Figure 4.2.	Unit treatment processes carried out in public water treatment plants in County Mayo	53
Figure 4.3	Unit treatment processes carried out in public water treatment plants in County Galway	54
Figure 4.4	Unit treatment processes carried out in public water treatment plants in County Leitrim	55
Figure 4.5	Unit treatment processes carried out in public water treatment plants in County Roscommon	56
Figure 4.6:	Unit processes carried out during the treatment of drinking water in Connaught	57
Figure 4.7	Methods of disinfection in the Connaught Region	58
Figure 4.8	Substances used to achieve chlorination at public water treatment plants in County Mayo	59
Figure 4.9	Substances used to achieve chlorination at public water treatment plants in County Galway	60
Figure 4.10	Substances used to achieve chlorination at public water treatment plants in County Leitrim	60
Figure 4.11	Substances used to achieve chlorination at public water treatment plants in County Roscommon	61
Figure 4.12	Extent to which different substances are used in public water treatment plants in the region of Connaught.	62
Figure 4.13	Frequency of Total Organic Carbon monitoring in public water treatment plants in County Mayo	63
Figure 4.14	Frequency of Total Organic Carbon monitoring in public water treatment plants in County Galway	64
Figure 4.15	Frequency of Total Organic Carbon monitoring in public water treatment plants in County Roscommon	65
Figure 4.16	The frequency of TOC analysis at public water treatment plants in Connaught.	65
Figure 4.17	Frequency of bromide monitoring in public water treatment plants in County Mayo	66
Figure 4.18	Frequency of bromide monitoring in public water treatment plants in County Galway	67
Figure 4.19	Frequency of bromide analysis in public water treatment plants in the Connaught region	68
Figure 4.20	The frequency of cleaning of water distribution lines arising from public water treatment plants in County Mayo	69
Figure 4.21	The frequency of cleaning of water distribution lines arising from public water treatment plants in County Galway	70
Figure 4.22	The frequency of cleaning of water distribution lines arising from public water treatment plants in County Leitrim	71

Figure 4.23 The frequency of cleaning of water distribution lines in County Roscommon 72
Figure 4.24 Issues dealt with in drinking water action plans in County Mayo... 73
Figure 4.25 Issues dealt with in drinking water action plans in County Galway 73
Figure 4.26 Issues dealt with in drinking water action plans in County Leitrim 74
Figure 4.27 Issues dealt with in drinking water action plans in County Roscommon 74
Figure 4.28 Issues dealt with in drinking water action plans in Connaught. 75

List of Appendices

Appendix 1: Standards for potable water abstraction set by the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking) Regulations, 1989.

Appendix 2: European Communities (Drinking Water) Regulations, 2000.

Appendix 3: List of water supply zones in each region in Connaught.

Appendix 4: Questionnaire sent to water treatment plant caretakers.

List of Abbreviations

DBP	Disinfection by-product
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
NOM	Natural Organic Matter
PAH	Polyaromatic hydrocarbons
THM	Trihalomethane(s)
TOC	Total Organic Carbon
US EPA	United States Environmental Protection Agency

1.0 Introduction

The production, distribution and monitoring of public drinking water supplies in Ireland is the responsibility of local sanitary authorities. They are responsible *inter alia*, for:

a) the treatment of water at a water treatment facility to a standard that meets the requirements of the EC (Drinking Water) Regulations, 2000;
b) the provision and maintenance of water distribution systems;
c) the protection of water supply sources;
d) monitoring of drinking water quality and reporting to the EPA.

Under the European Communities (Drinking Water) Regulations, 2000, it is the duty of a sanitary authority *"to take the necessary measures to ensure that water intended for human consumption is wholesome and clean and meets the requirements of the Regulations"*

The Environmental Protection Agency (EPA) also has specific responsibilities with regard to the quality of drinking water. These responsibilities include, *inter alia*:

a) the collection and verification of monitoring results from sanitary authorities in each county to prepare an annual report on the quality of drinking water.
b) provision of both advice (guidance documents) and assistance to sanitary authorities to fulfil their duties under the EC (Drinking Water) Regulations, 2000.
c) ensuring that quality control systems are in place in laboratories undertaking the analysis of drinking waters.

According to EPA publication “The Quality of Drinking Water in Ireland- A Report for the Year 2004” there are currently 904 public water supply zones monitored for compliance with the EC (Drinking Water) Regulations, 2000. Such supplies serve 84 percent of the Irish population. Some households in Ireland are served by private group water schemes. The provision of drinking water to households from private group water schemes is beyond the scope of this report. The report states that public water supplies in Ireland are, in general, of satisfactory quality as compared to private group water schemes that are deemed to be, in general, of unsatisfactory quality. The report identifies that while there is a high rate of compliance (99.3%) with chemical parameters specified in the 2000 Regulations, significant improvements must be made in relation to some parameters including lead, fluoride, bromate and trihalomethanes.

Trihalomethanes are one of a number of compounds commonly referred to as disinfection by-products. As the name suggests these compounds may be formed during the disinfection of water for the purpose of producing potable water.

Research has shown that certain disinfection processes result in the formation of various DBP’s, for example the use of chlorine and its compounds as disinfecting agents may lead to the formation of trihalomethanes (EPA, 1998). Research has also highlighted that processes occurring in other unit treatments during the production of potable water may reduce of enhance DBP formation (Xie, 2004).

This dissertation is primarily concerned with the control of disinfection by-products in water treatment plants and distribution systems.

The aims of this study are:

a) To research literature in order to determine the mechanisms and processes that enhance DBP formation, specifically trihalomethanes at a water treatment plant and in the distribution network.

b) To research literature in order to determine how DBP formation can be controlled at a water treatment plant and in the distribution system.

c) To investigate the methods used in the production of potable water in the Connaught region of Ireland.

d) To determine the extent to which proactive measures are implemented in the control of DBP's during treatment.

e) To investigate the measures implemented to ensure the distribution of water that is of an adequate standard to the customer.

The literature review focuses on the process of water disinfection, disinfection by-products, specifically trihalomethanes, alternative methods of disinfection and disinfecting agents which may be utilised for the control of trihalomethanes and finally the control of trihalomethanes in distribution networks. The literature review also summarises the typical water treatment processes and alternative methods of disinfection and disinfecting agents, which may be used in the treatment of drinking water.

A vast expanse of literature exists in relation to drinking water quality, the disinfection of drinking water and indeed the by-products formed as a result of this treatment process. However research has highlighted that there is little information relating to this topic in an Irish context, this is the basis of the authors work.

2.0 Literature Review

2.1 Drinking Water Treatment Processes

Drinking water is produced in water treatment plants of various degrees of sophistication. Typical unit processes that may be observed at a water treatment plant are outlined in Figure 1 and Table 1 below.

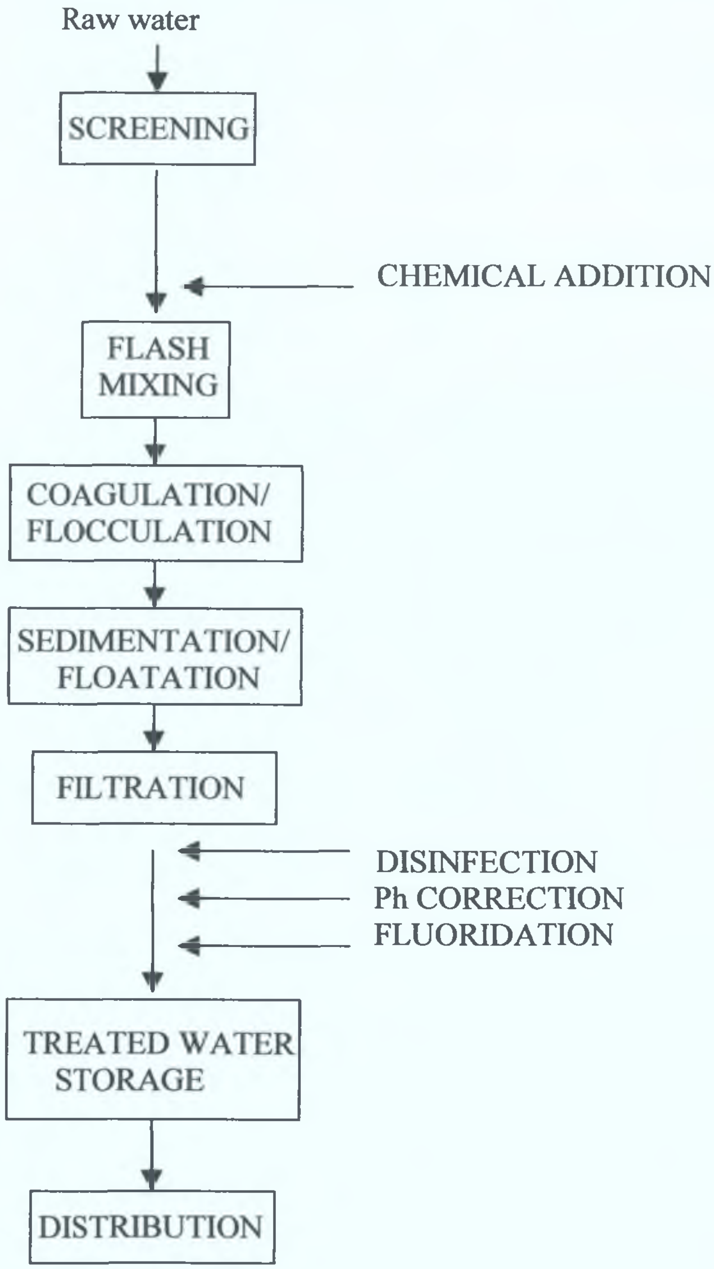

Figure 1: Typical water treatment processes, EPA (1998).

Table 1: Unit processes carried out for the treatment drinking water

Treatment process	Definition	Process objectives	Methods used	Advantages	Disadvantages	Literature Source
Pre-treatment storage	The storage of water in reservoirs, particularly from lower reaches of rivers to improve water quality.	1. Natural settling of suspended particles. 2. Natural death and decay of pathogens. 3. Reduce turbidity. 4. Reduce the concentration of ammonia and organic pollutants.	Storage of water in reservoirs.	1. Improves raw water quality and consistency of supply. 2. Decreases the number of certain pathogens e.g. 90% reduction in coliform and Cryptosporidium and Giardia oocysts.	1. Growth of algae during storage of nutrient enriched waters in spring and summer. 2. The removal of particles is dependant on an adequate residence time. 3. Water quality improvements dependant on duration and degree of mixing as well as time of year.	Binnie *et al* (2002)
Chemical pre-treatment	The use of chemicals to achieve specific desired effects e.g. the removal of algae with $CuSO_4$.	1. Remove algae and natural organic matter. 2. Reduce coliform bacteria.	The methods used are really dependant on chemicals added. The chemicals used are specific to the desired end result. 2. Pre-chlorination 3. Pre-ozonation	1. Improvements in water quality e.g. reduction in natural organic matter and pathogens	1. Some chemicals e.g. $CuSO_4$ is toxic to humans in the concentration necessary to remove algae. 2.The addition of chemicals generally results in the production of a sludge which must disposed of. 3. Potential for the formation of disinfection by-products.	Gray (2005)
Screening	The use of screens of varying sizes to remove floating debris/ materials.	1. Prevent debris from entering the water treatment plant causing damage to equipment 2. Removal of algae.	1.Coarse screening 2. Fine screening	1. Stops debris such as twigs leaves and larger objects form entering the treatment plant. 2. Fine screens remove filamentous algae, waterweed and small debris.	1. Screens may become clogged and must be cleaned regularly and maintained.	Binnie *et al* (2002)

Treatment process	Definition	Process objectives	Methods used	Advantages	Disadvantages	Literature
Coagulation / Flocculation	The addition of chemicals to destabilise colloidal suspensions, which will not otherwise settle, float or filter.	1. Remove turbidity. 2. Precipitation of soluble organic matter such as colour.	1. The method used is dependant on the chemicals used. Examples include aluminium sulphate, aluminium hydroxide, polyaluminium chloride Iron III chloride and lime.	1. Results in the removal of particles les<10um in size. 2. Ultimately results in a clearer water 3. Results in less solid material being carried forward to the filtration stage 4. An efficient process results in the generation of less disinfection by-products.	1. Some of the chemicals may reach the consumer. 2. Process is influenced by the pH, temperature and the degree of mixing of the water. 3. The amount of chemical added is critical.	Stevenson (1997) Binnie *et al* (2002) Mesdaghinia *et al* (2005)
Clarification	The process whereby floc are allowed to settle out of suspension though gravity settling.	The removal of suspended particles.	1.Sedimentation 2. Upward gravity flow 3. DAF The main criteria for the sedimentation tank is the surface loading rate, adequate depth and detention time for settling and weir loading rate to minimise turbulence.	1. Removal of particles through natural processes such as gravity. 2. Upward-flow settlement tanks provide enhanced flocculation as well as floc separation 3. DAF is a high rate clarification process with a short detention time, is better at treating water containing light flocs and algae, the sludge produced has a low water content and requires less space.	1. Resuspension of particles may be caused by excessive turbulence. 2. Sludges are produced, the water content of which depends upon the type of clarifier used in the process.	Hammer and Hammer (1996) Vigneswaran and Visvanathan, (1995) Gray (2005) Binnie *et al* (2002)

Treatment process	Definition	Process objectives	Methods used	Advantages	Disadvantages	Literature
Filtration	Passing water through a granular bed of sand or other medium. The media through which the water is passed retains solids contained in the water and allows the water to pass through.	1. Remove suspended particles. 2. Remove pathogens.	1. Slow sand filtration. 2. Rapid gravity filters. 3.Pressure filters (a from of Rapid gravity filter).	1. Filters provide both physical straining and biological treatment. 2. Good quality water may be filtered and distributed directly to consumer.	1. Filter beds can become clogged if the influent water has a high level of suspended solids. 2. May have carry over of organic matter or particles. 3. Sand filtration is a relatively slow process.	Binnie *et al* (2002) Gray (2002) Stevenson (1997)
Disinfection	A treatment process for the purpose of the destruction and inactivation of human pathogens.	1. Destroy pathogens 2. Provide additional protection against future contamination.	Use of a number of physical and chemical systems as outlined in table3.	1.Reduced incidents of illness and fatalities from waterborne diseases. 2. Removal of taste and colour. 3.Oxidises Fe and Mn. 4. Prevents biological re-growth in the water distribution system.	1. Potential for the formation of disinfection by-products. 2. The efficiency of the disinfection process is affected by a number of factors such as the pH, temperature, contact time and the concentration of disinfectants/ microbial contaminants.	United States Environmental Protection Agency (1999) Momba *et al* (2000) Sadiq and Rodriguez (2004),
Fluoridation	The process of adding fluoride to finished drinking water to yield fluoride ions (F^-).	1. Fluoridation of drinking water.	1. Addition of fluoride compounds such as ammonium fluosilicate, calcium fluoride, fluosilicic acid and sodium fluoride.	1. Chlorination has no effect on fluoride. .	1. Fluoride can be lost during coagulation, lime softening and activated carbon treatment. 2. Can be removed by precipitation with calcium and excess aluminium coagulant in finished water	Gray (2002)

The quality of water, which may be used for the abstraction of drinking water, is regulated under the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking) Regulations, 1989. The Regulations detail three categories of surface water quality, namely A1, A2 and A3, with respect to physical, chemical and microbiological characteristics (see Appendix 1). A1 waters are considered to be of high quality, while A3 waters may not be used for the abstraction of drinking water.

In Ireland, the specification requirements for drinking waters are set down in national legislation. The most current legislation governing drinking water quality requirements are the EC (Drinking Water) Regulations, 2000 (SI 439 of 2000), which came into effect in 2004. The Regulations prescribe 48 parametric values, including microbiological, chemical and indicator parameters to which drinking water must adhere (see Appendix 2). The EC (Drinking Water) Regulations, 2000 originate from Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

In general, the above guidelines ensure that water supplied for human consumption is:

a) free from disease-causing (pathogenic) organisms;
b) free from compounds toxic to human health
c) clear (i.e. low turbidity, little colour);
d) free from offensive taste or smell; and
e) free from chemicals or substances that may cause corrosion of the water supply system or stain clothes washed in it.

For the purpose of this study a) and b) above are of particular importance.

2.2 Disinfection

2.2.1 Pathogens

There are three different groups of micro-organism that can be transmitted via drinking water: these are viruses, bacteria and protozoa. They are all transmitted by the faecal-oral route and arise either directly or indirectly by contamination of water resources by sewage or, on occasion, animal waste.

Bacteria are the most important group in terms of reported outbreaks of disease. The most important bacterial diseases are commonly associated with faecal contamination of water by such bacteria as *Salmonella, Campylobacter, Shigella, Vibrio cholera* and *Mycobacterium*.

The two protozoa of most importance in water used for the supply of drinking water are *Cryptosporidium* and *Giardia lamblia. Cryptosporidium causes* gastroenteritis and, if the patient's immune system is suppressed, it may cause death. *Giardia lamblia* causes acute diarrhoeal illness.

Infectious hepatitis, enteroviruses and reovirus are all though to be transmitted via drinking water. Of the most concern is viral hepatitis. There are three subgroups of viral hepatitis, hepatitis A, B and C. Hepatitis A is transmitted by water and causes nausea, muscle ache and jaundice. Enteroviruses cause respiratory infections while Reovirus is thought to be associated with gastroenteritis.

Rather than list each pathogenic organism that may be potentially present in drinking water, the EC (Drinking Water) Regulations, 2000 stipulate that certain 'indicator' micro-organisms may not be present in water. According to Vigneswaran and Visvanathan (1995) "it is not practicable to test water for all the organisms that it might possibly contain. Instead, the water is examined for a specific type of bacteria that originates in large numbers from human and animal excreta and whose presence in water is indicative of faecal contamination". This ensures a high factor of safety against the passage of pathogenic organisms into the treated water supply, EPA (1998).

The presence of an indicator organism in drinking water is a good indication that either the source of the water has become contaminated or that the treatment process at the water treatment plant is not operating adequately. Indicators are principally used because:

1) they are present whenever pathogens are present;
2) they are easily detected and identified;
3) are present in far greater numbers than the pathogens;
4) show the same or better survival characteristics than pathogens;
5) they pose a reduced health risk to those carrying out analysis.

The indicator organisms used in the 2000 Drinking Water Regulations are *Escherichia coli* (*E.coli*), faecal streptococci and *Clostridium perfringes* (including spores). Other organisms that function as indicator organisms include: *Pseudomonas aeruginosa.*

As a result of the nature and size of micro-organisms present in water, their removal cannot be guaranteed by employing methods such as coagulation and filtration alone, thus disinfection is required.

2.2.2 The purpose of disinfection

Disinfection processes are utilised in order to achieve compliance with the microbiological specifications laid down in the 2000 Drinking Water Regulations. The disinfection of drinking water may be defined as "a treatment process for the purpose of the destruction or indeed inactivation of human pathogens" (Binnie *et al* 2002). The process of disinfection was first introduced in the nineteenth century and led to a substantial decrease in the incidents of illness and fatalities from waterborne diseases.

There are two aspects of disinfection, the first is the disinfection of the water to kill all pathogens that have passed through the various treatment stages of a water treatment plant and the second is to apply a residual disinfectant so that water leaving the treatment plant remains safe as it passes through the distribution system to the point of use. (Binnie *et al* 2002).

In order for a disinfectant to be effective in potable water, it must:

- destroy all pathogens introduced into potable water within a certain time period;
- be able to overcome fluctuations in composition, temperature, concentration and conditions of waters which are to be treated;
- be non- toxic and palatable to humans or domestic animals
- be dispensable at reasonable cost and risk to operators;
- persist within disinfected water in a sufficient concentration to provide reasonable residual protection against possible recontamination from pathogens before use

Source: Percival *et al* (2000)

2.2.3 Methods of Disinfection

Disinfection can be achieved by either physical or chemical means, these may be summarised as:

Disinfection Method	Example
Physical	Heat; storage
Light	Ultraviolet radiation
Metals	Silver
pH	Acids; alkalis
Oxidants	Chlorine; chlorine dioxide; ozone; iodine; chloramines
Others	Surface active agents

Table 2: Common Disinfection Techniques

Source: Government of Newfoundland and Labrador (1996).

Disinfection is one of the standard treatments for transforming A1 and A2 waters into water fit for human consumption. Generally disinfection is the final element of drinking water treatment to ensure as far as is reasonably practicable the absence of pathogenic micro-organisms and also to ensure that the disinfection effect continues throughout the distribution system until finally reaching the consumer.

The methods, which may be utilised, for the effective disinfection of water depend principally on the quality of the raw water to be treated. As stipulated in the European Communities (Quality of Surface Water intended for the abstraction of Drinking) Regulations, 1989 waters classified as A1 require "simple physical treatment and disinfection, e.g. rapid filtration and disinfection." A2 water must receive "normal physical treatment, chemical treatment and disinfection, e.g. pre-chlorination, coagulation, flocculation, decantation, filtration and disinfection." Finally A3 is considered to be unfavourable it terms of its abstraction for drinking water, however if such as source must be utilised, treatment must involve "Intensive physical and chemical treatment, extended treatment and disinfection, e.g. coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination)."

2.2.4 Disinfection processes currently in use

There are numerous well-established methods and technologies relating to the disinfection of drinking water. Such processes are summarised in Table 3 below.

Table 3: Current Disinfection Practices

Process	Definition	Generation of disinfectant	Advantages	Disadvantages	Literature
Chlorination	The use of chlorine gas which dissociates to form hypochlorous acid and hypochlorite ions, the reaction is pH dependent. Effective chlorination requires: a free chlorine residual of more than 0.5mg/l; a contact time of at least thirty minutes; a turbidity of less than 1 NTU and a pH of no more than eight.	Chlorine gas may be generated in a number of different ways, for example the electrolysis of alkaline brine or hydrochloric acid, the reaction between sodium chloride and nitric acid or the oxidation of hydrochloric acid.	1. It is readily available in numerous forms. 2. It is cheap in comparison to other disinfectants. 3. It is easy to apply because of its high solubility in water. 4. It leaves a residue. 5. It is toxic to most, but not all micro-organisms. e.g. can result in 99% removal of *Clostridium perfingens.* 6.Controls biofilm formation 7. Oxidises soluble iron, manganese and sulphides. 8. It is the most widely used disinfection method, therefore the most well known.	1. Efficiency of chlorine is affected by pH, (a pH of less than eight is desirable because a lower pH yields a greater amount of hypochlorous acid which is more effective than the hypochlorous ion), turbidity and the contact time. 2. Increased amount of natural organic matter in water result in an increased dose of chlorine being required for disinfection. 3. Micro-organisms present in high turbidity water may be protected from the action of chlorine by increasing the oxygen demand 4. Forms halogen-substituted by-products 5. Finished water may have taste and odour problems.	Galal-Gorchev, (1996) EPA, (1998) Binnie *et al*, (2002) Tebbutt, (1983) WHO
Chloramination	The addition of chloramines in the form of monochloramine, dichloramine or trichloramine to water for the purpose of disinfection.	The formation of chloramines involves the addition of ammonia to water; followed by the addition of aqueous chlorine The chloramine formed is dependant the amount of ammonia and chlorine present in the water.	1. Insignificant formation of disinfection by-products. 2. Eliminates certain taste and odour conditions associated with chlorine. 3. More stable residual in the water distribution system. 4. Introduction of chloramines is simple and similar to that of chlorine gas. 5. Chloramines are more stable than chlorine. 6. Are inexpensive and easy to make.	1. Not as effective as chlorine in deactivating bacteria, viruses and *Giardia.* 2. May produce chlorinated phenols, which gives taste to water. 3. May produce gas-poisoning hazards similar to that of chlorine. 4. Uncontrolled dosage of ammonia could lead to nitrification problems. 5. Takes a longer time than chlorine for effective disinfection. 6. Chloramines must be generated on-site.	Vigneswaran and Visanathan, (1995) US EPA, (1999)

Process	Definition	Generation of disinfectant	Advantages	Disadvantages	Literature
Chlorine dioxide	Addition of chlorine dioxide to adequately disinfect water, its application is effected by the maximum residual that does not cause adverse taste and odour and the amount of chlorite produced by reduction reactions.	Formed by the reaction between sodium chlorite and either chlorine or hydrochloric acid	1, Used for the control of tastes and odours and sulphides. 2. Does not form trihalomethanes. 3. Is a useful technology in the treatment of water from enriched sources, as it does not combine with ammonia. 4. It is a more effective disinfectant than chlorine but is less effective than ozone. 5. Biocidal properties are not influence by pH. 6. It is easy to generate. 7. Provides residual disinfection.	1. It is unstable, therefore must be generated on site. 2. Reactions produce chlorite and chlorate ions, the toxicity of which is not yet fully understood 3. Dose must be strictly controlled at a level of 1.5mg/l to control the formation of disinfection by-products. 4. Process forms chlorite and chlorate. 5. Equipment costs are high. 6. Generator efficiency and optimisation difficulty can cause excess chlorine to be fed at the application point, which can potentially form halogen-substitute disinfection by-products.	Binnie *et al*, (2002) Kazt and Narkis, (2001) US EPA, (1999)
Ozone	Addition of ozone gas to water to achieve disinfection.	Ozone is an allotropic form of oxygen produced by passing dry oxygen or air through an electric discharge.	1. Ozone can form other product; which have oxidising properties e.g. the hydroxyl radical which is more reactive than ozone itself, other products include: ozonide free radical anion, the superoxide free radical anion, the perhydrolyl free radical anion and hydrogen peroxide. 2. Effective against all microbial pathogens. 3. Results in a lower production of trihalomethanes. 4. Can react with NOM to change their potential for reaction with chlorine 5. Can reduce colour, taste and odour.	1. It is a relatively unstable gas, which readily decomposes. 2. Its solubility is dependant on the temperature of the water and the concentration of ozone. 3. Ozonation is effected by pH (effects the dose required for sufficient disinfection) and particulates e.g. inactivation of Giardia is decreased with and increase in turbidity. 4. In waters containing bromide the use of ozone oxidises the bromide to form bromate, which is considered to be genotoxic. 5. Does not have a residual disinfection action.	Bryant *et al*, (1992)

Process	Definition	Generation of disinfectant	Advantages	Disadvantages	Literature
Potassium permanganate	Potassium permanganate is used in combination with other treatment technologies, to solve specific water treatment problems cause by organic and inorganic constituents.	Potassium permanganate is only available in dry form. A concentrated solution (typically 1 to 4 percent is prapared on site.	1. Primarily used to reduce taste, colour, odour and microbial growth problems. 2. Can oxidise pre-cursors for the formation of disinfection by-products. 3 Oxidises iron and manganese. 4. Is easy to transport, store and apply. 5. Controls nuisance organisms. 6. Its use has little impact on other treatment processes at the water treatment facility. 7. Has been proven to be effective against certain viruses.	1. Efficiency is effected by: the concentration of permanganate, pH (acidic conditions enhance the capability of permanganate) and the presence of other oxidisable material (this will reduce the efficiency). 2. A long contact time is required. 3. It has a tendency to give water a pink colour. 4. It is toxic and irritating to skin and mucous membranes. 5. It is a strong oxidising agent.	US EPA (1999)
U.V.	Ultraviolet radiation is emitted from special lamps. In contrast to chemical disinfectants the mode of action of U.V. is to disrupt cell function and alter DNA.	The water to be disinfected flows between mercury arc discharge tubes and polished metal reflector tubes which gives efficient disinfection, with a retention time of a few seconds.	1. Provide exceptional disinfection of small micro-organisms such as bacteria and viruses, bacterial spores and parasite cysts.	1. It leaves no residual 2. Requires high clarity water 3. A large dose is required to inactivate larger protozoa such as *Giardia* and *Cryptosporidium*. 4. Certain organism can photo-reactivate and repair DNA damage; extent of reactivation depends on the type of organisms present. 5. Should only be used as a primary disinfectant followed by a chemical secondary disinfection to protect the distribution system against coliform proliferation and biofilm formation. 6.U.V. lamps must be kept free of fouling	Bryant *et al*, (1992) US EPA, (1999) Tebbutt, (1998)

2.2.5 Factors affecting disinfection

The efficiency of disinfection is dependant on a number of different factors as summarised in Table 4 below.

Disinfection Parameter	Typical impact on pathogen inactivation
Disinfectant type	Depends on inactivation efficiency of the specific disinfectant used.
Disinfectant concentration	The stronger the disinfectant, the quicker the disinfection process.
Disinfectant dose	Increasing the disinfectant dose increases the rate of disinfection.
Type of organism	Susceptibility to disinfection varies according to pathogen group. In general protozoa are more resistant to disinfectants than bacteria and viruses. Some disinfectants are less effective than others against various groups of pathogens.
Contact time	Increasing the contact time decreases the disinfectant dose required for a given level of inactivation.
pH	pH may affect the disinfectant form and in-turn the efficiency of the disinfectant.
Temperature	Increasing the temperature increase the rate of disinfection
Turbidity	Particles responsible for turbidity can surround and shield pathogenic micro-organisms from disinfectants and increase disinfectant dose required.
Dissolved organics	Dissolved organics can interfere with disinfection by creating a demand and reducing the amount of disinfectant available for pathogen inactivation.
Chlorine residual	It is recommended that a chlorine residual not less than 0.5 mg/l be maintained throughout the distribution network to prevent the growth of pathogens in the pipework.

Table 4: Summary of disinfection impacts adapted from EPA (1999).

2.3 Disinfection By-products

2.3.1 Introduction

According to the Water Resources Management Division "the disinfection process should balance the ability to kill or inactivate a wide variety of microbial pathogens, maintain a residual and minimise the formation of harmful by-products".

It is well established that the application of disinfection agents to drinking water reduces the microbial risks associated with its consumption (Gray; 2005 and Galal-Gorchev; 1996), however, the process also poses a toxicity risk in the form of their resultant chemical by-products.

Disinfection by-products (DBP's) are chemical, organic and inorganic substances that can form during a reaction of a disinfectant with naturally present organic matter or bromide in the water. Natural organic matter results from the decomposition of matter from the environment surrounding the watershed e.g. leaves, aquatic plants, dead animals and animal by-products. Bromide ions, (B^-) are naturally occurring in water in considerably low concentrations, however they are increasingly becoming recognised as a potential raw water pollution problem (Binnie *et al* 2002).

The formation of DBP's was first identified in the early 1970's (Gray, 1994). Over two hundred and fifty DBP's have now been successfully identified. The identification of these products has been greatly accelerated by technological advances in analytical techniques such as gas chromatography and mass spectrometry. (Bryant *et al* 1992). The major categories of DBP's formed by various disinfectants are summarised in Table 5 overleaf.

Disinfectant	Organohalogenic disinfection by-products	Inorganic disinfection by-products	Non-halogenic disinfection by-products
Chlorine (Cl_2)	Trihalomethanes, halogenic acetic acids, chloramines, chlorine hydrates	Chlorate (particularly the application of hypochlorite)	Aldehydes, alkanic acids, benzene, carboxylic acid
Chlorine dioxide (ClO_2)		Chlorite, chlorate	Unknown
Chloramines	Organic chloramines, chloramino acids, chlorohydrates	Nitrite, nitrate, chlorate	Aldehydes, ketones
Ozone (O_3)	Bromoform, bromine, monobromine acetic acid, dibromine acetic acid	Chlorate, iodate, bromate, hydrogen peroxide, ozonates	Aldehydes, ketones, ketoacids, carbonxylic acids

Table 5: Disinfection by-products formed from various disinfectants Adapted From US EPA (1999).

Note: Halogenated organic by-products are formed when natural organic matter reacts with free chlorine or free bromine. Non-halogenated by-products are also formed when strong oxidants react with organic compounds found in water, for example ozone and peroxone oxidation leads to the formation of aldehydes and keto-acids (US EPA, 1999).

Evidence shows that the circumstances of the disinfection process such as reaction time, temperature and pH of the water to be treated may influence to some degree the formation of DBP's (Xie, 2004).

2.3.2 Trihalomethanes

All disinfection techniques accomplish the essential task of disinfection to varying degrees. However all disinfectants form various types of disinfection by-products. It is generally accepted that the most common type of disinfection process carried out on drinking water worldwide is chlorination. This practice leads to the formation of chlorination by-products, the most important of these being trihalomethanes or THM's. (Gray 1994).

THM's were the first category of DBP's to be identified (Nikolaou *et al*, 1999) and are perhaps the most widely researched form. THM's are rarely found in raw water but are often present in finished water. They are simple, single carbon compounds, which have the general formulae CHX_3. The X may be either chlorine, bromine, fluorine or iodine or a combination of several of these. THM's therefore occur in four principle forms as illustrated in Figure 2 overleaf.

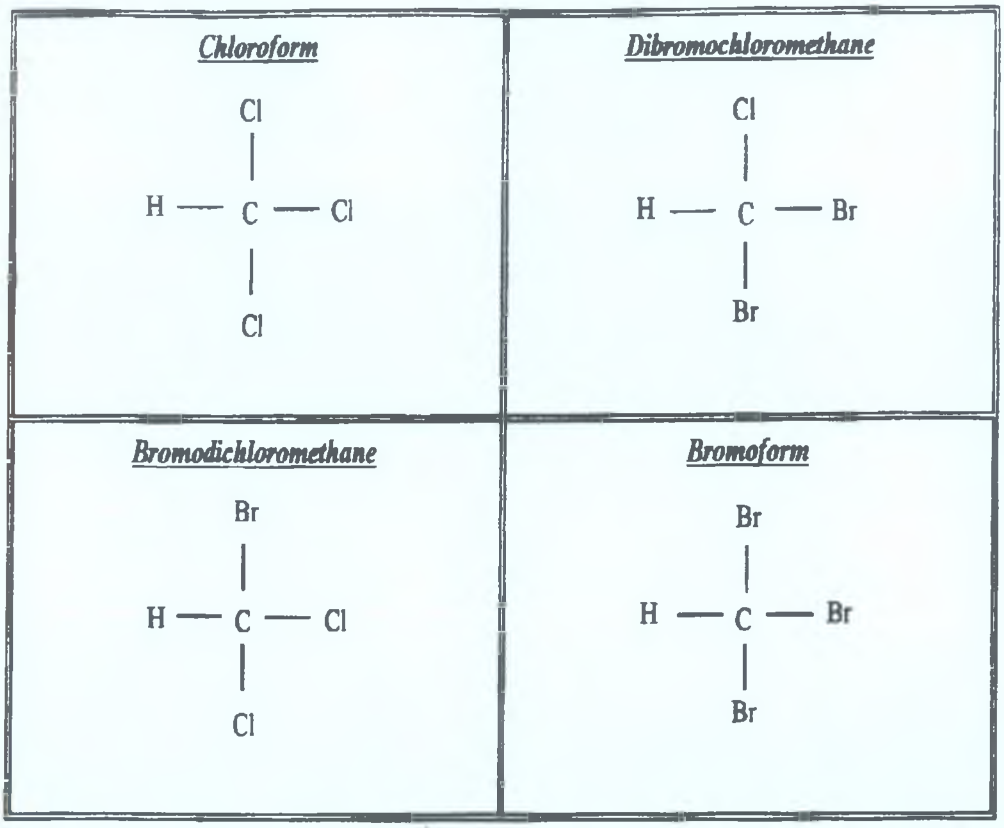

Figure 2: The chemical structure of four trihalomethanes: chloroform, ($CHCl_3$) dibromochloromethane ($CHBr_2Cl$), bromodichloromethane ($CHBrCl_2$) and bromoform ($CHBr_3$).

As a result of an increasing amount of concern regarding THM's, numerous attempts to determine the health effects of these substances have been made in the past twenty years. Research has involved both toxicological and epidemiology studies, however the effects of such substances still remains an area of great debate. A summary of toxicological information on THM's as determined by Sadiq and Rodriguez (2004) is provided in Table 6 below.

THM category	Carcinogenicity rating	Detrimental health effects
Chloroform	B2	Cancer, liver, kidney and reproductive effects
Dibromochloromethane	C	Nervous system, liver, kidney and reproductive effects
Bromodichloromethane	B2	Cancer, liver, kidney and reproductive effects
Bromoform	B2	Cancer, nervous system, liver and kidney effects

Table 6: Summary of toxicological information of THM's

Key: B2: Probable human carcinogen (sufficient laboratory evidence)

C: Possible human carcinogen

In contrast to information provided by Sadiq and Rodriguez (2004), other workers claim that the toxicological information regarding THM's and other DBP's show little evidence that they are the primary agents responsible for increased renal, bowel and other cancers resulting from exposures to chlorinated drinking-water. (Ashbolt 2004).

In view of the debated potential of THM's to cause cancer and cause other health effects, guideline values for the maximum concentration of these compounds permissible in drinking water have been set by World Health Organisation (W.H.O). These guideline values are shown in Table 7 below.

Substance	Guideline values
Chloroform	0.2mg/l
Bromoform	0.1mg/l
Dibromochloromethane	0.1mg/l
Bromodichloromethane	0.06mg/l

Table 7: THM guideline values, World Health Organisation (2005).

The EC (Drinking Water) Regulations, 2000 set a parametric value for total THM of 100ug/l. This target must be met by 25th December 2008.

The occurrence of THM's from chlorinated drinking waters and their resultant effects on human health has greatly emphasised the need for a significantly greater amount of research into disinfectant alternatives and new technologies. Evidence has highlighted that the health risks from pathogenic micro-organisms far exceed those potential health problems associated with THM production during the treatment of drinking water. Bearing these two points in mind finding a balance is essential.

2.3.3 Factors affecting the formation of THM's and other chlorination DBP's

The formation of chlorination DBP's and in particular THM's is affected by a number of factors such as:

- Concentration of natural organic matter
- Contact time
- pH
- Concentration of chlorine
- Temperature
- Presence of a biofilm
- Turbidity

Natural Organic Matter

Diverse organic compounds generated by the biological processes both in a water body and in a surrounding watershed are found in all surface waters. These compounds are referred to as natural organic matter or NOM (Matilainen *et al*, 2006). Chlorination DBP's are principally formed from the reaction of NOM with chlorine. The DBP's may be either intermediates of the reaction or end products. The degree of DBP formation increases with NOM concentration. Xie (2004) suggests that NOM affects the formation of DBP's in two different ways, firstly by increasing the level of pre-cursors and secondly increasing the chlorine demand leading to the need for significantly high chlorine doses thus increasing DBP formation.

NOM levels in water can be measured by analysing for total and dissolved organic carbon. An estimate of the potential for the formation of DBP's may be made from the total organic carbon (TOC) concentration, as it is generally accepted that as the amount of NOM increases so does the formation of DBP's when chlorine is used as the disinfecting agent.

Contact Time

The contact time afforded between the disinfecting agent and the water to be disinfected is an important factor determining whether intermediates or end products are formed. Xie (2004) suggests that if the DBP is an end product then increasing the reaction time with chlorine will act to increase its formation. If, however, the DBP is an intermediate product then increasing the contact time will in fact reduce the formation of DBP's, especially at high chlorine doses. Nikolaou *et al*, (2002) suggests, "with increasing contact time THM formation increases."

pH

As the pH of the water increases so does the production of THM's because the effectiveness of chlorine is lowered at a low pH and thus large doses are required.

Bromide ion concentration

Inorganic bromide may be oxidised by chlorine or ozone to form hypobromous acid or hypochlorite depending on the pH. These products react with NOM present in the water to form brominated DBP's. According to Xie (2004) "Since bromide will occupy the site for chlorine substitution, the formation of chlorinated species will be reduced."

Concentration and dosage of Chlorine

The stronger the disinfectant concentration and dose, the greater the amount of DBP's formed (US EPA, 1999). Research has shown that doubling the chlorine dose more than doubles the formation of THM's in a twenty-four hour period. EPA, (1998).

Presence of Biofilms

A biofilm is an organic or inorganic surface deposit consisting of micro-organisms, microbial products and detritus (Vigneswaran and Visanathan, 1995). Boifilms are described by Momba *et al* (2000) as "a layer of micro-organisms in an aquatic environment held together in a polymetric matrix and attached to a substratum such as pipes, tubercules or sediment deposits". The presence of biofilms have an adverse effect on drinking water quality in terms of bacterial contamination but they may also result in a greater concentration of disinfectant being used (to ensure drinking water that is adequate in quality) thereby increasing the potential for THM formation.

Turbidity

Increasing turbidity is typically associated with increased NOM thereby increasing the amount of DBP pre-cursors for the formation of DBP's when disinfectant is applied.

Temperature

Increasing temperature is associated with faster oxidation kinetics, hence, increased DBP formation. For this reason DBP concentrations are expected to be higher in summer than in winter.

2.4 Trihalomethane Control Strategies

Evidence has shown that the health risks associated with the consumption of drinking water containing pathogenic micro-organisms far exceed those potential health problems associated with consumption of THM's. (Galal-Gorchev 1996). It has recently been stressed by the W.H.O. that the risks of health hazards from DBP's are infinitesimal when compared with those due to ineffective disinfection (Binnie *et al* 2002). Nevertheless, the occurrence of THM's in chlorinated drinking waters and their potential health effects is a cause for concern. It is therefore prudent to control the formation of THM's at all stages during the water treatment process. According to the Water Resources Management Division "the disinfection process should balance the ability to kill or inactivate a wide variety of microbial pathogens, maintain a residual and minimise the formation of harmful by-products.

THM control strategies include:

- Control of source water quality
- Natural Organic Matter Removal at the water treatment plant
- Using alternative methods of disinfection
- Biofilm control strategies

- Changing the point of disinfection in the distribution network
- Increased monitoring

2.4.1 Source Water Quality Control

In Ireland the bulk of source waters used for the production of drinking water originate from surface waters (83%) while the remainder are from groundwater origin. Source water quality management is the first and perhaps the most proactive approach in controlling THM formation and ensuring an adequate supply of safe drinking water. Source water control strategies with regard to the control of the formation of THM's involve managing the source water to ensure lower concentrations of NOM and bromide ion.

In Ireland the quality of surface waters that may be used for the abstraction of drinking water is currently regulated under the EC (Quality of Surface Water intended for the Abstraction of Drinking) Regulations, 1989. From 2007 these Regulations will be repealed under the provisions of the new Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy).

Legislation governing the quality of source waters to be used for the production of drinking water is intended to achieve the necessary protection to avoid pollution of such water bodies. The methods, which may be utilised, for the effective disinfection of water depend principally on the quality of the raw water to be treated. As stipulated in the European Communities (Quality of Surface Water intended for the abstraction of Drinking) Regulations, 1989 waters classified as A1 require "simple physical treatment and disinfection, e.g. rapid filtration and disinfection." A2 water must receive "normal physical treatment, chemical treatment and disinfection, e.g. pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination)." Finally A3 is considered to be unfavourable it terms of its abstraction for drinking water, however if such as source must be utilised, treatment must involve "Intensive physical and chemical treatment, extended treatment and disinfection, e.g. chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination)."

Research has shown that algal growth leads to the production of DBP precursors therefore nutrient management is one method of controlling the THM formation potential of a source water (EPA, 1999). Algal control is perhaps the most common in-situ treatment for surface waters to be used as a source of abstraction for drinking water, (Binnie et al, 2002). This involves reducing the amount of nutrients available for algal growth and metabolism by controlling their inflow (from point and non-point sources) into the water body (Binnie *et al* 2002).

Algal control may also be achieved by the addition of copper sulphate pentahydrate ($CuSO_4.5H_2O$) and other chelated copper compounds. The practice of algalcidal copper addition to source waters is uncommon in Ireland, primarily because of the toxicity of copper and its compounds.

Studies by the American Environmental Protection Agency (1999) also suggest that potassium permanganate ($KMnO_4$) may be used as an algacide, and has been used to control algae that produce unwanted tastes and odours. It has also been introduced as a method to control algal growth in raw water reservoirs.

Extensive algal growths or 'blooms' may be prevented from entering the water treatment plant by employing the use of microstrainers. A microstrainer is a filtration apparatus constructed in the form of a revolving drum. The apertures in the drum are sufficiently small to retain the algae (and other small particles) while the water flows through to the water treatment plant.

2.4.2 Natural Organic Matter Removal

Natural organic matter has been identified as a major pre-cursor to the formation of many DBP's. A number of unit processes at a water treatment plant e.g. coagulation, clarification and filtration (see Table 1) will remove NOM to varying degrees. Inorganic constituents of NOM (e.g. bromide) are the most difficult elements to remove at a water treatment plant. These constituents are not removed by conventional processes such as coagulation and filtration.

Natural organic matter may be characterised using tests such as total organic carbon (TOC), other analytical methods used to a lesser degree include elemental analysis, UV adsorption analysis, carbon 13 nuclear magnetic resonance, and gas chromatography/mass spectrometry and fluorescence spectroscopy. It is beneficial that the characterisation and indeed the reactivity of NOM present in all waters are understood to ensure that the fraction most important when considering the possible formation of disinfection by-products is removed.

Oxidising substances such as chlorine dioxide and potassium permanganate may be utilised for the oxidation of NOM, thus reducing the potential for the formation of DBP's.

An investigation into the efficiency of activated carbon filtration with regard to the removal of NOM was carried out by Matilainen *et al* (2006); they concluded, "Filtration was effective to a degree but did not significantly remove the smallest molar mass organic matter fraction. Activated carbon was most effective in the removal of intermediate molar mass compounds."

2.4.3 Alternative Methods of Disinfection

The use of alternative disinfectant methods to chlorination have been investigated as a means of reducing THM formation. Such alternative disinfectant methods include ozonisation, UV radiation and perozone

Ozone

The use of ozone as a disinfectant has been summarised in Table 2. Ozone was once considered an attractive alternative to chlorine due to low production of THM's. Ozone reacts with NOM present in water causing a change in its potential for reaction with chlorine and other disinfectants (Bryant *et al*, 1994). However, in some instances it is documented that in situations where the ozone to organic ratio is low the production of THM's may actually increase as a result of a low level oxidation that cleaves the organic matter thus making it more accessible to reactions with chlorine.

Other problems if ozone is used as a disinfectant arise when source waters contain bromide. When waters containing bromide are oxidised, particularly with ozone, the DBP bromate is formed. Bromate is widely considered to be a genotoxic carcinogen. A limit of 10ug/L is imposed for bromate under the EC (Drinking Water) Regulations, 2000.

The reaction of ozone with bromide may also produce hypobromous acid, which may itself also react with NOM to produce the brominated DBP's bromoform, monobromoacetic acid, dibromoacetic acid, tribromoacetic acid and cyanogens bromide. A number of different factors affect the formation of brominated DBP's such as pH, ozone-to-bromide ion ratio and the TOC-to-bromide ion ratio. According to a recent study published by the United States EPA the formation of brominated DBP's can be controlled during ozonation by a variety of techniques, US EPA (1999).

The major drawbacks associated with the use of ozone as a disinfectant is that is does not provide a residual disinfection action within the distribution mains. This allows biological growth to develop which causes taste and odour problems. The problem may be further exacerbated by the effect of ozone on organic constituents within the water; ozone can increase the biodegradability of these components thus increasing the possibility of microbial growth. For this reason, low- level chlorination is often used after ozonation to prevent such growth resulting in the potential formation of a greater concentration of DBP's.

Ultra Violet Radiation

The use of ultra violet (UV) radiation as a disinfectant has been summarised in Table 2. The United States Environmental Protection Agency (1999) states that although UV provides exceptional disinfection of small micro-organisms such as bacteria and viruses, bacterial spores and parasite cysts, a much large dose is needed to inactivate larger protozoa such as *Giardia* and *Cryptosporidium.* For this reason, UV treatment is often carried out in conjunction with other treatment processes such as ozone and/or hydrogen peroxide to enhance disinfection effectiveness. This practice may increase the potential for the formation of DBP's.

The Water Resources Management Division of Newfoundland and Labrador state that THM's are not formed as a result of the use of U.V in the treatment of drinking water. The US EPA (1999) suggests " the U.V radiation of water can result in the formation of ozone or radical oxidants; because of this reaction, there is an interest in determining whether U.V. forms similar by-products to those formed by ozonation or advanced oxidation processes".

As U.V. does not provide a residual, its use must be followed by a chemical secondary disinfectant to protect the distribution system. The choice of secondary disinfectant will determine DBP formation.

Peroxone

Peroxone has also been investigated in the control of THM formation. The use of peroxone as a disinfectant has been summarised in Table 2. According to the US EPA, (1999) "the principle benefit for using peroxone for controlling THM formation appears to be that it eliminates the need for pre-chlorination and allows lower doses of free chlorine or chloramines to be applied later in the process train after pre-cursors have been removed by coagulation, sedimentation and/or filtration and at lower doses".

It is also stated by the US EPA "based upon studies and findings involving peroxone, there is no beneficial lowering of THM's as long as free chlorine is utilised as a secondary disinfectant, unless the application of peroxone allows chlorine to be applied later in the process train to water containing reduced pre-cursor concentrations".

Other DBP's may be produced during the use of peroxone. The DBP's, which may be formed due to the application of peroxone to water, are similar to those formed from the use of ozone. The use of peroxone does not result in the formation of halogenated DBP's when participating in oxidation/reduction reactions with NOM. It should be considered however that if bromide ions are present in the water they may react with peroxone to form halogenated disinfection by-products.

Potassium permanganate

The benefits of using potassium permanganate as a disinfectant have been summarised in Table 2. In terms of limiting THM formation its usefulness is due to its secondary role as an oxidant of precursors, namely NOM.

According to the United States Environmental Protection Agency (1999) there is no literature available that specifically addresses DBP formation when using potassium permanganate as a disinfectant, however, pre-treatment with permanganate in combination with post-treatment chlorination will result in lower DBP concentrations than would otherwise occur from traditional pre-chlorination. In a study undertaken by the American Water Works Association it was found that prior to switching from pre-chlorination to pre-oxidation with potassium permanganate, average daily trihalomethane concentrations at four different treatment plants were between 79-99ug/l; the average concentration was calculated to be 92ug/l. Following the conversion to potassium permanganate these values were reduced by up to 30 percent at three of the plants. (US EPA 1999).

2.4.4 Biofilm control strategies

The control of biofilm growth in a water distribution system is desirable for a number of reasons namely:

a) they have an adverse effect on drinking water quality;
b) they increase the risk of microbial contamination of drinking water;
c) they result in greater concentrations of disinfectants being used to ensure drinking water of adequate quality, thus the potential for the formation of DBP as a result of dose increases is amplified.

A degree of biofilm formation is inevitable in drinking water distribution networks and is of concern because they can cause the spread of waterborne diseases. Percival *et al* (2000) suggest in their review of the public health significance of biofilms in potable water that "Biofilms are known to harbour large numbers of micro-organisms that could remain undetected until they are sloughed off by possible water shear"

While not being specifically designed for the purpose of controlling biofilm formation in water distribution systems, research has shown that using certain disinfectants such as potassium permanganate and chlorine dioxide (at a continuous low level) can have a positive effect on the control of such microbial growth (US EPA, 1999). According to Momba *et al* (2000) some disinfectants "also enhance the formation of easily biodegradable organic substances which can be utilised by micro-organisms as an energy source and promote biofilm formation in distribution systems". Research has indicated that the use of chloramines for the purpose of water disinfection may act to increase the formation of biofilms; this is primarily due to high concentrations of nitrates in the water due to the application of chloramines.

Research has demonstrated that the use of chlorine, ozone and chlorine dioxide (at high doses) are not efficient disinfectants in relation to the control of biofilms.

Studies have shown that some bacteria can survive and multiply despite the presence of a residual; the resistance of the micro-organisms to disinfectants can also act to increase the formation of a biofilm.

Vigneswaran and Visanathan (1995) suggest that the total prevention of biofilm development in water supply is not practicable and that the best option available at present is the minimisation of biofilm accumulation. The measures which may be applied for the control of the formation of biofilms may be summarised as short-term and long-term control measures.

Short- term control measures

Short-term biofilm prevention methods typically utilised include regular cleaning of the piping system. According to the World Health Organisation, (2004) three methods are generally used to clean drinking water distribution pipes. These are flushing, air scouring and swabbing with compressible foam swabs. These methods are often referred to as non-aggressive techniques and their use is summarised in Table 8. An important attribute is that they can be used without having to cut into the mains and are therefore suitable for regular maintenance. Some cleaning methods (e.g. pressure jetting, mechanical scraping and abrasive swabs) do require cutting into

Table 8: Characteristics of the non-aggressive pipe cleaning methods WHO, (2004)

Method of Cleaning	Description	Advantages	Disadvantages	Comments in relation to the removal of NOM and biofilms
Flushing	Generating an increased water flow to remove deposits. The velocity required depends on the size of the particles to be removed and their gravity.	1. Simple to perform. 2. Relatively inexpensive process in comparison to other methods.	1. Uses a lot of water. 2. Of limited effectiveness unless high velocity waters are used. 3. Flushing in one area may lead to problems elsewhere in the system. 4. Not useful for large diameter mains (i.e. > 150mm).	Removal of deposits depends on particle size and specific gravity.
Air Scouring	The continuous injection of filtered compressed air into the mains.	1. Approximately 40% less water is used during air scouring than during swabbing or flushing. 2. Removes more deposits from pipes than flushing.	1. Only effective in pipes with a diameter < 200mm 2. Requires trained personnel 3. Consumers need to be isolated from the water supply during air scouring 4. Precautions must be taken to prevent air contaminated with pathogens entering the pipe work. 5. Slugs tend to lift up silt /sediment.	It is not as effective as swabbing for removing biofilms.
Swabbing	Cylindrical polyurethane swabs are inserted into the mains and driven along by water pressure pushing soft deposits before it.	1. Uses less water than flushing 2. No diameter limitations because foam swabs can be manufactured for practically all pipe sizes.	1. Consumers may be isolated from supply during cleaning operation 2. Swabs may break up in the piping system. 3. More expensive than flushing 4. Can produce a large amount of discoloured water that requires careful disposal. 5. Swabs used may become stuck in any unforeseen bore restriction.	Superior to air scouring and flushing in the removal of sediments and biofilms. Has the potential to remove almost all biomass and sediment.

mains and, if the pipe material is ferrous, also require subsequent relining of the pipe. Complexities like this require systematic rehabilitation planning.

The cleaning of drinking water distribution mains is a well-documented process and in Ireland it is required to be carried out by sanitary services. The EC (Drinking Water) Regulations, 2000-A Handbook on Implementation for Sanitary Authorities states, "the sanitary authority or private water supplier should consider maintenance, cleaning and flushing programme". Cleaning programmes are detailed in action plans for the protection of drinking water and are authorized by either the Senior Engineer or the Senior Scientific Officer.

Long-term control measures

According to Percival *et al* (2000) "long term biofilm growth seems difficult to stop, but there are several ways biofilms can be controlled." Control measures include:

1. A combination of a reduction of nutrient levels in rivers together with the use of materials in potable water systems that do not leach nutrients. Without nutrients, biofilms are not able to thrive and mature.
2. Effective management of hydraulics of distribution systems involving the avoidance of slow moving or stagnant pockets of water.
3. Ensuring the continuous presence of a disinfectant residual which has a suppressive effect.

4. The treatment of source water according to internationally approved standards to destroy pathogenic organisms.

2.4.5 Changing the point of disinfection in the distribution network

Changing the point of disinfection in the distribution can also help to control the formation of THM's, (Cozzolino *et al* 2004.) If a disinfectant, namely chlorine, is dosed at various stages in the distribution network this practice reduces the residence time in the distribution system, thus limiting the quantity that reacts with organic substances to form DBP's. By using this method it is also possible to control the total chlorine dosage and to maintain lower chlorine levels throughout the distribution network.

In a study carried out by Cozzolino *et al* (2004) it was discovered that both optimal dosage of disinfectant and allocation of the disinfection station are methods which can be used to control the formation of THM's, although it was noted that more research needs to be undertaken in this area.

2.4.6 Increased monitoring

The Irish EPA, in their report on the quality of drinking water for 2004 state that the level of monitoring for THM's in drinking water supplies in Ireland is insufficient and that there was no monitoring for these substances by three sanitary authorities.

In response to the outbreak of drinking water related diseases and a growing public concern regarding disinfection by-products the United States EPA developed a series of rules in an effort to ensure the safety of drinking water and to limit the public's exposure to disinfection by-products. According to Xie (2004) the rules that relate specifically to disinfection by-products are as follows:

1. Total trihalomethanes rule- this rule introduces an interim maximum contaminant level of 100ug/l for total trihalomethanes in treated water.

2. Disinfectants and disinfection by-products rule (stage one) - This rule covers many areas including DBP monitoring and reporting and best-available technologies for DBP control.

3. Disinfectants and disinfection by-products rule (stage two) - this rule builds on earlier rules that address disinfection by-products to improve drinking water quality and provide additional public health protection from disinfection by-products.

3.0 Methodology

3.1 Questionnaire development

A considerable amount of information is available in literature regarding drinking water treatment and in particular the disinfection process. In recent years an expanding amount of information has been obtained internationally regarding disinfection by-products (DBP's), though in a national context this information is limited.

In particular, limited information is available regarding the control of DBP's in Irish water treatment plants and distribution systems. With this in mind, this study attempted to investigate various aspects of relevance in the control of DBP's in an Irish context. It was hoped that this objective would be achieved through the sending of questionnaires to a representative number of public water supply systems.

There are 903 different water supply zones in the Republic of Ireland. Due to this considerable number it was decided that only water treatment supply zones in the Connaught region would be involved in the study.

Originally it was intended that detailed questionnaires would be sent to the sanitary services department of each local authority, requesting information relating to the treatment of public mains drinking water. It was hoped that a questionnaire would be completed for each supply zone within their functional area. Unfortunately, it was extremely difficult to contact and establish lines of communication with local authority staff in the sanitary services or Environmental departments. It was therefore necessary to send questionnaires to the caretakers of water treatment plants and supply zones.

A questionnaire was sent to each water treatment plant caretaker in the 113 supply zones in the Connaught region, namely Sligo, Leitrim, Mayo, Galway and Roscommon. (See Appendix 3 for the list of supply zones). Caretakers are the individuals responsible for the day-to-day operation of water treatment plants. Their duties include ensuring that the water entering the plant receives sufficient treatment to make it potable as well as dealing with maintenance problems on the site. Information regarding the public water supply zones in each region was obtained from Environmental Protection Agency website.

In order to develop the questionnaire the following publications in particular were referenced:

- European Communities (Drinking Water) Regulations, 2000 (S. I. 439 of 2000)- this piece of legislation was referenced in order to ascertain the requirements of drinking water in relation to microbiological and chemical quality.

- European Communities (Drinking Water) Regulations, 2000 (S. I. 439 of 2000) A Handbook on Implementation for Sanitary Authorities- this publication, produced by the Environmental Protection Agency, was referenced as it provides information in relation to the duties of sanitary authorities, the monitoring of drinking water and remedial actions that may be taken to ensure the distribution of safe drinking water.

- Environmental Protection Agency (1998) Water Treatment Manuals: Disinfection – this publication was used in the development of the questionnaire as it relates specifically to disinfection methods and technologies utilised in Ireland.

- Water Practice Manuals 4; Water Distribution Systems. Institution of Water Engineers and Scientists- this piece of literature was referenced to obtain information on the methods employed for the cleaning of water distribution lines.

3.2 Questionnaire design

When drawing up the questionnaire it was hoped that the questions chosen might reveal trends in relation to disinfection practices and techniques applied to control the formation of disinfection by-products. The majority of questions within the questionnaires could be answered by ticking the relevant box. This design was chosen to facilitate ease of answering. It also made the information received easier to interpret and tabulate.

The questions asked and the reason for asking them are as follows;

Question 1 Which of the following unit process are employed at the water treatment plant?

This question was asked in order to get an overview of the variety of unit processes that take place during water treatment at the different water treatment plants in the Connaught region.

Question 2 What is the principle method of disinfection used?

The literature review undertaken in this study revealed that chlorination is the predominant method of disinfection used in the treatment of drinking water in Ireland. This question was asked to ascertain the degree to which alternatives may be utilised in some water treatment plants. The choices given were chlorination, ozonation or other.

Question 3 If chlorination is carried out during treatment, which of the following substances are used - chlorine, chloramines, products releasing chlorine?

This question was asked to determine the degree to which other chlorine compounds have been used to disinfect water with a view to controlling disinfection by-products.

Question 4 Are any of the following methods used to control algae at water treatment plants?

It is well established that the amount of organic matter present in raw water affects the amount and type of DBP's formed. During the literature search for this study it was discovered that the control of algae, by various methods, in the pre-treatment stage of water treatment was beneficial in limiting precursors to DBP formation. This question was posed in order to ascertain whether any DBP pre-treatment control methods involving algae removal were employed at various water treatment plants. The choices given were the use of microstrainers, pre-ozonation or the application of potassium permanganate.

Question 5 Is analysis of the raw water undertaken for total organic carbon?

While not being stipulated as a monitoring requirement under the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989, research has shown that the analysis of this parameter may be useful in determining the amount of DBP, which may result from the disinfection process. This question was posed to determine to what extent the precursors to the formation of disinfection by-products are monitored.

Question 6 Is analysis of the raw water undertaken for bromide?

Bromide reacts with ozone to form bromate and chlorine to form bromoform and other brominated DBP's. The maximum permissible concentration of bromate allowable in drinking water is stipulated under the European Communities (Drinking water) Regulations, 2000; the limit imposed by the Regulations is 10ug/l. Trihalomethanes (THM's) include brominated DBP's. A maximum permissible concentration of 100ug/l Total THM's is allowable under the EC (Drinking Water) Regulations, 2000. This question was included in the questionnaire in order to ascertain the degree of proactive monitoring of the precursors of DBP's.

Question 7 What method is employed for the cleaning of drinking water mains?

As discussed in section 2.4.3 the presence of a biofilm within the distribution network can cause the recontamination of treated drinking water thus to ensure the safety of water for human consumption an increased dose of disinfectant may be applied to the water. This practice will increase the potential for the formation of DBP's. Biofilm control has been identified by literature as a method to control the formation of DBP's in water distribution systems.

Literature has demonstrated that different cleaning methods are of varying degrees of effectiveness with regard to biofilm formation this question was posed in order to compare the techniques used in the Connaught region with their effectiveness to remove or control biofilms.

It was hoped that this question would highlight trends in cleaning techniques, with a view to suggesting reasons for their application.

Question 8 In relation to the frequency of cleaning of distribution lines, which of the following applies? The choices given were weekly, monthly, bi-monthly, never and other- to be specified by caretaker.

The frequency of cleaning the distribution network is of interest in order to control biofilm formation. The intervals at which distribution lines should be cleaned are determined by water quality monitoring throughout the distribution network. Cleaning is also carried out in response to customer complaints.

The frequency of cleaning demonstrates both the effectiveness of the treatment processes and the integrity of the distribution system. In situations where treatment practices or indeed the integrity of the distribution system are questionable, a greater degree of disinfection may be required in order to ensure safe drinking water and thus the potential for the formation of DBP's, particularly chlorinated DBP's.

The question was posed in order to ascertain the degree to which preventative measures, such as the prevention of biofilms, are taken by local authorities with a view to the control of DBP's in distribution networks.

Question 9 In relation to an action plan for the protection of drinking water, if such a plan is in place, does any part of the plan deal with a) removal of algae, b) cleaning of reservoirs or c) source water protection?

This question relates to the proactive measures that may be adopted and incorporated into Action Plans prepared by sanitary authorities with a view to the control of the formation of DBP's at the water treatment plant.

Please see Appendix 4 for questionnaire sent to caretakers.

3.3 Conducting the questionnaire

Previous research projects requiring input from local authorities have concluded that the response rate from same tends to be considerably variable and dependant upon the topic in question. It was therefore decided to contact the sanitary services department of each local authority in the Connaught to ascertain the location of their water treatment plants and the network, which each plant serves. Unfortunately, the author was unsuccessful in establishing the necessary contact in most instances. For this reason, the next course of action involved contacting the environmental laboratory in each local authority region in order to obtain information in relation to the treatment of drinking water and its distribution in their respective functional area.

The lack of co-operation from some of the local authorities led to the list from the EPA website being used in order to try and successfully identify water treatment plants within each local authority's functional area.

3.4 Analysis of results

The information from the questionnaires was inputted into Microsoft Excel so that comparisons regarding the information collected could be made effectively and the information could be illustrated by graphical representation.

4.0 Results

Results and conclusions about the drinking water treatment practices and methods for the control of disinfection by-products within the Connaught Region can only be made for counties Mayo, Galway, Leitrim and Roscommon as completed questionnaires were not received from County Sligo.

Questionnaires were sent to 26 water treatment plants in County Mayo, 12 to treatment plants in County Sligo. 46 questionnaires were sent to the caretakers of water treatment plants in County Galway, 11 to treatment plants in County Leitrim and finally 18 questionnaires were sent to water treatment plants in County Roscommon.

Approximately 34% of the total questionnaires sent out were completed and returned i.e. 39 questionnaires out of a total of 113. Of this value there were 14 replies received from water treatment plants in County Mayo, 14 replies from County Galway, 5 from County Roscommon and 6 from County Leitrim.

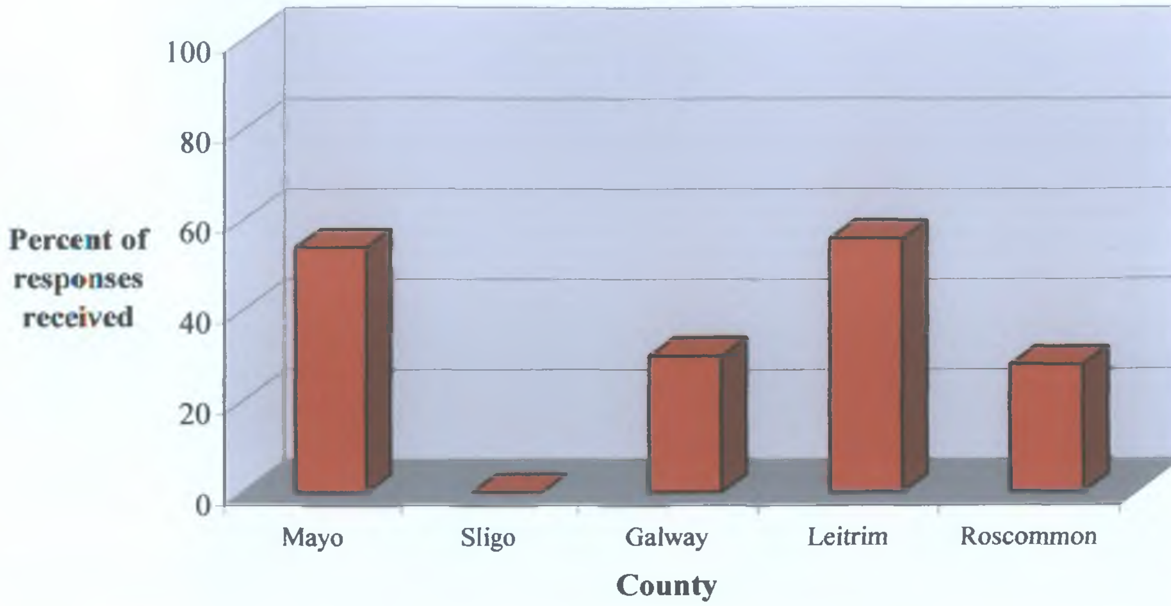

Figure 4.1: Percentage of completed questionnaires received from each region of Connaught.

The graph above illustrates that 54 percent of the questionnaires sent to County Mayo water treatment plants were returned; completed questionnaires were not received from County Sligo. With regard to County Galway, 30 percent of the 46 questionnaires that were sent to water treatment plants in the region were completed and returned. In County Leitrim 56 percent of the 11 questionnaires were returned and finally 28 percent of questionnaires were returned from treatment plants in County Roscommon.

4.1 Unit processes carried out at drinking water treatment plants

Question 1 asked what type of unit processes are carried out in the treatment of drinking water for each supply zone.

The results relating to the unit processes carried out at the water treatment plants in the different counties are as follows:

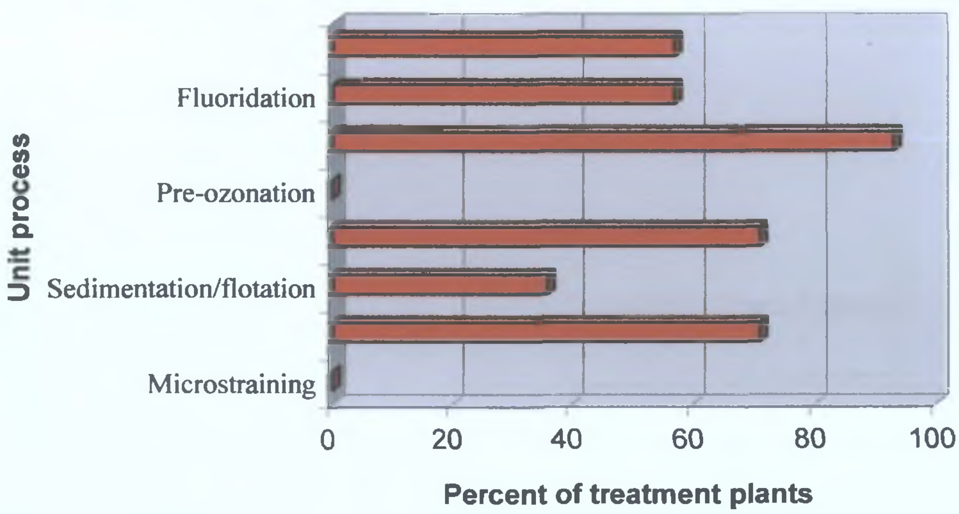

Figure 4.2. Unit treatment processes carried out in public water treatment plants in County Mayo

Figure 4.2 above reveals that the unit processes carried out at the water treatment plants in County Mayo are similar to those suggested by the Environmental Protection Agency. The graph also highlights that microstraining and the process of pre-ozonation are not carried out in County Mayo public water treatment plants. Figure 4.2 also illustrates that disinfection processes are carried out at 93 percent of water treatment plants. Processes such as flocculation and filtration are also commonly carried out in the treatment of drinking water in County Mayo as both processes are utilised at 71 percent of treatment plants. Fifty seven percent of plants that responded in the Mayo region use pH correction. Similarly 57 percent of treatment plants that responded use fluoridation. (This is of particular interest since all public water treatment plants in Ireland must fluoridate their water supplies by law).

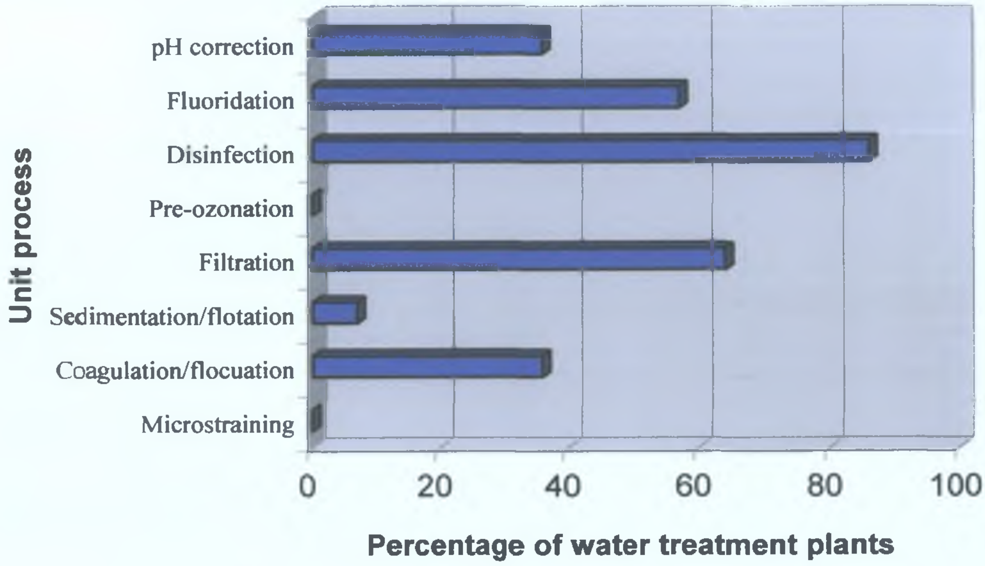

Figure 4.3 Unit treatment processes carried out in public water treatment plants in County Galway

The results obtained from County Galway water treatment plants are very similar to those of County Mayo in that the processes of microstraining and pre-ozonation are not carried out in water treatment plants (Figure 4.3). In County Galway disinfection of water is carried out at 86 percent of water treatment plants. Filtration processes are also frequently carried out in the treatment of drinking water in County Galway. The results concerning the fluoridation of drinking water are the same as in County Mayo in that fluoridation is carried out at 57 percent of treatment plants.

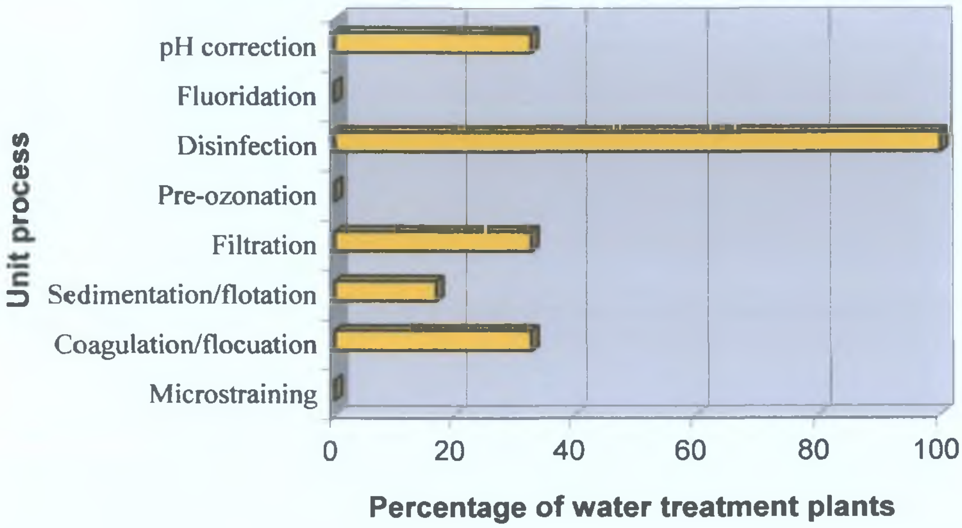

Figure 4.4 Unit treatment processes carried out in public water treatment plants in County Leitrim

The results concerning the treatment processes undertaken in County Leitrim are illustrated in Figure 4.4 above. The results reveal that pre-ozonation and microstraining are not part of the treatment process. The results also highlight that disinfection processes are carried out at all treatment plants, while processes such as coagulation and filtration are carried out at only 33 percent of treatment plants. This may be due to a high quality source water. The results also show that fluoridation is not carried out during the treatment of drinking water in County Leitrim.

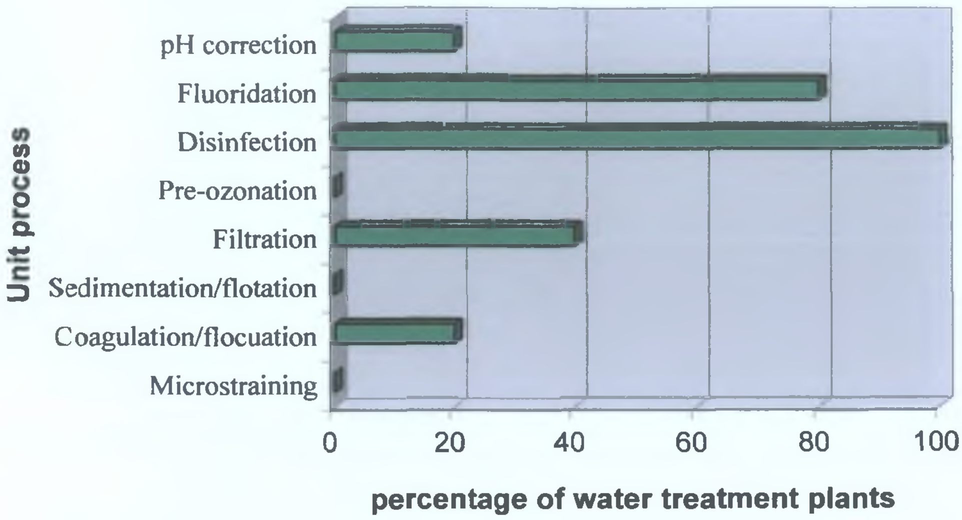

Figure 4.5 Unit treatment processes carried out in public water treatment plants in County Roscommon

It is not possible to generalise about the processes carried out in water treatment plants in County Roscommon as only five completed questionnaires were received out of 18 that were sent to water treatment plants. However the results obtained from respondents show that the quality of the raw water used must be of a considerably high standard as processes such as coagulation and sedimentation are not required.

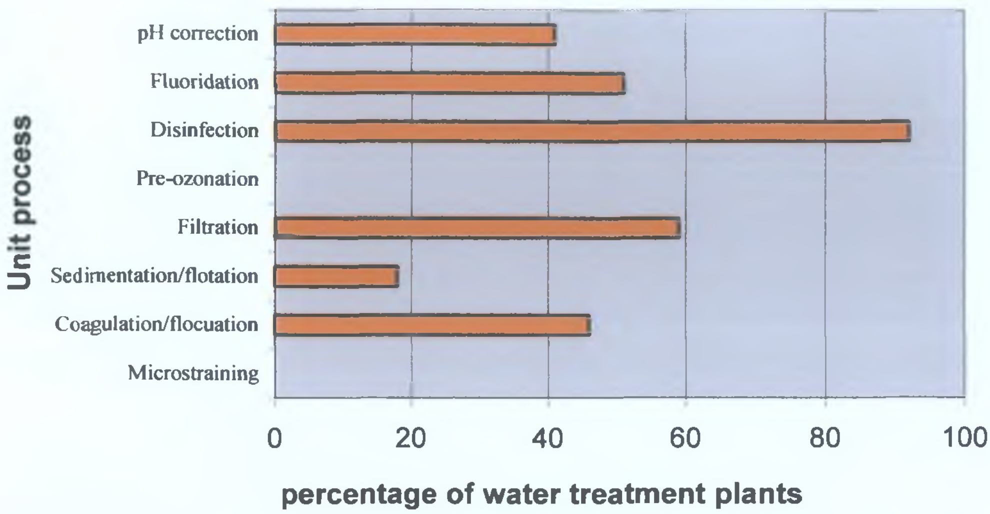

Figure 4.6: Unit processes carried out during the treatment of drinking water in Connaught

As illustrated by Figure 4.6, coagulation/flocculation processes are carried out at 46 percent of water treatment plants in the Connaught region that participated in the survey. Sedimentation processes are carried out at 18 percent of the treatment plants to which the results relate. The filtration of water is practiced at 59 percent of the treatment plants, while as already stated microstraining and pre-ozonation are omitted from the treatment of drinking water in Connaught. Disinfection is by far the most common process involved in the treatment of drinking water; disinfection is carried out at a total of 92 percent of the plants, which returned a completed questionnaire. Fluoridation processes are carried out at 51 percent of treatment plants and pH correction is carried out at 41 percent of treatment plants in the Connaught region involved in the study.

4.2 Methods employed for the disinfection of drinking water

Question two of the questionnaire asked what is the principle method used for the disinfection of drinking water.

With regard to the methods employed for the disinfection of drinking water the following was established:

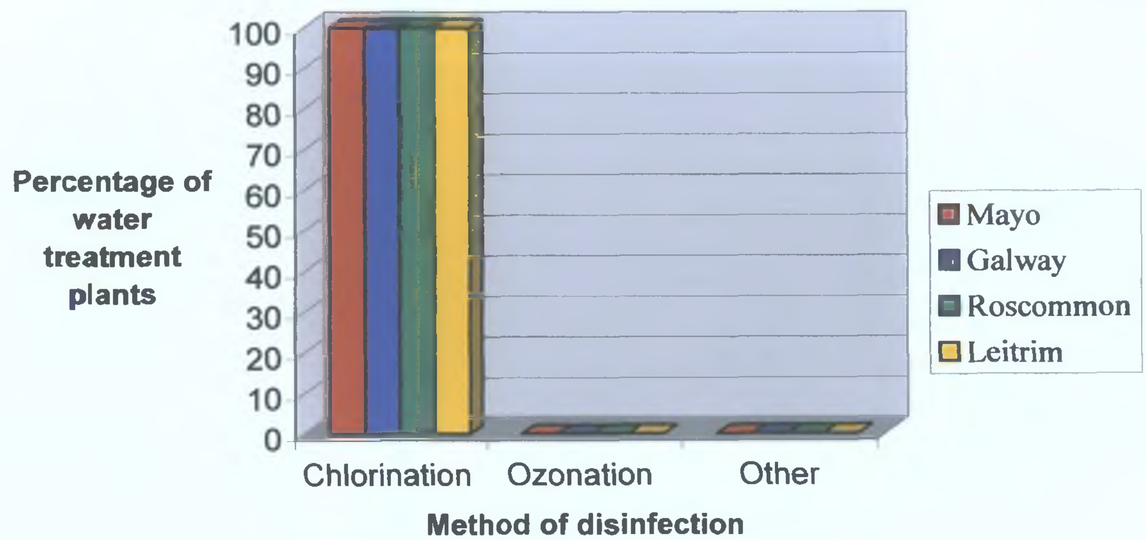

Figure 4.7 Methods of disinfection in the Connaught Region

As concluded by the Environmental Protection Agency, (1998) chlorination is the principle method of disinfection used in the treatment of drinking water; it is the only method that is employed by water treatment plants in public water treatment systems in Counties Mayo, Galway, Leitrim and Roscommon.

4.3 Substances used to achieve the chlorination of drinking water

Question three of the questionnaire asked what are the substances used to achieve the chlorination of drinking water.

The following information has been obtained with regard to the substances, which are used to achieve chlorination at water treatment plants:

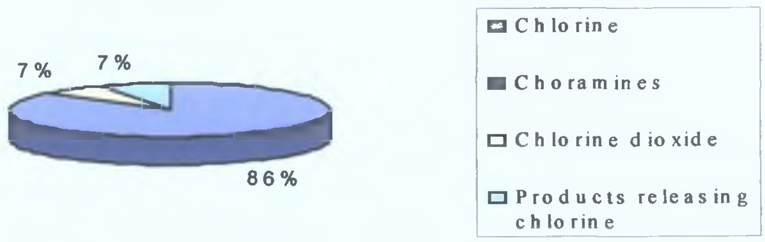

Figure 4.8 Substances used to achieve chlorination at public water treatment plants in County Mayo

Figure 4.8 shows that in County Mayo water treatment plants, three different substances are used to achieve the chlorination of drinking water, namely chlorine, chlorine dioxide and products that release chlorine (sodium hypochlorite and calcium hypochlorite). The results reveal that chlorine is the principle substance that is utilised; being used at 86 percent of water treatment plants in the Connaught region.

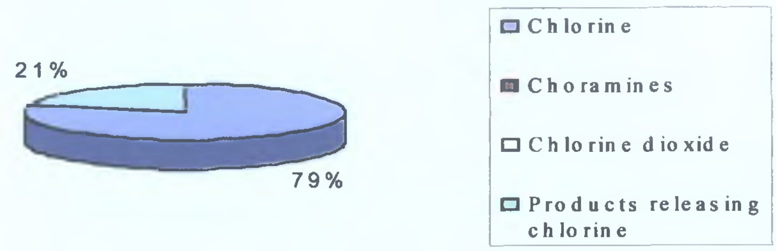

Figure 4.9 Substances used to achieve chlorination at public water treatment plants in County Galway

The results concerning the substances that are used to achieve chlorination in County Galway are shown in Figure 4.9 above. Only two different substances are used i.e. chlorine and products releasing chlorine, with chlorine being used in 79% of the treatment plants from which completed questionnaires were received.

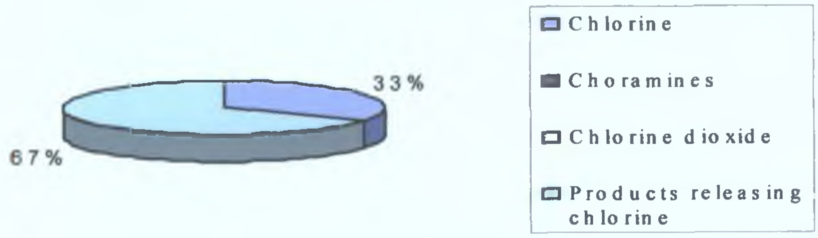

Figure 4.10 Substances used to achieve chlorination at public water treatment plants in County Leitrim.

Figure 4.10 above shows that products releasing chlorine are principally used for the chlorination of drinking water at public water treatment plants in County Leitrim; such products are used at 67 percent of the treatment plants, which responded to the questionnaire in Co. Leitrim.

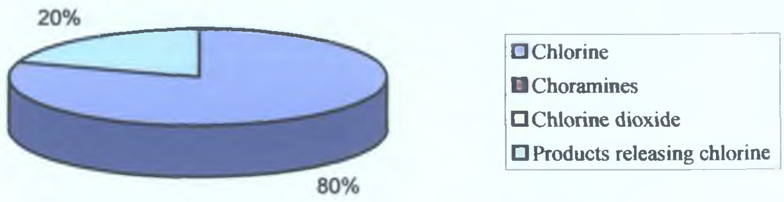

Figure 4.11 Substances used to achieve chlorination at public water treatment plants in County Roscommon

The results from County Roscommon reiterate the extent of the use of chlorine in the treatment of drinking water. Chlorine is used during the treatment of drinking water at 80 percent of water treatment plants, while products releasing chlorine are utilised to a 20 percent of plants in County Roscommon (Figure 4.11).

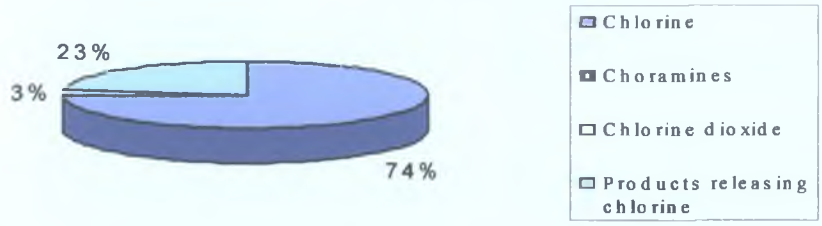

Figure 4.12 Extent to which different substances are used in public water treatment plants in the region of Connaught.

As depicted by Figure 4.12 chlorine is undoubtedly the most common disinfecting agent used in the treatment of drinking water in the Connaught region. Products releasing chlorine are applied at 23 percent of treatment plants for the disinfection of drinking water. The application of chlorine dioxide is practiced at only one treatment plant in Connaught, this amounts to three percent of treatment plants when considering the 39 water treatment plants that responded to the questionnaire.

4.4 The control of algae at water treatment plants

Question four enquired as to how algae are controlled at the intake of water treatment plants.

The results regarding the control of algae in all the water treatment plants show that in only one case i.e. in County Galway, are methods employed for algal control. The method used in the Galway City public water treatment plant in County Galway is microstraining of the raw water.

4.5 Total Organic Carbon monitoring

Question 5 asked 'What is the frequency at which the TOC concentration of raw water is analysed'?

With specific regard to the analysis of total organic carbon in raw water, the following information was determined:

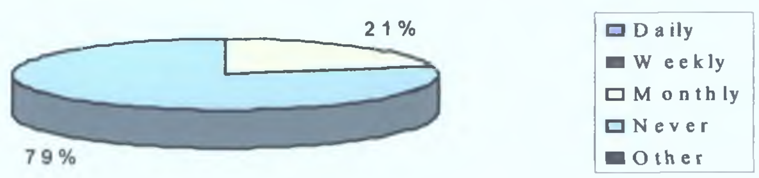

Figure 4.13 Frequency of Total Organic Carbon monitoring in public water treatment plants in County Mayo

Figure 4.13 shows that the monitoring of total organic carbon in raw water is carried out at only 21 percent of water treatment plants that responded to the questionnaire in County Mayo.

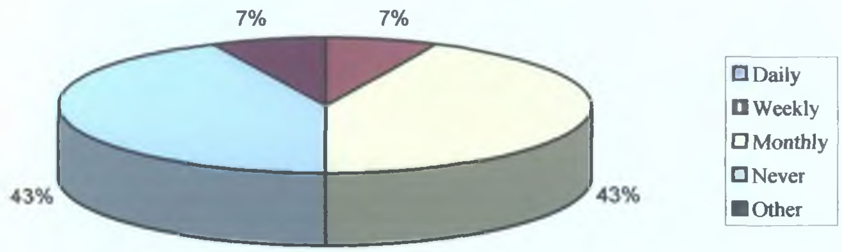

Figure 4.14 Frequency of Total Organic Carbon monitoring in public water treatment plants in County Galway

Figure 4.14 reveal that monitoring of total organic carbon is carried out at a total of 43 percent of public water treatment plants that responded to the survey in County Galway. In one case the water is sent to the County Health Board laboratory for analysis, this amounts to seven percent of the 14 water treatment plants involved in the survey.

The monitoring of TOC in raw water is not carried out in County Leitrim.

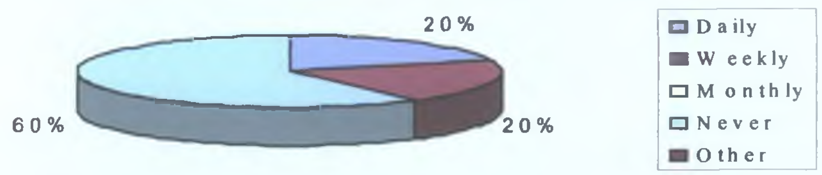

Figure 4.15 Frequency of Total Organic Carbon monitoring in public water treatment plants in County Roscommon

With regard to the monitoring of total organic carbon in County Roscommon water treatment plants, the results indicate that monitoring is carried out at 40 percent of the treatment plants involved in the study. TOC analysis is not undertaken at 60 percent of treatment plants (Figure 4.15).

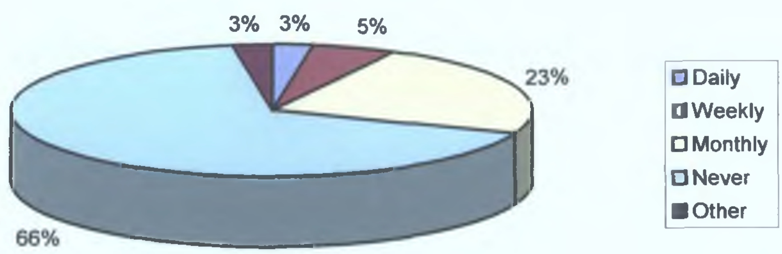

Figure 4.16 The frequency of TOC analysis at public water treatment plants in Connaught.

As can be seen from Figure 4.16 above, out of the 39 water treatment plants that took part in the survey 66 percent of those do not carry out TOC analysis on raw water, 23 percent monitor TOC monthly, 5 percent carry out analysis on a weekly basis, while analysis is carried out on daily basis or at another interval at 3 percent of treatment plants.

4.6 Bromide analysis

Question 6 enquired as to the frequency at which bromide analysis is carried out on raw water.

Information relating to bromide monitoring of raw water in water treatment plants is as follows:

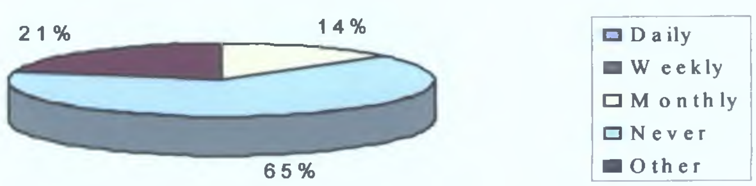

Figure 4.17 Frequency of bromide monitoring in public water treatment plants in County Mayo

As can be seen from Figure 4.17 above, only five treatment plants of the 14 that returned completed questionnaires in County Mayo carry out the monitoring of bromide in raw water. Of this amount 21% carry out monitoring for bromide on a weekly basis and 14% on a monthly basis.

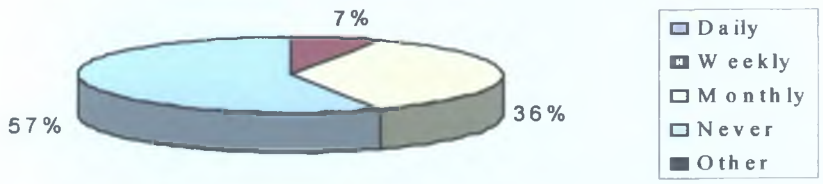

Figure 4.18 Frequency of bromide monitoring in public water treatment plants in County Galway

As indicated in Figure 4.18 above bromide analysis is not commonly carried out on raw water at the majority (i.e. 57 percent) of public water treatment plants in County Galway. Of the 14 plants that responded to the questionnaire 36 percent carry out the analysis of bromide on a monthly basis and seven percent monitor bromide on a weekly basis.

The analysis of bromide in raw water is not carried out at the six water treatment plants that responded to the questionnaire in County Leitrim or the five treatment plants that responded to the questionnaire in County Roscommon.

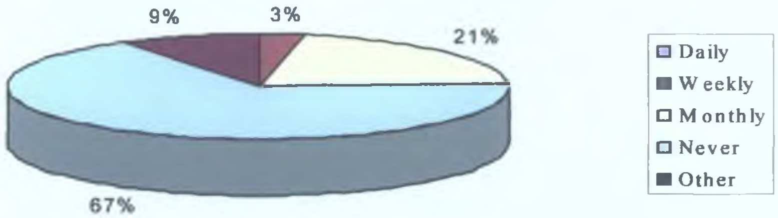

Figure 4.19 Frequency of bromide analysis in public water treatment plants in the Connaught region

Figure 4.19 above highlights that the analysis of TOC is not common practice at public water treatment plants that responded to the questionnaire in Connaught. Monitoring is not carried out at 67 percent of the water treatment plants. Monitoring is carried out on a monthly basis at 21 percent of plants, on a weekly basis at 3 percent of plants and at other intervals at 9 percent of treatment plants.

4.7 Methods employed for the cleaning of distribution lines

Question 7 of the questionnaire asked 'What is the method utilised for the cleaning of drinking water distribution line?'. The choices given were flushing, air scouring or swabbing.

Completed results obtained from public water treatment plants in the Connaught region highlight that flushing is the most widely used technique employed for the cleaning of drinking water distribution lines being used in all but one case in areas that replied to the questionnaire. Of all the water supply regions that responded only one i.e. the Westport water treatment in County Mayo uses air scouring as a method of cleaning pipes.

4.8 The frequency of cleaning of distribution lines

Question 8 of the questionnaire asked the interval at which water distribution lines are cleaned, the options give were weekly, monthly, bi-monthly, never or at another interval.

The frequency of which distribution lines are cleaned within the different regions is outlined below:

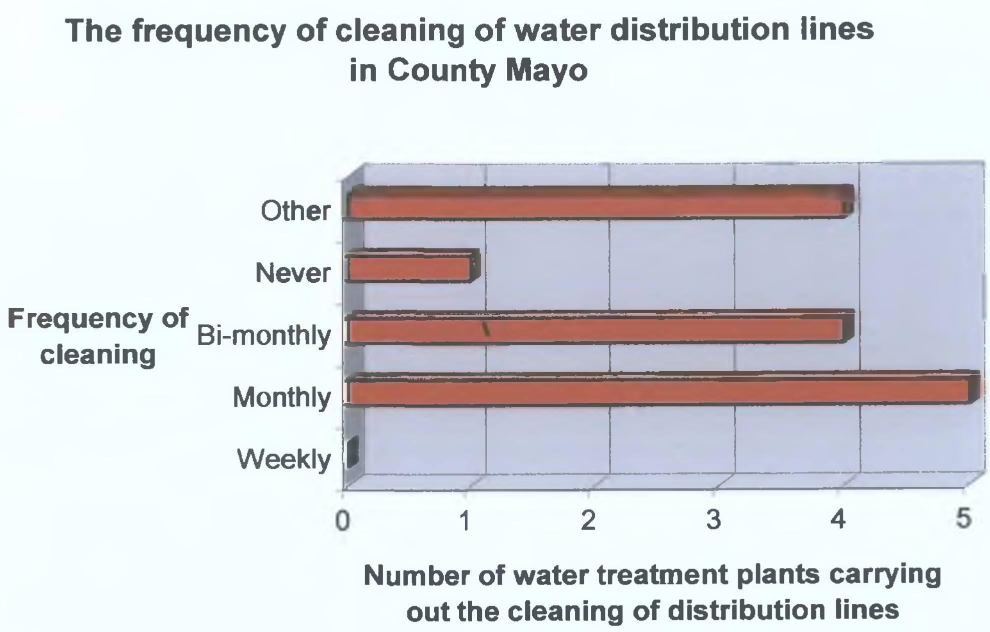

Figure 4.20 The frequency of cleaning of water distribution lines arising from public water treatment plants in County Mayo

Figure 4.20 shows the frequency of cleaning of distribution lines arising from public water treatment plants in County Mayo. As evident from the graph, cleaning is carried out regularly taking place either monthly or bi–monthly. Results also revealed that in areas with water quality problems cleaning was carried out more frequently or as required due to customer complaints.

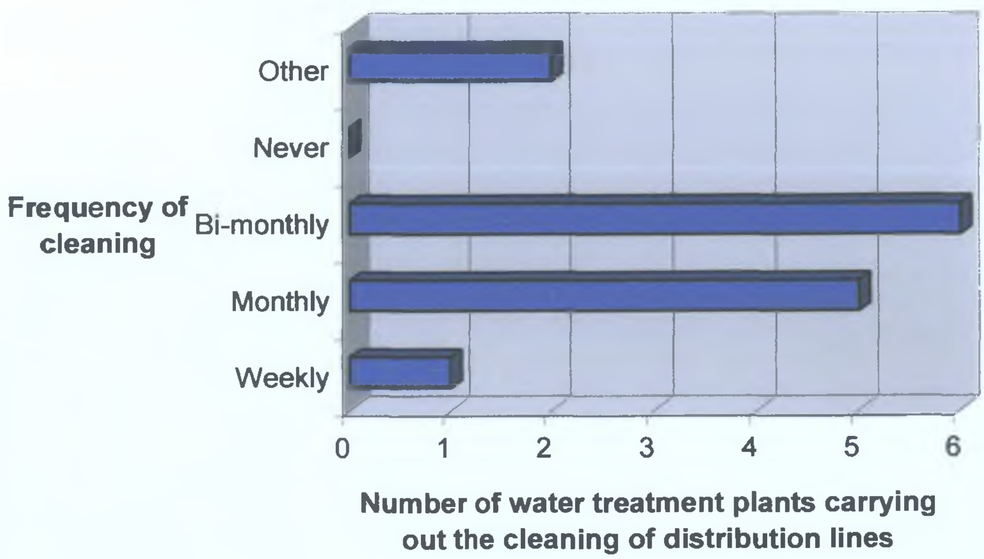

Figure 4.21 The frequency of cleaning of water distribution lines arising from public water treatment plants in County Galway

The situation in Galway, as portrayed in Figure 4.21, is broadly similar to that in County Mayo, in that cleaning is carried out principally either on a monthly or bi-monthly basis. It was also indicated by the caretakers of the treatment plants that cleaning is also carried out when there are customer complaints about the quality of water received.

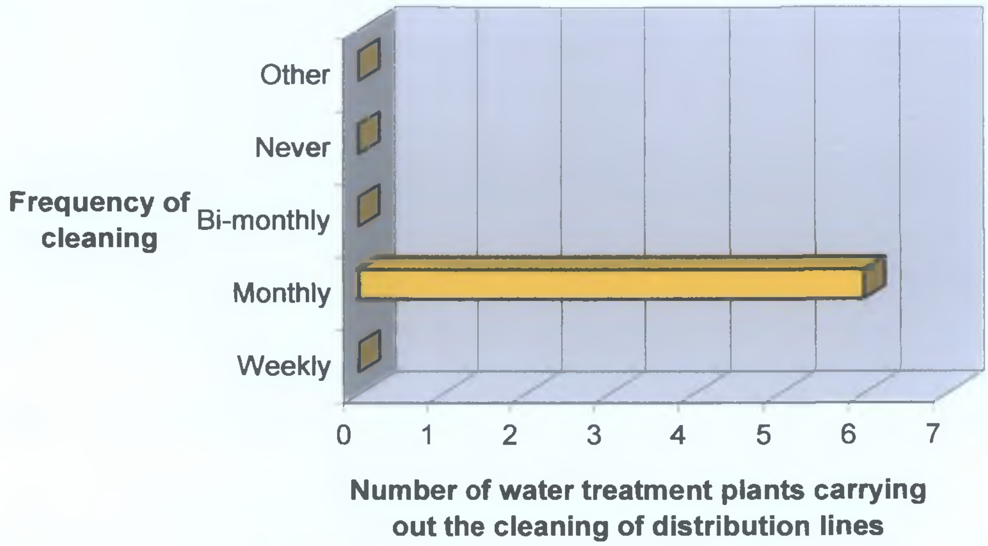

Figure 4.22 The frequency of cleaning of water distribution lines arising from public water treatment plants in County Leitrim

The results concerning the cleaning of distribution mains in County Leitrim are shown in Figure 4.22 and show that cleaning is carried out on a monthly basis on all distribution lines to which the 6 completed questionnaires and the respective supply zones relate.

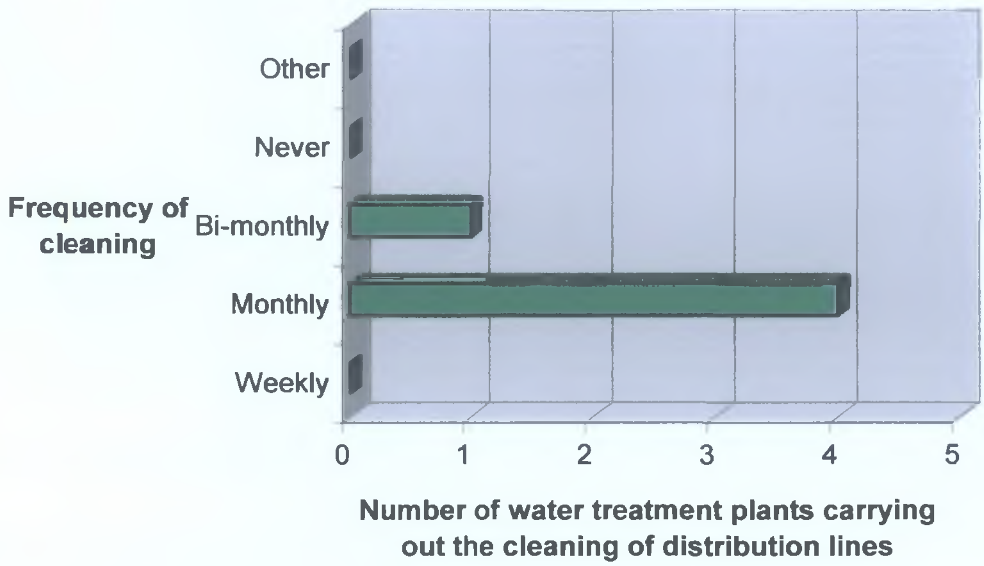

Figure 4.23 The frequency of cleaning of water distribution lines in County Roscommon

Analysis of the completed questionnaires received from County Roscommon show that the cleaning of water distribution lines is typically carried out on monthly intervals (Figure 4.23). Cleaning is also carried out on a bi-monthly basis on one supply zone to which the completed questionnaires relate.

4.9 Issues dealt with in Action Plans of the Protection of Drinking Water

Question 9 of the questionnaire asked the following 'What issues relating to the control of disinfection by-products at the water treatment plant and in the distribution network are dealt with in action plans for the protection of drinking water'?

Specifically with regard to the control of disinfection by-products, the removal of algae, cleaning of reservoirs and source water protection are of the utmost importance. The following has been established about the information contained in drinking water action plans for public water treatment plants that responded to the questionnaire.

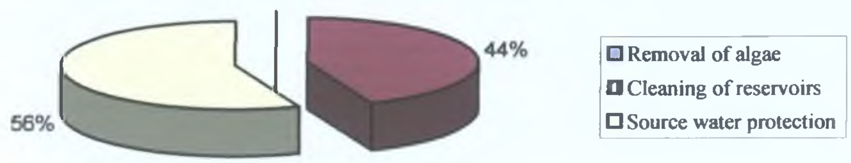

Figure 4.24 Issues dealt with in drinking water action plans in County Mayo

Figure 4.24 above reveals that action plans in relation to the protection of public drinking sources water in County Mayo deals principally with the cleaning of reservoirs and the protection of source water; some of the plans deal with both issues. It should be considered that the results depict the result for 14 water treatment plants in the region, which took part in the survey.

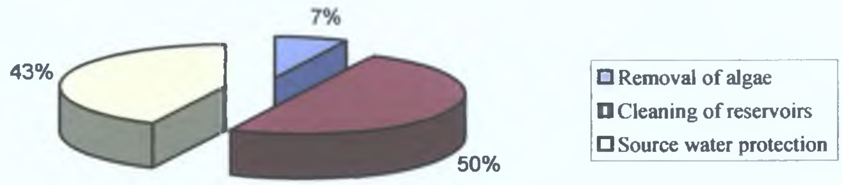

Figure 4.25 Issues dealt with in drinking water action plans in County Galway

From the 14 water treatment plants in County Galway that returned completed questionnaires, the following has been determined: - in the action plans for the protection of drinking water in County Galway, 50 percent deal with the cleaning of reservoirs, 43 percent with source water protection and the seven percent with the removal of algae (Figure 4.25).

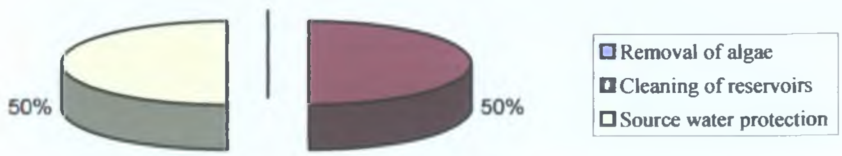

Figure 4.26 Issues dealt with in drinking water action plans in County Leitrim

The results, shown in Figure 4.26, regarding the information contained in drinking water action plans in County Leitrim show that two issues are dealt with in all of the action plans, namely: the cleaning of reservoirs and source water protection.

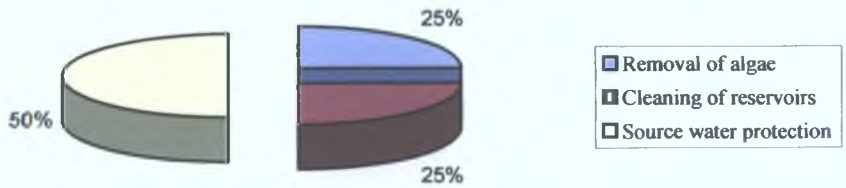

Figure 4.27 Issues dealt with in drinking water action plans in County Roscommon

The results from County Roscommon show that action plans deal with the removal of algae, cleaning of reservoirs and source water protection (Figure 4.27). It should however be considered that only five completed questionnaires were received from water treatment plants in County Roscommon.

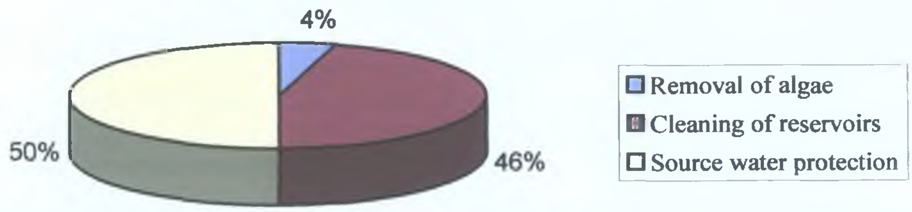

Figure 4.28 Issues dealt with in drinking water action plans in Connaught.

The results concerning the issues detailed in drinking water action plans in the Connaught region are portrayed in Figure 4.28 and show that source water protection is the predominant issue dealt with in such plans. The cleaning of reservoirs is detailed in 46 percent of plans. Finally 4 percent of plans consider the removal of algae.

5.0 Discussion

5.1 Introduction

As stated by Gray, (2002) the objective of water treatment is to produce an adequate and continuous supply of water that is chemically, bacteriologically and aesthetically pleasing. Water treatment plants must produce drinking water of a consistently high quality regardless of demand pressures. Measures must also be taken to ensure that recontamination of drinking waters is limited in the distribution mains to ensure that consumers receive water that is not harmful to their health.

Disinfection by-products (DBP's) and the general public's exposure to such substances has become an issue of debate. As a result, specific guideline values have been established for the concentration of trihalomethanes such as bromoform, bromodichloromethane, dibromochloromethane and chloroform in drinking water by the World Health Organisation. A limit of 100ug/l for Total Trihalomethanes in drinking water has also been imposed by the Council Directive 98/83/EC of 3 November 1998 'on the quality of water intended for human consumption', which has been transposed into Irish law as European Communities (Drinking Water) Regulations, 2000.

A comprehensive search of literature available on DBP's and methods to control the formation of such substances was undertaken by the author. Using this information an attempt was made to investigate the control strategies that are currently being undertaken in public water treatment plants and water distribution systems in the Connaught Region in the Republic of Ireland. To this end, questionnaires were distributed to the caretakers of these public water treatment plants.

In discussion of the methods used to control DBP's at public water treatment plants and in distribution systems, it should be noted that questionnaires were sent to a total of one hundred and thirteen different supply zones and their respective water treatment plants in the Connaught region. Upon receiving a total of thirty-nine completed questionnaires, the results presented represent approximately one third of treatment plants in the Connaught region. Thus, only a limited amount of information can be generated and subsequently evaluated upon regarding the control of disinfection by-products at water treatment plants and distribution systems in the Connaught region

5.2 Unit processes used at public water treatment plants

The formation of disinfection by-products (DBP's) in drinking water has been particularly associated with one unit process undertaken at water treatment plants and that is disinfection. Disinfection is carried out at 92 percent of WTPS in the Connaught region ranging from 86 percent in county Galway, 93 percent in County Mayo and 100 percent in Counties Leitrim and Roscommon. Disinfection is required on all water including A1 waters under the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking) Regulations, 1989.

DBP's are formed from the reaction of a disinfecting agent with natural organic matter (NOM) present in the raw water (see section 2.3: Disinfection by-products). Controlling the amount of NOM (including algae) present in source water is of the utmost importance in relation to the formation of disinfection by-products (Bryant *et al* 1992). It is generally accepted that water from surface water sources contain greater concentrations of NOM than groundwaters. Therefore, in order to ensure effective control of the formation of DBP's in waters originating from surface waters, processes such as sedimentation and filtration are considered to extremely important, (US EPA 1999). It is indicated by the EPA that 84% of Irish drinking water originates from surface water sources and as such may contain a considerable amount of NOM. The results concerning the unit processes carried out at drinking water treatment plants in Connaught show that sedimentation processes are carried out at 17 percent of treatment plants, which took part in the survey. Filtration techniques are employed at 59 percent of the water treatment plants to which the results relate. It is therefore possible to deduce that the processes relied upon to remove NOM (precursors to DBP's) are utilised only at a limited number of treatment plants in the region.

The removal of algae from the source water at an early stage in the treatment process is believed to be an effective control strategy for the formation of DBP's (Bryant *et al* 1992). The removal of such matter may be achieved by employing methods such as microstraining or pre-ozonation at the earliest possible stage of water treatment (Bryant *et al*, 1992). The results concerning the utilisation of such methods highlight that such measures are not generally utilised in water treatment plants in the Connaught region.

It is indicated in the EPA report 'Water Quality in Ireland 1998-2000- lakes' that lakes in the west of Ireland are generally oligotrophic therefore it may be the case that algal growths, and therefore the removal of algae, are not an issue in the majority of water treatment plants using lake water as a source of abstraction of drinking water. Microstraining methods are employed in the treatment of water abstracted from Lough Corrib in County Galway. It is indicated in the above EPA report that Lough Corrib is mesotrophic, thus algal growth may be an issue with regard to the treatment of water abstracted from this source.

As well as having the potential to influence the formation of DBP's, the presence of algae in raw water can cause operational problems for the treatment plant, as it will block filters. In addition, algal decay causes problems with taste and odour in the treated water. The final problem posed by the presence of algae in water intended for the abstraction of drinking water according to Gray (1994) is that "algae will become either a source of food for micro-organisms growing on the walls of supply pipes, or the source of food for larger animals infesting the supply system". In this situation in order to inhibit the growth of these micro-organisms, a larger dose of disinfection agent may be required; hence the potential for the formation of disinfection by-products will also increase.

The results concerning the different treatment processes carried out at water treatment plants show that the degree of treatment varies and the number of unit processes involved varies significantly with the quality of the raw source water. Information regarding the quality of the raw water was obtained on the EPA website. As would be expected the cleaner the raw water, the fewer treatment steps are required.

This point is perhaps best illustrated using the results regarding the unit processes carried out at public water treatment plants in County Roscommon (Figure 4.5). From the results received from the completed questionnaires and information contained on the EPA website in relation to drinking water quality, it has been determined that the source water in each of the cases is either groundwater or spring water. These waters are treated by filtration, chlorination and fluoridation only. Chemical treatment is not undertaken.

In Galway, surface water sources are predominantly used for the abstraction of drinking water; therefore a greater number of treatment processes are required to treat the water to an acceptable standard. For example water abstracted from Lough Corrib, which serves a population of 66,774 people, is treated by means of a more extensive process involving coagulation, sedimentation, filtration, disinfection, fluoridation and finally pH correction

In County Mayo, Lough Mask provides the largest supply of water intended for the abstraction of drinking water. Treatment of this surface water involves numerous unit processes such as coagulation, filtration, disinfection, fluoridation and pH correction (Figure 4.2). In contrast, the treatment of groundwater in this region generally consists of one process, namely disinfection.

In relation to the information received from County Leitrim public water treatment plants, the results show that only minimal water treatment processes are carried out to ensure the safety of drinking water. This may be due to the fact that springs are primarily those water sources used for the abstraction of drinking water in County Leitrim.

5.3 The prevalence of chlorination as a means of disinfection at water treatment plants

The chlorination of drinking water may be achieved by using substances such as chlorine gas, chloramines, chlorine dioxide and products releasing chlorine (see Table 3, Section 2.2.4). Results from the questionnaires indicate the chlorination is the sole method of disinfection at all water treatment plants that participated in the survey in the Connaught Region. This is in agreement with information from the EPA, which states that chlorination is the most widely used form of disinfection of drinking water in this country (EPA, 1998). Furthermore, results from the questionnaire reveal that chlorine gas is the principal substance used to achieve chlorination. Within the Connaught region, 74 percent of public water treatment plants that replied to the questionnaire use chlorine gas as a disinfecting agent. This value ranges from 33 percent in County Leitrim to 86 percent in County Mayo (see Figures 4.8-4.12). Products that release chlorine are used at 23 percent of water treatment plants that replied to the questionnaire in the Connaught region. This value ranged from 7 percent in County Mayo to 67 percent in County Leitrim. Chlorine dioxide is used as a method of chlorination in County Mayo only. Chloramines are not used in any of the water treatment plants that replied to the questionnaire in the Connaught region.

The reasons for the extensive use of chlorine for the disinfection of drinking water are best described by Tebbutt, (1983) who suggests that its extensive use is predominantly due to its availability, cost, the ease with which it may be applied to water, its high solubility and finally and perhaps more importantly that chlorine leaves a residual in the drinking water which continues to destroy pathogens. The importance of the latter is that the use of chlorination prevents recontamination of the drinking water in the water distribution system. The United States EPA (1999) provide other benefits regarding the use of chlorine, they suggest that extensive use of chlorine also relates to the fact that it is "effective against a wide range of pathogens found in water and it has an extensive track record of successful use in improving water treatment operations."

Research has shown that the chlorination of drinking water using chlorine gas results in the formation of DBP's and more specifically trihalomethanes (Water Resources Management Division of Newfoundland and Labrador 1996). The use of alternative disinfectants and alternative chlorination methods has been identified by some workers as a simple method, which may be employed to limit the formation of disinfection by-products. Many researchers such as Hammer and Hammer (1996), Bryant *et al* (1996) and Viessman and Hammer, (2005) have provided details of the effect of alternative disinfectants on the formation of disinfection by-products. In summary these workers state that:

(a) ozone does not form any halogenated DBP's (though other non-halogenated DBP's may be formed)

(b) the use of UV radiation does not result in the formation of DBP's,

(c) chloramines form fewer halogenated DBP's as compared to chlorine gas and do not form THM's

(d) chlorine dioxide in general forms fewer halogenated DBP than chlorine gas,

Since ozone and U.V radiation is not used in any of the public water treatment plants surveyed in the Connaught region, the merits of using these disinfectants in relation to DBP control will not be achieved.

Chloramines are not used in water treatment plants in the Connaught region. According to the US EPA (1999) the application of chloramines results in the formation of chlorinated organic material, although it occurs to a much lesser degree than from the equivalent dose of free chlorine. The Water Resources Management Division of Newfoundland and Labrador indicates that THM's do not result when chloramines are used for the chlorination of water. Again, since chloramines are not used in water treatment plants that replied to the survey in the Connaught region, the benefits of using these substances in relation to DBP control will not occur.

Research has indicated that chlorine dioxide in general forms fewer halogenated DBP than chlorine gas (US EPA, 1999). It is also stated by the US EPA that "the application of chlorine dioxide does not produce THM's. The use of chlorine dioxide is practiced at a very small number of public water treatment plants in the Connaught region. Its use is restricted to 7 percent of water treatment plants in County Mayo.

It is worth noting that while a number of disinfecting agents may be useful in the control of DBP's, research has shown that there is no substance that is considered to be completely ideal for the disinfection of drinking water. The degree to which alternative disinfecting agents are utilised in the treatment of drinking water may be affected by factors such as the efficiency of pathogen removal, the cost, the complexity of the technology they require or the quality of the raw water used for abstraction. Although the use of ozone and U.V radiation in water treatment does not result in the formation of halogenated DBP's, they may not be beneficial in all circumstances e.g. in cases where the raw water has a significant amount of suspended solids (see section 2.4.3: Alternative methods of disinfection). Other alternatives such as chloramines or chlorine dioxide may not be used for a number of reasons as summarised in Table 3, Section 2.3.4.

Results obtained from the survey also show that disinfection is a process carried out at the treatment plant only. Information received from a water treatment plant in County Galway reiterates this, documentation received in addition to the completed questionnaire states "the usual point for disinfection is before the water enters the treated water storage tank" thus it may be assumed that additional application of a disinfection agent dose not take place in the distribution system. In such situations a larger dose of disinfecting agent is required to ensure that a sufficient residual remains in the distribution system (0.2mg/l) until the point of use. Such considerable dosing may increase the potential for the formation of DBP's. (See section 2.3.3: factors effecting the formation of THM's and other chlorination DBP's)

5.4 Measurement of DBP precursors in the raw water

A substantial amount of research has been undertaken on the subject of the control of DBP formation. It is suggested by Xie, (2004) "To better control the formation of DBP's in finished water and distribution systems, there is a need to evaluate the DBP precursors". Research has indicated that as the amount of total organic carbon (TOC) in raw water increases so too does the potential for the formation of disinfection by-products. As suggested by the EPA, (1998) "the TOC content of water prior to chlorination influences the formation of THM's." (See section 2.3.3- Natural Organic Matter). It is therefore considered that the analysis of this substance in the source water may prove useful in determining the potential for the formation of DBP's.

Miettinnen et al, (1997) suggests, "The availability of organic carbon is considered the key factor to regulate microbial re-growth in drinking water networks". It is possible to deduce therefore that the amount of TOC in the treated water may also inadvertently effect the formation of DBP's by increasing the dose required to ensure the safety of the water because of the re-growth of micro-organisms.

The results of the survey established that monitoring for TOC in the raw water to a water treatment plant varied from one region to another. In general of the water treatment plants in the Connaught region that responded to the questionnaire, 66 percent of plants never analyse for TOC in the raw water; this value ranged from 57 percent in County Galway to 100 percent in County Leitrim. On average 23 percent of public water treatment systems in the Connaught region that replied to the questionnaire analyse for TOC in the raw water on a monthly basis; this value ranged from zero percent in Counties Leitrim and Roscommon to 43 percent in County Galway. Analysis is carried out daily at one treatment plant in County Roscommon and weekly at one plant in County Galway.

Analysis for total organic carbon is not a requirement of the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989, however, the EC (Drinking Water) Regulations, 2000 specify that there should be no abnormal change in the concentration of total organic carbon in treated drinking water.
In the EPA publication "The Quality of Drinking Water in Ireland- A report for the Year 2004" it is revealed that all supplies monitored for TOC show compliance with the 2000 Regulations. The analysis of samples reveals that there have been no abnormal changes in the concentration of TOC in drinking water in 2004.

Research has illustrated that the bromide ions serve as a precursor to DBP formation and in particular Trihalomethanes, (Xie, 2004). The measurement of bromide in raw water is seen as a somewhat proactive approach in the prevention of DBP's at water treatment plants as analysis may give an indication of the potential for the formation of brominated DBP's. Analysis for bromide at water treatment plants that took part in the survey is very variable with analysis being carried out as frequently as weekly in some situations.

The results obtained show that bromide analysis is not carried out on a daily basis at any of the water treatment plants; analysis is carried out weekly at three percent of the plants that took part in the survey and on a monthly basis at 21 percent of treatment plants. The results indicate bromide analysis is omitted from raw water monitoring at 67 percent of water treatment plants. The results also highlight that analysis is carried out at other intervals for example bi-annually.

The analysis of bromide ions is not a requirement under the European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989. It was indicated by the Environment Sections of the local authorities that returned completed questionnaires that the analysis of bromate is carried out at regular intervals on treated water only. The analysis of bromate by sanitary authorities is carried in accordance with the EC (Drinking water) Regulations, 2000. These Regulations impose a limit of 10ug/l of bromate in treated drinking water by 25th December 2008. The presence of bromide in raw water is of particular importance when ozone is used as a disinfection agent since ozone oxidises bromide ions to form bromate (Bryant *et al*, 1992). In situations where chlorine is utilised to disinfect drinking water, bromide is oxidised to produce hypobromous acid, which then results in the formation of DBP's such as the THM, bromoform.

According to the EPA publication "The Quality of Drinking Water in Ireland-A Report for the Year 2004", there was 98.6% compliance of supplies in relation to the limits stipulated in the European Communities (Drinking water) Regulations, 2000 with regard to the acceptable level of bromate in treated drinking waters.

5.5 The control of biofilm formation

Biofilms have an adverse effect on drinking water quality not only due to the potential for microbial contamination but also because they may result in greater concentrations of disinfectants being used to ensure drinking water that is adequate in quality, thereby increasing the potential for DBP formation.

As previously discussed (see section 2.3.3), the control of the formation of a biofilm is important in terms of the control of disinfection by-products. Control techniques commonly adopted include the cleaning of water distribution pipes (see Table 8-section 2.4.4). The EPA document The European Communities (Drinking Water) Regulations, 2000 (S. I. 439 of 2000): A Handbook on Implementation for Sanitary Authorities suggests that sanitary authorities should develop a cleaning and maintenance programme to limit the possibility of recontamination of treated water in the distribution system. The cleaning of drinking water distribution pipes may be achieved by employing methods such as flushing, swabbing and air scouring.

Results obtained from completed questionnaires in relation to the cleaning of drinking water distribution lines confirm that flushing is the preferred method utilised by all but one of the treatment plants to which the results relate.

The flushing of drinking water distribution lines may be common practice for a number of different reasons for example (a) it is a simple operation to carry out (b) it is relatively inexpensive and (c) it may be successfully carried out by one or two people. Research has highlighted that in fact flushing techniques are ineffective in the removal of biofilms from distribution pipes (WHO, 2004). The process does however remove sediments and NOM, which may react with disinfecting agents to form DBP's. For the latter reason, the flushing of water distribution lines may be considered as partially effective in controlling the formation of chlorinated DBP's. It should also be considered that the removal of sediments will result in improved characteristics of the water, namely taste and odour.

It appears that there is no completely ideal method for cleaning water distribution pipes. With specific regard to the control of DBP's in distribution systems, swabbing techniques are considered to be the best option for the removal of precursors and biofilms. Swabbing is not used as a method of cleaning pipes in water distribution systems in the Connaught region.

The intervals at which distribution lines are cleaned is important with regard to the formation of a biofilm within the distribution system. The frequency at which cleaning is required is determined from the monitoring of water quality and maintenance records (WHO, 2004). If a biofilm is allowed to develop re-contamination of the water may occur and require that further disinfection is carried out to ensure that water reaching the consumer is not injurious to their health. Subsequent applications of a disinfecting agent will increase the potential for the formation of DBP as it may react with NOM remaining in the treated water (Percival *et al*, 2000).

Results from the completed questionnaires reveal that the frequency of cleaning distribution lines varies from one source zone and county to another. Generally, the cleaning of distribution lines is carried on a monthly basis by 54 percent of treatment plants in the Connaught region; this value varies from 35 percent of plants in County Galway to 100 percent of treatment plants in County Leitrim. Cleaning is carried out on a weekly basis by four percent of plants and bi-monthly by 28 percent of treatment plants. From the results it is clear that cleaning operations are most frequent in water supplies in County Leitrim, as cleaning is carried out on a monthly basis at all treatment plants in the region.

Results of the questionnaires also revealed that in areas with water quality problems such as taste and colour, pipe cleaning is carried out more frequently and is usually initiated by complaints from consumers.

5.6 Proactive measures contained in Action Plans

The final question posed by the questionnaire relates to issues considered in action plans for the protection of drinking water. The development of such an action plan is the responsibility of local authorities as detailed in the Circular letter L14/92. Specifically in relation to the formation and control of DBP's at water treatment plants and in distribution systems, issues such as the removal of algae, cleaning of reservoirs and source water protection are important. The removal of algae from source water has been previously discussed.

Cleaning of reservoirs should take place at 1-5 year intervals, depending on factors such as water quality measurements, the efficiency of water treatment in removing deposit-forming substances, the presence of animals and information from previous inspections (WHO, 2004). The storage of raw water, as indicated in Table 1, typically results in the removal of microbial pathogens and a reduction in the concentration of NOM, thus reducing both the requirement for disinfection and disinfection precursors. Cleaning of reservoirs will limit the potential of the re-suspension of settled material and further microbial contamination of stored water (see Table 1 section 2.1).

Source water protection is also an important aspect of controlling DBP formation as outlined in section 2.4.1. Effective source water protection is imperative in order to control the concentration of disinfection precursors present in raw water as well as the concentration of nutrients in the water, which may act to increase the formation of biofilms due to their availability to microbial pathogens.

Source water protection typically involves the development of a water quality management plan and a code of practice, outlining potential pollution threats to raw water sources, a vulnerability assessment of the waters and assessment of pollution loading to the source water.

Waters used for the abstraction of drinking water are deemed to be ‘protected’ areas under the Water Framework Directive, 2000. As such, it is necessary for local authorities to “ensure the necessary protection of bodies of water identified with the aim of avoiding deterioration in order to reduce the level of purification treatment required in the production of drinking water". Action plans for the protection of drinking water are a means of ensuring the achievement of this duty.

Analyses of results obtained from completed questionnaires indicate that the issues of removal of algae, cleaning of reservoirs and source water protection are important, to varying degrees, in Action Plans. Most plans include efforts in relation to the protection of water sources and the cleaning of reservoirs and to a lesser extent the removal of algae.

Results from the completed questionnaire indicate that the issue dealt with most frequently in Action Plans is the protection of water sources. The issue is dealt with in 56 percent of plans in County Mayo, 43 percent of plans in County Galway, 50 percent of plans in County Leitrim and also in 50 percent of plans in County Roscommon.

The cleaning of reservoirs was dealt with in 46% of Action plans created by water treatment plants that replied to the questionnaire in the Connaught region. This varies from 25 to 50 percent of plans. More specifically, 25 percent of action plans for the protection of drinking water in County Roscommon, 44 percent of plans in County Mayo and 50 percent of action plans in Counties Galway and Leitrim.

The removal of algae from source water was detailed in only 4 percent of drinking water action plans in the Connaught region to which the results relate. On a regional basis the removal of algae is dealt with in action plans in Counties Galway and Roscommon only.

6.0 Conclusions

From the information contained in this study the following conclusions may be made:

1. Although the disinfection of drinking water must not be compromised in an effort to control DBP formation, extensive research has shown the health effects associated with exposure to such substances to be considerable. With this in mind efforts should be made to control DBP formation at the raw water source, the water treatment plant and within the distribution system.

2. The literature review has revealed that methods to control DBP formation include;

    a) Protection of source water quality in terms of DBP precursors such as NOM, nutrient and bromide.
    b) Removal of the above DBP precursors from source waters by means of such pre-treatment methods as microstraining and pre-ozonisation and ensuring adequate control of unit processes within the water treatment plant to ensure removal of DBP precursors.
    c) Monitoring of the concentration of DBP precursors such as NOM (in the form of TOC) and bromide in the source water.
    d) Correct choice of disinfecting agent to ensure the lowest possible concentrations of DBP's in treated water leaving the distribution plant without compromising disinfection. This aim must be balanced with providing the most effective removal of pathogenic organism in order to safeguard human health.

e) The control of biofilm formation within water distribution systems.

f) Changing the point of disinfection to include application in the distribution network.

g) The formulation of Action Plans to cover factors that are considered to be important in controlling DBP formation.

h) Regular monitoring of DBP concentrations in drinking water.

3. Analysis of results of questionnaires completed by caretakers of public water treatment plants in the Connaught Region revealed the following:

a) that those unit processes (i.e. microstraining and pre-ozonisation) designed to remove natural organic matter from source waters are not performed at the majority of public water treatment plants, with the exception of one plant, whose water treatment stages involves microstraining. It is possible therefore to deduce that only basic water treatment processes are relied upon to control the formation of disinfection by-products by limiting the concentration of precursors present in the water.

b) Monitoring of the DBP's precursors TOC and bromide is not extensively carried out in the Connaught region. More specifically TOC monitoring is not carried out at 66 percent of water treatment plants while bromide analysis does not take place at 67 percent of plants.

c) Disinfection is carried out at 92 percent of water treatment plants in the Connaught region. Chlorination is the only method employed for the disinfection of drinking water in this Region. This process is typically achieved through the application of chlorine gas; being used at 74 percent of treatment plants. Chlorine dioxide is used for the chlorination of drinking water in one treatment plant in County Mayo, while products releasing chlorine are used at 23 percent of treatment plants. Alternative disinfectants such as ozone, UV or potassium permanganate are not used in water treatment plants surveyed in the Connaught region. It is apparent from the results that the methods used to achieve the chlorination of drinking water will result in the highest possible potential for the formation of disinfection by-products.

d) Flushing has been identified as the predominant method used to clean drinking water distribution pipes and to prevent the formation of a biofilm in water distribution systems arising from water treatment plants in the Connaught region. Air scouring is used in one supply zone in County Mayo.

e) The development of drinking water action plans by local authorities for the protection of drinking water highlights that while the control of disinfection by products may not be the plan's primary goal, their development and implementation may go some way in limiting and controlling disinfection by-products and the general public's exposure to such substances.

7.0 Recommendations

While extensive research was carried out in relation to the control of disinfection by-products, it is recommended that further research be performed specifically in relation to the extent of which control methods are utilised and their success or obstacles to it.

It is also recommended that the cost of implementing control methods be appropriately investigated, as this is often an important determining factor in whether or not a technology or process is adapted and is often a major stumbling block.

Recently combinations of primary and secondary disinfectants are being used in an attempt to minimise the formation of harmful by-products, it is therefore recommended that this specific control method be researched in significant detail.

The study highlighted that monitoring of substances known to influence the formation of disinfection by-products is carried out on an inconsistent basis, it is therefore recommended that further research be undertaken to ascertain why such inconsistencies exist.

Further investigation should be carried out in order to determine the efficiency of flushing processes, specifically relating to the technique's effectiveness in the removal of biofilms.

Finally it is recommended that further study be carried out with regard to effectiveness of methods detailed in local authority action plans for the protection of drinking water, particularly those which may affect the formation and control of disinfection by-products.

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Appendices

Appendix One

Treatment type	A1		A2		A3	
Parameter (mg/l except where noted	Guide limit	Mandatory limit	Guide limit	Mandatory limit	Guide limit	Mandatory limit
pH units	6.5-8.5		5.5-9.0		5.5-9.0	
Colour units	10	20	50	100	50	200
Suspended solids	25					
Temperature (^{0}C)	22	25	22	25	22	25
Conductivity (uS/cm)	1000		1000		1000	
Odour (DN[a])	3		10		20	
Nitrate (as NO_3)	25	50		50		50
Fluoride	0.7-1.0	1.5	0.7-1.7		0.7-1.7	
Iron (soluble)	0.1	0.3	1.0	2.0	1.0	
Manganese	0.05		0.1		1.0	
Copper	0.02	0.05	0.05		1.0	
Zinc	0.5	3.0	1.0	5.0	1.0	5.0
Boraon	1.0		1.0		1.0	
Arsinc	0.01	0.05		0.05	0.05	0.1
Cadmium	0.001	0.005	0.001	0.005	0.001	0.005
Chromium (total)		0.05		0.05		0.05
Lead		0.05		0.05		0.05
Selenium		0.01		0.01		0.01
Mercury	0.0005	0.001	0.0005	0.001	0.0005	0.001
Barium		0.1		1.0		1.0
Cyanide		0.05		0.05		0.05
Sulphate	150	250	150	250	150	250
Chloride	200		200		200	
MBAS	0.2		0.2		0.5	

Treatment type	A1		A2		A3	
Parameter (mg/l except where noted	Guide limit	Mandatory limit	Guide limit	Mandatory limit	Guide limit	Mandatory limit
Phosphate (as P_2O_5)	0.4		0.7		0.7	
Phenol		0.001	0.001	0.005	0.01	0.1
Hydrocarbon (ether soluble)		0.05		0.2	0.5	1.0
PAH[b]		0.0002		0.0002		0.001
Pesticides		0.001		0.0025		0.005
COD					30	
BOD (with ATU[c])	<3		<5		<7	
DO[d] per cent saturation	>70		>50		>30	
Nitrogen (kjeldahl)	1		2		3	
Ammonia (as NH_4)	0.05		1	1.5	2	4
Total coliforms/100ml	50		5000		50000	
Faecal coliforms/100ml	20		2000		20000	
Faecal streptococci/100ml	20		1000		10000	
Salmonella	Absent in 5l		Absent in 1l			

Mandatorylevels 95% compliance, 5% not complying should not exceed 150% of mandatory level. [a]DN: dilution number; [b]PAH: polycyclic aromatic hydrocarbons; [c]ATU: allythiourea; [d]DO: dissolved oxygen.

Appendix Two

STATUTORY INSTRUMENTS

S. I. No. 439 of 2000

EUROPEAN COMMUNITIES (DRINKING WATER) REGULATIONS, 2000

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INDEX

Article		Page
1.	Citation	1
2.	Commencement	1
3.	Interpretation	1
4.	Duty of sanitary authority	3
5.	Departures from standards	4
6.	Point of compliance	5
7.	Monitoring of water quality	6
8.	Protection of human health	6
9.	Remedial action	7
10.	Quality of treatment, equipment and materials	9
11.	Power of entry	9
12.	Charges by sanitary authority	9
13.	Recommendations of Minister	10
14.	Offences and penalties	10
15.	Information in case of exempted supplies	10
16.	Quality to be maintained	11
17.	Revocation	11

Schedule

Part I.	Parameters and parametric values	11
Part 2.	Monitoring	16
Part 3.	Specifications for the analysis of parameters	19
Part 4.	Matters to be specified in grant of departure under article 5.	23

<u>**S. I. NO. 439 of 2000**</u>

EUROPEAN COMMUNITIES (DRINKING WATER) REGULATIONS, 2000

The Minister for the Environment and Local Government in exercise of the powers conferred on him by section 3 of the European Communities Act, 1972 (No. 27 of 1972) and for the purpose of giving effect to the Council Directive of 3 November, 1998 (No. 98/83/EC)[1] hereby makes the following Regulations:

Citation

1. These Regulations may be cited as the European Communities (Drinking Water) Regulations, 2000.

Commencement

2. These Regulations shall come into operation on 1 January, 2004.

Interpretation

3. (1) In these Regulations, save where the context otherwise requires -

"the Agency" means the Environmental Protection Agency established under the Environmental Protection Agency Act, 1992 (No. 7 of 1992);

"authorised person" means a person appointed by a sanitary authority to be an authorised person for the purposes of these Regulations;

---

[1] O.J. No. L330, 5.12. 1998, P.32.

"the Directive" means Council Directive 98 / 83 / EC of 3 November 1998 on the quality of water intended for human consumption;

"domestic distribution system" means the pipework, fittings and appliances within the curtilage of a premises which are installed between the distribution network and the taps that are normally used for the provision of water for human consumption

"exempted supply" means a supply of water which –

(a) (i) is provided from either an individual supply providing less than $10m^3$ a day on average or serving fewer than 50 persons, and

(ii) is not supplied as part of a commercial or public activity, or

(b) is used exclusively for purposes in respect of which the sanitary authority is satisfied that the quality of the water has no influence, either directly or indirectly, on the health of the consumers concerned;

"the Minister" means the Minister for the Environment and Local Government;

"monitoring" includes inspection, measurement, sampling or analysis whether periodically or continuously;

"premises" includes any land, any waterworks as defined in section 2 of the Public Health (Ireland) Act, 1878 and any building, structure or private dwelling;

"private water supply" means a water supply which is not in the charge or ownership of a sanitary authority;

"sanitary authority" means a sanitary authority for the purposes of the Local Government (Sanitary Services) Acts, 1878 to 1964;

"water intended for human consumption" means –

(a) all water, either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network or from a tanker,

(b) all water used in any food production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the sanitary authority are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form, other than –

- natural mineral waters recognised by the responsible authority as defined in the European Communities (Natural Mineral Waters) (Amendment) Regulations, 1998 (S.I. No. 461 of 1998)
- water supplied in bottles or containers
- waters which are medicinal products within the meaning of Council Directive 65/65/EEC of 26 January, 1965[2], or
- an exempted supply.

(2) In these Regulations :-

(a) a reference to an article or schedule which is not otherwise identified is a reference to an article or schedule of these Regulations, and

(b) a reference to a sub-article which is not otherwise identified is a reference to a sub-article of the article in which the reference occurs.

Duty of sanitary authority

4. (1) It shall be the duty of a sanitary authority to take the necessary measures to ensure that water intended for human consumption is wholesome and clean and meets the requirements of these Regulations, except where a departure is granted under article 5.

(2) Water shall be regarded as wholesome and clean if –

(a) it is free from any micro-organisms and parasites and from any substances which in numbers or concentrations, constitute a potential danger to public health, and

(b) it meets the quality standards specified in Tables A and B in Part 1 of the Schedule.

(3) A sanitary authority shall not be in breach of its obligations under this article, article 6(a) or article 9(2)(a) in case of water supplied to a premises (other than a premises where water is supplied to the public, including schools, hospitals and food outlets) where non-compliance with a parametric value is due to the domestic distribution system in that premises or the maintenance thereof and the distribution system is

[2] O.J.No. L22,9.2.1965 p.369 as last amended by Directive 93/39/EEC (O.J.No. L214 24.8.1993,p22)

not in the charge or control of the water supplier in its capacity as a water supplier.

(4) In a case where sub-article (3) applies and there is a risk that water covered by article (6)(a) would not comply with the parametric values specified in Part 1 of the Schedule, a sanitary authority shall nevertheless ensure that:-

(a) (i) appropriate measures are taken to reduce or eliminate the risk of non-compliance with the parametric values, such as advising property owners of any possible remedial action which could be taken by them, or

(ii) other measures, such as appropriate treatment techniques, are taken to change the nature or properties of the water before it is supplied so as to reduce or eliminate the risk of the water not complying with the parametric values after supply,

and

(b) the consumers concerned are duly informed and advised of any possible additional remedial action that should be taken by them.

Departures from standards

5. (1) A departure from the parametric values specified in Table B in Part 1 of the Schedule may, on application by a sanitary authority, be granted by the Agency in relation to a water supply provided no such departure constitutes a potential danger to public health and provided that the supply of water intended for human consumption in the area concerned cannot otherwise be maintained by any other reasonable means

(2) An application to the Agency for the grant of a departure under this article in respect of a water supply shall be made by a sanitary authority in whose area a water supply is located.

(3) An application for a departure under this article shall contain such information as may be specified by the Agency.

(4) A departure granted under this article shall –

(a) be subject to such conditions as may be specified by the Agency,
(b) have effect for as short a period of time as possible, which shall not exceed three years,
(c) subject to sub-article (5), specify the matters set out in Part 4 of the Schedule, and
(d) be reviewed by the Agency prior to the end of the period of the departure so as to determine whether sufficient progress has been made in the opinion of the Agency.

(5) (a) Subject to paragraph (b), sub-article (4) shall not apply in case where the Agency considers that

(i) the non-compliance with the parametric value is trivial, and
(ii) the action taken in accordance with sub-article 9(2)(a) is sufficient to remedy the problem within 30 days,

and in such a case a departure granted under this article need specify only the maximum permissible value for the parameter and the time allowed to remedy the problem.

(b) Paragraph (a) shall not apply in the case of a water supply where failure to comply with any one parametric value in relation to that supply has occurred on more than 30 days in aggregate during the previous twelve months.

(6) In exceptional circumstances a second departure which shall not exceed three years may be granted by the Agency and the Agency shall notify the Minister of the granting of such a departure.

(7) A sanitary authority which has recourse to a departure granted under this article shall ensure that –

(a) the population affected by such departure is promptly informed of the departure and of the conditions governing it, and

(b) advice is given, where necessary, to particular population groups for which the departure could present a particular risk.

Point of compliance

6. A sanitary authority shall ensure that the parametric values specified in Part I of the Schedule are complied with in the case of :-

(a) water supplied from a distribution network, at the point, within a premises or an establishment, at which it emerges from the tap or taps that are normally used for the provision of water for human consumption;

(b) water supplied from a tanker, at the point at which it emerges from the tanker;

(c) water used in a food-production undertaking, at the point where the water is used in the undertaking.

Monitoring of water quality

7. (1) A sanitary authority shall take all measures necessary to ensure that regular monitoring is carried out at the points of compliance specified in article 6 in relation to the quality of water intended for human consumption.

(2) For the purposes of sub-article (1), a sanitary authority shall specify the points at which samples shall be taken for analysis and establish a monitoring programme in accordance with Part 2 of the Schedule.

(3) Samples taken in accordance with sub-article (1) shall be representative of the quality of the water consumed throughout the year.

(4) A monitoring programme established under sub-article (2) shall comply with the specifications for the analyses of parameters specified in Part 3 of the Schedule and may provide for the use of -

(a) methods of analysis other than those specified in section 1 of Part 3 of the Schedule provided that the Agency is satisfied that the results obtained are at least as reliable as those produced by the specified methods, and

(b) any method of analysis for those parameters listed in sections 2 and 3 of Part 3 of the Schedule provided that it meets the requirements set out therein.

(5) A sanitary authority shall ensure that additional monitoring is carried out on a case-by-case basis of substances and micro-organisms for which no parametric value has been specified in Part 1 of the Schedule, if there is reason to suspect that such substances and, or micro-organisms may be present in amounts or numbers which constitute a potential danger to human health.

Protection of human health

8. (1) Where a sanitary authority considers that a supply of water intended for human consumption constitutes a potential danger to human health the authority shall ensure that –

(a) the supply of such water is prohibited or the use of such water is restricted, or such other action is taken as is necessary to protect human health, and

(b) consumers shall be informed promptly thereof and given the necessary advice.

(2) A sanitary authority shall decide what action should be taken under sub-article (1) having due regard to the risks to human health which would be caused by an interruption of the supply or a restriction in the use of water intended for human consumption.

(3) The duty imposed on a sanitary authority by sub-article (1) shall apply whether or not any failure to meet a parametric value has occurred.

Remedial action

9. (1) A sanitary authority shall ensure that any failure to meet the parametric values specified in Part 1 of the Schedule is immediately investigated so as to identify the cause of such failure.

(2) Where it is found, as a result of monitoring carried out under article 7, that the quality of water intended for human consumption does not meet the parametric values specified in Part 1 of the Schedule, the sanitary authority shall, subject to any departures in force under article 5 :-

(a) ensure, subject to article 4, that the necessary remedial action is taken as soon as possible to restore the quality of the water and shall give priority to its enforcement action, having particular regard to the extent to which the relevant parametric value has been exceeded and to the potential danger to human health,

(b) in the case of a public water supply, prepare an action programme within 60 days of receipt by the sanitary authority of the monitoring results and implement such action programme for the improvement of the quality of the water so as to secure compliance with these Regulations as soon as possible and not later than –

(i) one year from the date of finalisation of an action programme in relation to the water quality standards specified in Tables A and B in Part 1 of the Schedule in relation to matters which present a risk to public health, and

(ii) two years from the date of finalisation of an action programme in relation to all the water quality standards specified in Table B in Part 1 of the Schedule, other than those referred to in paragraph (i),

(c) in the case of a private water supply serve, within 14 days of receipt by the sanitary authority of the monitoring results, a notice in writing on the person or, where there is more than one such person, each person responsible for that supply requiring that person, or persons as the case may be, to prepare within 60 days of the date of said notice an action programme and to implement such action programme, including such interim measures as may be appropriate, for the improvement of the quality of the water so as to secure compliance with these Regulations as soon as possible and not later than –

(i) one year from the date of finalisation of an action programme in relation to the water quality standards specified in Tables A and B in Part 1 of the Schedule in relation to matters which present a risk to public health, and

(ii) two years from the date of finalisation of an action programme in relation to all the water quality standards specified in Part B in Part 1 of the Schedule, other than those referred to in paragraph (i).

(3) An action programme under sub-article (2)(b) shall include such interim measures as may be appropriate.

(4) An action programme under sub-article (2)(c) shall have regard to the provisions of any strategic rural water plan for the area in which the water supply is situate.

(5) A sanitary authority shall ensure that, where remedial action is taken in relation to a water supply, consumers are informed of such action save where the authority considers the non-compliance with the parametric value to be trivial in nature or extent.

(6) (a) In the event of non-compliance with the parametric values or with the specifications provided for in Table C in Part 1 of the Schedule in the case of a public water supply, a sanitary authority shall consider whether such non-compliance poses a risk to human health.

(b) Where such risk exists, a sanitary authority shall take remedial action in accordance with sub-article (2)(a) and (b) and (3) to restore the quality of the water where it is necessary to protect public health.

(7) (a) In the event of non-compliance with the parametric values or with the specifications provided for in Table C in Part 1 of the Schedule in the case of a private water supply, a sanitary authority shall consider whether such non-compliance poses a risk to human health.

(b) Where such risk exists, a sanitary authority shall initiate the provisions of sub-article (2)(c) and the person or persons responsible for such supply shall take remedial action to restore the quality of the water within the timeframe specified.

Quality of treatment, equipment and materials

10. (1) A water supplier shall take all measures necessary to ensure that no substances or materials for new installations used in the preparation or distribution of water intended for human consumption or impurities

associated with such substances or materials for new installations remain in water intended for human consumption in concentrations higher than is necessary for the purpose of their use and do not, either directly or indirectly reduce the protection of human health provided for in these Regulations.

(2) Where disinfection forms part of the preparation and, or distribution of water intended for human consumption, a water supplier shall ensure that the efficiency of the disinfection treatment is verified and that any contamination from disinfection by-products is kept as low as possible without compromising the disinfection.

Power of entry

11. (1) An authorised person may at all reasonable times enter any premises for the purposes of these Regulations.

(2) When exercising the power conferred by this article, an authorised person shall, if so required, produce evidence of his or her authority.

Charges by sanitary authority

12. (1) A sanitary authority may charge for monitoring the quality of private water supplies intended for human consumption.

(2) A charge made by a sanitary authority by virtue of sub-article (1) shall be of such amount as the authority considers appropriate but shall not exceed the cost of such monitoring.

(3) A charge made by a sanitary authority by virtue of sub-article (1) shall be payable by and recoverable from:-

(a) in the case of a private water supply, the trustees or other persons responsible for providing that supply, and

(b) in any other case, the occupier or occupiers of the premises supplied.

(4) A sanitary authority may recover the amount of any charge made by them under this article from the person or persons by whom it is payable as a simple contract debt in any court of competent jurisdiction.

Recommendations of Minister

13. The Minister may, from time to time, issue recommendations to sanitary authorities in relation to the carrying out of any of their duties under these Regulations and sanitary authorities shall have regard to any such recommendations.

Offences and penalties

14. (1) Where a notice is served on a person under Article 9(2)(c) in relation to the preparation or implementation of an action programme in respect of water quality standards specified in Part 1 of the Schedule, regarding matters which present a risk to public health, and that person fails to comply with the terms of the notice, that person shall be guilty of an offence in respect of such failure and shall be liable on summary conviction to a fine not exceeding £1,500 or to a term of imprisonment not exceeding six months or, at the discretion of the court, to both such fine and such imprisonment.

(2) Where a person, after conviction of an offence under sub-article (i), continues to contravene the provision, that person shall be guilty of an offence on every day on which such contravention is continued and for each such offence that person shall be liable to a fine, on summary conviction, not exceeding £200.

Information in case of exempted supplies

15. A sanitary authority shall take measures to notify the population served by an exempted supply of –

(a) the fact that these Regulations do not apply to such supply,

(b) action that can be taken to protect human health from the adverse effects resulting from any contamination of water intended for human consumption, and

(c) appropriate advice where a potential danger to human health arising from the quality of such supply is apparent.

Quality to be maintained

16. Measures taken by a sanitary authority or a water supplier to apply the provisions of these Regulations shall in no case have the effect of allowing, directly or indirectly, either any deterioration in the existing quality of water intended for human consumption so far as that is relevant for the protection of human health or an increase in the pollution of waters used for the production of drinking water.

Revocation

17. The European Communities (Quality of Water Intended for Human Consumption) Regulations, 1988 (S.I. No. 81 of 1988) are hereby revoked with effect from 1 January, 2004.

SCHEDULE

Part 1

PARAMETERS AND PARAMETRIC VALUES

TABLE A
MICROBIOLOGICAL PARAMETERS

	Parameter	Parametric value (number/100 ml)
1	Escherichia coli (E.coli)	0
2	Enterococci	0

TABLE B
CHEMICAL PARAMETERS

	Parameter	Parametric value	Unit	Comments
3	Acrylamide	0.10	ug/l	Note 1
4	Antimony	5.0	ug/l	
5	Arsenic	10	ug/l	
6	Benzene	1.0	ug/l	
7	Benzo(a)pyrene	0.010	ug/l	
8	Boron	1.0	mg/l	
9	Bromate	10	ug/l	Note 2
10	Cadmium	5.0	ug/l	
11	Chromium	50	ug/l	
12	Copper	2.0	mg/l	Note 3
13	Cyanide	50	ug/l	
14	1,2-dichloroethane	3.0	ug/l	
15	Epichlorohydrin	0.10	ug/l	Note 1
16	Fluoride	1.0	mg/l	Note 11
17	Lead	10	ug/l	Notes 3 and 4
18	Mercury	1.0	ug/l	
19	Nickel	20	ug/l	Note 3
20	Nitrate	50	mg/l	Note 5
21	Nitrite	0.50	mg/l	Note 5
22	Pesticides	0.10	ug/l	Notes 6 and 7

23	Pesticides – Total	0.50	ug/l	Note 6 and 8
24	Polycyclic aromatic hydrocarbons	0.10	ug/l	Sum of concentrations of specified compounds; Note 9
25	Selenium	10	ug/l	
26	Tetrachloroethene and Trichloroethene	10	ug/l	Sum of concentrations of specified parameters.
27	Trihalomethanes – Total	100	ug/l	Sum of concentrations of specified compounds; Note 10
28	Vinyl chloride	0.50	ug/l	Note 1

Notes

Note 1: The parametric value refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.

Note 2: For the water referred to in sub-articles 6 (a), (b) and (c) the parametric value to be met by 1 January, 2004 is 25 ug/l. A value of 10 ug/l must be met by 25 December, 2008.

Note 3. The value applies to a sample of water intended for human consumption obtained by an adequate sampling method* at the tap and taken so as to be representative of a weekly average value ingested by consumers and that takes account of the occurrence of peak levels that may cause adverse effects on human health.

*The Copper, Lead and Nickel parameters shall be monitored in such a manner as the Minister shall determine from time to time.

Note 4 For water referred to in sub-articles 6 (a), (b) and (c), the parametric value to be met by 1, January 2004 is 25 ug/l. A value of 10 ug/l must be met by 25 December, 2013.

All appropriate measures shall be taken to reduce the concentration of lead in water intended for human consumption as much as possible during the period needed to achieve compliance with the parametric value.

When implementing the measures priority shall be progressively given to achieve compliance with that value where lead concentrations in water intended for human consumption are highest.

Note 5 Compliance must be ensured with the conditions that [nitrate]/50 + [nitrite]/3 $\leq$ 1, the square brackets signifying the concentrations in mg/l for nitrate (NO_3) and nitrite (NO_2) and the value of 0.10mg/l for nitrites ex water treatment works.

Note 6 Only those pesticides which are likely to be present in a given supply require to be monitored.

"Pesticides" means:

- organic insecticides,
- organic herbicides,
- organic fungicides,
- organic nematocides,
- organic acaricides,
- organic algicides,
- organic rodenticides,
- organic slimicides,
- related products (*inter alia*, growth regulators)

and their relevant metabolites, degradation and reaction products.

Note 7 The parametric value applies to each individual pesticide. In the case of aldrin, dieldrin, heptachlor and heptachlor epoxide the parametric value is 0.030 ug/l.

Note 8 "Pesticides – Total" means the sum of all individual pesticides detected and quantified in the course of the monitoring procedure;

Note 9 The specified compounds are:

- benzo(b)fluoranthene
- benzo(k)fluoranthene
- benzo(ghi)perylene
- indeno(1,2,3-cd)pyrene.

Note 10 The specified compounds are: chloroform, bromoform, dibromochloromethane and bromodichloromethane.

For the water referred to in sub-articles 6 (a), (b) and (c), the parametric value to be met by 1 January, 2004 is 150 ug/l. A value of 100 ug/l must be met by 25 December, 2008.

All appropriate measures must be taken to reduce the concentration of THMs in water intended for human consumption as much as possible during the period needed to achieve compliance with the parametric value.

When implementing the measures to achieve this value, priority must progressively be given to those areas where THM concentrations in water intended for human consumption are highest.

Note 11 The parametric value is 1.0mg/l for fluoridated supplies. In the case of supplies with naturally occurring fluoride the parametric value is 1.5mg/l.

TABLE C
INDICATOR PARAMETERS

	Parameter	**Parametric value**	**Unit**	**Comment**
29	Aluminium	200	ug/l	
30	Ammonium	0.30	mg/l	
31	Chloride	250	mg/l	Note 1
32	Clostridium perfringens (including spores)	0	number/100 ml	Note 2
33	Colour	Acceptable to consumers and no abnormal change		
34	Conductivity	2500	uS cm^{-1} at 20 ^{0}C	Note 1
35	Hydrogen ion concentration	$\geq$ 6.5 and $\leq$9.5	pH units	Note 1
36	Iron	200	ug/l	
37	Manganese	50	ug/l	
38	Odour	Acceptable to consumers and no abnormal change		
39	Oxidisability	5.0	mg/l 0_2	Note 3
40	Sulphate	250	mg/l	Note 1
41	Sodium	200	mg/l	
42	Taste	Acceptable to consumers and no abnormal change		
43	Colony count 22^{0}	No abnormal change		
44	Coliform bacteria	0	number/100 ml	
45	Total organic carbon (TOC)	No abnormal change		Note 4
46	Turbidity	Acceptable to consumers and no abnormal change		Note 5

RADIOACTIVITY

	Parameter	**Parametric value**	**Unit**	**Comments**

47	Tritium	100	Bq/l	Notes 6 and 8
48	Total indicative dose	0.10	mSv/year	Notes 7 and 8

Notes

Note 1: The water should not be aggressive

Note 2: This parameter need not be measured unless the water originates from or is influenced by surface water. In the event of non-compliance with this parametric value, the supply shall be investigated to ensure that there is no potential danger to

human health arising from the presence of pathogenic micro-organisms, e.g. cryptosporidium.

Note 3: This parameter need not be measured if the parameter TOC is analysed.

Note 4: This parameter need not be measured for supplies of less than 10 000m^3 a day.

Note 5: In the case of surface water treatment, a parametric value not exceeding 1.0 NTU (nephelometric turbidity units) in the water ex treatment works must be strived for.

Note 6: Monitoring frequencies to be set at a later date in Part 2 of the Schedule.

Note 7: Excluding tritium, potassium –40, radon and radon decay products; monitoring frequencies, monitoring methods and the most relevant locations for monitoring points to be set at a later date in Part 2 of the Schedule.

Note 8:

A. The proposals required by Note 6 on monitoring frequencies, and Note 7 on monitoring frequencies, monitoring methods and the most relevant locations for monitoring points in Part 2 of the Schedule shall be adopted in accordance with the Committee procedure laid down in Article 12 of Council Directive 98/83/EEC.

B. Drinking water need not be monitored for tritium or radioactivity to establish total indicative dose where, on the basis of other monitoring carried out, the levels of tritium of the calculated total indicative dose are well below the parametric value.

PART 2

MONITORING

TABLE A

PARAMETERS TO BE ANALYSED

1. Check monitoring

The purpose of check monitoring is regularly to provide information on the organoleptic and microbiological quality of the water supplied for human consumption as well as information on the effectiveness of drinking-water treatment (particularly of disinfection) where it is used, in order to determine whether or not water intended for human consumption complies with the relevant parametric values laid down in Part I of this Schedule.

The following parameters must be subject to check monitoring:

Aluminium (Note 1)
Ammonium
Colour
Conductivity
Clostridium perfringens (including spores)(Note 2)
Escherichia coli (E. coli)
Hydrogen ion concentration
Iron (Note 1)
Nitrite (Note 3)
Odour
Taste
Coliform bacteria
Turbidity

Notes

Note 1: Necessary only when used as flocculant (*).

Note 2: Necessary only if the water originates from or is influenced by surface water (*).

Note 3: Necessary only when chloramination is used as a disinfectant (*).

(*) In all other cases, the parameters are in the list for audit monitoring.

2. Audit monitoring

The purpose of audit monitoring is to provide the information necessary to determine whether or not all the parametric values specified in Part I of this Schedule are being complied with. All such parameters must be subject to audit monitoring unless it can be established by a sanitary authority, for a period of time to be determined by it, that a parameter is not likely to be present in a given supply in concentrations which could lead to the risk of a breach of the relevant parametric value. This paragraph does not apply to the parameters for radioactivity, which, subject to Notes 6, 7 and 8 in Table C in Part 1 of the Schedule will be monitored in accordance with monitoring requirements adopted under the Committee procedure set out in Article 12 of Council Directive 98/83/EC.

TABLE B

Minimum frequency of sampling and analyses for water intended for human consumption supplied from a distribution network or from a tanker or used in a food-production undertaking

Samples must be taken at the points of compliance as defined in Article 6 to ensure that water intended for human consumption meets the requirements of these Regulations. However, in the case of a distribution network, samples may be taken within the supply zone or at the treatment works for particular parameters if it can be demonstrated that there would be no adverse change to the measured value of the parameters concerned.

Volume of water distributed or produced each day within a supply zone (Notes 1 and 2) m^3	Check monitoring – number of samples per year (Notes 3, 4 and 5)	Audit monitoring – number Of samples per year (Notes 3 and 5)
≥ 10 ≤ 100	2	Note 6
> 100 ≤ 1000	4	1

> 1000	≤10 000		1 + 1 for each 3 300 m^3/d and part thereof of the total volume
> 10 000	≤100 000	4	3 + 1 for each 10 000 m^3/d and part thereof of the total volume
> 100 000		+ 3 for each 1 000 m^3/d and part thereof of the total volume	10 + 1 for each 25 000 m^3/d and part thereof the total volume

Notes

Note 1 : A supply zone is a geographically defined area within which water intended for human consumption comes from one or more sources and water quality may be considered as being approximately uniform.

Note 2: The volumes are calculated as averages taken over a calendar year. The number of inhabitants in a supply zone may be used instead of the volume of water to determine the minimum frequency, assuming a water consumption of 200 l/day/capita.

Note 3: In the event of intermittent short-term supply the monitoring frequency of water distributed by tankers is to be decided by the sanitary authority concerned.

Note 4: Where the values of the results obtained from samples taken during the preceding two years are constant and are significantly better than the values specified in Part 1 of the Schedule, and no factor is likely to cause deterioration in the quality of the water, the number of samples specified in Table B of Part 2 of the Schedule and the reduction shall not (except in the case of a supply where the volume of water distributed or produced each day within a supply zone does not exceed 100m^3) be more than 50%.

Note 5: As far as possible, the number of samples should be distributed equally in time and location.

Note 6: To be determined by sanitary authority.

PART 3

SPECIFICATIONS FOR THE ANALYSIS OF PARAMETERS

Each laboratory at which samples are analysed must have a system of analytical quality control that is subject from time to time to checking by a person who is not under the control of the laboratory and who is approved by the Agency for that purpose.

Section 1

PARAMETERS FOR WHICH METHODS OF ANALYSIS ARE SPECIFIED

The following principles for methods of microbiological parameters are given either for reference whenever a CEN/ISO method is given or for guidance, pending the possible future adoption, in accordance with the Committee procedure laid down in Article 12 of Council Directive 98/83/EC of further CEN/ISO international methods for these parameters. Sanitary authorities may use alternative methods, providing the provisions of sub-articles 7 (4)(a) and (b) are adhered to.

Coliform bacteria and Escherichia coli (E.coli) (ISO 9308-1)

Enterococci (ISO 7899-2)

Clostridium perfringens (including spores)

Membrane filtration followed by anaerobic incubation of the membrane on m—CP agar (Note 1) at $44 \pm 1\ ^0C$ for 21 ± 3 hours. Count opaque yellow colonies that turn pink or red after exposure to ammonium hydroxide vapours for 20 to 30 seconds.

Notes

Note 1: The composition of m-CP agar is :-

Basal medium		
Tryptose		30 g
Yeast extract	20g	
Sucrose		5 g
L-cysteine hydrochloride		1 g
$MgSO_4.7H_2O$	0.1g	
Bromocresol purple		40 mg
Agar		15 mg
Water		1 000 mg

Dissolve the ingredients of the basal medium, adjust pH to 7.6 and autoclave at 121 ^0C for 15 minutes. Allow the medium to cool and add:

D-cycloserine	400 mg	
Polymyxine-B sulphate		25 mg

Indoxyl-β-D-glucoside to be dissolved in 8 ml sterile water before addition — 60 mg

Filter – sterilised 0.5% phenolphthalein diphosphate solution — 20 ml

Filter – sterilised 4.5 % $FeCl_3 \cdot 6H_20$ — 2 ml

Section 2

PARAMETERS FOR WHICH PERFORMANCE CHARACTERISTICS ARE SPECIFIED

For the following parameters, the specified performance characteristics are that the method of analysis used must, as a minimum, be capable of measuring concentrations equal to the parametric value with a trueness, precision and limit of detection specified. Whatever the sensitivity of the method of analysis used, the result must be expressed using at least the same number of decimals as for the parametric value considered in Tables B and C in Part I of the Schedule.

Parameters	Trueness % of parametric value (Note 1)	Precision % of parametric value (Note 2)	Limit of detection % of parametric value (Note 3)	Conditions	Com-ments
Acrylamide				To be controlled by product specification	
Aluminium	10	10	10		
Ammonium	10	10	10		
Antimony	25	25	25		
Arsenic	10	10	10		
Benzo(a)pyrene	25	25	25		
Benzene	25	25	25		
Boron	10	10	10		
Bromate	25	25	25		
Cadmium	10	10	10		
Chloride	10	10	10		
Chromium	10	10	10		
Conductivity	10	10	10		
Copper	10	10	10		

Cyanide	10	10	10		Note 4
1,2-dichloroethane	25	25	10		
Epichlorohydrin				To be controlled by product specification	
Fluoride	10	10	10		
Iron	10	10	10		
Lead	10	10	10		
Manganese	10	10	10		
Mercury	20	10	20		
Nickel	10	10	10		
Nitrate	10	10	10		
Nitrite	10	10	10		
Oxidisability	25	25	10		Note 5
Pesticides	25	25	25		Note 6
Polycyclic aromatic hydrocarbons	25	25	25		Note 7
Selenium	10	10	10		
Sodium	10	10	10		
Sulphate	10	10	10		
Tetrachloroethene	25	25	10		Note 8
Trichloroethene	25	25	10		Note 8
Trihalomethanes – Total	25	25	10		Note 7
Vinyl chloride				To be controlled by product specification	

For hydrogen ion concentration the specified performance characteristics are that the method of analysis used must be capable of measuring concentrations equal to the parametric value with a trueness of 0.2 pH unit and a precision of 0.2 pH unit.

Notes

Note 1 (*): Trueness is the systematic error and is the difference between the mean value of the large number of repeated measurements and the true value.

Note 2 (*): Precision is the random error and is usually expressed as the standard deviation (within and between batch) of the spread of results about the mean. Acceptable precision is twice the relative standard deviation.

(*) These terms are further defined in ISO 5725.

Note 3: Limit of detection is either:

- three times the relative within batch standard deviation of natural sample containing a low concentration of the parameter, or

- five times the relative within batch standard deviation of a blank sample.

Note 4: The method should determine total cyanide in all forms.

Note 5: Oxidation should be carried out for 10 minutes at 100 ^{0}C under acid conditions using permanganate.

Note 6: The performance characteristics apply to each individual pesticide and will depend on the pesticide concerned. The limit of detection may not be achievable for all pesticides at present, but sanitary authorities should strive to achieve this standard.

Note 7: The performance characteristics apply to the individual substances specified at 25% of the parametric value in Part I of the Schedule.

Note 8: The performance characteristics apply to the individual substances specified at 50% of the parametric value in Part I of the Schedule.

Section 3

PARAMETERS FOR WHICH NO METHOD OF ANALYSIS IS SPECIFIED

Colour
Odour
Taste
Total organic carbon
Turbidity (see note)

Note: For turbidity monitoring in treated surface water the specified performance characteristics are that the method of analysis used must, as a minimum, be capable of measuring concentrations equal to the parametric value with a trueness of 25%, precision of 25% and a 25% limit of detection.

PART 4

Matters to be specified in grant of departure under article 5

1. The grounds for the departure.

2. The parameter concerned, previous relevant monitoring results, and the maximum permissible value under the departure.

3. The geographical area, the quantity of water supplied each day, the population concerned and whether or not any relevant food-production undertaking would be affected.

4. An appropriate monitoring scheme, with an increased monitoring frequency where necessary.

5. A summary of the plan for the necessary remedial action, including a timetable for the work and an estimate of the cost and provisions for reviewing.

6. The required duration of the departure.

Given under the Official Seal of the Minister
for the Environment and Local Government
this 18th day of December, 2000

L.S. NOEL DEMPSEY

Minister for the Environment and Local Government

EXPLANATORY NOTE

(This note is not part of the Instrument and does not purport to be a legal interpretation.)

These Regulations prescribe quality standards to be applied in relation to certain supplies of drinking water, including requirements as to sampling frequency, methods of analysis, the provision of information to consumers and related matters. The

Regulations come into operation on 1 January 2004 and revoke SI No. 81 of 1988. The Regulations give effect to provisions of EU Council Directive 98/83/EC on the quality of water intended for human consumption.

Appendix Three

County Galway

Scheme name/ water supply	Groundwater /surface/ spring
Ahascragh P.S.	Spring Water
Ballinasloe Rwss	Surface Water
Ballyconneely Ps	Surface Water
Ballygar Ps	Groundwater
Ballymoe Ps	Spring Water
Brierfield Ps	Spring Water
Carna Ps	Surface Water
Carraroe Pws	Surface Water
Clarinbridge Pws	Spring Water
Cleggan/Claddaghduff	Surface Water
Clifden Ps	Surface Water
Clonbur Ps	Surface Water
Cornamona Ps	Surface Water
Craughwell	Surface Water
Derryinver P.S.	Surface Water
Derryrush P.S.	Surface Water
Dunmore/Glenamaddy Ps	Spring Water
Eyrecourt Ps	Spring Water
Galway City RWSS	Surface Water
Glenamaddy	Spring Water
Gort	Surface Water
Headford Public Supply	Surface Water
Inisboffin Ps	Surface Water
Inishere P.S.	Groundwater
Inishmore	Spring Water
Kilconell PWS	Spring Water
Kilkerrin/Moylough	Spring Water
Killimor PWS	Surface Water
Kinvara P.S.	Groundwater
Leenane P.S.	Surface Water
Letterfrack P'WS(Dawros)	Surface Water
Loughrea	Surface Water
Mid-Galway	Spring Water
Mountbellew P.S.	Spring Water
Oughterard	Surface Water
Portumna PS	Surface Water
Rosmuc Ps	Surface Water
Roundstone PWS	Surface Water
Spiddal Rwss	Surface Water
Teeranea/Lettermore P.S.	Surface Water

Tuam PS	Surface Water
Tully-Tullycross	Surface Water
Williamstown p.s.	Spring Water
Woodford Ps	Spring Water
Galway City Council Public W.S.S. (old)	Surface Water
Galway City Council Public W.S.S. (new)	Surface Water

County Leitrim

Scheme name/ water supply	Groundwater /surface/ spring
Ballinamore Canal	Surface Water
Carrigallen	Surface Water
Dowra	Surface Water
Dromahair	Surface Water
Drumkeeran	Spring Water
Fivemilebourne	Spring Water
Kiltyclogher	Spring Water
Kinlough/Tullaghan	Spring Water
Manorhamilton	Groundwater
Rossinver	Spring Water
South Leitrim Regional	Surface Water

County Mayo

Scheme name/ water supply	Groundwater /surface/ spring
Achill	Surface Water
Balla	Surface Water
Ballina Lisglennon PWS	Surface Water
Ballina Wherrew	Surface Water
Ballycastle	Spring Water
Belmullet	Surface Water
Bonniconlon	Spring Water
Charlestown	Groundwater
Cong	Surface Water
Crossmolina	Groundwater
Foxford	Surface Water
Kilkelly	Groundwater
Kilmaine	Spring Water
Kiltimagh	Surface Water
Lough Mask - Ballinrobe	Surface Water
Lough Mask - Castlebar	Surface Water
Lough Mask - Claremorris	Surface Water
Lough Mask - Kilbree	Surface Water
Lough Mask -Ballyhaunis	Surface Water
Lough Mask- Barnacarroll	Surface Water
Lough Mask- Tourmakeady	Surface Water
Louisburgh	Surface Water
Mulranny	Surface Water
Newport	Surface Water
Shrule	Surface Water
Swinford	Spring Water
Westport P.W.S	Surface Water

County Sligo

Scheme name/ water supply	Groundwater /surface/ spring
Calry Public Water Supply	Spring Water
Killaraght Water Supply	Surface Water
Kilsellagh (Borough)	Surface Water
Kinsellagh Public Water Supply	Surface Water
Lough Easkey Regional Water Supply	Surface Water
Lough Gill - Cairns Hill (Borough)	Surface Water
Lough Gill - Foxes Den (Borough)	Surface Water
Lough Gill Regional Water Supply	Surface Water
Lough Talt Regional Water Supply	Surface Water
North Sligo Regional Water Supply	Surface Water
Riverstown Public Water Supply	Spring Water
South Sligo Regional Water Supply	Surface Water

County Roscommon

Scheme name/ water supply	Groundwater /surface/ spring
Arigna	Groundwater
Arigna Rover	Groundwater
Ballinlough/Loughglynn	Groundwater
Ballyfarnan	Groundwater
Ballyleague	Spring Water
Bellanagare	Groundwater
Boyle/Ardcarne	Spring Water
Castlerea Regional	Spring Water
Castlerea Urban	Surface Water
Cortober	Surface Water
Grangemore	Surface Water
Keadue	Groundwater
Knockcroghery/Lecarrow	Groundwater
Mount Talbot/Four Roads	Spring Water
North East Regional Water Supply Scheme	Surface Water
North Roscommon Regional Water Supply	Surface Water
Roscommon Central Water Supply Scheme	Mixture
South Roscommon Regional water Supply	Spring Water

Appendix Four

The Control of Disinfection By- Products in Water Treatment Plants and Distribution Systems

Name of Local Authority ______________________

Name of raw water supply used for the public scheme

____

In relation to the public water supply please answer the following questions using the tick boxes or the space provided. Thank you for your help.

1. **Which of the following unit processes are employed at the water treatment plant?**
   - ☐ Microstraining
   - ☐ Pre-ozonation
   - ☐ Coagulation/flocculation
   - ☐ Disinfection
   - ☐ Sedimentation/flotation
   - ☐ Fluoridation
   - ☐ Filtration
   - ☐ pH correction

2. **What is the principle method of disinfection used?**
   - ☐ Chlorination
   - ☐ Ozonation
   - ☐ Other, please specify ______________

3. **If chlorination is carried out during treatment, which of the following substances is used:**
   - ☐ Chlorine
   - ☐ Chloramines
   - ☐ Chlorine dioxide
   - ☐ Products releasing chlorine e.g. chloride of lime, hypochlorite solution or chlorine tablets

4. **Are any of the following methods used to control algae at water treatment plants?**
   - ☐ Micro strainers
   - ☐ Use of potassium Permanganate
   - ☐ Pre-ozonation

5. **Is the analysis of the raw water undertaken for Total Organic Carbon carried out:**

☐ Daily ☐ Weekly

☐ Monthly ☐ Never

☐ Other, please specify: ____________

6. **Is the analysis of the raw water undertaken for Bromide is carried out:**

☐ Daily ☐ Weekly

☐ Monthly ☐ Never

☐ Other

7. **What is the method employed for the cleaning of drinking water mains?**

☐ Flushing ☐ Swabbing ☐ Air scouring

8. **In relation to the frequency of cleaning of distribution lines, which of the following applies:**

☐ Weekly ☐ Monthly

☐ Bi-monthly ☐ Never

☐ Other, please specify _________________________

9. **In relation to an action plan for the protection of drinking water, if such a plan is in place, Do any of the part of the action plan deal specifically with:**

☐ Removal of algae ☐ Cleaning of reservoirs

☐ Source water protection

Please feel free to make any further relevant comments:

____

____

____

____

If you have any further comments/queries I can be contacted on 087-9921506. Please return the questionnaire to me at the following address:
Kristina Lundy,
Rhue,
Tubbercurry,
County Sligo.