The Cooperative Research Centre for

Water Quality and Treatment

Point of Entry/ Use Treatment for Delivery of Potable Water

Research Report 50

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Point of Entry/Use Treatment for Delivery of Potable Water

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FOREWORD

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EXECUTIVE SUMMARY

The use of commercially available point of entry (POE) and point of use (POU) treatment units to provide potable drinking water from poor quality water sources was investigated. Three POE mobile water treatment plants (MWTP) were constructed and they were used to treat four different raw water sources throughout Victoria. The MWTP consisted of a sand filter, carbon filter, cartridge filter UV disinfection, storage and reverse osmosis (RO) if the water was saline. Two ultrafiltration (UF) units were tested at two other locations, and a pre-filter (cartridge filter) was included in these systems.

Turbidity was effectively removed by the MWTP with turbidities of <2 NTU reliably achieved and turbidity of <1 NTU regularly achieved. UF reliably produced turbidity of <0.4 NTU. The MWTP required little maintenance over the period of the trials (3-4 months), and the sand and carbon filters were automatically backwashed once a week. The UF unit was backwashed daily and cleaning of the UF unit was required after 2-3 months when fed with water with turbidity of >3 NTU was applied.

Colour reduction was limited to approximately 50% for the water tested, (Timberline Road and Rupanyup), and for some waters (Avoca or Lexton) very little colour reduction was achieved. Colour was the most problematic of water parameters and control using commercially available equipment was limited. The production of small scale nanofilters that are capable of removing dissolved organic carbon that contribute to colour were not tested, however, they appear to be able to bridge the gap and provide colour/DOC removal necessary for the provision of potable water.

E. coli and total coliforms were effectively removed by the MWTP and the UF unit, with no *E. coli* or total coliforms detected in any of the treated waters. The UV units used in the MWTP performed reliably, and this was attributed to limiting the flow through these units to less than their maximum design flow-rate for the UV unit and having effective pre-treatment, while the UF units effectively sieved the microorganisms from the water. The UF units demonstrated an ability to maintain water quality even when spikes in *E.coli* and total coliforms were detected in the feed water.

Bacterial re-growth of HPC bacteria was, however, found inside the clear water tank at Avoca and Timberline Road. It is recommended to disinfect the clear water tank once a month by adding a chlorine tablet. No re-growth of *E. coli* or total coliform bacteria was found in the clear water tanks.

POU reverse osmosis systems demonstrated reliable performance for reducing electrical conductivity (EC) over the trials at Lexton and Avoca. The average EC reduction by the Merlin RO unit at Avoca was 78% and produced treated water with an EC of less than 450 μS/cm. The Merlin RO did foul during the trials, indicating that regular cleaning was required. A six monthly cleaning frequency seemed suitable for the Avoca water which had EC levels of 3,000 μS/cm.

The trials at Rupanyup determined that activated carbon in the POE unit was able to remove trihalomethanes (THM) from the water. The activated carbon did not have to be replaced during the life of the trials (2 months). Where water is centrally disinfected, using activated carbon adsorption was sufficient to deliver better quality water to customers.

Water recoveries for both the MWTP and the UF units were satisfactory, except for the overall recovery when RO units were used. The overall water recoveries varied between 70% at Timberline Road and Dadswells Bridge to 97% at Rupanyup and could be increased by longer intervals between the backwash cycles. The water recoveries through the POU RO units were only 20-30%.

It is advised to use all the treatment units that were included in the MWTP unit and to ensure that the flow rate through the unit does not exceed the design flow-rate of the disinfection unit to ensure microbiologically safe drinking water at all times. Additionally, construction of a fail safe system should be considered, so that water is not processed when the UV lamp is not working. This could be achieved by detecting when there is no current flow in the UV lamp and then either activating a solenoid valve to prevent flow or deactivating the feed pump.

A pre-filter (sand filter, a cartridge filter or a sedimentation tank) to lower the feed turbidity should be employed when using an ultrafiltration unit to prevent the UF from rapid fouling.

Preliminary cost calculations suggest that POE may be cheaper than building centralised treatment plants with widespread distribution systems for towns with less than 150 households.

The technology currently available 'off the shelf' can capably produce potable water that meets ADWG parameters with the exception of coloured water. New nanofiltration membranes have been shown to reduce colour/DOC in full scale operation (Ostarcevic 2006). The trials completed as a result of this project indicate that commercially available equipment can produce safe drinking water generally at a lower cost per household than centralised treatment if a distribution per household network is in place.

This project identifies the key issue associated with POE/POU systems, which is the maintenance, operation and monitoring of these systems to satisfy water safety legislation and their attendant regulations. In addition, the principle of ownership and management of the treatment facilities is an important consideration for water supplies, consumers and regulators.

Centralised ownership of the treatment systems can impose significant resource constraints on water corporations that provide services to small communities that are geographically dispersed. Having established the efficacy of treatment equipment it is clear that more research and consultation is required to determine the management models available for the ownership, operation, maintenance and monitoring of these systems until suitable management systems are developed. A lifecycle cost cannot properly be developed to satisfactorily compare this technology with existing systems.

Five different models to manage onsite water treatment systems were introduced together with a case study and industry wide discussion is suggested to consider how best to manage POE or POU systems.

Additional work is required to:

- develop management guidelines for POE/POU systems,
- develop monitoring regimes to protect public health and assist with cost estimation for these systems,
- development of maintenance schedules, and
- integrate capital and management cost to develop lifecycle costs for direct comparison with other alternatives.

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ABBREVIATIONS

ADWG	Australian Drinking Water Guidelines
CHW	Central Highlands Water
CTP	Centralised treatment plant
DBP	Disinfection by-products
DHS	Department of Human Services (Victoria)
DSE	Department of Sustainability and Environment (Victoria)
EC	Electrical conductivity
GAC	Granular activated carbon
GWMWater	Grampians Wimmera Mallee Water
HPC	Heterotrophic plate counts
MF	Microfiltration
NF	Nanofiltration
NTU	Nephelometric turbidity units
PAC	Powdered activated carbon
PCU	Platinum cobalt units (colour units)
POE	Point of entry
POU	Point of use
PVDF	Polyvinylidene fluoride
RO	Reverse osmosis
SDA	Safe drinking water act (Victoria)
TDS	Total dissolved solids
UF	Ultrafiltration
USEPA	United States Environmental Protection Agency
UV	Ultraviolet disinfection
VU	Victoria University
WHO	World Health Authority
YVW	Yarra Valley Water

1 INTRODUCTION

Australia is currently in the grip of one of its longest droughts on record. Below average rainfall over the last ten years has led to low water levels in many reservoirs and very poor raw water quality because of limited inflow from rivers and catchments. Small towns are often limited to a single water source, which makes decreasing water quality a major issue. Under the terms of the Victorian Safe Drinking Water Act (SDA) (2003) and its attendant Safe Drinking Water Regulations (2005), water corporations are required to supply safe drinking water to customers throughout the year.

Many local water authorities in rural Victoria, such as Grampians Wimmera Mallee Water (GWMWater), Central Highlands Water (CHW) and Yarra Valley Water (YVW), have difficulty delivering potable water to many small, remote communities in their area. GWMWater has to deal with a range of communities where current water quality does not meet Australian Drinking Water Guidelines.

GWMWater supplies 40 towns, many with populations of less than 100 people, with untreated water. Partially treated (disinfected only) water is also provided to a further 17 towns, with populations ranging from 87 to 1380. This places at risk a number of businesses and community services including food preparation businesses, schools and local hospitals. It is recognised that supplying drinking water to many of these towns through traditional water treatment systems is not economically viable.

Point of entry (POE) or point of use (POU) treatment devices may offer a feasible option for providing drinking water to these communities. A workshop on POE and POU treatment was organised by the CRC Water Quality and Treatment in July, 2003, and Jeffery Kempic from the USEPA was the keynote speaker. The workshop highlighted the use of POU devices in the USA to effectively treat chronic health issue contaminants such as arsenic, with a conservative approach taken to maintenance of these systems (i.e. adsorption cartridges replaced when the adsorption capacity was estimated to 2/3 consumed). Monitoring of a sample of the treatment units was performed rather than monitoring of all the POU or POE units when contaminants associated with chronic health issues where being addressed, in order to lower the cost of implementation. However, the USEPA required monitoring of all POE units when contaminants associated with acute health issues, such as the microbiological quality, were being addressed. This approach effectively means that POE and POU systems are only implemented for the treatment of chronic health issues, as the monitoring costs associated with regular water quality monitoring of all POU and POE systems made them uneconomic.

Therefore, GWMWater in conjunction with DSE, CHW and CSIRO, and as part of the CRC for Water Quality and Treatment, developed and implemented a project to identify the performance and maintenance requirements of POE and POU systems as an option for supplying safe drinking water to small communities. This project was also supported by DHS and Victoria University towards the end of the project. CHW also hired GHD as consultants to this project for a short period of time, and the input of Michael Chapman was helpful.

As part of a pilot program, three mobile water treatment plants and two POE membrane systems using commercially available devices, were designed, constructed, installed and operated to trial various technologies on different water sources. The aim of the project was to assist GWMW, CHW and YVW explore opportunities for the use of POE and/or POU treatment devices to provide drinking water to small remote communities. This included trialling the units at several remote locations in Victoria to see how they perform, what maintenance was required and to ascertain if the treated water is safe under the requirements of SDA (2003). The level of treatment required for different raw water quality criteria such as colour, with or without turbidity, was also identified as was an assessment of the reliability and cost effectiveness of POE and POU devices.

2 WATER TREATMENT SYSTEM PROCESSES

2.1 Centralised treatment plants (CTP)

The most widely used systems for water treatment are centralised water treatment plants (CTP). They are centrally located and used to treat all water that is delivered to a community. The traditional water treatment processes used in a CTP are a combination of coagulation, sedimentation, filtration and disinfection [1]. The advantage of CTP is that the water quality is constantly monitored, which reduces the risk of sub-optimal water treatment and contamination of the treated water. They are more cost effective to operate at large scales and are therefore considered to be the most suitable option for delivering potable water to medium to large communities. However, in the event of a breakdown or failure in treatment performance, all customers are exposed to a potential health risk.

2.2 Point of Entry (POE)

Point of Entry (POE) devices are used to treat water at the entrance of the property. Instead of treating water before it enters the reticulation system, POE units are placed at individual customer sites. Therefore, one POE water treatment system is required per household or small collective grouping. The major advantage of POE units is that they may have lower capital costs compared to CTP, particularly if reticulation costs are included for remote communities. POE devices may include a treated water storage tank to handle peak flow rates or they may be designed to accommodate peak flows without storage. Since they are set up at the property, the treated water does not remain for long periods of time in the reticulation system and the chance for subsequent contamination is low. The main problem with POE, however, is that continuous monitoring of the water quality can not be provided economically.

2.3 Point of Use (POU)

Point of use devices are used to treat water at a single tap instead of treating all incoming water to a property. These devices handle very small volumes and are usually set up underneath the kitchen sink and provide only that tap with treated water. POU devices are available in a range of treatment technologies, such as filtration, disinfection or desalination using reverse osmosis membranes. Recently, nanofiltration membranes have been developed to remove colour/dissolved organic carbon (DOC) at the POU/POE scale. The type of treatment depends on the raw water quality and the units are very small, light and easy to install. POU devices are widely used by homeowners to reduce taste and odour problems usually on reasonably good quality water. A great variety of POU devices is already commercially available.

A common problem is that homeowners install devices and may use them for years without ever monitoring the water quality. However, most of the devices have only a limited life expectancy, which makes them unreliable after prolonged use. Regular maintenance is required to ensure that they perform well and that the water is safe for drinking. Since they are generally installed inside individual households, it makes it difficult for water authorities to monitor and maintain them. Moreover, since POU devices are usually installed only at the kitchen tap, homeowners need to be aware that they can not drink water from any other tap without being exposed to health risks if they are relying on POU devices for a potable water supply. The main differences between POE and POU devices is that not all taps receive treated water for POU devices.

The main concerns about POU units are:

1. whether they can supply safe water reliably and consistently
2. potential health risks posed by not treating all incoming water to a house
3. if water authorities can monitor and maintain the equipment properly.

3 QUALITY OF DRINKING WATER

“Drinking water is intended for human consumption, either by drinking directly or indirectly via cooking food or ice making” [2]. The quality of water is defined by its physical, chemical and microbiological quality. The basis for the characterisation of drinking water is a set of parameters that determine its quality. It is almost impossible to obtain water with no contamination and water does not need to be absolutely pure to be safe for drinking. It is essential that it does not contain harmful concentrations of chemicals or disease-causing microorganisms, and should be safe to drink for people in most stages of normal life. Ideally it should be aesthetically pleasing with regard to appearance, taste and odour. Parameters that indicate the quality of drinking water are discussed below and acceptable limit guidelines recommended by the Australian Drinking Water Guidelines (ADWG) [3] are presented.

3.1 Microbiological quality of drinking water

This section discusses the microbiological characteristics of water quality and describes the microorganisms found in drinking water that can be harmful to human health. The most common contaminants affecting human health in drinking water are from human or animal excreta and the microorganisms contained in faeces. If the contamination is recent, some of these microorganisms may be present in the water and drinking or using it in food preparation can cause disease. Some bacteria, viruses and protozoa are disease-causing (pathogenic) organisms and the diseases they cause vary in severity. The classic waterborne diseases are caused by organisms originating in the gut of humans or other animals. But there are also many organisms of environmental origin that are normally not associated with diseases, but which can, under certain circumstances, cause disease in humans. The main problem with microorganisms in drinking water is infection, although there are other issues that may affect humans. For example certain algae and bacteria can produce toxins that may remain in the water even when the organisms producing the toxins have been removed. Other organisms can cause taste, odour, and colour problems or can promote deposition and corrosion. Waterborne pathogens found in Australian water sources include bacterial pathogens (such as *Salmonella*), protozoa (such as *Giardia* and *Cryptosporidium*), viruses and cyanobacteria (blue-green algae). To supply safe drinking water the entry and transmission of pathogens has to be prevented. To detect faecal pollution in drinking water the following three indicator parameters are used:

- *E. coli*
- Total coliforms
- Heterotrophic plate count

A short overview of these follows.

3.1.1 Escherichia coli (*E. coli*) and thermotolerant coliforms

E. coli and thermotolerant coliforms belong to the same family of bacteria living in the intestine, known as Enterobacteriaceae. Most *E. coli* are harmless and abundant in the intestines of humans and other warm-blooded animals. Some strains, however, may cause illness. The presence of *E. coli* in a drinking water sample almost always indicates recent faecal contamination which means that there is a greater risk that disease-causing organisms (pathogens) are present. It is therefore considered as the most specific indicator of recent faecal contamination, since it is the most common thermotolerant coliform present in faeces. Testing for *E. coli* is recommended to indicate the presence of faecal contamination. It might be simpler to test for thermotolerant coliforms, but it is more accurate to test for *E. coli* because some environmental coliforms are thermotolerant. Chapter 10 of the ADWG recommends a detection limit of zero *E. coli* in a 100 mL sample; however a practical operational limit of one positive per 50 samples is permissible considering errors in analysis.

3.1.2 Total coliforms

Total coliforms is a grouping of various bacteria including *E. coli* and other related enterobacteria. Total coliforms includes a component of the normal intestinal population in humans and animals, as well as many bacteria that have an environmental origin and are inhabitants of soil and water. Coliforms are capable of multiplying in water to high numbers when the conditions are right. They can be in water as a result of faecal contamination, the presence of bio films on pipes, or following contact with soil. Total coliforms have, in the past, been regulated in potable water but this is no longer required in Australia due to the absence of a strong link between the presence of low concentrations of total coliforms and adverse health outcomes. They are still used as indicators, but not regulated to zero because their abundance makes them useful in monitoring the efficiency of water treatment and disinfection processes. Increases in coliform levels in treated water indicates that the treatment efficiency has changed and system performance has to be improved. No coliforms immediately after the disinfection process demonstrates successful disinfection.

3.1.3 Heterotrophic plate count

Heterotrophic microorganisms are broadly defined as organisms that use organic chemicals as a carbon source [4]. A variety of simple culture-based tests that are intended to recover a wide range of microorganisms from water are collectively referred to as "heterotrophic plate count" or "HPC test" procedures. These tests reflect the number of heterotrophic microorganisms in the water supply that are able to grow and produce colonies on the growth medium used for the test under specified conditions (e.g. incubation time, temperature). HPC are usually determined after incubation at 20-22°C or 35-37°C. The tests are not recommended to indicate faecal contamination but may be useful in assessing the efficacy of water treatment processes such as coagulation, filtration and disinfection, each of which reduces bacterial numbers. Heterotrophic bacteria are naturally occurring, and their presence in drinking water is not indicative of a public health risk. It has been speculated that growth of HPC bacteria in POE or POU devices could represent a health risk; however an expert workshop convened by the World Health Organisation (WHO) concluded that there was no direct relationship between ingestion of HPC bacteria in drinking water and human health effects in the general population. In some instances however, regrowth of HPC bacteria may affect the aesthetic quality of water including taste and odour [5]. The ADWG state that large numbers of aerobic heterotrophic bacteria in treated water can interfere with the interpretation of tests for the coliform group by masking their presence, thus yielding false-negative results [6]. HPC is also used as an indicator of system stability and increases in HPC levels may indicate that the treatment process needs to be modified.

3.2 Physical quality of drinking water

The physical quality of drinking water is how people experience water when they drink it. It includes the water’s appearance, taste and odour. Other physical characteristics can indicate whether corrosion is likely. The physical characteristics of water affect its aesthetic quality and are generally not of direct public health concern. Section 3.2 describes the measurable characteristics which determine the physical and chemical quality of drinking water and outlines their acceptable limits as recommended by the ADWG.

3.2.1 Turbidity

Turbidity is the measure of the cloudiness of water, which originates from fine suspended particles, such as soil or microscopic organisms. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are likely to be present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. Moreover the particles can shield bacteria from disinfecting Ultra Violet light (see Chapter 4.3.2) thereby reducing its effectiveness. Turbidity is measured in nephelometric turbidity units (NTU) using a turbidity meter. The detection limit is 0.1 NTU. The guideline for turbidity is 5 NTU, based on aesthetic reasons. However, turbidity of greater than 1 NTU may shield microorganisms from disinfectants such as UV, and so turbidity of less than 1 NTU is recommended for disinfection purposes.

3.3 Colour

Colour is a result of dissolved organic matter arising from soil and decaying vegetation in water. It can also be caused by the presence of certain bacteria such as blue-green algae. Iron contributes to colour and surface waters increase in colour with an increase in pH. Colour itself is not a health risk to humans. However, particles that contribute to colour are likely to react with disinfectants thus reducing the effectiveness of the disinfection process, increasing the disinfection dose requirements and potentially leading to disinfection by-products that are regulated and described in section 3.3.2. Colour is measured in platinum cobalt units (PCU) using spectrophotometry or with a visual comparator. There are two different expressions for colour. “Apparent” colour is how it really appears and includes diffraction resulting from particulate matter, while “True” colour is measured after filtering the water to remove particulate matter and measures the absorbance of dissolved material. ADWG recommends true colour of ≤15 PCU which is just visible in a glass.

3.3.1 Hardness and total dissolved solids

Total dissolved solids (TDS) includes inorganic salts, very fine clay, colloidal iron, manganese oxides and silica. TDS is used as a measure of salinity. The ADWG guidelines state that there are no known health effects of TDS, but rather components may pose a risk. It is assumed that sodium chloride is of main interest. TDS is a measure of the total ions in solution, and is analysed by filtering out the suspended material, evaporating the filtrate and weighing the remaining residue. A parameter related to TDS is electrical conductivity (EC). It is measured in micro Siemens per centimetre [µS/cm] and is a measure of the ionic activity of a solution in terms of its capacity to transmit current [7]. High TDS levels generally indicate hard water which can cause scale build up in pipelines, valves and filters, reducing performance. The guideline for TDS is based on taste perception and is set at 500 mg/L. 500-1000mg/L is "acceptable" while > 1000mg/L is associated with scaling, corrosion and a bad taste.

3.3.2 pH

The major reason for controlling pH is to avoid corrosion and encrustation in pipes and fittings. Based on this, the pH of drinking water should be between 6.5 and 8.5.

3.3.3 Temperature

The temperature of the treated water is an aesthetic issue, therefore no guideline is set for drinking water temperature. However, an increase in water temperature results in increasing biological re-growth in the distribution system.

3.4 Chemical quality of drinking water

Some organic and inorganic chemicals, including some pesticides in drinking water, are a health concern, because they are toxic to humans or suspected of causing cancer. Some can also affect the aesthetic quality of water.

3.4.1 Inorganic chemicals

The presence of inorganic chemicals in drinking water can result from natural leaching from mineral deposits into source waters, carryover of small amounts of treatment chemicals, addition of chemicals such as chlorine and fluoride or corrosion and leaching of pipes and fittings.

3.4.1.1 Iron

Iron occurs commonly in soil and rocks as oxide, sulfide and carbonate minerals. There has not been a health-based guideline for the amount of iron in drinking water. The recommended limit for iron in drinking water is 0.3 mg/L based on aesthetic considerations, but it does not become a health concern unless the concentration is higher than 3 mg/L.

3.4.1.2 Lead

Lead can be present in drinking water as a result of dissolution from natural sources or from household plumbing systems containing lead. Lead is known to be a health risk to humans and the recommended detection limit in drinking water is 0.01 mg/L.

3.4.1.3 Manganese

Uncontaminated rivers and streams generally have low concentrations of naturally occurring manganese. Manganese is not considered to be a health risk unless the concentration exceeds 0.5 mg/L, but aesthetic considerations limit the concentration of manganese in drinking water to less than 0.1 mg/L.

3.4.2 Organic compounds

Organic compounds in drinking water can either occur naturally or from human activities and are usually present in very low concentrations. Disinfection by-products (DBPs) are commonly found organic contaminants in Australian drinking water supplies. DBPs are the products of reactions between disinfectants and naturally occurring organic material. Most disinfectants used to remove pathogens from drinking water will produce by-products during the disinfection process. A number of epidemiological studies have suggested an association between chlorinated by-products and various cancers. Although there is currently no conclusive evidence showing any association between DBPs in water with cancer or other health effects, there are some concerns, given the research information and the large number of people drinking chlorinated water [8]. Based on health considerations, the guideline value for chlorine in drinking water is 5 mg/L. Naturally occurring organic compounds are generally not a human health concern. Other organic contaminants that could be present in Australian drinking water as a result of human activities are pesticides. Pesticides should be authorised for use in catchment areas only where necessary. Pesticides not authorised for such use should not be present in drinking water.

4 WATER TREATMENT TECHNOLOGIES

Most source waters used for public drinking water supplies are not of suitable quality for consumption without some form of treatment. Different types of treatment technologies improve water quality and make it safe for drinking. Each of the basic treatment technologies that can be used in small systems are discussed below. The technologies are first described separately, but are normally used in combination. How different treatment technologies can be combined and what combination best suits different raw water types is discussed in chapter 5.

4.1 Filtration

Filtration can be broadly defined as a process that separates suspended particles from a liquid phase by passage of the suspension through a porous medium [9] or filter material. The three major filtration processes; sand filtration (a subset of media filtration), cloth filtration and membrane filtration are described in this chapter.

4.1.1 Sand filtration

In the process of sand filtration, the untreated water is percolated slowly through a bed of fine porous sand. The water is usually pre-treated with coagulants to achieve higher removal efficiencies. The treated feed water is applied on top of the filter bed and the treated water is drained from the bottom. It operates over a cycle of two stages, a filtration stage and a backwash stage. During the filtration stage water flows downwards through the filter bed, with a flowrate of 2 to 5 m/h, and particles collect within the bed. The collected particles are flushed from the system during the backwash stage by directing the water in the opposite direction. The backwash stage is only a short part of the filtration cycle, and is used to remove the collected particles from the filter bed and to prepare it for further filtration [10]. Sand filtration removes fine suspended solids and larger microorganisms from the water and so reduces the turbidity.

Sand filtration is more efficient when the water being treated passes through the sand filter very slowly, and it may not need any pre-treatment to remove very fine particles. Under these circumstances, the removal action includes a biological process in addition to physical and chemical processes. After a period of time, a biological ecosystem grows in the sand bed. On top of the filter media, a biologically active layer builds up and assists filtration. The filtration rate for slow sand filtration is between 0.1 and 0.4 m/h [11], and backwashing is not practiced with slow sand filtration. Rather, the surface of the filter is scraped at approximately six monthly intervals.

4.1.2 Membrane Filtration

Membranes are classified as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) or reverse osmosis (RO) membranes [12]. In NF and RO membrane processes, differences in permeability of water components are used as a separation mechanism. The membranes are usually made using synthetic material and are less than 0.1mm thick. They are semi-permeable, which means they are highly permeable to some components in the feed stream and less permeable to others. Water is pumped at high pressure across the surface of the membrane, causing a portion of the water to pass through the membrane as shown schematically in Figure 1. In cross flow mode, there is a continuous bleed of waste from the system in order to maintain a velocity profile across the membrane surface. It results in a highly clean product stream (permeate) and a very concentrated waste stream (retentate).

MF and UF are porous membranes and have a similar set up to that shown in Figure 1 or may have come in hollow fibre form. MF and UF filtration processes usually function in dead end mode, where the water is pumped through the membrane and particles bigger than the pore size of the membrane are removed. MF and UF membranes are backwashed on a regular basis to unblock the pores. The backwash stream is a highly concentrated waste stream, but it is not a continuous waste stream as in cross flow membrane filtration.

One criterion of membrane filtration performance is permeate recovery. Recovery is the ratio of the flow of permeate to the total flow of feed water. The higher the recovery the better, because less water is wasted. Pretreatment is also required to delay or prevent scaling and fouling, which happens when particulate matter, biological matter, insoluble inorganic salts or soluble metals precipitate at the membrane and reduce their performance.

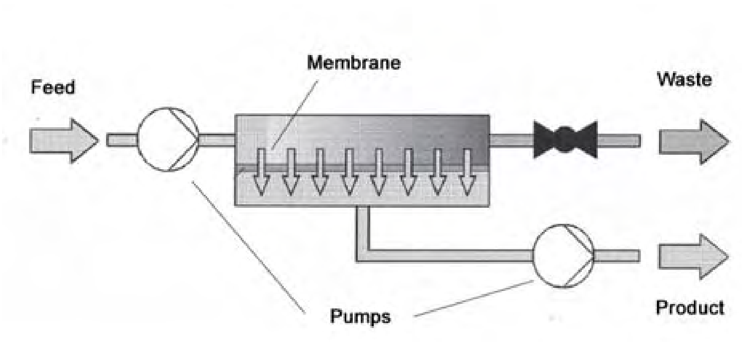

Figure 1: Functional principle of membrane filtration [13]

4.1.2.1 MF and UF membranes

MF and UF membranes are highly porous and separation occurs because of physical size exclusion [14]. MF is defined as a membrane separation process using membranes with a pore size of approximately 0.1 to 5 µm [15] and an operating pressure of approximately 50 to 400 kPa [16]. They remove materials such as sand, silt, clays, algae and bacterial species. UF membranes have pore sizes between 0.1 and 0.01 µm [15]. There are two types of UF membranes: high pressure and low pressure. Because of their lower density with a pore size of 0.1 µm, low pressure UF membranes may operate at pressures of less than 50 kPa. High pressure UF membranes operate at pressures of 200 to 700 kPa [16]. They reject all species removed by MF as well as some viruses and humic material. However, the rejection of viruses is highly dependent upon the pore size, with loose UF (longer pore size) having low rejections and the tighter UF (smaller pore size) membranes having high rejections.

4.1.2.2 NF membranes

NF are semipermeable membranes that use same ‘filtration’ mechanisms as reverse osmosis membranes use for desalination. Their pore size is around 0.001 µm [15] and they operate at a pressure of approximately 600 to 1000 kPa [16]. They can remove all viruses and humic material. NF membranes also reject divalent ions such as sulphate and phosphate, as well as having a lower rejection of monovalent ions. NF membranes have been used to remove dissolved organic carbon compounds that contribute to colour in water without the need for chemical coagulation.

4.1.2.3 RO membranes

RO membranes have a dense polymer layer with no visible pore structure. The permeate dissolves in the membrane material and then diffuses through the membrane down a concentration gradient. If a membrane that is freely permeable to water, but much less permeable to salt, separates a salt solution from pure water, water will pass through the membrane from the pure water side to the salt side to equalise the salt concentrations in the water on both sides of the membrane. This process is called osmosis. If a sufficient hydrostatic pressure is applied to the salt side of the membrane the flow can be stopped. This pressure is called the osmotic pressure. If the pressure is increased even further the flow is reversed and water begins to flow from the salt solution to the pure water side of the membrane. This process is called reverse osmosis [17]. The operating pressures in RO are much higher than those in the other membrane filtration technologies because the osmotic pressure has to be overcome to remove the salts. Pressures range from approximately 1,400 kPa to as high as 10,000 kPa for seawater. RO membranes reject most solute ions and molecules, allowing water of very low mineral content to permeate. RO units remove sodium, calcium, nitrate and fluoride, as well as pesticides, solvents and pathogens [18]. They do allow some small, neutrally-charged organic compounds to permeate.

4.1.3 Cartridge filtration

Several types of cartridge filters exist, using different media to remove suspended matter from water in the range of 0.5 to 50 µm or larger. They remove particulate matter depending on the pore size of the filter material thus reducing the turbidity of the water. Filter replacement is necessary after a period of time and they are often used to protect subsequent water treatment devices such as UV disinfection and RO units. The filters can be made in different forms such as discs, cartridges and candles [19].

Figure 2 shows the filtration ranges of different filtration technologies. It compares membrane filtration to conventional filtration technologies. As described earlier, reverse osmosis filtration filters particles with sizes smaller than 0.001µm including aqueous salts and metal ions. With nanofiltration sugar and some aqueous salts can be removed. Ultrafiltration removes particles with sizes larger 0.001µm and viruses. Microfiltration can remove all particles with sizes of greater than 0.1µm and bacteria. Conventional filters such as sand filters or cloth filters can remove particles with sizes as low as 1 µm and some bacteria.

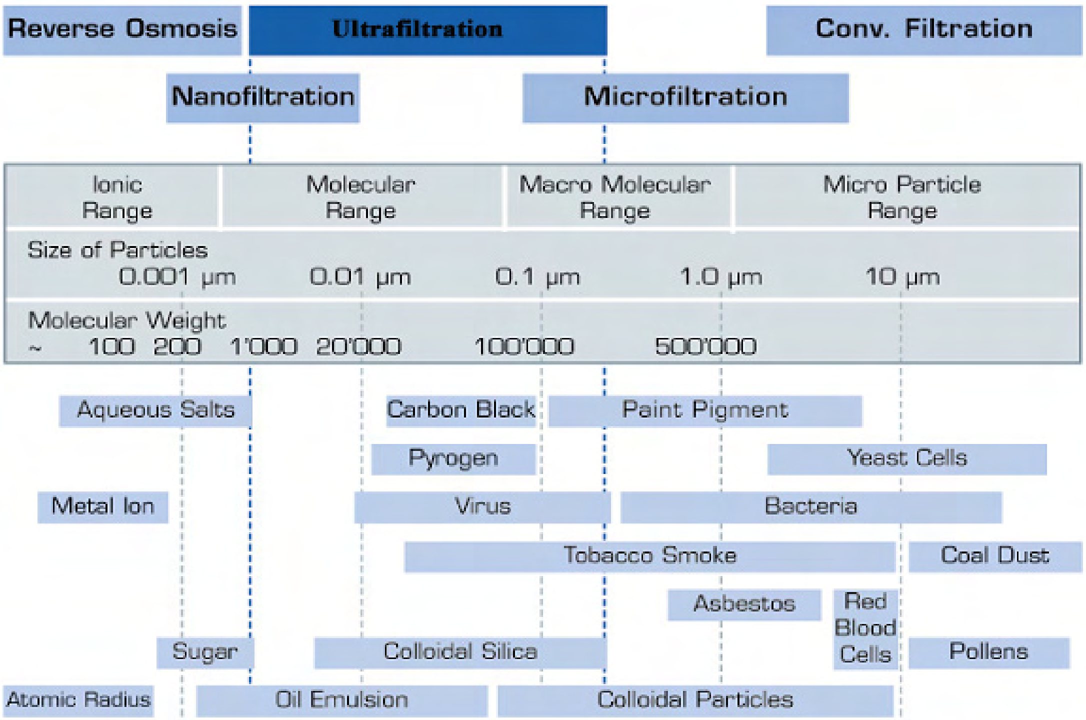

Figure 2: Filtration ranges of different filtration technologies [20]

4.2 Adsorption

In the process of adsorption, contaminants in the water are removed from a liquid phase by adsorption or accumulation on a solid phase. The component that is adsorbed is called the adsorbate, and the component (solid phase) that adsorbs it is called the adsorbent. The dissolved components are transported into the porous solid adsorbent granule by diffusion and are adsorbed onto the inner surface of the adsorbent where they adhere by chemical reaction (chemisorption) or physical attraction (physical adsorption). Physical adsorption is reversible, because the contaminants are attached to the surface of the adsorbent by non-specific binding mechanisms such as Van der Waals forces, and it is the most common adsorption mechanism used in water treatment.

There are three common types of adsorption materials available for use in water treatment: zeolites, synthetic polymeric adsorbents and activated carbon, of which the most commonly used are powdered activated carbon (PAC) and granular activated carbon (GAC). Activated carbon is a highly porous material that can be manufactured from carbonaceous material such as coal, wood, coconut husks or nutshells. PAC can be applied at various locations within the water treatment plant by adding it directly into the water. It is removed by sedimentation or filtration. GAC, however, operates in a bed of carbon granules through which the water percolates. Activated carbon is available in a wide range of pore sizes and can remove large organic molecules such as natural organic matter (NOM) and synthetic organic compounds (SOC) like solvents and fuels [22]. Once the carbon is saturated with the contaminants, it needs to be replaced or regenerated by heating it to a high temperature [23] and washing it in phosphoric acid solution. Adsorption is commonly used to remove organic contaminants such as herbicides, pesticides, algal toxins and metabolites; it is also used to remove compounds that may impact on the taste and odour of water [21]. GAC can also be used to dechlorinate drinking water [22].

4.3 Disinfection

Disinfection is an important step to ensure water is safe to drink. Disinfectants are added to destroy or inactivate microorganisms that may be present in the water thus eliminating the risk of spreading waterborne diseases. It is also used to prevent regrowth of microorganisms in the distribution system. Water treatment with disinfection is either used alone or as the final step after, for example, filtration. The efficiency of disinfection depends greatly on the quality of the source or treated water, and can also be strongly affected by conditions such as chemical contact time, pH, turbidity and organic content of the water [24]. The two most common processes used to kill microorganisms in water are oxidation with chemicals and irradiation with ultraviolet (UV) radiation [25].

4.3.1 Chemical oxidants

Four chemical disinfection agents are commonly used in drinking water treatment. They are free chlorine, combined chlorine (for example chloroamination), ozone and chlorine dioxide. There is no ideal disinfectant and each has advantages and disadvantages. Chlorine dioxide (ClO_2) generates, compared with chlorine, a smaller amount of disinfection by-products (DBPs). However, it reacts with organic material to produce chlorites, so ClO_2 is most effective when organic content of water is low. Chloroamination (Cl_2 and NH_3) is the most common combined disinfectant, and is used in long distribution systems because it is persistent in water. Of the four, the most commonly used by far is free chlorine. Combined chlorine is also quite common; however its use is often limited to residual maintenance. It is recommended to pre treat the water to the lowest possible turbidity level and organic content before adding chemical oxidants. Large amounts of particulate matter in water can protect microorganisms from the action of disinfection chemicals. Moreover organic matter in water can react with the disinfection chemicals to form DBPs [27].

4.3.2 UV disinfection

This technology uses ultraviolet (UV) radiation to inactivate microbes. When UV light penetrates the cell wall of an organism, its genetic material is disrupted making survival difficult unless the organism is able to repair the damage. UV light is defined by wavelengths expressed in nanometres [nm]. Effective wavelengths for killing germs range from 200 to 300 nm [28], with 254mm most commonly used. The effectiveness of UV disinfection depends on how much energy is absorbed by the organism, which is determined by the lamp intensity, the time of exposure, the UV absorbance of the water and the amount of UV shielding by particulate matter in the water. If the energy dose is too low, the organism’s genetic material might only be damaged instead of destroyed [29]. An advantage of using UV light for disinfection purposes is that is has not been shown to produce DBPs at levels of concern and it is effective for disinfection of *Cryptosporidium oocysts*. However, UV disinfection is very energy intensive and pre-treatment is recommended with poor raw water quality to prevent UV lamps from becoming fouled from substances occurring naturally in the source water [30] and to reduce the level of turbidity and organic compounds that reduce the effectiveness of UV treatment. UV units require electricity and black outs will interfere with their performance, letting pathogens pass without disinfection. UV radiation does not provide any residual disinfection after the initial dose.

4.4 Commercially available POE/POU devices

There are many commercially available POE and POU devices available, and only some of those are listed in this section. A database of available treatment units was also developed (poe_db.mdb), but again it only lists a small sample of the devices available on the market. When considering the specific devices to be used in an application, it is suggested that the users undertake their own survey of units available on the market and use the results of this report to provide an indicative estimate of performance.

4.4.1 Zenon ultrafiltration unit

Zenon developed a home water filtration system, called Homespring Purifier (Figure 3). It treats all water that enters the house in two stages. The first stage uses granulated activated carbon (GAC) to pre-filter the water and remove unwanted taste and odours. If the raw water is not chlorinated, the manufacturer provides for a 20µm particle filter to protect the ultrafilter. The second stage uses hollow fibre membranes with a pore size of 0.02µm, where turbidity and bacteria are removed. The membrane material is reinforced polyvinylidene fluoride (PVDF). It has good heat stability and offers similar phosphoric chemicals resistant to Teflon [31]. Many strands of hollow fibre membranes are arranged in a filter housing. In the Homespring Purifier, the feed flows around the membrane strands, the contaminants that are bigger than the pore size of the membrane are not able to pass through it and leave the housing when the filter is backwashed. Only water and contaminants smaller than the pores are able to pass through the membrane (Figure 4). The Homespring Purifier effectively blocks and removes particles larger than 0.02µm nominal from the feed water. The carbon prefilter or the particulate filter removes large particles from the source water to protect and extend the life of the membranes. The filter reduces unwanted tastes and odours associated with disinfectants added to the water. The use of a pressurised water supply enables the filter to operate at up to 34 L/min. The unit is automatically backwashed at least once a day, using a pressurised storage tank. This configuration reduces the power required, as power to run a timer and solenoid valves for the automatic backwashing is all that is needed. No pumping is required if the supply is pressurised. The unit is 1.88 m high and 0.45 m in diameter. The unit is rated for inlet temperatures between 0 and 38°C.

Figure 3: Zenon Homespring unit

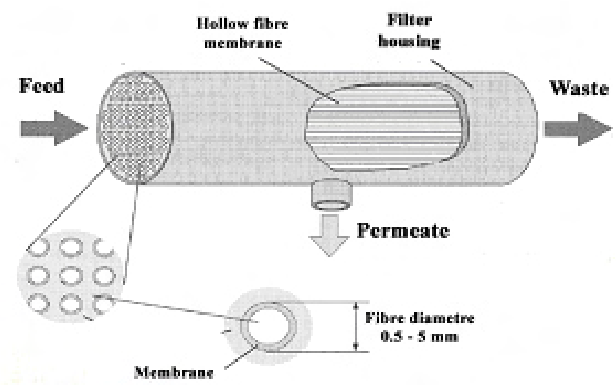

Figure 4: Hollow fibre membrane [13]

4.4.2 Merlin RO unit

The Merlin reverse osmosis system was developed by GE Water & Process Technologies as a point of use device to install directly under the kitchen sink. It contains a carbon prefilter and two RO elements. It has a height of 43.3 cm, a length of 51.7 cm and a depth of 24.6 cm. The permeate flow range is between 1.9 and 3.8 L/min and concentrate flow is between 3.8 and 7.6 L/min. Its Total Dissolved Solids rejection lies between 90 and 99%. The RO Element has an average life expectancy of three years, whereas the carbon filters have to be changed after six months depending on the treated water quality. Figure 5 shows the Merlin RO unit and the recommended minimum and maximum operating conditions are shown in Table 1. The RO elements in this unit are spiral wound elements. Figure 6 shows how this type of element is built. They consist of different layers that are wrapped around the perforated central tube in the middle. The feed enters the element between the layers in the so-called feed channel spaces. A permeate carrier spacer material prevents the inside surfaces from touching each other and provides a flow path for the permeate. The open end is connected to a central tube where the permeate is collected. The rejected water (concentrate) flows through the feed channel spaces and leaves the element at the opposite end.

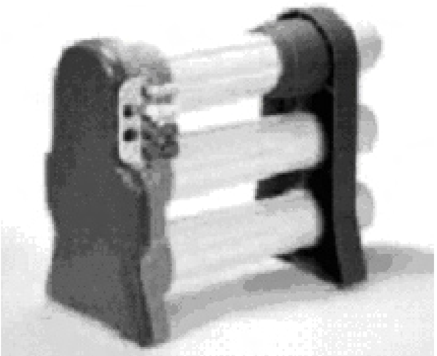

Figure 5: Merlin RO system

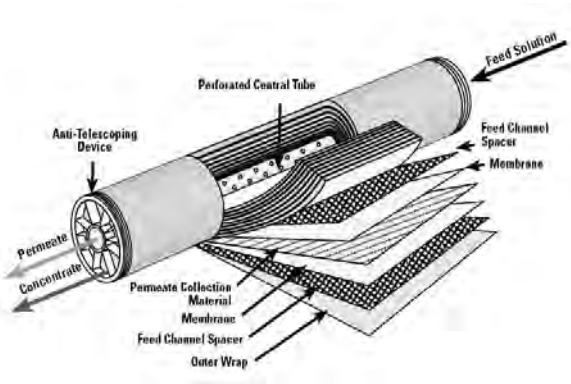

Figure 6: Spiral wound RO element [32]

Table 1: Minimum and maximum operating conditions for Merlin RO unit

Condition	Minimum	Maximum
Inlet Pressure	2.76 bar	5.52 bar
Inlet	4.44 °C	37.78 °C
Inlet TDS	50 mg/l	2,000 mg/l
Inlet Hardness	0 mg/l	171 mg/l
Inlet Chlorine	0 mg/l	1.0 mg/l
Inlet Iron	0 mg/l	0.3 mg/l
Inlet Manganese	0 mg/l	0.1 mg/1

4.4.3 Media Filters

The media filters used in these trials were Waterways CS2 automatic filters (waterways@adelaide.on.net). These are pressure filters that can be filled with a filter media of the user's choice. Both sand and carbon media were used in these trials. The units were fitted with an automatic backwash valve that was operated by the data acquisition and control unit. However, the backwash can also be set via a timer or pressure drop across the filter, which would provide a cheaper solution when implementing a POE system. These units were 320 mm in diameter and 1300 mm in length, and a media depth of approximately 600 mm was used.

There are many suppliers of such devices and the efficiency will be related to the filtration rate, depth of filter media and the specific filter media used. Automatic backwash valves are also commonly available.

4.4.4 Cartridge filters

Cartridge filters come in a range of pore sizes (0.5 μm to 50 μm) and filter lengths. Absolute pore size ratings are quoted for cartridge filters that use a paper or cloth filter. The paper or cloth has a relatively uniform pore size, in a manner similar to a membrane filter, and separation of particles larger than the quoted absolute pore size can be guaranteed. Cartridge filters without an absolute pore size rating operate in a manner similar to a depth filter, where particles are removed as they pass through a thick open filter, and particles are removed as they collide with the filter media as they pass through the filter. These filters may be made of a wound string or foam media.

4.4.5 Ultra-violet disinfection

There are many UV disinfection systems available to the market, and some are listed in Table AI-1 in Appendix I. The devices have a maximum UV dose guaranteed at the end of their lamp life and a maximum flowrate to ensure disinfection at the end of the lamp life. Additional details are given in Table AI-1 (Appendix I).

5 WATER TYPES OF INTEREST

Chapter 4 indicated that no single water treatment technology is able to remove all contaminants in raw water. Therefore, a combination of different technologies for water treatment has to be used depending on the raw water quality and specific water quality issues. Surface water in central Victoria usually has high values for turbidity and colour. Salt and iron are water quality issues when water is supplied from bores.

Filtration is used to remove turbidity and iron. Activated carbon adsorption is used to remove colour and organic matter. Salt and iron filtration can be removed by reverse osmosis systems. A disinfection unit is usually included when there is no central pre-treatment with chemical disinfectants such as chlorine. This chapter discusses which treatment technologies are appropriate for different raw water qualities.

5.1 High turbidity

When the source water is high in turbidity but low in colour, a treatment process like that shown in Figure 7 is appropriate. The main component of the treatment process is the sand filter, where turbidity is reduced by removing suspended solids and larger microorganisms from the water. The subsequent cartridge filter removes fine particulate matter (<1 μm) thus reducing turbidity to lower values. The water can then be disinfected using UV irradiation unit, where microbes are inactivated. For the point of entry systems used in this project, the maximum flow rate was determined by the UV unit. This unit had a maximum flowrate of 4 L/min. Therefore, a storage tank was included so that peak water demands could be met. Microfiltration or ultrafiltration could also be used instead of the sand and cartridge filters.

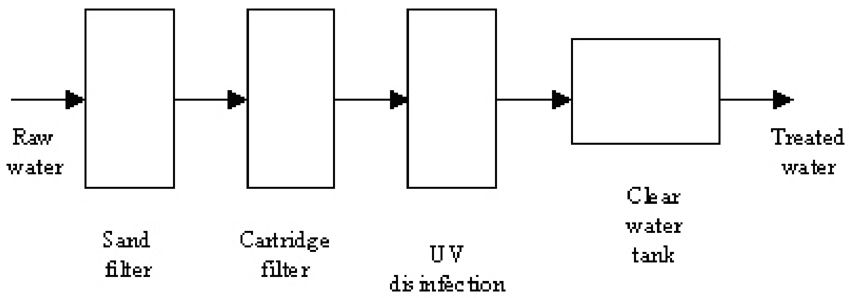

Figure 7: Water treatment process for high turbidity water

5.2 High colour

Raw water with high levels of colour are best treated using a process shown in Figure 8. The main treatment component here is the activated carbon adsorption process, which removes organic contaminants thus reducing the colour of the water. A cartridge filter is used to remove particulate matter and inorganic particles. This protects the subsequent UV disinfection unit against breakthrough and ensures good disinfection at all times. This recommended treatment process to treat water with high values in colour also included a clear water storage tank to provide for high peak flows.

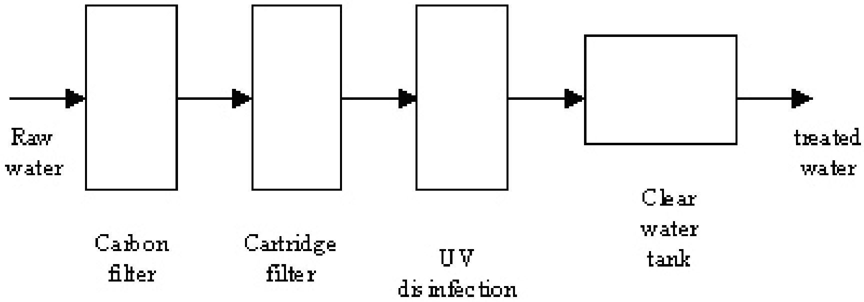

Figure 8: Water treatment process for high colour water

5.3 High turbidity and high colour

When the source water is high in turbidity and high in colour, the treatment process shown in Figure 9 is suggested. The first step, the sand filter, removes suspended solids and larger microorganisms from the water thus reducing its turbidity. The subsequent carbon filter reduces colour by adsorbing organic contaminants. A cartridge filter is installed downstream to ensure good turbidity removal under all conditions. As a last treatment step, before the water flows into the clear water tank, the water is disinfected by a UV disinfection unit where all remaining microorganisms are removed. This treatment system could also use microfiltration instead of the sand filter as an alternative.

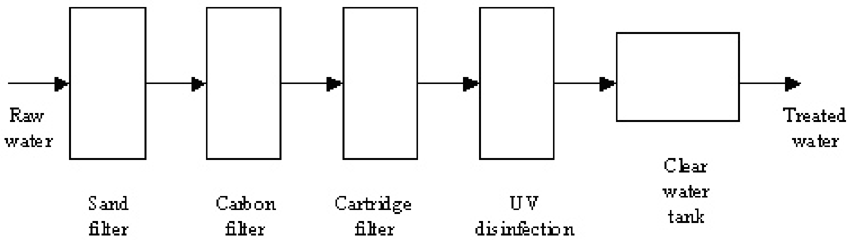

Figure 9: Water treatment process for raw water with high turbidity and high colour

5.4 High salinity

The unit for treating water with high salinity is reverse osmosis. As indicated previously, RO membranes reject most solute ions and molecules, allowing water of very low mineral content to permeate. RO can remove sodium, calcium, nitrate and fluoride, as well as pesticides, solvents and pathogens. The sand, the carbon and the cartridge filters upstream pretreat the water before it enters the RO unit. If the water is not pretreated before the RO unit, the membranes foul quickly resulting in signifcantly lower treated water flows. Instead of the carbon filter, a sand filter or a membrane filtration unit could also be used. If using a MF or UF filtration unit instead of the sand or carbon filter, no cartridge filter is required. If the unit includes a clear water storage tank, a carbon and a cartridge filter need to be built into the RO unit for security and to treat re-contamination from the tank. The flowsheet in Figure 10 shows the water treatment process for raw water with high salt levels.

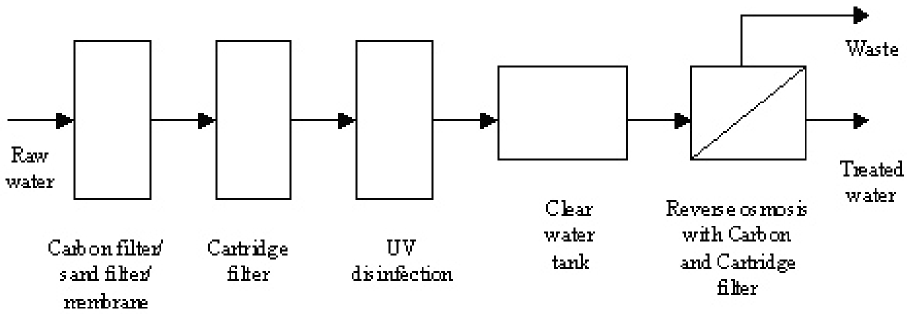

Figure10: Water treatment process for raw water with high salinity

5.5 High turbidity and high colour with centralised disinfection

Some remote communities in central Victoria are supplied with centrally disinfected water. Chlorine is generally used to disinfect raw water supplies, however, some community water supplies are disinfected using monochloramine. This produces microbiologically safe water, but when disinfection is performed on poor quality waters, high levels of disinfection byproducts are produced and the water quality does not confirm to ADWG. These waters may also have high turbidity and/or colour, making the water aesthetically unpleasing. Where this is the case, the treatment process shown in Figure 11 is recommended to supply potable water to customers. The water is treated by sand filtration to reduce turbidity. The activated carbon adsorption unit removes some organics, DBP and chlorine. A UV disinfection unit is also included in the treatment process to remove any remaining microorganisms. If centrally disinfected water is treated by membrane filtration, the water would need to be pretreated with activated carbon to remove the remaining chlorine, as chlorine will oxidise the membrane. Alternatively, a chlorine resistant membrane such as PVDF can be used.

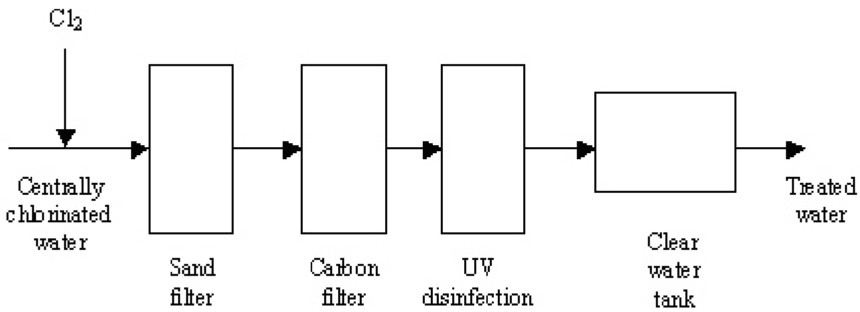

Figure 11: Water treatment process for centrally disinfected water with high colour and high turbidity

6 PRE-TREATMENT SYSTEM DESIGN EXPERIMENTS

Several preliminary trials were undertaken to investigate if commercially available point of use or entry devices were capable of treating poor quality waters. Many of these devices are designed to remove contaminants from reticulated potable water - for example, to improve taste. The performance of these devices with high concentrations of contaminants was not known. The preliminary experiments were designed to identify if longer term trials could be conducted or if the units failed too quickly to warrant further testing. A RO system was tested to investigate its performance in the treatment of water that is pre-treated with chloramines and how that affects their performance for salt rejection. These trials were undertaken to determine if rapid failure of the RO units occurred, while additional filter tests were undertaken to identify the particle sizes that need to be removed to lower the turbidity to the target value of <1 NTU.

6.1 Filter trial at Moyston and Landsborough

Different pore size filter papers were assessed to estimate the extent of turbidity removal in each size range, and, the efficiency of colour removal by an activated carbon was tested as a function of time. Both trials used water samples from Moyston and Landsborough. Raw water data for both water samples are shown in Table 2. Table 3 shows the results for the turbidity removal. Filters with pore sizes of 0.2 to 0.45 µm yielded in good values for turbidity (<0.5 NTU) for both Moyston and Landsborough water and indicated that sub-micron particle removal is required for the production of high quality water.

Table 2: Raw water data at Moyston and Landsborough

	Moyston	**Landsborough**
Colour [PCU]	8	4
EC [µS/cm	136	3,600
PH	7.8	7.7
Turbidity [NTU]	1.4	1.3

Table 3: Turbidity removal via different pore size filter papers

Filter pore size [µm]	**Landsborough Turbidity [NTU]**	**Moyston Turbidity [NTU)**
Raw water	1.3	1.4
1.0	0.8	0.7
0.45	0.1	0.27
0.2	0.1	0.22

Two different types of activated carbon were used to assess colour removal. Figure 12 shows the results for Calgon carbon (CAS# 7440-44-0, type WPL Pulv.) and Figure 13 shows the results for the tests with James Cumming carbon (MDW3545CB Powder). The results show that Calgon carbon performed better for both water samples than James Cumming carbon during the recorded time. However, the adsorbance of Calgon carbon on Moyston water had not reached a constant value after 30 minutes of testing.

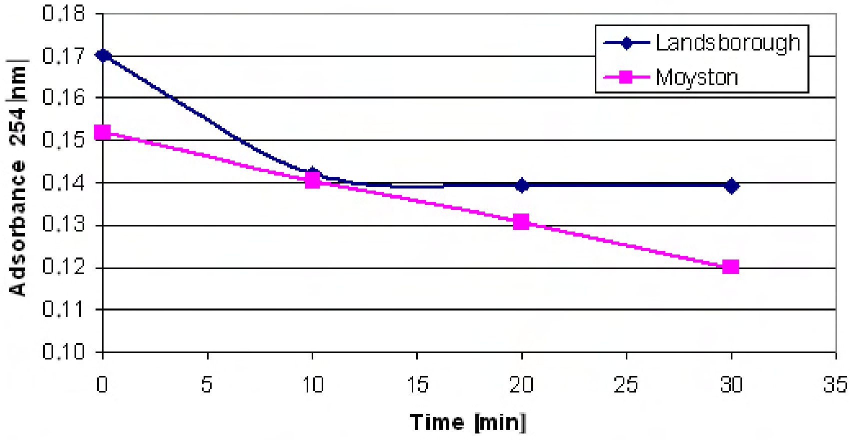

Figure 12: Adsorbance removal versus time for Calgon carbon adsorption tests

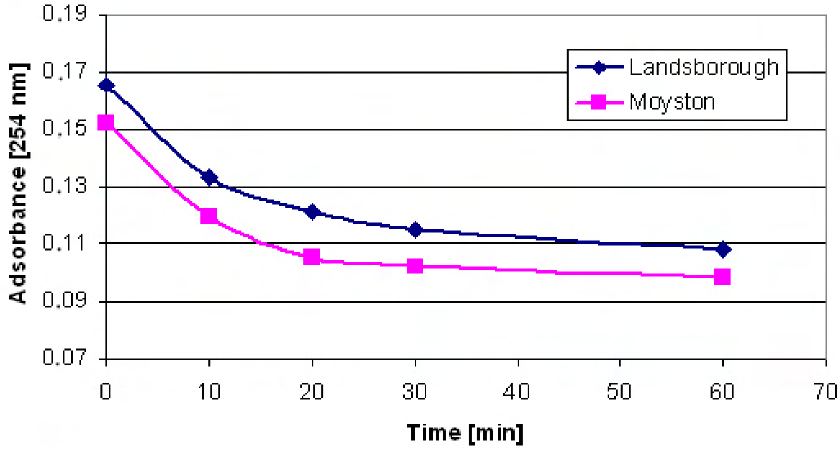

Figure 13: Adsorbance removal versus time for James Cumming carbon adsorption test

These results indicate, that the carbon needs a contact time of about 30 minutes. The contact time in the water treatment units was approximately 25 minutes at Rupanyup and around 15 minutes at Timberline Road and Lexton.

6.2 RO unit on Ballarat water

The aim of this trial was to look at the water recovery and the effect of total dissolved solids (TDS) on water recovery and fouling. An RO unit was tested on Ballarat water and operated continuously. Figure 14 shows the experimental set up with sediment filter, carbon block filter and RO unit. The inlet pressure was 380 kPa and was consistent throughout the experimental period. Negligible pressure drops were recorded through the sediment filter and the carbon block.

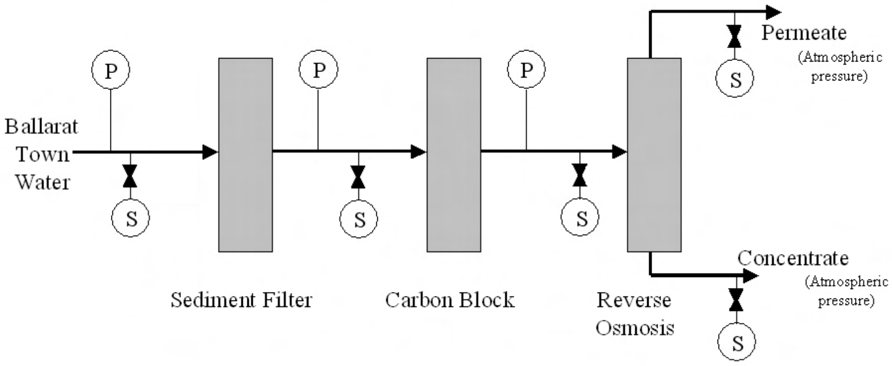

Figure 14: Experiment set up for trials on Ballarat water

Figure 15 shows total permeate flow and permeate recovery. As the total flow increased, the permeate recovery decreased, indicating that the unit was fouling. Given the high quality of this feed water, it suggests that fouling of POU RO will be important even when operated at relatively low recovery levels (ie. 30%).

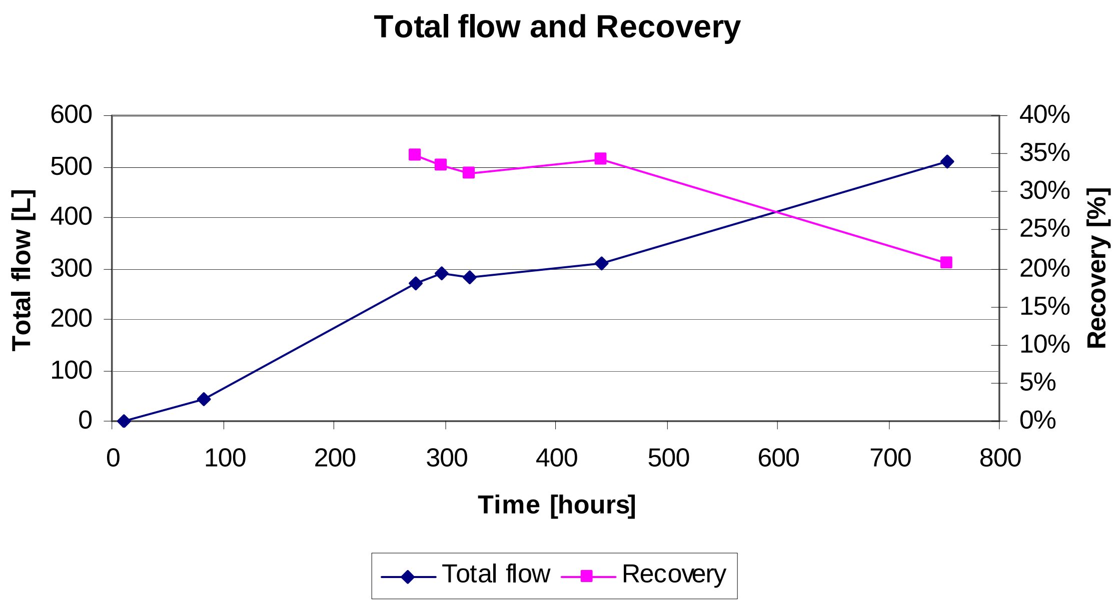

Figure 15: Total flow and permeate recovery

Figures 16 to 18 show the concentration of chloramines, the electrical conductivity and turbidity before and after treatment. Chloramines were successfully removed during the first week of experiments. After ten days a low concentration of chloramines was detected in the permeate and this concentration grew steadily to 5 mg/L until the testing was over (19 days). Polyamide membranes are known to degrade when exposed to oxidants [33], and leakage of the chloramines through the membrane suggests this is occurring for the POU RO system. However, Figures 16 and 17 show that an increase in chloramines in treated water did not affect the performance of the membrane in reducing electrical conductivity and removing turbidity. Electrical conductivity of the treated water was very low with values ranging between 5 and 10 µS/cm. Turbidity of treated water did not exceed the value of 0.1 NTU. However, the raw water was low in turbidity as well. Colour was less than 5 PCU for raw and treated water throughout the tests.

The results demonstrated that the units were worth testing in long term trials on poor quality water.

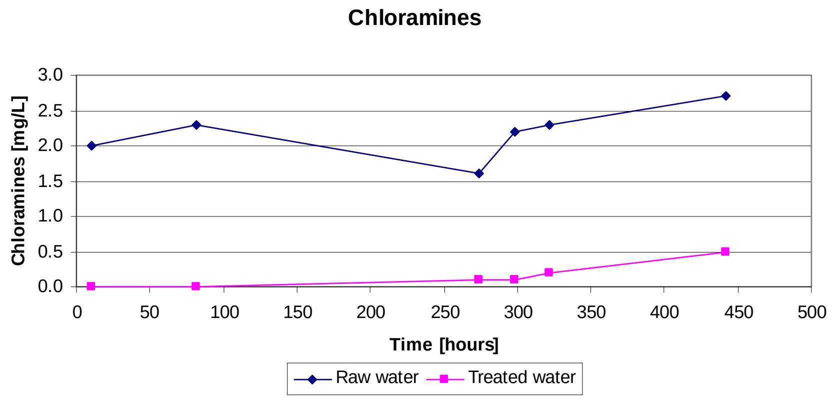

Figure 16: Chloramines in raw and treated Ballarat water

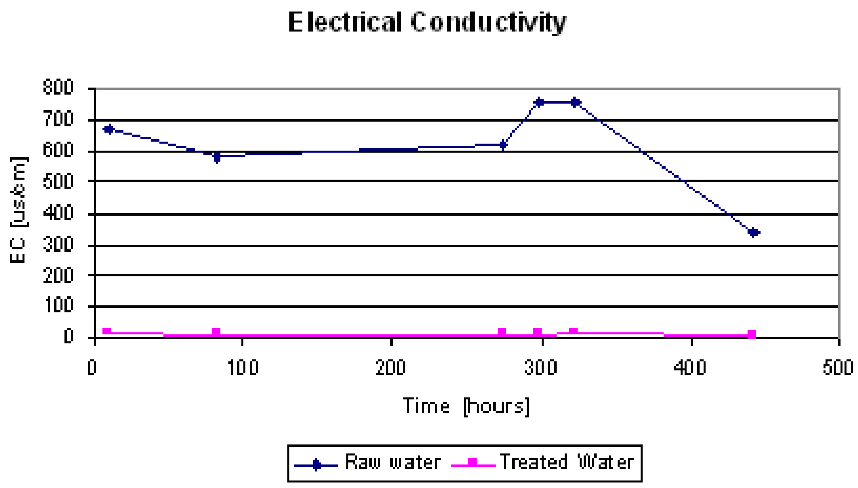

Figure 17: Electrical conductivity of raw and treated Ballarat water

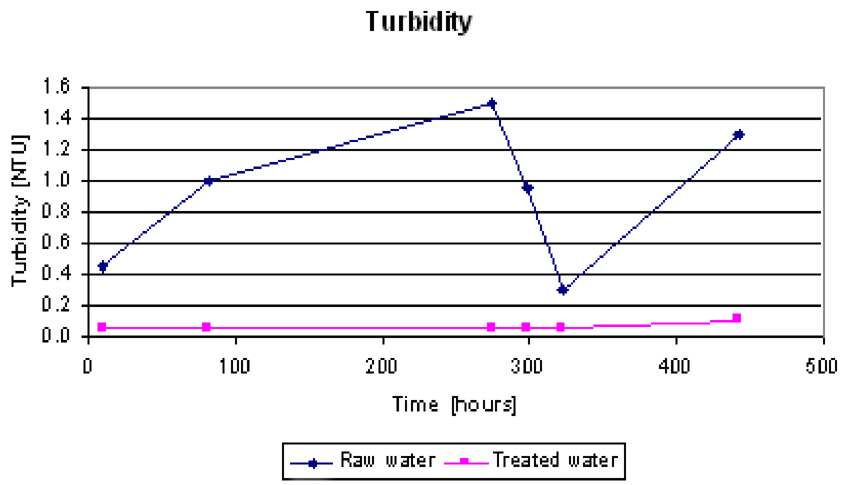

Figure 18: Turbidity of raw and treated Ballarat water

7 EXPERIMENTAL

Figure AII-1 in Appendix II shows the flowsheet for the mobile water treatment plants (MWTP). An inlet pump, which has a maximum flow rate of 20 L/min, delivered raw water through the system. Coagulant may be added after the feed pump, although this was not practiced during these experiments. The feed was then treated by sand filtration for removal of suspended particles, while the subsequent carbon filter was included for colour and turbidity removal. Both the sand and carbon filters were regularly cleaned by automated backwashing. The water passed through a cartridge filter before entering the UV disinfection unit, to protect the UV disinfection process from any break through from the sand and carbon filters and to ensure good disinfection at all times. A 1000 L treated water storage tank was set up to provide sufficient water to meet peak demands, as the POE treatment process was limited to a maximum flow rate of 4 L/min. This flow rate was determined by the UV unit, to ensure effective disinfection of the treated water at all times. Customer demands can then be serviced at different rates, while the flow through treatment device remains constant, producing water that is consistent in quality. To enable the water to pass the RO Unit, the pressure had to be increased by a second pump. The RO unit was located after the storage tank providing water to a single tap. It removes salt, and therefore softens the water.

Six sampling points were included in the mobile water treatment plant. The first sampling point was for sampling the raw water before treatment. There was also one sampling point after each filter. The fifth sampling point was installed after UV disinfection and before the treated water enters the storage tank. The last sampling point was located after the water tank and water could also be sampled from the tap after the RO unit. Moreover, the mobile water treatment plant was fitted with two turbidity meters. The first measures the turbidity of the raw water and the second the turbidity of the water before it enters the UV disinfection unit. Data loggers monitored turbidity, flow rate and pressure to identify changes in water quality and treatment conditions. All three mobile treatment plants had the same flowsheet; with differences in the size of filter media, type of carbon and manufacturer of the treatment units.

7.1 Grampians Wimmera Mallee Water MWTP

Figures 19, 20 and 21 show one of the two mobile treatment plants developed by GWMW. Figure 19 shows the two large Waterways filter housings for sand filtration and carbon adsorption. The cartridge filter was installed in front of the filter housings and the clear water tank was located on the left. It also shows the pump that is used to backwash the filters with water from the clear water tank and the flowmeter that measures the backwash flowrate. Figure 20 shows the back of the GWMW MWTP. It shows the pumps that pump the water in and out of the unit with the flowmeters measuring inlet and outlet flow rates. The cabinet in Figure 21 contains the Wedeco Aquada UV disinfection unit on the left hand side and two turbidity meters measuring turbidity before the sand filter and after the cartridge filter. It also contains the control panel and the data acquisition system. The raw water passes through the two filters as a first treatment step. After that, it flows through the cartridge filter before entering the UV unit, where the water is disinfected. It then enters the clear water storage tank which holds 1000 litres. Inlet, post sand and post carbon pressures were monitored online by the data loggers. They also recorded turbidity before the sand filter and after the UV disinfection unit. The inlet, outlet and backwash flowrates were logged as well.

Figure 19: Front of GWMW trailer

Figure 20: Back of GWMW trailer

Figure 21: Inside the case of GWMW trailer

7.2 Central Highland Water MWTP

In Figure 22, the outside of the CHW trailer can be seen. It shows the clear water tank on the right hand side. The case on the left contains all treatment units and has the control and data acquisition unit attached to the front of the cabinet. Figure 23 shows the inside of the cabinet. The CHW trailer was equipped with two Waterways CS2 automatic filter housings. They could be filled with either sand for sand filtration or with activated carbon for adsorption. The cartridge filter was located left of the large filter housings. For UV disinfection, a Steriflo Ultraviolet Steriliser SF300 S was used, which was located behind the Waterways filter housings. Figure 23 also shows the two turbidity meters; one before the sand filter and one after the cartridge filter. Turbidity before the sand filter and after the UV disinfection unit was monitored online. The data loggers also recorded inlet pressure, pressure after the sand filter and after the carbon filter. The inlet, outlet and backwash flowrates were recorded as well.

Figure 22: CHW trailer

Figure 23: Inside of CHW trailer

7.3 Zenon Units

Two Zenon homespring units were installed on private premises. The homespring units were installed with a cartridge filter before the membrane to remove larger particles and protect the membranes from fouling. The Homespring units are backwashed from a pressurised tank at the bottom of the device. Permeate fills the tank and it is released back through the membranes when a series of solenoid values and closed and opened. The frequency of the backwash cycle is controlled on a time basis.

Figure 24: Homespring unit installed at Horsham

8 TRIALS

8.1 Rupanyup

The township of Rupanyup in the Grampians Wimmera Mallee Water region is supplied with water that is centrally disinfected using chlorine. One MWTP was set up at Rupanyup to investigate if it could be used to deliver potable water quickly to the community (Figure 25).

Figure 25: MWTP at Rupanyup

The reservoir water was tested for microbiological quality, turbidity and colour three times during the trials and the average, minimum and maximum values are shown in Table 4.

Table 4: Raw water quality data at Rupanyup

	E.coli [MPN/100ml]	Total coliforms [MPN/100ml]	colour [PCU]	Turbidity [NTU]
Average	3	39	9	14
Maximum	6	84	9	33
Minimum	0	4	9	4.3

The raw water had low concentrations of *E. coli* and total coliform bacteria. However, microbiological quality was controlled by chlorine. The major issue with the raw water at Rupanyup was its high values for colour and turbidity. When high turbidity and highly coloured water is disinfected with chlorine, disinfection by products, such as trihalomethanes (THMs) are generated and these compounds are suspected of being implicated in adverse health effects.

Therefore, the effectiveness of the carbon filter in removing THMs from the water was investigated. The unit operated continuously over a period of 50 days with an inlet flow rate of 4 L/min to ensure that all incoming water passed through the UV disinfection. unit in the design flow rate range. The water was filtered through a sand filter to reduce turbidity. Turbidity and colour were subsequently reduced by granular activated carbon adsorption. A cartridge filter with a pore size of 5 µm then filtered the water thus reducing turbidity and colour further and to optimise UV disinfection. During the first three weeks of the trials, water was tested for colour, turbidity and microbiological quality three times per week. Samples were taken after each treatment step to determine their performance. Disinfected and treated water was also analysed for THMs. THM concentrations were measured once after each treatment step, to determine which treatment unit was responsible for the reduction of THMs. Samples of the backwash water were taken twice during the period of the trials and tested for turbidity, colour, microbiological quality and THM concentration. After the first three weeks, samples were only taken from the disinfected and the treated water and the sampling schedule was reduced to once every week for a further 4 weeks. Figure 26 shows the flow chart with the sampling points.

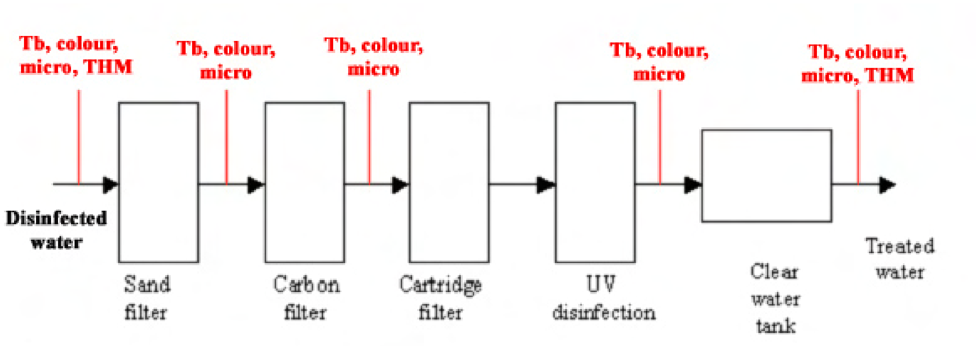

Figure 26: Flow chart with sampling points of MWTP at Rupanyup

The disinfected and the treated water quality data are recorded in Table 5 and Table AIII-1 in Appendix III shows the results for the samples taken in between each treatment unit and the results for raw and backwash water.

The microbiological quality of the water was very good, because the water was centrally disinfected with chlorine. The water entering the POE MWTP was therefore already free from pathogens.

Turbidity and colour of the water entering the MWTP were low, with maximum values for turbidity of 7 NTU and maximum values for colour of only 3 PCU. However, as Table 5 clearly shows, the disinfected water contained a large concentration of THMs.

The MWTP reduced the colour of the water to values even lower than the 1-3 PCU of the feed water. Table AIV-1 in Appendix IV shows that samples taken after the UV unit had the lowest values for colour. The colour reduction at this point was 50% on average. When the colour of the incoming water was only 1 PCU, the unit was not able to reduce colour any further. The carbon filter was mainly responsible for the colour reduction, although the sand and the cartridge filter also assisted.

Table 5 shows that turbidity of the water entering the unit was low, with maximum values of 7 NTU and the turbidity of the treated water was around 2.2 NTU. The water leaving the UV disinfection unit usually had the lowest values for turbidity. The average turbidity reduction was 46%. Each of the three filters – sand, carbon and cartridge – removed a small amount of turbidity.

The results in Table 5 and Figure 27 indicate clearly, that the MWTP was able to reduce the concentration of THMs in the water. Samples taken after each treatment unit indicate that the carbon filter reduced THMs to concentrations of less than 10 mg/L throughout the trials. The results show that the reduction of THMs was better during the first two weeks of the trials than later results. However, THM reduction was 98.6% on average with no clear decrease over the time. The ADWG recommends that the concentration of THMs in drinking water should not exceed a level of 250 mg/L based on health considerations. Although the concentrations of THM in the treated water were below the required standard the trial illustrated that activated carbon adsorption does reduce THM levels well below the standard.

The results also show that a carbon filter alone could be used to improve the water quality at Rupanyup, given the values for turbidity, colour and microbiological quality of the feed water to the MWTP.

Table 5: Quality of disinfected and treated water at Rupanyup

	E.coli [MPN/100ml]		Total coliforms [MPN/100ml]		True Colour [PCU]		Turbidity [NTU]		Trihalomethanes [mg/l]	
Date	inlet	outlet	inlet	outlet	inlet	outlet	Inlet	outlet	Inlet	outlet
03.07.2007	0	0	0	0	2	<1	4.7	2.8	0.2	<0.001
04.07.2007	0	0	0	0	2	<1	4.8	4.4	0.19	<0.001
09.07.2007	0	0	0	0	3	<1	6.9	2.5	0.156	<0.001
10.07.2007	0	0	0	0	3	1	4.6	2.6	0.178	<0.001
11.07.2007	0	0	0	0	2	1	4.8	2.6	0.137	0.009
16.07.2007	0	0	0	0	2	1	3.5	2.2	0.165	0.002
17.07.2007	0	0	0	0	2	2	3.3	2.2	0.187	0.001
18.07.2007	0	0	0	0	3	2	4.3	2.2	0.228	0.002
25.07.2007	0	0	0	0	1	1	3.3	2	0.194	0.001
02.08.2007	0	0	0	0	1	1	3	1.7	0.213	0.002
08.08.2007	0	0	0	0	2	1	3.7	2.3	0.177	0.005
15.08.2007	0	0	0	0	4	3	6.6	1.7	0.173	0.005
Average	0	0	0	0	2.1	1.3	4.5	2.4	0.183	0.003
Minimum	0	0	0	0	1	<1	3.0	1.7	0.137	<0.001
Maximum	0	0	0	0	3	2	6.9	4.4	0.213	0.009

It should be noted that the raw water colour was oxidised by the addition of chlorine with the resulting production of THM. While the MWTP has some capacity to remove colour compounds, carbon adsorption is better at removing the disinfection by-products.

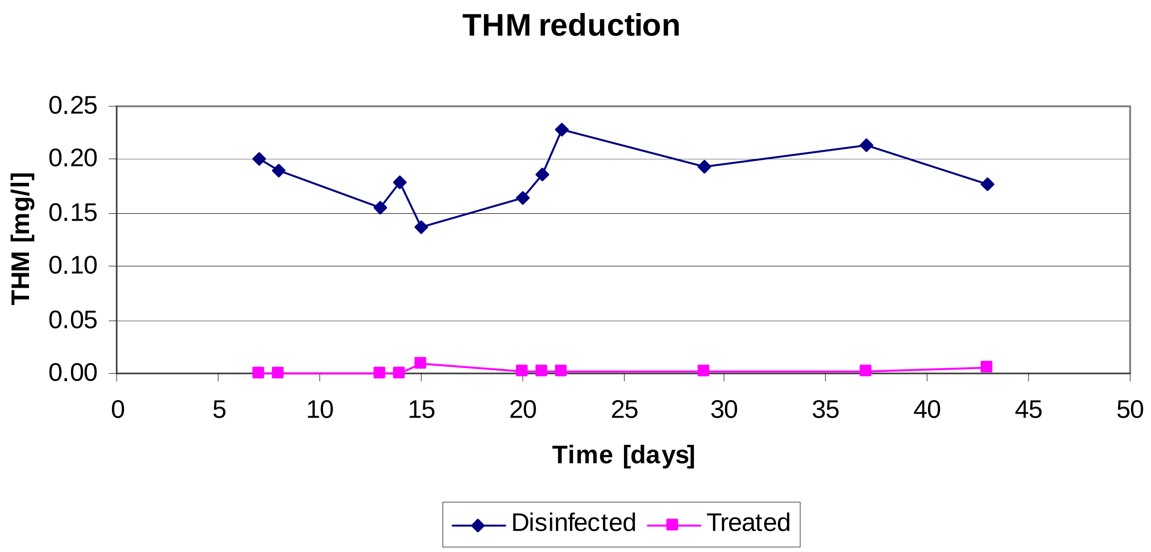

Figure 27: THM reduction at Rupanyup

Centralised disinfection to produce biologically stable water that also oxidises the organic carbon followed by carbon filtration can be considered an effective way to reduce colour but pre-treatment is still preferable to avoid DBP Production.

Samples of the backwash water from the sand and the carbon filters was taken once during the trial and Table 6 compares the quality of the backwash water and the disinfected water. The filters were backwashed with treated water and no *E. coli* or total coliform bacteria were present in the sample. A considerable amount of colour, turbidity and THM were removed by the carbon and the sand filters. The overall water recovery of the POE unit at Rupanyup was 97%.

Table 6: Water quality of inlet and backwash water on the 18th of July

	E.coli [MPN/100ml]	Total coliforms [MPN/100ml]	True colour [PCU]	Turbidity [NTU]	Trihalomethanes [mg/1]
inlet	0	0	3	4.3	0.228
backwash	0	0	2	5	0.234

8.2 Horsham

One Zenon unit was installed just outside Horsham to run on a blend of dam water and stormwater stored in a tank. The trials were undertaken to determine the capability of the Zenon ultrafiltration unit to reduce turbidity. Therefore, only the inlet and outlet turbidity was measured. The difference between inlet and outlet pressure was also measured to determine fouling of the membranes. Raw water was sourced from a dam and from stormwater runoff from the shearing shed roof. This combination generated significant variation in water quality, particularly turbidity.

The water was pre-treated by a cartridge filter with a pore size of 30 µm to reduce the feed water turbidity and protect the membrane from large particles and maintain membrane performance. The system was set to be flushed once a day with two flushes per cycle. The volume of water used to flush the unit was 69 L/day. The flush water was collected in a pressurised tank after treatment. A pressure booster pump was used to pump the water through the treatment system. Figure 28 shows the set up location with the feed water tank. Figure 29 shows the set up of the ultrafiltration unit with the cartridge prefilter.

Figure 28: Feed water tank

Figure 29: Ultrafiltration unit with prefilter

Table 7 and Figure 30 show the results for this trial. Inlet turbidity and inlet pressure were measured after the cartridge filter. Figure 30 shows how the ultrafiltration unit performed in removing turbidity.

The inlet turbidity was quite low because the water was prefiltered. But even when the turbidity was higher than 4 NTU, the ultrafiltration unit reduced the turbidity of the water to 0.1 NTU. Table 7 shows the values for inlet and outlet turbidity, for inlet and outlet pressure and for the pressure drop. The pressure drop over the Homespring unit increased after the first months of testing and the trials were stopped after 80 days because the unit started to foul, even though the unit was cleaned twice during this time. The total water recovery of the unit was 90%. The ultrafilter was cleaned using a solution of sodium hydrochlorite.

The Homespring unit was capable of producing treated water but fouling of the membrane was an issue for high turbidity events. A pre-filter or backwashable sand filter should be used before these units to improve the frequency of backwashing and chemical cleaning.

Table 7: Results for Zenon trial at Horsham

Time [days]	Inlet turbidity [NTU]	Outlet turbidity	Inlet pressure [PSI]	Outlet pressure [PSI]	Pressure drop [PSI]
1	3.1	0.1	42	36	6
14	3.3	0.1	42	36	6
31	3.1	0.1	42	36	6
44	2.9	0.1	44	34	10
53	2.7	0.1	44	22	22
58	3.5	0.1	44	36	8
65	4.2	0.1	44	32	12
72	3.8	0.1	43	35.5	7.5
79	3.7	0.1	43	32	11

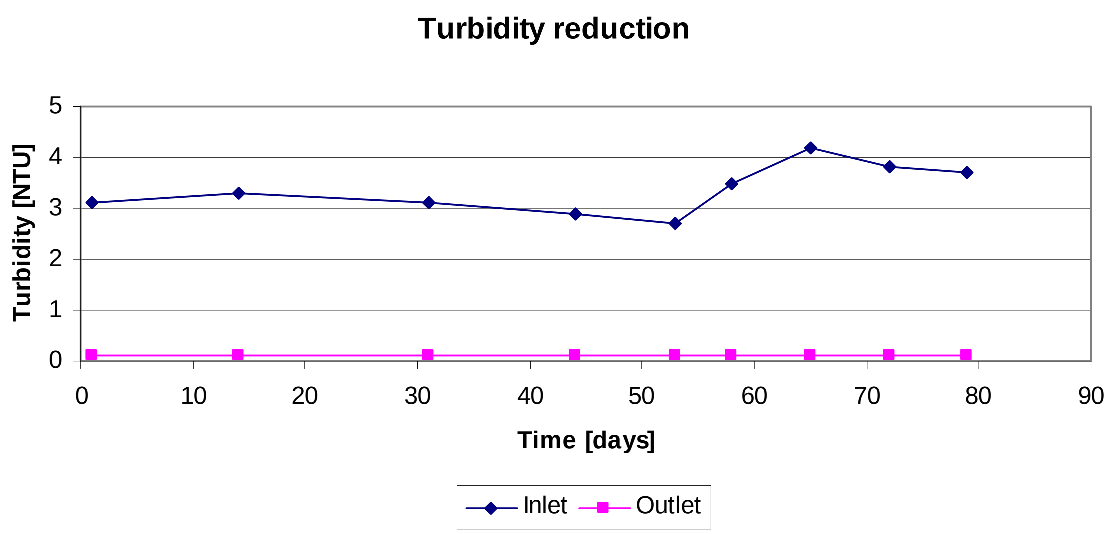

Figure 30: Turbidity removal at Horsham

8.3 Dadswells Bridge

A second Zenon ultrafiltration system was installed at a property in the GWMW region near the township of Dadswells Bridge. Groundwater is sourced from a bore on the property. No raw water quality data was available, but groundwater in that area has very high levels of iron which can clearly be identified by the colour of the water. The homeowner has an onsite wastewater treatment system on the property. While it is not located next to the bore, contamination of the ground water can not be excluded. The ultrafiltration system was to reduce the iron and, to a lesser extent, manganese levels in the water, and also to provide a barrier for disease causing microorganisms that might be present in the ground water. Extracted groundwater is initially oxygenated and then stored in a concrete tank that acts as a sedimentation basin. Larger flocs are deposited in this tank before filtration. Before entering the UF unit, the water was pre-treated by a cartridge filter with a pore size of 5 µm to remove some iron from the water and to preserve the ultrafiltration unit. Samples were taken before and after the ultrafiltration unit and were tested for *E. coli*, total coliforms, turbidity, colour, iron and manganese around once every month. The unit was backwashed automatically every night at midnight. Figure 31 shows the set up of the trials at the property just outside of the township of Dadswells Bridge. The inlet and outlet pressures of the ultrafiltration unit were also monitored to identify if the unit fouled.

Figure 31: Ultrafiltration unit on property outside of Dadswells Bridge

After one year of operation, the homeowner had used 200,000 L of treated water (providing the total supply of water for a 5 person household) and the unit used 50,000 L for backwashing, providing a total water recovery of the unit of 80%.

Figure 32 compares the amount of water that the homeowner was using to the pressure drop over the ultrafiltration unit. The POE device required a clean-in-place (CIP) procedure every three months to recover membrane performance. Membrane performance has not been adversely affected over the life of the trial.

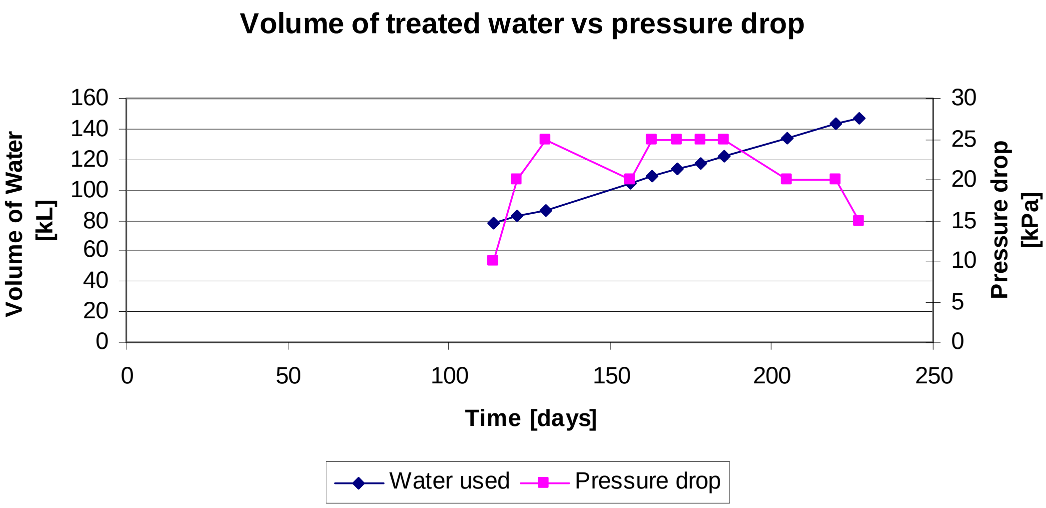

Figure 32: Volume of treated water versus pressure drop

Table 8 shows the water quality results before and after the ultrafiltration unit. No *E. coli* was detected in the raw water during the period of testing and no conclusion can be drawn on the unit performance regarding the removal of *E. coli*. Total coliform bacteria in the raw water was detected four times during the trial with maximum values of 11,000 MPN/100ml. The ultrafiltration unit removed total coliform bacteria from the water and the concentration of total coliforms in the treated water was zero at all times.

True colour of the raw water was low with values of 1 PCU or less. The Zenon unit did not reduce true colour of the water any further.

Turbidity of the raw water was low and the values did not exceed 1 NTU. The unit was able to reduce turbidity even further so that the maximum values of treated water turbidity were always less than 0.4 NTU. Raw water iron levels fed to the ultrafiltration unit were less than 3 mg/L, which is the limit for risk to health. This is due to the cartridge prefilter which reduced the iron levels of the water noticeably.

The iron levels were further reduced by the ultrafiltration unit and did not exceed 0.15 mg/L at any time. This is below 0.3 mg/L, which is the level for iron in drinking water recommended by the ADWG based on aesthetic considerations.

Manganese levels were also within the guidelines, with the maximum concentration in the treated water at 0.04 mg/l. The ADWG recommends a limit of manganese in drinking water of less than 0.1 mg/L based on aesthetic considerations. However, it is not considered to be a health risk unless the concentration is higher than 0.5 mg/L.

The results show that the Zenon ultrafiltration unit performed very well in reducing total coliform bacteria, turbidity, iron and manganese on water with small levels of contamination.

Table 8: Water quality results before and after the ultrafiltration unit

Time [days]	E.coli [MPN/100ml]		Total Coliforms [MPN/100ml]		Colour [PCU]		Turbidity [NTU]		Iron [mg/l]		Manganese [mg/1]	
	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated
5	0	0	550	0	1	1	0.1	0.05	0.14	0.14	0.03	0.03
12	0	0	11000	0	1	1	0.4	0.4	0.11	0.04	0.06	0.04
40	0	0	0	0	1	1	0.2	0.15	0.07	0.06	0.04	0.03
89	0	0	0	0	1	1	0.05	0.05	0.09	0.09	0.03	0.03
104	0	0	0	0	1	1	0.65	0.15	0.38	0.17	0.03	0.03
112	0	0	0	0	1	1	0.1	0.1	0.06	0.05	0.04	0.04
168	0	0	0	0	1	1	0.15	0.2	0.08	0.05	0.04	0.04
181	0	0	0	0	1	1	0.1	0.05	0.15	0.07	0.04	0.04
210	0	0	0	0	1	1	0.1	0.1	0.06	0.06	0.04	0.04
223	0	0	0	0	1	1	0.3	0.05	0.16	0.08	0.04	0.04
339	0	0	14	0	1	1	0.1	0.1	0.09	0.08	0.04	0.04
355	0	0	140	0	1	1	0.2	0.15				
Average	0	0		0	1	1	0.2	0.1	0.2	0.1	0.04	0.04
Minimum	0	0	0	0	1	1	0.05	0.05	0.06	0.04	0.03	0.03
Maximum	0	0	11000	0	1	1	0.65	0.15	0.38	0.17	0.06	0.04

Because of high iron concentrations in the feed water, the cartridge filter used to precondition the feed water before it entered the ultrafiltration unit had to be replaced after 5 months. A direct observation made by the family was that the water quality improvement was evident after the first day and the dark ring in the bathtub as a result of iron and manganese was no longer evident.

8.4 MWTP at Lexton

The township of Lexton in the Central Highlands Water region receives its water from the Lexton reservoir where it is currently treated by ultrafiltration with post chlorination. The water in the reservoir is a mixture of surface and groundwater, and the raw water quality is therefore variable. The capacity of the Lexton Reservoir is 120 ML and water in the reservoir has high levels of natural colour and dissolved salts. Minimum, maximum and average values for raw water quality at Lexton Reservoir are shown in Table 9.

Table 9: Raw water data of Lexton reservoir

	E.coli (MPN/100 ml)	EC (μS/cm)	Hardness (mg/L)	Coliforms (MPN/100 ml)	TDS (mg/L)	Colour (PCU)	Turbidity (NTU)
Max	220	2,000	420	37,000	1,000	40	4.5
Min	0	610	130	160	850	13	0.6
Average	51	1,730	368	6,208	940	27	2.3

The CHW mobile water treatment plant was set up at Lexton reservoir (Figure 33), to identify whether the POE unit could reliably remove turbidity peaks, colour, TDS and total coliform bacteria.

Figure 33: CHW trailer at Lexton reservoir water

Manganese Greensand, which requires regeneration with $KMNO_3$ and has a density of 1.4 kg/L, was used for sand filtration. For the adsorption process, activated carbon GC1200 (coconut base) with a density of 0.5 kg/L was used. The trials were run continuously over two months at a flow rate of 4.5 L/min. Testing commenced after four to six weeks to allow a biofilm to develop on the filters. On-line measurements of turbidity, flow rate and pressure were taken every minute and water quality samples were taken from the six sampling points and from the treated water every week. They were tested for electrical conductivity, microbiological quality and colour. The sand filter and carbon filter were automatically backwashed daily and this was expected to slough off any extraneous biological material but maintain a viable thin biofilm culture to assist with treatment.

As Table 10 shows, the CHW trailer provided acceptable water quality for all parameters apart from true colour. Microbiological quality of the treated water was very good with no occurrence of *E. coli* or coliforms after reverse osmosis. Electrical conductivity was reduced to an average value of 510 µs/cm which complies with the ADWG and turbidity of treated water was very good with less than 0.5 NTU before reverse osmosis. Average true colour was within the ADWG which suggested a limit of 25 PCU as long turbidity is less than 5 NTU. The RO operated at 50% recovery with no obvious fouling and the pressure drop was approximately 2 kPa.

Table 10: Values for raw and treated water at Lexton reservoir

	E. coli (MPN/100ml)	EC (S/cm)	Coliforms (MPN/100ml)	Colour (PCU)	Turbidity (NTU)
Av. Inlet	2	1,900	105	22	2.1
Av. Outlet	0	510	0	21	0.3

Figure 34 shows the development of inlet and outlet turbidity across the sand filter. The average outlet turbidity was 0.3 NTU. The average inlet turbidity (blue line) was 2.1 NTU with a maximum of 20.5 NTU. The spikes of the treated water turbidity (pink line) represent the turbidity during the backwash process of the filters and this suggests that a ripening period is required. This is shown in Figure AIV-1 in Appendix IV, where the backwash flow rate overlays with the spikes in Figure 34. Figure 34 shows that the turbidity of the raw water was reliably reduced to values less than 1 NTU almost during the whole period of testing. Between day 7 and day 9 and on day 29 the turbidity of the treated water was higher than 1 NTU, but did not exceed values of more than 2.5 NTU. This complies with the ADWG which recommend a limit of 5 NTU. The higher value for turbidity on day 29 was due to higher turbidity in the raw water. The pressure drop over the carbon and the sand filter are also shown in Appendix IV in Figure AIV-2, and show that pressure drop increased by approximately 50 to 100 kPa over the day until the filters were backwashed and the pressure increased again. The overall water recovery of the POE unit at Lexton was 49% due to the recovery across the RO unit of 50%.

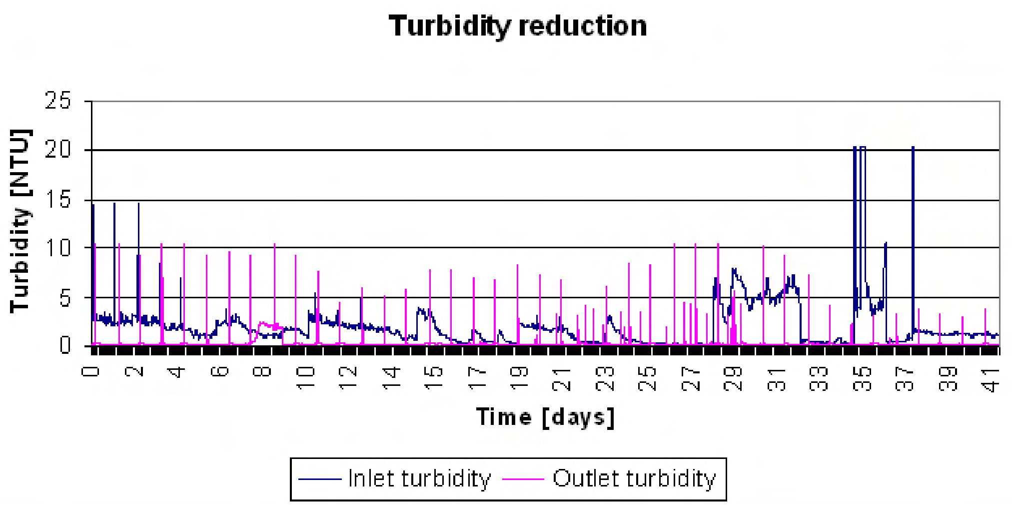

Figure 34: Inlet and outlet turbidity at Lexton

8.5 Avoca Primary School

The township of Avoca in the Central Highlands region is supplied with potable water of very poor quality. There are 609 connected services and the delivered water volume is 134 ML per year. The community receives water from the Sugarloaf Reservoir (capacity 363 ML) and Lead Reservoir (capacity 118 ML). The surface supply is supplemented with groundwater from the Bung Bong Bore, a very reliable water source but with significant levels of natural salts. The water is treated by sedimentation, filtration and chlorination. Table 11 shows the water quality data for the water that is delivered to the Avoca community. The water is potable quality with no *E. coli* or total coliforms and good values for true colour and turbidity. However, electrical conductivity is very high with an average of 3,090 μS/cm and a minimum of 2,900 μS/cm. As stated in Chapter 3.2.3 high electrical conductivity is not hazardous to people consuming the water but it contributes to taste issues. Samples were taken over a one year period to collect water quality data during all seasons.

Table 11: Avoca water quality data

	E.coli [MPN/100ml]	EC (μS/cm)	Hardness [mg/l]	Iron [mg/l]	Manganese [mg/l]	Total Coliforms [MPN/100ml]	Colour [PCU]	Turbidity [NTU]
Average	0	3,090	809	0.20	0.008	0	1	0.22
Minimum	0	2,900	750	0.08	0.003	0	0	0.04
Maximum	0	3,300	3,300	0.33	0.010	0	4	0.40

The primary school in Avoca also has access to an alternative water supply harvested from roofs. The children were drinking rain water collected in a tank. Due to contamination of tank water, one of the GWMW trailers was set up at the primary school in Avoca to run on town water and deliver better quality drinking water. The POE unit was tested to identify whether the unit could handle the high salinity levels. Both filters were filled with activated carbon and were backwashed automatically once every week. The adsorption process was the first treatment step after the raw water entered the MWTP. After the adsorption process, the water passed through a cartridge filter. It was then disinfected by a Wedeco UV disinfection unit and in the final step the water went through a Merlin RO unit to reduce the high salinity levels in the water. The treated water was stored in a 1000 L storage tank before being distributed to drinking fountains. Figures 35 and 36 show the GWMW trailer at Avoca Primary School. In Figure 36, the three filters of the Merlin RO unit can be seen in the foreground.

Figure 35: GWMW trailer at Avoca   Figure 36: Merlin RO unit at GMWM trailer

The carbon filters were backwashed automatically once a week and an average of 200 L was wasted every time. The school used an average of 71.2 L of water each day. There were issues with the material selection. The drinking fountains were connected to the clear water tank with copper pipes. When reverse osmosis is being used for water treatment, the treated water can be corrosive [35]. The copper pipes at Avoca Primary School were corroding due to the low salinity in the water, leading to copper contamination in the supplied water which was indicated by the greenish colour of the water. To avoid pupils drinking the contaminated water, the teachers were advised to flush the pipes until the water came out clear every morning before the children could drink it. It took around thirty seconds of flushing for each tap every morning, and 1 L of water was wasted every day. To reduce corrosion, the pipes should be changed to plastic pipes which are resistant to low salt levels.

Weekly water samples taken from the treated water storage tank and the drinking fountains were tested for *E. coli*, total coliforms, true colour, turbidity, HPC, EC and hardness. Table AV-1 in Appendix V shows complete results.

True colour of the raw water was very good and the MWTP did not reduce the values much further. Table AV-1 shows maximum values for true colour at 3 PCU.

As expected, no *E. coli* or total coliform bacteria were detected in the treated water since the incoming water was disinfected via UV irradiation and further treated with RO. However, there were high numbers of heterotrophic plate count bacteria detected in the treated water. Figure 37 shows the results for the heterotrophic plate count bacteria in treated water over the test period. They was a period of constant low HPC values followed by a period were the HPC values increased rapidly. This indicates that bacterial regrowth was occurring in the clear water tank, as Figure 37 shows that the concentration of heterotrophic plate count bacteria was little different inside the clear water storage tank and at the drinking fountains. However, as explained in section 2.1.3 heterotrophic bacteria are naturally occurring, and their presence in drinking water is not indicative of a public health risk. No regrowth of *E. coli* or total coliforms were detected. Large numbers of aerobic heterotrophic bacteria in treated water can, however, interfere with the interpretation of tests for the coliform group by masking their presence. To reduce the number of plate count bacteria, the tank was cleaned by flushing with 500 mL hypochlorite whenever the results were very high (around once every six weeks).

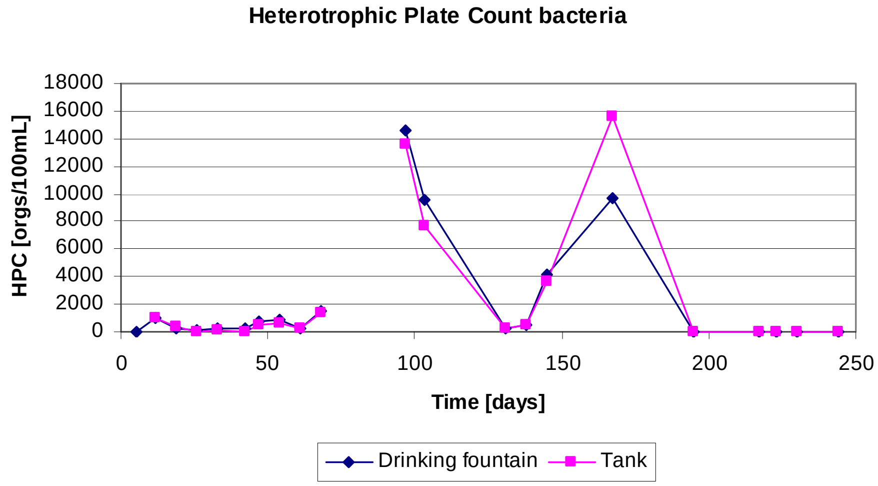

Figure 37: Heterotrophic plate count bacteria in treated water

Except for the bacterial regrowth in the tank, the mobile water treatment plant performed very well. During the first 60 days of the trial, samples of raw and treated (post RO) water were also taken and tested for turbidity and electrical conductivity.

Figure 38 shows turbidity reduction. The treated water (pink) did not exceed values greater than 1 NTU during the first 60 days of testing. Even when the raw water turbidity was relatively high, with values of 4.5 NTU, it reduced the turbidity to values lower than 1 NTU.

Figure 39 shows that the RO unit was removing salts and total dissolved solids reliably in the first period of testing. The electrical conductivity of the treated water was always below 500 µS/cm. Figure 39 shows that the Merlin RO unit can handle hardness of incoming water at levels higher than recommended by the manufacturer. Table 1 in section 4.4.2, where the Merlin RO unit is described, states that the maximum recommended value for hardness is 171 mg/L. The raw water quality of the incoming water, however, averages 809 mg/L with a maximum of 3,300 mg/L. The Merlin RO unit was able to reduce hardness to values of less than 450 mg/L at all times.

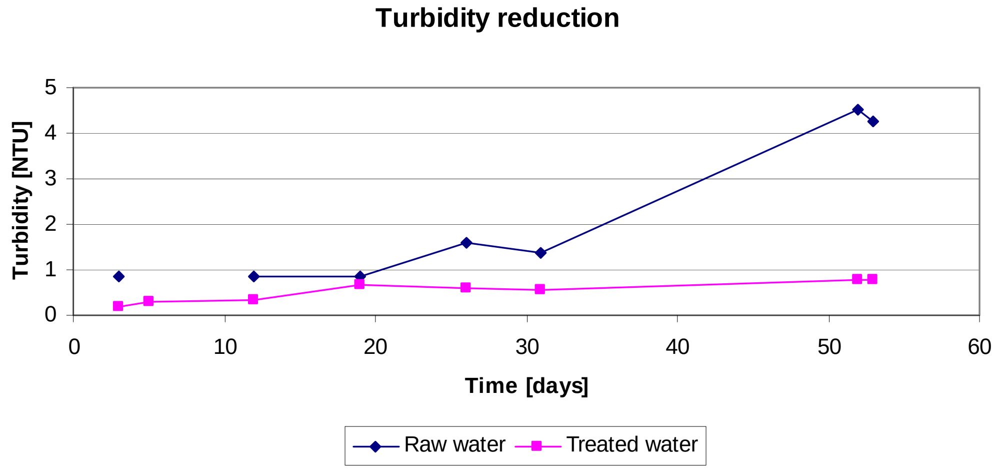

Figure 38: Turbidity reduction

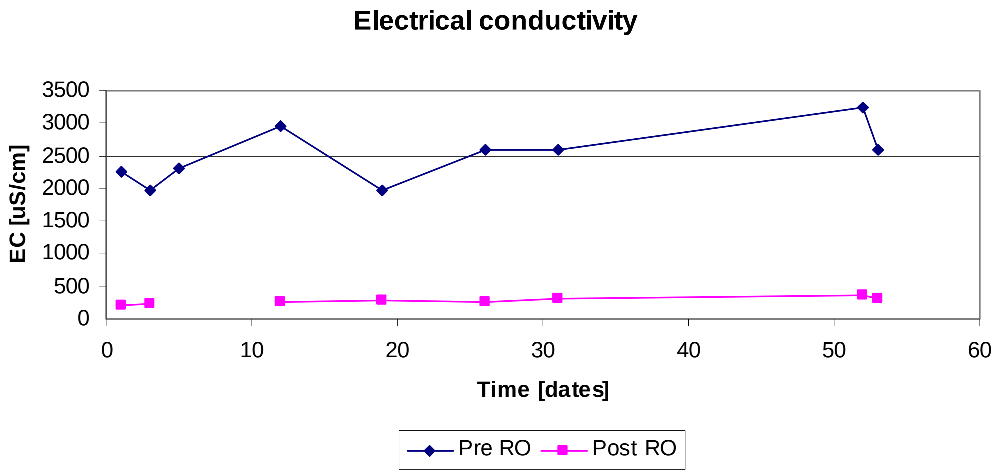

Figure 39: Electrical conductivity reduction by the RO unit

However, after running the unit for more than 150 days, the electrical conductivity of the treated water began to increase significantly. Figure 40 shows the development of the values for electrical conductivity over a period of 250 days. The graph shows that the values for electrical conductivity in the clear water tank and at the drinking fountains were roughly the same. Values for electrical conductivity were rising constantly with time due to fouling of the RO unit. They reached a maximum of 3200 µs/cm after 226 days and as a consequence, the Merlin RO element was changed to a new unit after 230 days of testing. This resulted in an immediate decrease in the values for electrical conductivity.

Figure 41 shows, that turbidity reduction was not affected by time and remained low throughout the testing period. Turbidity levels at the drinking fountains were higher than turbidity levels in the tank. This may have been due to contamination of the taps through the children touching the fountains with dirty fingers or from corrosion of the copper pipes. Turbidity levels of the tank water remained below the ADWG recommended limit of 5 NTU only at the beginning and towards the end of the trial. The levels exceed the recommended limit five times with a maximum turbidity inside the tank of 33 NTU.

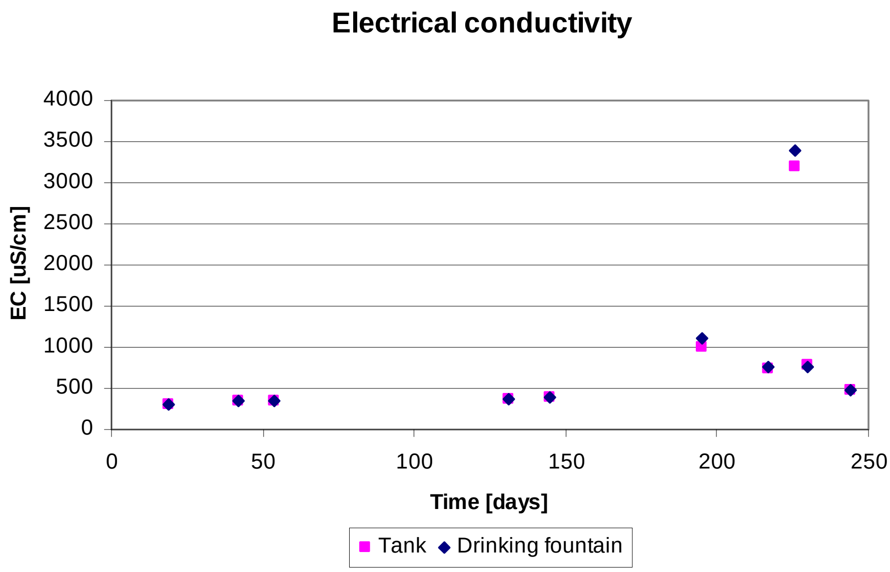

Figure 40: Electrical conductivity of tank water and water at the drinking fountains

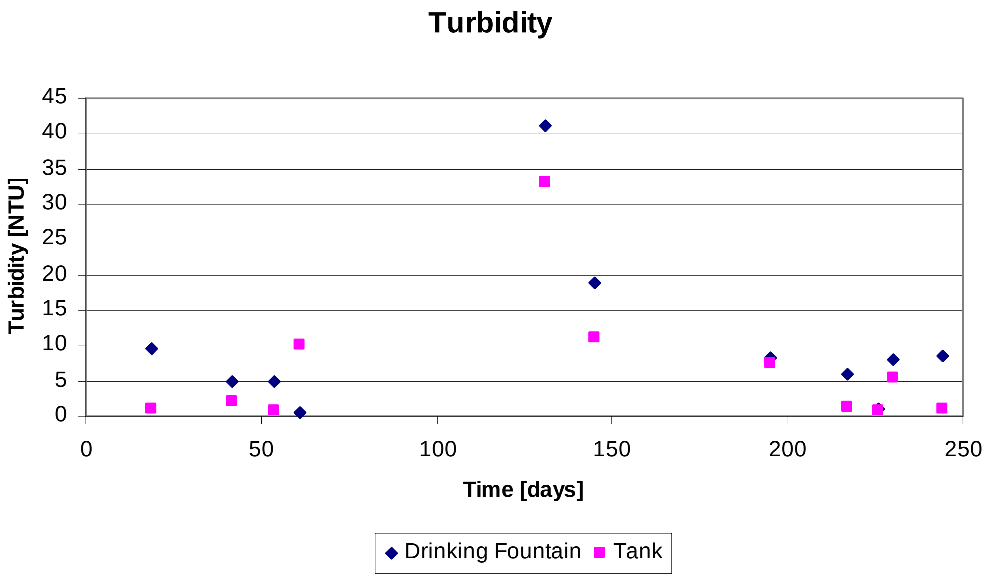

Figure 41: Turbidity of tank water and at the drinking fountains

The water recovery across the RO unit was around 80% at the start of the trial. After 226 days of operation it had dropped to around 20%, which means that 80% of the incoming water was wasted. The total water recovery was 70% at the start of the trials, when the recovery of the RO unit was still 80%. When the recovery across the RO unit was only 20%, total water recovery dropped to 17%.

The RO waste was tested for electrical conductivity, hardness, pH, turbidity and iron after 226 days of operation and the results are shown in Table 12. It shows that the carbon filters removed a considerable amount of turbidity from the water and also a little bit of hardness and EC. The RO unit was still removing a large amount of EC and hardness. To save more water, the backwash water and the RO waste may be used for gardening.

Table 12: Water quality of RO waste and backwash water

	RO waste	**Backwash carbon filters**
EC [(μS/cm)	3,200	3,400
Hardness [mg/l]	860	910
[pH]	7.3	7.4
Turbidity [NTU]	0.65	1

8.6 Timberline Road

The residents of Timberline Road in the township of Woori Yallock in the Yarra Valley Water region are provided with untreated water. The water is supplied from an open aqueduct (Figure 42) and distribution to each house is via a number of individual pipelines (Figure 43). The non-potable nature of the water requires the home owner to boil water for at least three minutes prior using it for drinking and the preparation of food. To supply these customers with potable water the CHW MWTP was commissioned for Yarra Valley Water to test on one of the properties (Figure 44).


Figure 42: Open aqueduct


Figure 43: Tapping the pipeline


Figure 44: CHW trailer

The raw water at Timberline Road is usually of reasonable quality. However, high turbidity events caused by rainfall in the catchment can produce high variations of the water quality because parts of the distribution system are not covered. Table 13 shows the raw water data for the supplied water to the customers in Timberline Road with average, maximum and minimum contamination for colour, turbidity and *E. coli.* Raw water was sampled once every month between June 2005 and November 2006. It shows that the biggest issue is microbiological quality with maximum concentrations of *E. coli* bacteria of 610 orgs/100mL, while colour and turbidity spikes are also issues following rainfall. The data shown in Table 13 does not cover all the changes in raw water quality since samples were taken only once a month. Turbidity was higher on some days during the trials, with maximum values of 60 NTU.

Table 13: Raw water data for Timberline Road

	True colour [PCU]	**Apparent colour [PCU]**	**Turbidity [NTU]**	**E.coli [orgs/100ml]**
Average	22	24	1.4	71
Maximum	40	45	5.7	610
Minimum	11	10	0.3	3

Before starting the trials, the mobile water treatment plant was serviced and some changes were made. The reverse osmosis unit was removed, due to low salinity in the water supply. Both filter media were replaced. Manganese Greensand was used for sand filtration. The underbed volume was 12 L and the media volume 56.6 L. For the absorption process, a coconut based activated carbon with a density of 0.5 kg/l was used. It had an underbed volume of 12 L and a media volume of 55 L. The minimum empty bed contact time was 10 minutes. The cartridge filter had a pore size of 50 µm. Since the incoming feed pressure at Timberline Road was too great (>1,000 kPa) for some components of the mobile treatment plant, an adjustable pressure relief valve was installed to reduce the incoming feed pressure to 500 kPa. Both filter vessels were backwashed for eight minutes and fast rinsed for three minutes. For the sand filter, a backwash rate of 30 $m^3/(m^2 \cdot h)$ was used. The carbon filter was backwashed at a flowrate of 20 $m^3/(m^2 \cdot h)$ to prevent excessive breakage of the carbon.

The trials started on the 1st of April 2007 and operated for a period of 20 weeks. The data logger recorded inlet, outlet and backwash flow and the pressure drop over the sand and carbon filters. The turbidity meters were not operational during the entire trial period and data was logged only during certain weeks. This was because the turbidity meters required a constant flow of water through them and this wasted more water than was desired.

Samples were taken once every week and after high turbidity events following rainfall to assess the treatment performance and to determine if regrowth occurred within the tank. Figure 45 shows the treatment units that were included in the MWTP along with the sampling points, and indicates which parameters were measured after each treatment step. Turbidity samples (Tb) were taken of the raw water, after the sand filter, after the carbon filter, after the UV unit and of the final treated water at the front tap. Raw water, post carbon and treated water were also tested for colour (C) and dissolved organic carbon (DOC). Microbiological quality (micro) was tested in the raw water, the water leaving the UV unit and the final treated water. This included testing for *E. coli*, total coliform and HPC bacteria. The raw and the treated water were also tested for copper, lead, iron and manganese (metals) and the transmittance of the water after the UV disinfection unit was measured. Transmittance is the ratio of the intensity of the light exiting the sample to the light entering the sample and provides an estimate of the efficiency of UV penetration through the water sample.

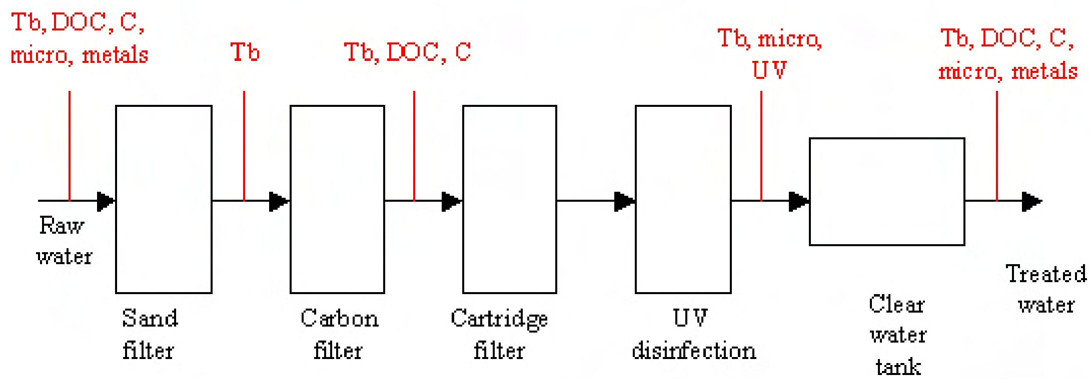

Figure 45: Experimental setup at Timberline road with the sampling points and parameters

Table 14 shows the results for raw and final treated water quality for the weekly sampling scheme. Table AVI-1 in Appendix VI shows the results of the water quality after each treatment step.

Table 14: Weekly sampling results for raw and treated water

	Turbidity [NTU]		True colour [PCU]		DOC [mg/1]		Plate Count [orgs/ml]		Total coliforms [orgs/100ml]		*E. coli* [orgs/100ml]	
Date	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
19.04.2007	1.1	0.9	30	18			1,100	1,100	2,400	0	3	0
23.04.2007	0.9	0.9	30	20	6	3	2,800	1,200	200	0	5	0
04.05.2007	1.6	0.7	30	14	3	1	1,200	4,700	200	0	18	0
09.05.2007	1.1	0.8	26	14	4	3	290	76	200	0	2	0
16.05.2007	1.1	0.6	25	8	5	6	340	240	200	0	3	0
01.06.2007	3	0.6	40	14	8	2	1,100	900	39	0	24	0
07.06.2007	4.4	0.8	40	18	5	1	590	45	200	0	7	0
08.06.2007	0.7	0.5	25	12	7	3	110	18	13	0	2	0
14.06.2007	60	1.6	25	20	3	2	1,400	10	2,400	0	12	0
29.06.2007	60	1.6	25	20	3	2	1,400	10	2,400	0	12	0
06.07.2007	3.4	0.5	30	12	4	1	11	13	14	0	3	0
13.07.2007	1.5	0.5	30	12	2	1	700	10	43	0	10	0
20.07.2007	7.6	2.4	25	18	3	1	200	10	7	0	2	0
27.07.2007	4.3	1.2	18	12	2	1	290	21	5	0	0	0
Average	11	1	29	15	4	2	824	597	594	0	7	0
Minimum	60	2.4	40	20	8	6	2,800	4,700	2,400	0	24	0
Maximum	0.7	0.5	18	8	2	1	11	10	5	0	0	0

The biggest issue for water in Timberline Road was the microbiological quality as raw water data in Table 13 shows. The results of the weekly sampling showed that no total coliforms and no E. coli were detected in the treated water at any time. Even when the raw water microbiological concentrations were very high, the water treatment unit removed all total coliform and E. coli bacteria reliably. The maximum concentration of total coliforms in the raw water was detected on the 19th of April with values of 2400 orgs/100mL and the maximum concentration of E. coli was 24 orgs/100mL on the 1st of July. The results for the treated water on these dates show no occurrence of E. coli or total coliforms. Table 14 also shows the concentration of heterotrophic plate count bacteria for raw and treated water. The values for treated water were higher than the values for raw water on some days. However, Table AVI-1 in Appendix VI indicates that the UV disinfection unit continuously reduced the concentration of plate count bacteria to smaller than 100 orgs/mL. This indicates that bacterial regrowth did occur inside the tank. However, the presence of HPC bacteria is not indicative of a public health risk, as most heterotrophic bacteria are non-pathogens. It is important that no regrowth of disease causing E. coli or total coliform bacteria was found.

Raw water turbidity was low most of the time before treatment, and was further reduced by the sand filter. Even when the inlet turbidity was high, the final turbidity values were low with maximum values of 2.4 NTU. This was on the 20th of July 2007 when the inlet turbidity was only 7.3 NTU, and appears to be an anomalous result not consistent with the majority of recorded data. Turbidity after the UV disinfection unit was constantly lower than 2 NTU. The highest value for turbidity of the feed water was 60 NTU and was detected on the 14th of June. Table 14 shows that the MWTP reduced turbidity to 1.6 NTU. Table AVI-1 in Appendix VI shows that the sand filter removed most of the turbidity. However, samples taken on that day show that the very high raw water turbidity was reduced to 3.6 NTU by the sand filter and the subsequent carbon filter reduced the turbidity to 1.1 NTU. This demonstrates that the carbon filter contributed to the removal of turbidity spikes. Turbidity was constantly under the ADWG recommended value of 5 NTU.

Colour removal was approximately 50% on average and the colour values were always smaller than 20 PCU which complies with the acceptable limit guidelines recommended by the ADWG. The ADWG recommends true colour of less than 15 PCU. However, up to 25 PCU is acceptable if turbidity is lower than 5 NTU and turbidity was lower than 5 NTU throughout the trials. Raw water colour was highest on the 1st of June at 40 PCU. On that day, the colour of the treated water was reduced to 16 PCU corresponding to a colour reduction of approximately 60%. The highest value for the colour of treated water was 20 PCU. Colour was removed by the sand, the carbon and the cartridge filter, which is shown in Table AVI-1 in Appendix VI.

The water was also tested for dissolved organic carbon (DOC), caused by organic materials such as plants. DOC is reduced by activated carbon adsorption and Table 14 shows that the levels for DOC were reduced by the MWTP. The average reduction of DOC was around 50%. Table AVI-1 in Appendix VI shows that DOC was continuously reduced and values for DOC after the carbon filter are lower than for the raw water. This shows that the sand or the carbon filter successfully reduced DOC.

The raw and treated water were also analysed for iron, manganese, lead and copper concentrations. The iron reduction was 46% on average and the MWTP reduced copper by an average of 56%. Since only the raw and the treated water were tested for these metals, the unit removing the iron and copper can not be specifically identified. The concentrations of lead in the raw and the treated water were very low, and no increase or decrease in the concentration was identified. There were significantly higher levels of manganese in the treated water than in the raw water. This was probably because Manganese Greensand was used for sand filtration and the sand released manganese into the water. Even though manganese concentrations in this range are not a health concern, it is recommended that a different type of sand be used for this water source.

Transmittance of the water was 85% on average with a maximum of 96% and a minimum of 71%. This indicates that the water was suitable for UV disinfection. The overall water recovery for the MWTP was 70%.

Figure 46 shows the pressure drop over sand and carbon filter. Pressure drops over both filters were very consistent with a pressure drop over the sand filter smaller than 20 kPa and pressure drop over the carbon filter smaller than 15 kPa. The very consistent pressure drops indicate that the unit was performing well and the frequent backwashing of the unit prevented the filters from clogging. There were higher pressure drops over both filters when the filters were backwashed because of the higher flowrates during the backwash process. The pressure drop over the sand filter was much higher than the pressure drop over the carbon filter during the backwash process. This was because the flowrate to backwash the sand filter was higher than the backwash flowrate of the carbon filter.

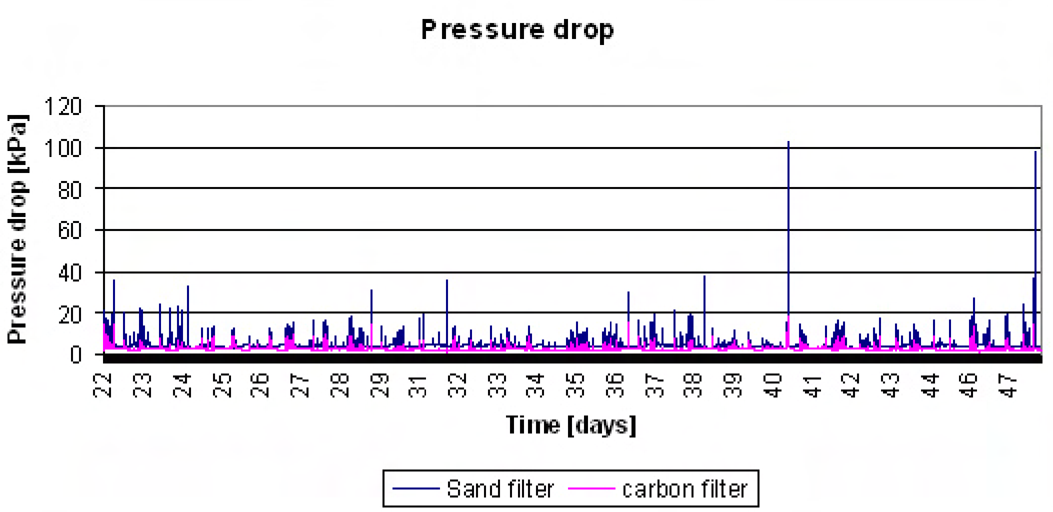

Figure 46: Pressure drop over sand and carbon filter

The unit was inspected after 90 days of operation and all treatment units were checked for their actual condition. No alarms were triggered at the UV unit which means that it functioned without need of maintenance over the period of the trials. It is anticipated that the UV lamp would need to be replaced once every 12 months. The final cartridge filter was not replaced over the 20 weeks of the trial, and it appeared to be in good condition when the trial was stopped.

The treated water quality for these trials was very good, with no disease-causing microorganisms and low values for colour, DOC and turbidity. This is due to the fact that the flow rate through the filters and especially through the UV disinfection unit was very low. The filters were therefore able to reduce turbidity and colour to values sufficiently low to ensure effective UV disinfection at all times.

9 COSTING COMPARISON

A preliminary evaluation of the financial aspects associated with providing potable water to small, remote communities with POE treatment systems compared to building centralised treatment plants (CTP) and a water distribution network was undertaken. The first part of this section compares the costs of the POE systems which were developed to the costs of CTP which were recently built by GWMWater for small towns in their area such as Willaura/Lake Bolac and Underbool. The second part compares the costs of the POE systems to the costs of using Zenon ultrafiltration units with cartridge filter for pre-treatment of the raw water before the unit. The costs for the POE systems, however, do not include the costs for the trailer, the instruments and the data loggers. Only the equipment that is needed to treat the water was considered.

9.1 POE vs CTP

Table 15 shows that the establishment of one POE system costs around $5,000. It includes two Waterways filters housing and the cost for filter material such as sand and activated carbon, one cartridge filter housing with cartridge filter, a 1,000 L storage tank and a UV disinfection unit. It also includes the estimated costs for fittings and for installation of the system.

Table 15: Costs for one POE system

	Costs
2 Waterways filter housing	$1,800
Activated carbon	$100
Sand	$50
Cartridge filter housing	$80
Cartridge filter	$100
UV disinfection unit	$600
Tank and fittings	$700
Pressure pump	$500
Meter/restrictor	$80
Installation	$1,000
Total	**$5,010**

GWMWater recently built two CTP to deliver potable water to three small towns in their area. One was built in Underbool to provide a potable water supply to a community of 230 people with a water consumption of around 17 ML per year. The capital cost for that treatment plant was $650,000. A second treatment plant was built to service the townships of Willaura with a population of 303 people and Lake Bolac with a population of 235 people. Several customers living in between those two towns were also supplied with potable water from this treatment plant. The overall number of customers receiving water from the treatment plant in the Willaura scheme is, therefore, around 545. The cost for that treatment plant was $2,284,000 and includes costs for water storage tanks and for a widespread distribution system to service the two communities some 30km apart. The equivalent cost for the provision of safe drinking water from a centralised treatment facility varies from $2830 per person at Underbool and $4190 per person at Willaura. These costs do not reflect the total cost to provide safe drinking water because the water distribution network was existing. Based on the average occupancy of households in remote rural communities of approximately 2 persons per household, the cost to deliver water using a centralised scheme varies from $5670 - $8380 in these two examples. These costs are exclusive of water distribution costs that would easily double the total cost of delivery. On this basis, it suggests that POE/POU are commercially viable and more so if new water distribution networks are required in addition to treatment facilities. The RO system was not included in this calculation, because the raw waters at Underbool and Willaura have low levels for salt and a reverse osmosis process is therefore not necessary. However, if RO has to be included due to high salinity in the raw water, the costs for one POE unit increases to around $5,750.

Table 16: CTP vs. POE

	capital cost	Number of households	cost/hh
Underbool	$650,000	77	$8,478
Willura	$2,284,000	182	$12,550
MWTP	$5,000	1	$5,000

The results show that the capital costs would be cheaper to use POE water treatment systems to supply potable water to the townships of Underbool, Willaura and Lake Bolac than building centralised treatment plants. However, the operational maintenance and monitoring requirements require further attention.

9.2 POE vs. Zenon ultrafiltration unit

Table 17 shows that treating raw water with one Zenon ultrafiltration unit with a cartridge prefilter and a storage tank costs around $7,910.

Table 17: Costing for Zeonon ultrafiltration system

	Cost
Prefilter	$250
Homespring	$6,500
Tank and fittings	$660
Installation	$500
Total	**$7,910**

One Zenon ultrafiltration unit can produce 34 L/min of potable water. The average household consumption across the Grampians Wimmera Mallee region is 300 kL/year or around 800 litres per household per day. One Zenon ultrafiltration unit can therefore comfortably supply sufficient water to an average household. In Figure 47 the costing of POE systems is compared to Zenon ultrafiltration units for different numbers of households. The calculations assume that the Homespring units can service more than one household and that these units can be combined to produce small centralised treatment plants for these communities. Figure 47 shows that in supplying potable water to communities with less than 4 households, it is cheaper to use POE systems for water treatment. For any community with four households or more, it is more cost effective to use one or more Zenon ultrafiltration systems in a centralised treatment plant configuration.

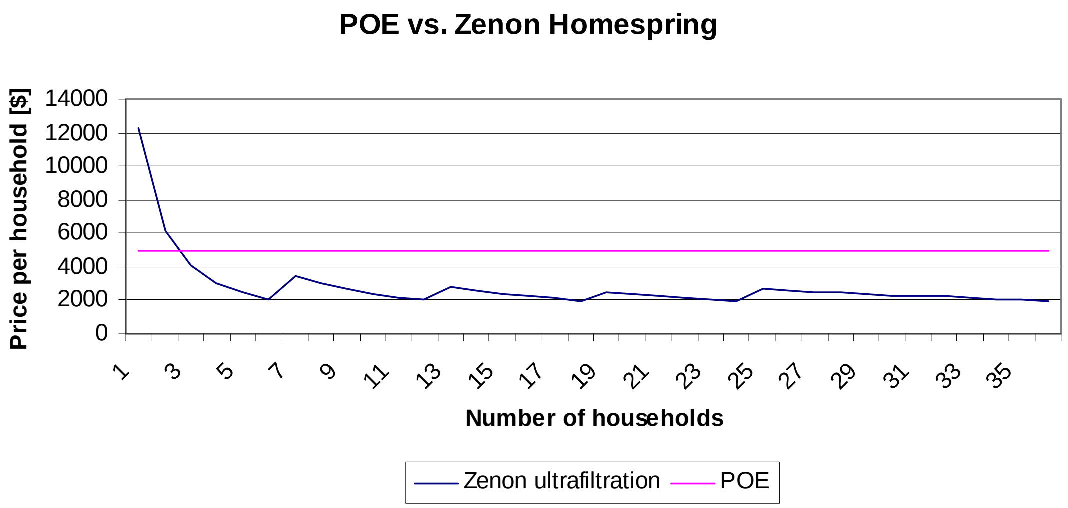

Figure 47: Cost comparison of POE systems vs. Zenon ultrafiltration systems

However, trials with the Zenon ultrafiltration unit showed that the unit is not suitable for all types of raw water quality. The unit performed very well when the incoming water was low in turbidity and colour. When the turbidity of the entry water was around 3 to 4 NTU, the unit started to foul after a very short period of testing. The experiments at Dadswells Bridge showed that the unit completely removed even high concentrations of total coliform bacteria from the water. The use of Zenon ultrafiltration units to deliver potable water to small communities can therefore only be recommended where the water is low in turbidity and colour. Alternatively a sand filter or sedimentation tank could be installed prior to the unit to ensure that turbidity reductions were kept to a minimum. No experiments were undertaken to identify the response of the ultrafiltration system to chlorine in the water.

10 MANAGEMENT OF POE/POU TECHNOLOGY

The major advantage of centralised water treatment plants is that they are relatively easy to manage, with an organisation dedicated to water treatment services taking responsibility for their operation, maintenance and routine monitoring. The customer is not involved in the management of the system and does not have to be aware of it. For small POE or POU systems the process may be located on the customer's property and they may have to take some responsibility for its operation, maintenance and routine monitoring. POE/POU devices can experience two types of failures: operational failures and functional failures. Functional failures, where the system continues to treat the water but contaminants are not properly removed, cause the most concern to public health. Operational failures are usually detected immediately, because water flow is usually affected in the home. Functional failures may not be detected immediately, therefore posing a greater risk to public health. This is also one reason why these devices have not previously been considered to be reliable for delivering potable water.

However, POE/POU devices can be a viable alternative to centralised treatment plants for small communities, provided that the systems are properly managed. Organised management of on-site systems is not well defined. It may be hard to develop a management program for on-site technologies due to a lack of previous experience or knowledge on the subject. However, a management program can minimise the public health risk while providing operational experience for POE units.

To approach on-site technology management, technical management was categorised in the following five functions [36]:

- Planning
- Design and construction
- Installation
- Operation and performance monitoring
- Maintenance

If each of the five functions is properly performed, any water treatment technology can meet its treatment objectives. If any one function is weak, the entire system's capability is weak. The regulation of planning, design and installation has been relatively well established, but requirements for operation and maintenance remain largely in question. Operation and maintenance information on POE/POU water treatment systems is hard to access, incomplete, and often poorly referenced. In some cases, the information is highly speculative because the technology is so recent that there is little field experience, and this is the case with Zenon Homesprings Ultrafiltration POE. There is, however, some experience in centralised management of wastewater systems, and this literature will form the basis of the following review as the issues are common to both services.

The Unites States Environmental Protection Agency (USEPA) has developed the Voluntary National Guidelines for management of onsite and clustered (decentralised) wastewater treatment systems [37] to raise the level of performance of onsite and wastewater treatment systems through improved management programs. This guide consists of a series of five different management models depending on the sensitivity of the environment and the complexity of the systems. These models were applied to POE/POU systems and are described in section 10.2. However, further industry discussion is required to determine when specific management models are appropriate, and the discussion in section 10.2 is provided to commence this discussion.

10.1 Selecting the appropriate model

The following two aspects should be considered when selecting the right model for POE/POU management: 1. Public health risk and 2. Complexity of treatment systems

The management program should be based on the potential health risk of POE/POU water treatment systems. The potential for public health risks can be determined by the raw water quality. The level of control that is included in the management program should increase as the potential for negative impacts on public health increase. The major parameter to be considered in assessing public health risk is the microbiological quality of the water entering the POE/POU water treatment system. This is consistent with the Safe Drinking Water Act (2003) principles.

The second aspect to be considered when selecting a model is the complexity of the treatment systems. As the complexity of the system increases to meet management objectives or system performance standards, the need for a higher level of operation and maintenance and monitoring increases to ensure that the system does not fail.

10.2 Management Models

10.2.1 Model 1: Homeowner awareness model

This management model is recommended for areas where the risks to public health are low and the suitable treatment technologies are passive and robust. The treatment systems are owned and operated by individual property owners. Failures in the treatment process that might occur and stay undetected will pose a relatively low level risk to public health. All systems are documented and inventoried by the regulatory authority and system owners need to be informed of the maintenance needs of their systems through timely reminders. This model intends to provide an accurate record of the types and location of installed systems and to raise homeowners' awareness of basic system maintenance required. Only trained and licensed service providers should be used. Water distribution networks are already established and centralised disinfection is operated by water authority.

Case study

This model is suitable for households, where the water delivered to the property is already safe for drinking, but has, for example, high salinity and bad taste. The water authority can advise the customers to buy conventional, available POE/POU devices such as the Merlin RO unit or the Homespring unit to improve drinking water quality. The homeowner needs to be aware of the purpose, use and care of the treatment system and needs to be informed of existing rules. The water authority assists the user in choosing the right treatment technology and installing the unit. The owner has to make sure that the system is regularly inspected and repaired, if necessary. The water authority maintains a record of the location of the system and provides the owner with notices regarding operation and preventive maintenance recommendations, such as filter replacement and cleaning. Notification of this type can be incorporated into water billing processes.

10.2.2 Model 2: The Maintenance Contract Model

This program is recommended where more complex system designs are applied for the water treatment process. For instance, the water treatment systems include units that have mechanical components and are sensitive treatment processes that require periodic observation and maintenance in order to perform satisfactorily. These systems should only be allowed where trained operators are under contract to perform periodic operation checks and routine maintenance.

Case study

This management model could be applied where customers are being supplied with poor quality drinking water. For example, it could be used when the water is centrally disinfected by chemical oxidants and has therefore no diseases causing microorganisms, but where values for turbidity and colour are high. The treatment process includes sand filtration and carbon adsorption units, which have mechanical treatment processes and require periodic observation and maintenance. The water authority chooses, plans and installs the appropriate water treatment system and informs the owner of the purpose, use and care of the treatment system. The owner of the treatment system has to maintain the system in proper working order and has to attest to the water authority that a valid contract exists with a certified operator to perform necessary system maintenance.

10.2.3 Model 3: The Operating Permit Model

The operating permit model may be appropriate where sustained performance of on-site water treatment systems is critical to protect public health. It has to be ensured that the systems continuously meet their performance criteria. The property owner gets operating permits that are valid for only a limited time. These permits are renewable for another term if the owner demonstrates that the system is in compliance with the terms and conditions of the permit. That might only be a requirement that routine maintenance was performed and the system was inspected periodically when conventional treatment technologies are used. With more complex systems, process monitoring may be required. The property owner should be encouraged to hire a licensed maintenance operator. The advantage of this model is that systems can be used safely if their performance meets the requirements reliably and consistently. The permit helps to provide continuous control of the system performance.

Case study

The operating permit model is suitable where the microbiological contaminant values of the raw water are low and therefore the risk of infection is low. Where the raw water is high in turbidity and high in colour and where the raw water quality is variable, but where the values for microbiological quality are continuously low. The treatment system for similar raw water quality includes sand filtration, activated carbon adsorption and a UV disinfection unit. All of these treatment devices require periodic maintenance in order to perform properly. The Water Authority chooses, plans and installs the right water treatment system and informs the owner of the purpose, use and care of the system. The owner has to operate and maintain the system in accordance with the operating permit regulations and has to submit monitoring reports to the Water Authority regularly.

10.2.4 Model 4: The responsible management entity (RME) operation and maintenance model

This model is recommended where frequent and highly reliable operation and maintenance is required. The permit is issued to an RME instead of the property owner thus providing better control over the performance of the water treatment system. An RME takes responsibility for the proper operation and maintenance in exchange for a service fee. This reduces the number of permits and system failures are reduced as a result of routine and preventive maintenance. The operation permit is the same to that of Model 3 except that the permit is granted to a public or private RME.

Case study

This management model is to be supplied where homeowners receive raw water with very poor microbiological quality and the risk of infection is very high when raw water is ingested. The appropriate water treatment system includes sand filtration, carbon adsorption, UV disinfection and possibly a RO unit. All of these treatment devices need to be maintained on a regular basis in order to ensure that the homeowners are not exposed to a health risk. This model is suitable where the water is supplied only to a single household and the risk of infection is limited to the residents of the house.

10.2.5 Model 5: The Responsible Management Entity (RME) ownership model

This is the only model where the ownership of the water treatment system is not with the owner of the property. The RME owns, operates and manages the system in the same way centralised water treatment systems are organised. Therefore, RME maintains control of planning, management, operation and maintenance. This model provides the highest level of control of system performance. It eliminates the possibility of a conflict between property owner and RME when the property owner fails to fully cooperate with the RME. Existing units can more easily be replaced by newer units with better performance when necessary.

Case study

This management model is suitable where the same issues as described in the case study for management model 4 arise, and especially where water is supplied to places such as schools and hospitals, where more people are exposed to a potential health risk.

11 DISCUSSION

The aim of this project was to determine whether commercially available POE units are a safe method to supply drinking water to small, remote communities.

Three MWTP were developed and set up at four locations around Victoria to investigate their performance on water sources with varying raw water quality. The unit located at the Lexton reservoir was used to determine its ability to reduce turbidity using sand filtration, activated carbon adsorption, and UV disinfection. It also had a cartridge filter and a clear water storage tank. Following the Lexton trials, the unit was cleaned, and sand and carbon replaced. It was then moved to a property in Timberline Road. There it was tested on aqueduct water that is subject to high turbidity and colour variations after rainfall events. The unit's ability to handle changes in turbidity, colour and microbiological quality was investigated. The reduction of DOC, manganese and metals was also determined. The third trial was at Avoca primary school, were the water that entered the unit was already potable but had high salt concentrations, which deterred school children from drinking sufficient water. No sand filter was included in this unit, but both filters were filled with activated carbon. In addition to the treatment units mentioned above, it had a reverse osmosis unit included to reduce the salt concentration and this was located before the storage tank. The last trial was done at Rupanyup, with a MWTP identical to the unit at Timberline Road. The water was centrally disinfected with chlorine and was therefore of good microbiological quality. However, the poor raw water quality meant that there were significant concerns regarding the disinfection by-product, THM.

As part of the project, the performance of two Zenon ultrafiltration units was also studied at two different places. One was set up just outside Horsham, where its efficiency in reducing turbidity was tested. The second ultrafiltration unit was located at a property in Dadswells Bridge, where it was running on ground water with high iron levels. Performance at this site examined the extent of iron removal and if the UF unit could be used as a barrier for microbiological contamination. Both ultrafiltration units had a cartridge filter installed upstream to avoid early fouling of the UF membranes.

For the MWTP plants, the sand filter was responsible for most of the turbidity removal. The carbon filter removed turbidity spikes during the trials at Timberline Road, while the trials at Rupanyup indicated that the cartridge filter also removed some turbidity in this instance. All trials, except for Rupanyup, showed that the units were able to reduce turbidity to values smaller than 1 NTU on average, which is good quality water (The ADWG recommend turbidity in drinking water of less than 5 NTU). For UV disinfection processes, the recommended limit is less than 1 NTU. If turbidity in the UV disinfection unit is greater than 1 NTU, microorganisms may be shielded from UV radiation hence allowing them to pass through the UV unit without being deactivated. The trials at Avoca, Lexton and Timberline Road showed that the unit was able to remove turbidity to suitable values for the UV disinfection unit. The trials at Timberline Road also showed, that after four months of operation, the sand filter was still performing well. It did not release any contamination into the water and weekly backwashing appeared sufficient to prevent breakthrough. Disinfection of the sand filters may be required after extended run times, in order to prevent biological growth on the sand. However, this was not evident in the four months of operation at Timberline Road or at any of the other locations.

Both of the ultrafiltration units achieved high turbidity removals and low final turbidity values. The incoming water for both UF units had turbidity values of less than 5 NTU due to prefiltration of the water with a cartridge filter. The trials at Horsham, where inlet turbidity had maximum values of 4.2 NTU, produced water with turbidity levels of 0.1 NTU throughout the trial. It also showed, however, that the unit started to foul after 80 days. The trial at Dadswells Bridge showed no fouling after 12 months of operation. The inlet turbidity values were less than 0.5 NTU after the cartridge filter. The cartridge filter was replaced after five months due to high iron contamination. When using an UF unit for water treatment it is recommended to prefilter the water before the unit to achieve values smaller than 5 NTU to prevent the unit from fouling.

If high turbidity reductions and low final turbidity (less than 1 NTU) are required, it is advised to use a UF unit with prefilter. If treated water with turbidity values of 1 NTU is sufficient, a sand filter will suffice. A sand filter is cheaper for a single household, is able to cope with high inlet turbidity values and requires less maintenance. However, it does not provide microbiologically safe water while UF treatment may. Sand filters are not able to remove very fine particles (smaller than 1 µm) which are responsible for significant levels of turbidity in some waters, for example at Rupanyup.

Colour removal by the POE units was poor at all four different raw water sources, but the colour of treated waters was always below the ADWG recommended limit. The ADWG recommend colour of less than 15 NTU, but up to 25 PCU is acceptable if turbidity is low (less than 5 NTU). The units at Timberline Road and Rupanyup performed better for colour removal than the units at Lexton and Avoca. The average reduction was 50%. The trials at Rupanyup showed that most of the colour was removed by carbon adsorption and the cartridge filter removed some colour as well. The results at Timberline Road showed that the sand, carbon and cartridge filters were responsible for colour removal.

The UF unit at Horsham was not tested for its performance on colour reduction and the unit at Dadswells Bridge did not remove any colour. However, the colour of the incoming water was only 1 PCU, so it was very low in the feed water. The development of small scale POE type nanofiltration membranes to remove dissolved organic carbon (DOC) and colour may be a viable alternative but they were not evaluated under this project.

The removal of microorganisms by the POE units was very good at Lexton and Timberline Road. The units were able to remove all *E. coli* and total coliform bacteria from the water. Raw water at Avoca and Rupanyup was free of *E. coli* and total coliforms due to central disinfection. No *E. coli* or total coliform bacteria was found in the treated water. The good performance of the UV unit was due to the reduction of turbidity through the sand, carbon and cartridge filter to values less than 5 NTU. The flowrate through the POE unit at Lexton was 4.5 L/min, which was just over the design flowrate of 4 L/min of the UV disinfection unit. That flowrate was sufficient for the UV unit to kill disease causing microorganisms. The flowrate through the POE unit at Timberline Road was only 1 L/min, and this ensured the good performance of the UV disinfection unit in removing *E. coli* and total coliforms (coupled with the low turbidity of the water entering the UV unit). The UV unit at Timberline Road also reduced HPC bacteria to low values. However, concentrations of HPC in the treated water were higher than after the UV disinfection unit, which indicated there was bacterial regrowth inside the clear water tank.

Regrowth of HPC bacteria in the clear water tank was also detected at Avoca. There, the tank was flushed with hypochloride to reduce the number of HPC bacteria whenever the numbers started to increase. It is therefore recommended to disinfect the clear water tank with a chlorine tablet once every month to prevent bacterial regrowth, even though the ADWG states that HPC bacteria in drinking water are not a human health concern. High numbers of HPC bacteria in the clear water tank, may, however interfere with the interpretation of tests for the coliform group by masking their presence and also affect the aesthetics of delivered water. We did not investigate which HPC organisms were growing. No regrowth of *E. coli* or total coliform bacteria was detected at any time at the different locations.

The microbiological water quality in the trials with the UF unit at Horsham was not tested and no conclusion can be drawn to determine its performance in removing bacteria. The UF unit at Dadswells Bridge reduced even high concentrations of total coliform bacteria to zero. The incoming water did not show any occurrence of *E. coli*, and neither did the treated water.

The performance of the POE units in reducing electrical conductivity was investigated at Lexton and Avoca. The MWTP at Lexton performed very well with an average reduction of EC by 75%. The EC of the treated water was 500 µS/cm on average. The Merlin RO unit (a loose RO membrane) at Avoca reduced EC to values less than 450 µS/cm during the first five months of the trial. The average reduction of EC by the POE unit was 90%. After five months in operation however, the values for EC increased and the water recovery across the Merlin RO unit dropped from 80% at the start of the trial to 20%. The RO unit was replaced by a new unit after eight months and the EC of the treated water decreased again. It is therefore recommended to change or to clean the Merlin RO unit after three to six months operation or replace the membrane after 6 months.

The trials at Rupanyup determined that activated carbon in the MWTP was able to remove THMs from the water. The average reduction was 99% with no decrease over the time. Where water is centrally disinfected, using activated carbon adsorption is sufficient to deliver better quality water to customers.

Recovery of water for both the MWTP and the UF units were acceptable, except for the overall recovery at Avoca when the Merlin RO unit started to foul. The overall water recovery at Lexton was

49% due to the low recovery across the RO unit. The overall water recovery of the MWTP varied from 70% at Timberline Road to 97% at Rupanyup which is due to the different backwash setups. Backwashing once a week rather than once a day would have improved water recovery at Lexton, Rupanyup and Avoca. When the water recovery across the Merlin RO unit at Avoca had dropped to 20%, however, the overall water recovery of the process (pre-treatment and RO) decreased to only 17%.

The UF unit at Horsham had an overall water recovery of 90% and the water recovery of the UF unit at Dadswells Bridge was 70% because of the different water usage patterns.

The results for the trials suggest, that the POE treatment train can be customised to suit raw water quality while colour remains difficult to remove using conventional process units – NF membranes may be useful where raw water colour is variable. It has to be pointed out, that the trials have led to very satisfying results, especially for turbidity reduction and for removing microbiological contamination. Leaving one of the filters out of the configuration may result in high turbidity water entering the UV disinfection unit, thus reducing its performance in destroying bacteria. If it was decided to use POE units to treat non-potable water to drinking water quality, all units (except for the Merlin RO unit) should be included in the small scale water treatment plant, and this reduces the risk of poor performance if the feed water varies.

If using a UF unit to produce high quality water it is recommended to prefilter the water with a cartridge filter. A sand filter or storage/sedimentation tank is recommended were raw water is subject to turbidity spikes. The inlet turbidity to the UF unit should be around 1 NTU to prevent the unit from fouling quickly. Both of the UF units were backwashed once every day and it is advised to do so.

As part of the project, an investigation into the cost effectiveness to deliver potable water to small, remote communities with POE and UF units than building centralised treatment plants. The costs of centralised treatment plants, recently built by GWMWater, were compared to the costs for POE units. The comparison suggests that POE is competitive with CTP for capital cost and that it could be considered for communities of less than 150 households. It was also shown, that Homespring UF units, which can supply four households with potable water, are more cost effective than building four individual POE treatment trains, and therefore using POE units in a centralised mode may be economically advantageous when there is more than 3 households. The capital cost can be seen to compare favourably to those of centralised treatment but, the operating paradigm may adversely affect this outcome. Key consideration must be given to the performance monitoring and maintenance (replacement) regime to ensure consistent and reliable production of safe drinking water.

A statistically valid performance monitoring regime must form part of any decentralised water treatment development to satisfy safety is verified to the satisfaction of water regulators. Further, a replacement and maintenance regime that ensures elements are replaced before they fail, with some service factor, is seen as critical to the successful implementation of decentralised treatment where the risks dictate such intervention.

12 CONCLUSION AND RECOMMENDATIONS

The project investigated the possibility of providing safe drinking water with point of entry and point of use devices to small, remote communities. As part of the project, three POE MWTP were developed and tested on four different raw water sources throughout Victoria. In addition, two ultrafiltration units were trialled at two more locations. The trials showed that the POE units were able to reduce turbidity to values less than 1 NTU, which made the water suitable for UV disinfection and produced good quality safe drinking water. The sand filter operated reliably for at least four months. The UF units produced high quality water for turbidity, with treated water turbidity of less than 0.5 NTU. The trials showed, however, that the water entering the UF unit should have values less than 1 NTU in order to prevent rapid fouling. The water must, therefore, be prefiltered by sand filtration, a cartridge filter or sedimentation tank. The units are then able to produce high quality water for a very long period of time. Only the prefilter had to be replaced during the trials at Dadswells Bridge.

The colour reduction by the POE units was not very good in general with an average reduction of 50% at Timberline Road and Rupanyup and hardly any reduction at Avoca or Lexton. Recent developments in nanofiltration membranes has the potential to remove more than 90% of colour and dissolved organic carbon (DOC), however these units were not evaluated during this project. NF membrane performance should be evaluated for POE applications.

The MWTP also performed very well in removing disease-causing microorganisms. No *E. coli* or total coliform bacteria were found in treated water at any of the trials. The UV disinfection unit also removed HPC bacteria to very low values. Bacterial regrowth of HPC bacteria was, however, found inside the clear water tank at Avoca and Timberline Road. It is therefore recommended to disinfect the clear water tank once a month by adding a chlorine tablet. No regrowth of *E. coli* or total coliform bacteria was found. The UF unit at Dadswells Bridge completely removed even high concentrations of total coliform bacteria.

The POE treatment train at Lexton performed well in reducing electrical conductivity during the three months of testing. The average EC reduction by the Merlin RO unit at Avoca was 78% at the start and after the unit was replaced, producing treated water EC of less than 450 µS/cm. The Merlin RO did foul during the trials and if using one of these units for EC removal, it should be cleaned regularly. A six monthly cleaning frequency seemed suitable for the Avoca water which had EC levels of 3,000 µS/cm.

The trials at Rupanyup determined that activated carbon in the POE unit was able to remove THMs from the water. The activated carbon did not have to be replaced during the life of the trials (2 months). Where water is centrally disinfected, using activated carbon adsorption is sufficient to deliver better quality water to customers.

Water recovery for both the MWTP and the UF units was very satisfactory, except for the overall recovery when RO units were used. The overall water recoveries varied between 70% at Timberline Road and Dadswells Bridge to 97% at Rupanyup and could be increased by longer intervals between the backwash cycles.

The trials showed that the MWTP units produced potable quality drinking water over the life of the trials. The ultrafiltration units also produced high quality drinking water with very low turbidity.

When choosing to use POE treatment units to deliver potable water to a remote property, it is advised to use all the treatment units that were included in the MWTP unit and to ensure that the flow rate through the unit does not exceed the design flowrate of the disinfection unit to deliver microbiologically safe drinking water at all times. It may be possible to build in a fail safe system so that no water is processed when the UV lamp is not working. This could be achieved by detecting when there is no current flow in the UV lamp and then either activating a solenoid valve to prevent flow or deactivating the feed pump.

When using an ultrafiltration unit to produce high quality drinking water, it is recommended to prefilter the water with a sand filter, a cartridge filter or a sedimentation tank to reduce turbidity, thus preventing the unit from rapid fouling.

Consideration was also given to when it might be more cost effective to provide drinking water with POE/POU technologies to small, remote communities rather than provide potable water from a CTP. The calculations suggest that POE may be cheaper than building centralised treatment plants with widespread distribution systems for towns with less than 150 households. However, use of POE devices in a centralised mode (eg. manifolding of homespring units) may provide economic advantages when there are three or more households. Use of POE devices in this mode would also overcome issues associated with management of many individual units.

Five different models to manage onsite water treatment systems were introduced together with a case study. However, additional discussion is required to consider when specific models are appropriate to implement.

Performance monitoring and maintenance/replacement schedules are considered essential to ensure the production of safe drinking water is consistently and reliably delivered. Decentralised water production changes the performance monitoring paradigm and water regulators and proponents of this technology need to develop testing and monitoring schedules that have the capacity to ensure public health and safety. In conjunction with performance monitoring, hardware maintenance and replacement needs to be driven by the performance of the weakest element, not the average. So certification of operating life and replacement may be necessary. The water industry and consumers need to fully evaluate the merits of POE/POU in these terms as well as the financial imperatives.

Further work is required to:

1. develop management guidelines for POE/POU,
2. develop testing regime to protect public health and assist with developing costs for these systems,
3. develop maintenance schedules, and
4. integrate capital and management cost to develop lifecycle costs for direct comparison with other alternatives.

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APPENDIX I: UV POE/POU TREATMENT UNITS

Table AI-1: Summary of POE/POU UV treatment units*

	Culligan (Aqua-Pure)		Cuno Pacific Pty Ltd		VA TECH Australia Pty. Ltd	WEDECO AG	Freshwater Systems	
	Sterilight S12Q-PA	Sterilight S1Q-PA	UV-S8Q/220	UV-S2Q-P	Steriflo SF300S	Aquada 1 Proxima	FWS-Ultra Violet sterilizer	FWS-Ultra Violet sterilizer
Design Flow Rate	49 lpm	7.5 lpm	30 lpm	7.5 lpm	9 lpm	11 lpm	5 lpm	40 lpm
Dose at end of life	30mJ/cm^2	30mJ/cm^2	30 to 40 mJ/cm^2 [4]	30 to 40 mJ/cm^2 [4]	40 mJ/cm^2	40 mJ/cm^2	30 to 40 mJ/cm^2 [4]	30 to 40 mJ/cm^2 [4]
Power Consumption (Installed Power)	42W	16W	110W	40W	35W	35W		
Lamp Watts	39W	14W	36W	17W	20W	20W		
Max Operating Pressure	125psi	125psi	125psi	125psi	150psi	10 bar		
Cost per Unit[1]	$550	$280	$1,100	$435	$585[2]	$756	$510	$1,245
Lamp Replacement Cost[1]		$85 (includes O-Rings)	$200	$96 (includes O-Rings)	$124[3]	$105	$108	
Quartz Cost[1]		$35		$43	$82[3]	$82	$95	
O Ring cost[1]						$10		
Lamp Failure Alarm	Yes (Audible)	Yes (Audible)	Yes (Audible and Visual)	Yes (Visual)	Yes (Audible and Visual)	Yes (Audible and Visual)		
Sleeve Material	Quartz	Quartz	Quartz	Quartz	High Purity Quartz	Quartz		Quartz
Reactor Chamber Material	304 S.S or 316L	304 S.S or 316L	Anodized Aluminum	304 S.S or 316L				316 S.S
Housing Material	304 S.S or 316L	304 S.S or 316L	304 S.S or 316L	304 S.S or 316L	304 S.S	304 S.S (1.4301)		
All Weather Housing					Under cover use	UV Unit IP 65, Control Box IP 54		
Technical Brochures Available	Yes	Yes	Yes	Yes	Yes	Yes		
Contact Name	Timothy Gordon	Timothy Gordon	Richard Cormick	Richard Cormick	Rod Smith	Graeme Hespe	John Henery	John Henery
Phone	(02) 9560 1900	(02) 9560 1900	(03) 9320 9408	(03) 9320 9408	(03) 9264 9927		(08) 8351 7800	(08) 8351 7800
Email	tgordon@culligan.com.au	tgordon@culligan.com.au	rcormick@cuno.com.au	rcormick@cuno.com.au	rsmith_wabag@bigpond.com	graeme.hespe@wedeco.co.au	jh@freshwatersystems.com.au	jh@freshwatersystems.com.au

(1) Prices Exclude GST
(2) Less 10% for purchase of 15 units
(3) For quantity 6 or more
(4) Most likely, but not provided or in information to come

* Table developed and supplied by Michel Chapman, GHD, as a consultancy to CHW.

APPENDIX II: MOBILE WATER TREATMENT FLOWSHEET

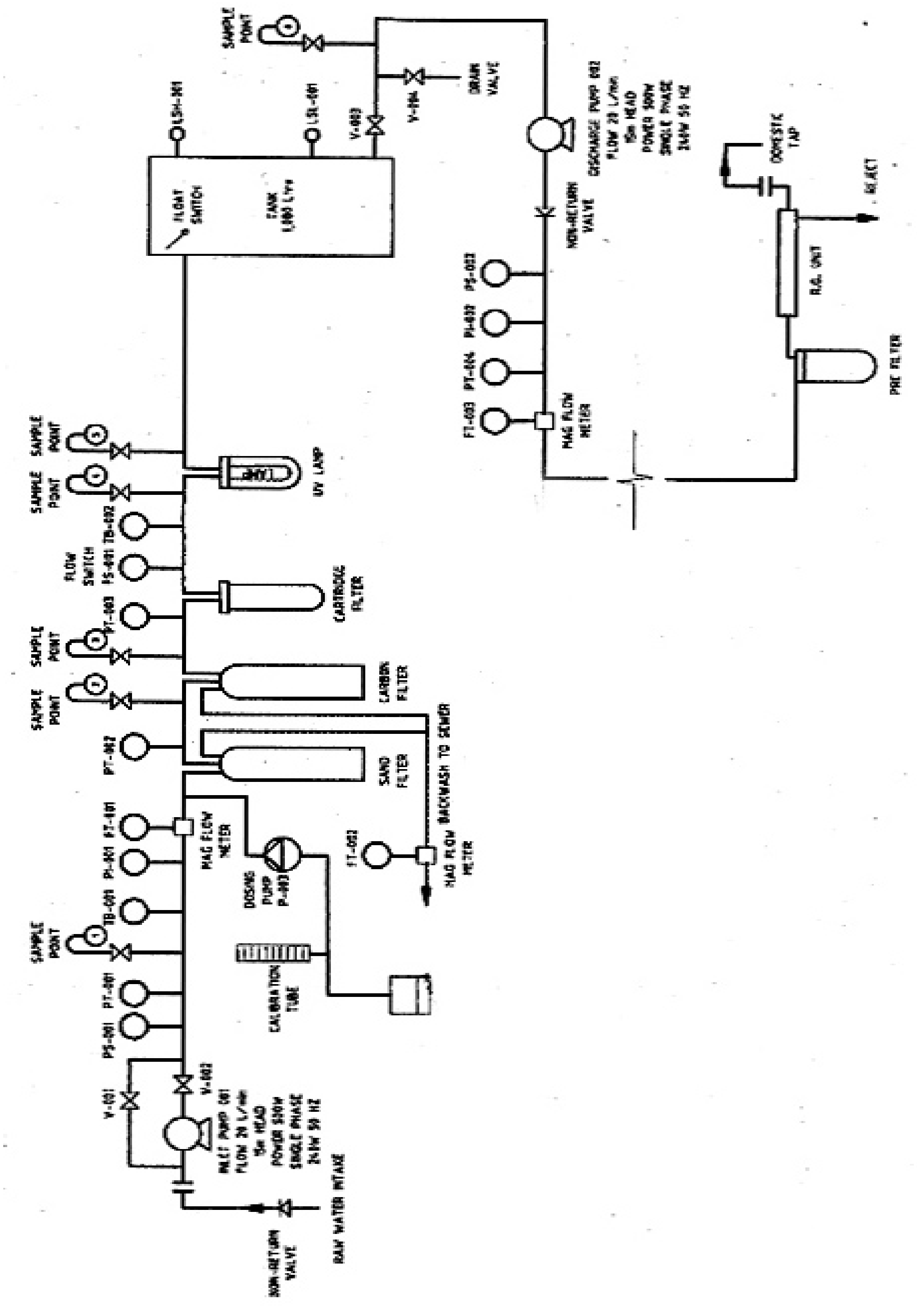

Figure AII-1: Process flow sheet of CHW mobile water treatment plant

APPENDIX III: RUPANYUP DATA

Table AIII-1: Results for trials at Rupanyup

Date	Parameter	Disinfected	Post Sand	Post Carbon	Post UV	Treated
03.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	2	10	<1	<1	<1
	Turbidity [NTU]	4.7	5.9	2.6	3.5	2.8
	Trihalomethanes [mg/l]	0.2	0.19	<0.001	<0.001	<0.001
04.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	2	2	1	1	1
	Turbidity [NTU]	4.8	11	2.5	2.4	4.4
	Trihalomethanes [mg/l]	0.19				<0.001
09.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	3	6	1	<1	<1
	Turbidity [NTU]	6.9	3	1	1	2.5
	Trihalomethanes [mg/l]	0.156				<0.001
10.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	3	2	1	1	1
	Turbidity [NTU]	4.6	3.6	3.1	2.6	2.6
	Trihalomethanes [mg/l]	0.178				<0.001
11.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	2	3	1	<1	1
	Turbidity [NTU]	4.8	2.9	2	1.8	2.6
	Trihalomethanes [mg/l]	0.137				0.009
16.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	2	2	1	1	1
	Turbidity [NTU]	3.5	2.6	2.3	2.3	2.2
	Trihalomethanes [mg/l]	0.165				0.002
17.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	2	3	2	2	2
	Turbidity [NTU]	3.3	2.7	2.7	2.2	2.2
	Trihalomethanes [mg/l]	0.187				0.001
18.07.2007	E.coli [MPN/100ml]	0	0	0	0	0
	Total coliforms [MPN/100ml]	0	0	0	0	0
	True colour [PCU]	3	2	2	2	2
	Turbidity [NTU]	4.3	2.7	2.2	2.2	2.2
	Trihalomethanes [mg/l]	0.228				0.002
25.07.2007	E.coli [MPN/100ml]	0				0
	Total coliforms [MPN/100ml]	0				0
	True colour [PCU]	1				1
	Turbidity [NTU]	3.3				2
	Trihalomethanes [mg/l]	0.194				0.001
02.08.2007	E.coli [MPN/100ml]	0				0
	Total coliforms [MPN/100ml]	0				0
	True colour [PCU]	1				1
	Turbidity [NTU]	3				1.7
	Trihalomethanes [mg/l]	0.213				0.002
08.08.2007	E.coli [MPN/100ml]	0				0
	Total coliforms [MPN/100ml]	0				0
	True colour [PCU]	2				1
	Turbidity [NTU]	3.7				2.3
	Trihalomethanes [mg/l]	0.177				0.005
	E.coli [MPN/100ml]					
	Total coliforms [MPN/100ml]					
	True colour [PCU]					
	Turbidity [NTU]					
	Trihalomethanes [mg/l]					

APPENDIX IV: LEXTON DATA

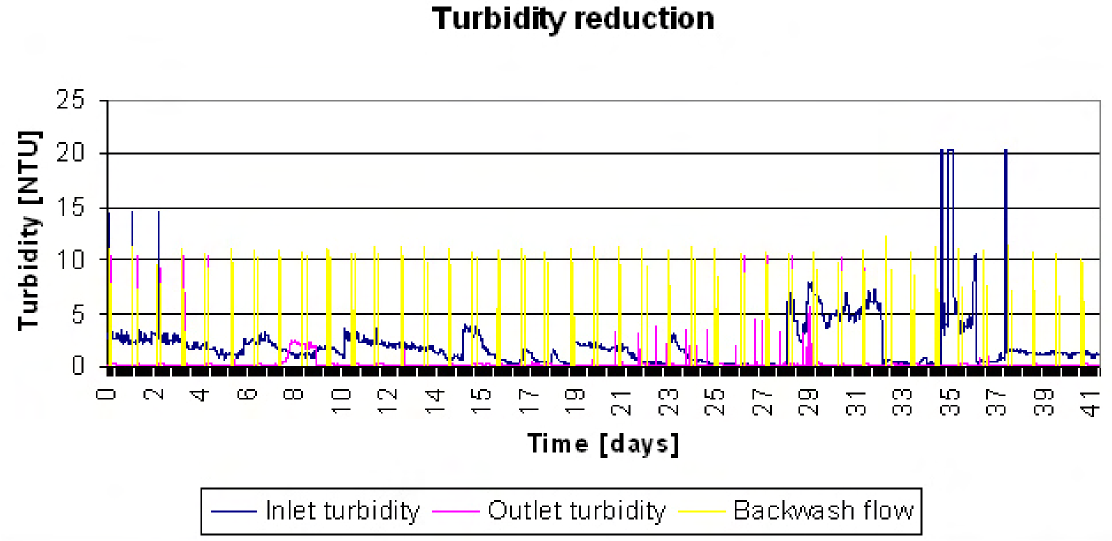

Figure AIV-1: Backwash process responsible for high turbidity of treated water - Lexton

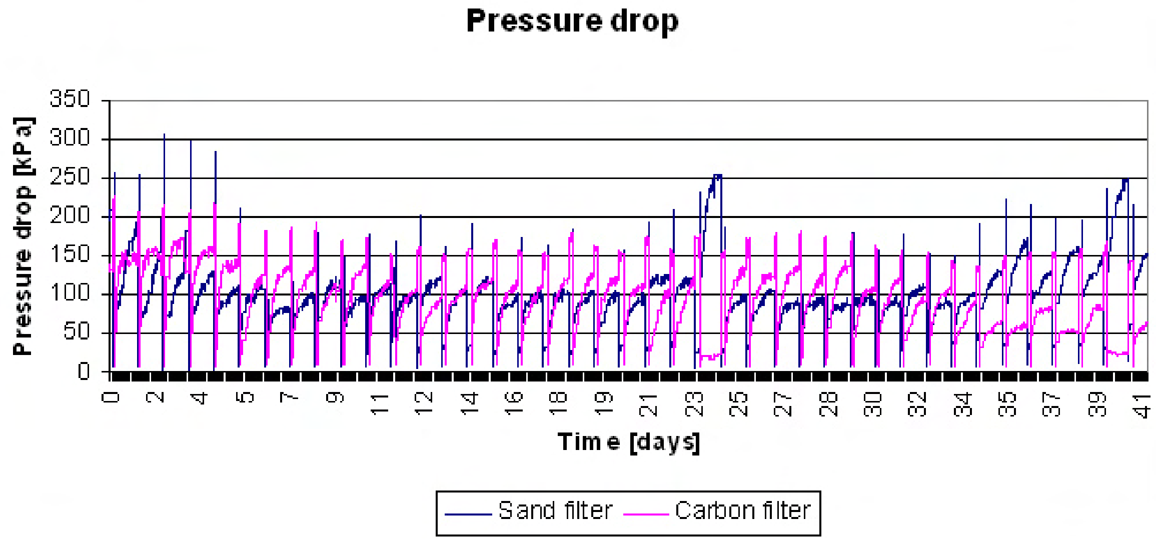

Figure AIV-2: Pressure drop over sand and carbon filter - Lexton

APPENDIX V: AVOCA PRIMARY SCHOOL

Table AV-1: Water quality data in the clear water tank - Avoca

Tank							
time [days]	E.coli [MPN/100mL]	Total coliform [MPN/100mL]	HPC [orgs/mL]	Hardness [mg/L]	EC [uS/cm]	Colour [PCU]	Turbidity [NTU]
1	0	0					
5							
12	0	0	960				
19	0	0	340	27	310	1	1.1
26	0	0	55				
33	0	0	140				
42	0	0	22	33	340	3	2.1
47	0	0	540				
54	0	0	600		350	1	0.75
61	0	0	270			1	10
68	0	0	1400				
82	0	0		0			
97	0	0	13600				
103	0	0	7700				
131	0	0	310	34	360	2	33
138	0	0	480				
145	0	0	3700	40	400	1	11
167	0	0	15600				
195	0	0	1		1000	3	7.4
217	0	0	1	45	750	2	1.4
223	0	0	1				
226				830	3200		0.65
230	0	0	2	42	790	1	5.4
244	0	0	1	37	470	1	1

Table AV-1: Water quality data at the drinking fountain – Avoca

Drinking fountain							
time [days]	E.coli [MPN/100mL]	Total coliform [MPN/100mL]	HPC [orgs/mL]	Hardness [mg/L]	EC [uS/cm]	Colour [PCU]	Turbidity [NTU]
1	0	0					
5	0	0	19				
12	0	0	1000				
19	0	0	310	27	310	1	9.5
26	0	0	85				
33	0	0	230				
42	0	0	210	5	340	1	5
47	0	0	760				
54	0	0	870		340	1	4.9
61	0	0	250			1	0.45
68	0	0	1500				
82							
97	0	0	14600				
103	0	0	9600				
131	0	0	230	36	360	3	41
138	0	0	460				
145	0	0	4200	41	400	1	19
167	0	0	9700				
195	0	0	1		1100	2	8.2
217	0	0	1	43	760	2	5.9
223	0	0	1				
226				910	3400		1
230	0	0	1	43	760	1	8
244	0	0	1	36	470	1	8.5

APPENDIX VI: TIMBERLINE ROAD

Table AVI-1: Results after each treatment unit – Timberline Rd

Date		raw water	pre carbon	post carbon	Post UV	garden tap
19.04.2007	Turbidity [NTU]	1.1	0.7	0.9	0.8	0.9
	Colour [PCU]	30	25	20	18	18
	Transittance [%]				88	
	Plate Count 22C [orgs/mL]	1100	1100	1100	40	1100
	Coliforms [orgs/100mL]	280	>2400	610	0	0
	E.coli [orgs/100mL]	3	6	0	0	0
	Temperature [C]	17	17	17	17	17
	pH	6	7.3	8.2	8.9	8.4
23.04.2007	Turbidity [NTU]	0.9	1.8	0.7	0.6	0.9
	DOC [mg/L]	6		2		3
	EC [uS/cm]	42				53
	True Colour [PCU]	30				20
	Apparent Colour [PCU]	35		18		22
	Transittance [%]				91	
	Plate Count 22C [orgs/mL]	2800			70	1200
	Coliforms [orgs/100mL]	>200			0	0
	E.coli [orgs/100mL]	5			0	0
	Copper [mg/L]	0.022				0.011
	Iron [mg/L]	0.1				0.09
	Lead [mg/L]	0.002				0.003
	Manganese [mg/L]	0,002				0.008
04.05.2007	Turbidity [NTU]	1.6	1.1	1	0.9	0.7
	DOC [mg/L]	3		1		1
	EC [uS/cm]	51				42
	True Colour [PCU]	30		20		14
	Apparent Colour [PCU]	35				12
	Transittance [%]				87	
	Plate Count 22C [orgs/mL]	1200			23	4700
	Coliforms [orgs/100mL]	200			0	0
	E.coli [orgs/100mL]	18			0	0
	Copper [mg/L]	0.027				0.006
	Iron [mg/L]	0.09				0.06
	Lead [mg/L]	0.002				0.003
	Manganese [mg/L]	0.003				0.01
09.05.2007	Turbidity [NTU]	1.1	1.1	0.9	0.7	0.8
	DOC [mg/L]	4		3		3
	EC [uS/cm]	43				47
	True Colour [PCU]	26		22		14
	Apparent Colour [PCU]	30				16
	Transittance [%]				88	
	Plate Count 22C [orgs/mL]	290			4	76
	Coliforms [orgs/100mL]	200			0	0
	E.coli [orgs/100mL]	2			0	0
	Copper [mg/L]	0.017				0.004
	Iron [mg/L]	0.09				0.07
	Lead [mg/L]	0.001				0.004
	Manganese [mg/L]	0.002				0.02

16.05.2007	Turbidity [NTU]	1.1	1	0.8	0.7	0.6
	DOC [mg/L]	5		3		6
	EC [uS/cm]	44				49
	True Colour [PCU]	25				8
	Apparent Colour [PCU]	33		18		9
	Transittance [%]				87	
	Plate Count 22C [orgs/mL]	340			25	240
	Coliforms [orgs/100mL]	200			0	0
	E.coli [orgs/100mL]	3			0	0
	Copper [mg/L]	0.019				0.002
	Iron [mg/L]	0.11				0.06
	Lead [mg/L]	<0.001				0.003
	Manganese [mg/L]	0.003				0.067
01.06.2007	Turbidity [NTU]	3	1.3	1	1	0.6
	DOC [mg/L]	8		5		2
	EC [uS/cm]	33				42
	True Colour [PCU]	40				14
	Apparent Colour [PCU]	50		35		16
	Transittance [%]				72	
	Plate Count 22C [orgs/mL]	1100				900
	Coliforms [orgs/100mL]	39			0	0
	E.coli [orgs/100mL]	900			0	0
	Copper [mg/L]	0.023				0.04
	Iron [mg/L]	0.15				0.06
	Lead [mg/L]	0.03				0.006
	Manganese [mg/L]	0.006				0.37
07.06.2007	Turbidity [NTU]	4.4	2.4	1	1	0.8
	DOC [mg/L]	5		3		1
	EC [uS/cm]	35				39
	True Colour [PCU]	40				18
	Apparent Colour [PCU]	50		35		18
	Transittance [%]				71	
	Plate Count 22C [orgs/mL]	590				45
	Coliforms [orgs/100mL]	200			0	0
	E.coli [orgs/100mL]	7			0	0
	Copper [mg/L]	0.03				0.008
	Iron [mg/L]	0.14				0.05
	Lead [mg/L]	0.002				0.004
	Manganese [mg/L]					
08.06.2007	Turbidity [NTU]	0.7	0.8	0.7	1.3	0.5
	DOC [mg/L]	7		3		3
	EC [uS/cm]	38				39
	True Colour [PCU]	25				14
	Apparent Colour [PCU]	25		10		12
	Transittance [%]				85	
	Plate Count 22C [orgs/mL]	110				18
	Coliforms [orgs/100mL]	13			0	0
	E.coli [orgs/100mL]	2			0	0
	Copper [mg/L]	0.014				0.004
	Iron [mg/L]	0.08				0.06
	Lead [mg/L]	0.001				0.003
	Manganese [mg/L]					

14.06.2007	Turbidity [NTU]	60	3.6	1.1	1.2	1.6
	DOC [mg/L]	3		2		2
	EC [uS/cm]	35				39
	True Colour [PCU]	25				20
	Apparent Colour [PCU]	160		20		20
	Transittance [%]				84	
	Plate Count 22C [orgs/mL]	1400				10
	Coliforms [orgs/100mL]	2400			0	0
	E.coli [orgs/100mL]	12			0	0
	Copper [mg/L]	0.019				0.008
	Iron [mg/L]	0.23				0.05
	Lead [mg/L]	0.002				0.003
	Manganese [mg/L]	0.005				0.27
29.06.2007	Turbidity [NTU]	60	3.6	1.1	1.2	1.6
	DOC [mg/L]	3		2		2
	EC [uS/cm]	35				39
	True Colour [PCU]	25				20
	Apparent Colour [PCU]	160		20		20
	Transittance [%]				84	
	Plate Count 22C [orgs/mL]	1400				10
	Coliforms [orgs/100mL]	2400			0	0
	E.coli [orgs/100mL]	12			0	0
	Copper [mg/L]	0.019				0.008
	Iron [mg/L]	0.23				0.08
	Lead [mg/L]	0.002				0.003
	Manganese [mg/L]	0.005				0.27
06.07.2007	Turbidity [NTU]	3.4	1.1	1	1	0.5
	DOC [mg/L]	4		3		<1
	EC [uS/cm]	32				36
	True Colour [PCU]	30				12
	Apparent Colour [PCU]	35		30		13
	Transittance [%]				96	
	Plate Count 22C [orgs/mL]	11			880	13
	Coliforms [orgs/100mL]	14			0	0
	E.coli [orgs/100mL]	3			0	0
	Copper [mg/L]	0.016				0.007
	Iron [mg/L]	0.05				<0.02
	Lead [mg/L]	<0.001				0.003
	Manganese [mg/L]	0.001				0.22
13.07.2007	Turbidity [NTU]	1.5	0.9	0.9	1.8	0.5
	DOC [mg/L]	2		2		<1
	EC [uS/cm]	33				36
	True Colour [PCU]	30				12
	Apparent Colour [PCU]	30		25		12
	Transittance [%]				82	
	Plate Count 22C [orgs/mL]	700			11	10
	Coliforms [orgs/100mL]	43			0	0
	E.coli [orgs/100mL]	10			0	0
	Copper [mg/L]	0.018				0.005
	Iron [mg/L]	0.05				<0.02
	Lead [mg/L]	<0.001				0.002
	Manganese [mg/L]	0.001				0.21

20.07.2007	Turbidity [NTU]	7.6	0.8	1	0.9	2.4
	DOC [mg/L]	3		2		1
	EC [uS/cm]	36				38
	True Colour [PCU]	25				18
	Apparent Colour [PCU]	35		20		14
	Transittance [%]				84	
	Plate Count 22C [orgs/mL]	200			8	10
	Coliforms [orgs/100mL]	7			0	0
	E.coli [orgs/100mL]	2			0	0
	Copper [mg/L]	0.025				0.009
	Iron [mg/L]	0.05				0.02
	Lead [mg/L]	<0.001				0.003
	Manganese [mg/L]	<0.001				0.21
27.07.2007	Turbidity [NTU]	4.3	3	1.9	1.1	1.2
	DOC [mg/L]	2		2		1
	EC [uS/cm]	36				39
	True Colour [PCU]	18				12
	Apparent Colour [PCU]	20		16		14
	Transittance [%]				88	
	Plate Count 22C [orgs/mL]	290			12	21
	Coliforms [orgs/100mL]	5			0	0
	E.coli [orgs/100mL]	0			0	0
	Copper [mg/L]	0.011				0.007
	Iron [mg/L]	0.05				0.04
	Lead [mg/L]	<0.001				0.003
	Manganese [mg/L]	<0.001				0.2

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