2009-9

Chemical-free Iron Removal and Disinfection Unit of Drinking Water for Single House Application

Michael O'Hehir
Technological University Dublin, Michael.Ohehir@tudublin.ie

Recommended Citation

O'Hehir, M. (2009). *Chemical-free Iron Removal and Disinfection Unit of Drinking Water for Single House Application*. Masters dissertation. Technological University Dublin. doi:10.21427/D7M918

CHEMICAL-FREE IRON REMOVAL AND DISINFECTION UNIT OF DRINKING WATER FOR SINGLE HOUSE APPLICATION.

Michael O'Hehir.

This thesis is presented for the award of MPhil.

Dublin Institute of Technology.

September 2009.

Abstract.

Drinking Water Treatment System for Domestic Applications

Abstract
The supply of safe drinking water is a major worldwide problem. In the developed world the frequency of water related problems are increasing The shortage of fresh water supply is as a result of pollution from industrial, agricultural and natural disasters. To make water suitable for human consumption, it must first be treated. However, consumers do not always receive potable water even after public treatment. In some cases the consumer must treat the water being supplied to them, or have to source their own water from private wells and treat it prior to use.

The purpose of this research was to develop a water treatment unit, that may be used for re-treating "mains" supplied water or water abstracted from private wells. In the case of re–treating water, the unit re–disinfects the water. This ensures that all pathogenic bacteria has been neutralised. In the case of treating well water, the main focus of this work is the removal of dissolved iron, followed by disinfection. The main application for this unit is mainly for single house operation under following parameters,

- That the treatment is carried out without the use of chemicals
- It is simple to maintain
- It can be constructed from readily available components
- It is inexpensive to build and operate
- It is small and compact

Prior to designing and building the prototype test unit samples of ferruginous and bacteriologically contaminated water were first sourced. These samples were aerated to oxidise the dissolved iron out of solution to form solid particles, which could then be filtered out. Testing of various types of granular filter media was then carried out to ascertain their suitability, these tests were carried out in different filter body configurations in order to quantify flow rates of the water. This information was then used as a tool to aid the design of suitable filter units. Typically these samples were used directly from the source, in the case of ferruginous contamination. Samples of The bacteriologically contaminated water were taken from the source, some were processed through the treatment system, while the remainder were left untreated. The samples were delivered to the testing laboratories, as "before and after treatment" within the specified time limit, generally delivered within 3-4 hours.

Activated carbon filters were also used to remove the taste and odour associated with ferruginous water. The final stage of the treatment was disinfection, carried out by the use of ultraviolet radiation.

Based on results obtained for various treatments undertaken, the water treatment unit developed for this research has proven to be a satisfactory method of producing potable water for domestic drinking and use.

While the design of this unit concentrates on single dwelling application, it is possible that the unit could be expanded to treat small groups of dwellings.

Declaration.

I certify that this thesis which I now submit for examination for the award of MPhil, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for an award in any other Institute or University.

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Signature Michael O'Helion Date 15/Sept '09.

Candidate

Acknowledgements.

I would sincerely like to thank my supervisors Dr, David Kennedy, and Dr, Thomas Dunphy, for their continued guidance and encouragement throughout the course of this research. To Dr Ray Ekins internal reader, I would also like to express my gratitude to the Dublin Institute of Technology, for the opportunity and facilities to complete this work.

I would like to make very special reference to Mr John Lawlor without whom, this project would not at all have been possible. I would also like to thank Dr Niall Murphy for his much valued comments.

I would like to thank my friends and colleagues, in the Department of Applied Technology and Design, throughout the campus, and the library staff for their support.

Finally I would like to express my sincerest thanks to my wife Patricia and daughter Eimear, for their continued patience and support.

Glossary of Abbreviations.

Alum	Aluminium Sulphate
$Al (Oh)_3$	Aluminium Hydroxide
BOD	Biological Oxygen Demand
C Parvum	Cryptosporidium Parvum.
Cl	Chlorine.
CO_2	Carbon Dioxide
DBPs	Disinfection By Products
DE	Diatomaceous Earth
DNA	Deoxyribonucleic Acid)
DRL	Defence Research Laboratory
E Coli	Escherichia Coli
Fe	Iron
$Fe(Oh)_3$	Ferrous Hydroxide
GAC	Granular Activated Carbon
GSI	Geological Survey Of Ireland
H_2Sif_6	Fuorosilicic Acid
Hcl	Hydrochloric Acid
HOCl	Hypochlorous Acid
Hse	Health Service Executive
Iru	Iron Removal Unit
L/D	Litres/ Day.
L/H/D	Litres / Head / Day.
Mf	Membrane Filter
µG/L	Micro Gram Per Litre.
Mg/L	Milli Grams Per Litre
MnO_2	Manganese Dioxide
MPN	Multipore Nutrient Test
MRC	Minimum Required Concentrations
MT	Multiple-Tube
Na_2Sif_6	Sodium Silicofluoride
Na Fl	Sodium Fluoride

NDP	National Development Plan
nm	Nano Metres
Nrv	Non-Return Valve
NSF.	National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
OCl	Hypochlorite Ion
PAC	Powdered Activated Carbon
PLC	Programmable Logical Controller
POU	Point Of Use
PPM.	Parts Per Million.
PVC	Poly Vinyl Chloride
RO	Reverse Osmosis
Ssf	Slow Sand Filter
SWOT	Strengths, Weaknesses, Opportunities And Threats)
Thm^{s}	Trihalomethanes
UC	Uniformity Coefficient
USEPA	U.S. Environmental Protection Agency
Uv	Ultra Violet
Voc^{s}	Volatile Organic Chemicals
WHO	World Health Organization
(Ca(Hco$_3$)$_2$)	Calcium Bicarbonate
(CaCo$_3$)	Calcium Carbonate
(EPA)	Environmental Protection Agency
(GWS)^{S}	Private Group Water Schemes.
(GWSs)	Public Ground Water Supplies.
H$_2$Co$_3$	Carbonic Acid
(IRP)^{S}	Iron Removal Plants
(MAC)	Maximum Allowable Concentration
(Mn)	Manganese

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CHAPTER 1.

INTRODUCTION

1.1 The Value of Water

Water fit for human consumption was at one time considered to be a freely available commodity, which would never be in short supply. The result of this way of thinking led to overuse, waste, and abuse of water supplies. This is clearly demonstrated by our standards of living in the modern world. According to The World Health Organization more than three million people die each year as a result of water related diseases, making it the leading cause of sickness and death in the world, greater than war, terrorism and weapons of mass destruction combined [1]. Most of the victims are children. Water sources contaminated by raw sewage account for the majority of the fatalities. In Ethiopia, one in five children die before they reach the age of five due to water related diseases [1].

The contamination of water can take many forms. These include Microorganisms, metals, and pesticides. Turbid or cloudy water may also be classified as contaminated since the solid particles responsible for the turbidity form sites to which viruses may become absorbed. Naturally occurring and synthetic chemical compounds may occasionally be present in drinking water. Such water has the greatest affect on children, older people, pregnant women, and people whose immune systems have been compromised. The use of any contaminated drinking water can result in infection or other ill health. An example of illness caused by dissolved metals in water is aggravation of a medical condition known as hemochromatosis, (iron overload disease caused by excessive iron in the body). Hemochromatosis is a hereditary condition, which is exacerbated in susceptible people by dissolved iron in drinking water [2, 3].

The presence of Manganese (Mn) in groundwater is always associated with ferruginous water. The effect of Mn in water is primarily staining of washing [3].

Many sanitary authorities and Government agencies have highlighted illegal dumping and quarrying in Ireland as causes of water contamination [4].

Water is contaminated in three primary ways [5].

(i) Natural pollutants
(ii) Waste run off.
(iii) Pathogenic contamination.

Natural pollutants are added to water as it passes through the ground where it dissolves and leaches elements and metals out of the soil. These pollutants include iron, manganese, arsenic, aluminium, salts and fluoride. Pollution from waste run-off can be as a result of by-products of human activities i.e. industry, farming and dumping. Pathogenic contamination can take many forms. Such pathogens can be protozoan, parasitic, bacterial and viral [6].

Climate change can also be a contributory factor in water pollution. Dr Jeremy Hess from the centre for disease control and prevention (CDC) explored the possibilities of storm intensity and the quality of water. He points out the high correlation between outbreaks of diseases and storm intensities. This is the result of studies carried out in the US for the period 1948 to 1994, and 1975 – 2001 in Canada. He also made the point that there could be increases in water borne pathogens depending on their sensitivity to warmer temperatures [7]. Examples of these pathogenic infections are listed in Table 1.1 [8].

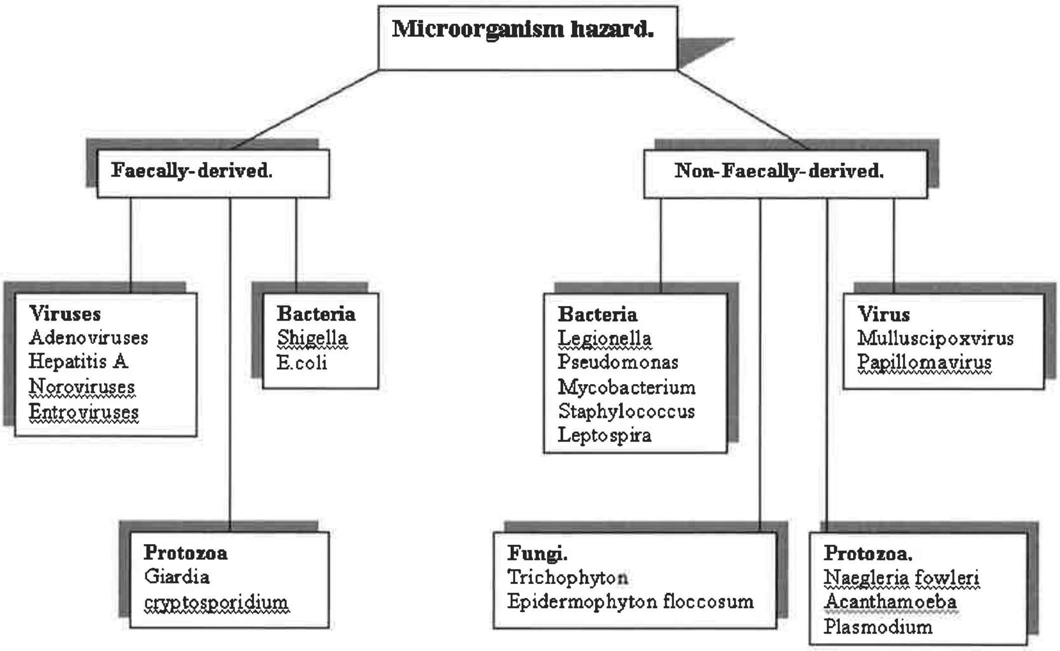


Table 1.1. Pathogenic Infections.

Approximately 0.8% of the earth's water is available as drinking water [9]. This water is ground water or surface water. The amount of fresh drinking water available is on the decline as industrialised and developing countries are polluting more of this water [9]. In their efforts to provide wholesome drinking water for the ever-increasing populations, many solutions have been proposed and include the following.

(i) Greater numbers and capacities of their water treatment systems.

(ii) Increased chemical treatment [10].

(iii) Alternative methods of sourcing water (sea water desalination).

1.2 Water Supply and Quality in Ireland.

Water in Ireland, is supplied to the public by,

• Local authorities.	81.8%
• Public group schemes.	3.2%
• Private group schemes.	6.0%
• Small private supplies.	0.3%
• Exempted supplies.	8.7%.

Exempted supplies are those taken from private sources, serving less than 50 persons, or supplying less than $10m^3$ per day. This exemption applies to water that has no impact on the health of its consumers [11]. These supplies use surface water, i.e. water in rivers and lakes which account for 82% of drinking water. The other sources of supply are groundwater 12% and springs 6%. The overall rate of compliance with the Environmental Protection Agency (EPA) standards for drinking water in 2004 was 96.4% (up slightly from 96.1% in 2003). The quality of drinking water provided to 84% of the population by the sanitary authorities in public water supplies and public ground water supplies. (GWSs) was satisfactory, the quality of drinking water provided to less than 7% of the population by private group water schemes, (GWS)^{s} was unsatisfactory. Figure 1.1. shows the number of private group water schemes contaminated with E.coli during 2006. This map highlights the poor quality of water supplied by (GWS)^{s} .Galway has 68 and Mayo has 52 compared to a national average of 4.8 for the rest of the country. Another striking contrast is the quality of the water between the Tipperary north and south regions [11].

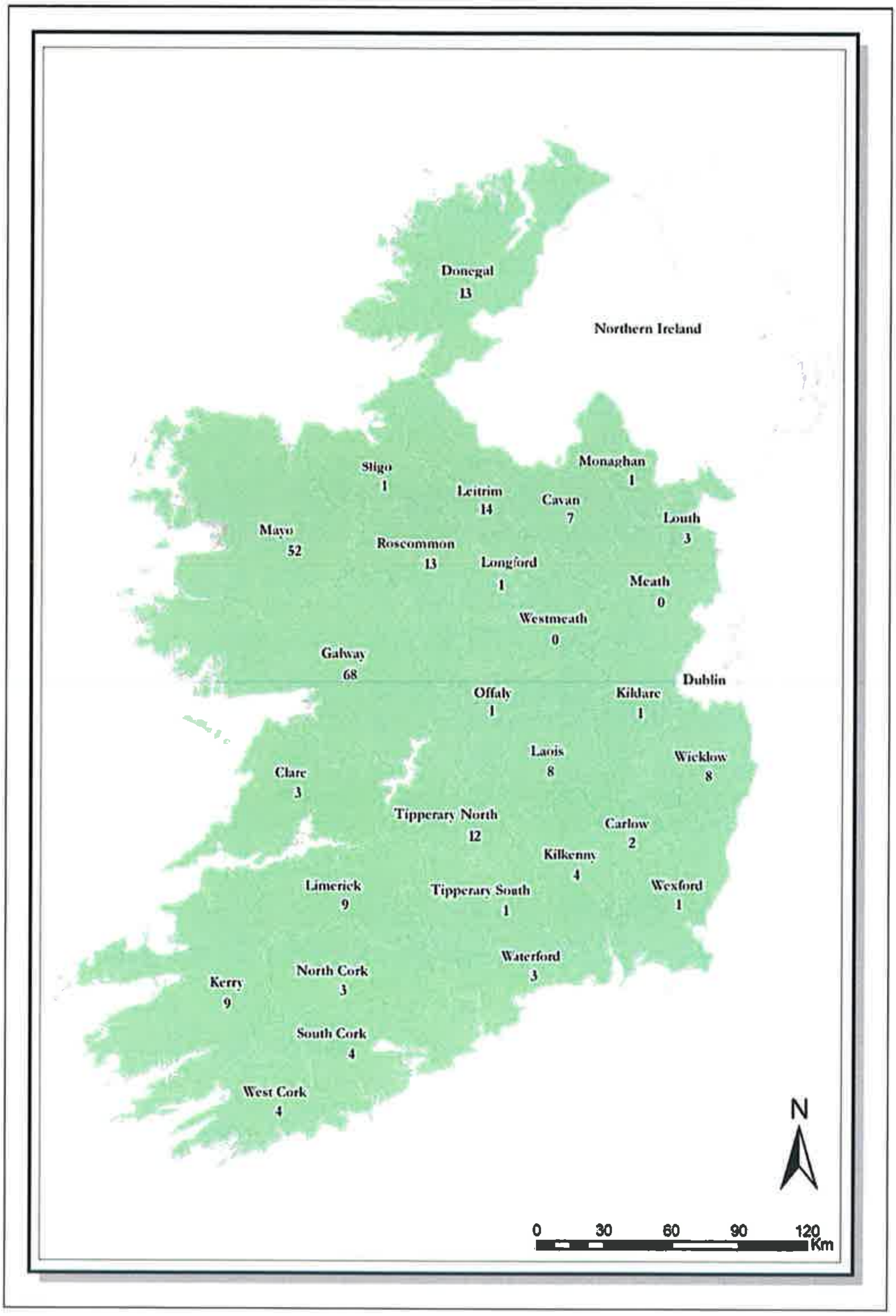


Figure 1.1 The Number of Private Group Water Schemes Contaminated with E.Coli During 2006.

1.3 Current Trends in Drinking Water Treatment.

At present the normal treatment for potable water carried out by local authorities and group water schemes is to disinfect the water with chlorine and add a coagulation agent aluminium sulphate (alum) to assist filtration. Finally, before distribution fluoride is added to protect the public's teeth. These chemicals can have an adverse effect on consumers.

- Chlorine is associated with the formation of trihalomethanes (THM)s These by-products are known to be carcinogenic [12].
- Fluoride, which is used to stop dental decay, has been shown to actually damage teeth (dental fluorosis) [12,13].

Despite chlorination of the water supplies, other microorganisms such as cryptosporidium can be passed on to the consumer. This is an infection of the protozoa class that has the same ill- health effects as E.Coli but is resistant to chlorine. This was evident in the case of the cryptosporidium outbreak in Galway in March 2007. The water was tested 500 times in 2006, and was found to be 99.1% compliant with the then EPA regulations. This figure was above the national average of compliance [14]. However, the water was not tested for cryptosporidium. This resulted in cryptosporidium being present in water that was otherwise thought to be safe. As a result of this problem the Health Service Executive (HSE) reported 242 cases of Cryptosporidiosis and this situation led to "Boil water" notices being sent out to consumers. These notices were not lifted until September 2007. Table 1.2. shows the total number of "Boil water" notices placed on water supplied for the period May – September 2007 [14]. The EPA have now put in place a risk screening methodology for cryptosporidium [15].

According to an EPA report published in the Irish independent Friday October 12 2007 [16] "one household in five is supplied with drinking water from polluted sources". A copy of the report is contained in Appendix A. From the recent outbreaks of water contamination in Ireland people are turning to alternative methods of ensuring the water they are drinking is safe. Such measures include using bottled water, or installing some type of small water treatment unit. The most common type of treatment unit is a reverse osmosis (RO) system, however these measures have their disadvantages. In the case of bottled water, apart from it being an expensive alternative recent research conducted in 2008 by Olga Naidenko et al [17]. has shown that in some cases bottled water contains the same contaminants as tap water. In July 2008 "pure spring water" was withdrawn from distribution. This was due to faecal contamination, the products affected were bottled water and water for use in office water coolers. This was a category 1 alert issued by the Food Safety Authority of Ireland (FSAI). The action taken in this instance was that the FSAI requested Environmental Health Officers (EHO's), to contact premises and retailers known to be in possession of this water and return it to the producers [18]. A further recall of bottled water was issued on December 15th 2008, in this case faecal contamination was found to be in the water. The order to remove the product from retailer's shelves came from the FSAI. The same producers were at the center of a product recall in January of this year. Following laboratory tests carried out on samples of water produced by the same company on the 27th of November 2008, the water was found to be contaminated by coliforms and pseudomonas bacteria. Pseudomonas are considered to be opportunistic and can be fatal.

In the case of reverse osmosis (RO) treatment, almost pure water is produced by pumping the water through a semi-permeable membrane. This treatment removes almost everything from the water including minerals beneficial to health [19]

Local Authority	***Name of Water Supply.***	***Reason.***	***Population Affected.***	***Date.***
Cork.	Adrigole.	E.coli.	200.	Aug-07.
Cork.	Dromore.	E.coli.	50.	Jul-07.
Fingal.	Leixlip.	E.coli.	500.	Aug-07.
Galway city.	Galway city supply.	Cryptosporidium.	90,000.	Mar-07.
Galway.	Headford.	Cryptosporidium.		Mar-07.
Galway.	Luimneagh	Cryptosporidium.		Mar-07.
Galway.	Mid Galway.	E.coli.	2,083.	Jul-07.
Kerry.	Glenbeigh.	Coliforms.	750.	Aug-07.
Laois.	luggacurran	Coliforms.	20.	May-07.
Laois.	Modubeigh.	Coliforms.	30.	Apr-07
Limerick.	Ballingarry.	Nitrates.	562.	Mar-07.
Mayo.	Swinford.	E.coli.	2000.	Sept-07.
Mayo.	Lough mask.	E.coli.	700.	Sept-07.
Mayo.	Cong.	Cryptosporidium.	500.	Mar-07.
Meath.	Ballivor	E.coli.	1,280.	Aug-07.
Sligo.	North Sligo	E.coli.	N/A	Jul-07.
South Tipperary.	Clonmel.	Cryptosporidium.	11,500.	Jul-07.
Waterford.	Ballinacorty	Turbidity.	1,500.	Jun-07.
Wicklow	Avoca	E.coli.	1,349.	Mar + Jul –07.
Wicklow.	Templecarrig.	E.coli.	300.	Jun-07.

Table 1.2. Total Number of "Boil" Notices Placed on Water Supplied for the Period May – September 2007 [14].

The table above shows that both E.Coli and cryptosporidium are the major contaminants in the drinking water system in Ireland. Cryptosporidium was also responsible for 100 fatalities and numerous cases of illnesses in Milwaukee in 1993 [20]. Another example of contamination was in the case of the water supply in Swords Co Dublin [21]. The source of the contamination was not readily identifiable, however three possibilities were considered.

(i). The main supply line was damaged, allowing contaminants to leach in.

(ii). A consumer allowed their supply to become contaminated, which had migrated back into the main pipe.

(iii). A fire hydrant was breached, thereby allowing the possible ingress of polluted surface water [21]

Water experts in America agree that the most vulnerable part of a domestic water supply is the distribution system. Furthermore they agree that the most accessible point in the system is fire hydrants. To protect water distribution systems from terrorist attacks, both biological and chemical, a stealth valve which was invented in the 1970s is being retrofitted to fire hydrants to prevent the ingress of contaminants to the system via the hydrant outlet [22].

One of the most recent outbreaks of cryptosporidium in drinking water was reported in the area serviced by the Anglian water supply board Northamptonshire England. In this outbreak 250,000 people were affected and served with “boil water” notices, while fifteen schools had to close due to lack of drinking water [23]. Details of the cryptosporidium pathogen are shown in Appendix B [24]. The outbreak of E- Coli in Galway (a major tourist resort in the west of Ireland) [11] has been attributed to a fracture of the supply pipe by excavation works. From the above information, it is highly likely that a significant number of people are being supplied with drinking water which is unfit for human consumption. It has been suggested that a portion of the drinking water in Ireland is unsafe, despite improvements, and is a real threat to the public health [25].

In December 2005, the Minister for the Environment outlined the measures being taken to upgrade the drinking water quality in Ireland. These are as follows

(i). A €3.7 billion National Development Plan (NDP) investment in water services infrastructure up to the end of 2006.

(ii). The publication of a new Water Services Investment Programme 2005 – 2007.

(iii). Substantially increased investment in resolving GWS non-compliance with bacteriological standards.

(iv). Anticipated expenditure of €125 million in 2005, up 45% on 2004 expenditure of €86 million [26].

There is a need for a system that will treat groundwater as well as water supplied by the municipal authorities. Such a system should,

(i) Assure the consumer that their water is safe to use.
(ii) Be inexpensive to install.
(iii) Be inexpensive to run.
(iv) Be simple to maintain.

The purpose of this research is to explore the possibilities of designing and manufacturing such a system. The main emphasis however is to produce a system capable of removing dissolved iron and manganese from groundwater and to neutralise any infectious pathogens.

1.4 Aims and Objectives of this Research.

The main aim of this research is to produce potable drinking water via a small domestic water treatment unit, which can be used to treat a private groundwater supply, group scheme water or municipal supply water, without the use of chemical treatments.

The main objectives are to:

(i) Design and manufacture a small domestic scale water treatment unit.

(ii) Oxidise and remove dissolved iron and manganese from the subject water.

(iii) Remove the odour associated with ferruginous water.

(iv) Disinfect the water that has been filtered.

This study focused on the production of quality drinking water by removing dissolved iron and manganese from ground water. The design and construction of a small treatment unit was necessary to realise this. One further objective was to evaluate the performance of various filter media to determine a suitable filter to produce the desired quantity of filtrate. The filter design also covers the removal of tastes and odours using charcoal filters. An important feature of the design is to treat ground water without the use of chemicals, and to make it more accessible to single dwellings in rural areas. The subject water of this study is ferruginous water, water that is primarily contaminated with dissolved iron. The focus of the filtration and disinfection process was to remove two main contaminants in water. These contaminants are:

(i) Dissolved iron and manganese.

(ii) Pathogenic bacteria, e.g. E Coli.

Some of the main problems associated with iron in water are:

(i) It forms solid rust particles in the water when oxidised thus turning it a brown colour and making it aesthetically unpleasant.

(ii) It can cause an unpleasant taste in the water.

(iii) When the iron precipitates out of solution it can clog up valves, small bores, pipes and other water accessories.

(iv) The "brown water" is ineffective for washing.

(v) The iron can give rise to "iron bacteria". (Iron bacteria; organisms that prey on iron compounds, for example frenothrix, gallionella, leptothrix).

The effects of iron in water can be clearly seen in Figures1.2 and 1.3 the bacteria give the water a bad taste and odour, but are not harmful. Figure 1.2. shows the accumulation of precipitated iron in an attic storage tank, over a six year period. The black substance seen floating indicates the presence of iron bacteria Figure1.3. Shows a toilet cistern with excess iron in the water. A build up of precipitated iron (Fe) in the ballcock valve restricts the visible flow of water.

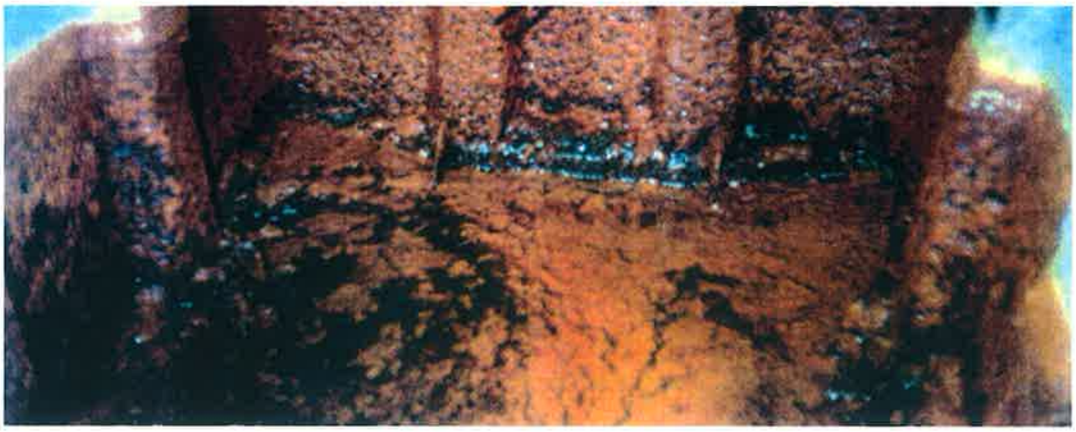


Figure 1.2. Accumulation of Precipitated Iron in an Attic Storage Tank

Figure 1.3. Toilet Cistern with Excess Iron in the Water.

1.5 Methodology.

The research work was conducted using both a theoretical and experimental approach.

The theoretical approach as shown in Figure 1.4. The method of this approach was based on;

(i) Literature review and research conducted by others,

(ii) Study of the effects of iron, manganese and other water hazards/diseases,

(iii) Evaluation of the nature and the scale of the problems associated with dissolved iron in water, and how best these problems may be solved,

(iv) A conceptual design of a system,

(v) A literary review of relevant aspects of water treatment associated with ground water,

(vi) Design a working model of the proposed water treatment unit, The experimental approach involved:

(i) The random sampling of a number of water sources and establishing which sources have either iron or bacteriological contamination, or both.

(ii) The testing of water to measure the success of removing the iron, manganese and pathogenic bacteria.

(iii) Manufacture of the treatment unit which incorporates the following,

    (a) Aeration tank.
    (b) Sedimentation tank.
    (c) Clean water tank.
    (d) Micro pore filter.
    (e) Carbon filter.
    (f) Ultraviolet disinfecting unit.

(iv) The treated water was tested and the results of the experimental stage of this project were compared with the anticipated results from the theoretical stage.

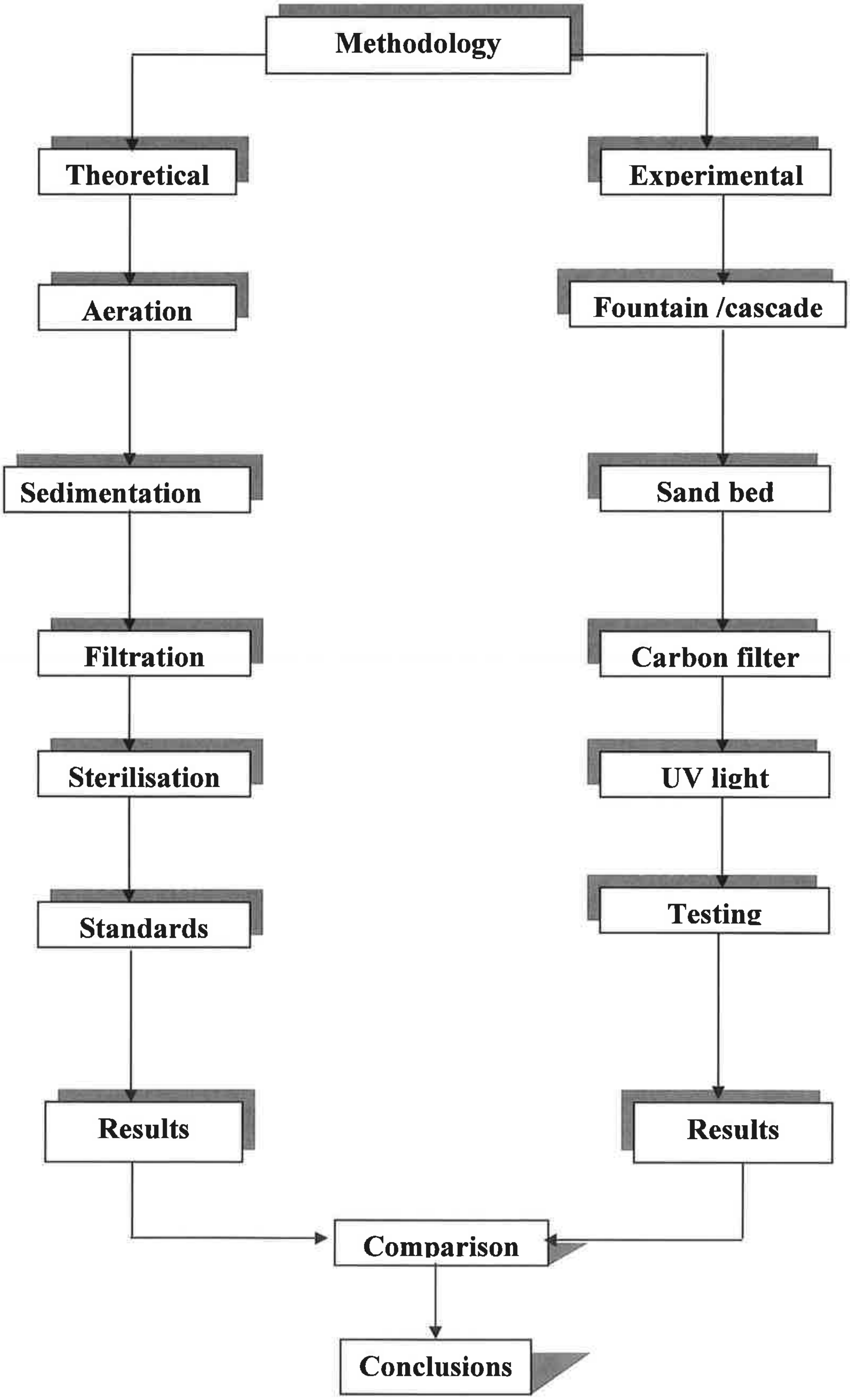


Figure 1.4. Methodology.

1.6 Thesis Outline.

The following section outlines the main topics dealt with in subsequent chapters.

Chapter 2

Background.

This chapter is a study of water sources, i.e. hydrology, groundwater and surface water, including the commonly found contaminants in the drinking water. This study will also explore the associated illnesses and the methods used to treat the contamination. The distribution systems and the implications associated with the treatment methods used to produce potable water.

Chapter 3.

Design of the System.

This chapter is concerned with the issues to be considered in the design of the system and is subdivided in the following sections.

(i) Aeration.

Different aeration methods will be tested so as to effectively oxidise dissolved iron out of the water.

(ii). Various filter materials will be tested for uniformity of the materials, porosity, grading and effectiveness in retaining solid particles,

(iii). Filter tests.

When suitable filtering materials have been chosen filters can be manufactured in various sizes and tested for flow rates. Filters with single and dual stratified media will also be manufactured and tested for their filtering capacity and their ability to be regenerated by backwashing.

(iv). Construction details.

In this section, details on the construction and installation of the equipment used including, filters, aeration tanks, UV unit will be examined.

Chapter 4.

Treatment System Development.

This chapter outlines the actual design and manufacture of the water treatment unit. The areas covered will include: The Physical layout of the system and overall required size of the treatment unit to accommodate the various components being used. The Construction materials, components and the manufacturing methods used will then lead on to the final design, which will include, details of the working model, working drawings and images.

Chapter 5.

Testing and results.

In this chapter the unit and its performance will be tested and the results of the system, will be based on the level of pollutants in water samples taken. Evaluation of the suitability of the water for human consumption, before treatment. After being processed the water will be tested for compliance with set standards for human consumption.

Chapter 6

Findings and conclusions.

At this stage the quality of the treated water will be checked against the stated system objectives. Opportunities for further development of the unit will be discussed.

CHAPTER 2.

Water Sources.

2.1 Introduction.

Water accounts for two thirds of the earth's surface, and the human body consists of 75 % water. It is therefore one of the prime elements responsible for life on earth. The average adult human body contains 42 litres of water and with a loss of just 2.7 litres it can suffer from dehydration, giving symptoms of irritability, fatigue, nervousness, dizziness, weakness, and headaches. If the condition is left to develop the body can reach a state of pathology. During the average day the human body may lose between 2-3 litres of water, caused by perspiration, urination and respiration. Consumption of beverages such as, tea, coffee and alcohol which are diuretics cause further dehydration The most efficient way of replenishing the lost water is to drink wholesome water. This is water that has beneficial minerals and is healthy to drink [25].

2.2 Demand for Water.

The main demands on water supplies can be classified as.

(i) Domestic.
(ii) Agriculture.
(iii) Industrial.
(iv) Public.
(v) Losses / waste.

2.2.1 Domestic.

Domestic water demand is the water required for drinking, cooking, ablution, sanitation, house cleaning and laundry. The daily water demand for a family home is averaged as the quantity of water per head per day [27].

From trial metering observations on domestic dwellings, consumer demands average out at 225 litres / head / day. (l/h/d). Washing machines, dish washers etc, each count as one person for consumption needs. Drinking water accounts for approximately 1 l/h/d of the above figure, demands for water are catered for by two types of supply, namely municipal and non-municipal supplies [27].

2.2.2 Municipal Supplies and Non-Municipal Supplies.

Municipal water supplies are basically those which large villages, towns and cities depend upon. Public uses include public parks, sewer flushing and fire fighting. It is generally surface water that has been treated, and then distributed to the various consumers through a pipe network. Non-municipal supplies include private supplies and group water schemes.

2.2.3 Agriculture.

This is water that is used for crops, livestock, dairies, horticulture and greenhouses.

These demands can be categorised as follows:

(vi) Cattle 150 l/d drinking and washing

(vii) Land 571 l /d per hectare

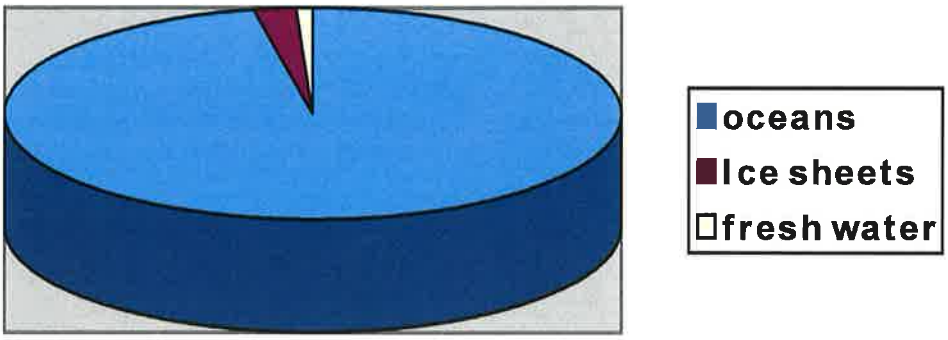
(viii) Depending on their size, glasshouses use between 12.5m^3 / d to 36 m^3/ d (summer) [27].

2.2.4 Industrial.

Industrial consumption includes factories, shops, offices, restaurants, and public buildings etc. The average demand for water in these cases is 100 – 150 l/h/d Institutional uses are schools, colleges, hospitals etc [27].

2.3 Availability of Water.

From Figure 2.1 it can be seen how little of the world's water is available as drinking water [9]. The majority of the 0.85% fresh drinking water is held under ground as ground water. Only a very small percentage of this water forms rivers and lakes.



PERCENTAGE	TYPE OF WATER
97	OCEANS
2.15	ICE SHEETS.
0.85	DRINKING.

Figure 2.1. Availability of Water [9].

2.3.1 Water Sources.

Water for human use is obtained from two main sources, classified as surface water and groundwater. Rivers, lakes, and reservoirs contribute to surface water supplies. The other main source of water, groundwater is sourced from beneath the ground,

2.3.2 Surface and Ground Water.

When rain falls to the ground, some of the water flows down hills to form lakes and rivers. This type of water is used by municipal bodies for supply for public consumption. Water that does not form rivers or lakes as surface water, percolates (soaks) through the ground and is soaked up by porous subsoil to form aquifers [28]. These are accessed by boreholes to yield ground water, mainly to private dwellings, These boreholes are referred to as wells.

2.3.3 Aquifers.

An aquifer may be defined as any stratum or combination of strata that stores or transmits groundwater [9]. The subject water for this study is drawn from the aquifer of "The Eastern Water Resource Region"[GSI]. This area is approximately 7,700km^2 extends from Northern Ireland, southwards to Wicklow and westerly to Westmeath. The area includes the counties, Louth, Meath, Dublin large parts of Wicklow, Kildare, Westmeath and to a lesser degree parts of Offaly, Cavan and Monaghan [GSI groundwater resources of the republic of Ireland section v]. The quality of the water from aquifers must be monitored at regular intervals. The Geological Survey of Ireland EPA [9]. carries out this operation through a large number of monitoring stations around the country. Since aquifers differ greatly so too does the quality of the water they yield. This aspect is dealt with in movement of groundwater in section 2.8.

2.4 The Hydrological Cycle

The supply of ground or surface water is totally dependent on the hydrological cycle. The hydrological cycle [28,5]. occurs when water from the earth's surface evaporates and returns to earth in the form of rain, snow and hail. Water is located in all regions of the Earth but water resources vary widely. The supply is dependent on topographic and meteorological conditions since these influence precipitation and evapotranspiration. In Ireland, the greatest amount of annual rainfall is experienced along the west coast while the greatest population density is along the east coast. A better understanding of the cycle of water can be obtained from the diagram of the hydrological cycle shown in Figure 2.2.

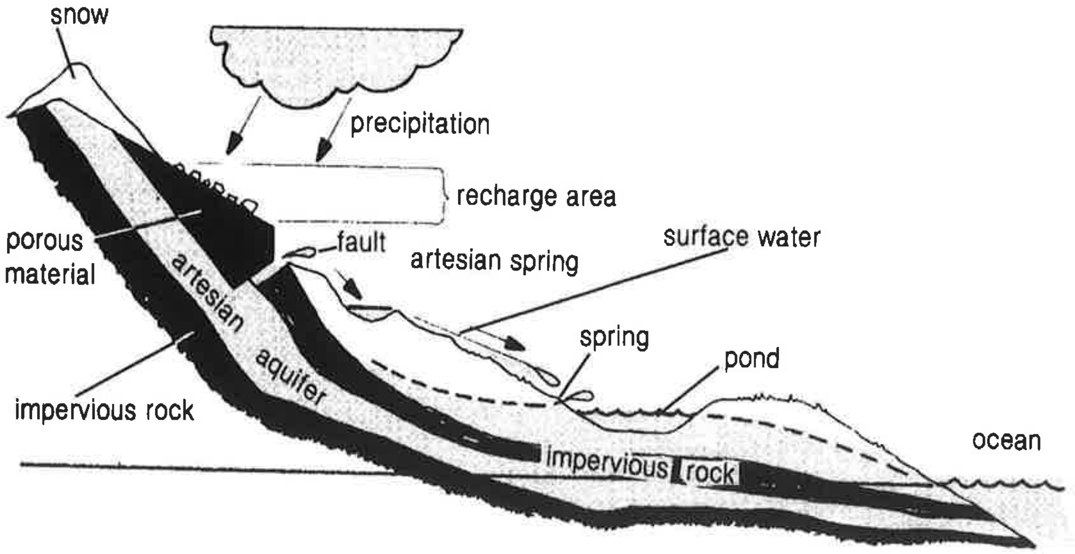


Figure 2.2. The Hydrological Cycle [28].

As seen in Figure 2.2, all fresh water on the earth's surface falls as snow, hail, rain, or mists, that has been previously evaporated from the oceans and carried over the land by winds and air currents. It drains into streams, rivers, and underground streams and eventually back into the oceans from where it came. In order to ensure that drinking water is of good quality, the EPA (Environmental Protection Agency), have introduced a set of directives w.e.f 1 / 1/ 04, set out by the European Communities (Quality of Water Intended for Human Consumption) [80/778/EEC]. These directives are set out in Appendix C [11]. The EPA operates numerous groundwater-monitoring stations around the country, thereby monitoring any changes in the water quality, which may occur. A map showing the locations of these stations is shown in Appendix "D". These monitoring stations check many parameters of water contamination including, iron and manganese.

2.5 Ground Water Usage in Ireland.

There are no exact figures for the ground water usage in Ireland, due to the fact that the abstraction of ground water is not a licensed activity [9]. If the drilling / boring of wells were to be licensed then indiscriminate sinking of wells could be avoided, and permitted by the authorities only in areas known to be capable of yielding good quantities of quality water. It is estimated however, as may be seen from the Table in Appendix "E" that the usage is 23%, but since the table does not include supplies less than 5m^3 /day. The true figure is closer to 25% [9]. Such indiscriminate sinking of wells is a cause of major concern in Vietnam. The article by Ngoc Tu of the Vietnam news 30th May 2008, points out that citizens and businesses are drilling illegal wells in an effort to reduce costs. The department of geology and minerals estimates that there are 20,000 such wells in the city of Hanoi. These wells pose a danger of pollution to the underground water supplies since some of them are sited close to sources of pollution, and act as conduits to the underground supplies [29].

2.5.1 Losses /Wastage.

A significant amount of surface water is lost by evaporation or by the uptake of water by growing vegetation. Wastage includes consumer wastage, leakage, overuse, and misuse by the consumer. There are also distribution losses, leaks in pipes, valves, hydrants and overflows from service reservoirs. The total losses accounts for 25% of the water produced [27]. This wastage of treated surface water highlights the need for some alternative source of water. The solution to this problem could be further exploitation of ground water resources.

2.5.2 Future Production of Potable Water.

Future production of water is dependent on several factors, these include [27]. Natural increase of population.

(i) Migration into or out of an area.
(ii) Improvement in housing and standard of living.
(iii) Increased installation of water consuming apparatus in homes.

The above points highlight the fact that the demands for supplies of good quality water are ever increasing. This increase in demand requires extra production of water, which may be offset to some extent by rural householders sourcing and treating their own water.

2.6 Contamination of Drinking Water.

The pollution of drinking water is a mixture of hazardous commercial chemicals, and bacteria, viruses and inorganic minerals. Such water is unsuitable for human consumption. Archer [10]. refers to an estimate of 60,000 tonnes of fifty different chemicals being deliberately added annually to Australia's water.

2.6.1 Natural Contaminants.

As shown in Figure 2.2, water, which starts as rain, can become contaminated as it falls through the atmosphere, gathering minute pollutants from the contaminated air, especially in industrialized regions (acid rain). When it makes contact with the ground and percolates through the ground to replenish the aquifers, (water bearing rocks) it leaches out contaminants from the ground. As the surface water run-off forms rivers and lakes, these bodies of water are open to pollution, especially due to by-products of farming, such as, leachate of fertilizers nitrates, slurry pits and silage making activities [9,30]. The more common water contaminants are shown in Figure 2.3.

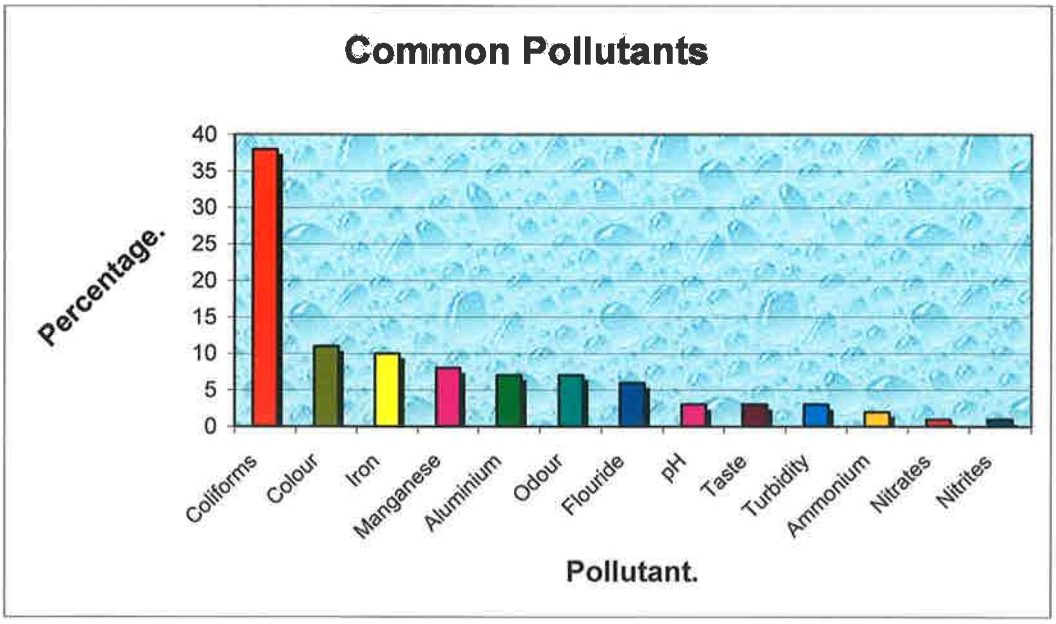


Figure 2.3. Common Pollutants Present in Water.

These pollutants can have the following effects on the quality of water and on the health of consumers;

2.6.2 Coliforms.

These are regarded as indicator organisms. The presence of coliforms does not mean that pathogens are present, however large numbers would indicate that the water has been polluted by waste from warm blooded animals, therefore the water should be tested prior to consumption [31]. Tests are carried out by filtering a quantity of water through a glass filter with openings of 0.5μm. The retained material is cultured and the results can reveal coliforms, faecal coliforms and faecal streptococci [31].

2.6.3 Colour, Odour, Taste and Turbidity.

These are referred to as the physical properties of water. They all contribute to the aesthetics of the water. If it is coloured and has an unpleasant odour, people would be reluctant to drink it [31]. Taste is a result of the reaction of the water to dissolved minerals and metals. Taste in water is generally accepted, provided it is not objectionable. Excess concentrations of chlorine with a taste threshold of 0.16mg / l at pH 7 are reported to be quite objectionable [33]. Turbidity not only contributes to the aesthetics but turbid or cloudy water may also be infected with bacteria, since the particles causing the turbidity can hinder the disinfection process. This will be discussed later in section 2.15. Turbidity [31].

2.6.4 Iron and Manganese.

The effects of these metals in water greatly affect its physical properties. The presence of iron and manganese in water can be responsible for the occurrences of colour, odour, taste and turbidity. These issues are dealt with in greater detail in sections 2.10 – 2.14.

2.6.5 Ammonium.

This is a derivative of ammonia. It is formed when ammonia reacts with water as shown in equation 2.1 where ammonia combined with water results in an ammonium ion and a hydroxyl ion. This reaction is reversible.

$$NH_3 + H_2O \leftrightarrow NH^+{}_4 + OH^- \qquad \text{Equation 2.1 [34].}$$

The principal cause of this contaminant is farming activities [34]. The use of ammonia-rich fertilizer, ammonia based cleaning products, septic systems, and improper disposal of ammonia products all contribute. Ammonia in the atmosphere is a by-product of combustion processes such as domestic heating and internal-combustion engines. This area is further dealt with in section 2.7 [34].

2.6.6 Aluminium,

This metal is associated with neurodegenerative diseases e.g. Alzheimer's disease [32]. It can also have adverse effects on dialysis patients, since they receive approximately 400 L of dialysis fluid weekly, the make up water must be of a very high quality [33].

2.6.7 pH,

The pH of a substance is a measure of its acidity or alkalinity. If the pH of water is incorrect it can lead to corrosion of pipes (acidic) or deposition of salt (alkaline) [33]. These issues will be discussed in sections 2.11 and 2.13.9

2.6.8 Fluoride.

This is one of the most toxic inorganic poisons known, yet it is added to drinking water for dental health. However the maximum allowable concentration (MAC) must not exceed 1mg/l excess fluoride can lead to dental fluorosis. This is a condition where the teeth become mottled in appearance. It also causes brittleness in bones. [31,33].

2.6.9 Nitrates.

This form of pollutant in drinking water is as a direct result of farming. The nitrates leach into the aquifers affecting groundwater or as farm run-off running into rivers, streams and lakes, affecting surface water supplies. The main health concern of nitrate pollution is "blue baby" syndrome or methaemoglobinaemina [31].

2.7 Pollution Through Human Activity.

Human induced pollution can take on many forms such as [34].

(i) Industrial pollution; this can give rise to the atmosphere being polluted with toxic dust e.g. asbestos, pesticides, nuclear fallout etc. Toxic gases are the by-products of burning lead-based fuels, spray residues, hydrocarbons from factory chimneys.

(ii) Agricultural pollution. This type of pollution is a result of silage by-products. Fertilizers and animal waste can leach through the ground or run-off into streams and rivers thus polluting the ground and surface water.

(iii) Human waste disposal. This type of pollution would originate from septic tanks and waste disposal sites. Each of these leaches polluted matter into the ground water [32].

The most common bacterial pollutants diseases are as follows.

2.7.1 Typhoid.

Typhoid is also known as Salmonella typhosa and is an infection of the digestive system. It is the most serious of the communicable diseases. It can be transmitted by faecal contamination in food or water. If left untreated it can have a mortality rate of between 10-15% [32,38].

2.7.2 E coli.

Various strains of E Coli exist. Some of which are more dangerous than others Escherichia coli is regularly blamed as a cause of travellers diarrhoea (Turista). It is found in the excrement of man, animal and fish. An image of a cluster of the rod like bacteria is shown in Figure 2.4 [37].

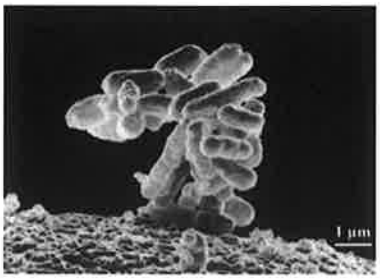


Figure 2.4. E Coli Cluster.

2.7.3 Cryptosporidium.

This is a microscopic parasite classified as protozoa that is present in almost all surface waters. When ingested through drinking water, it can cause cryptosporidiosis, an illness characterised by severe abdominal cramps and diarrhoea, which can be fatal to children and individuals with suppressed immune systems. It can lead to impaired physical and cognitive development in children [40]. Cryptosporidium is resistant to chlorination because it is an "ocyst" i.e. the parasite is encased in a shell, which protects it from chlorine. In the Milwaukee Cryptosporidium outbreak of 1993 for instance, despite testing the chlorinated water, no coliforms were detected even though high levels of cryptosporidium were present [20]. It was estimated that 403,000 humans were affected with watery diarrhoea and over 100 deaths were attributed to this outbreak, mostly among the elderly and immuno-compromised. The reasons for such an outbreak were attributed to poor filtration systems, poor water quality standards and inadequate testing of patients [41]. An Immunofluorescence image of Cryptosporidium parvum oocysts is shown in Figure 2.5 [37]. after it was purified from murine fecal material. The oocysts were stained with commercially available immunofluorescent antibodies. Oocysts have an intense apple green fluorescence on the periphery of their oocyst wall and measure 4 to 6 microns in diameter.

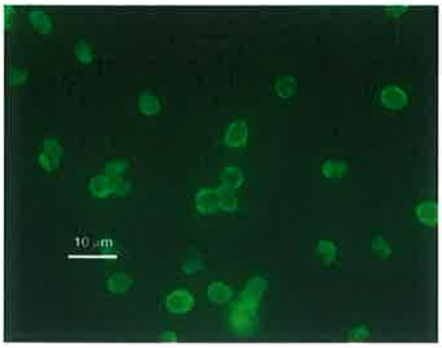


Figure 2.5. Immunofluorescence Image of Cryptosporidium.

2.8 Industrial Activities.

Industrial activities such as mining, smelting and oil exploration can give rise to mineral contamination. The by-products of these industries introduce metals such as lead, tin, arsenic, zinc, copper, iron, to amongst others. While all of these metals can occur naturally in water, the aforementioned operations concentrate the amounts leached into surface and ground water [9].

2.8.1 Movement of Water Through the Ground.

Water is stored in the aquifers that exist beneath the ground's surface. The level at which the water sits is called the water table and is governed by several factors, the

most influential being the amount of rainfall. It is from beneath this water table that wells abstract water. Aquifers vary in composition; some such as sand and gravel are an open porous type structure, which allow movement of water through their pores. In a sand or gravel aquifer the movement of the water is slow, therefore the water is filtered naturally [43,9].

Other solid types of aquifer such as bedrock depend on fractures within the rock structure to transmit water. The majority of the solid aquifers in Ireland are limestone and the water depends on the presence of cracks within the rock structure which allow it to travel underground to feed wells and rivers etc.

The limestone is made up of calcium carbonate ($CaCO_3$). When rain falls and comes into contact with soil it becomes a slight acid solution called carbonic acid (H_2CO_3).

This acidic solution dissolves the limestone producing calcium bicarbonate ($Ca(HCO_3)_2$), which is then washed away. This erosion process is called karstification, [9]. which allows these fissures (cracks) to widen, thereby allowing more water to pass through and cause even more erosion. Karstification has the effect of allowing large amounts of water to travel very quickly, the flow velocity may be up to 200 meters / hour.

Since a lot of water can pass through a karst system very quickly, then any pollutant that enters the water system can be spread quickly over a large area. These pollutants can originate in farmyards, industrial sites and septic tanks, even though these sites may be many kilometers away from a well [9].

2.9 Monitoring of Drinking Water Quality.

The environmental protection agency (EPA), has the responsibility of monitoring the quality of the nations drinking water. The EPA covers a total of 53 bacteriological, chemical and physical parameters and they have set MAC for contaminants and MRC (Minimum Required Concentrations) for treatment additives. These limits apply to water that is treated prior to distribution [49]. A survey conducted by the EPA for the period 1994 to 1996 shown in appendix ”F” outlines some of the impurities, their levels and their exceedances in relation to the MAC standards [49].

2.10 Iron And Manganese in Water.

Iron and manganese are the main non-biological contaminants examined in this study. The following is a brief discussion of their effect on the water supply system.

2.10.1 Iron And Manganese.

Iron and manganese are common metallic elements found in the earth's crust. The earth’s crust is composed of many other elements, 5% of which is iron [36]. They are non-hazardous elements which can nonetheless be a nuisance in a water supply. While they are completely different metals, they cause similar problems in water supplies [31].

Of these two contaminants in water supplies, iron is the most common. Manganese is typically found in iron-bearing water. In the ferrous state, (Fe^{2+}) iron is soluble in water and is oxidised in the presence of air into the insoluble form of (Fe^{3+}) ferric form. These metals are not harmful to health in general, but their effects are aesthetically unpleasant as they impart a cloudy appearance, odour and a bitter taste to water which are detectable at very low concentrations [31]. Although ferruginous water is perfectly safe to the majority of people, it can pose a health risk to a minority of people who suffer a condition of heredity hemochromatosis. This condition is discussed in section 2.12 [50].

2.11 pH Levels.

The pH value of most natural waters is in the range of between 4 – 9. Water with low pH levels (acidic water) is said to be soft and is found in peat land areas of a low pH value 4 – 6.9, water that originates in chalky limestone areas are regarded as hard water with high pH values 7.1 – 9. Water with a pH of 7 is neutral [27].

As the pH of the water rises the levels of carbon dioxide are reduced, so too is the tendency for the water to dissolve the iron in the ground. It is for this reason that the unit processes of precipitation, coagulation/flocculation and chlorination are usually preceded by pH adjustment. It is therefore crucial to ensure that the solution pH is kept within specific limits in order to ensure that the required chemical reaction proceeds as quickly as possible [27].

2.12 Iron Overload or Hemochromatosis.

Iron Overload or Hemochromatosis is a health problem associated with excessive amounts of iron in drinking water. The symptoms of hemochromatosis vary and can include: chronic fatigue, arthritis, heart disease, cirrhosis, cancer, diabetes, thyroid disease, impotence, and sterility. In the United States iron overload is primarily due to a genetic disorder known as hereditary hemochromatosis. It is characterized by lifelong excessive absorption of iron accumulating in body organs, from, for example ferruginous drinking water. The effect of body iron content with age is shown in Figure 2.6 [49,50].

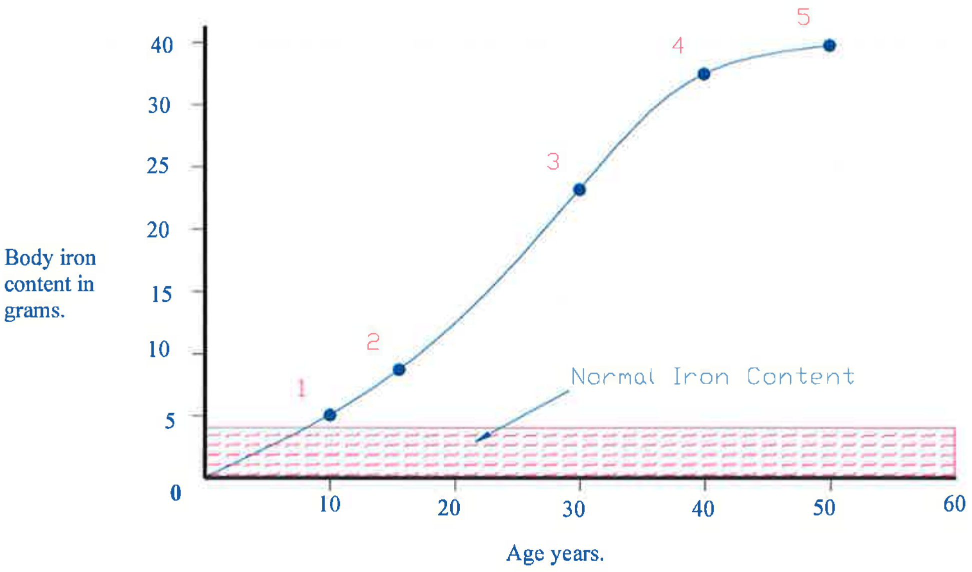


Figure 2.6. Effects of Increased Iron Absorption.

Key to graph.

1 Indicates increased serum iron content.

2 The point at which increased hepatic iron concentration occurs.

3 Tissue damage occurs at this point.

4 Cirrhosis, organ failure and premature death [44].

For these reasons drinking water supplies should not contain more than 0.3 mg/l of iron or 0.05 mg/I of manganese. These limits are the MAC specified by the EPA [7, 50]. While they are not harmful, iron and manganese interfere with laundering operations, cause objectionable stains to plumbing fixtures, and difficulties in distribution systems by supporting growths of iron bacteria, and the formation of sedimentry deposits which can lead to blockages in pipes [31]. They create serious problems in public water supplies. The iron, as it precipitates out of solution, leaves a residue. The problems are more acute with underground waters, where anaerobic conditions exist (conditions devoid of air). These problems may be encountered in surface water during certain seasons of the year in waters drawn from some rivers and some impounded surface supplies i.e. reservoirs or lakes. [51] This phenomenon is known as thermal stratification [45].

2.13 Iron in Water.

Iron is a ubiquitous mineral and can exist in nearly all soils and find its way into many water supplies mainly as insoluble ferric oxide iron sulphide (pyrite) or ferrous carbonate (siderite), which is slightly soluble. Carbon dioxide plays a significant role in ground-water and appreciable amounts of ferrous carbonate may be dissolved in the water by the reaction shown in equation 2.2

$$FeCO_3 + CO_2 \longrightarrow Fe^{2+} + 2HCO^{3-} \quad \text{Equation 2.2 [39].}$$

2.13.1 Soil Conditions

Iron and manganese in water can arise from iron minerals in rock and soils. Such soil types include dark muddy limestone, and peaty areas. See section 2.3.3 The Eastern Water Resource Region comprises largely of

(i) Waulsortian limestone, this is a fine-grained limestone.

(ii) Boston hill formation, a nodular & muddy limestone and shale combination [46]

Oxygen deficient conditions can be brought about by naturally occurring organic breakdown in peaty areas, or by organic breakdown of organic wastes from septic tanks and farms [50]. The production of carbon dioxide is the end product of both aerobic and anaerobic activity [43]. Manganese is generally associated with iron and is a good indicator of pollution by organic wastes with a high BOD (Biological Oxygen Demand) e.g. silage effluent. If organic wastes are discharged into areas where wells produce good-quality water, low in iron and manganese, anaerobic conditions in the soil can be created, therefore causing the well to produce ferruginous water [50].

2.13.2 Solubility of Iron in Groundwater.

The amount of iron that can be dissolved in groundwater is dependent on a number of factors, which include.

- Carbon dioxide levels.
- pH of the water.
- Redox potential of the water.

2.13.3 Indications of Iron and Manganese

In deep wells, where oxygen content is low, the iron/manganese-bearing water is clear and colourless (the iron and manganese are dissolved). Water from the tap may be clear, but when exposed to air, iron and manganese are oxidized and change from colourless, dissolved forms to coloured, solid forms. Oxidation of dissolved iron in water changes the iron to yellow and finally to red-brown solid particles that settle out of the water. Iron that does not form particles large enough to settle out and that remains suspended (colloidal iron) leaves the water with a red tint. Manganese usually is dissolved in water, although some shallow wells contain colloidal manganese (black tint). These sediments are responsible for the staining properties of water containing high concentrations of iron and manganese. These precipitates or sediments may be severe enough to plug water pipes [31].

2.13.4 Effect of Iron and Manganese on Food and Beverages.

Iron and manganese can affect the flavour and colour of food and water. They may react with tannins in coffee, tea and some alcoholic beverages to produce a black sludge, which affects both taste and appearance. Manganese is objectionable in water even when present in smaller concentrations than iron. Figure 2.7 shows a photograph of tea made with ferruginous water. The scum can be clearly seen on top of the tea [31].

Figure 2.7. Scum Layer Floating on Tea.

The maximum iron concentrations in mg/l for iron content in water for some applications are listed in the chart, Table 2.1.

Application / use.	Iron content. mg / l.
Baking.	0.2
Brewing.	0.1 – 1.0
Cooling water.	0.5.
Laundering.	0.2.
Textiles.	0.1 – 1.0.

Table 2.1.

2.13.5 CO_2 in Water.

The solubility of carbon dioxide is about 90 cm^3 of CO_2 per 100 ml of water. In an aqueous solution, carbon dioxide exists in many forms. First, it simply dissolves.

$$CO_{2(g)} \rightarrow CO_{2(aq)} \qquad \text{Equation 2.3 [45].}$$

Then, equilibrium is established between the dissolved CO_2 and H_2CO_3, carbonic acid.

$$CO_{2(aq)} + H_2O \leftrightarrow H_2CO_{3(aq)} \qquad \text{Equation 2.4 [45].}$$

Only about 1% of the dissolved CO_2 exists as H_2CO_3. Carbonic acid is a weak acid, which dissociates in two steps [2,45].

The carbon dioxide enters the water by being absorbed from the atmosphere. This occurs when the pressure of carbon dioxide within the water is less than the pressure of the carbon dioxide in the atmosphere. Decomposition of vegetation can also give rise to carbon dioxide being produced in waters. In such cases, the pressure of carbon dioxide in the water may exceed that of the atmosphere and carbon dioxide will escape from the water to the atmosphere. Since the carbon dioxide in the surface water tries to maintain equilibrium with the atmosphere, the surface water is constantly giving up, or absorbing, carbon dioxide to and from the atmosphere. These aerobic conditions are not very favourable for the formation of dissolved iron [2, 45].

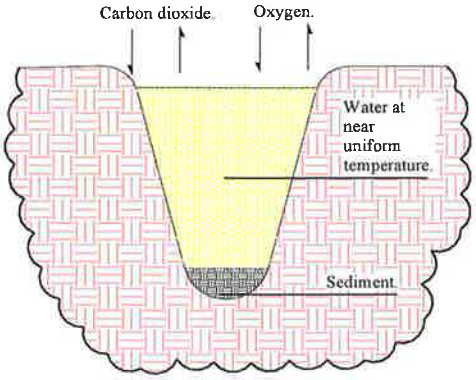
2.13.6 Iron and Carbon Dioxide.

Waters that have high levels of dissolved iron and manganese will be found in anaerobic conditions which have high amounts of carbon dioxide present. The presence of carbon dioxide indicates that organic matter is being decomposed. This can cause concern for bacterial pollution, the development of anaerobic conditions is essential for appreciable amounts of iron and manganese to gain entry to a water supply. In peaty soil areas, the degradation of vegetable matter gives rise to the formation of humic acid [47]. The humic acid acts as a chelator, which allows metals to become dissolved. These metals are typically positively charged multivalent ions such as Mg^{2+}, Fe^{2+} [48] Humic acid increases the concentration of dissolved iron in water. Only under anaerobic conditions is acidic water produced and the soluble forms of iron, Fe(II), and manganese, Mn(II), are possible. The water percolating through soil and rock can dissolve minerals containing iron and manganese and hold them in solution. Occasionally, iron pipes also may be a source of iron in water [45,43]

2.13.7 Spring / Autumn Turn Over.

Water impounded in certain lakes undergoes what is known as a "spring / autumn" turn over. This is due to the fact that during the winter the complete body of water stabilises at a uniform temperature. This means that the wind blowing across the surface of the water can mix the upper and lower levels of the water thereby aerating the water. However during the winter and summer period there is a temperature difference between the upper and lower regions of the water in lake. This causes stratification (layering) within the lake, thus causing the less dense body of water to float on top of the cooler denser body below. The upper warm region is called the epilimnion and the cooler dense layer the hypolimnium. Between these two layers there exists the thermocline or temperature gradient of the lake, see Figure 2.8b. The stratification prevents the upper and lower levels mixing thus causing the hypolimnium to be excluded from aeration.

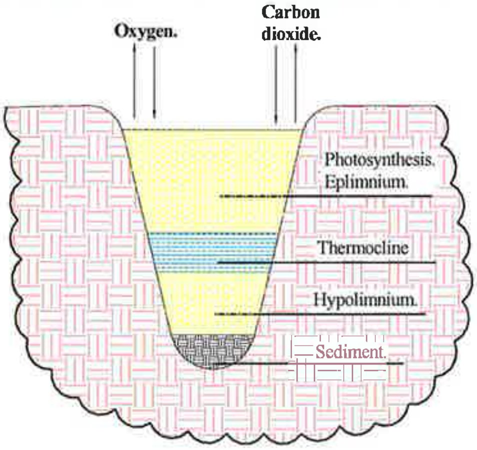
Iron and manganese can exist in impounded surface water supplies; this is the case with lakes and reservoirs that stratify, in which anaerobic conditions develop in the hypolimnion. The soluble iron manganese released from the bottom mud is contained in the waters of the hypolimnion until the autumn overturn occurs. At that time they are distributed throughout the reservoir. The waters in such cases remain turbid until sufficient time has elapsed for oxidation and sedimentation to occur under natural conditions. The four phases of lake stratification can be seen in Figures 2.8a – 2.8d [45,43].



Spring turnover.

Figure 2.8a

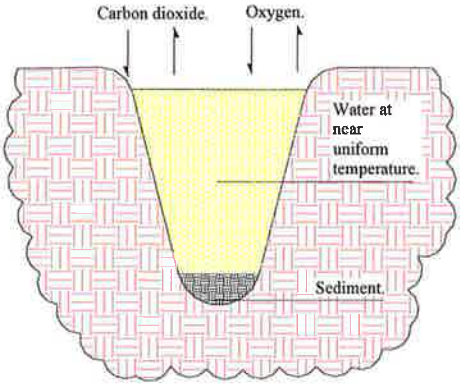
This Diagram of the Spring Turnover Cycle is Identical to Autumn Turnover Shown in Figure 2.8c.



Summer turnover.

Figure 2.8b.

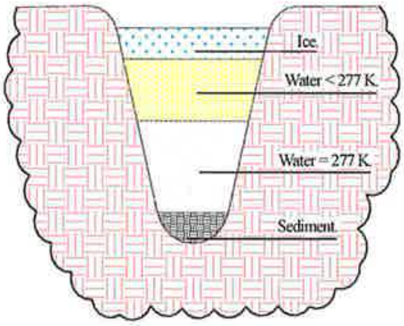
Figure 2.8b. shows the summer turnover of lake showing stratification. Photosynthesis takes place in the upper warmer levels. And the colder regions of the lake remain at the bottom. This volume of water is therefore devoid of oxygen and creates ideal conditions for iron to become dissolved in the water..



Autumn turnover.

Figure 2.8c.

During the autumn turnover cycle, the water is at uniform temperature, aeration caused by wind allows the CO_2 to be dissipated to the atmosphere. Thus allowing the dissolved iron to come out of solution.



Winter turnover.

Figure 2.8d.

During the winter turnover cycle, the upper surface of the lake is often covered with ice. The water is therefore sealed off from the atmosphere. This phase is similar to the summer turnover where the lower regions of the lake are lacking oxygen. Dissolved CO_2 is abundant, creating ideal conditions for ferruginous water.

A spring overturn occurs as surface water temperatures rise. Shallow lakes like Lough Neagh in Northern Ireland (average depth only 12 m) will rarely demonstrate a stable thermal stratification except in the hottest of summers, while very deep lakes, like the African Rift Valley lakes are permanently stratified [45,49,50].

Thermal stratification has major effects on both oxygen concentration and nutrient supplies. When the lake is stratified, no mixing occurs between the top and bottom layers. The hypolimnion receives no oxygen that has diffused into the surface waters and becomes increasingly anoxic i.e. devoid of oxygen. The epilimnion, where the plants are, receives no dissolved nutrients from the bottom, where decomposition occurs, so primary productivity becomes nutrient limited and declines over the summer. When the overturn occurs, the hypolimnion is replenished with oxygen and the epilimnion with dissolved nutrients. Excessive deoxygenation of the hypolimnium in summer, which can arise as a result of strong eutrophication of the water body, can result in dramatic disturbances to the rest of the lake system on overturn and decreasing quality of the water resource [43,49,7,50].

2.13.8 Origins of Fe and Mn in the Subject Water.

As stated previously the main objective of this study is to remove dissolved Fe and Mn from groundwater. The water under examination is extracted from an aquifer as outlined in sections 2.3.3 with a bedrock formation as outlined in section 2.13.1. The majority of the upper exposed surface of the area is peat land.

The concentration of humic acid is high, therefore creating ideal conditions for producing ferruginous water. See section 2.13.6

2.13.9 pH Levels and Fe / Mn Concentrations.

One of the characteristics of acids is that they produce hydrogen ions in aqueous solutions. Therefore a method of expressing the hydrogen ion concentration must be devised. Checking the pH of the solution does this. Consider a solution that has 0.1-mole nitric acid in one litre of solution. The nitric acid dissociates completely into a hydrogen ion and a nitrate ion.

$$HNO_3 \leftrightarrow H^+ + NO_3 - \qquad \text{Equation 2.5.}$$

Therefore the concentration of hydrogen ion is 0. 1 mole per litre.

i.e [H+] = 0. 1 mole per litre.

When an acid is added to water, the hydrogen ion concentration increases, resulting in a lower pH number. Conversely, when an alkaline substance is added, the OH^- ions unite with the free H^+, lowering the hydrogen ion concentration and causing a higher pH. The pH scale, ranging from 0 to 14, is acid from 0 to 7 and basic from 7 to 14.while 7, the mid point value is neutral [49,6,52].

(The ' p ' in pH stands for the power or index and the H in pH stands for hydrogen ion.) The greater the hydrogen ion concentration the lower the pH.

2.13.10 The pH of Pure Water

Pure water dissociates to a very slight extent this is shown in equation 2.6.

$$2H_2O \leftrightarrow H_3O + OH^-$$ Equation 2.6. [53].

Therefore, pure water always has a small concentration of hydrogen ion present (and also hydroxyl ion). Accurate measurements have proven that, in pure water

$[H^+] = 10^{-7}$ mole per litre

$\Rightarrow \log_{10}[H^+] = -7$

$\Rightarrow -\log_{10}[H^+]\ 7$

$\Rightarrow$ pH = 7. Equation 2.7 [53].

Therefore the pH of pure water is 7. It is known that pure water is neither a basic nor an acidic solution, i.e., it is neutral. Therefore the pH of a neutral solution is 7. A solution with a pH more than 7 is basic, while one that has a pH less than 7 is acidic [32 ,52, 53].

Neutral pH

A schematic of a pH scale is shown in Figure 2.9. It can be seen the greater the deviation from "7" the more acute the concentration becomes.

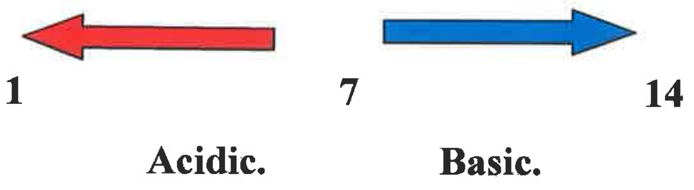


Figure 2.9. Schematic of pH Scale.

2.13.11 pH Indicators

An indicator is a compound used to measure the pH of a solution. An indicator is generally a weak acid, and is coloured. It changes colour according to the pH of the solution under test.

A list of acid base indicators is shown in Table 2.2.

Indicator Name.	Acid Solution. (Colour)	Alkaline Solution. (colour)
Litmus.	Red.	Blue.
Bromothymol blue.	Yellow.	Blue.
Methyl orange.	Red.	Yellow.
Phenolphthalein.	Clear.	Red.
Phenol red.	Yellow.	Red.

Table 2.2. Some Acid Base Indicators.

While these indicators give only an "indication" of the pH of a solution a more accurate result can be obtained by means of a pH meter.

The pH value of most natural waters is in the range of between 4 – 9. Water with low pH levels (acidic water) are said to be soft and are found in peat land areas of a low pH value. Hard water with high pH values, 7 – 9, originates in chalky limestone areas by percolating through alkaline rock formations. This water when used with soap for washing purposes prevents the formation of lather, and forms a lime scale in cooking utensils and washing appliances [27,39].

As the pH of the water rises the levels of carbon dioxide are reduced, so too is the tendency for the water to dissolve the iron in the ground. It is crucial to ensure that the pH of solution is kept within specific limits in order to ensure that the required chemical reaction proceeds as quickly as possible.

2.14 Redox Reactions.

The term "Redox" is an abbreviation for a reduction and oxidation process. It is a very important reaction for the removal of iron and manganese [32]. Many chemical changes involve the addition of oxygen and/or the change of valence of one of the reacting substances. Oxidation is the addition of oxygen or removal of electrons, and reduction is the removal of oxygen or addition of electrons. A classic example of an oxidation reaction is the rusting of iron by oxygen. This reaction is the fundamental equation in the removal of dissolved iron from ground water. This is shown in equation 2.8

$$4Fe + 3O_2 = 2Fe_2O_3 \qquad \text{Equation 2.8 [32].}$$

The iron is oxidized from Fe to Fe $^{+++}$ while the oxygen is reduced from O to O $^{--}$.

An oxidation-reduction reaction in water treatment is the removal of soluble ferrous iron (Fe^{2+}) from solution by oxidation. Potassium permanganate is a common oxidising agent, in the equation below it can be seen the iron gains one positive charge while the manganese in the permanganate ion is reduced from a valence of 7^+ to 4^+. Equation 2.9.

$$3Fe^{2+} + Mn^{7\,+}O_4^{-} \rightarrow 3Fe_3 + O_2 \downarrow + Mn^{4+}O_2 \downarrow \qquad \text{Equation 2.9.}$$

Note, this equation is not balanced and the precipitates of iron oxides and manganese dioxide are removed from suspension by sedimentation and filtration of the water. The precipitation is indicated by the vertical arrows [53].

2.15 Turbidity.

Turbidity is a term used to measure the cloudiness or the degree to which the water loses its transparency due to the presence of suspended particulates [30].p120 The higher the number of suspended solids the more turbid the water is. It is caused by various factors some of these are:

(i) Sediments from erosion.
(ii) Algal growth.
(iii) Aerated water that contains dissolved metals such as, iron or manganese [30].p120.

Turbidity is measured by photometers known as turbidimeters. They measure the intensity of scattered light, which is caused by opaque particles in the water [30]. The calibration standard for turbidimeters is

1mg/l of SiO_2 = 1 turbidity unit (1 NTU). (Nephelometric Turbidity Units) [31].

2.15.1 Consequences of High Turbidity.

The main concern of turbidity for drinking water is the appearance and the presence of minute particles suspended in the water. These solids can hinder the disinfection of water by shielding some pathogens especially when using UV treatment, or in some cases, the pathogens may be embedded in the particle. This situation can also affect chlorination. However the consequences for riparian life is much greater. The suspended particles in the water absorb heat from the sunlight, making turbid waters become warmer, and so reducing the concentration of oxygen in the water as the colder the water, the higher the rate of oxygen solubility. See Appendix G page 171. However, work done by McGuigan et al, which investigates the effectiveness of inactivating water borne pathogens using solar disinfection "SODIS" suggests that the inactivation of Ecoli in turbid water (200 NTU) is successful. This is due to the heating effect of the water, the heating effect being accelerated by the dark cloudy nature of the water. The inactivation of cryptosporidium is not so successful due to its higher thermo-tolerance. The Swiss Federal Institute of Aquatic Science and Technology (EAWAG 2005) have indicated that the solar heated water would have to exceed 45°C for there to be any effect. It has also been highlighted that the inactivation of cryptosporidium may not be permanent if the solar radiation is not complete. A repair process within the DNA may commence when the water is removed from the sunlight. The suspended particles scatter the light, reducing the photosynthetic activity of plants and algae, causing a reduction level of oxygen even further. This in turn leads ultimately to fish kills. The turbidity of drinking water should be no more than 5 NTU, and should ideally be below 1 NTU [49,53].

2.16 Necessity for Water Treatment.

Prior to human use raw water must undergo several treatment processes. These treatment processes remove,

(i) Harmful bacteria which may be removed by disinfection or sterilisation.

(ii) Various metals and minerals.

(iii) Tastes and odours.

(iv) Excessive hardness.

2.16.1 Water Treatment Processes.

Water can be treated on three basic levels. These include;

(i) Large scale or municipal treatment. (River or lake supply).

(ii) Small scale, group scheme level. (River, lake supply or Borehole supply).

(iii) Micro scale, single house treatment systems. (Borehole supplies).

The treatment required for water differs from source to source.

Appendix H outlines the various treatment processes required for water from different sources [35].

(i) Represents good quality water abstracted from a borehole, requiring minimal treatment.

(ii) Represents similar quality water but, with some dissolved iron present.

(iii) Represents poor quality surface water abstracted from river supply. This water requires substantial treatment.

2.17 Disinfection of Drinking Water.

Disinfection is the removal of microbes that may cause disease. This is generally the final stage of water treatment. This treatment is used to control pathogenic viruses and bacteria. Other viruses would have been removed by slow sand filtration in previous treatments [43].

2.17.1 Hygienic Requirements.

Drinking water must be of such a good quality so to ensure that it does not give rise to any health hazards. These hazards may either be chemical or microbial. While the effects of chemicals are slow due to accumulation, microbial contamination constitutes an immediate danger. Public water supply authorities have the responsibility to distribute a wholesome drinking water free from pathogens. This is quite easy in cases where underground water is available from a well-protected aquifer of fine porosity that is naturally free from pathogens [54]. but not necessarily the case with water drawn from aquifers in karst areas.2.8.1 In most cases the water needs to be treated and disinfected. The attempt to achieve a sufficient degree of disinfection by applying a disinfectant without further treatment is bound to fail if there is particulate matter in the water which may shield the pathogens from attack by the disinfectant. This point is especially important as it is in the case of ultraviolet treatment. The prerequisite for a reliable disinfection is therefore to remove suspended solids in a first step and then apply the disinfectant.

2.17.2 Contamination.

As stated in 1.1, the contamination of water can take many forms including, microorganisms, metals, pesticides, naturally occurring, and synthetic chemical compounds may occasionally be present in drinking water. Dr Jeremy Hess CDC shows concern for climate change on water contamination 1.1. Dr Sharon Roy &Mark LeChevallier CDC, point out that contamination may be as a result of improper premise plumbing and deficiencies in point of use (POU) water treatment devices. [21, 55].

2.17. 3 Types of Biological Contaminants.

Micro organisms encompass a wide variety of unique structures and can be grouped into five basic groups:

(i) Bacteria.

(ii) Virus.

(iii) Fungi.

(iv) Protozoa.

(v) Algae.

Figure 2.10. Shows the typical structure of a micro-organism.

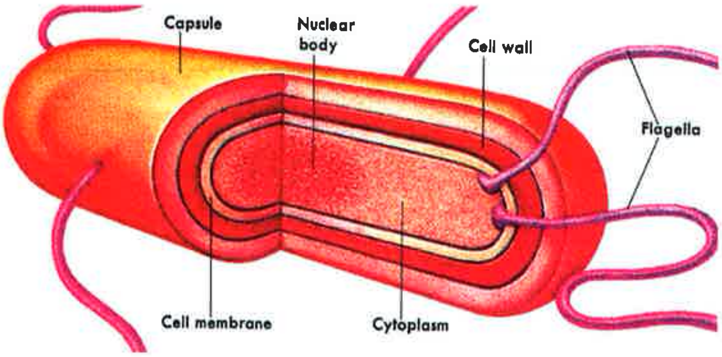


Figure 2.10. Structure of a Microorganism.

As shown in Figure 2.10. a microorganism is made up of the cell wall, cytoplasmic membrane and the cell's genetic material, nucleic acid [50].

2.17.4 Definition of Disinfection.

Disinfection refers to the elimination of pathogens. The U.S. Environmental Protection Agency (USEPA) and World Health Organization (WHO) define water disinfection that shows no presence of indicator coliform bacteria. Disinfection being generally the final stage of water treatment and is used to control pathogenic viruses and bacteria that have not been already removed by slow sand filtration in previous treatments [32].

2.17.5 Sterilisation.

Sterilisation is an absolute phenomenon and is the destruction of all infectious agents from an environment. This includes algae, bacteria, fungi, protozoa and viruses.

Sterilisation is not necessary for the production of potable water, but the water must conform to the drinking water standards of the Public Health Service or those of the EPA. It should be remembered that disinfection is not sterilization. One feature of disinfection is that with correct management it can be continuous, effective and adjustable [27].

2.18 Methods of Disinfection.

There are three preferred methods of disinfection.

(i) Chlorination.
(ii) "Ozonation".
(iii) Ultraviolet radiation.

2.18.1 Chlorination.

Chlorination is by far the most commonly used method for disinfection purposes and can be applied in gaseous form. e.g.

(i) Chlorine hypochlorite,
(ii) Chlorine dioxide
(iii) Chloramines.

These compounds of chlorine are inexpensive and are easy to add to water with a solubility rate of 7000 mg/l. The residues left in the system continue to be active in killing off pathogens in the distribution network. Chlorine however [51]. is a very toxic substance in concentrated form, but when added to drinking water in the correct proportions is considered to be relatively harmless to humans [51]. If too little is added this may result in inadequate disinfection, if too much is added the result will be odours and unpleasant tastes [56]. Therefore, careful monitoring is required [35]. Due to the toxicity of chlorine wind socks must be used to indicate the direction a cloud of chlorine gas may take should a leak occur. Due to its toxicity, chlorine is mixed with water in special chlorinators.

The reaction of chlorine with water is as follows [57].

$$Cl_2 + H_2O \rightarrow HOCL + HCL \rightarrow HOCL \Rightarrow H_2 + OCL \qquad \text{Equation 2.10}$$

Where Chlorine combines with water yielding Hypochlorous acid, hydrochloric acid and a hypochlorite ion.

In dilute solutions this reaction takes place in about 1 second. HOCl and OCl both act as disinfectants but HOCl is more active as a bactericide than OCl by a factor of 80. When a quantity of chlorine is added to pure water (distilled) it produces the same amount of chlorine residue, ie there is a direct proportionality producing a 45^0 line as shown on the graph in Figure 2.11 [35]. In raw, or potable water there is extra chlorine added initially to satisfy the "combined chlorine" demands. In many cases it is common practice to add ammonia at the chlorination stage. This is what form chloromins. Excess chlorine is added until the "breakpoint" is reached. At this point there is no further reaction between the chlorine and the contaminating elements, further addition of chlorine produces residual chlorine and hence residual disinfection. Residual disinfection as mentioned previously, is necessary to ensure disinfection to the point of use and the graph will run parallel to that for chlorine in pure water. It is necessary to pass this breakpoint threshold in order to ensure the presence of chlorine residues. This breakpoint is an indication of specific chlorine demand for water in various processes, and distribution networks [57,58].

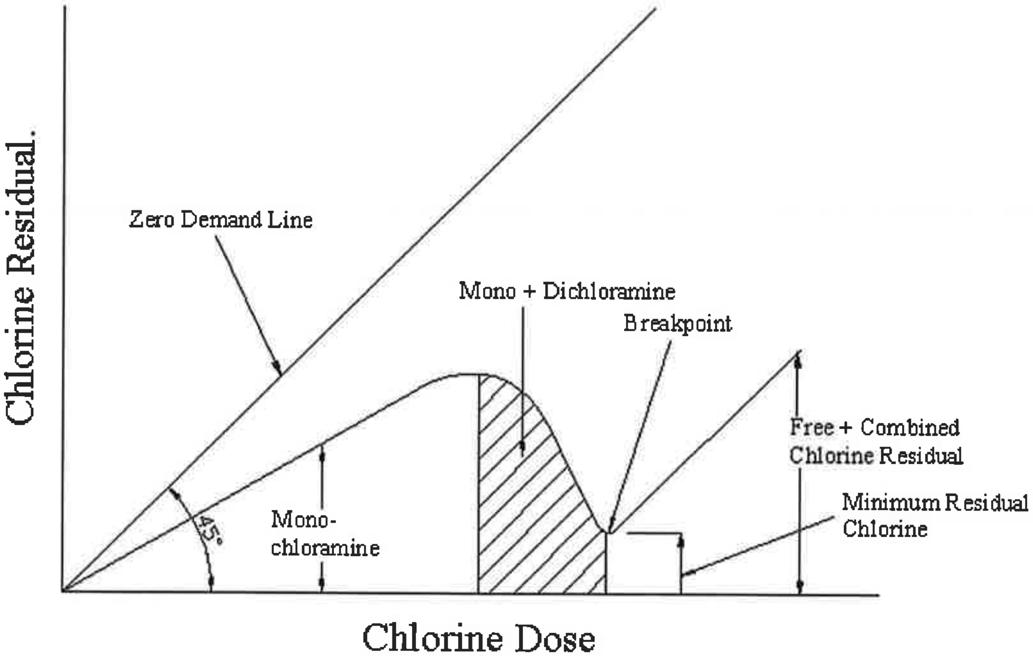


Figure 2.11. Chlorination Breakpoint Graph [35].

2.18.2 Chlorine Demand.

This is the amount of chlorine that must be added to water to produce an excess of chlorine or chlorine residue after reacting with the contaminants in the water [35].

2.18.3 Distribution of Disinfected Water.

After leaving the treatment plant the water is delivered to the consumer through a system of pipes and valves, known as the distribution network. This water will typically have a low turbidity, a pH of 6.8 -7.8 and a residual chlorine concentration of 1.0 - 1.2 mg/l. The level of concentration depends on the length of the pipeline to the first consumer who must not receive more than 0.5mg/l. This level of residual chlorine will be adjusted according to consumers' activities. The last consumer should receive not less than 0.20mg/l at periods of maximum consumption [35]. It must be stated at this point that, while chlorine is effective in deactivating most pathogens, it is of little effect in the case of ocysts such as giardia or cryptosporidium. These two pathogens are encased in a shell that protects them from chlorination.

The disinfection system should also have the capacity to deal with emergencies such as outbreaks of water borne diseases, large water demands, for example pipe breaks, fires, repair work. Before a new distribution system is put into service, it must first be physically cleaned out. It must then be disinfected with a chlorine concentration of between 50 – 25 mg/L The system should be able to supply doses of disinfectant at 200% the normal dose [32].

Another problem area is that of "dead ends" such as hydrants. These can cause a growth of bacteria due to the lack of residual chlorine. Routine maintenance requires that the hydrants be opened periodically to flush out these dead ends [33].

2.18.4 Handling of Chlorine.

Chlorine must be handled carefully as it is a dangerous substance. Specific safety standards must be adhered to from manufacture to final point of use. Personnel who are required to handle this material should receive proper training and must be equipped with protective clothing such as breathing apparatus, face masks, goggles, gloves, and the facility using chlorine should be equipped with a deluge shower and eye washing facilities [32].

2.18.5 By-Products of Chlorination.

One of the major drawbacks of chlorination is the formation of by-products and reactions that take place within the water. Chlorine reacts with ammonia and humic acids (peaty water). This reaction interferes with the disinfection process. Where phenol is present, the reaction affects the odour and taste.

Another problem was discovered with the development of gas chromatography and mass spectrometry. This new technology can "expose" natural and man-made organic compounds with concentrations of less than 1 μg/l which were otherwise undetectable. Some of these compounds e.g humic acid, could react with chlorine to form complex and sometimes dangerous chemicals known as Trihalomethanes THM^s [32]. (First discovered in drinking water from the Rhine [59]. They are all considered to be carcinogens [33]. According to a study carried out by Krishna Gopal et al the development of disinfection by-products (DBPs), of which there are in excess of 300 types, in water is dependent on the: [60].

(i) Temperature.
(ii) Contact time.
(iii) Dose.
(iv) pH.
(v) Inorganic and organic natural componds in the water.

Huseyin Salcuk et al. measured (DBPs) and toxicity levels on treated water. They mention many species of THM which include chloroform which is the major and most dominant THM. Other THMs mentioned in his work are dibromochloromethane and bromoform. They have been linked epidemiologically to intestinal tract and bladder cancer, as well as adverse birth outcomes [61].

One of the many by-products of chlorine is chlorine dioxide. This compound, according to Gopal is effective in the destruction of oocysts such as Giardia and Cryptosporidium, which are resistant to chlorine. They [60]. also discuss that it has been used for the removal of,

(i) iron and manganese.
(ii) Taste and odour.
(iii) Hydrogen sulphide.

However, Chlorine dioxide has some disadvantages, these are,

(i) The disinfection by-products,which are chlorite and chlorate can create problems for dialysis patients.
(ii) Chlorine dioxide is about 5 to 10 times more expensive than chlorine. Chlorine dioxide is usually made on site. This makes it unsuitable for use on a small scale installation.
(iii) Chlorine dioxide is effective for the deactivation of pathogenic microorganisms. It is less effective for the deactivation of rotaviruses and E. coli bacteria [62]. It is a very hazardous compound rated according to the national polutant inventory (NPI). They give it a hazardous rating of 3.3 and rank it 42. Figure 2.12 that is compared with a hazard rating of 2.7 for chlorine which is ranked at 41, Figure 2.13 [63].

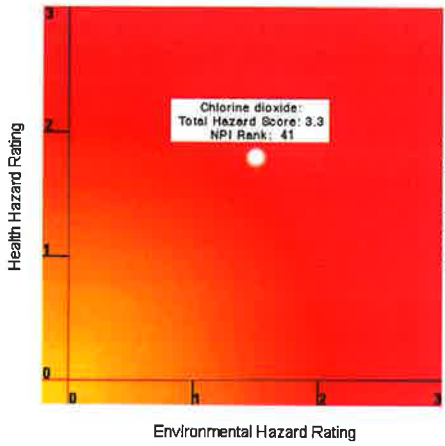


Figure 2.12.

Hazard Rating for Chlorine Dioxide.

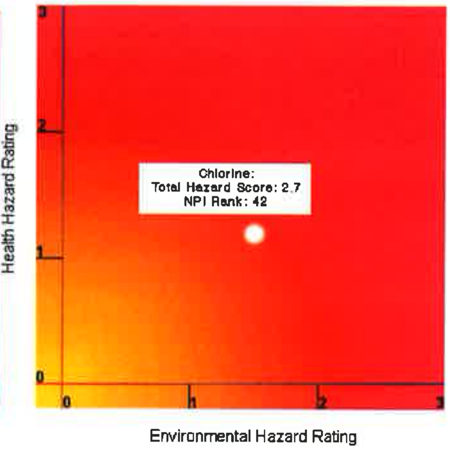


Figure 2.13.

Hazard Rating for Chlorine.

2.18.6.Chlorine as a Disinfectant.

While chlorine is used to disinfect drinking water, there are concerns relating to the validity of its use M.E.Hellard et al. 2002 [64]. raised these concerns in a study of occurrences of gastroenteritis in a large city before and after chlorination. He concluded that there were no appreciable differences in the admissions or the attendances to the accident and emergency department of the Royal Children's Hospital in Melbourne before and after chlorination. He also cites the idea that water was not the dominant contributing factor to the outbreaks of gastrointestinal disease, even though it was known to be contaminated with faecal coliforms. However Jonathan Yoder of the center for disease control and prevention (CDC) Atlanta points out that even though water is implicated in the spread of disease, it can also be spread through food or person-to-person contact [65].

2.19 Ozonation.

This is another effective method of disinfecting water. Which, according to Huseyin Salcuk et al [61]. is superior to chlorine when it comes to inactivation of Giardia and Cryptospordium. But because it does not create residual disinfection, as is the case with chlorine, it has not replaced chlorination. However, it is used in place of chlorine in waters that contain chemicals that would react with chlorine to form unpleasant odours and tastes. Ozone is sometimes used in conjunction with activated carbon, and at a dose rate of 1ppm, can eliminate all bacteria within 10 minutes. After water has been treated with ozone it is often chlorinated in order to maintain a clean pipeline.

This process can also produce bromate as a by-product; it can also be a side effect of using activated carbon. Apart from the formation of bromate, ozonation does not form any harmful THMs as is the case with chlorination [49].

Ozonation can achieve the following results in water treatment.

(i) Control taste and odour.
(ii) Control excessive colour.
(iii) Oxidise manganese and iron.
(iv) Aid flocculation. (Unification of colloidal particles).

G. R. Nabi Bidhendi et al. conducted tests on the use of ozone as a viable water disinfectant. In their studies they uses the SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis method for evaluating the suitability of ozone. SWOT matrix for ozone from their conclusions, ozone may be suitable for large-scale applications, it would not be practical for use on a domestic treatment system [66].

2.20 Fluoridation.

Fluoride is added to drinking water in order to control tooth decay. However the practice of fluoridation is a controversial issue. The concentration levels must lie between 0.6 mg/l to 1mg/l. Levels in excess of 1.5 mg/l gives rise to brittle and mottled teeth (fluorosis) while some countries around the world are ceasing fluoridation, other countries are adopting the practice [33]. It is a common belief amongst dental care professionals that fluoride over-dosing can occur by using fluoridated water and fluoride based toothpaste. They also believe that sufficient fluoride can be acquired by toothpaste alone. While it is added by several water treatment authorities, it does not contribute to the disinfection process [31].

2.20.1 Methods of Fluoridation.

Water can be fluoridated by three methods;

(i) Sodium fluoride NaF may be in concentrations of up to 4%. This form is the most common one, as it is the easiest to dissolve to obtain the required concentration.

(ii) Sodium silicofluoride Na_2SiF_6 is more difficult to dissolve in water and therefore concentration levels tend to vary. This form however is the least expensive.

(iii) Fuorosilicic acid H_2SiF_6 is easily fed into water .it is the most corrosive of all the fluoride compounds and is added to the water direct from the suppliers without the need for dilution [32,33].

2.21 Ultraviolet Radiation.

The term ultraviolet or "UV" light, as it is commonly referred to, is a proven means of addressing microbiologically contaminated waters. This simple, safe technology is suitable for both small flow residential applications as well as large flow commercial projects.

Disinfection with UV radiation in the range of 240-290 nm is currently being used as an alternative to conventional chemical disinfectants because by-product formation is negligible. The benefits of this method of disinfection are borne out in a study conducted by Alicia Cohn et al [67] . University of California, Berkeley (Energy and Resources Group) on the effectiveness of an Ultraviolet (UV) Water Disinfection System in Mexico as an appropriate water disinfection technology. The conclusions were that the UV system performed as predicted. Typical UV housings are made from stainless steel. This material is expensive to source and process. This study found that the UV housing could be effectively and affordably constructed using local materials, e.g. pottery or concrete, as opposed to traditional stainless steel.

UV is a proven technology for the inactivation of Cryptosporidium. LeChevallier and Au [68]. confirmed this in a report issued on behalf of the World Health Organisation 2004, in which they showed that Ultraviolet light inactivates microorganisms through reactions with microbial nucleic acids and is particularly effective for the control of Cryptosporidium. In the United States, the US EPA have implemented a groundwater rule, requiring that any site with a cryptosporidium risk must put in place relevant technology to eliminate that risk. They have referred to UV as an acceptable treatment option for this problem. It is capable of killing off all microorganisms provided that the exposure time to the light source is adequate. Therefore, it could be categorized as a sterilization process. The radiation has an electromagnetic wavelength of 260 nano metres (nm). It is the genetic material or DNA (deoxyribonucleic acid) that is the target for the UV light. As UV penetrates through the cell wall and cytoplasmic membrane, it causes a molecular rearrangement of the microorganism's DNA which prevents it from reproducing. If a cell cannot reproduce, it is considered dead [50]. These units are housed in stainless steel cartridges, and are plumbed into the supply pipeline, as close as possible to the point of use to reduce, or eliminate, the risk of further contamination. They are available in various sizes and are ideally suited for domestic applications that are supplied by a private well. Tests have shown that even at high flow rates uv radiation can kill off 99.7% faecal coliforms. Apart from being convenient to use they are also very economical and effective [32].

Ultraviolet is one energy region of the electromagnetic spectrum which lies between the x-ray region and the visible region. UV itself lies in the ranges of 200 nanometers (1 nanometer (nm) = 10^{-9} meter) to 390 nanometers. Since energy levels increase as the wavelength increases. The UV spectrum is divided into four regions, which are designated Vacuum UV, UV-A, UV-B, and UV-C [32]. The latter two are of particular importance for the sterilisation of water.

UV-A or long-wave ultraviolet, which occurs between 325-390nm bands, is represented by naturally occurring sunlight. This range has little germicidal value.

UV-B or middle-wave ultraviolet occurs between 295 - 325 nm and is best known for its use in sun tanning lamps. These middle-waves may also be found in sunlight and provide some germicidal effect if exposure is sufficient. K.G. Mc Guigan et al [69] conducted studies on the use of UVB, using batch solar disinfection (SODIS). Both natural sunlight and simulated sunlight were used. The simulated solar light source was a 1000W xenon arc lamp. The wave length of the light produced was set at a maximum of 320 nm, at a constant temperature of 40°C. They concluded, that Giardia was inactivated after an exposure time of 4 hours, and cryptosporidium inactivated after 10 hours exposure. Therefore this system could only be expected to be successful in regions of continuous sunshine.

UV-C or short-wave ultraviolet occurs between 200-295 nm and is where the most effective germicidal action occurs. The optimum UV germicidal action occurs at 265 nm.

Since short-wave ultraviolet is screened out by the earth's atmosphere, naturally occurring UV-C is rarely found on the earth's surface. UV-C is generated in a low-pressure mercury vapour lamp. UV light is produced as a result of the electron flow through the ionized mercury vapour between the electrodes of the lamp. These UV lamps are similar in design to standard fluorescent lamps with a few notable exceptions. UV lamps are typically manufactured with a quartz "hard glass" sleeve, see Figure 2.14. as opposed to "soft glass" found in fluorescent lamps. This quartz allows for a transmittance of over 90% of the UV radiated energy. Fluorescent lamps also contain a thin coating of phosphorous inside the lamp that converts the UV to visible light [34,36]

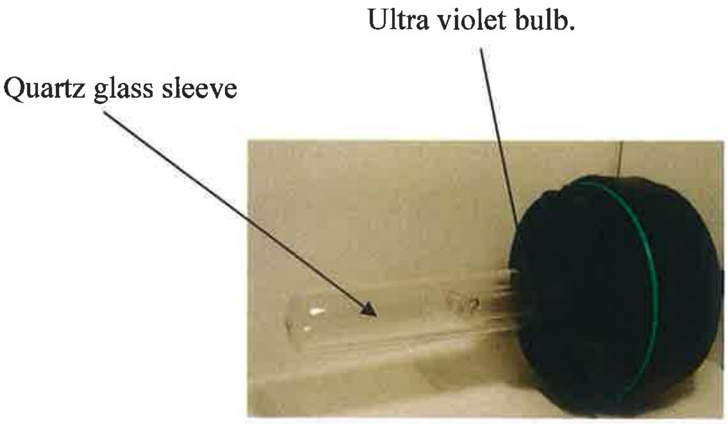


Figure 2.14. Ultra Violet Bulb in Quartz Glass Sleeve.

UV lamps emit about 90% of their radiated energy at 253.7 nm, which, by coincidence, is very close to the peak germicidal effectiveness of 265 nm. The degree of pathogenic destruction depends on both contact time of the water in the UV chamber and the intensity, which is the amount of energy per unit area (calculated by dividing the output in watts by the surface area of the lamp). This product of intensity and time is known as the Dose and is expressed in milliwatt seconds per centimeter squared (mW-sec/cm^2).

The US EPA (United States Environmental Protection Agency) accepts 50mW-sec/cm^2 as the minimum dose for UV water treatment while 38mW-sec/cm^2 is the standard set by the National Sanitation Foundation. Figure 2.15. shows the dose required for inactivation of various organisms [63,70,71].

The intensity of ultraviolet is expressed in milliwatt seconds per square centimeter mWs/cm^2 and is the product of the lamp output in watts, the length of time exposure and the cross-sectional area of the column of water being treated.

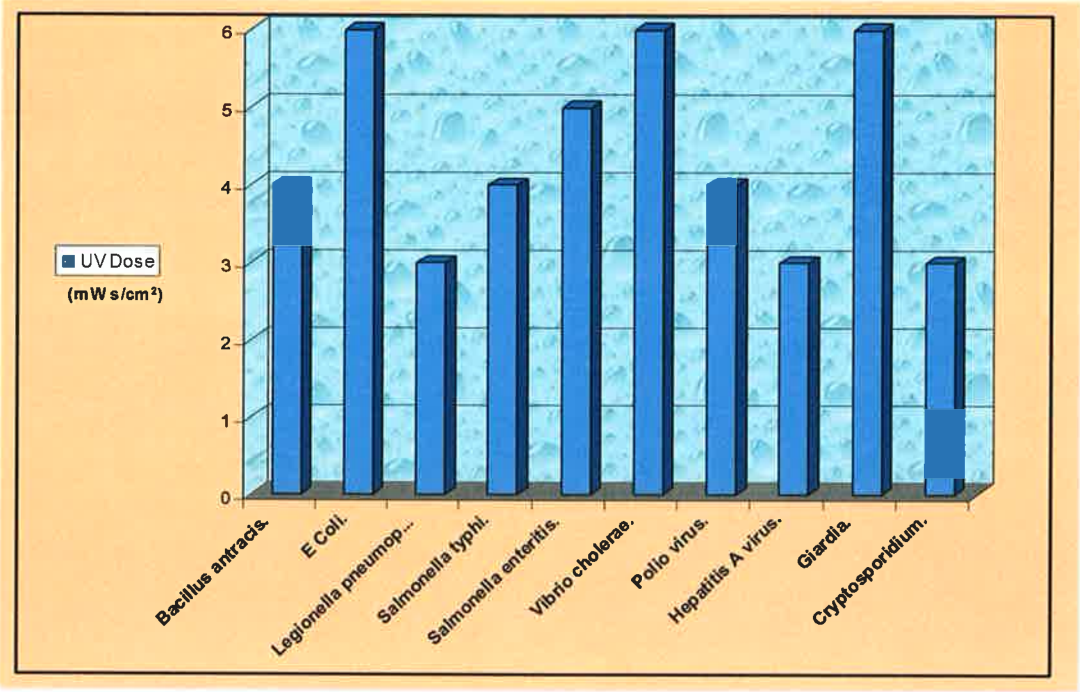


Figure 2.15. Inactivation Levels and Doses.

Figure 2.16. Shows the inactivation levels of various microorganisms compared with standards set by the US EPA. (Upper boundary line). And the standards set by the National Sanitation Foundation.(lower boundary line) [63,70,71].

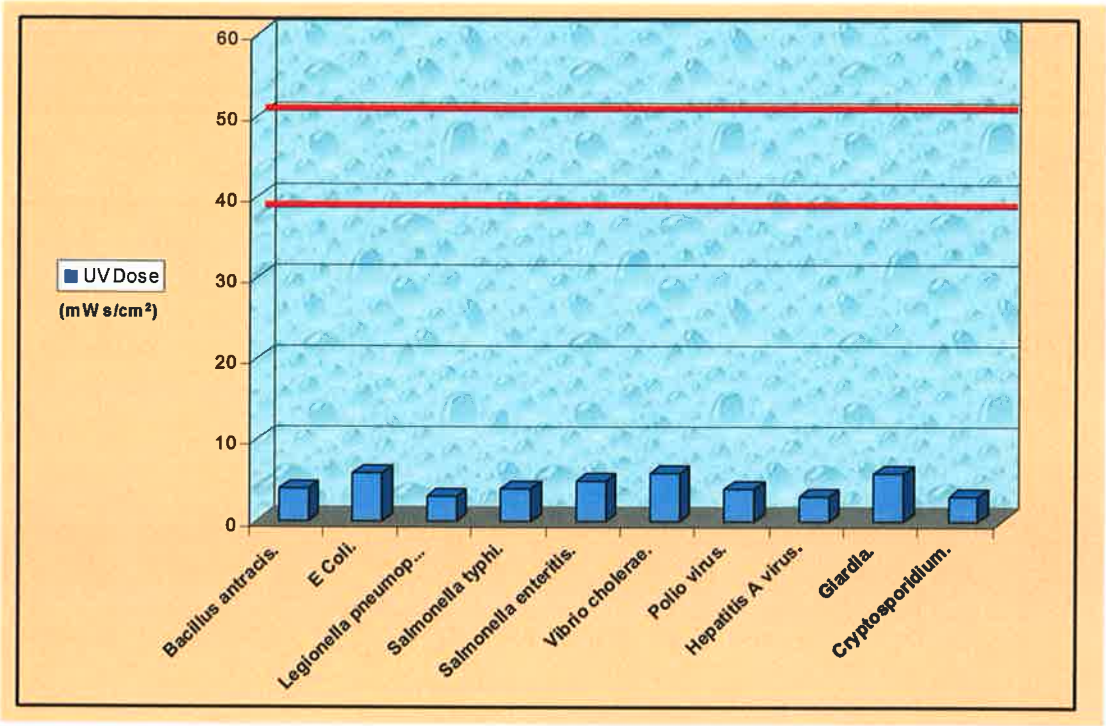


Figure 2.16. Inactivation Levels of Microorganisms Compared to Set Levels.

2.21.1 Optional Features for UV Units.

The variety of optional features that may be built into the sterilizers include:

(i) UV monitoring devices that measure the actual UV output at 253.7 nm,

(ii) Solenoid shut-off devices that will stop water flow in the event of system failure,

(iii) Flow control devices to properly limit the water flow through the units,

(iv) Audible and visual alarms (both local and remote) to warn of lamp failures,

(v) High temperature sensors to monitor excessive temperature in the reactor chamber or control panel,

(vi) Hour meters to monitor the running time of the UV lamps [72].

2.21.2 Factors Affecting UV.

The effectiveness of a UV system in eliminating microbiological contamination is directly dependent on the physical qualities of the influent water supply. Suspended solids or particulate matter (turbidity) cause a shielding problem in which a microbe may pass through the sterilizer without actually having any direct UV penetration [73]. This shielding can be reduced by the correct mechanical filtration of at least five microns in size. Iron and Manganese will cause staining on the lamp or quartz sleeve at levels as low as 0.03 ppm. of iron and 0.05 ppm of manganese. Proper pre-treatment is required to eliminate this staining problem [33].

Calcium and Magnesium hardness will allow scale formation on the lamp or quartz sleeve. This problem will be especially magnified during low flow (or no flow) times when the calcium and magnesium ions tie up with carbonates and sulphates to form hard scale build up inside the sterilizer chamber and on the lamp or sleeve [72,74].

2.21.3 Advantages of UV Lights.

Advantages of UV lights include:

(i) They are Environmentally friendly, and there are no dangerous chemicals to handle or store and no problems of overdosing.

(ii) Low initial capital cost as well as reduced operating expenses when compared with similar technologies such as ozone, chlorine, etc.

(iii) Immediate treatment process, as there is no need for holding tanks, long retention times, etc.

(iv) Extremely economical, (hundreds of litres may be treated for each cent of operating cost).

(v) No chemicals are added to the water supply and therefore no by-products are produced (i.e. chlorine + organics = trihalomethanes).

(vi) No change in taste, odour, pH or conductivity or the general chemistry of the water.

(vii) Automatic operation without special attention or measurement, operator friendly.

(viii) Simplicity and ease of maintenance, periodic cleaning (if applicable) and annual lamp replacement, no moving parts to wear out [72,74].

2.21.4 Disadvantages of UV Treatment Systems.

The major disadvantages of UV treatment are,

(i) The lack of residual disinfection.

(ii) High purity level requirement for the water.

(iii) The UV bulb must be changed annually, as its intensity diminishes.

Appendix J Shows a list of U.V. light configurations and their applications, ranging from, small scale drinking water applications to large scale waste water treatment units with integral lamp wipers [72].

Appendix K. Shows the relevant position of UV waves in relationship to visible light [72].

2.22 Treatment for Ferruginous Water.

The reasons for treating ferruginous water are:

(i) To remove the iron and manganese.

(ii) To neutralise tastes and odours.

(iii) To remove turbidity.

To achieve these objectives several treatments exist, the choice of which is dependent on

(a) The levels of Fe and Mn concentrations of the raw water.

(b) The quality requirements of the finished water.

There are five basic methods for treating water containing iron and manganese, which include.

(i) Phosphate compounds

(ii) Ion exchange water softeners,

(iii) Oxidizing filters,

(iv) Aeration followed by filtration

(v) Chemical oxidation followed by filtration.

2.22.1 Phosphate Treatment.

Phosphates prevent the iron and manganese particles from precipitating out of solution by forming a microscopic film around these particles. Therefore phosphates must be introduced into the water before oxidation can take place, i.e. at, or before, the point of abstraction. They are limited to low levels of contamination up to 3mg/l. At this level the dissolved iron and manganese are stabilised and dispersed, and cannot react with the oxygen. Since the metals are not removed, odour and taste of the iron remain in the water. Phosphate compounds are not stable at high temperatures. If the water is boiled the treated water becomes de-stabilised, the iron and manganese will come out of solution, oxidise and precipitate [75].

2.22.2 Ion Exchange Water Softener.

This method is limited to a maximum of 5 mg/l. and anything over this limit is liable to block up the system. The principle is the same as that used to remove the hardness minerals, calcium and magnesium; i.e., iron in the untreated water is exchanged with sodium on the ion exchange medium. When the system requires cleaning i.e. the exchange medium becomes loaded with precipitated iron, the unit is backwashed. Ion exchange iron removal units use sodium in the process; therefore the treated water will contain sodium. This can cause concern for people on a sodium-restricted diet [33,76].

2.22.3 Oxidizing Filter.

An oxidizing filter treatment system operates by passing the water through a filter of manganese greensand or manufactured zeolite coated with manganese oxide. These minerals oxidize the iron and manganese out of solution. The process can handle concentrations up to 15 mg/l. Synthetic zeolite (minerals consisting of hydrated aluminosilicates) [50] requires less backwash water and softens the water as it removes iron and manganese.

2.22.4 Aeration Followed by Filtration.

This is a natural approach to iron and manganese oxidation. The water being treated is aerated by pumping air through it. This accounts for the fact that there is no dissolved iron or manganese in fast running water, it is self-oxidising. High levels of dissolved iron and manganese can be oxidized by this method. Once the water has been oxidised, it is then passed through various filters, which will remove the precipitated iron and manganese, along with taste and odour where a charcoal filter is used. The maintenance of such a filter requires regular backwashing, the frequency of the backwashing is dependent on the loading of the filter medium [33,76].

Aeration processes have been used to improve water quality since the earliest days of water treatment. In this process, air and water are brought into intimate contact with each other to transfer volatile substances to or from the water. The removal of a gas from water is classified as desorption, or stripping. The transfer of a gas to water is called gas adsorption. The U.S. Environmental Protection Agency (USEPA) has identified air stripping as the best available method for the removal of volatile organic chemicals (VOCs) in contaminated groundwater.

Aeration of water has many benefits which include:

(i) Dissipation of free carbon dioxide,

(ii) The introduction of oxygen,

(iii) The precipitation of iron and the removal of certain odours due to volatile substances.

Aeration effectively removes odour due to hydrogen sulphide but only partially removes, or leaves unaffected, tastes and odours caused by organic matter, biological growths or chlorination [27].

Efficient aeration takes place in fast-flowing streams, particularly when the water splashes over rocks, weirs, etc., and it plays an important part in the self-purification of rivers. From stagnant streams and impounding reservoirs, and occasionally from underground sources, poorly oxygenated water is obtained, and aeration is then a valuable part of the purification processes and improves the palatability of the waters.

2.23 Aeration Methods.

Structures or equipment for aeration or air stripping may be classified into four general categories, waterfall aerators, diffusion or bubble aerators, mechanical aerators, and pressure aerators.

The waterfall type of aeration accomplishes gas transfer by causing water to break into drops or thin films, increasing the area of water exposed to air. The more common types are [77].

(i) Spray aerators

(ii) Multiple-tray aerators

(iii) Cascade aerators

(iv) Cone aerators

2.23.1 Spray Aerators.

Spray aerators see Figure 2.17 direct water upward, vertically or at an inclined angle in a manner that causes water to be broken into small drops. Installations commonly consist of fixed nozzles or a pipe grid located over an open-top tank [78].

Spray aerators are usually efficient with respect to gas transfer such as carbon dioxide removal or oxygen addition. However, they require a large installation area, are difficult to house, and pose operating problems during freezing weather. Spray aerators are effective provided they can be economically designed. As a decorative fountain they can be attractive. They do however have some limitations. To produce an atomizing jet, a large amount of energy is required [79]. The losses and the nuisance problems from the wind carry-over of the spray can be considerable. Climatic conditions, particularly in cold regions, limit their usefulness.

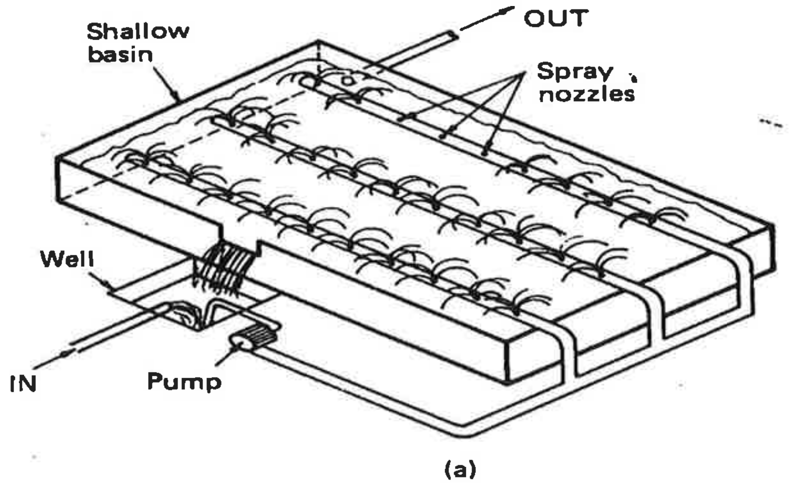


Figure 2.17. Spray Aerator.

2.23.2 Multiple-Tray Aerators.

Multiple-tray aerators consist of a series of trays equipped with slatted, perforated, or wire-mesh bottoms. Water is distributed at the top, cascades from each tray, and is collected in a basin at the base. It is important to have an even distribution of water from the trays to obtain optimum unit efficiency.

2.23.3 Cascade Aerators.

With cascade aerators, increases in exposure time and area-volume ratio are obtained by allowing water to flow downward over a series of steps or baffles. The simplest cascade aerator is a concrete step structure that allows water to fall in thin layers from one level to another [79]. See Figure 2.18. The exposure time of air to water can be increased by increasing the number of steps, and the area-volume ratio can be improved by adding baffles to produce turbulence.

As with tray aerators, operating problems include corrosion and slime and algae build up.

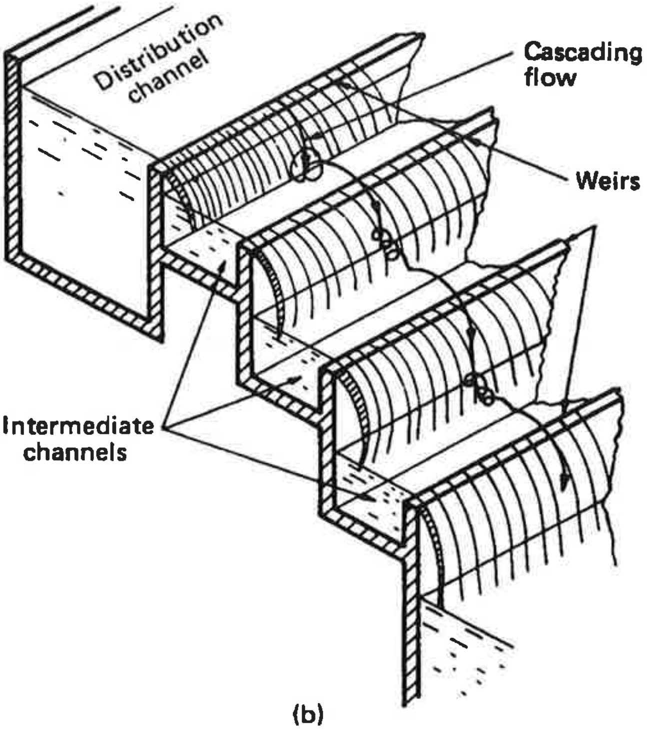


Figure 2.18. Cascade Aerator.

2.23.4 Cone Aerators.

Cone aerators are similar to cascade aerators. They have several stacked pans arranged so that water fills the top pan and cascades down to each succeeding pan. Figure 2.19 shows such an arrangement.

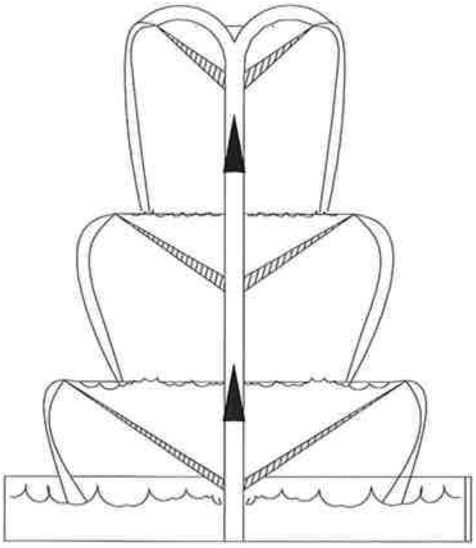


Figure 2.19. Schematic of a Typical Cone Aerator.

2.23.5 Chemical Oxidation Followed by Filtration

This treatment uses oxidizing agents such as chlorine, potassium permanganate, or hydrogen peroxide. The precipitated Fe and Mn are then filtered out. High levels of dissolved Fe and Mn greater than 10 mg/l can be treated by chemical oxidation. If colloids are present, aluminium sulphate (alum) is sometimes added to the water to aid filtration by allowing larger Fe and Mn particles to form. This process is called flocculation. The oxidizing chemicals are put into the water in a similar manner to the phosphate treatment method. A special metering pump is employed for this task, as the quantities of chemicals added must be carefully monitored. If there is excess chlorine in the water, the result is an unpleasant taste and, in the case of potassium permanganate, if it is not mixed correctly, a poisonous compound is produced. Consideration must be given to the pH of the raw water. For chlorination to work well the ideal pH is between 6.5 and 7.5. A pH greater than 9.5 is required for complete oxidation of water with high levels of manganese, it is therefore not suitable in this case [33,69,75].

2.24 Coagulation Flocculation Sedimentation.

Basic water treatment comprises four common procedures namely; Coagulation, Flocculation, Sedimentation and Filtration. However, due to the structure of aquifers from which soft ground water is abstracted (see sections 2.33 and 2.13.1), the water is generally considered to be filtered and therefore free from pathogens, a fact that is borne out in a field study carried out on groundwater by Sarah Hindle. For these reasons the processes of coagulation, flocculation and sedimentation shall not be dealt with in great detail in this study [80]. In conjunction with Cranfield university UK, Hindle conducted an M Eng research project into filtration of ferruginous water in Uganda. the subject water was ground water, and had high concentrations of dissolved iron. The districts under investigation were

(i). The Rakai district. Central Uganda.

(ii). The Hoima district. Western Uganda.

Tables 2.3 and 2.4. below outline the iron concentrations in the water of each of the districts.

Borehole No.	**Fe Mg/l.**	**Uses of water.**
1	71	W
2	3.4	DC,W
3	44	W
4	15	DC,W,L
5	6.0	DC,W,L
6	71	N
7	9.5	W
8	3.2	W
9	1.2	DC,W,L

Table 2.3. Iron Concentrations in the Water of the Rakai District. Central Uganda.

Borehole No.	**Fe Mg/l.. (2000)**	**Fe Mg/l.. (2002)**	**Uses of water.(2002)**
1	0.4	2.7	DC,W,L
2	48	44.3	N
3	53	40.5	W^{x}
4	68	14.1	DC,W,L^{x}
5	1.2	1.5	DC,W,L
6	9.3	14.7	W

Table 2.4. Iron Concentrations in the Water of the Hoima District. Western Uganda.

"X". these boreholes had simple iron filters attached to the pumps. The reduction in concentrations can be clearly seen.

Key to symbols.

DC .	Drinking , Cooking.
W.	Washing hands, dishes etc
L.	Laundry.
N.	Not used.

The research was carried out with collaboration with other countries who have developed their own iron removal plants (IRP)^{s} .these countries are outlined in table 2.5.

Country.	**No of IRP Units**
India.	500.
Ghana.	11.
Philippines.	9.

Table 2.5. Other Countries with Ferruginous water Problems

The design of the filter system was a simple concept. The main criterion apart from iron removal, was maintenance. However, after a two-year trial period the filters had not performed as well as expected. The failure was attributed to lack of maintenance by the locals.

2.24.1 Coagulation.

Fine particles <10μm do not settle readily. Settling velocities are shown in table 2.6.

Particle size (μm).	**Settling velocity (m / h)**
1000	600
100	2
10	0.3
1	0.003
0.1	0.00001
0.01	0.0000002

Table 2.6. Settling Velocities of Particles as a Function of Their Size.

The fine particles are all negatively charged which inhibits their uniting and the formation of larger settleable particles [35]. Coagulation is always considered along with flocculation and is used to remove particles which cannot be removed by sedimentation or filtration alone. The particles can be aggregated by adding trivalent cations. These are added as chemical coagulants.

Chemicals commonly used as coagulants in water treatment are aluminium and ferric salts which are present as the ions Al^{3+} and Fe^{3+}. These positively charged multivalent ions neutralise the naturally occurring negatively charged particles, thus allowing the particles to unite. The use of aluminium sulphate can also produce aluminium hydroxides, which are sticky and heavy and are beneficial in clarification of the water. The equation can be represented as,

$Al^{+++} + 3OH^{-} \rightarrow AlOH_3 \downarrow$ [31]. P 92 Equation 2.11.

2.24.2 Flocculation.

Flocculation is the process whereby the minute colloidal particles are united which enables them to settle under their own weight, into larger particles or flocs that can then be removed from the water. Floc is an open structure containing large quantities of water, with a density slightly higher than that of water. However, it undergoes a structural change with time, called syneresis [81]. which results in it losing water and becoming more dense as it ages. In order for flocs to grow, they must be brought together so that they unite with each other. There are two types of flocculation

- Perikinetic flocculation
- Orthokinetic flocculation

2.24.3 Perikinetic Flocculation.

This is brought about by natural Brownian motion, which takes time. It is sometimes speeded up, either by the addition of coagulation chemicals known as Polyelectrolytes [81], Al $(OH)_3$ Aluminium Hydroxide or $Fe(OH)_3$ Ferrous Hydroxide.

2.24.4 Orthokinetic Flocculation.

This mechanical flocculation can be achieved by the use of paddle stirrers or by baffled tanks, as shown in Figure 2.20 [81].

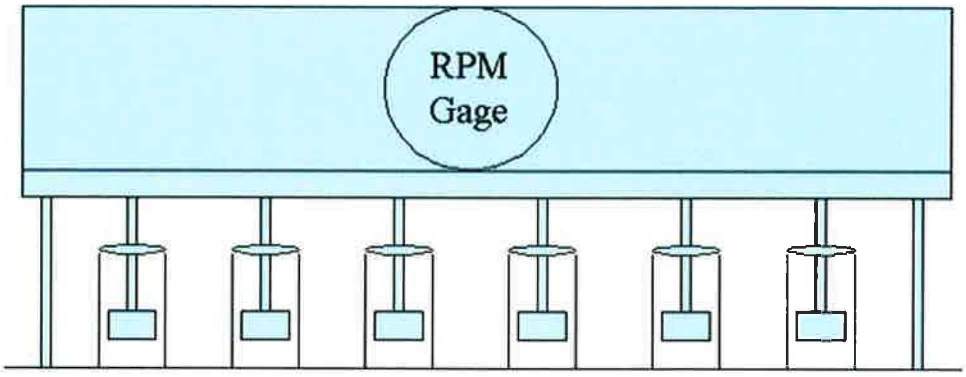


Figure 2.20. Paddle Stirrer System.

2.24.5 Sedimentation.

Sedimentation is the settlement of particles, which have a higher density than the liquid in which they are suspended under the influence of gravity. Simple settlement in horizontal settling tanks is widely used for the preliminary treatment of water with large numbers of suspended solids, such as river water

2.25 Filtration.

2.25.1 Solids Removal by Filtration.

Filtration is a process which is used to remove unwanted particles from common substances. It is a combination of chemical, physical and mechanical processes, where the substance being treated is passed through a series of tortuous paths. It can be applied to both gases and liquids. Filtering can also be achieved by bacterial processes. (See section 2.26.1).

2.25.2 Filter Materials.

Ideally filter materials should be of such a nature and size so as produce clean water with a minimum head loss, and they should be easily cleaned by backwashing [82]. Ideally, the perfect filter medium should posses the following qualities.

(i) Be coarse enough to maintain sufficient flow rates.

(ii) Have sufficiently small cavities to trap suspended solids.

(iii) Be suitably graded to prevent "blinding" [44].

These properties are discussed in greater detail below. The most important properties are the effective size and the uniformity coefficient

(i) The effective size of a filter medium is the sieve size through which 10% by weight of the medium will pass.

(ii) The uniformity coefficient. (UC) is the size of the aperture through which 60% of the media will pass divided by the size of the aperture through which 10% of the media will pass. This is an indication of the distribution of particle size in the media [83].

The use of a finer medium results in a greater retention rate and smaller particles being filtered out, however the head loss is greater. A more uniform filter medium allows the filter to be used to a greater depth. Coarser materials permit greater throughput of the filter and lower head loss with the result that more particles get through. In an effort to maximise the performance of filters, more than one medium may be used in one filter. Such a filter is referred to as a dual media filter where two grades of filtering media is used, a filter using more than two grades of filter media is known as a multi-media filter [84]. These filters operate on the principle of removing the debris from the water on a gradual basis. This principle will be examined in greater detail in section 3.10.

2.25.3 Filter Material Types.

Various media are employed in the filtration process, such as sand, charcoal, and diatomaceous earth. Below are some of the commonly used filter media.

(i) Sand.

This is the least expensive and therefore the commonest filter medium. It must, however, be clean with an effective size of between 0.45 to 0.60 mm and a UC (uniformity coefficient) between 1.2 – 1.7. The typical specific gravity of silica sand is in the order of 2.65 [36]. Therefore, sand with a diverse grade including very fine particles (fines) would be unsuitable, as the fines promote clogging, and hence rapid increased head loss [32].

(ii) Garnet.

These materials are very dense with a specific gravity of 4.2. They are normally only used as a component of a multi media filter [36].

(iii) Anthracite.

This material is a form of hard coal and is sometimes used as a filter medium along with sand in a dual media filter. It has an effective size of at least 0.7 mm, its UC is less than 1.75 and its specific gravity of 1.4 [32,36]. These properties make anthracite a very suitable dual media filter material, since it is coarse enough as a “pre filter” and has a specific gravity far less than that of sand, thereby enabling the filter to retain its stratified structure after backwashing. Specification of such filter materials is shown in Table 2.7. Figure 2.21. shows a typical dual media filter. i.e. coarse medium on top with the finer medium beneath.

Upper layer (pre- filtration).	
Material.	Anthracite.
Specific gravity.	1.4-1.6.
Effective size.	0.9-1.1 mm
Uniformity coefficient.	< 1.7
Lower layer (fine – filtration).	
Material.	Sand.
Specific gravity.	2.65
Effective size.	0.45 – 0.55 mm.
Uniformity coefficient.	< 1.7

Table 2.7. Specifications of a Dual Media Filter.

Figure 2.21. Dual Media Filter.

(iv) Diatomaceous Earth.

Diatomaceous earth (DE) is a fossil-like skeleton structure of microscopic water plants called diatoms, ranging in size from between 5 μm to 100 μm. Its odourless, tasteless, and chemically inert characteristics make DE safe for filtering water or other liquids intended for human consumption.

DE filtration relies upon a layer of diatomaceous earth placed on a filter element or septum, which is referred to as pre-coat filtration [30]. This pre- coat is deposited at a rate of 0.3kg/m^2. DE filters are effective in removing Cysts, e.g. Giardia and C parvum. It is also a proven method in the removal of iron algae, and asbestos from water [84,86].

(v) Carbon Filters.

Carbon filters are normally referred to as activated carbon filters. Activated carbon is available as

(a) Granular activated carbon (GAC) or
(b) Powdered activated carbon (PAC).

It can be prepared from nearly all organic solids. All the volatile matter is driven off leaving a porous carbon skeleton like structure. Most of the Activated Carbon used for general water treatment is made by carbonising coconut shell. The carbon is `activated' by steam in an oxygen-free environment at a temperature of between 700 – 950°C. This leaves the carbon with a minute porous structure while retaining a high crush resistance. This open structure has a very large surface area per unit volume [32]. During organic filtration with Activated

Carbon, the molecules of the contaminant travel into the pores and are trapped. Since the material is positively charged by the adsorption of hydrogen ions in its preparation, the negatively charged colloids can easily be adsorbed, a process which can be enhanced by elevated temperatures [32]. Eventually, all of the pores become filled and the Activated Carbon needs to be changed or reactivated.

Activated carbon is an ideal medium for the removal of the organic materials responsible for tastes and odours. It is also very effective for dechlorination of water. Chlorine removal is a catalytic process in which the media does not become exhausted or blinded by the Chlorine. However, the catalytic sites on the surface of the Activated Carbon will eventually become blinded by other contaminants in the raw water so that the media will still need to be changed (typically every 1-3 years), even when the primary use of the media is for dechlorination [36, 81].

PAC is added to the water as slurry at the rate of between 5 – 10 g/m^3. It must be added prior to filtration since it must be removed after adsorption. It is mainly used on an intermittent basis to control occasional odours and tastes that occur with seasonal changes [32]. As it mixes with sludge from the overall process it must be discarded after use, i.e. when it becomes saturated [27].

2.25.4 Saturation.

Saturation is the state where the pores in the carbon have become clogged, and is detected by odour and or taste breakthrough at which point it must either be replaced or regenerated. Regeneration of the carbon is achieved by re-heating it with steam. However, large amounts of up to 25% of carbon may be lost in the operation [27]. Reactivated GAC is less efficient than new carbon [31,35]. PAC also has the disadvantage that, when it becomes packed, the bed offers greater resistance to flow hence requiring more energy to pump the water through. This problem is not as acute when using a high grade PAC [85].

GAC is easier to use, as it is a continuous process that takes place in a sealed column, and the flow can either be downward or upward. An upward flow maximises the contact between water and filter, resulting in better performance [35,85].

2.26. Sand Filtration.

Sand Filtration uses granular media to remove low levels of suspended solids from water. These are classified as either slow or rapid and can be operated either by gravity or pressure. Filtration is used in all aspects of water treatment and for pre-treatment in applications as:

(i) Filtration of borehole water to remove iron and manganese;
(ii) Direct filtration of upland waters after in-line coagulation;
(iii) Removal of residual suspended solids after clarification
(iv) Pre-filtration to protect membrane processes;
(v) Removal of residual precipitates from industrial effluents [57].

2.26.1 Gravity Filtration.

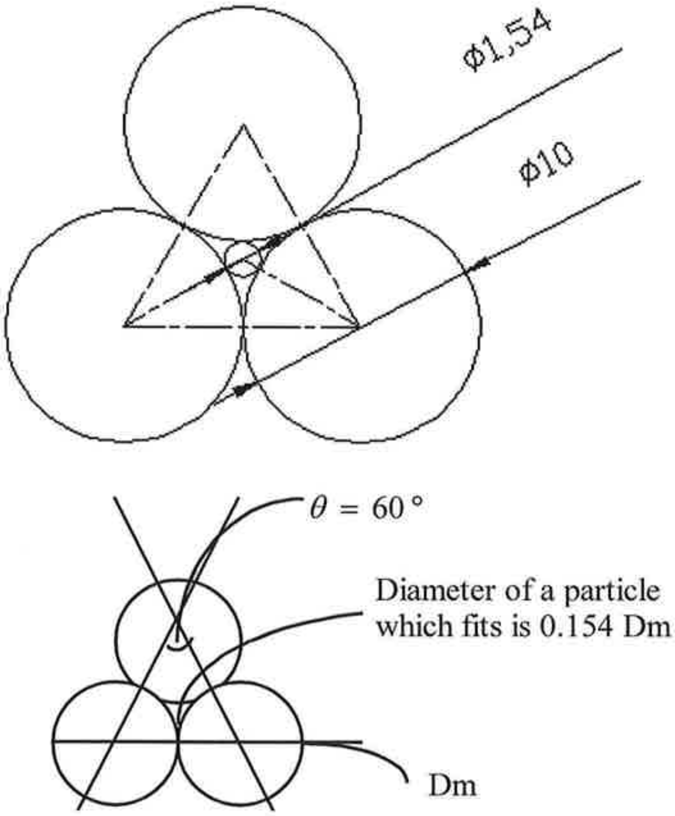
Gravity filtration is commonly referred to as slow sand filtration (SSF). The quality of treated water is excellent but, because of the high land area required, the capital cost is very high and this method of filtration is largely outdated. Normally, there are a number of filter units in a system and each filter is run for a period of time usually around 24 hours, then taken offline for cleaning by backwashing [32,51].

The usual filter medium is sand but other materials such as anthracite, garnet, manganese oxide, and dolomite amongst others are used. Raw water is filtered through a bed of fine (0.25mm) sand about 1.0-2.0 m deep [32,33]. The flow velocity is slow (around 0.1 m/h) and on the surface of the sand, a gelatinous layer forms that removes turbidity, colour, taste and odour, by a combination of filtration and biological activity (bacteria, and algae), called the schmutzdecke [32,51]. As it builds up, the flow through the filter declines and, after a few weeks, the top layer of sand is removed by manual or automatic scraping. The sand is washed and subsequently returned to the filter [57,77].

2.26.2 Rapid Sand Filtration.

Rapid filtration has some of the benefits of slow sand filtration but uses a much smaller area. Typical approach velocities are in the range 5 - 20 m / h using 0.8mm sand.

The Calculation of the particle size, which will just fit through the media, is shown in Figure 2.22. The grit diameter "10" is a nominal figure, to show the relationship between the grit size and the void between the grit particles.



$$\cos 30^\circ = \frac{R_m}{R_m + R_P} = 0.866$$

Where; Dp = diameter of the particle.

$R_m = (R_m + R_P)\ 0.866$

$R_P = 0.154\ R_m$

$D_P = 0.154\ D_m$

Dm = diameter of the material.

Rp = radius of the particle.

Rm = radius of the medium.

Therefore the diameter of the particle, which fits between the filter media, is 0.154 x media diameter

Figure 2.22. Calculation of the Particle Size [87].

The above calculation is carried out on the assumption that all of the sand particles are both identical in size and also spherical, which is not the case.

However, the calculations work well in general terms. Figure 2.23. is a more realistic representation of the nature of the media grains. Figure 2.24 depicts the separation of the filter media grains and the dislodgment of the trapped debris particles during the backwash operation.

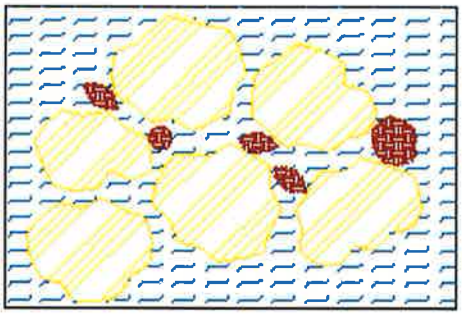


Figure 2.23 Representation of Media Grains With Trapped Debris.

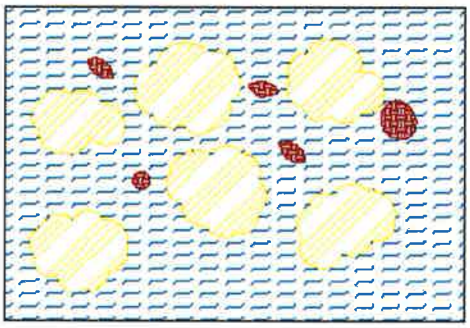


Figure 2.24. Debris Being Dislodged by Fluidisation of Filter Bed Grains.

2.27 Dual Media Filters.

These filters typically are comprised of anthracite and sand as shown in Figure 2.21. This type of filter acts as a combined pre-filter and finishing filter. Work done on dual media filters by A. Zouboulis et al [88]. on a water treatment facility in Greece, explores the advantages of such filtering methods. In his study he used 60/40 sand

D_{10} 0.64 mm, and anthracite D_{10} 1.0 – 1.0mm, on full size filter beds, with a total depth of 1.0m. The filters proved effective in that, the pre-filter facility increased the service intervals between backwashing, compared to the performance of a single medium sand filter. This increase was found to be three times greater, which represented 10% higher water production. However, in their article they omit stating the reason for choosing anthracite. The reason why anthracite is chosen is due to its reduced density compared to sand [32,36]. This property of anthracite ensures that the stratified nature of the filter is maintained after backwashing, due to the lower settling velocity of the lighter medium. The settling velocity for a 0.6 mm sand with a relative density of 2.65 is, 6.3cm/s, compared to, 4.0 cm/s for a 1.0mm anthracite with a relative density of 1.5 [27]. If the size difference of the particles is greater than 5:1, then settling velocities of the two media tend to coincide resulting in the larger and smaller particles settling together. The result of this is that the spaces between the larger particles become blocked with the smaller particles, resulting in inefficient operation of the filter [Solt and Shirley]. Another point that seemed to be overlooked by Zouboulis was the backwash rate. The terminal velocity for the lighter anthracite is less than the sand, care must be exercised when setting the backwash flow rate. There is a danger of washing the lighter material out to waste if there is not sufficient headroom.

2.27.1 Fluidisation of Filter Bed.

The sand bed removes particles much smaller than the interstices between the grains including cryptosporidium ocysts (5μm) and some bacteria (0.5μm) by a process called depth filtration. As water flows downwards between the sand grains, simple straining or

surface filtration traps particles larger than 50μm. Smaller particles are deposited on the surface of sand grains by a variety of processes including:

(i) Direct interception, where particles are carried on to the grains by the water flow stream lines;

(ii) Diffusion, where random movements (Brownian motion) of the particles across the stream lines cause collisions between particles and sand grains;

(iii) Inertial deposition, where the particle's inertia carries it into collision with the sand grain when the stream line changes direction;

(iv) Sedimentation, where the particle's mass causes it to settle from the stream line onto the sand surface [50].

As the filter run proceeds, the removed solids take up more and more of the available deposition spaces within the sand grains and the penetration of solids moves further down the bed. Eventually, the capacity of the filter is reached and suspended solids begin to appear in the filtered water and are detected as dirty water passing through or a turbidity breakthrough. This would normally be accompanied with a reduction in the filtrate flow.

The loading time interval of the filter may be lengthened by the use of a multi media filter. This unit would typically have a coarse medium resting on top of a much finer grit. The advantage is the coarser grains pre-filter the water prior to passing through the finer material. It must be remembered however, that this configuration must remain the same after backwashing. This is achieved by using a "top" material of less density than the finer filtering grains. The settling velocity of the finer sand is greater than the anthracite that settles at a slower rate. This differential settling rate maintains the correct stratification of the filter unit. The sand bed is contained in a filter shell, which may be circular or rectangular in plan, and may be open-topped operating under gravity flow (gravity filter) or closed and operated under pressure (pressure filter). As solids accumulate in the filter bed, the water flow through the bed is restricted causing an increase in the head loss. In a gravity filter, the static head of water above the sand bed provides this head, while in a pressure filter it is a pumped head.

2.27.2 Backwashing.

Backwashing is the term used to describe the cleaning process of a filter. It must be carried out when the head loss becomes too-high or when turbidity breakthrough is detected. At this point the filter is taken off line and backwashed. Filtered water is pumped upwards through the sand. When the up flow velocity of the wash water reaches the terminal velocity of the sand grains (the point at which the particles become suspended), the bed starts to fluidise, that is the sand grains begin to separate from each other and to float freely [49,83]. It is important that the backwash flow rate is kept to the minimum to achieve the terminal velocity for the lighter filter medium. (eqn) 2.13 If this velocity is exceeded then there is a risk of backwashing the filter media to waste. The fluidisation of the sand releases the retained suspended solids, a process assisted by bubbling air through the sand bed (air scouring) which causes the sand grains to rub against each other, thereby dislodging the retained solids from the sand surface. The suspended solids are then washed from the sand bed and out to waste Figure 2.25. shows a newly constructed multi media filter at rest Figure 2.26. shows the filter during the backwash cycle. Note, the dispersion of the anthracite throughout the entire filter. These views show the turbulence and expansion of the filter bed, while Figure 2.27. shows the filter after backwashing, the stratification of the multimedia filter is still clearly visible.

2.27.3 Effective Filter Backwashing.

Effective filter backwashing can only be accomplished when the packed filter media is fluidised. The required head loss required to cause fluidisation and expansion of the filter bed can be calculated from the following expression.

$$h_{fb} = L(1-\varepsilon)(\rho m - \rho w)/\rho w. \qquad \text{Equation 2.12}$$

Where h_{f_b} = required head loss / pressure

L = bed length

$(1-\varepsilon)$ = filter media as a fraction of filter bed (packed)

ρm = density of the filter medium.

ρw = density of the water.

2.27.4 Backwash Rate.

Desirable backwash rates, must be less than $4.7D_{60}$m/min for anthracite with a specific gravity of 1.55 and greater than $10D_{60}$m/min for sand, with a specific gravity of 2.65. This is applicable where the sand being used is a D_{60} grade [32,79]. The flow velocities for fluidisation can be calculated from the following expression.

$$V_h = V_t \times f^{4.5}$$ Equation 2.13 [32].

Where V_h = Minimum fluidisation velocity.

V_t = Terminal velocity required to drive medium from bed.

f = Porosity of medium [79].

Figure 2.25. Multi Media Filter at Rest.

Figure 2.26. The Filter During the Backwash Cycle,

Figure 2.27. The Filter at Rest after Backwashing.

2.28 Determination of Fe and Mn in Ground Water.

The initial indications that iron or manganese is present in water are described in section 2.13.3. However these indications are crude, and indicate only high contamination levels in the water. The speed with which discolouration takes place and the degree of discolouration is dependent upon the levels of contamination. For more accurate measurements atomic absorption spectrophotometry and colourimetric methods are used [43].

2.28.1 Phenanthroline Method

The phenanthroline method is the preferred standard procedure for the measurement of iron in water at the present time, except when phosphate or heavy metal interferences are present [43].

2.28.2 Principle of the Test.

Beer's law.

Beer's law is based on the principle that light is absorbed relative to solution concentration. It states that the intensity of a ray of monochromatic light decreases exponentially as the concentration of the absorbing medium increases. Once a coloured complex is formed, the wavelength of light which is most strongly absorbed is found by measuring the absorbance at various wavelengths between 400 - 600 nm. After the most suitable wavelength is determined, a series of iron standards is measured at this wavelength and a calibration plot of absorbance vs. concentration is prepared. The absorbance of the unknown sample is measured and the calibration curve is used to calculate the concentration of iron in the sample

$$A = \varepsilon bc \qquad \text{Equation 2.14.}$$

A is dimensionless

b = is the pathlength of absorbing medium or cell thickness (cm)

c = concentration of absorbers (mol/L)

ε = molar absorptivity or a proportionality constant $(L/mol/cm)$

2.28.3 Persulfate Method.

The persulfate method is best suited for routine determinations of manganese because pre-treatment of samples is not required to overcome chloride interference. Ammonium persulfate is commonly used as the oxidizing agent. It is subject to deterioration during prolonged storage, for this reason, it is always good practice where samples are not run routinely to include a standard sample with each set of samples to verify the potency of the persulfate used [43].

2.28.4 Periodate Method.

The periodate method is somewhat more sensitive to small amounts of manganese than the persulfate method, and the coloured solutions produced are stable for longer periods of time. It is especially applicable where manganese concentrations are below 0.1 mg/l. Chlorides interfere, and it is often necessary to expel them as HCI by evaporating the sample with sulphuric acid to the point at which the sulphuric acid begins to distill. This is recognized by the formation of white fumes resulting from the condensation of water vapour in the atmosphere by the sulphuric acid as it distills.

The oxidation of manganese from its lower oxidation states to permanganate by periodate is normally accomplished without the aid of a catalyst. However, where small amounts of manganese are involved, the use of Ag^+ (silver) as a catalyst is recommended. The reaction involved may be represented as follows:

$$2Mn^{2+} + 5IO_4^- + 3H_2O \rightarrow 2MnO_4^- + 5IO_3^- + 6H^+$$ Equation 2.15 [43].

2.29 Existing Methods of Iron Removal.

At present there are various methods used for removal of iron from ground water

Iron removal media

2.29.1 Birm

Birm is aluminium sulphate coated with Manganese dioxide MnO_2. It is used as a filter material commonly used for the reduction of iron and or manganese from water supplies. It oxidizes the iron and gives good removal at a relatively low cost. It is generally suited to waters that would be considered hard in nature, its performance is adversely affected by the presence of chlorine, organic contaminants and some chemical treatments.

It acts as a catalyst between the oxygen and the soluble iron compounds, and enhances the oxidation reaction of Fe^{++} (dissolved iron) to Fe^{+++} (oxidized iron) and produces ferric hydroxide which precipitates and may be easily filtered. Because it is a granular material it is easily cleaned by backwashing to remove the trapped debris. The limitations of this method are that chlorine in some water greatly reduces the effectiveness. High concentrations of chlorine compounds may deplete the catalytic coating. The water must not contain hydrogen sulphide, the organic material must not exceed 4-5 ppm. With a pH of at least 6.8 therefore pH adjustment is necessary in some cases. It should be noted that ferruginous water should have a pH of below 8.5

High pH conditions may cause the formulation of colloidal iron, which is very difficult to filter out [88].

2.29.2 Filox R.

Filox-r is the raw, unrefined ore used in the manufacture of filox filtration media. Chemically, filox-r (Raw) is a naturally occurring ore that has been properly screened and sized. It's major constituent is manganese dioxide MnO_2 75-85%. The following lists some general specifications and application considerations [89].

Filox-r has a much higher level of activity than BIRM, and is more suitable across a greater range of waters. It is chlorine resistant and can be used to help in the removal of hydrogen sulphide (the bad egg smell that is sometimes encountered). It is stable within a range of 5.0 to 9.0 pH. While the acceptable range for drinking water is 6.5 to 8.5 pH. The efficiency of this treatment is greatly enhanced by the addition of oxidation agents such as oxygen, chlorine, ozone, hydrogen peroxide, potassium permanganate [89].

2.29.3 Manganese Greensand.

Manganese greensand is only used in industry for iron and manganese removal, as it requires chemical regeneration (with Potassium Permanganate) to restore its activity.

Manganese Greensand is formulated from a glauconite greensand which is capable of removing iron, manganese, and hydrogen sulfide from water through oxidation. When the oxidizing capacity power of the Manganese Greensand bed is exhausted, the bed has to be regenerated with a weak potassium permanganate [89].

2.29.4 Aeration.

Aeration oxidizes out the iron / manganese, removes volatile organic chemicals (VOCS) and radon. It is unaffected by the pH of the water and does not require recharging

$$4Fe^{++} + 3O_2 = 2Fe_2O_3 \qquad \text{Equation 2.16 [44]}$$

2.30 Water a Global Issue.

The worldwide contamination of drinking water is such a large concern that many studies have been conducted to ascertain the magnitude of the problems, and how to address them. Such research includes

2.30.1 Defence Research Laboratory (DRL) [90].

This laboratory is situated in Tezpur India. A premier Laboratory under the Defence Research and Development Organisation (DRDO), has now come up with an "Iron removal Unit" (IRU) from water The Indian Army Defence Research Laboratory DRL had successfully designed and developed an Iron removal Unit IRU to provide clean drinking water for Army Barracks and small communities as well as in rural and remote areas.

2.30.2 Hanna Andersson and Jenny Johansson [91].

Hanna Andersson and Jenny Johansson are two science students in the department of Environmental Engineering (Sanitary Engineering) Lulea University of Technology Sweden conducted a field study, for the removal of iron from groundwater in the Rakai district of Uganda. They concluded that with a simple approach the iron content of 10mg/L could be reduced to an acceptable level from between 10 - 15 mg/l to an acceptable level of 1mg/l. They also state that while numerous methods for iron removal exist, it remains a case of selecting an appropriate system for a specific water source.

2.31. Summary.

Water is vital for sustaining life; it must therefore be safe and wholesome. Water used for drinking purposes is abstracted from either beneath the ground i.e.

groundwater or from rivers and lakes i.e. surface water. Prior to use it must undergo various treatment processes, which include;

(i) Oxidation,
(ii) Sedimentation,
(iii) Filtration,
(iv) Disinfection,
(v) Fluoridation,

Oxidation is used mainly on groundwater that contains dissolved iron and manganese. This type of water is referred to as ferruginous water and is the subject water of this study. The purpose of oxidation is to oxidise the dissolved iron and manganese out of solution so that they may be removed as solid substances. Oxidation may be induced either chemically using potassium permanganate or chlorine, both of these chemicals are toxic. Oxidation may also be carried out by natural aeration without the use of chemicals, the route selected for this research. Sedimentation is the process of allowing the solid oxidised particles to settle thus forming a removable mass. Any remaining suspended solids will be removed by filtration. Various grades of filter materials are used ranging from sand and anthracite for removal of suspended particles. Charcoal for removing the tastes and odours associated with ferruginous water, and woven fabric for removing fine suspended particles prior to disinfection. Final woven fabric filtration is only necessary prior to the ultra violet disinfection process employed in this project. The more common large-scale disinfection process used is chlorination, however this disinfection process is effective on the more common infectious pathogens such as E coli. It has proven ineffective in neutralising other harmful and potentially fatal pathogens such as cryptosporidium. Chlorine may also produce harmful compounds known to be carcinogenic. UV disinfection systems have proven to be effective against E coli and cryptosporidium, while producing no harmful compounds or having side effects on consumers from the treated water.

Drinking water supplied to the majority of consumers is treated by their local sanitary authorities therefore the large scale treatment necessitates the use of chemicals that would not otherwise be used by individuals or small group scheme operators. these chemicals include aluminium sulphate as an aid to fine filtration, and fluoride as a dental hygiene supplement. Both of these chemicals carry health risks. When the water is distributed to the consumers they are not guaranteed clean safe water, as it passes through many kilometres of a rusty and sometimes cracked pipe network

The treatment unit developed in this project uses none of the above-mentioned hazardous chemicals and it may be used to treat groundwater abstracted from a private well, or it may also be effective at re-treating water supplied by the municipal authorities.

CHAPTER 3

PRELIMINARY TESTING.

3.1. Testing.

Prior to testing the water treatment unit suitable subject water had to be sourced. What was required was a supply of water that showed evidence of contamination of an appreciable amount of dissolved iron, as well as bacteriological contamination.

3.2 Samples Taken.

Four samples were taken from various areas [46]. in an attempt to find suitable water samples for tests on the treatment unit. The results of the public analysts' report Appendix L on the samples taken are outlined in Table 3.1. The presence of coliforms indicates the presence of bacteria in the water, which renders it unfit for human consumption.

The samples taken were from the counties of Kildare, Laois and Meath.

(i) Sample one was taken from a deep bored well in a peaty area, Robertstown (Co Kildare).

(ii) Sample two came from a dug, unprotected shallow well, Enfield (Co Meath).

(iii) Sample three came from a deep bored well in a limestone region, Mountmellick (Co Laois).

(iv) The fourth sample came from a council main supply, Clane (Co Kildare).

The results of the tests on the samples taken were as shown in table 3.1.

Sample Area	**Sample No**	**Sample Source**	**Coliforms Per 100ml.**	**Iron Mg/l**	**Manganese Mg/l**
Robertstown.	1	Deep well	<1	10.0	5.0
Enfield.	2	Shallow well	5.0	5.0	3.0
Co Laois.	3	Deep well	3.0	–	–
Clane.	4	Mains supply	<1	–	–

Table 3.1. Water Samples.

Determination of a water source with an iron problem was straightforward.

(i) A simple visual examination of the distribution system showing built up deposits of rust indicates the presence of iron in the water.

(ii) A colour coded analytical dipstick will indicate the presence or absence of dissolved iron in the water, and also the concentration levels.

(iii) Visual examination of a sample of water drawn from the suspect source will change colour on contact with air.

The source chosen was the well showing the greatest iron content, in this case the Robertstown deep well with dissolved iron content of 10 mg/l.

The determination of iron in water is always colourmetric i.e. the colour of a sample of water that contains iron will change when a suitable reagent is used. The degree of colour change can be compared to a master colour chart to determine the concentration levels. These tests would usually be done in a laboratory, however it is possible to carry out “field tests” using reactive dipsticks. The dipstick method was the method used in this instance. As stated before the presence of iron in drinking water is not a health problem. However, problems are associated with aesthetics (appearance and taste), and practical considerations such as staining, and industrial uses. Iron-bearing waters, with no dissolved oxygen, may appear clear when drawn from a well or stratified reservoir, and their clarity may be maintained in an anaerobic distribution system. However, when the water is exposed to air it will become turbid due to precipitation of the iron and manganese resulting from oxygen transfer. Iron-bearing waters will have a red-brown colour.

3.3 Dipstick Method.

The dipsticks used were “Eisen” Test analytical test strips. The procedure for using the test dipsticks is as follows;

(i) Immerse the dipstick in the sample for 1 second and remove.

(ii) Shake off excess liquid, and wait for 10 seconds.

(iii) Compare the colour of the reactive tab to those on the master colour chart to determine the iron content.

3.4 Test for the Presence of Total Coliforms.

The determination of the presence of total coliforms is a test, best carried out in a laboratory. These tests are listed below. However it should be noted that not all water samples can be tested by the one test. The following chart in Figure 3.1. outlines the most suitable test for different water conditions [42].

i) The multiple tube method.

ii) The membrane filter method.

iii) " Readycult" method

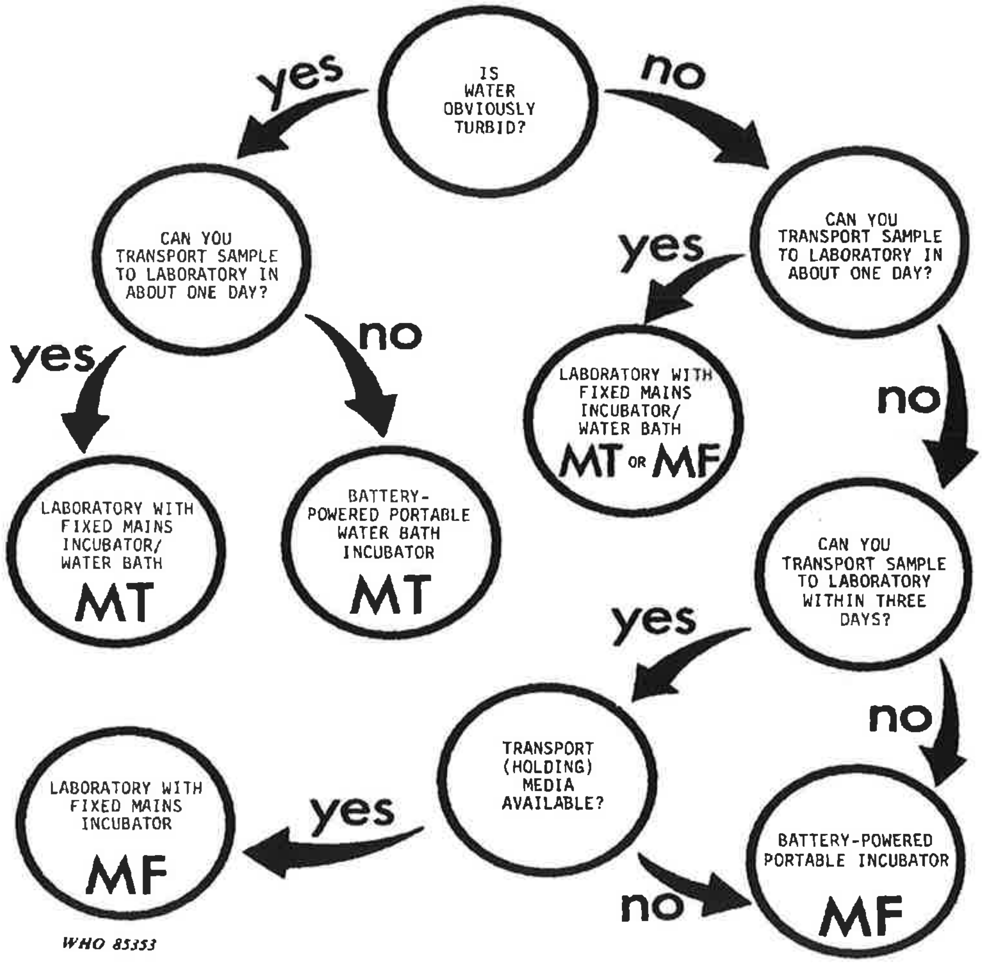


Figure 3.1. Selection network for deciding the method of bacteriological analysis.

3.4.1 Multiple-Tube Method

In the multiple-tube (MT) method, a series of tubes containing a suitable culture medium is inoculated with test portions of a water sample. After a specified incubation time at a given temperature, each tube showing gas formation is regarded as "presumptive positive" since this indicates the possible presence of coliforms. However, since other organisms may also produce the gas, a subsequent confirmation test is advisable. The two tests are known, respectively, as the presumptive and confirmed tests.

For the confirmed test, a more selective culture medium is inoculated with material taken from the positive tubes. After an appropriate time interval, the tubes are examined for gas formation as before. The concentration of bacteria in the sample can then be estimated from the number of tubes inoculated, and the number of positive tubes obtained in the confirmed test.

3.4.2 MPN Testing.

The MultiPore nutrient test (MPN), was the method of testing carried out by the “city analyst’s laboratory”, when testing the water samples. The results of these tests are contained in Appendix **L**. Measured volumes of water samples are incubated in liquid nutrients, which encourage the growth of any coliform bacteria present.

3.4.3 Membrane Filter Method

In contrast to the multiple-tube method, the membrane-filter (MF) method gives a direct count of total coliforms and faecal coliforms present in a given sample of water. The method is based on the filtration of a known volume of water through a membrane filter consisting of a cellulose compound with a uniform pore diameter of 0.45 microns; the bacteria are retained on the surface of the membrane filter. When the membrane containing the bacteria is incubated in a sterile container at an appropriate temperature with a selective differential culture medium, characteristic colonies of coliforms and faecal coliforms develop, which can be counted directly.

3.4.4 Field Testing for Bacteriological Contamination Using the "Readycult Method"

This method of testing the quality of water is very convenient for monitoring the sterilising progress of the water. This method enabled samples to be taken and tested for different flow rates through the steriliser unit.

3.4.5 Testing for Total Coliforms.

Samples of water known to be coliform positive according to the public analysts report see section 3.2 and table 3.1 were tested with the reagent kit as a means of "calibrating" it. The samples with varying amounts of iron present were then subjected to ultra violet radiation. These samples were then tested as follows.

i) Add 50ml of the water sample to a sterile glass vessel with a screw cap.

ii) Within six hours of collecting the sample add the "Readycult" granules and mix thoroughly.

iii) Incubate for 18 – 24 hours at 35°C.

iv) After incubation examine the broth for colour change the colours would be,

Yellow ....Negative.

Blue green ....Positive, i.e. coliforms present.

Fluorescence under UV light .... E Coli present.

3.4.6 Validity of the “Readycult” method.

This method is not a quantitative method. It only indicates the presence or absence of pathogens. Where a more “accurate” result is required the membrane filter method is recommended.

3.5 Precipitation of Dissolved Iron.

The first experiment in removing the iron from the water taken from the well at the Robertstown site was to measure the length of time taken for the iron to come out of solution by static exposure to the air (no induced aeration). This involved taking the sample and measuring the iron concentration. This measurement was repeated every fifteen minutes, and the physical appearance of the water noted i.e. the turbidity. Although at this stage the turbidity was not quantified. The fact that the sample was visibly cloudy indicated that turbidity was high. The results of the precipitation test are shown in Table 3.2. and Figure 3.2. These tests were carried out on site using “Eisen test” field test strips. These tests are colourimetric and the result is arrived at by comparing the colour of the reagent material against a master reference chart calibrated in whole units of Fe concentration.

Time (minutes)	Fe concentration mg/l .	Physical appearance. Visual.
0.	10.0.	Clear.
15.	8.0.	Beginning to cloud.
30.	6.0.	Becoming cloudier.
45.	4.0.	Cloudy.
60.	3.0	Colour deepening.
75.	3.0.	Brown.
90.	2.0.	Colour stable.
105.	1.0	Colour stable.
120.	0.0	Colour stable.

Table 3.2 Results of the Precipitation Test.

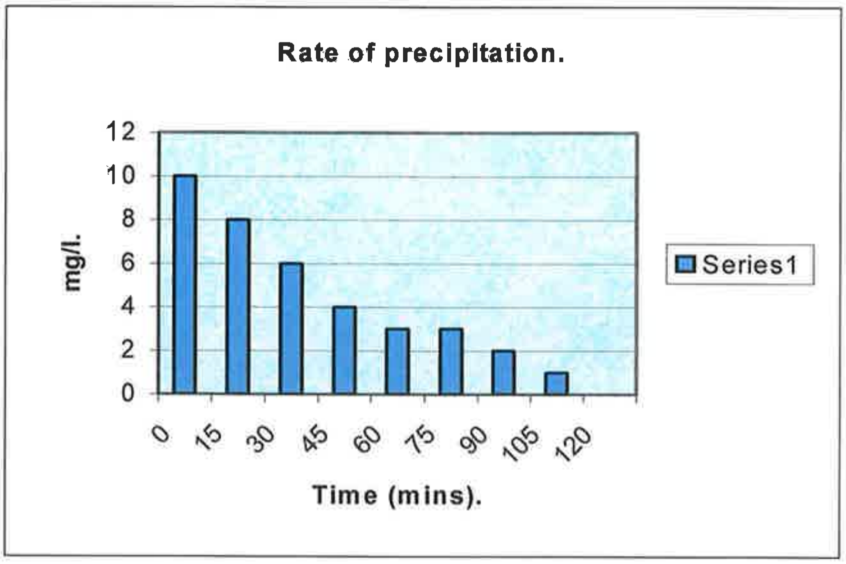


Figure 3.2 Precipitation Rate of Dissolved Iron.

3.5.1 Removal of Iron Using the Aeration and Sedimentation Tank.

In this experiment the water was aerated by re-circulating it over the cascade weir in the aeration and sedimentation tank. Two sizes of weir were used. The first was a three-stage weir the surface area of which was 360 cm^2. Then the water was pumped over a four-stage weir. The area of the weir was increased by 25% and the water was flowing at $2m^3/hr$ in each case. The results of the test are outlined in Figure 3.3.

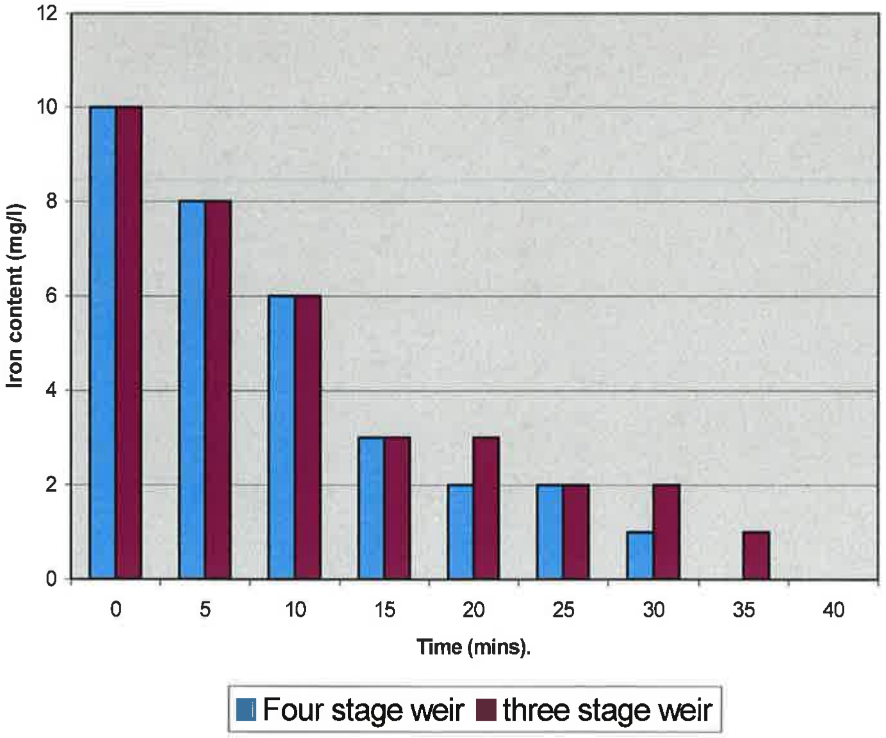


Figure 3.3. Rate of Precipitation.

3.5.2 Results of the Aeration Test

It can be clearly seen that the rate of precipitation of dissolved iron out of the water is more efficient with induced aeration. However the increase of the surface area of the weir by 25% does not reduce the exposure time significantly, therefore this experiment was not repeated.

When both aeration tests were completed, (i.e. no iron in solution), the precipitated iron remained in suspension, thus accounting for the turbid nature of the aerated water. The iron precipitate took 2.0 hours to come out of suspension thus forming a thin film of "rust" on the bottom of the container. After the water had cleared it still had an odour and a metallic taste.

3.6 Filter Design.

Prior to construction and testing of the prototype unit, a series of tests had to be carried out on various filter media in order to ascertain their suitability as filters. These tests involved constructing several filters of different sizes and using different filter media, then measuring their performance rates (See section 3.10.2).

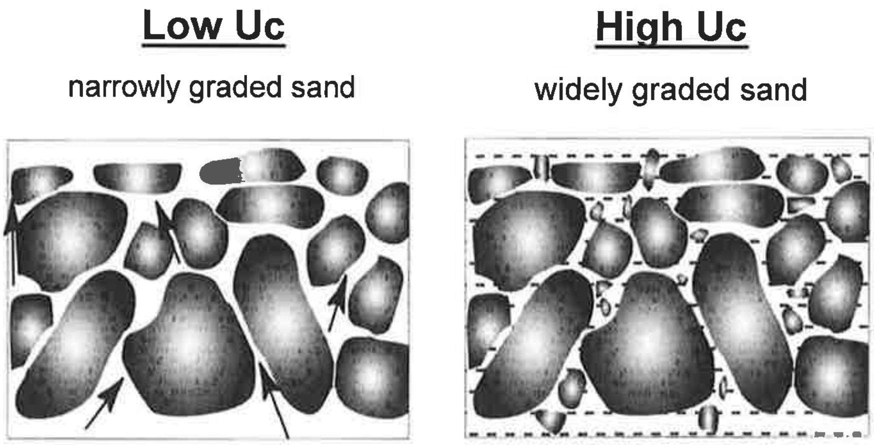
3.6.1 Sand Selection.

The success of an effective water filter is dependent on the selection of a suitable filtering material, such a medium is usually sand. Random samples of sand were selected and tested, the tests were carried out on the samples to determine;

- (i) The uniformity constant of the samples.
- (ii) The average grain size.
- (iii) The permeability of the various filter media.

3.6.2 Uniformity Constant.

The Uniformity constant (UC) (See section 2.25.2,) is determined from a graph of the concentration of particles versus size. The grain size graph is useful when comparing sands and also when determining the UC. Grain size graphs are used to design and select materials for drain systems. The UC of a sand along with the particle size analysis is the most useful tool for estimating a sand's performance. The UC is a numeric estimate of how a sand is graded. The term graded relates to where the concentration of sand particles is located. Sand with all the particles in two size ranges would be termed a narrowly graded sand and would have a low UC value. Sand with near equal proportions in all the fractions would be termed a widely graded sand and would have a high UC value. The UC is a dimensionless number. Filtration sands for water treatment will have a low UC to promote movement of water. Figure 3.4 graphically represents the essential differences between widely and narrowly graded sand.



Large pore space allows rapid oxygen diffusion and unsaturated flow around the sand particles.

Inclusion of small particles filling interspaces between large particles encourages clogging.

Figure 3.4. High and Low Graded Sand.

3.6.3 Samples Chosen.

The samples chosen were as shown in Table 3.3.

Sample No	**Sand Type.**
1	Garnet.
2	Proprietary filter sand.
3	Builder's white sand.
4	Play sand.

Table 3.3. Sand Samples.

3.6.4 Testing.

The testing involved drying out completely a sample of the sand under test. This process was carried out by baking the sample in an oven overnight at 105 ^{0}C. (See Figure 3.5). The sample was then placed in a "sieve stack" see Figure 3.6. These openings in the sieves ranged from 75 μm to 2.36mm. This stack of sieves was assembled in order of decreasing size of the openings from coarse to fine, as shown in Figure 3.7. They were then vibrated until all of the dry mass had passed through the progressive stages. Figure 3.8. shows the stack broken down with the retained sand in each unit. The results are shown in Tables 3.5 – 3.7

Figure 3.5. shows a sand sample that has been dried completely as described earlier.

Figure 3.5. Sand Sample after Drying, Ready for Grading.

The sieve stack is now assembled before being placed into the "shaker". The stack is shown in Figure 3.6.

Figure 3.6. Sieve Stack.

After the “shaking” process is complete, the individual sieves are separated and the retained mass of sand in each one is weighed. The amount retained by each sieve is recorded and entered into the result sheet for each of the “sands” tested. Figure 3.7. shows the individual sieves, each with the retained granules, for the aperture size of the particular sieve.

Figure 3.7 Sieve Stack Broken Down, Showing Graded Sand.

3.6.5 Sand Classification Sheet.

Tables 3.5 to 3.8 show the sand classification sheets for the sand samples tested. The information contained on each sheet is detailed in Table 3.4.

Term used.	**Explanation.**
Sand classification.	Name or identification of sample.
Total mass of dry sample.	Total mass of dry sample (grams).
BS Test sieves.	Aperture size of the sieve. (mm & µm.).
Mass of Sieve.	Mass of empty sieve (grams).
Sieve / Sample.	Combined mass of sieve and sample (grams).
Mass Retained. *	Mass of sand retained by each sieve after shaking (grams).
Percentage Retained. *	Amount of sample retained as a percentage of the total sample (grams).
Total Cumulative Passing.	The total amount of the sample that passes through each sieve (grams).

Table 3.4. Explanation of Sand Specification Sheet.

* (Note the highest retention figure for a sample indicates the size of that sample. e.g. sample No 1 garnet, has a retained mass of 550.15g of a total sample of 559.02g.therefore, this sample is classified with a granule size of 300µm). A copy of an original soils laboratory test result sheet is shown in Appendix M.

3.6.6 Garnet.

Garnet, a well-proven filter medium, was tested to investigate its properties and to chart them as a standard. Table 3.5 below shows 98.4% retention at 300µm, and very little deviation from that figure.

Sample No; 1		**Sand classification.** Garnet		**Total mass of dry sample** 559.02g	
BS Test sieves.	Mass of Sieve	Mass of Sieve / Sample	Mass Retained	Percentage Retained.	Total Cumulative Passing.
	G	g	g	%	%
2.36mm	428.51	428.51	0	0	100
1.18mm	390.68	390.68	0	0	100
600µm	433.31	658.46	2.68	0.48	99.52
300µm	321.82	406.09	550.15	98.4	1.12
150µm	338.37	338.37	6.19	1.2	0
75µm	326.58	326.59	0	0	0
Tray	268.15	268.15	0	0	0
Total.			559.02	100.08	

Table 3.5. Grain Distribution of Garnet.

3.6.7 Proprietary Filter Sand.

A sample of proprietary filter sand was chosen because, as with garnet, it is a widely used filter medium. It is much coarser than garnet and they both should reveal interesting results. As with garnet, Sample #1. 72.76% is retained at 600 µm and 27.23% retained at 300µm with no deviation from these sizes. Both samples 1and 2 are narrowly graded sand samples. (See table 3.6).

Sample No; 2		**Sand classification.** Proprietary filter sand		**Total mass of dry sample** 309.44g.	
BS Test sieves.	Mass of Sieve	Mass of Sieve / Sample	Mass Retained	Percentage Retained.	Total Cumulative Passing.
	g	g	g	%	%
2.36mm	428.51	428.51	0	0	100
1.18mm	390.68	390.68	0	0	100
600µm	433.31	658.46	225.15	72.76	27.24
300µm	321.82	406.09	84.27	27.23	0
150µm	338.37	338.37	0	0	0
75µm	326.58	326.59	0.01	0	0
Tray	268.15	268.15	0	0	0
Total.			309 .43	99.99	

Table 3.6. Grain Distribution of Proprietary Filter Sand.

3.6.8 Builder's Sand and Play Sand.

Builder's sand and children's play sand samples were chosen for testing purposes to ascertain their qualities as a potential filter medium. These samples of sand were also selected because they are readily available in convenient quantities in hardware outlets. However, from the tests conducted they were unsuitable as filter sand media. In the case of sample #3 table 3.7. builders sand, the grains range in size from 2.36 mm to dust.

Sample No; 3 Builders		**Sand classification.** Unspecified.		**Total mass of dry sample** 653.18g.	
BS Test sieves.	Mass of Sieve	Mass of Sieve / Sample	Mass Retained	Percentage Retained.	Total Cumulative Passing.
	g	g	g	%	%
2.36mm	428.51	497.23	68.72	10.52	89.48
1.18mm	390.68	540.24	149.56	22.90	66.58
600μm	433.31	611.98	178.67	27.35	39.23
300μm	321.82	479.66	157.84	24.16	15.06
150μm	338.37	411.49	73.12	11.19	3.87
75μm	326.58	348.06	21.58	3.29	0.58
Tray	268.15	271.94	3.79	0.58	0.00
Total.			653.18	99.99	

Table 3.7. Grain Distribution of Builder's Sand.

3.6.9 Children's Play Sand.

Children's play sand sample # 4,Table 3.8, when tested was found to be similar to sample #3, but was not as coarsely graded. Samples 3 ad 4 are widely graded sands and therefore, not suitable as filtering media. The results of other tests carried out on sand samples confirm this fact. See section 3.10.2.

Sample; 4		**Sand classification.** Playsand		**Total mass of dry sample** 363.5g	
BS Test sieves.	Mass of Sieve	Mass of Sieve / Sample	Mass Retained	Percentage Retained.	Total Cumulative Passing.
	g	g	g	%	%
2.36mm	428.51	428.55	0	0	100
1.18mm	390.68	390.89	0	0	100
600μm	433.31	440.18	6.87	1.89	98.11
300μm	321.82	470.40	148.58	40.87	57.24
150μm	338.37	485.34	147.97	40.07	17.17
75μm	326.58	378.64	52.06	14.32	2.85
Tray	268.21	276.23	8.02	2.2	0
Total.			363.5	99.35	

Table 3.8. Grain Distribution of Playsand.

3.6.10 Graphical Representation of Sand Particle Distribution

Figure 3.8 graphically outlines the particle size distribution of the sand samples tested. The narrower the range and the higher the peak, the sand will have a low UC, e.g. sample #1 garnet. The results of this test highlighted the magnitude in the difference of the sand grading. These results were considered sufficient information on which to base the filter material selection.

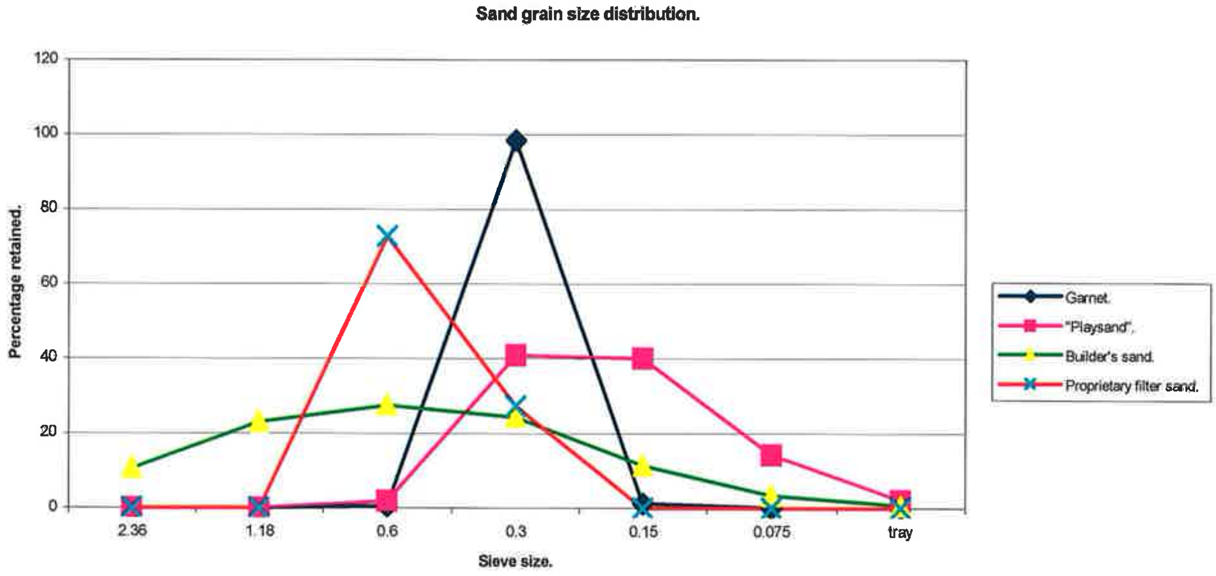


Figure 3.8. Graph of Sand Particle Distribution.

The sand grain size distribution graph in Figure 3.8. shows the diversity of the grain distribution in the various sand samples tested.

- **Sample # 1.** Garnet shows the smallest distribution area, and therefore depicts a very closely graded sand. However as will be seen in section 3.10.2 (filter performance), it is not a suitable filter medium in this case.

- **Sample # 2.** Children's playsand, has a wider distribution area, therefore it is prone to premature loading.

- **Sample # 3.** Builders sand is similar to sample #3, but with a wider distribution area, and therefore totally unsuitable as a filter medium.

- **Sample # 4.** Proprietary filter sand has a closer distribution area than samples #2 and 3 and is not as dense as garnet. Because of its distribution it is a suitable filtering media. This will be discussed further in section 3.10.2 (filter performance).

3.7 Sand Tests.

Apart from testing sand for its UC, sand used for filters must fulfill other criteria. These are:

(i) Porosity.
(ii) Retention rate.
(iii) Permeability.
(iv) Fines content.

3.7.1 Grant Sand Test.

The Grant sand test is a commonly used test for sand selection for filtration purposes. The test ascertains the permeability of the subject sand, e.g. if the specimen sand is widely graded then the time taken for the water to pass through sand will be higher than that of narrowly graded sand. The information obtained from the test is whether or not a particular grade or type of sand is suitable as a filter medium. The test is outlined in Figure 3.9. The principle of the test is that 0.5 L of water is passed through a 100 mm diameter column of sand 200 mm deep [Catherine boutin cemagref] [91]. The time taken for the water to pass through the column is recorded. Several, but generally 5 or 6 such tests, are carried out on different sand types. A support base of 6mm "pea" gravel 40 mm deep is used to allow the sand to drain freely.

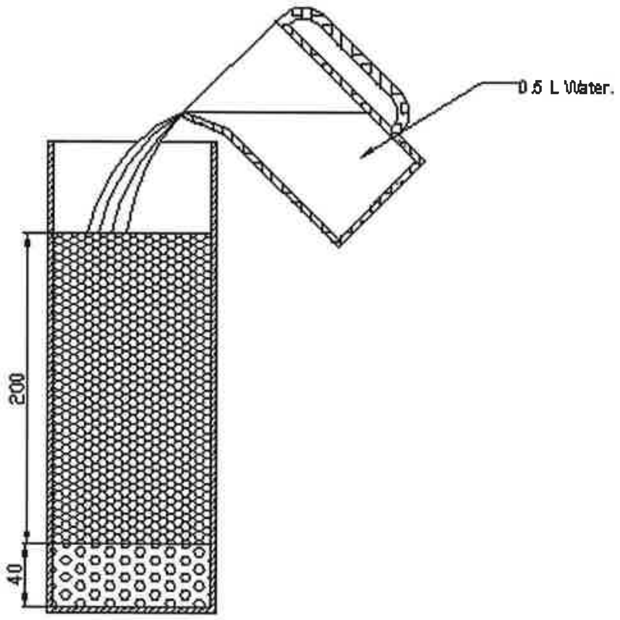


Figure 3.9 Grant Sand Test.

3.7.2 Geotextile Membrane.

A geotextile membrane was used instead of gravel to support the filter sand, it was found however, that the use of a geotextile material is an unsuitable choice as the textile retards the flow of water. Figure 3.10. shows the time difference in through- flow rate due to the membrane being blocked up prematurely by fines in the sand, Hence the reduction in the flow rate. The graph shown represents water being passed through the same filter

(i). Series 1 shows the times taken when using gravel as a support medium.

(ii). Series 2 represents the times taken by using a support membrane.

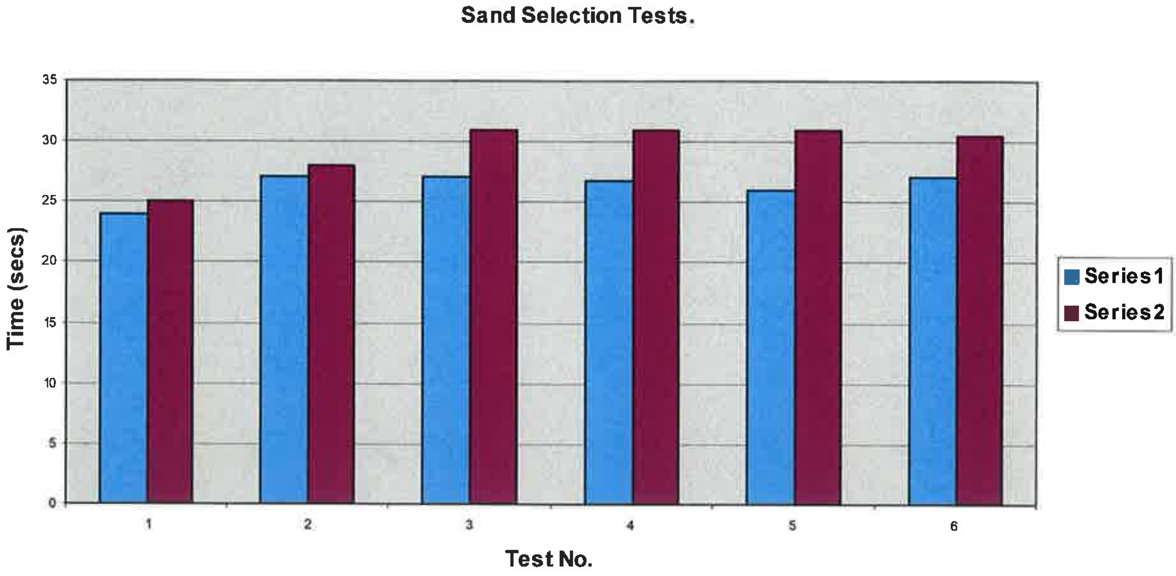


Figure 3.10. Water Flow Rates Geotextile Material Vs Gravel.

3.7.3 Fines Content.

The fines content (fine particles of sand) in sand plays an important role in the performance of sand as a filtration material Figure 3.11. shows the percolation time difference due to the fines content.

(i). Series 1 sand with fines widely graded.

(ii). Series 2 sand without fines, narrowly graded.

The graph Figure 3.11. below shows that there is a large decrease in flow rate due to the fines content of series 1.

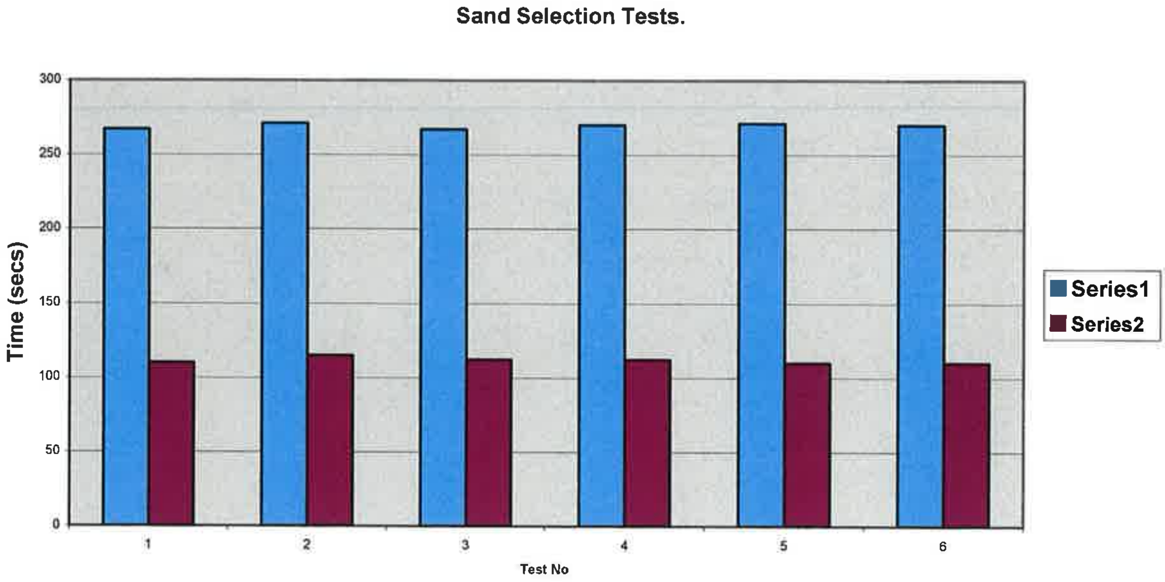


Figure 3.11. Flow Comparison Between Widely and Narrowly Graded Sand.

3.8 Filter Tests.

In an effort to establish the suitability of a filter material, trials on model filters were carried out. The testing procedure for filter performance was based on the following criteria:

1. Determining the quantity of suspended solids in the subject water. This was determined by measuring the mass of solids filtered out of 100ml water sample.
2. Determining the average particle size of the solids. A 100x magnified image of the particles is shown in Figure 3.12.
3. Select a suitable range of sand grit sizes capable of trapping the range of suspended solids in the water.
4. Checking the permeability rates of various "suitable" sand samples.
5. Analyse the range of grit sizes in all of the chosen samples.
6. Tabulate the filtration and flow rates of the filters on the following basis.
    - (i). Surface area of the filter.
    - (ii). Filtration rate with respect to filter depth.
    - (iii). Performance of a layered type filter.
7. Backwashing intervals required for different filtration media.

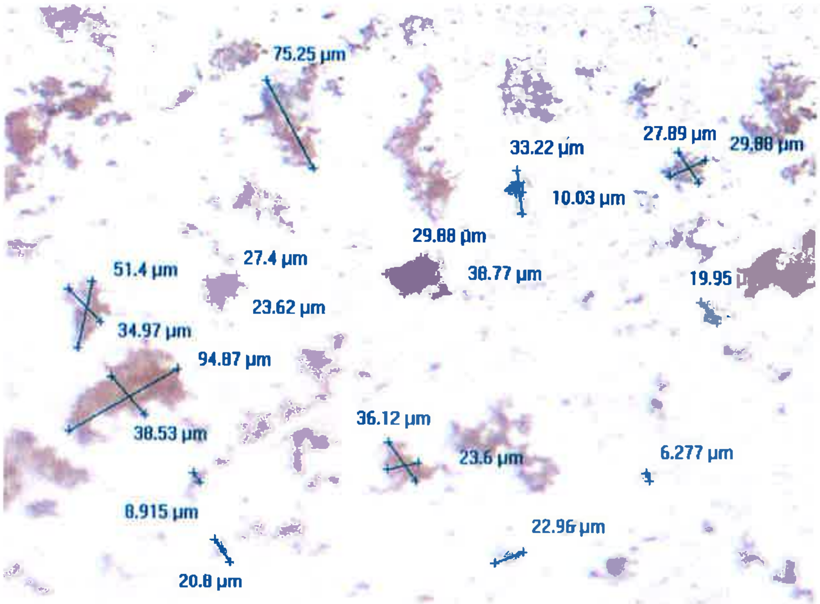


Figure 3.12. Particle Size 100x Magnification.

3.8.1 Flow Tests Carried out on Sand Samples.

1. Permeability tests carried out according to the "Grant" test.
2. Grit size distribution tests carried out on several sand samples.
3. Effect of surface area on the filtration rate
4. Effect of sand depth on the filtration rate.
5. Layered filter tested using a support bed of 4mm gravel, with and without a separating membrane.
6. Selection of a suitable sand grit size may be determined by the fact that the diameter of a suspended solid particle which may be trapped by a sand filter is 0.7 times the filter sand grit diameter [86].

3.9 Test Filters.

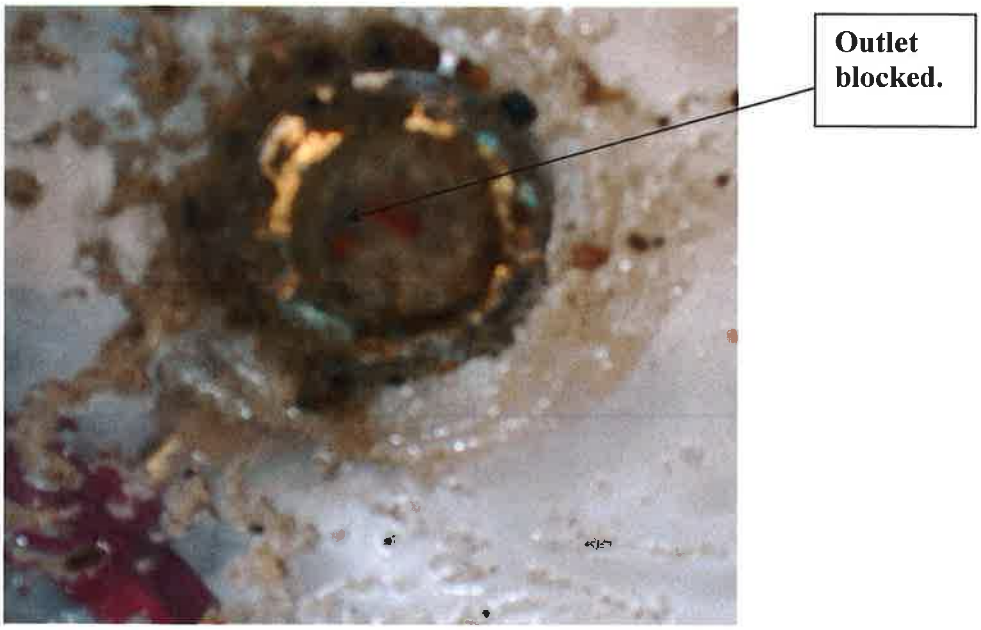
A number of transparent test filters were constructed in order to observe the behaviour of various filter media under test. The filters were of different diameters, e.g. 70mm, 100mm, 150mm and 200mm with different internal parts. Figure 3.13. shows a 200mm diameter filter. The filter in this instance comprises a gravel base topped with 0.6mm sand. The "tide mark" from backwashing can be clearly seen.

Figure 3.13. 200 mm Diameter Filter with Gravel Support Base.

Figure 3.14. shows the migration of the sand through the support gravel. This migration blocks the interstices in the larger support gravel base.

Figure 3.14. The Effects of the Fines in the Sand on the Support Gravel.

The filter outlet shown viewed from the top of the filter in Figure 3.15. can be seen to be completely blocked with the finer filtration sand. Figure 3.16. shows the “debris” removed from the process pipe by backwashing.



Outlet blocked.

Figure 3.15. Blocked Outlet of the Test Filter.

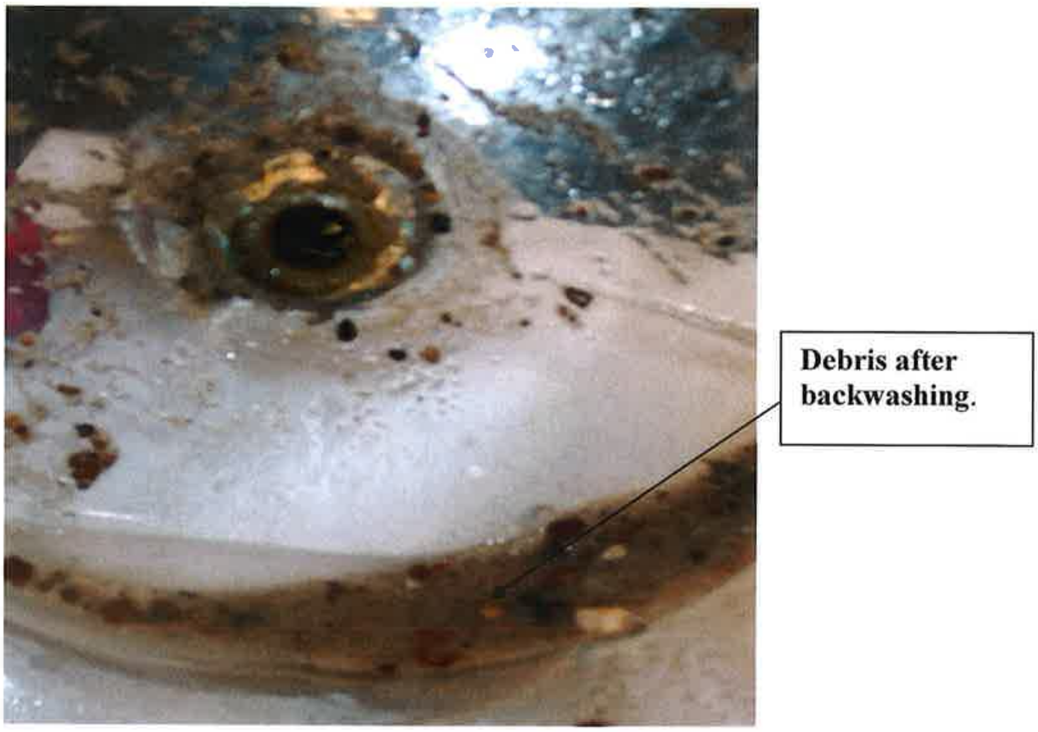


Figure 3.16. Fines after Backwashing.

The filter in Figure 3.17. is 70mm diameter fitted with a fine perforated convex disc. The valve "A" shown facilitates backwashing of the filter. While valve "B" is connected to the service line. The top of the rose is convex, which ensures uniform expansion of the filter medium during the backwash cycle, this support unit for the filter medium is a commercially available rubber bodied 15 mm bore water sprinkler rose. This rose has fine perforations diameter 0.5mm, which prevent the filter medium accessing the water pipe, yet coarse enough so as not to impede the water flow. The rose head is secured to the pipe using a stainless steel pipe clip.

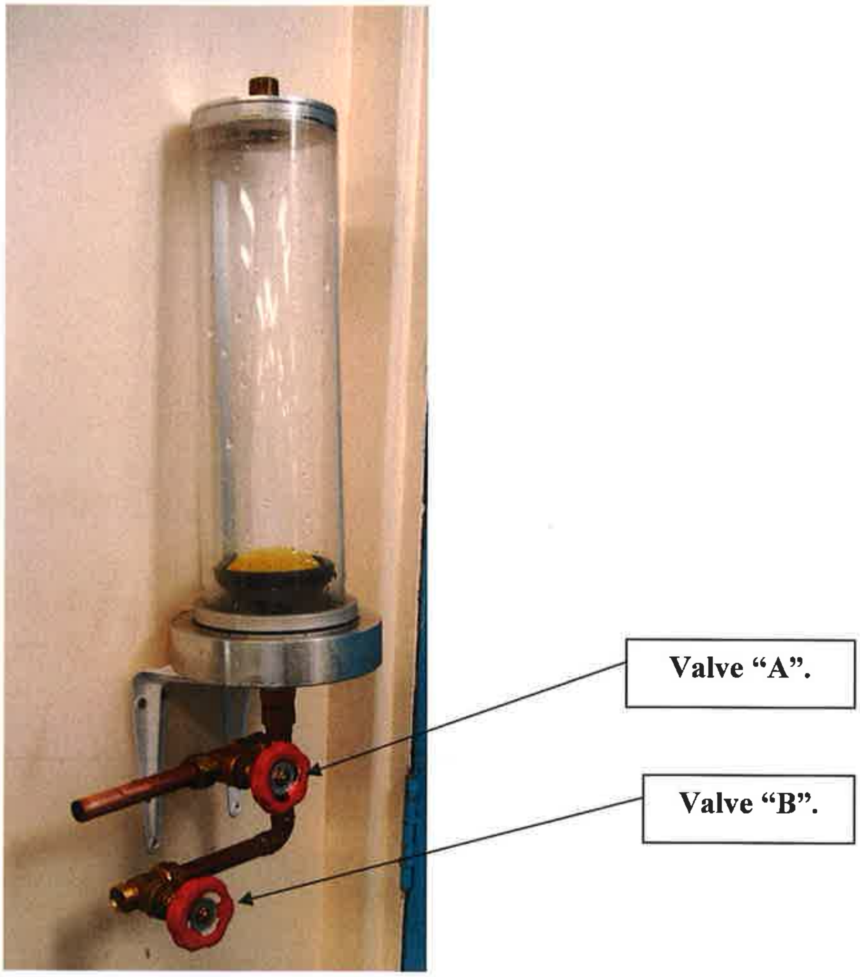


Figure 3.17. Transparent Filter Showing the Perforated Convex Separating Membrane.

Figure 3.18. shows a close-up detail of the convex grit separator. The convex nature of the disc promotes even distribution of the backwash water, thus ensuring uniform expansion of the filter medium.

Figure 3.18. Detail of Spray Head and Grit Separator.

Figure 3.19. shows the filter at rest, using a sample of 600μm sand ready for testing.

Figure 3.19. Filter at Rest.

Figure 3.20. shows the filter with the sand bed expanded and fluidised during a backwash cycle. The filter bed is expanded by 100 %. Close-up examination of Figure 3.20. will reveal the turbulent nature of the backwash cycle.

Figure 3.20. Filter Bed Expanded During a Backwash Cycle.

3.10 Dual Media Filters

While single medium filters have the capacity to work satisfactorily, they do, however, require backwashing from time to time. The time interval between backwash cycles varies owing to the contamination level of the water. Water may be filtered on a gradual basis using a dual media filter. Such a filter would typically comprise two granular materials such as,1mm anthracite and 600µm sand. The coarser anthracite will filter out the larger particles, while allowing the finer particles to pass through to be filtered out by the finer medium. Using this method the time interval between backwashing cycles can be increased.

3.10.1 Dual Media Filters.

A dual media filter comprising sand and anthracite is shown in Figure 3.21. sufficient headroom must be allowed for, so that the filter media, while being expanded for cleaning purposes, is not washed to waste during backwash.

Figure 3.21. Dual Media Filter.

The filter is shown during a backwash cycle in Figure 3.22. The turbulent nature of the backwash can be clearly seen by the "swirling" pattern of the filter media. The dispersion of the two media is also quite evident. Even at the required expansion there is still some "free space" above the filter medium.

Figure 3.22. The Filter During the Backwash Cycle.

Enlarged View of the Swirling Action During Backwash.

After the backwash cycle is complete the filter bed settles down and the stratified nature of the dual media system is still evident. This is due to the different settling velocities of the two media anthracite (the less dense material) and sand, Figure 3.23. shows the re-stratification of the filter media after 10 backwash cycles.

Figure 3.23. The Filter at Rest after Backwashing.

3.10.2 Filter Performance.

Once the characteristics of the various filter media had been established, filter units were constructed. These tests involved using different diameter cylinders, and using different filter bed depths, it was therefore possible to ascertain the performance of filters with various surface areas and depths. In each case, water was fed into the filter and the length of time taken for 1 litre to flow from the filter was measured. The water used in each case was clear water, and therefore only the sand's performance was being tested. When there was a significant decrease in the flow rate from the filter, it was backwashed and the test continued. This decrease in flow rate would only have been due to the particular characteristics of the sand, and not as a result of debris being filtered out of the water.

The tests were carried out with the other media, the results for all the tests are shown in Tables 3.9 to3.14. Although garnet is a filter material, it was not used in these tests due to its "fineness". The flow rate through it would not be sufficient. It is a material used as a component in "water polishing". This filter material was not chosen as a subject sample for any of the performance tests.

This test involved the testing of the builders sand using a filter 100mm diameter. The initial run with filter medium immediately excluded it from being used as a viable filter, with a flow rate of 50 seconds per litre. After 8 litres had been passed through the filter, the fines blocked it to such an extent that water would flow only when air was drawn back up into the filter, causing it to cavitate. Backwashing the filter did not restore its original flow rate.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	100	70	50	
2			50	
3			60	
4			60	
5			80	
6			85	
7			100	
8			110	Cavitating, air bubbles.
9			120	
10			60	Backwash.
11			60	

Table 3.9. Test no 1 Builder's Sand Grit Size Varies Sample 3.

In this test the white builders sand with wide grading is used. The finer particles in the sand block it up and hinder its performance.

The second filter test was performed using the same filter body as in test 1, but on this occasion the play sand (a widely graded sample) was chosen. Initially the flow rate from this sand was superior to that of test 1. This was due to the fact that sample 2 was more uniform than sample 1, even though sample 2 had a finer grit. However, again this filter suffered cavitation. Backwashing in this case did restore the filter's original flow rate.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	100	50	15	
2			15	
3			18	
4			22	
5			27	
6			27	
7			28	
8			30	Cavitating, air bubbles.
9			15	After backwash.

Table 3.10. Test No 2 Play Sand Sample No 4.

Test 3 was performed using the proprietary grade filter sand as with tests 1and 2, the filter diameter was the same. The performance in this case was much improved and the flow rates were constant. Backwashing restored the filters original performance.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	100	70	10	
2			10	
3			10	
4			11	
5			10	
6			10	
7			11	
8			12	Backwash.
9			10	
10			10	

Table 3.11. Test no 3. Fine Sand 600 Microns Sample 2

In this test, proprietary filter sand is used closely graded at 600µm. The flow rates through this filter are very consistent.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	80	70	15	
2			15	
3			16	
4			16	
5			15	
6			16	
7			17	
8			17	Backwash.
9			15	
10			15	
11				

Table 3.12. Test no 4 Sample 2.

In this test, the same proprietary filter sand sample 2 is used on a smaller diameter filter body, due to the reduction in surface area the flow rate is reduced. However, the flow is consistent.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	80	150	15	
2			15	
3			15	
4			17	
5			16	
6			17	
7			17	
8			15	Backwash.
9			15	
10				Depth of filter has little effect.
11				

Table 3.13. Test 5 Sample 2.

In this test, the depth of the media is increased to 150 mm with sample sand 2. it can be clearly seen that the flow rates are the same as in test 3.this indicates that the depth of the filter media has little or no effect on the filters performance.

RUN	DIAMETER mm	DEPTH mm	SECONDS/LITRE	COMMENTS
1	200	70	8	
2			8	
3			9	
4			8	
5			9	
6			8	
7			9	
8			9	
9			10	
10			10	

Table 3.14. Test 6 Sample 2.

In this test, the diameter of the filter is increased to 200mm. There is a marked improvement in the flow rate through the filter. This indicates that the surface area of the filter has the greatest effect on its performance.

3.10.3 Summary.

The main focus of this chapter was to test the ability of filters to successfully remove precipitated iron and manganese from oxidised water.

Prior to designing the treatment unit, samples of water had first to be tested to ascertain their suitability for treatment. Various elements of water treatment had to be investigated. These investigations centred on the successful oxidation of the subject water by natural aeration. The aeration was carried out by passing the subject water over various weirs so as to cause turbulent flow and so encourage aeration of the water. Filter media and filtration methods, including single and dual media filter configurations were also investigated, these investigations included testing the permeability of filter media, this included the effects of fines in the sand and uniformity of the size of the grains, construction and testing flow rates through different filter units of different areas and depths. The most effective filter medium was found to be a close graded sand, 0.6mm. Sample No 2 table 3.6 as other media were prone to clogging up prematurely, or impeding the water flow. Dual media filtration prolonged the service life of the filter as the coarser upper filter medium removed the larger particles first, thus allowing the unit to filter the water on a gradual basis. The coarser medium in this case was anthracite, owing to its lighter density, the stratification of the different media was maintained after backwashing. It was found that larger area shallow filters are more effective than deeper narrower units. This can be readily seen in tables 3.12 and 3.13, where the depth of the filter has been doubled there was no increase in filtration flow rate.

CHAPTER 4.

DESIGN AND CONSTRUCTION OF WATER TREATMENT UNIT.

4.1 Laboratory Test Unit Overview.

Once the preliminary testing of the sand, water and filter samples was completed the design and construction of a laboratory test unit began. The unit, which was primarily designed as "proof of concept" was constructed using a proprietary laboratory grade, extruded aluminium section, that allow flexibility in the construction and alteration of the design, see Figure 4.1.

Figure 4.1 Laboratory Test Unit.

There were additional features incorporated into the design and construction of this unit compared to the prototype working model these features included:

1. A flow meter and a flow control valve. These components allow for the backwash flow rate to be monitored and varied, see Figure 4.2.
2. Multiple filters. These allow various filter media to be compared simultaneously, as in Figure 4.3.
3. A transparent dual media filter. To allow the action of the backwash cycle, and the re-stratification of the filter media can then be observed.
4. A membrane filter. This filter separates debris from the backwash effluent, so that the particles being removed from the water can be analysed.
5. The unit is mounted on castor wheels to allow mobility.

Figure 4.2 Flow Control Valve and Flow Meter.

Figure 4.3 Multiple Filter Units.

Figure 4.4 Transparent Filter Unit.

4.1.1 Design of the Test Unit.

The main criteria for the design of the test unit are as follows.

Along with the key design features to filter and clean water the following points were also considered in the construction of the test unit.

(i). Be mechanically strong enough to support the combined weight of the water, the filter media and all the associated fittings.

(ii). Be physically large enough to accommodate the required units, yet sufficiently narrow to allow easy passage through a standard 760 mm doorway.

(ii). Be of flexible construction, which allows for easy modifications to be carried out.

4.2 Components and Their Applications.

The components and their applications are as follows:

(i). Three 50 litre PVC water storage tanks. Each of these tanks performs a separate function. Tank #1 is used as the aeration tank. In this tank the water flows along a baffle plate weir see Figure 2.18 this weir is attached to the water outlet of the ballcock valve. See photograph figure 4.5. This tank is the holding tank for the aerated water. Tank #2 serves as a sedimentation tank. Both of these tanks combined are the water storage and supply tanks for the unit. Tank #3 is the “clear water” tank. This water is semi- treated water and serves as backwash water for the filters.

(ii). Three filter units. Two of these filters are dual media, while the third is a single media filter. These are connected together and are each controlled by shut off valves. This means that, for testing purposes, the filters can be used as one unit or individually. Using the filters individually means that separate filter performances can be assessed. For example, performance of single media filters can be compared with dual media filters.

(iii). One carbon filter similar in construction to the "sand" filters. This filter is used to remove taste and odours.

(iv). One transparent dual media filter. This filter can be used to demonstrate visually the backwashing cycle and the stratification of the filter media.

(v). One flow meter. This meter allows the backwash flow rate to be monitored.

(vi). One fine pore cartridge type filter. This filter ensures that the water is free from particulate matter to within specified standards prior to passing into the UV disinfection unit.

(vii). One UV disinfection unit. This is the final stage of treatment.

(viii). One pump unit. This pump is of the pressure set type that would normally be used for supplying water to a house. It also pumps the backwash water through the filters.

A labeled image of the laboratory treatment unit is shown in Figure 4.6.

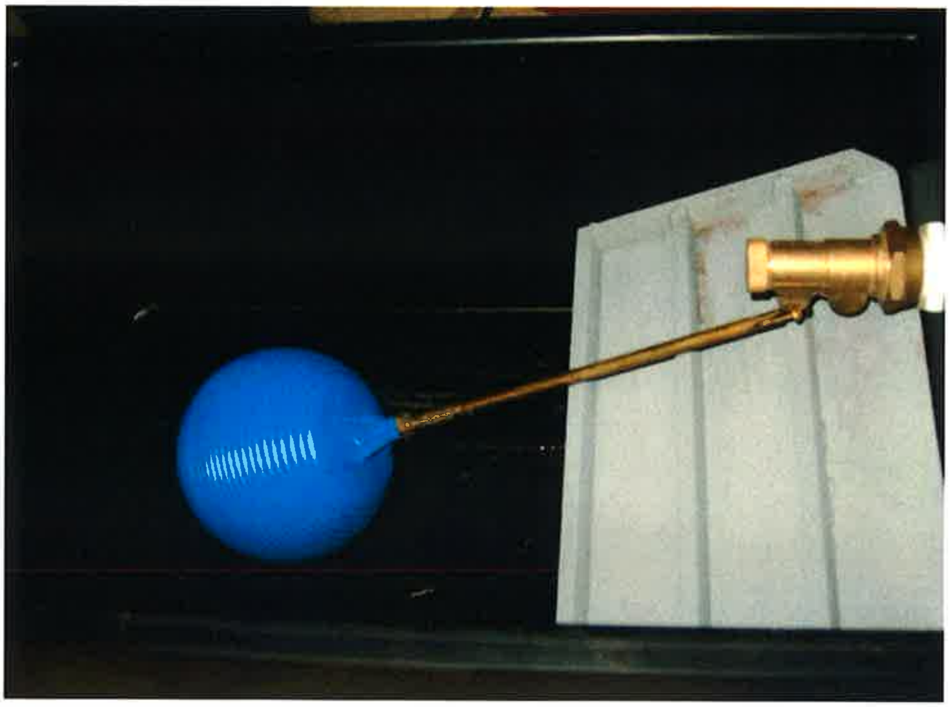


Figure 4.5 Ballcock Valve Assembly and Baffle Plate Weir.

Figure 4.6 Labeled Image of the Laboratory Treatment Unit.

4.2.1 Pump Specifications.

The pump used is a “DAB” jet 82 model, fitted with a 19 L pressure vessel.

The pumping capacity of this unit is. 4500 L per h at 100 kPa

The pump is a self-priming standard domestic well centrifugal pump with excellent suction capacity even when there are air bubbles. Particularly suitable for water supply in domestic installations, small-scale agriculture, gardening and wherever self-priming operation is necessary.

The pump body and motor support are cast iron, with a techno polymer impeller, diffuser, venturi tube and sand guard. Stainless steel adjustment rings. Carbon/ceramic mechanical seal. A synchronous motor closed and cooled by external ventilation. Built in thermal and current overload protection and a capacitor permanently on in the single-phase version. Figure 4.7 shows a performance curve for the pump.

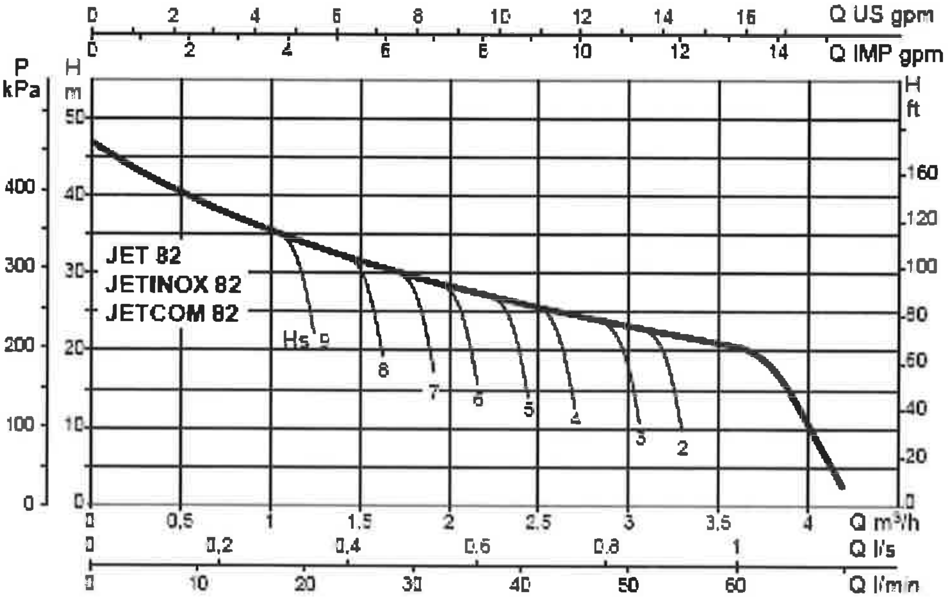


Figure 4.7 Pump Performance Curve.

4.3. Construction Details.

The basic frame is of rectangular construction. All sections are secured via M12 cap head set screws, screwed in to the ends of lateral rails while the head engages in the "T" slot groove on the appropriate faces of the vertical struts. The top of the frame is sheeted over with 4 mm aluminium sheet.

This sheet forms a level support surface for the aeration and sedimentation tanks, as well as the UV unit. To prevent the tanks sliding off the top surface, a peripheral rim is fixed to the top surface. Horizontal support bars running longitudinally along the back of the frame are used to support the filter units. The bottom surface of the frame is sheeted similarly to the top surface. Support bars beneath the surface sheet are used to offer strong support and location for the pump. The wheels are placed at each corner of the frame, thereby ensuring maximum stability.

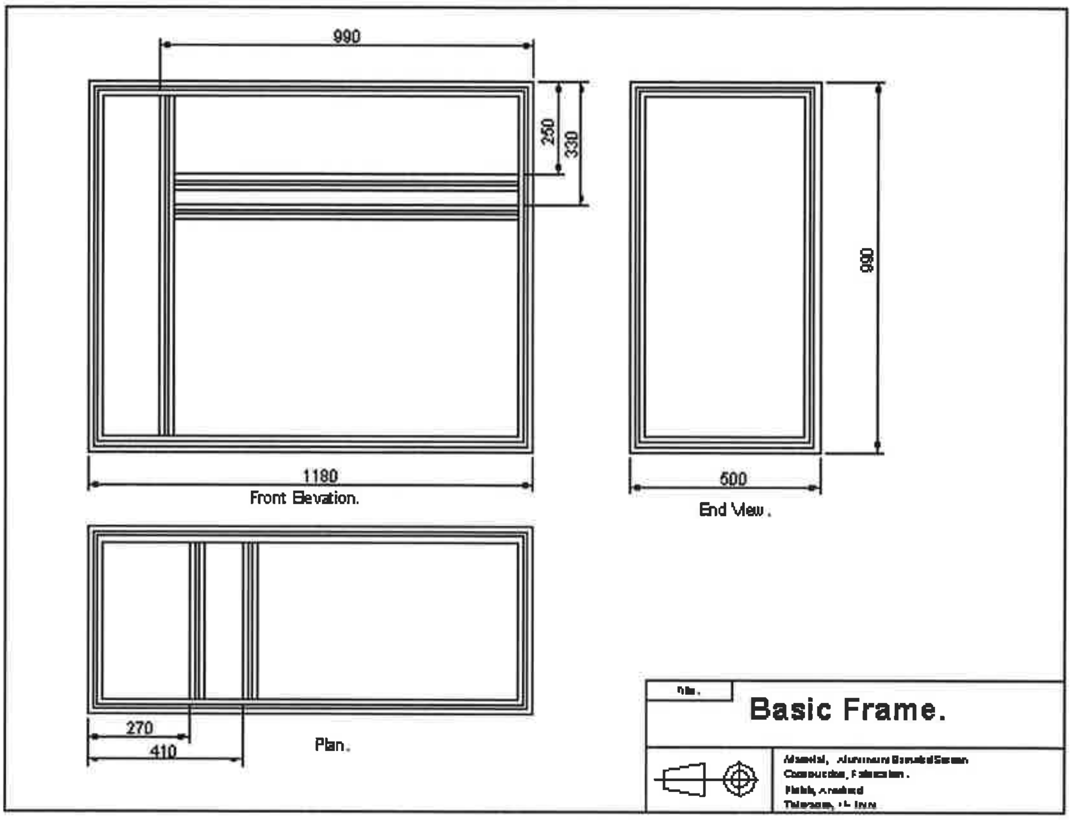


Figure 4.8 Basic Frame.

4.4 **Filter Units.** The filter units were constructed from commercially available 110mm diameter, PVC pipe. wavin, pipe D3760 The ends of the pipe are closed off using pipe couplers wavin coupler D4001 with screwed cleaning eye units. wavin cleaning eye D4077 A less expensive option was to use a plain blank cap wavin plain stopper D4088 but these caps are very difficult to remove, compared with screw caps, and therefore would make maintenance more difficult. The water pipe access to the filter is achieved using a proprietary flanged brass tank fitting through the end cap. instantor 350 15mm, see Figure 4.9. the support membrane for the filter medium is a commercially available stainless steel strainer This strainer has fine perforations, which prevent the filter medium accessing the water pipe, yet coarse enough so as not to impede the water flow. The strainer is secured in place by clamping it between the screwed cap and pipe. See Figures

4.10 to 4.12 The overall length of the filter unit is 400 mm, with a total media height of 200 mm. sufficient space above the medium is necessary to ensure that the filter material is not washed out to drain during the backwash cycle. These filters are secured in place by standard pipe wall brackets wavin pipe bracket C8042.

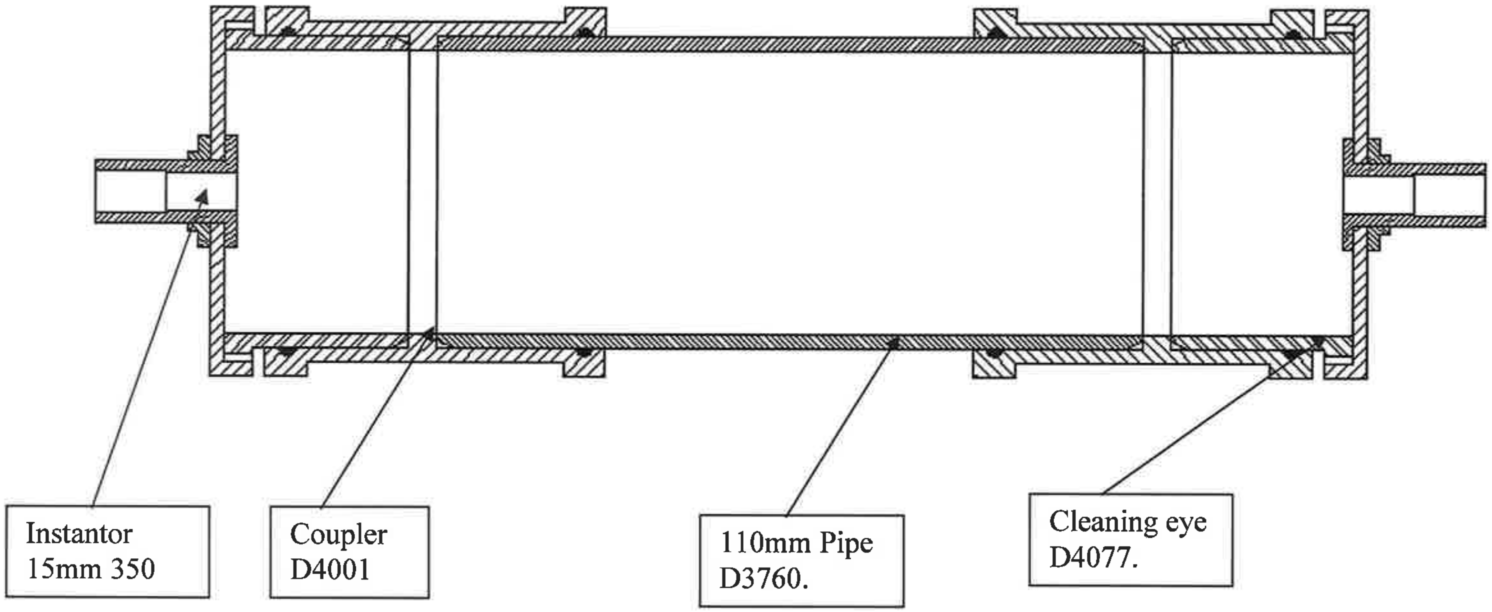


Figure 4.9 Filter Body Construction

Figure 4.10. End Cap with Water Connection.

Figure 4.11. Strainer.

Figure 4.12. Assembled Strainer and

End Cap Ready for Assembly onto Pipe.

4.5 Disinfection System.

The disinfection system used in this system is ultraviolet radiation, and a commercially available PVC bodied unit was chosen. See (Appendix N). The standard UV units are manufactured from stainless steel, and are far more expensive than the PVC unit chosen. The stainless steel unit costs approximately €400, whereas the PVC unit is readily available at less than €100, both these units demonstrate the same bactericidal capacities. Because UV does not provide residual disinfection, a chlorine injection point is provided after the UV unit, Valve # 25. This provides disinfection from UV up to the point of use. It is particularly useful especially when the system has been left unused for a period of time.

4.6 Pipes and Fittings.

All rigid pipe work is completed using seamless drawn copper tube and flexible pipes are food grade polythene tube. Copper pipe connections are made by proprietary screwed compression brass fittings. The connections to the various fittings, valves, couplings, pump etc are effected by standard compression fittings. The compression fittings allow the system to be disassembled easily for maintenance purposes. Attachments to the flexible pipe are done by means of spigots with threaded ends, secured in the tube using screwed hose clips.

4.7 System Layout.

A schematic diagram of the system layout during the normal running mode is shown in Figure 4.13. The system comprises an aeration tank #1, which is fed with raw water from the source. The water level is controlled by a ballcock valve #2 the water is aerated by a baffle plate #3,which is attached to the ballcock, (not shown). From this tank the water passes to the sedimentation tank #4. Water from this tank is then fed via a non-return valve, (nrv) #5 into the "sand" filters, # 6,7, and 8. The nrv prevents backwash water from back flowing to the storage tanks during the backwash cycle. A fourth "sand" filter #9 is incorporated into the system. This filter is transparent, and has dual media filtering material, and allows the operation of backwashing and stratification of the filter media to be observed. The operation and isolation of these filters is controlled by shut off valves #10,11,12, and 13. The filtered water passes through the carbon filter #14. A 3-way diverter valve #15, which isolates the carbon filter during the backwash cycle, controls the water supply to this filter. After passing through the carbon filter, the water is stored in the "clean water" tank #16. The pressure set pump#17 complete with gas charged accumulator (air), and pressure switch draws this water, via a nrv #18, which prevents the water from flowing backward through the pump, thus causing a siphoning effect and passes it through the fine pore woven fabric filter #19, before the water goes through the UV disinfection unit #20.

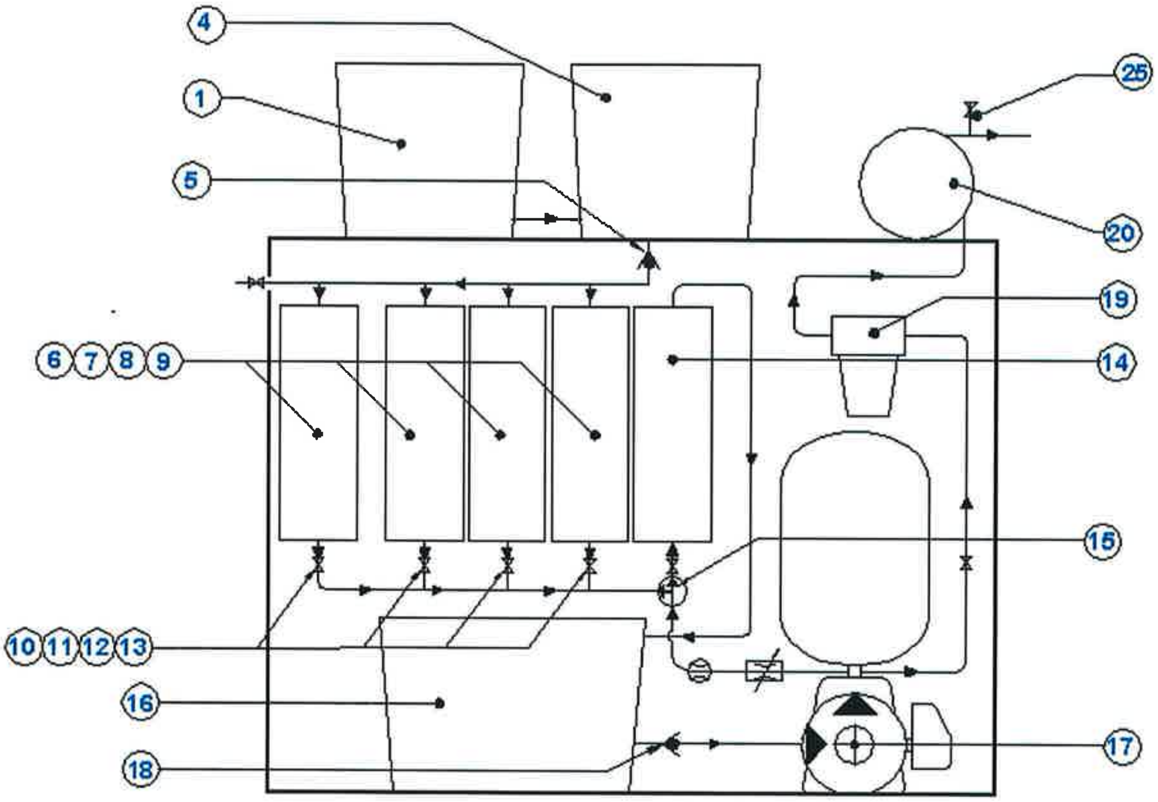


Figure 4.13. System Layout Normal Running.

4.8 System Operation.

The stream of raw water entering the aeration tank is dispersed using a baffle plate, this ensures maximum contact between air and water. The water then flows into the sedimentation tank, quiescent conditions allow the iron particles to precipitate out of the water. After sedimentation, the water enters the filters, where the "solid" iron and manganese is removed. The next stage is removal of taste and odour, this happens when the water is passed through the charcoal filter. With the iron, manganese, taste and odour removed, the water goes through the final stages; these are the fine pore filter to remove any residual particles, then on to the UV unit for disinfection. At this stage the water is ready for consumption.

4.8.1 Initial Running of the System.

Prior to putting the new system into operation, it must first be cleaned thoroughly. This is achieved by:

(i) Removing all visible debris from the water tanks, and checking all joints are secure.

(ii) Filling Clearwater tank 16 with "clean" water.

(iii) Run the system on backwash, emptying tank 16. This operation rinses out the filter sand in the sand filters.

(iv) Turning on the water supply to the system, filling aeration tank #1. Setting the system for normal running ensuring that the filter element is removed from filter body # 19. This ensures that the fine pore element is not prematurely blocked by fine debris in the system.

(v) Having completely rinsed and drained the system , fitting a new filter element into filter body # 19.

(vi) Disinfecting the post UV pipe-work by introducing chlorine into the chlorine addition point and run the system.

(vii) The system is now ready for use.

4.8.2 System Maintenance.

Apart from keeping the system clean and free from leaks. The system requires a small amount of maintenance. This maintenance involves backwashing the sand filters when the flow rate is reduced, or when turbidity breakthrough is evident. The charcoal filter is not backwashed, as it does not benefit from the operation. The micro-pore filter is renewed periodically. The time interval between changes is solely dependent upon the volume of particulate matter suspended in the water entering it, and is changed when there is an appreciable reduction in water flow rate. The recommended maintenance of the UV lamp by the manufacturers is that the bulb it is renewed annually. The pump pressure accumulator requires periodic attention i.e., the air pressure should be checked regularly, and adjusted accordingly to the manufacturers specifications, to ensure the pump works at maximum efficiency.

4.8.3 Backwash Cycle.

When backwashing of the filters is required, water is directed from the delivery side of the pump, by way of a diverter valve #15, and directed to the outlet side of the “sand” filters. A variable flow control valve #21 set in conjunction with a flow meter #22, controls the backwash rate thus preventing the filter media from being washed out to waste. The waste discharge is controlled by shut off valve # 24. The backwashed water can then be collected for analyses. See Figure 4.14

4.8.4 Backwash Operation.

When the system requires backwashing, the correct sequence of valve operation is important. The sequence is as follows.

(i). The outlet valve of the filter(s) being serviced is left open, the other valves are closed.

(ii). The 3-way diverter valve #15 is turned to backwash position.

(iii). Valve #21 is opened, this pressurises the backwash system.

(iv). Waste control valve # 24 is opened slowly, and left open until the effluent water runs clear.

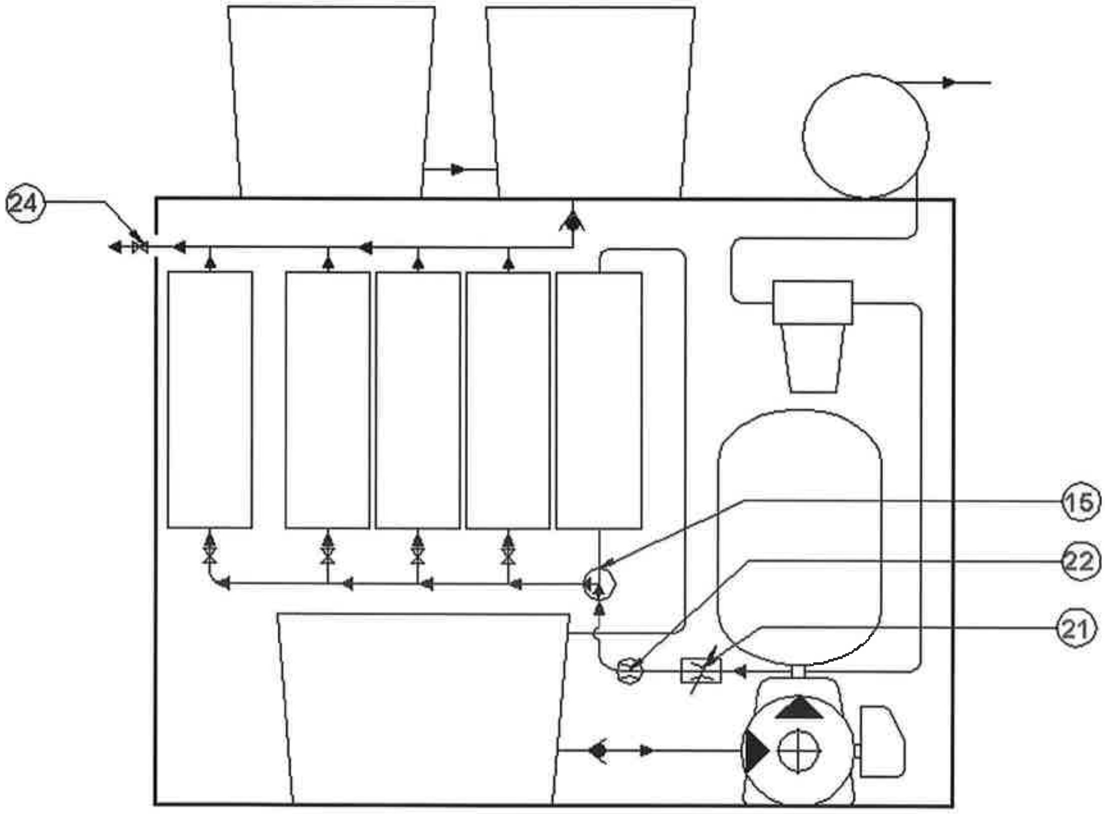


Figure 4.14 System Layout Backwash Cycle.

4.8.5 Returning the System to Working Mode.

When backwashing is complete, the system must be returned to normal service. This is completed as follows.

(i). Close shut off valve #21.

(ii). Close waste valve #24.

(iii). Turn 3-way diverter valve # 15 to, “normal running”.

Chapter 5

RUNNING AND TESTING THE TREATMENT UNIT.

5.1 Flow Rates Through the Treatment Unit.

When the initial tests were being carried out on the unit it was found that the flow rate of the filtered water was much less than the 6 to 7 litres / minute expected. This was the expected flow rate of the system as a result of trial flow tests carried out on various filter units. This was due to the positioning of the carbon filter, while the water was being fed through the 4 sand filters with a head pressure of 0.5 m the up flow through the carbon filter, which was set at the same height as the sand filters Figure 4.1 reduced this head pressure to less than 0.2 m. when the carbon filter was by- passed the flow rate from the sand filters was 6.5 l / min this flow rate equates to 400 l/hr. See table 5.1 and Figure 5.1. Table 5.1 shows the increased hourly flow rates with an increased filter surface area

Number of Filters	Filter Diameters mm	Flow sec/l	Flow l/hr
1	70	20	180
2	70 +100	17	212
3	70 + 100 +100	13	277
4	70 + 100 +100+100	9	400

Table 5.1 Cumulative Flow Rates Through Filters.

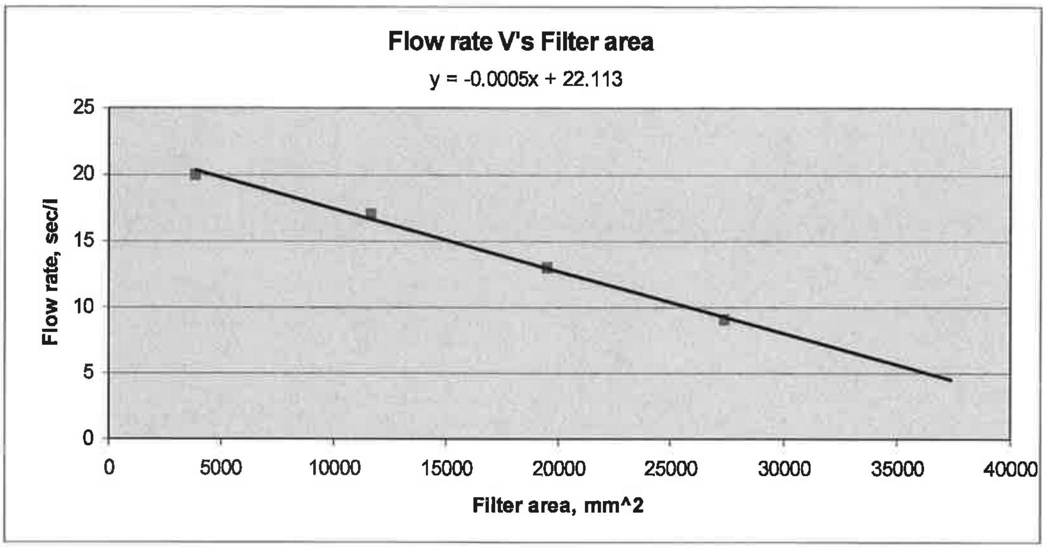


Figure 5.1 Cumulative Flow Rates Through Filters.

Figure 5.2 shows graphically the increased hourly flow rates through the combined filter units. It also shows the decreased time taken for the water to pass through the treatment unit as the effective surface area of the filter bed is increased.

(i) Series 1 shows the decline in time for the water to pass through the filter system.

(ii) Series 2 shows the increased flow rate and hence the increase in the capacity of the treatment unit

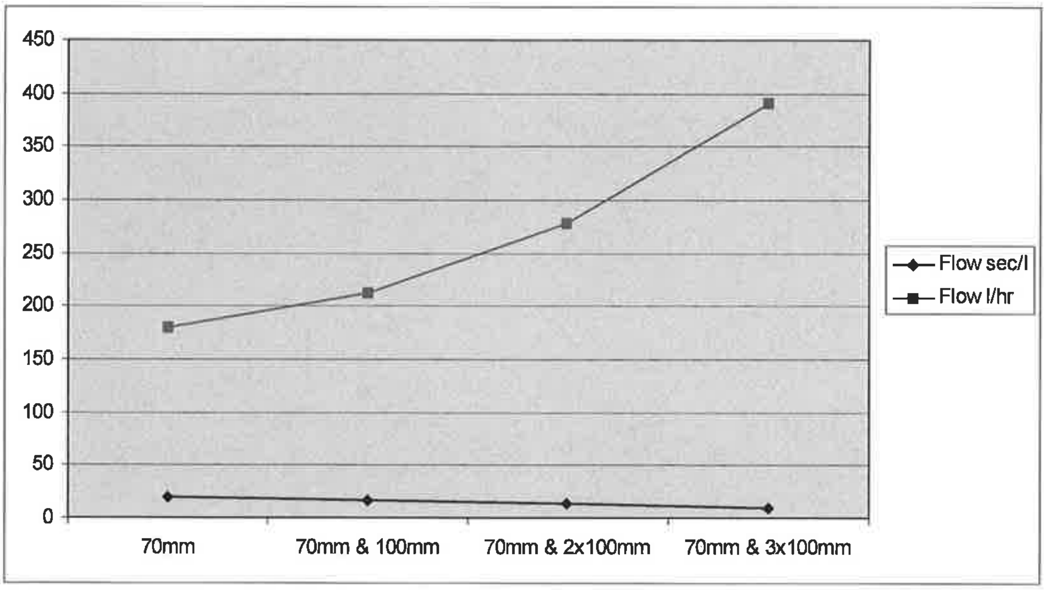


Figure 5.2 Increased Hourly Flow Rates Vs Decreased Time Taken for the Water to Pass Through.

5.2 Repositioning of the GAC Filter.

To overcome the flow impediment of the carbon filter, a more compact unit was constructed and repositioned adjacent to the clear water filter. Because this filter is not subjected to the same type of operation as the particulate filter, and used only to remove odours and tastes it can therefore afford to be physically smaller, as it is not subjected to clogging by particulate matter. The reconstructed unit is shown in Figures 5.3 and 5.4.

With the newly constructed filter in place, the flow rate achieved by the treatment unit was 6.5 L / min with all four filters operating.

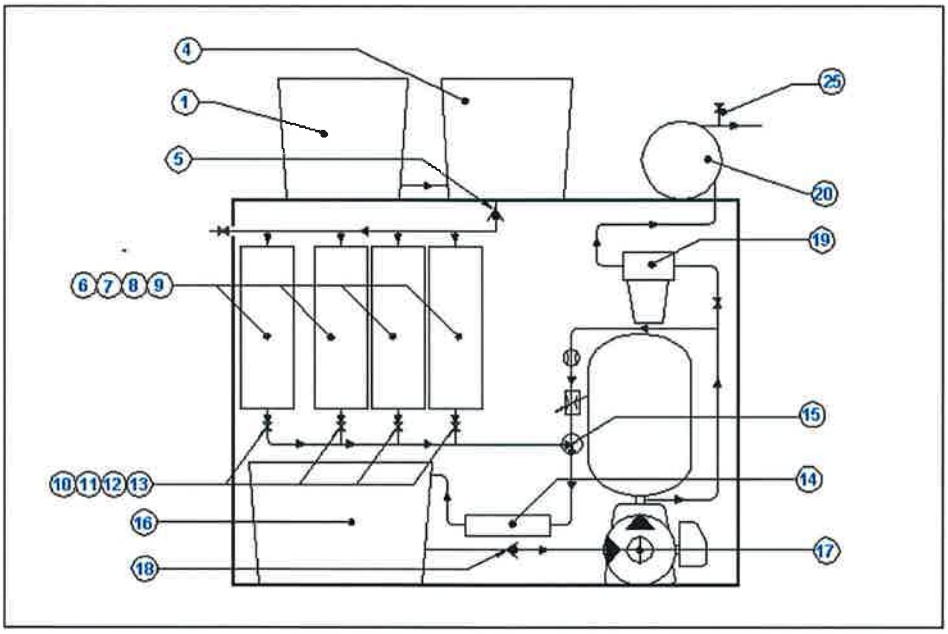


Figure 5.3 System Layout Normal Running Repositioned Carbon Filter, No 14.

Figure 5.4 Modified Carbon Filter in Revised Position.

5.3 Water Samples Tested and Results.

For final testing of the treatment unit two samples of water were taken. The first sample had an abundance of dissolved iron and manganese with no coliforms. This was the "coolree before" sample, Appendix L. Total iron 200µg/l, total manganese 50 µg/l . The second sample chosen was from a local canal.

5.3.1 Coolree Water Test Results.

The ferruginous water from the deep well at the coolree site was passed through the treatment system, and re-tested, this time using the "Eisen test" field test strips. The results indicated the Fe content to be < 20 µg/l. The odour, taste, and turbidity were negative.

5.3.2 Canal Water.

Canal water was chosen as a source of bacterial contamination. Previous tests carried out on the ferruginous coolree water proved to be negative from a bacteriological perspective. Refer to section 3.2 , Appendix L.

The canal samples are referenced as;

"GC Robertstown 1", this was the raw water sample taken from the Grand Canal.

"GC Robertstown 2", this was the treated water.

Although the treatment unit is not designed for treating water heavily contaminated with pathogens, the level of contamination expected from the canal water will be a good indicator of the unit's performance as a disinfection device.

5.3.3 Contamination Levels of the Canal Water.

The sample of water taken from the canal appeared clear ie, little or no turbidity, with a slight "musty or earthy" odour, these were sensory observations. Neither turbidity nor olfactory tests were carried out on this water. The sample was tested by the city analyst, and was found to have the following level of bacterial contamination. The results can be seen in Appendix L.

Total coliforms,	1046.2 MPN/100ml.
EColi,	14.5 MPM/100ml.

5.3.4 Results of the Disinfection Process on Canal Water Sample.

When the water samples "GC Robertstown 1", was treated through the sand , carbon , micro pore filter, and the UV unit, the sample "GC Robertstown 2",the odour was not present, and the sample was clear. It was sent to the city analyst's laboratory for bacteriological testing. The results were,

Total coliforms,	47.2 MPN/100ml.
EColi,	7.3 MPM/100ml.

While the results were good they were not what was expected, even though the water resembled wastewater, rather than drinking water. The reason for this situation was the fact that the flow rate "Q" for the pump at 100 kPa was 4500L per hour. This was in excess of the flow capacity of the UV unit. Throttling the water flow rate caused the water to "foam" resulting in "white" cloudy water. This condition reduced the effectiveness of the UV disinfection unit, and was caused by excessive water flow rates due to the flow capacity of the pump being used in the system. However this problem did not occur in the "on site working model" as the flow rate of water was much less, since the water flowing through the UV unit was emitting from the attic storage tank.

5.4 Previous Water Samples Tested.

During the initial stages of this project drinking water with a mild level of contamination was treated using the UV unit at a flow rate comparable to the average domestic flow of 600l/h.

The level of contamination of this sample was;

Coliforms MPN per 100ml	>200.0
Ecoli MPN per 100 ml	1.0

This water was deemed to be unfit for human consumption without treatment.

The post treatment results of this water were as shown below.

Coliforms MPN per 100m	<1.0
Ecoli MPN per 100 ml	< 1.0

Copies of the city analyst's result sheets are contained in appendix.L

These results show that UV treatment of mildly contaminated drinking water flowing at an acceptable rate produces satisfactory results.

5.5 Disinfection Unit Used.

The UV unit selected for the treatment unit was a readily available "Hozelock"© cyprio uvc disinfection unit. This unit is capable of treating water at a flow rate of 1100 l/hr. a sectional view of this unit can be seen in appendix N. This unit is shown in position on the treatment unit in Figure 5.5.

Figure 5.5 Disinfection Unit in Position.

On completion of tests on the test bench unit a working prototype unit was installed on site as shown in Figures 5.6 and 5.7 the details and performance data of the unit are shown in table 5.2. A photograph of the micro pore filter and the UV disinfection unit in position is shown in Figure 5.7

5.6 System Layout.

Water is drawn from the well #1, by pump #2 then delivered to the aeration tank #3. The water then passes through to sedimentation tank #4. From here it flows down to the sand filter #5, from here it flows up through the charcoal filter #6,it flows into the clearwater tank #7. It is then pumped by pump # 8 into the house where it is stored in the attic storage tank#9. The final stages of treatment are where the water passes through the micro pore filter #10 then on to the point of use via the UV disinfection unit # 11. A schematic diagram of the system layout is shown in Figure 5.6

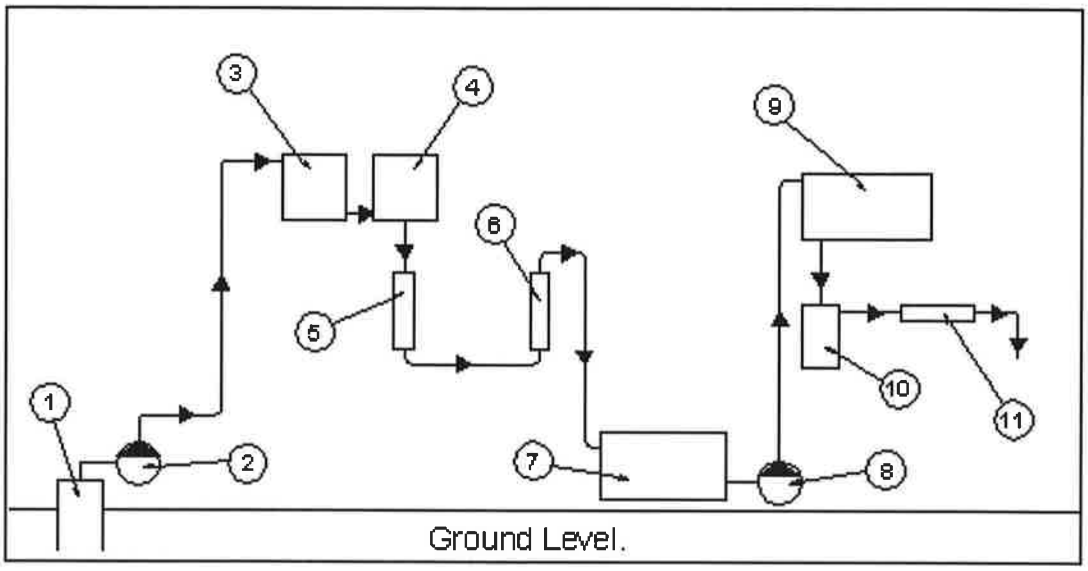


Figure 5.6 Schematic of System Layout

5.7 Working Model.

After completing tests on the laboratory model, a working model was constructed on site and tested. Figures 5.7 and 5.8. Since the well water had no bacteriological contamination, suitably contaminated water was introduced into the system. The results of these tests are shown in Table 5.2. This model comprised the same principle components as the laboratory model. i.e.

(i) Aeration tank (not shown).
(ii) Sedimentation tank.
(iii) Sand filter
(iv) Charcoal filter.
(v) Clearwater tank.
(vi) Pump.
(vii) Attic storage tank.
(viii) Micro pore filter.
(ix) UV disinfection unit.

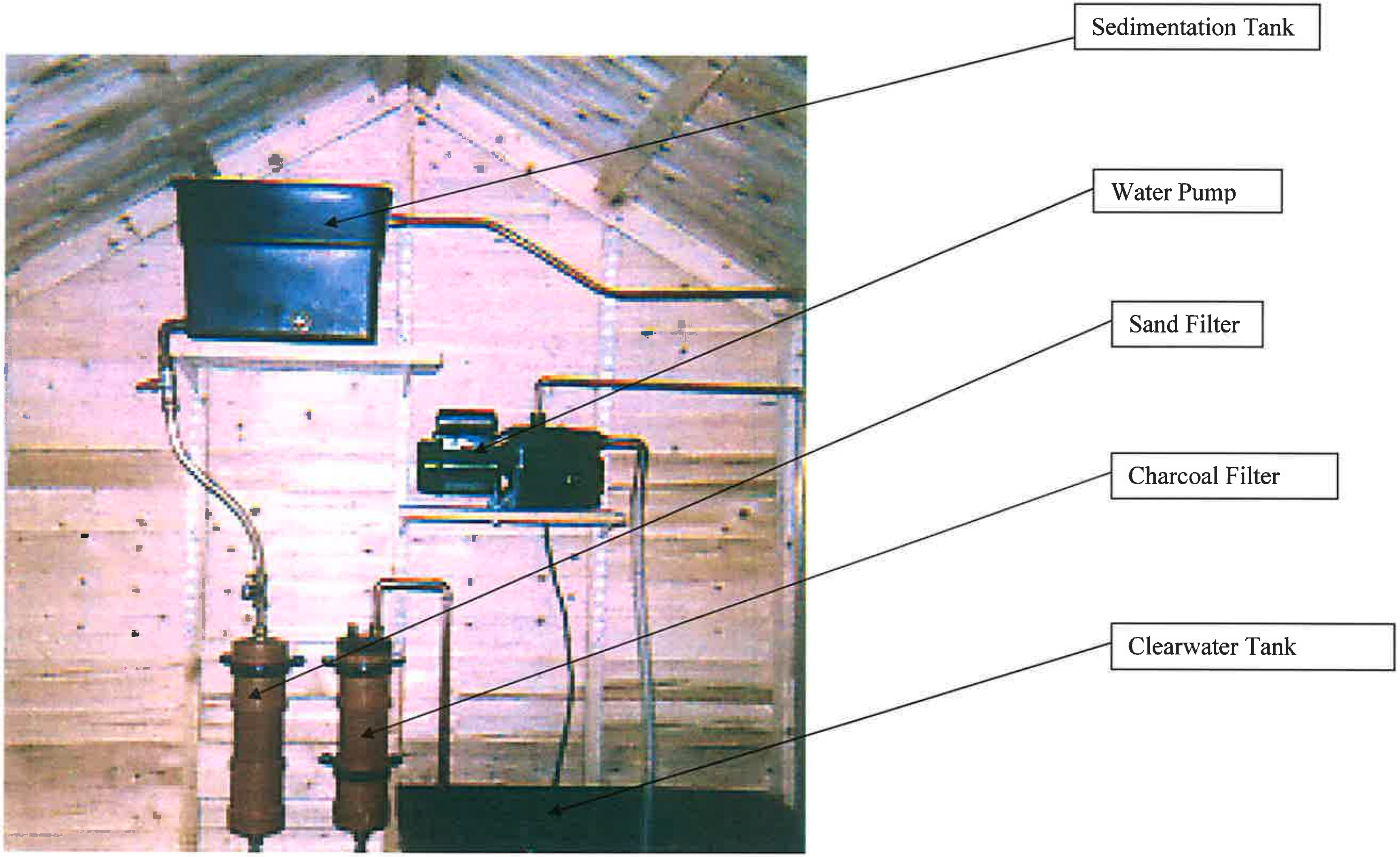


Figure 5.7 Prototype Being Tested on Site.

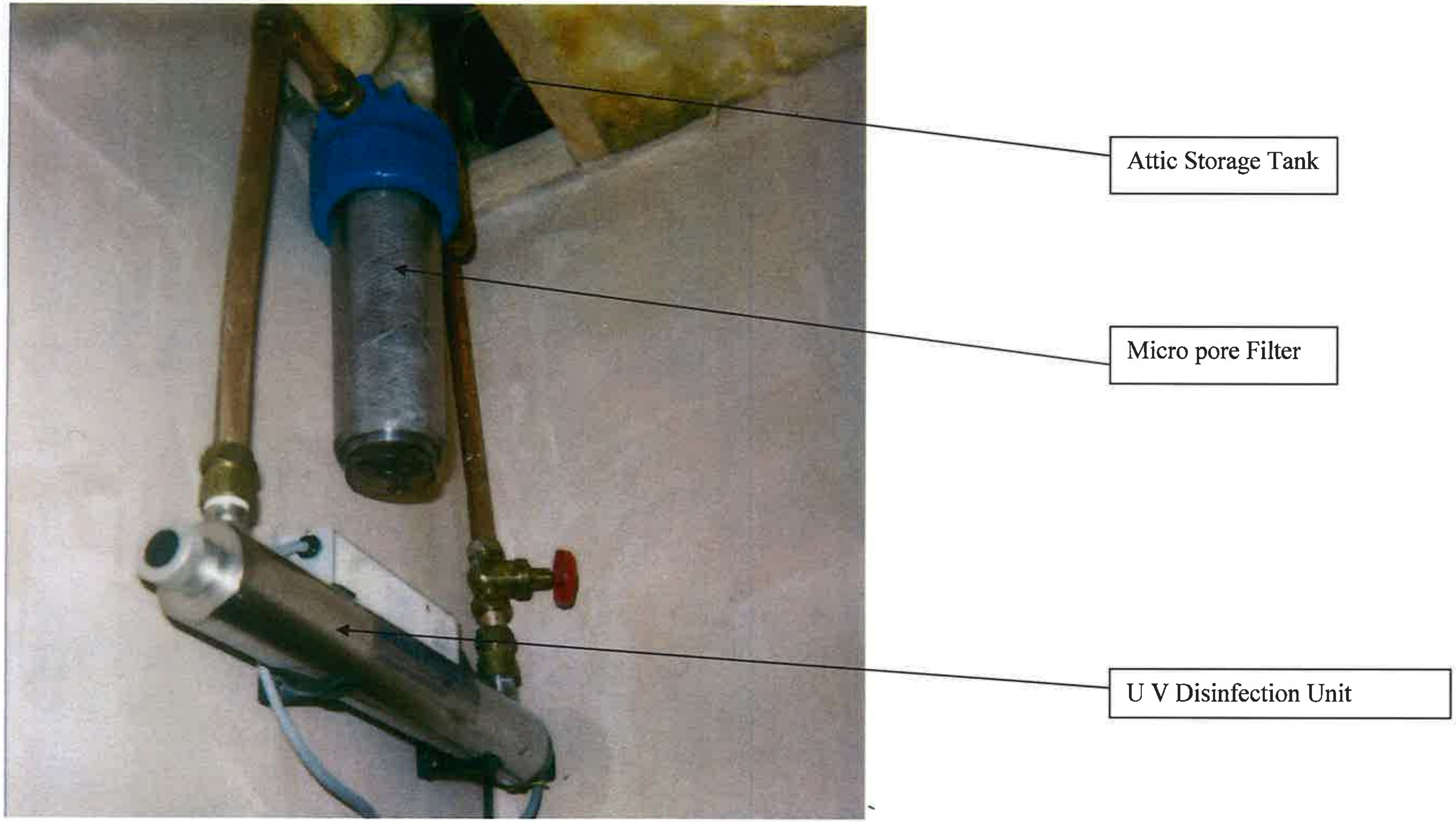


Figure 5.8 Ultra Violet Disinfection Unit in Position.

No	Feature	Value
1	Sand depth 200 mm	100 mm dia.
2	Carbon depth 300 mm	100 mm dia.
3	Permeability of selected sand	180 L / hr.
4	Inlet flow rate	660 l / hr.
5	Flow rate through complete system	120 l / hr
6	Iron concentration raw water	10 mg / l.
7	Iron concentration, from tank	> 3mg / l.
8	Iron concentration, sand filter exit	0 mg/ l.
9	Iron concentration, final outlet	0 mg / l.
10	Taste and odour of water in tank	Positive.
11	Taste and odour at GAC filter outlet	Negative.
12	Bacterial contamination before UV Coliforms MPN in 100ml	>200
13	Bacterial contamination after UV Coliforms MPN in 100ml	<1.0
14	Head pressure	1.5 m.
15	Supply lines	19 mm dia.

Table 5.2 Results from Running and Testing the Prototype Unit Installed on Site

Chapter 6.

Conclusions and Further Work.

6.1 Aims and Objectives of this Research.

The main aim of this research was to produce potable drinking water via a small domestic water treatment unit, which can be used to treat private supply groundwater, group scheme water or municipal supply water. Without the use of chemical treatments.

6.2 Conclusions.

While this treatment unit did not achieve total disinfection of the canal water, as there was high levels of bacterial contamination in it. It could be safe to assume, that moderately contaminated drinking water, flowing through the system at the flow rate specified for the UV unit, then total disinfection of the water would be achieved. The basis of this assumption is outlined in paragraph 5.4.

There are a number of different features that could be used for further development and improvement on this unit. These areas of improvement could be, converting the system to run automatically. This automatic system would largely negate the need for human control. Instead of backwashing the system on a timed interval basis, which can be a waste of semi-treated water especially if carried out prematurely or if the system is backwashing when not in use. The automatic system could monitor the quality and flow rates of the water, and perform any required remedial actions.

It must be remembered however, that aquifer and well protection is as big a part of water treatment as is the filtration and disinfection processes. It is also necessary for private water supplies to be tested regularly. Shallow wells are not as dependable and are more susceptible to bacterial contamination, when compared to deeper wells that will normally be fed from a larger water source, that has a large natural sand filter bed.

6.3 Further Research.

This study while only being concerned with the removal of iron and manganese and the neutralisation of any potential pathogenic infection, it uncovered a range of issues that could be dealt with in a further study. These issues include:

i. In the case of bottled water several studies have revealed that Bottled water contains disinfection by-products, fertilizer residue, and pain relief medication. This is according to research carried in out in October 2008 by Olga Naidenko, [17] in Ireland December 2008 bottled water was withdrawn from circulation due to the presence of E.coli. the Health Service Executive (HSE), informed the Food Safety Authority of Ireland of the risk [89]

ii. Lead in drinking water, this one of the latest developments in a series of water contamination issues. Since lead is one of the more dangerous metals to be contained in drinking water, testing for this and similar metals should be carried out as a routine matter. The investigation and development of a treatment unit for the removal of these metals could be undertaken.

iii. In light of the recent spate of water contamination issues in Ireland, there has been a shift towards homeowners treating their own water. This has led to much confusion with regard to which system is best suited for a particular situation. Reverse osmosis systems are becoming increasingly popular since they are reputed to be capable of producing near pure water. This it does by removing almost everything from the water including health beneficial minerals.

iv. In a report issued by the ERSI in the Irish independent on July 16th 2009, they recommend that, the control of drinking water treatment to be removed from the county councils. A copy of the full report is attached in appendix O

v. In most cases the only treatment required is
    i. Ensuring removal or inactivation of any pathogenic infection, with particular attention to cryptosporidium. See section 1.3. This can be achieved very effectively by UV radiation.
    ii. Removal of tastes and odours, especially Hydrogen sulphide and chlorine. GAC is effective in this role. See section 2.25.3 page 65.
    iii. Elimination of turbidity, this process can be achieved by simple filtration. This is a pre-requisite for the use of UV systems.
    iv. If the presence of VOC's or radon is suspected in the water then aeration is generally all that is required. See section 2.29.4 page 80.

These processes may be applied to any potable water system, whether it is GW, or treated water supplied by the municipal authorities, or GWS's. In the majority of cases these processes are all that is required to render water fit for human consumption, without removing beneficial minerals, and without the use of chemical intervention.

There are however, situations in regard to water pollution e.g. heavy metals where this passive treatment is not sufficient. In such cases a more aggressive course of treatment is required. These situations in Ireland are the exception rather than the rule. See section 2.9, page 27. Such contamination and treatment methods were not the subject of this study.

6.4 Well Contamination.

During the course of this project various samples of drinking water were collected for testing purposes. These samples included water from, municipal mains supplies, deep narrow bore steel lined wells and shallow large diameter concrete lined wells. The mains supply water was not suspected to have bacterial contamination, however it was tested as a curiosity. The deep steel lined well was known to be contaminated with dissolved iron. Bacterial contamination of this source was not suspected, (confirmed by the Public Analyst's report Appedix L) as the well is deep 20 metres, and the steel liners are welded together as they were being inserted into the ground. The shallow well was suspected with bacterial contamination, due to a number of conditions, these include; the well is shallow 3 metres deep, therefore this water is surface water. The well being of a "dug" type well is lined with 1 metre diameter concrete liner pipes, sealed at the joints with cement mortar. There was an offensive odour from the well when opened. The well was tested in 2004, and found to be slightly contaminated with Ecoli at a concentration of in excess of MPN of 200 coliforms per 100 ml, and Ecoli >1 per 100 ml. The odour was a definite indication of bacterial contamination. When re-tested in February 2008, this and other samples were sent to the Dublin City Analysts laboratory. This particular sample gave a positive result of an MPN of coliforms in excess of 517200 per 100ml water, and E.coli MPN 5120 per 100ml water. Copies of the laboratory reports are contained in appendix L. The cause of the pollution was investigated and found to be a damaged sewer pipe in the vicinity of the well. This pipe was permitting raw sewage to leach into the ground around the site of the well, thus polluting it. Since the level of pollution of this source was so high the water was no longer suitable as a test specimen. The problem with the sewage leak was repaired and the well shut down.

6.5 Monitoring the Quality and Flow Rates of the Water Could be Carried out as Follows.

(i) The unit may be controlled automatically by incorporating it to a PLC unit (programmable logic controller). The PLC is capable of monitoring and controlling and controlling the following meters and sensors.

(ii) Turbidimeters, for detecting turbidity breakthrough from the filters, and hence initiate the backwash cycle.

(iii) Turbidimeters, for monitoring clear water emitting from the waste pipe, once detected, the backwash cycle would be stopped.

(iv) Timers, these would run the backwash cycle for a fixed period of time. However, this idea may not be the best solution as the backwash cycle may be too short, and therefore not clean the filters sufficiently.

Or it may be too long resulting in wasting clear treated water and wasting power by pumping excessive water to waste.

(v) Water level detectors that would monitor the water level in the tanks, and would shut the system down if they ran empty.

(vi) Pressure sensors that would monitor the air pressure in the pump pressure tank.

(vii) Flow meters that could monitor the water being used.

(viii) Changing filter units for removing elements other than iron and manganese.

Publications.

MATRIB Conference Croatia 2007.

A Possible Solution to the Current Water Crises in Galway and Users of Public and Private Water Supplies.

Published in the Engineer's Ireland Journal. Volume 61,issue 6, July August 2007

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APPENDICES.

Appendix A.

Report on the Quality of Drinking Water Supplied to Consumers [17].

ALMOST a third of rivers supplying drinking water to hundreds of thousands of families nationwide are polluted, a damning Environmental Protection Agency report reveals today.

The crisis is worsening with an alarming 60pc of groundwater supplies sampled during the year-long investigation polluted by e-coli from human and animal waste.

Almost one-in-five householders get their tap water from groundwater supplies which are increasingly contaminated, according to the report.

Bacteria such as e-coli and cryptosporidium, which can cause serious illness, is increasing in our groundwater, the nationwide-probe concludes.

Local authorities' sewage discharges and slurry and fertiliser run-off from farms are branded the main culprits for the pollution.

The report comes in the wake of the recent Galway pollution crisis where more than 90,000 people could not drink their publicly-supplied water as it was contaminated by the deadly cryptosporidium bug from Lake Corrib.

Hundreds of people fell ill as a result. Fish kills are also at "an unacceptably-high level" due to sewage from council plants and farms, according to the EPA report.

"There remains an unacceptable and sizeable level of water pollution in the country," it concludes.

A total of 29pc of river channel length, 8pc of lake surface area and over 22pc of the estuarine/coastal water bodies examined are polluted and will not meet the EU Water Framework Directive.

"The level of bacterial and nutrient contamination in our groundwaters is increasing and the number of fish kills in our rivers remains unacceptably high," it finds.

The Water Quality in Ireland 2006 Report reveals:

- almost 30pc of all our rivers are badly polluted;
- 57pc of groundwater tested was contaminated by fecal e-coli from human and animal waste, an increase on the previous year;
- a total of 25pc of groundwaters have excessive levels of nitrates which cause blue-baby syndrome when the nitrates turn to nitrites in the bottle and react with blood haemoglobin. This is worst in the south and south east of the country;
- 19pc of coastal waters and estuaries are also grossly contaminated and the problem is worsening.

Dr Mary Kelly, EPA director general, said that although water extracted from groundwater sources is treated before being used in public supplies, increased contamination puts further pressure on drinking water treatment plants.

More stringent protection of groundwater resources was now urgently required, she said.

Dr Kelly said urban-sewage treatment licensing, farm-nutrient management and catchment management for discharges needed to be tackled immediately.

The report dealt with 13,200km of river and stream channel, 421 lakes, 69 tidal water bodies (from 21 estuarine and coastal areas) and 285 groundwater sources. Phosphates and nitrates, both of which come from farming and sewage plants, are the main causes of water pollution.

These chemical combinations cause eutrophication whereby rivers and lakes get over-enriched with nutrients, have too much growth, and fish life is killed off, having been starved of oxygen.

Of the 449 lakes assessed, water quality in 66 of these was less than satisfactory, with 15 lakes being highly polluted. There were 34 fish kills recorded in 2006, caused by local authority services and agriculture."The number of instances of these events remains at an unacceptably-high level," according to the report.

The overall quality in the 69 water bodies from 21 estuarine and coastal areas declined, with an increase in the numbers showing enrichment.

Shellfish are also suffering, with their waters showing more pollution than they had in previous years.

The report says that in Ireland, groundwater is a significant source of drinking water supply.

Worryingly, the number of groundwater samples and sampling locations showing bacteriological contamination, in the period 2004--2006, showed an increase for the first time since 1995. Some 13pc of samples that the survey took were grossly contaminated.

Appendix B.

Cryptosporidium the Organism.

Cryptosporidium is an oval-shaped protozoan parasite found in man, mammals, birds, fish, and reptiles. As of 2006, fourteen different *Cryptosporidium* species have been described and validated. Of the 14 species described, two, *Cryptosporidium parvum* and *hominis*, are responsible for the vast majority of human disease. In addition to these, 5 additional species, C.meleagridis, C. canis, C. felis, C.suis, C. muris, and 2 genotypes, monkey and cervine, are known to cause disease in humans.

The parasite has a complicated lifecycle (Figure 1), which goes through many forms and unlike other coccidian species, can complete its entire life cycle within a single host. Thick-walled Cryptosporidium oocysts (3 to 6 µm in diameter) are stable in the environment and have been found to remain viable in water for up to 140 days. Oocysts are resistant to disinfection with chlorine and chloramines. Cryptosporidium infection follows the ingestion of viable oocysts. Once in the gastrointestinal tract, oocysts release sporozoites which then invade the surrounding mucosal epithelial cells. Within the cell, the sporozoites move to the next developmental stage, and are known as trophozoite. Trophozoites undergo sexual and asexual reproduction. Asexual reproduction spreads the parasite to adjacent cells while sexual reproduction forms a zygote within a thick-walled shell. Before leaving the host, the zygote undergoes sporulation and is therefore capable of infection immediately following excretion in the fecal matter.

Appendix C

Quality of Water Intended for Human Consumption.

(i). All water for human consumption, whether in its original state or after treatment, regardless of origin, is covered, including water used in the food industry but excluding natural mineral waters or medicinal waters;

(ii). National quality standards, the legal limits that must not be exceeded, are fixed for over 50 parameters;

(iii). In particular circumstances, and only where there is no risk to public health, the Minister for the Environment may grant "departures" [i.e. exemptions] from the standard set for particular parameters;

(iv). Minimum frequencies of sampling and analysis, for the respective groups of parameters, which are also defined, are established by the Regulations. Samples are to be taken from water at the point where it is made available to the consumer; that is, at the consumer's tap.

In regard to remedying water quality deficiencies confirmed by sampling and analysis, the Regulations are explicit, requiring sanitary authorities to:

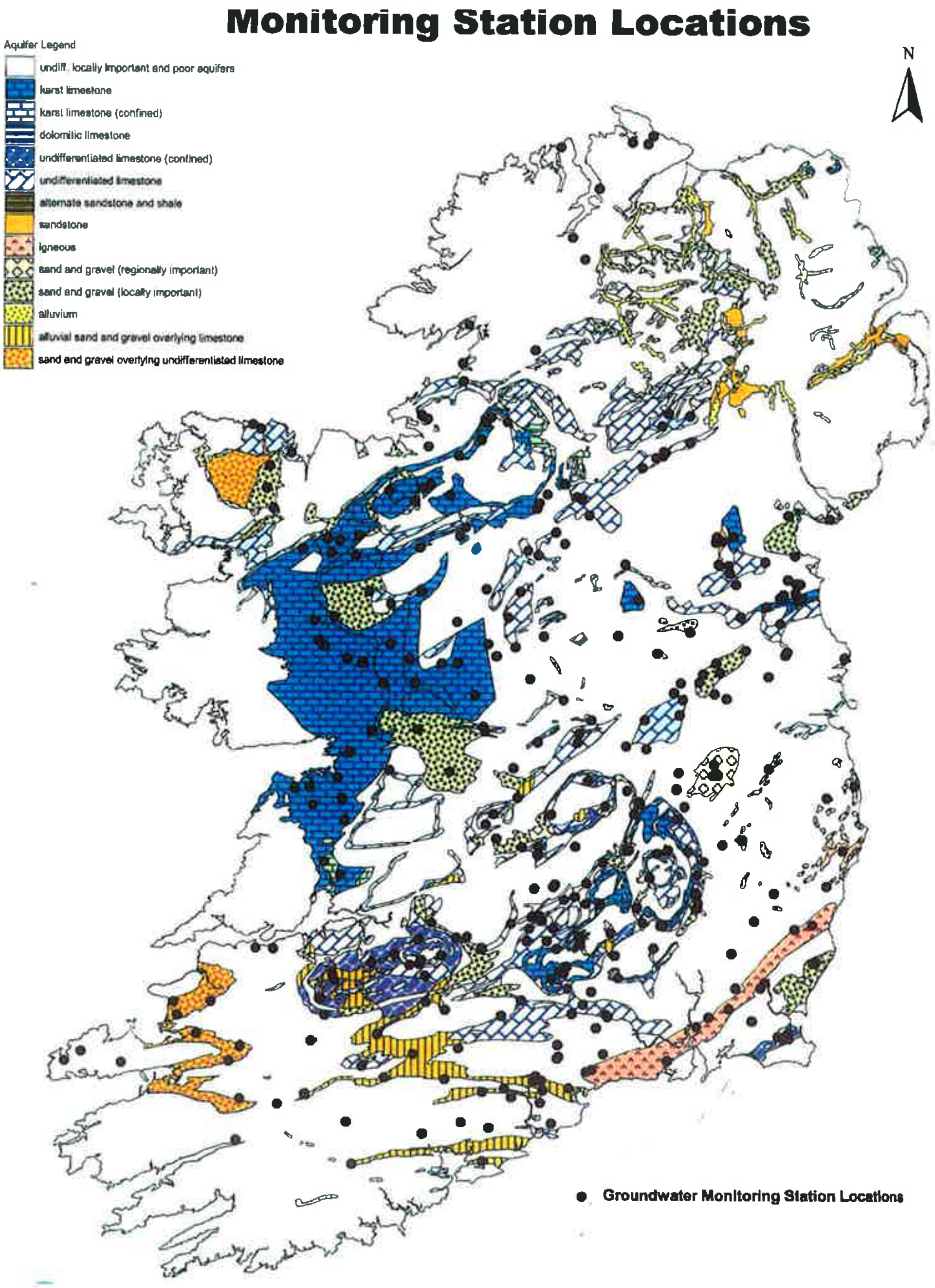
(v). Take all reasonable steps to warn users of a supply found to be an unacceptable risk to public health,

(vi). Prepare, in the case of a public water supply, an action programme for the improvement of the quality of the water as soon as practicable, and

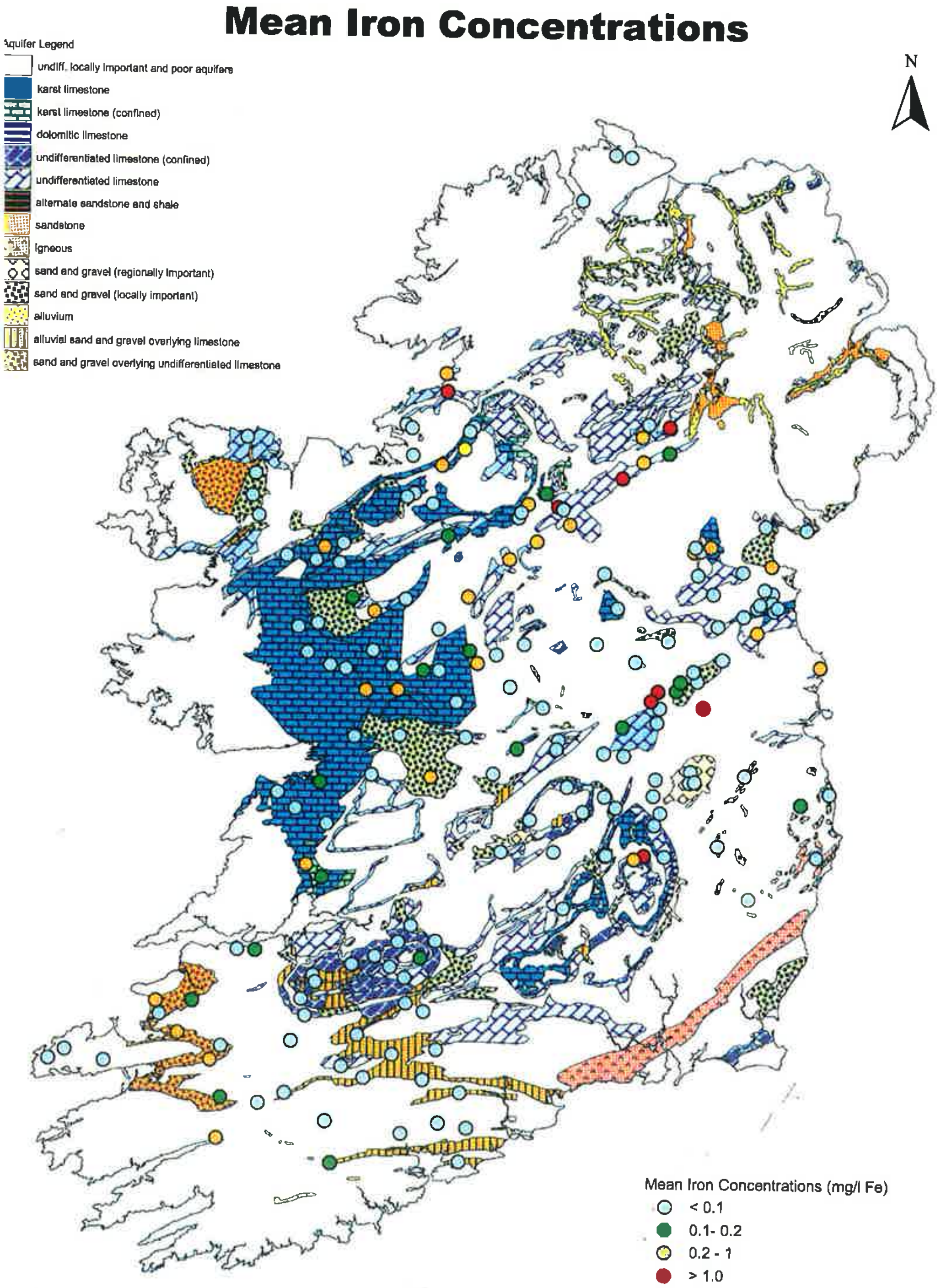
(vii). Notify, in the case of a private water supply [e.g. a group water scheme], the person(s) responsible for the supply as soon as practicable of the measures which should be taken for the improvement of the quality of the water.

Appendix D

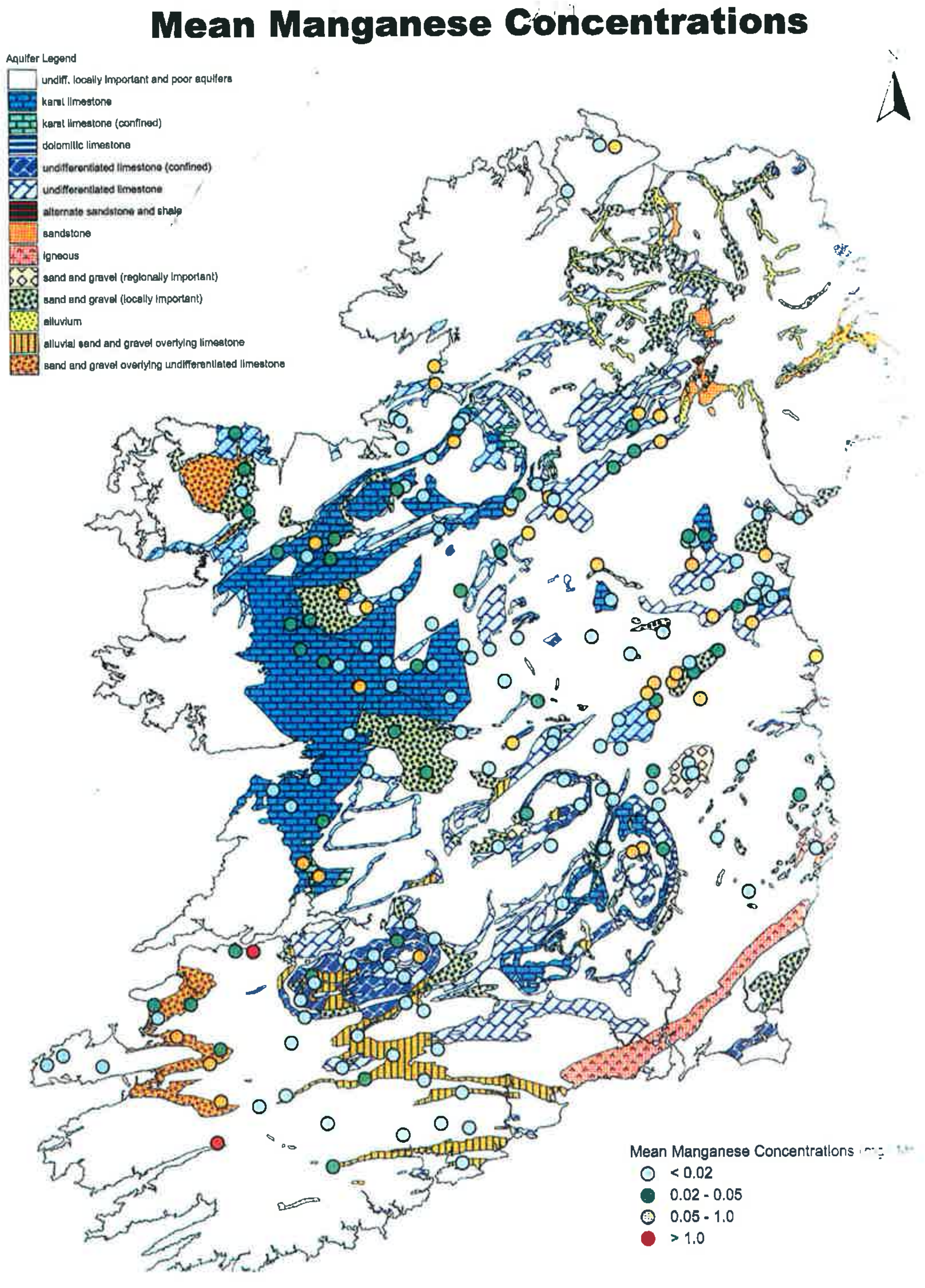
Locations of Groundwater Monitoring Stations



Mean Iron Concentration Levels in Groundwater.



Mean Manganese Concentration Levels in Groundwater.



Appendix E

Table of ground water usage in Ireland as a percentage of the total water used.

County	**Public supply Mm^3/yr**		**Industrial & private Supplies Mm^3/yr**		**Total supply Mm^3/yr**	**Groundwater as % of Total water used.**
	Surface water	**Ground water**	**Surface water**	**Ground water**		
Carlow.	2.206	1.738	0.365	1.327	5.637	54.4
Cavan.	2.475	0.292	4.275	1.643	8.684	22.3
Clare.	3.707	0.713	4.357	0.321	9.279	11.1
Cork.	39.603	6.552	0.730	13.14	60.02	32.8
Donegal.		0.164			7.466	2.2
Dublin.				1.82	109.5	1.6
Galway.		3.650		0.183	16.07	23.8
Kerry.	10.990	3.0	0.151	2.115	16.26	31.5
Kildare.		0.548		1.094	5.133	32.0
Kilkenny.	3.876	5.412	0.365	2.306	11.959	64.5
Laois.	0.40	3.835	0.365	0.2	4.8	84.1
Leitrim.	0.715	0.904		0.174	1.8	59.9
Limerick.	10.853	3.61	3.0	1.890	19.356	28.4
Longford.	2.102	0.707	0.33	0.478	3.62	32.7
Louth.	5.497	0.268	0.613	1.221	7.598	19.6
Mayo.		1.825		0.183	16.425	11.1
Meath.	11.408	0.288	0.287	0.726	12.71	8.0
Monaghan.	2.770	0.180	1.818	0.846	5.614	18.3
Offaly.	2.931	2.337			5.268	44.4
Roscommon.	0.05	9.558			9.608	99.5
Sligo.	3.548	1.129	0.1	0.058	4.842	24.5
Tipperary N	6.691	2.054	0.2	0.855	9.8	29.7
Tipperary S		3.65		1.825	10.95	50.0
Waterford.	9.678	4.328	3.0	0.455	17.454	27.4
Westmeath.	5.355	0.680	0.04	0.018	6.09	11.5
Wexford.	9.273	3.573	2.54	0.606	15.99	26.1
Wicklow.		0.365			5.475	6.7
Total		**61.362**		**33.489**	**407.428**	**23.3**

Appendix F

Table of Contaminant Concentration Level Changes for the Years 1994 – 1996.

CHANGES IN PERCENTAGES OF EXCEEDANCES : 1994 - 1996

	Percentages			Changes +/-		
Parameter	**1994**	**1995**	**1996**	**1994/95**	**1995/96**	**1994/96**
Aluminium	8.9	8.7	7.0	- 0.2	- 1.7	- 1.9
Ammonium	1.0	1.3	0.9	+0.3	- 0.4	- 0.1
Coliforms	12.8	12.5	12.15	- 0.3	- 0.35	- 0.65
Colour	6.8	6.8	9.4	± 0	+2.6	+2.6
Fluoride	13.3	12.2	9.45	- 1.1	- 2.75	- 3.85
Heavy Metals	0.5	0.7	0.8	+0.2	+0.1	+0.3
Iron	7.7	9.1	10.6	+1.4	+1.5	+2.9
Manganese	11.8	11.2	8.3	- 0.6	- 2.9	- 3.5
Nitrates	0.8	0.8	1.5	± 0	+0.7	+0.7
Nitrites	0.7	0.7	0.7	± 0	± 0	± 0
Odour	8.7	7.6	8.3	- 1.1	+0.7	- 0.4
pH	2.0	1.8	1.9	- 0.2	+0.1	- 0.1
Taste	9.9	9.7	6.7	- 0.2	- 3.0	- 3.2
Turbidity	3.4	3.3	2.8	- 0.1	- 0.5	- 0.6

Appendix G

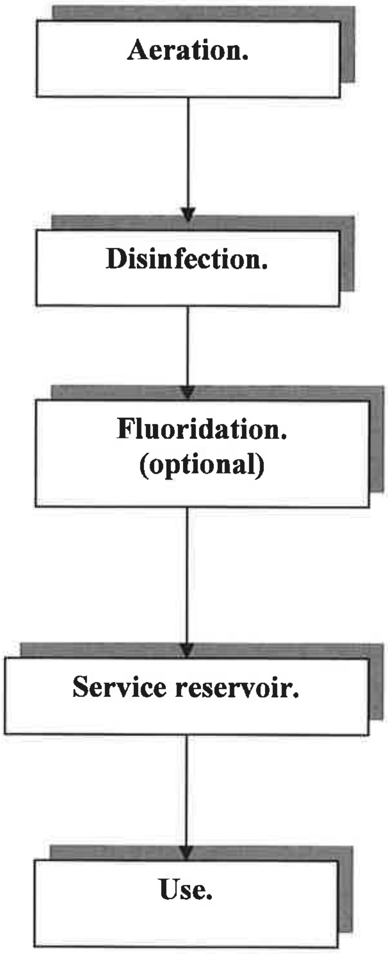
Saturation Concentration of Oxygen in Water at Different Temperatures

Temperature (°C)	**Solubility of oxygen in water C_s ($g\ m^{-3}$) in equilibrium with air at 1 atmosphere ($1.013\times10^5\ N\ m^{-2}$ or 101.3 kPa)**	**Correction to be subtracted for each degree of salinity (expressed as g total salts per 1000 g water)**
0	14.65	0.0925
1	14.25	0.0890
2	13.86	0.0857
3	13.49	0.0827
4	13.13	0.0798
5	12.79	0.0771
6	12.46	0.0745
7	12.14	0.0720
8	11.84	0.0697
9	11.54	0.0675
10	11.26	0.0653
11	10.99	0.0633
12	10.73	0.0614
13	10.48	0.0595
14	10.24	0.0577
15	10.01	0.0559

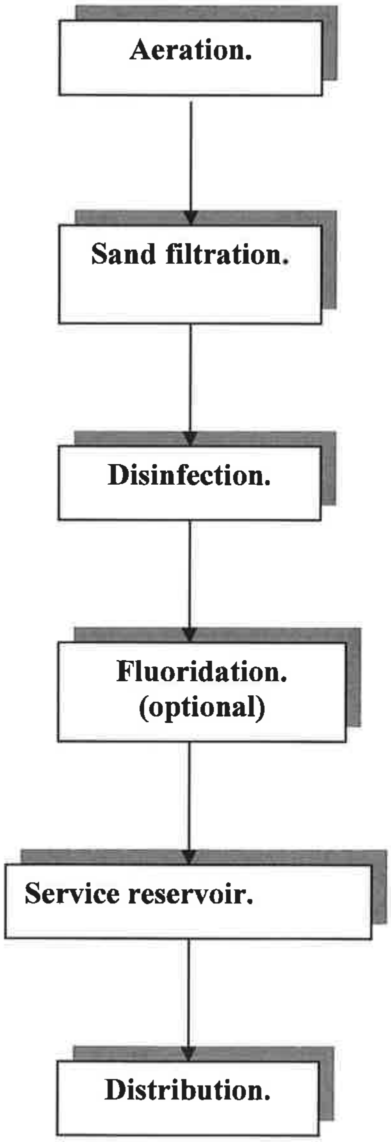
16	9.79	0.0543
17	9.58	0.0527
18	9.38	0.0511
19	9.18	0.0496
20	8.99	0.0481
21	8.80	0.0467
22	8.63	0.0453
23	8.45	0.0440
24	8.29	0.0427
25	8.12	0.0415
26	7.97	0.0404
27	7.81	0.0393
28	7.66	0.0382
29	7.51	0.0372
30	7.36	0.0362

Appendix H

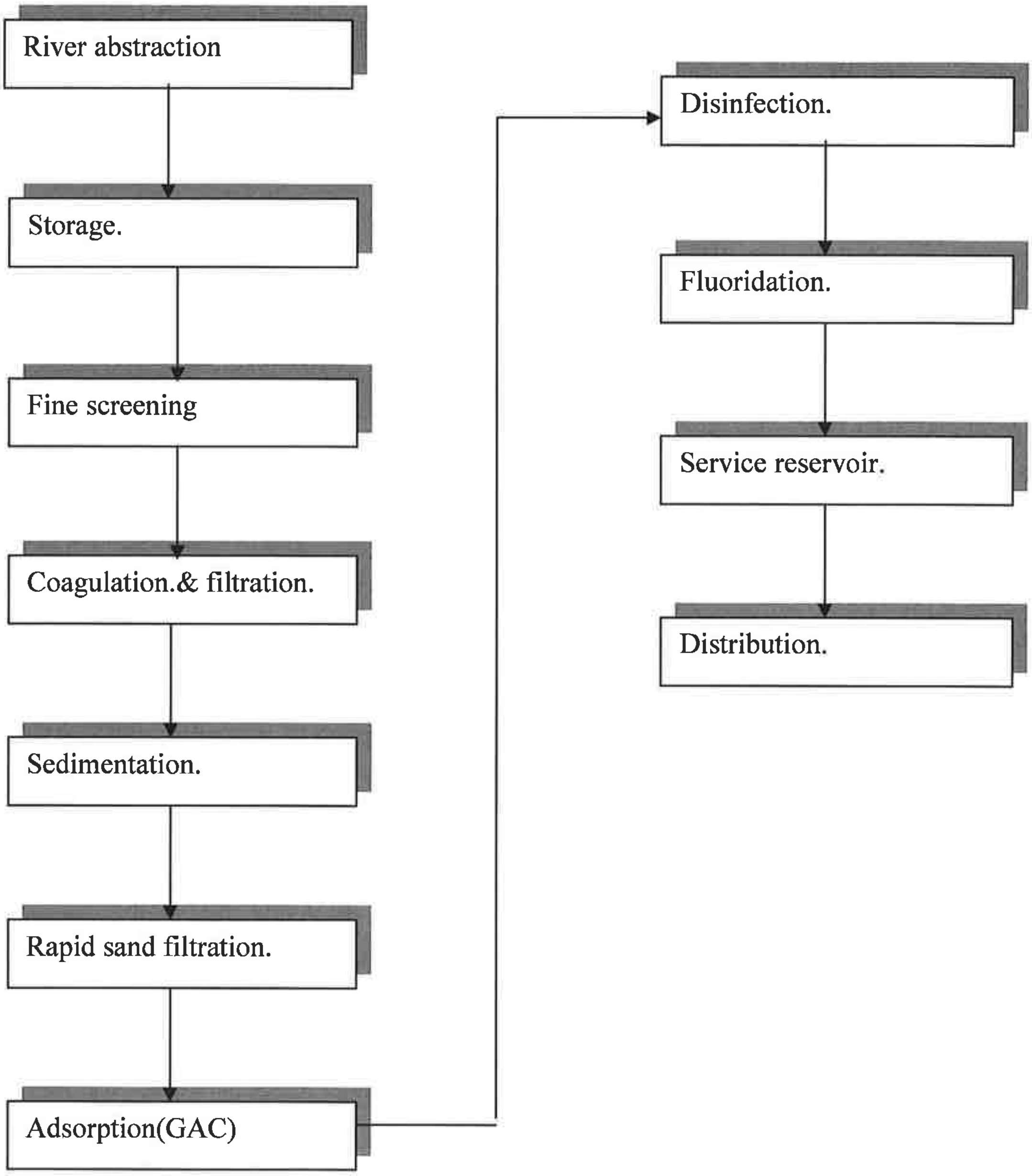
Drinking Water Treatment Procedures.



(i) Well water requiring minimal treatment



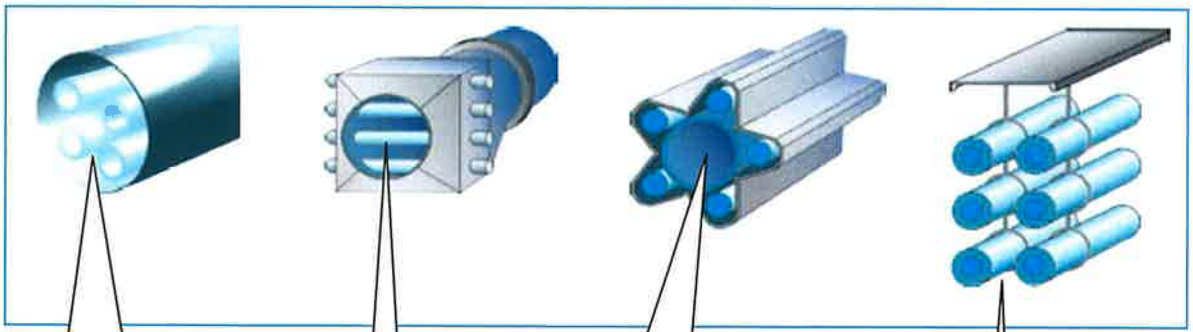
(ii) Well water with iron and manganese present



(iii) Surface Water Requiring Extensive Treatment.

Appendix J

Ultraviolet Reactor Chamber Configurations.



Stainless steel multiple tube UV tubes, aligned parallel to water flow. Up to 600 m^3/h.

Stainless steel multiple tube UV tubes, aligned perpendicular to water flow. Up to 1000 m^3/h.

Quartz glass reactor multiple tube UV tubes, positioned externally aligned parallel to water flow. Up to 120 m^3/h.

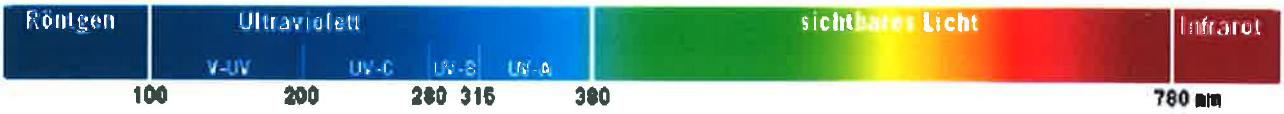
Stainless steel multiple tube UV tubes, aligned parallel to water for integration in open concrete effluent channels flow. Up to 10000 m^3/h.

Appendix K

Spectrum of Light Ranging From “X-Rays to Infrared Light.

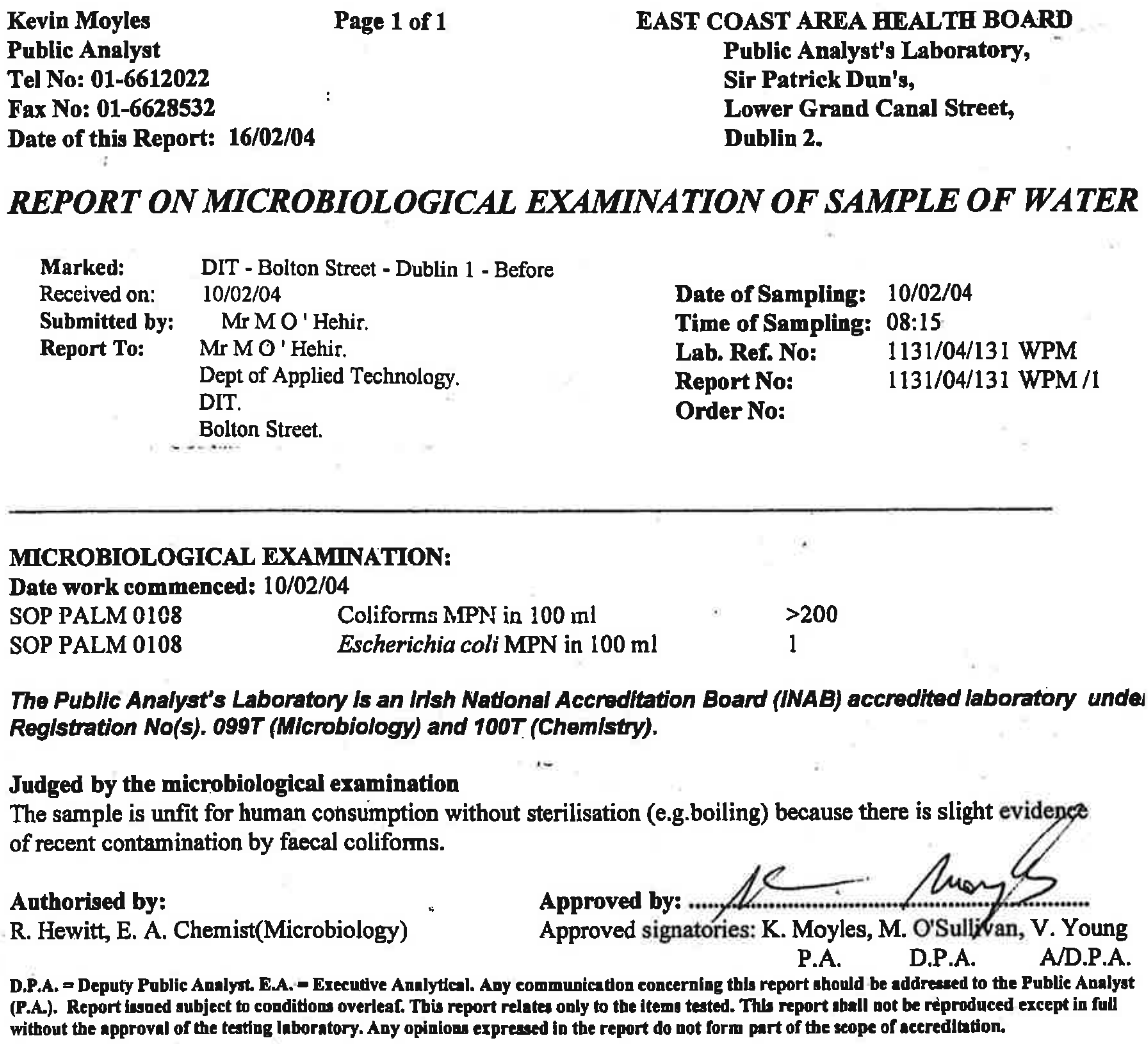
X-Ray Ultraviolet Visible light

Infrared



Appendix L

Water Test Report.



Kevin Moyles
Public Analyst
Tel No: 01-6612022
Fax No: 01-6628532
Date of this Report: 16/02/04

Page 1 of 1

EAST COAST AREA HEALTH BOARD
Public Analyst's Laboratory,
Sir Patrick Dun's,
Lower Grand Canal Street,
Dublin 2.

REPORT ON MICROBIOLOGICAL EXAMINATION OF SAMPLE OF WATER

Marked: DIT - Bolton Street - Dublin 1 - Before
Received on: 10/02/04
Submitted by: Mr M O ' Hehir.
Report To: Mr M O ' Hehir.
Dept of Applied Technology.
DIT.
Bolton Street.

Date of Sampling: 10/02/04
Time of Sampling: 08:15
Lab. Ref. No: 1131/04/131 WPM
Report No: 1131/04/131 WPM /1
Order No:

MICROBIOLOGICAL EXAMINATION:
Date work commenced: 10/02/04

SOP PALM 0108	Coliforms MPN in 100 ml	>200
SOP PALM 0108	*Escherichia coli* MPN in 100 ml	1

The Public Analyst's Laboratory is an Irish National Accreditation Board (INAB) accredited laboratory unde Registration No(s). 099T (Microbiology) and 100T (Chemistry).

Judged by the microbiological examination
The sample is unfit for human consumption without sterilisation (e.g.boiling) because there is slight evidence of recent contamination by faecal coliforms.

Authorised by:
R. Hewitt, E. A. Chemist(Microbiology)

Approved by: ....
Approved signatories: K. Moyles, M. O'Sullivan, V. Young
P.A. D.P.A. A/D.P.A.

D.P.A. = Deputy Public Analyst. E.A. = Executive Analytical. Any communication concerning this report should be addressed to the Public Analyst (P.A.). Report issued subject to conditions overleaf. This report relates only to the items tested. This report shall not be reproduced except in full without the approval of the testing laboratory. Any opinions expressed in the report do not form part of the scope of accreditation.

Results of Bacteriological Water Test on Ballinafagh Shallow Well Water before Treating with UV 2004.

Kevin Moyles
Public Analyst
Tel No: 01-6612022
Fax No: 01-6628532
Date of this Report: 16/02/04

Page 1 of 1

EAST COAST AREA HEALTH BOARD
Public Analyst's Laboratory,
Sir Patrick Dun's,
Lower Grand Canal Street,
Dublin 2.

REPORT ON MICROBIOLOGICAL EXAMINATION OF SAMPLE OF WATER

Marked: DIT - Bolton Street - Dublin 1 - After
Received on: 13/02/04
Submitted by: Mr M O'Hehir.
Report To: Mr M O'Hehir.
Dept of Applied Technology.
DIT. Order No:
Bolton Street.

Date of Sampling: 13/02/04
Time of Sampling: 10: 15,
Lab. Ref. No: 1153/04/131 WPM
Report No: 1153/04/131 WPM 1

MICROBIOLOGICAL EXAMINATION:
Date work commenced: 13/02/04

SOP PALM 0108	Coliforms MPN, in 100 ml	<1.0
SOP PALM 0 108	Escherichia coli MPN in 100 ml	<1.0

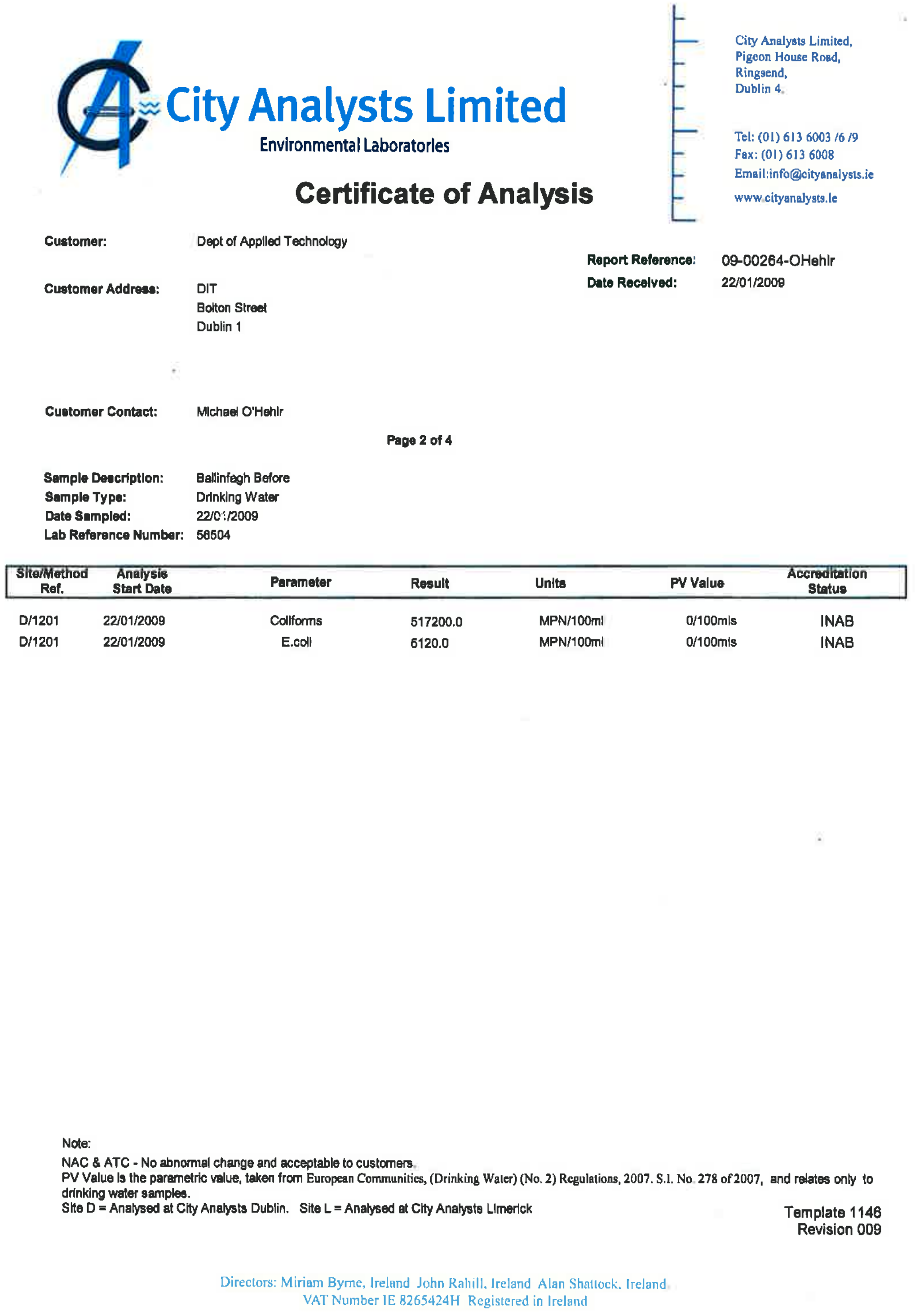
The Public Analyst's Laboratory is an Irish National Accreditation Board (INAB) accredited laboratory under Registration No(s). 099T (Microbiology) and 100T (Chemistry).

Authorised by:
R. Hewitt, E. A. Chemist(Microbiology)

Approved by: M O'Sull
Approved signatories: K. Moyles, M. O'Sullivan, V. Young
P.A. D.P.A. A/D.P.A.

D.P.A. = Deputy Public Analyst. E.A..= Executive Analytical. Any communication concerning this report should be addressed to the Public Analyst (P.A.). Report issued subject to conditions overleaf. This report relates only to the items tested. This report shall not be reproduced except in full without the approval of the testing laboratory. Any opinions expressed in the report do not form part of the scope of accreditation.

Results of Bacteriological Water Test on Ballinafagh Shallow Well Water after Treating with UV 2004.



City Analysts Limited

Environmental Laboratories

Certificate of Analysis

City Analysts Limited,
Pigeon House Road,
Ringsend,
Dublin 4.

Tel: (01) 613 6003 /6 /9
Fax: (01) 613 6008
Email:info@cityanalysts.ie
www.cityanalysts.ie

Customer: Dept of Applied Technology

Report Reference: 09-00264-OHehir
Date Received: 22/01/2009

Customer Address:
DIT
Bolton Street
Dublin 1

Customer Contact: Michael O'Hehir

Page 2 of 4

Sample Description: Ballinfagh Before
Sample Type: Drinking Water
Date Sampled: 22/01/2009
Lab Reference Number: 56504

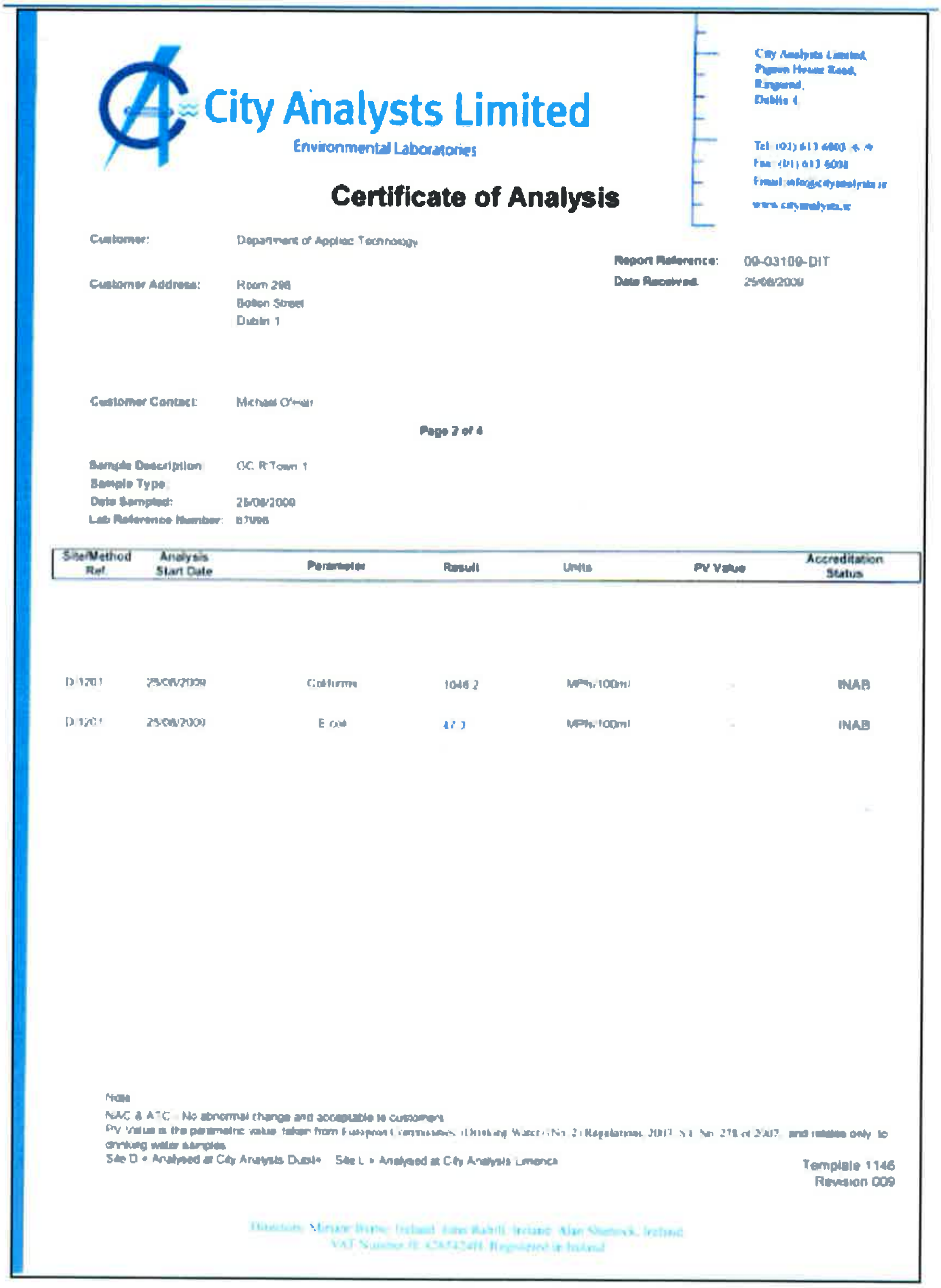
Site/Method Ref.	Analysis Start Date	Parameter	Result	Units	PV Value	Accreditation Status
D/1201	22/01/2009	Coliforms	517200.0	MPN/100ml	0/100mls	INAB
D/1201	22/01/2009	E.coli	6120.0	MPN/100ml	0/100mls	INAB

Note:
NAC & ATC - No abnormal change and acceptable to customers.
PV Value is the parametric value, taken from European Communities, (Drinking Water) (No. 2) Regulations, 2007. S.I. No. 278 of 2007, and relates only to drinking water samples.
Site D = Analysed at City Analysts Dublin. Site L = Analysed at City Analysts Limerick

Template 1146
Revision 009

Directors: Miriam Byrne, Ireland John Rahill, Ireland Alan Shattock, Ireland
VAT Number IE 8265424H Registered in Ireland

Results of Bacteriological Water Test on Ballinafagh Shallow Well Water 2009.



City Analysts Limited
Environmental Laboratories

City Analysts Limited,
Pigeon House Road,
Ringsend,
Dublin 4

Tel: (01) 613 6000
Fax: (01) 613 6008
Email: info@cityanalysts.ie
www.cityanalysts.ie

Certificate of Analysis

Customer: Department of Applied Technology

Report Reference: 09-03109-DIT
Date Received: 25/08/2009

Customer Address:
Room 298
Bolton Street
Dublin 1

Customer Contact: Michael O'Neill

Page 2 of 4

Sample Description: GC R'Town 1
Sample Type:
Date Sampled: 25/08/2009
Lab Reference Number: 67098

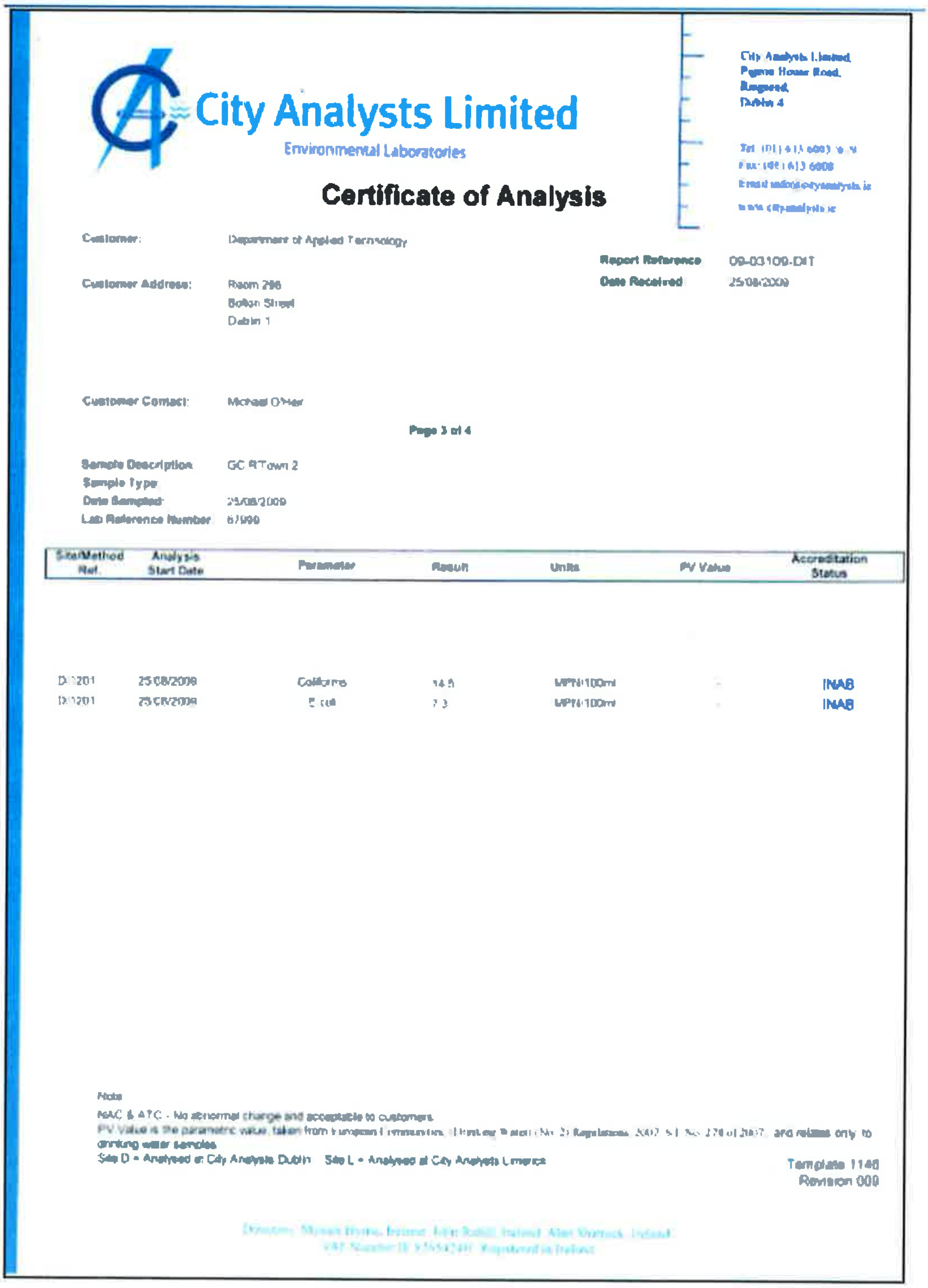
Site/Method Ref	Analysis Start Date	Parameter	Result	Units	PV Value	Accreditation Status
D 1201	25/08/2009	Coliforms	1046.2	MPN/100ml	-	INAB
D 1201	25/08/2009	E coli	47.3	MPN/100ml	-	INAB

Note
NAC & ATC = No abnormal change and acceptable to customers
PV Value is the parametric value, taken from European Communities (Drinking Water) (No. 2) Regulations 2007 S.I. No. 278 of 2007, and relates only to drinking water samples
Site D = Analysed at City Analysts Dublin   Site L = Analysed at City Analysts Limerick

Template 1146
Revision 009

Directors: [illegible]
VAT Number IE [illegible] Registered in Ireland

Results of Bacteriological Water Test on Canal Water Prior to Treating with UV.



City Analysts Limited
Environmental Laboratories

City Analysts Limited,
Pigeon House Road,
Ringsend,
Dublin 4

Tel: (01) 613 6000 [illegible]
Fax: (01) 613 6008
Email: info@cityanalysts.ie
www.cityanalysts.ie

Certificate of Analysis

Customer: Department of Applied Technology

Report Reference 09-03109-DIT
Date Received 25/08/2009

Customer Address:
Room 296
Bolton Street
Dublin 1

Customer Contact: Michael O'Her

Page 3 of 4

Sample Description GC RTown 2
Sample Type
Date Sampled 25/08/2009
Lab Reference Number 67999

Site/Method Ref.	Analysis Start Date	Parameter	Result	Units	PV Value	Accreditation Status
D1201	25/08/2009	Coliforms	14.5	MPN/100ml	-	INAB
D1201	25/08/2009	E coli	7.3	MPN/100ml	-	INAB

Note
NAC & ATC - No abnormal change and acceptable to customers
PV Value is the parametric value, taken from European Communities (Drinking Water) (No. 2) Regulations 2007 (S.I. No. 278 of 2007) and relates only to drinking water samples
Site D = Analysed at City Analysts Dublin   Site L = Analysed at City Analysts Limerick

Template 1148
Revision 009

Directors: [illegible] Byrne, Ireland; [illegible], Ireland; Alan [illegible], Ireland
VAT Number IE [illegible] Registered in Ireland

Results of Bacteriological Water Test on Canal Water after Treating with UV.

City Analysts Limited
Environmental Laboratories

City Analysts Limited,
Pigeon House Road,
Ringsend,
Dublin 4.

Tel: (01) 613 6003 /6 /9
Fax: (01) 613 6008
Email:info@cityanalysts.ie
www.cityanalysts.ie

Certificate of Analysis

Customer: Dept of Applied Technology

Report Reference: 09-00264-OHehir
Date Received: 22/01/2009

Customer Address:
DIT
Bolton Street
Dublin 1

Customer Contact: Michael O'Hehir

Page 3 of 4

Sample Description: Coolree Before
Sample Type: Drinking Water
Date Sampled: 22/01/2009
Lab Reference Number: 56505

Site/Method Ref.	Analysis Start Date	Parameter	Result	Units	PV Value	Accreditation Status
D/1201	22/01/2009	Coliforms	<1.0	MPN/100ml	0/100mls	INAB
D/3001	03/02/2009	Iron, Total	4262	ug/l	200 µg/l	NON
D/3001	03/02/2009	Manganese, Total	56	ug/l	50 µg/l	NON

Note:
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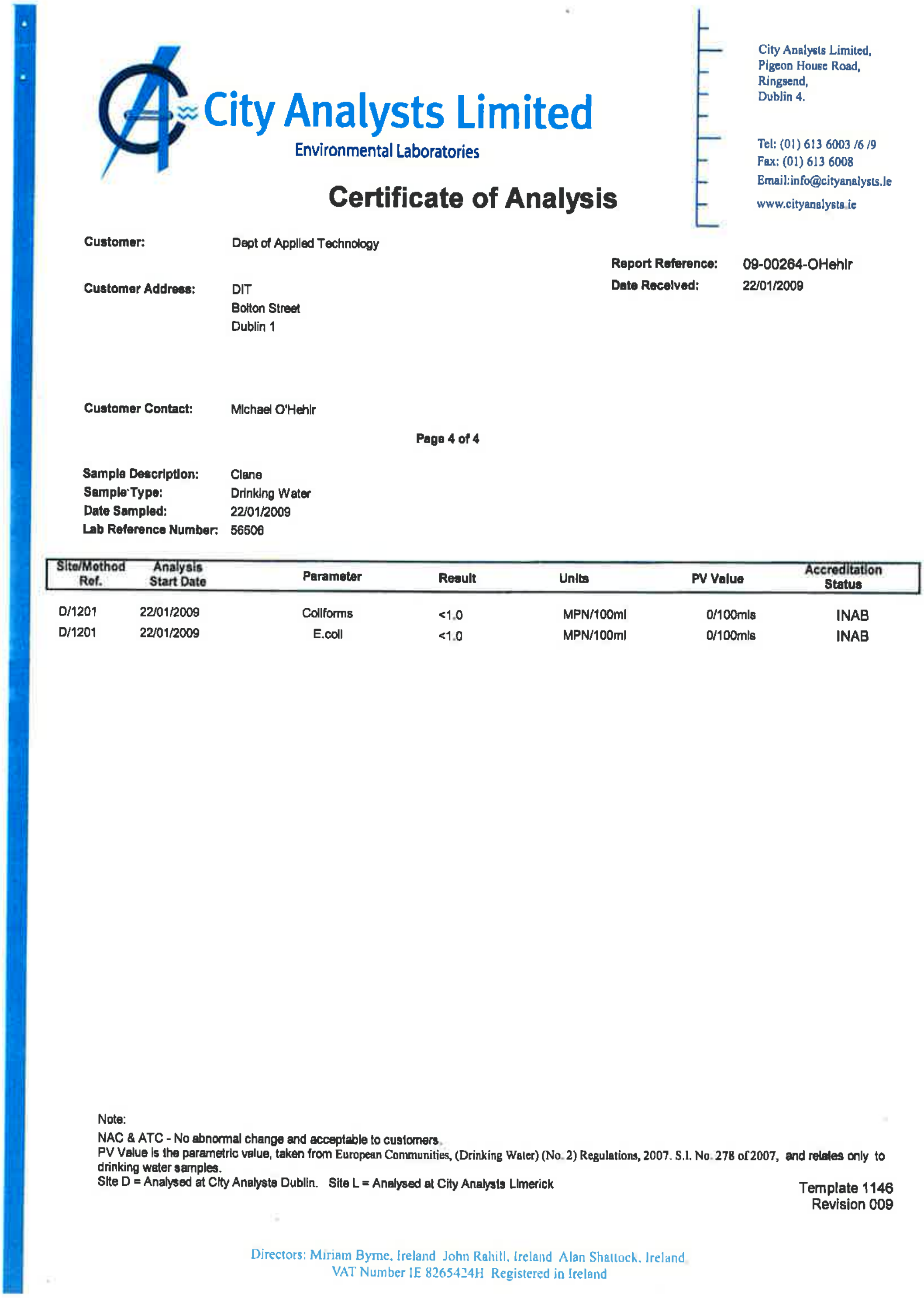
PV Value is the parametric value, taken from European Communities, (Drinking Water) (No. 2) Regulations, 2007, S.I. No. 278 of 2007, and relates only to drinking water samples.
Site D = Analysed at City Analysts Dublin. Site L = Analysed at City Analysts Limerick

Template 1146
Revision 009

Directors: Miriam Byrne, Ireland John Rahill, Ireland Alan Shattock, Ireland
VAT Number IE 8265424H Registered in Ireland

Results of Bacteriological and metal Water Test on Coolree Well Water Prior to Treatment.



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Dublin 4.

Tel: (01) 613 6003 /6 /9
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Dublin 1

Customer Contact: Michael O'Hehir

Page 4 of 4

Sample Description: Clane
Sample Type: Drinking Water
Date Sampled: 22/01/2009
Lab Reference Number: 56506

Site/Method Ref.	Analysis Start Date	Parameter	Result	Units	PV Value	Accreditation Status
D/1201	22/01/2009	Coliforms	<1.0	MPN/100ml	0/100mls	INAB
D/1201	22/01/2009	E.coli	<1.0	MPN/100ml	0/100mls	INAB

Note:
NAC & ATC - No abnormal change and acceptable to customers.
PV Value is the parametric value, taken from European Communities, (Drinking Water) (No. 2) Regulations, 2007. S.I. No. 278 of 2007, and relates only to drinking water samples.
Site D = Analysed at City Analysts Dublin. Site L = Analysed at City Analysts Limerick

Template 1146
Revision 009

Directors: Miriam Byrne, Ireland John Rahill, Ireland Alan Shattock, Ireland
VAT Number IE 8265424H Registered in Ireland

Results of Bacteriological Water Test on "Mains" Supply Water.

Appendix M.

Copy of Soils Laboratory Test Result Sheet.

Job Ref	Sample No 2
Location Soils Lab	Description No Fines
Date 2/03/2004	Operator C Keaney

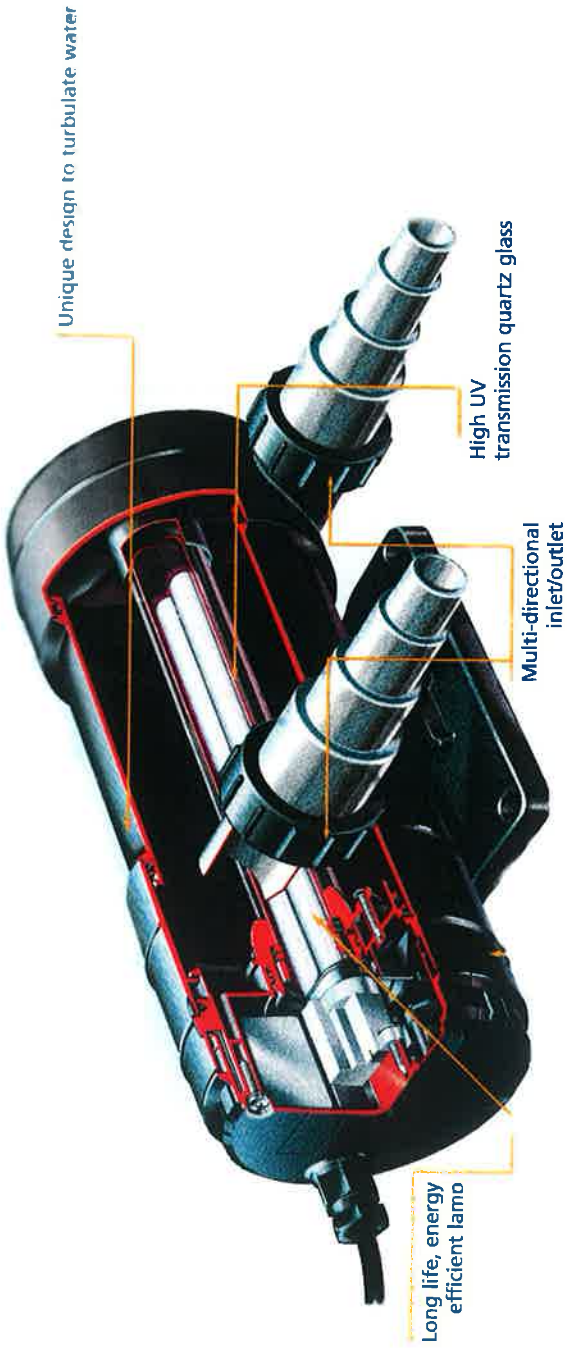
Total mass of dry sample 653.18 g

BS Test sieves	Mass of Sieve	Mass of Sieve / Sample	Mass Retained	Percentage Retained	Total Cumulative Passing
	g	g	g	%	%
75.0 mm					
63.0 mm					
37.5 mm					
20.0 mm					
14.0 mm					
10.0 mm					
5.0 mm					
Tray					
TOTAL					

	g	g	g	%	%
9.5 mm					
4.75 mm					
2.36 mm	428.51	497.23	68.72	10.52	89.48
1.18 mm	390.68	540.24	149.56	22.90	66.58
600 µm	433.31	611.98	178.67	27.35	39.23
300 µm	321.82	479.66	157.84	24.16	15.06
150 µm	338.37	411.49	73.12	11.19	3.87
75 µm	326.58	348.06	21.58	3.29	0.58
Tray	268.15	271.94	3.79	0.58	0.00
TOTAL			653.18		

Appendix N

Sectional View of Ultraviolet Disinfection Unit Used.



Appendix "O"

Call to Take Drinking Water Role away from Councils

The operation of drinking water treatment plants should be taken away from local authorities and outsourced to private companies because of repeated failures to provide safe water, the ESRI says.

The economic think-tank has called for a national authority to be established to take responsibility for providing water which meets EU safety standards.

Using data from the Environmental Protection Agency, the ESRI says that at least one water supply in all Irish cities and counties failed to meet EU standards in 2007.

It also notes that more than 5pc of the population-had their drinking water polluted with manganese, iron, lead or aluminium, and that the percentage of people suffering from biological contamination, including e-coli, is "even larger".

"At first sight, these results are alarming" it says.

The 'Drinking Water Quality' bulletin published yesterday says that in 2007, the most recent year for which data is available, water quality was not much better than in 2006.

Skills

In 2006, 88pc of people had something wrong with their water and in 2007 this was 85pc. Many sources that reported a problem in 2006 continued to report the same problem in 2007. "Maintaining drinking water quality requires particular skills and expertise as well as resources. Given the results set out above, it is questionable whether the existing system, with the local authorities at the centre, is equipped to guarantee drinking water quality," the report says.

It adds that in some counties, the number of people using local supplies do not justify employing a full-time expert to operate plants, and that the civil service "does not offer a career perspective" for specialists. While local authorities should remain responsible for ensuring safety standards are met, the operation of the plants should be outsourced to specialist companies.

"These problems can be addressed. For example, county councils could outsource the operation of drinking water facilities to specialised companies or responsibility for water services could be transferred to a single national authority."

The City and County Managers Association rejected claims there was no career path for specialists, adding that a "wide range" of approaches were used to manage water infrastructure. It added there was a need for continued investment to ensure standards were maintained.