OVERVIEW OF WATER TREATMENT PROCESS
IN SARAWAK USING PEAT AND GROUND WATER
SOURCE COMPARING WITH EMERGING BEST PRACTICE

Submitted by: Chang Kuet Shian (30137908)
2003
OVERVIEW OF WATER TREATMENT PROCESS IN SARAWAK USING PEAT AND GROUND WATER SOURCE COMPARING WITH EMERGING BEST PRACTICE

Master of Science Dissertation
N500
School Of Environmental Science
Murdoch University
Western Australia

Submitted
by

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2003

I declare that, except where I have indicated, the work contained in this dissertation is of my own work and has not been previously submitted for assessment at any other institution

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Chang Kuet Shian
August 2003
ABSTRACT

Water is one of the more important natural resources of mankind, in its natural form contains impurity. The method used to treat water into potable form involves complex and diverse technologies, depending on the nature of water; the treatment can be simple filtration or complex involving chemicals and extensive infrastructure.

Surface water from peat source and ground water are harder to treat to potable standards compared to other water source. Peat water is characterized by high colour, low pH and turbidity with pungent smell while groundwater contains high manganese, iron and other volatile gases. This paper gives an overview of the State of Sarawak current treatment processes for peat and groundwater, investigates the treated water quality, and recommends improvements and enhancement of the current processes and practice based on emerging technologies. The data for the assessment are obtained form Public Works Departments records and the Public Health Section of the Ministry of Health, Malaysia.

The high residue aluminium of the treated water quality suggests that the current conventional processes cannot treat peat water efficiently and effectively. The recommendations for improvement and enhancement are divided into treatment plant operations, treatment processes, water quality monitoring and regionalization of treatment plants.

The limitations are the reliability of the records and the year assessed is only 2000 and 2001. A number of future research projects are identified.
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1.0 INTRODUCTION

Water: A Precious Resource

Water is the most important natural resource on earth, without it there is no life. For humans, only air precedes water in importance, without air human cannot survive more than a few minutes; without water cannot survive more than a few days. Although the Earth and its atmosphere contains large amounts of water only about seven percent of all water is fresh (potable); 96.5 % of all water is saline (seawater) and most freshwater is incorporated in polar icecap and glaciers. Only about 0.7 percent of the earth’s water exists as freshwaters in lakes and rivers. This resource is even more limited since it is unevenly distributed in relation to population density; the most abundant or water-rich regions lie in the tropics or in places of low population density. This leads to significant water scarcity and water stress in some countries (Tebbutt, 1998).

Water has also been regarded as an infinite resource and a natural repository for any and all contaminants. Coastal water bear the biggest brunt of the pollution as population are usually along the coast. (Boyce, 1997).

A Shift In Water Development Projects

Problems related to scarcity of water resources are on increase in many countries around the world. Improved water resources management thus gains importance and may be seen as a sound economic alternative and solution for water scarcity problems (Cumning et al. 1996). The increasing demand for fiscal austerity in most countries
leads to growing concern with least cost and at the same time high technology alternatives for meeting water needs (World Bank Technical Paper, 349). There is also growing awareness on the environmental impacts related to the construction of hydraulic infrastructure. However increased human activities and growing population coupled with increased standard of living around the world leads to escalating demand and high water stress. All these changes have brought about fundamental shift in the way water resources development is heading (World Bank Technical Paper, 349). These shifts are looking at construction of ‘storage’ and improved water resource management as a means to overcome part of the water stress. This change from ‘building bigger’ facilities to a ‘management’ approach describes a new generation of water-related projects (Cumming et al. 1996). Most new water projects aims at enhancing and modernization of a country’s capacity to collect, preserve and use water sparingly.

Traditionally, water supply projects are seen as a civil engineering scope. However in my opinion, water supply projects involve other multi disciplinary fields such as chemical, scientific, mechanical-electrical and environmental management expertise working together as a team producing what can be termed as the ‘best treated water at the cheapest cost with least environmental impacts’.

Drinking water must be obviously fit for human consumption; of potable quality, water should be palatable (aesthetically attractive) and free from other harmful pollutants Most water supplies are not only for drinking but also for other domestic and probably agricultural and industrial uses Thus there is a demand for different standards of potable water. This balance of water quality standards can be quite
subjective, but in most cases, the quality and standard comply with WHO standards in which human consumption comes first. (Tebbutt, 1998).
1.1 BACKGROUND OF WATER SUPPLY IN SARAWAK

1.1.1 History of Water Supply in Sarawak. (Source from JKR HQ)

The earliest record of water supply system was in Kuching in 1887. The Batu Kitang water treatment plant was commissioned in 1957. Among the few towns in Sarawak with the earliest record of a reticulated water supply system are Sibu, Mukah, Miri, Bintulu and Sri Aman. JKR\(^1\) operates and maintain 85 water supply authorities and each consist of a treatment plant complex, storage facilities and distribution to a specific town.

Kuching and Sibu Water Boards are statutory bodies established in January 1959 to take over the management of water supply system for Kuching and Sibu Town. A General Manager under a Board of Management and a Chairman heads each of the Water Boards. In January 1996, Laku Management Sdn Bhd, a wholly owned company of the State Government of Sarawak was established with the corporate office in Miri. Laku Management Sdn Bhd took over the management of Miri, Bintulu and Limbang water supply authorities. These four water supply operators manage and operate the water supply system for the State of Sarawak.

Under the Water Ordinance 1994, the Sarawak Water Authority was set up to administer the various Water Supply Authorities in the State. The State Financial Secretary was appointed as the State Water Authority on 1\(^{st}\) June 1995.

The Medical Department of Sarawak, under its Rural Health Sanitation Scheme implement simple gravity feed water supplies to the rural settlements and

\(^1\) JKR is the State of Sarawak’s Public Works Department.
communities that do not have access to treated water supply from the water authorities. The local communities maintain such schemes with assistance from Medical Department.

1.1.2 Management and Administration of Water Supply

Under the Water Ordinance 1994, chapter 13 of the Laws of Sarawak, the State Water Authority shall have general control and supervision of all water supply authorities and the management of all water resources and catchments areas in Sarawak. The State Water Authority may, with the approval of the Minister, delegate any of its powers and functions to any statutory body or another public officer or any other person.

Apart from water supply authorities’ management by Kuching and Sibu Water Boards and Laku Management Sdn Bhd, JKR Sarawak continues to perform the function and responsibility of developing and administering water supplies in Sarawak.

1.1.3 JKR Water Supply

The water supply branch of JKR Sarawak operates and maintains the eighty-five smaller water supply systems with most of the treatment plants located in the rural district in the State. Each water treatment plant and its distribution system are called Water Authorities. The name of the water authority is usually adopted from the name of the town or the river source. The State of Sarawak is divided into 11 Divisions. The 11 Divisions are Kuching, Sri Aman, Sibu, Bintulu, Miri, Limbang, Sarakei, Samarahan, Kapit, Mukah, and Betong. Each Division has a JKR office in which the
Divisional Engineer (DE) heads it. Under the DE, are staffs consisting of engineers, technicians and supporting clerical staff. The waterworks section headed by a civil engineer looks after the water supply systems in the Division.

A typical scenario would be a civil engineer looking after a few water authorities that could range from a minimum of 5 to maybe 10 water authorities. Trained technicians in operation of waterworks should support him, but this is not the case. Experiences in operation and maintenance of water supply for the engineer are from on job training and from courses conducted from time to time.

The smallest treatment plant capacity is 0.66MLD and forms the majority of the water treatment plants in the State (the biggest water treatment plant supplies water to the city of Kuching with a design capacity of 300MLD). These small water treatment plants were built to supply potable water to the rural population of the State and are scattered over the State of Sarawak. The water sources are of mountain stream, surface river, peat and ground water. Twenty-one of the treatment plants use either ground or peat water source.

The water treatment process is conventional with the exception of two plants using Dissolved Air Flotation (DAF) and one plant using Continuous Membrane Filtration (CMF) process.
1.1.4 Sarawak Water Supply Consultative Committee (SWSCC)

The SWSCC is set up to develop and to come up with standard guidelines for water supply in the State. Under the SWSCC, 5 Permanent Working Taskforce Committee (PWTC) were set up. They are

i. Finance and ICT

ii. Operation and Maintenance

iii. Water Quality

iv. HR and Customer Service

v. Technical PWTC

The members of the SWSCC are drawn from the officers from the State Financial Secretary Office, Water Supply Branch, JKR, Kuching Water Board, Sibu Water Board and LAKU Management Sdn. Bhd.

Guidelines and Requirements for Water Supply Systems in Sarawak

SWSCC/DIR.1/2002WTC 1/98

The aim of this guideline is to promote uniform standard of design and practices in all Water Supply Systems in Sarawak.

Part 1 ‘DESIGN GUIDELINES AND REQUIREMENT’ is for the use of Water Supply Engineers for Water Supply Projects in Sarawak. The consultants on Water Supply Projects are to base their design criteria on these guidelines such as MWA Guidelines For Water Supply Systems and other guidelines agreed to by the relevant Water Supply Authorities.

Part 2 ‘PROCEDURE FOR SUBMITTING & MONITORING OF DESIGNS AND REPORTS’ shall apply to all works undertaken by the consultants and water supply engineers.
1.2 OBJECTIVES

While there is generally not much problem associated with the current water treatment processes and performance of water treatment plants in the State, there is however a relatively significant amount of violations for treatment plants using peat and ground water sources. The most obvious and largest number of violations is high residue aluminium. Moreover these types of water source are usually located in the remote part of Sarawak and thus supervision and operations of the water treatment plant following the guidelines and procedures is difficult. This dissertation looks into the current treatment processes and its problems and quality of treated water using peat and ground raw water including reviewing the emerging technologies for peat and ground water applicable to the State of Sarawak. Basically the objectives of the dissertation are

- Overview of the current water treatment processes and practices for peat and ground water of JKR Sarawak’s water treatment plants
- Review current best practices and developments in water treatment applicable to peat and ground water characteristics
- The quality of treated water produced from conventional process based treatment plants using peat and ground water source
- Recommendations of improvement to the current water treatment operations and processes for treating peat and ground water in the State of Sarawak.

Hypothesis

The quality of treated water from conventional treatment plants using peat and groundwater source do not meet the National Drinking Water Quality Standard 2000.
Specific Water Treatment Plants Studied.

This dissertation examines water treatment plants with peat and ground water sources only. Of the ninety (90) water treatment plants in Sarawak, twenty-two plants use peat or ground water sources (Water Supply Branch, JKR Sarawak). This dissertation investigates the water treatment processes in Sarawak for peat and ground water and the current processes and practices used for treating peat and ground water. The water treatment plants under study are listed in chapter 2, page 15. Figure 1.5 shows the locality of treatment plants under study.
1.3 OUTLINE OF DISSERTATION

This dissertation contains six chapters. Chapter 1 gives an introduction for the dissertation, the organizational set-up of the Water Supply Branch of the Public Works Department and objectives for the study including the specific area of investigation.

Chapter 2 reviews the characteristics of peat and groundwater, current treatment process, water sampling protocols, water standards and emerging technologies in water treatment including disinfection by-products. This chapter looks at the problems experienced in treatment of peat and groundwater and the initiatives taken to overcome them. The recent water sampling protocol by the Chemistry Department of Malaysia would be discussed. Water standards deal with the National Drinking Water Quality Standards 2000 (NDWQS 2000) with brief reference to WHO and other countries standards. The emerging technologies in water treatment would be investigated and discussion on the upcoming new process of membrane filtration, coagulation control system, enhancement and optimization the treatment process, and alternative disinfection.

Chapter 3 covers the methodology used for the dissertation and how the results and findings were arrived. This chapter includes limitations of the study.

Chapter 4 (Results) computes the raw data obtained from the Water Supply Branch on water quality and converts them into violation tables. This would give an overview of the quality of treated water from the water treatment plants under study. This chapter
also includes the field works done for the individual treatment plant under study and summarizes the findings.

Chapter 5 (Discussion) correlates the findings in chapter 2 and chapter 4 and integrates them together. This chapter also discusses the findings and observations from the field visit to some of the treatment plants under study. The applicability of emerging technologies and certain enhancement to improve the performance and quality of treated water are included.

Chapter 6 (Conclusions and Recommendations) gives recommendation and conclusion of the study and offers areas of future research.

Although the specific area of study is for treatment of peat and ground water, the optimization and enhancement using emerging best practices and technologies is basically the same for other types of water short of sewage.
CHAPTER 2

2.0 LITERATURE REVIEW

2.1 CHARACTERISTIC OF WATER

Natural water inevitable contains some form of impurities; the states of impurities are either in the suspended, colloidal or dissolved states. Method of treatment or removal of these impurities or the reduction to an acceptable standard like potable water depends on the states of impurities. The finer the impurities, the more costly and sophisticated the method of removal. However, sometimes the method of removal involves addition of chemicals, which could adversely alter the chemical properties and further add pollutants to the water.

The characteristics of water can be divided into physical, biological and chemical characteristics, and generally can qualify a particular water sample. Analysis can be costly and complex, thus only certain characteristics are investigated in water supply monitoring. Appendix A1 described the properties of water normally monitored for drinking water.

In Sarawak, the raw water can be categorized into mountain stream, river, peat and groundwater. Mountain stream has good quality that needs very little treatment and at most simple sand filtration can produce potable water. River water requires conventional treatment process for the production of potable water. The coagulant is aluminium sulphate while soda ash is for pH adjustment. However peat and groundwater present some problems in Sarawak due to the low pH and high colour.
Most of the peat and groundwater sources are located in the coastal region of Sarawak. Out of a total of 90 water treatment plants in Sarawak, currently only 17 plants use peat water source, 2 plants use a combination of peat and groundwater, and only 2 plants use groundwater fully. These plants using peat and groundwater source are located along the coast of Sarawak. Certain peat river source is also influenced by tidal (salt intrusion) due to their proximity to the sea usually during drought season.

This chapter deals with the characteristic of peat and groundwater. Appendix A1 gives a general review of the characteristic of raw water and the associated key parameters.

2.1.1 Peat Water

The characteristic of peat water is low pH (4.9 to 5.5), high colour (300 to 900 Hazen), low turbidity and smell similar to that of decaying vegetation. In Sarawak, these waters are surface water subject to the effects of seepage form swampy soils, characterized by high sulphide contents and iron-aluminium complexes. During dry weather, the sulphide is oxidized and when rain occurs, the sulphates are leached out into the water resulting in highly coloured water, with low suspended matter content and very low pH. Iron, aluminium, manganese and other mineral compounds in the soils also dissolve into the water. The presence of humic and fulvic acids from the decay of vegetation in this swampy areas also contributes to the high colour of the raw water (Voon and Lim, 1994).
2.1.2 Groundwater

For groundwater, the problems are high colour (500-600 Hazen) and presence of iron and manganese. The colour is caused by the presence of dissolved iron and manganese, which when exposed to the atmosphere becomes oxidized to give a brown colouration to the water (Voon and Lim, 1995).

### TABLE 2.1 WATER TREATMENT PLANTS IN SARAWAK USING PEAT AND GROUNDWATER

<table>
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<th>Water Treatment Plant</th>
<th>Source Type</th>
<th>Source Name</th>
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<td>Peat</td>
<td>Sg. Sterap</td>
</tr>
<tr>
<td>2 Lingga</td>
<td>Peat</td>
<td>Sg. Stugok</td>
</tr>
<tr>
<td>3 Spaoh</td>
<td>Peat</td>
<td>Sg. Pakasi</td>
</tr>
<tr>
<td>4 Beladin</td>
<td>Peat</td>
<td>Sg. Dumit</td>
</tr>
<tr>
<td>5 Maludam</td>
<td>Peat</td>
<td>Sg. Maludam</td>
</tr>
<tr>
<td>6 Pusa</td>
<td>Peat</td>
<td>Sg. Undai</td>
</tr>
<tr>
<td>7 Kabong</td>
<td>Ground Water</td>
<td>Ground Wells</td>
</tr>
<tr>
<td>8 Stumbin/Bijat</td>
<td>Peat</td>
<td>Sg. Stumbin</td>
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<td>9 Igan</td>
<td>Ground Water</td>
<td>Sg. Lasai Dagan</td>
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<td>10 Oya</td>
<td>Ground Water</td>
<td>Btg. Benutus</td>
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<td>11 Kut</td>
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<td>Sg. Lasai Dagan</td>
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<td>12 Kuala Balingian</td>
<td>Peat</td>
<td>Btg. Balingian</td>
</tr>
<tr>
<td>13 Beluru</td>
<td>Peat</td>
<td>Sg. Bakong</td>
</tr>
<tr>
<td>14 Kuala Lawas</td>
<td>Peat</td>
<td>Btg. Lawas</td>
</tr>
<tr>
<td>15 Kampung Tian</td>
<td>Peat</td>
<td>Sg. Mabun</td>
</tr>
<tr>
<td>16 Matu</td>
<td>Peat</td>
<td>Btg. Jemorong</td>
</tr>
<tr>
<td>17 Daro</td>
<td>Peat</td>
<td>Sg. Daro</td>
</tr>
<tr>
<td>18 Kuala Tatau</td>
<td>Ground Water</td>
<td>Ground Wells</td>
</tr>
<tr>
<td>19 Asajaya</td>
<td>Peat</td>
<td>Sg. Asajaya</td>
</tr>
<tr>
<td>20 Sebuyau</td>
<td>Peat</td>
<td>Sg. Sebuyau</td>
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<tr>
<td>21 Sebangan</td>
<td>Peat</td>
<td>Sg. Sebangan</td>
</tr>
</tbody>
</table>

**SOURCE:** WATER SUPPLY BRANCH, JKR HQ, KUCHING.
Note: Highlighted column indicates production and design capacity almost equals...
2.1.3 Key Water Quality Parameters

pH

Based on the National Drinking Water Quality Standard 2000 (NDWQS 2000), the pH value for raw water is 5.5 – 9.0 and for Drinking water is 6.5 – 9.0. The Australian Drinking Water Guideline (ADWG), the WHO guideline 1984, the Canadian, the US and the EEC recommend a pH value of 6.5 – 8.5.

The control of pH in drinking water is mainly for minimizing corrosion and encrustation in pipe system, while pH values of above 9.5 can cause bitter taste in drinking water. However above pH value of 10 and below 4 irritation of skins and eyes can occur. Chlorine disinfection efficiency is impaired above pH 8.0.

pH is closely related to many aspects in water quality and is thus an important parameter to monitor. The pH of peat water source in Sarawak is generally between 4.9 – 5.5.

Total Dissolved Solutes (TDS)

The NDWQS 2000 recommends a value of not more than 1500mg/l for raw water and not more than 1000mg/l for drinking water. The 1993 WHO guidelines indicate that a concentration above 1000mg/l may give rise to consumer complaints. The Australian, US and Canadian standard recommend 500mg/l.
TDS consist of organic salts and small amounts of organic matter that are dissolved in water and comprise of sodium, potassium, sodium, calcium, magnesium, chloride, sulphate, bicarbonate, carbonate, silica, organic matter, fluoride, iron, manganese, nitrate and phosphate (ADWG, 2000).

The removal of TDS from drinking water is difficult; reverse osmosis, ion exchange and distillation are suitable technologies for its removal. There has been no health effects specifically associated with high TDS concentrations.

**Colour**

The NDWQS 2000 recommends 300TCU for raw water and 15 TCU for drinking water. JKR’s standard is 5 Hazen Units. The Australian, US, Canadian and EEC and WHO 1993 standard is 15 Hazen Units. Colour can be measured spectrophotometrically or by visual comparator, and the unit of measurement is Hazen units. True colour is often quoted as true colour units (TCU); the numerical values are identical to Hazen Units.

Colour is mainly due to the presence of dissolved organic matter, humic and fulvic acids from soils and decaying vegetation. In groundwater, colour is caused by oxidation of iron and manganese. Colour removal can be quite costly and tedious. Removal by oxidation process using chlorine and ozone can produce undesirable by-products. In the production of potable water, if colour is high at time of disinfection, disinfection by-
products (DBPs) should be checked but might not mean that DBPs is low when colour is low.

**Turbidity**

The NDWQS 2000 recommends a value of 5 NTU and most standards in other countries recommends a value of not more than 5 NTU. Less than 1 NTU is recommended if disinfection is required, due to difficulty in maintaining adequate disinfection when turbidity exceed 1.

Highly turbid water is not necessarily a health hazard but may constitute a health risk if the suspended matter harbour microorganisms, toxic organic and inorganic compounds. Disinfection efficiency can be reduced and potential for recontamination of the water if turbidity exceeds 1 NTU.

Conventional process can produce water below 1 NTU however membranes separation will definitely produce water below 1 NTU.

**Aluminium**

The NDWQS 2000 limit for aluminium in drinking water is 0.2mg/l and this is also the standard for Australian guidelines and other countries.

Aluminium may be present in water through natural leaching from soil and rock and from use of aluminium salts as a coagulant. In the later, post flocculation effects can
occur if soluble aluminium exceed 0.2mg/l and result in formation of a whitish precipitate of aluminium hydroxide causing ‘milky water’. Aluminosilicates on the other hand is insoluble and has no post-flocculation effects.

Aluminium has been linked to conditions associated with the used dialysis unit including osteomalacia (softening of bones) and anemia. For this reason, RO or deionization is used to the feed water for dialysis, keeping the concentration to below 0.01mg/l. Parkinson Disease (PD) has been associated with aluminum intake and Alzheimer’s disease was thought to be linked to aluminium in drinking water; however recent evidence suggest that aluminium in drinking water is not related to increased risk of Alzheimer’s Disease.

The conventional water treatment process can reduce aluminium in drinking water and a well-operated treatment plant can achieve concentration of less than 0.1mg/l. There is concern of possible health effects of aluminium in drinking water and aesthetic qualities when concentration exceeds 0.2mg/l and thus the concentration should be kept as low as possible, of less than 0.1mg/l.

**Manganese**

The NDWQS 2000 for manganese in drinking water is 0.1mg/l. The ADWG also recommend similar concentration and states that it would not be a health consideration unless exceeded 0.5mg/l. Concentration of 0.1mg/l is based on aesthetic, taste and stain problems.
Groundwater water source has higher level of manganese concentration and thus water treatment plant using groundwater source has an aerator to oxidize and precipitate the manganese, which is further removed by filtration process. Beside aerator, oxidizing agent like chlorine and ozone can also be used to reduce manganese concentrations.

According to the ADWG, there is no evidence that manganese is carcinogenic and may in fact have anticarcinogenic effect. Manganese toxicity mainly resulted from inhalation of manganese dust over long periods and oral consumption is one of the least toxic elements.

**Iron**

Both the NDWQS 2000 and the ADWG recommend that the concentration of iron in drinking water should not exceed 0.3mg/l, based on aesthetic consideration. The taste threshold for iron in water is about 0.3mg/l and becomes objectionable at above 3mg/l.

Peat water source contains significant level of iron but groundwater in Sarawak experiences higher concentration than surface water. The most noticeable concern of higher concentration of iron is the staining problem though there have not been any reported cases of complains of taste due to high iron concentration in drinking water in Sarawak. However any complains of taste in water is usually due to a combination of factors\(^2\).

\(^2\) In Sarawak, the negative feedback in drinking water is mainly aesthetic factors like colour, TDS and to a lesser extends smell.
In Sarawak, groundwater source is aerated to treat iron and further removed by the conventional process of coagulation and filtration. If required, chlorine can be used to oxidize iron.

Iron is an essential trace element for humans and is used by our body in the production of haemoglobin, myoglobin and a number of enzymes (ADWG, 2000). The ADWG also quote that there is no evidence that iron induces cancer in laboratory animals and most iron salts have been inactive in tests for mutagenicity and do not induce chromosome aberrations in human cells.

Fig. 2.1 A concrete tower aerator at Kabong Water Supply. Photo by Chang KS, 2003.
2.2 WATER TREATMENT PROCESS

This chapter covers the water treatment process related to peat water and groundwater in Sarawak. Appendix A2 gives an overview of water treatment processes for normal surface water.

2.2.1 Current Water Treatment Processes for Peat and Groundwater

In Sarawak the treatment of peat water employs the conventional method with the processes of coagulation, flocculation, sedimentation, filtration and disinfection. Coagulation and flocculation occurs in the raw water channel and the clarifier; the v-notch helps in the mixing of the coagulant (the coagulants and pH correction is added just before and after the v-notch). Most of the small capacity treatment plants do not have any mixers. The coagulants used are aluminium sulphate and sodium aluminate; pH correction is by soda ash and disinfection is by calcium hypochlorite. The use of sodium aluminate and aluminium sulphate gives better floc formation which is termed double coagulation. In other surface water the coagulant used is aluminium sulphate only. Polyelectrolyte is used in some of the plants to assist in floc formation. The use of polyelectrolyte greatly assists in better floc formation resulting in better quality. However the control of the dosage of polyelectrolyte requires more attention as overdosing can a hazard to health and can cause the filters to be covered by a layer of film. The exact causes of this film are not known and when this happen, it is very difficult to clean the filters. However it is suspected that the wrong dosing position of polyelectrolyte can cause this formation of thin film on the filters. The polyelectrolyte
requires micro floc to assist flocculation and without them the process is incomplete and forms a thin film on the filters.

Sand and pebbles or different sizes are predominantly used as the filter media and only certain bigger plants have air backwash facility. The majority uses water to backwash the filters. Most of the filter backwashing system needs reconditioning and as such the filters are not effective. This resulted in the need of filter media replacement in most plants. GAC was introduced to replace the sand layer in Beluru and the most obvious changes were the taste and smell of the treated water.

The control of pH is vital for the successful treatment of peat water. However pH control is not easy due to the high organic content, colour and acidity of peat water. Peat water has little buffering capacity and is thus sensitive to metal salts coagulants.

Temperature is an important factor to consider as the light floc ‘boils’ in the heat. For this reason, most treatment plant sedimentation tanks are covered to reduce the solar heat. The ‘boiling effect reduce production throughput and quality of the settled water.

The high dissolved organic carbon (DOC) in peat water also gives concern to disinfection by-products (DBP) especially when chlorine is used. This is critical when the treatment process cannot remove the DOC in peat water and all treatment plants in Sarawak uses chlorine as a disinfectant (either in the form of calcium hypochlorite or liquid chlorine gas).
For groundwater, the treatment processes are the same as for peat water except with the addition of an aerator. The aerator is of tower type, construction of concrete with perforations at the bottom of each layer. There are different types of aerators and the spray aerator tends to be the most efficient and easy to construct. The aerator at Kabong is tower type and packed with limestones. The aerator function is to oxidize the iron and manganese in the groundwater before the normal process of coagulation and flocculation. There is no problem associated with treatment of groundwater as the aerator works very well to remove the iron and manganese. However there is occasional violation in manganese and iron in treated water.

2.2.2 Treated Water Quality

There is not much problem associated with treatment of groundwater but the same cannot be said for peat water. The major problems in treating peat water are removal of the colour, iron, aluminum, taste and odour. The conventional process of using aluminium sulphate cannot remove colour effectively in the treated water and colour presence can still be observed. This prompted the use of sodium aluminate and together with aluminium sulphate can remove colour significantly. A typical treatment resulted in reduction of colour from 300 - 900 Hazen to between 5 – 10 Hazen. However the residue aluminium in the treated water usually exceeds the National Drinking Water Standards 2000 of 0.2mg/l. This is could be due to the high dosage of aluminium sulphate and sodium aluminate adopted to remove the colour. Other factors are related to operational problems like jar testing accuracy, actual dosing and maintenance of the filters.
For groundwater, there is occasional violation in iron and manganese in treated water. The quality of the groundwater is more consistent and thus easier to monitor and treat.

2.2.3 Use of Polyelectrolyte

The high percentage of violation in residue aluminium in peat water sources prompted the Department to look at alternative chemicals. The use of polyelectrolyte was introduced and trial run was carried out at Maludam (1989, 1990), Lingga (1993) Stumbin/Bijat (1993) and Kuala Matu (1994) water treatment plant. The polyelectrolyte on trial was

- Kemfloc 912: Nonionic polyacrylamide flocculant used as a flocculant aid
- Kemfloc 133: Prodefloc AC150/2.3-SAC/powder. Polyaluminium Chloride used as a coagulant
- Accofloc: Nonionic polyacrylamide flocculant used as a flocculating aid

The intention of the polyelectrolyte is to assist better floc formation by creating heavier and bigger floc, which could not be achieved from the use of alum and sodium aluminate.

The findings of the trial runs are (Voon and Lim, 1994),

- Use of polyelectrolyte can reduce the colour to within 5 Hazen, but with no significant reduction of residue aluminum in treated water
- Generally the treatment needs high doses of aluminium sulphate (70-180 mg/l) and sodium aluminate (40-70 mg/l). In some cases soda ash (30-120 mg/l) is
required to raise the pH to 6. A good settle able floc is more readily formed with the dosing of a polyelectrolyte of around 0.2 mg/l.

The use of polyelectrolyte did not reduce the residue aluminium in treated water to within 0.2mg/l. This indicates that a compromise is necessary on the colour standard of 5 Hazen or the residue aluminum of 0.2 mg/l.

The use of polyelectrolyte is continued in some of the treatment plants in view that using polyelectrolyte can reduce the amount of sodium aluminate dosage, resulted in better floc formation and higher throughput of the plant even though the level of residue aluminium is still above the permissible level. Level of residue aluminum is lower with the use of polyelectrolyte compared to just using alum or sodium aluminate with some cost savings from chemicals usage and significant colour reduction.

The findings by Voon and Lim, 1994, indicated that there are some problems encountered in the mixing, preparation and dosing of polyelectrolyte, which are:

- Difficulty in mixing and preparation of the chemical, tendency of the polyelectrolyte to form ‘fish-eyes’ or lumps if care is not taken in adding the powder to the water
- Over-dosing causes a thin film of the chemical to form on the filters
- Effect of over-dosing of the polyelectrolyte is uncertain

The recommendation of Voon and Lim, 1995 is that peaty waters should not be considered as a possible source unless there is no alternative. This is due to large
amount of chemical required, risk of high aluminium residuals, high operation cost and potential of DBPs from chlorination.

The Department is continuing looking at other options to treat peat water including

- Dissolved air floatation system in view of the light floc,
- More effective aeration or oxidation process for raw water
- Pre-sedimentation of raw water in ponds/basin
- Use of other more effective polyelectrolyte
- Use of advanced treatment processes

2.2.4 Other Treatment Process

In 2002, a continuous membrane filtration (CMF) plant was commissioned in Pusa. The initial result of the treated water was good compared to the previous conventional process. Initially the raw water was pumped direct from an off-river storage pond and pre-treatment was not necessary. The residual aluminium and colour were well within the NDWQS 2000 permissible level. Furthermore the operation was much easier as the plant is automatic. If initial capital and operational costs are compatible with other processes, this could prompt the replacement of conventional processes with membrane filtration for peat water short of looking at alternative source. However after the first year of operation, the cost increases dramatically due to more frequent CIP (cleaning of the membranes) in view of changes in raw water quality. In order to solve this problem, pre-treatment was introduced. There is no violation of treated water and the quality is better than other treatment plant using peat water source.
2.2.5 Use of other Coagulants

The most recent trial test was the used of Liquid Aluminium Chlorohydrate (ACH), and Liquid Polyaluminum Sulphate (PAS) in Asajaya, Pusa, Betong and Debak Water Supply. There is indication that use of ACH or PAS has an improvement on the residue aluminium of treated water. It is still too early to conclude which is the best coagulant as longer trial run period is necessary. The objective is to do away with double coagulation, reduce chemical dosage, reduce residue aluminium without compromising on the quality of treated water. Moreover sodium aluminate is very expensive, about 10 times the cost of alum.

2.2.6 Use of Coagulant Control System

The Department have yet to test coagulant control equipment like the Streaming Current Monitor (SCM) although there has been suggestion to include SCM in the Mukah new treatment plant. The SCM might assist in improving dosing accuracy of coagulants and coupled with a pH meter could be advantages. The SCM monitors the coagulation in real time thus ensuring that the reaction is at optimum.

It is without doubt that pH plays an important role in determining optimum coagulation and flocculation. The choice of coagulant depends on the pH range of the raw water and the working range of the coagulant. This range of pH must be compatible, without that whatever control system is used would not be of much help.
2.3 WATER SAMPLING PROTOCOLS

There is a sampling protocol from the Drinking Water Quality Monitoring Program prepared by the Public Health Branch, Engineering Services Division of the Ministry of Health, Malaysia. The protocol was prepared with the cooperation of Water Section, Public Health Division of the Chemistry Department, Malaysia.

The Drinking Water Quality Program (DWQMP) was first introduced in 1984 and subsequently in 1996 Multiple Sampling protocol was introduced. The main objective of the protocol is to ensure that the samples send for analysis contains the correct preservatives and sampled using the correct techniques in order to obtain actual, consistent and reliable results.

The DWQMP set out the monitoring schedules for sampling for all the treatment plants in Sarawak. The DWQMP is a national program and the only difference with the Sarawak and the Peninsula program is in Sarawak, JKR’s attendants collect the water samples while trained public health staffs of the Ministry of Health collects the Peninsula samples.

Appendix A3 contains the details of the sampling protocol. It is important to note here that most of the ground staffs involved in water treatment and samples collection are unaware of this protocol. The latter chapter would discuss more on this shortcoming.
Besides the sampling protocol, JKR has flow charts on Water Quality Analysis, Water Sampling and Production of Water Supplies. These flow charts are attached in Appendix A3.
2.4 WATER STANDARDS

In 1983, in response to the need for a realistic and appropriate set of guidelines regarding safe and potable water supply for Malaysia, the National Guidelines for Drinking Water Quality 1983 was published. This Guideline was done under the guidance from World Health Organization, Western Pacific Regional Centre for the Promotion of Environmental Planning and Applied Studies (WHO/PEPAS). The local representatives were from Public Works Department (PWD), Department of Chemistry (DOC), and Department of Environment (DOE) with the Drinking Water Quality Surveillance Unit, Engineering Services Division, and Ministry of Health Malaysia as the lead agency. This guidelines was revised in 1990, and further reviewed in 1998 and the latest revision to date is the National Drinking Water Quality Standards 2000 (NDWQS 2000).


The aim of the National Drinking Water Quality Standards 2000 is to set limits to constituents that may be present in water which may be hazardous to health or objectionable to the physical sense of the consumer.
The NDWQS 2000 is applicable to all water intended for human consumption and includes drinking water from all public water supplies, tanks supplies, and water used for bottled and ice manufacturing.

The raw water quality criteria included in NDWQS 2000 is intended to assist users in determining the appropriate treatment needed for raw water in order to produce water that will conform to the drinking water quality standards. If a raw water source has quality that does not conform to the recommended raw water quality criteria, then appropriate action shall be taken to identify and overcome the problem to allow for continued operation of the conventional treatment. Special treatment should only be considered as a last resort.

This NDWQS 2000 covers the procedures recommended for source protection, treatment of water, sanitary survey, monitoring, record keeping, etc., for the relevant authorities as means of achieving the drinking water quality standards.

The National Drinking Water Quality Standards 2000 consist of three sections, viz.,

1. Definition of Terms
2. Quality requirements
3. Recommended procedures

In section one, the definition of the various terms used in the Standards are described, while in section two, the requirements for both raw and drinking water quality are described, including the units used for the parameters. Section three covers the recommended procedures to achieve the drinking water quality standards. The topics in
this section include protection of source, preventive measure in security of facilities, water treatment requirements, sanitary survey requirements, monitoring program requirement and design, reporting of results, record keeping and data evaluation, remedial action procedures (for violations of standards), and medical examination of waterworks staff.

The values described in NDWQS 2000 are not regarded as legal standards, but hoped that judicious use of these standards and criteria will result in the provision of a safe and wholesome drinking water to the consumer.

The NDWQS 2000 is in Appendix A4.

The NDWQS 2000 is figure or number based, unlike the Australian Drinking Water Guideline, which is a rolling standard. The ADWG is constantly updated especially upon new findings and discoveries.
2.5 EMERGING TECHNOLOGIES IN WATER TREATMENT

There are many emerging technologies and best practice in the water treatment. However, this paper would short list emerging technologies and best practices for the treatment of water especially for peat and groundwater water. Both high and low technologies and some treatment optimization suited to State of Sarawak are included, with due consideration given to the level of competency of the plant operators and the maintenance ability of the support staff.

The emerging technologies would be

- Membrane Technologies
- Ion exchange
- Polymeric Flocculants in Water Treatment
- Ultra-violet Disinfection
- Microbiological test kids
- Treatment plant optimization with automation
- Alternative Disinfection

In view those membrane technology is the emerging technology in the industry; brief overviews would be presented. Membrane technologies in water treatment is fast becoming very competitive compared with other water treatment options due to the ease of operations and the development of cheaper methods in membrane manufacturing. This coped with the small site set-up requirement and avoidance use of hazardous chemicals and minimum associated disinfection-by-products make it a much-preferred option to conventional and other options in water treatment.
2.5.1 OVERVIEW OF MEMBRANES PROCESS (Smith, 1995).

The use of membranes processes in water and wastewater treatment is increasingly applied since the development of reverse osmosis as an economically viable desalination process in 1960. At present, there exist many large installations using membranes processes throughout the world either for treatment of potable water, wastewater or food and dye industries. Membranes processes can be classified into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) with decreasing pore sizes of the membranes. Depending on the contaminants to be removed, each process has its own advantages and uses. These processes all involve the application of pressure to the feed water, and a porous membrane, which acts as a barrier to particles, bacteria, virus, toxic organic solutes or dissolved salts, depending on the porosity of the membranes used. The feed water flows across the membrane surface preventing the membranes from blocking and keeping the output from declining. This process results in two streams of water, the filtrate and the concentrated feed water. MF and RO are more commonly applied to treatment of potable water while NF and UF are more suited to special removal of particular contaminants.

Microfiltration (MF)

Microfiltration (MF) is a process that removes particulate material from the feed water including bacteria, colloids and some virus particles. Membranes properties are characterized by the diameter of the pore sizes, which can be, varied during
manufacturing. MF membranes of 0.1\( \mu \)m are commercially available. MF is widely used for water and wastewater treatment.

**Ultrafiltration (UF)**

Pore sizes of ultrafiltration (UF) membranes are smaller than MF membranes and thus could remove much smaller solutes from feed water (proteins down to a molecular weight of about 1000 Daltons). In water and wastewater treatment, UF is used for the removal of colour and virus from surface waters for potable water supplies. Commercial UF membranes are specified by the molecular weight cut-off (MWCO).

**Nanofiltration (NF)**

Nanofiltration NF, a more recent developed technology is between UF and RO in terms of effective pore size (nanometer range). For uncharged solutes, the separation mechanism is similar to MF and UF, however for charged molecules, electrostatic forces interact. This result in divalent ions being more strongly rejected than monovalent ions and salt rejection is dependent on their concentration in the feed water. NF membranes are tailored to specific rejection of particular solutes such as sugar or sodium chloride at a given concentration as well as a product water flux at a given applied pressure and temperature.

**Reverse Osmosis (RO)**

Reverse Osmosis (RO) is the tightest membrane and essentially only water molecules can pass through, although dissolved gases and some low molecular weight hydrophilic
organic solutes can also permeate through with the product water. RO can thus be used to produce purified water from saline or contaminated supplies and to concentrate the solutes in a given wastewater (Smith, 1995).

The product water flux (L/m²/d) is dependent on the applied pressure and osmotic pressure of the feed solution. RO is specified in terms of water flux and salt rejection (of 1% NaCl solution) at a given applied pressure. RO is widely used for the production of potable water from brackish and seawater.

**Pretreatment required**

The performances of membrane process can be severely affected by contaminants in the feed water, which form deposits on the membrane surface. Fouling material on the membrane surface reduce the output of the product water. Fouling material can be colloidal and particular matter in suspension or precipitates formed at the membrane surface. Coagulation-filtration is usually used to reduce colloidal and particulates to acceptable levels. Precipitation can be prevented by addition of scale inhibitor and pH adjustment to feed water. Oxidizing agents like chlorine affects the long-term stability of the membrane. Cellulose acetate membranes are tolerant to low levels of chlorine but polyamide and composite types are totally intolerant to event trace levels of chlorine. Sulphite addition and use of GAC can remove chlorine but adds cost to system.
Membrane Materials

Majority of membranes are made from synthetic polymers, cast from solution into flat sheets with an asymmetric structure, or extruded as hollow fibers. Composite membranes are more complex and expensive with the active layer coated or formed in-situ on the surface of a pre-formed micro porous film. Lately a range of ceramic-based membranes has become available for MF. These membranes can be operated at high temperatures, and cleaned with aggressive chemicals but more expensive than synthetic polymers.

Advantage of Membrane Processes

In water and wastewater treatment, membranes processes are attractive due to

- modest energy requirement,
- performance are not affected by shock loadings of contaminants of feed water,
- equipment is compact compared to conventional processes,
- easily scaled-up by adding further units.

Limitation of Membrane Processes

Fouling of membrane surface reduces output water and hence some form of pretreatment is required. This is particular true for RO, which requires prefiltration in most cases. Temperature, pH limitation and chlorine intolerant (at low levels) are some of the limitation of membranes.
2.5.2 MICROFILTRATION IN WATER TREATMENT (MacCormick, 1995)

Continuous Microfiltration (CMF) is a patented technology of Memtec Limited. According to Memtec Limited, there are over 350 CMF plants in 14 countries on applications ranging from high purity water to primary treated sewage. CMF system uses a polypropylene microfiltration membrane capable of removing bacteria and viruses.

CMF systems

The CMF systems consist of the filtration membranes and the patented air backwash. Filtration membranes are hollow, porous, polypropylene fibers with a nominal diameter of 0.6mm with an internal tube diameter of 0.3mm. The walls of the fibers are porous with a nominal pore size of 0.2µm (smaller than the smallest bacteria). The membrane removes bacterial and most human viruses, which although smaller but attached to host particles and thus removed along with the host. The fibers are assembled into modules each containing about 12,000 m of fiber. Filtration is from fiber surface through wall into the center tube. Contaminants accumulate on the outer surface of the fiber wall while clean water passes through and out each end of the tube.

The patented air backwash becomes operational once the differential pressure across the fiber reaches a pre-set level and filtration stops and high-pressure air is injected into the fiber tubes (similar to air backwash of sand filter in a conventional process). The air blasts through the fiber wall dislodging accumulated sediment on the outer surface.
This is followed by sweep of feed water to flush dislodged sediments away. This patented air backwash overcomes the usual rapid decline in flow rates typical of non self-cleanable microfiltration systems.

**CMF Capabilities**

CMF has been widely used for treatment of surface water in Australia. It is claimed to able to achieve a filtrate turbidity of 0.3 NTU under high and variable feed turbidity. There is evidence to show that CMF can remove human pathogens such as *Giardia*, *Cryptosporidium*, faecal coliform bacteria, bacteriophage and human viruses. It is capable of 6 log removal of faecal coliform. CMF thus can also be a disinfection process though some form of disinfectant is usually added to filtrate to maintain the level of disinfection. Besides that, CMF can also remove algae cells, and up to one-third of true colour without the need of chemical coagulants.

**Conventional Treatment Versus CMF**

The shortcomings of conventional treatment listed in table 2.5 are not serious if the plants are constantly monitored and where raw water quality changes are not too erratic. In Sarawak this would not be much of a problem for large plants as there would be sufficient monitoring and contingency procedures in case of raw water quality changes. However in small plants where experienced operators are lacking and with minimum monitoring, this could lead to significant operational difficulties and violation of drinking water. The operational effectiveness and simplicity of CMF are an
advantage especially for small remote plants with low turbidity and highly coloured water.

Table 2.2 Conventional Treatment vs CMF (MacComick, 1995)

<table>
<thead>
<tr>
<th>Conventional Treatment</th>
<th>CMF</th>
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<tr>
<td>Rely on chemical coagulants to achieve effective filtration, and pH correction is necessary. Skills are required to administer correct dosage of coagulants to avoid overdosing; besides storage and maintenance of dosing facilities. Constant operators attention or automation monitoring required. Disinfection relies on chlorination to kill microorganism. Effectiveness of disinfection relies on media filter efficiencies. Media filtration is not an absolute barrier; heavy shock loads or poor backwash and filter cleaning can cause leakage. Where blue-green algae occurs in source water, coagulants might increase the release of cyanobacterial toxins by rupturing the algae cells.</td>
<td>CMF is not a chemical flocculation process and thus not handling of coagulants. CMF is a barrier filter thus provides consistent filtrate through positive mechanical retention of suspended solids and microorganism despite variable feed water. CMF being a physical barrier, microorganisms larger than 0.2µm are filtered out. It thus acts as primary means of disinfection. CMF followed by chlorination provides double disinfection. CMF removes algal cells softly without releasing toxins into the filtered water.</td>
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Besides the advantages of CMF over conventional process in table 2.5, CMF system also offers modular construction. This offers easy upgrading of treatment capacity with minimum space requirement. It is also suited for remote installation where the modules are built in container format.

The increasing concern of growing occurrence of Giardia and Cryptosporidium parasites in filtered water gives the CMF system an advantage over other system as the removal of such parasites and bacteria is almost 99% (MacComick, 1995). Furthermore, CMF system claims that the chlorine contact time can be reduced to one quarter of the conventional contact time.

**Recommendations**

The CMF process is suitable for the treatment of peat and groundwater in Sarawak. Some form of pre-treatment of the raw water would ensure a more effective performance of the CMF system. The CMF system can be used as a compliment to conventional treatment process to polish the final product water. CMF system was commissioned in Pusa in year 2002. There is marked difference in water quality. However it is used as a stand-alone and not as a compliment process to the conventional treatment plant.
Chapter 2 – Literature Review

Figure 2.2 CMF plant at Pusa Water Supply

Figure 2.3 Raw, pre-treated and treated water using CMF process


2.5.3 REVERSE OSMOSIS TECHNOLOGY

Reverse osmosis (RO) is the process treatment widely used to treat brackish water and seawater, and the recovery of industrial wastewater. In Australia, there are over one thousand RO plant installations and majority is used to treat brackish waters (Fergus, 1995). RO is a widely recognized and established technology which has been used extensively in many areas including the production of premium bottled water and ultra-clean water for the electronics industry. RO technology is used by Singapore to recycle domestic wastewater as indirect potable water and is termed as NEWater (www.pub.gov.sg/NEWater). RO application in Australia is dominated by applications in remote regions for the supply of water for domestic consumption (Fergus, 1995).

**Application of RO Technology (water supply)**

There are a number of innovative RO technology applications for water supply around the world. This section would discuss the applications in Australia and Singapore for treatment or pre-treatment of water for domestic consumption.

**Australia**

The largest potable water RO desalination system is in South Australia (Fergus, 1995). The Roxby Olympic Dam Project and the mining townships of Leigh Creek and Coober Pedy uses RO technology for their potable water needs. Their water source is groundwater. In Leigh Creek, the source water has high TDS (up to 7500ppm), hardness, sulphate, alkalinity and silica in brine. Similar problems were experienced at the other two projects. The use of RO systems managed to solve the water needs and
resulted in acceptable operating cost without the use of large hazardous quantities of chemicals and simpler operations.

In other parts of Australia, the use of RO systems is fast becoming the solution or preferred treatment option as most parts of Australia rely on groundwater or brackish water. This is due to the simpler operations and high quality filtrate of RO systems. Furthermore majority of Australian populations reside in the coastal fringe and thus the ultimate long-term source of water could be desalination of seawater.

Singapore

Singapore NEWater is a product from multiple barrier water reclamation process. The multiple barrier consist of microfiltration (MF), followed by reverse osmosis (RO) and finally by disinfection utilizing ultra-violet (UV). This multiple barrier system is claimed to produce water of even higher standards than the portable water supplied by Public Utilities Board (PUB). However due to psychological barrier associated with the idea of consuming reclaimed water, this NEWater is mixed to the raw water in the reservoir as a supplement of raw water.

Singapore receive the Award of Excellence by the National Water Research Institute (NWRI)\(^3\), USA for the NEWater Demonstration Plant Project and recognition of PUB’s outstanding contribution to MF technology on 4 May 2002 at the Microfiltration III Conference at Costa Messa, California, USA.

\(^3\) NWRI is a prestigious water research institute based in USA to promote the protection, maintenance, and restoration of water supplies and aquatic environments through the development of cooperative research work.
Beside the NEWater project, Singapore is also embarking on the desalination projects to treat seawater as an alternative source. However desalination need more energy due to the high salt content and thus at present not competitive compared to other options.

**Recommendations**

The RO process is suitable to be used for treating peat and groundwater source in Sarawak. Like the CMF process, some form of pre-treatment would ensure that the RO process is effective in terms of filtrate volume. However the process is quite expensive compared to other treatment options at present. The present raw water quality does not warrant the use of RO process as yet as the process is expensive. However with increasing innovative manufacturing process, the cost of the membrane might reduce and thus making the use of RO competitive in the very near future.
2.5.4 ION EXCHANGE

Dissolved Organic Carbon (DOC) has a major impact on treated water taste and odour, colour, appearance, coagulation and disinfection-by-products formation (DBP). The DOC effects on treatment of drinking water include

- reacting with disinfectants, which increases chemical demand and disinfection by-products,
- reacting with coagulant causing slower and less effective flocculation and thus increasing coagulant demand,
- acting as a food source for micro-organism, resulting in bacterial re-growth in distribution systems,
- interfering with the performance of activated carbon by competing with targeted compounds for active sites,
- reducing the capacity of membranes filtration by fouling.

Thus the cost effective management of DOC presence in water source is one of the key challenges facing current water treatment industry. Conventional treatment process cannot remove DOC effectively and involved complex treatment processes and significant increase in operational costs.

Orica Watercare together with CSIRO Division of Molecular Science and South Australian Water Corporation developed a simple and revolutionary process that incorporates the MIEX®DOC resin for the removal of dissolved organic carbon from potable water. The MIEX®DOC resin is a patented high capacity ion exchange resin, which includes a magnetic component. The combination of this magnetic resin with a
unique continuous ion exchange process offers a cost effective and environmental friendly removal of DOC. The MIEX<sup>R</sup>DOC resin is capable of

- cost effective removal of dissolved organic carbon,
- significant reduction in disinfection by-products,
- colour reduction,
- significantly reduced coagulant doses and chemical sludge volumes,
- reduction of chlorine demand in disinfection

**MIEX<sup>R</sup>DOC resin systems**

The MIEX<sup>R</sup>DOC resin system developed by Orica Watercare is unlike conventional ion exchange processes, in the sense that the overall ion exchange capacity is continuously maintained; thus producing consistent water quality with DOC controlled at a predetermined level. It hence offers a continuous and flexible process that can adjust to wide variations in raw water quality.

MIEX<sup>R</sup>DOC resin is dosed in a stirred contactor vessel and with a much smaller bead size than conventional resin beads; allowing for rapid DOC exchange in the contactor vessel. Small resin concentrations are only required to achieve DOC removal because of the efficient mass transfer in a uniformly mixed contactor. The resin suspension then passes to a separation stage where the resin is recovered and recycled. A magnetic component is dispersed within the resin bead structure so that when passed to a settler, the fine resin beads rapidly agglomerate into larger, fast settling particles. Most of the settled resin is recycled to the front of the process, while a small side stream is removed.
and sent for regeneration. The MIEX<sup>®</sup>DOC resin is regenerated in brine solution where attached organics are substituted for chloride ions, producing a concentrated stream of natural organics. In view that the process is continuous, the MIEX<sup>®</sup>DOC resin process can be used to treat raw water either at the start of the treatment processes, or at the finishing step at the end.

**Recommendations**

The MIEX<sup>®</sup>DOC resin system is a good compliment to the conventional treatment process in treating peat and groundwater, which contain high DOC, colour, odour and unpleasant taste. The removal of DOC is important due to the many detrimental health effects associated with it. This process is environmental friendly as the resins are recyclable and no harmful chemicals are used. Further information on the MIEX<sup>®</sup>DOC resin process/system can be obtained form website location at [www.miexresin.com](http://www.miexresin.com) or at Orica Watercare, Gate 4, Stanford Street, Ascot Vale, Victoria 3032, Australia.
2.5.5 POLYMERIC FLOCCULANTS IN WATER TREATMENT

Polymers are used as an enhancement to the conventional water treatment process of coagulation and flocculation. The polymers are usually referred to as coagulant aids. Polymer is added after the primary coagulant, which is a metal salt or alum. The polymer aids to enhance floc growth making the process more efficient and extend filter usage. Certain polymers can be used as a primary coagulant too.

In choosing the correct polymer, the characteristic of the source water needed to be considered, especially the nature of the organic impurities. This applies particularly to dissolve organic compounds, which are capable of polyelectrolytic behaviour. Dissolved organic carbon (DOC) in natural waters is formed by the biological degradation of organic life substances. The compounds present in DOC may include amino acids, fatty acids, phenols, sterols, sugars, hydrocarbons, urea, porphyrins and polymers (polypeptides, lipids, polysaccharides and humic substances) (Bolto, 1995). The mechanism of interaction of soluble polymers with the DOC and other impurities are described in more detail by Bolto, 1995; Thurman, 1985; Beckett, 1990; and Dixon, 1990.

Polymers maybe categorised by charge type, namely cationic, anionic, or nonionic. The charge density (CD) maybe high (50-100%), medium (25%) or low (10%) and molecular weight (MW), is usually defined as high (>10^7), medium (10^5-10^6) and low (10^4-10^5). There are restrictions on the use of certain polymers for water treatment and vary from country to country (Bolto, 1995).
Polymers as a Primary Coagulant

In water treatment process, a cationic polyelectrolyte of high CD and a low to medium MW can be used instead of a metal salt as a primary coagulant. It acts as a destabilizing agent via a charge neutralization-precipitation mechanism. The cationic polymer can eliminate the negative charge on the turbidity particles and humic substances, so that particles agglomeration is facilitated. The advantage is smaller sludge volume produced; less pH dependent and less dissolved salt required (Bolto, 1995).

Polymers as Coagulant Aids

Most polymers are used as a coagulant aids where it is added after the primary coagulant (alum). In this case, it acts as an aid to increase floc size; thus decreases settling time. After coagulation by the organic salt, the particles produced may have a slightly positive or negative charge depending on the dose of metal salt and type of raw water. If slightly positive charge, an anionic polymer of low or medium CD and high MW is appropriate and should results in substantial reduction in alum dose. On the other hand, if the coagulated solids have a slightly negative charge, a cationic polymer with low CD and high MW is effective. Carrying out jar tests can test the suitability of the chosen polymers.

Recommendations

The removal of DOC from water is essential for safe disinfection and minimized formation of disinfection by-products. The use of polymer can increase the
effectiveness of DOC removal as it is less pH dependent; due to more efficient coagulation and flocculation, resulting in savings of coagulants and increased throughput. Bolto, 1995 summarizes the benefits of using polymer:

- process is less pH dependent,
- 10% w/w of the dose of inorganic reagent is needed,
- less dissolve salt is added,
- lower usage of other chemicals,
- solid-liquid separation rate is increased,
- filter run times are extended,
- smaller sludge volume,
- wider range of waters can be treated

The disadvantages being:

- possibly higher operating costs which have to be justified by the above benefits,
- each type of water may need its own particular polymer
- overdosing can destabilize a dispersion, as can happen also for inorganic reagents,
- toxicity implications of residuals in potable water production,
- feed solutions of polymer may biodegrade

The use of polymers on water with high DOC involves complex reaction and thus requires trial and error to choose the correct types of polymers. The use of jar test would be the best option for initial polymer decision followed by on site trials. In
Sarawak, peat water sources usually involve the usage of polymer to reduce colour and taste, but overdosing could have health implications and filter blockage.
2.5.6 MICROBIOLOGICAL TEST KIT (H2S paper Strip Method)(Pillai \textit{et al.}, 1999)

One cheap, quick and simple bacteriological tests for faecal coliforms in drinking water is the H2S paper strip method. This simple and cheap method is developed by Pillai \textit{et al.}, 1999. The standard methods for detection of bacteriological contamination are the Most Probable Number Method (MPN) and Membrane Filtration Technique (MFT), which is expensive and require laboratory and technical support. In Sarawak logistic and transportation of water samples to a laboratory is difficult especially for remote water treatment plants. Getting the bacteriological water sample to the laboratory in time (within 24 hours) and preserving the sample at 4°C is a concern. Thus using the H2S paper strip method can be a cheaper alternative method to sending the samples to laboratory for the monitoring of bacteriological contamination of drinking water in remote water treatment plants.

The H2S is developed as an on-site microbial water testing method based on the detection of hydrogen sulphide producing bacteria. (Human faeces contain high concentration of sulphate reducing bacteria). This method has good correlations with the standard method. The test sample water turning black indicates bacterial contamination.

This H2S paper strip method can detect contamination down to 1 CFU/100ml of Coliform Bacteria and a working temperature range of 20°C to 44°C. Temperature range between 28°C to 37°C gives faster result; at 37°C giving the fastest result with
only 18 hours of incubation. No constant temperature incubator is required if the room temperature is within the stated range.

**Preparation of H$_2$S bottle**

H$_2$S medium is prepared by dissolving peptone (20g), di-potassium hydrogen phosphate (1.5g), ferric ammonium citrate (0.75g), sodium thiosulfate (1g) and teepol (detergent) (1ml) in 50ml of tap water. The addition of L-cystine could improve the rate of blackening.

![Figure 2.4 H$_2$S Test Kit](image1) ![Fig. 2.5 Black colour indicates contamination](image2)

**Recommendations**

The H$_2$S method is recommended as a compliment to the sending of samples to the laboratory for bacterial monitoring at remote water supply. It is a cheap and simple method and is should be utilized especially when quick confirmation is required to check on contamination.
2.5.7 DISINFECTION ALTERNATIVES

Disinfection is the final process to ensure that drinking water is safe by decreasing the likelihood presence of disease-causing organisms in potable water. Chlorine is generally used as a disinfectant but lately because of the potential carcinogenicity (THM and others), care has been taken in using chlorine and thus alternatives disinfectants are considered. This is especially true when water has high organic content. The most appropriate choice of disinfectant will depend on the local conditions and OSHA regulations and will usually involve compromise. Because of the toxic nature of most disinfectant, decision on which disinfectant to use would involve management, staff and the public in the vicinity for big plants. The management has to draw up emergency response program including fail-safe devices, staffs have to be trained on operation and maintenance including personal protective gear, the local hazard team have to be briefed of the facilities and the public too has to be informed. The ADWG Procedures Sheet 1 gives a very comprehensive description on the properties of ideal disinfectant and requirements for effective disinfection. The major factors in evaluating disinfectant alternatives are effectiveness, use-cost, practicality, pilot studies requirement, regulatory requirements and potential adverse effects (Spellman, 1999). Spellman also illustrates the use of matrix for choosing the disinfection alternatives. The ADWG Procedures Sheet 1.1 also describes the choice of disinfectant.

The common disinfection alternatives are

1. chlorine
2. chloramination
3. hypochlorination
4. chlorine dioxide
5. bromide chloride
6. potassium permangante
7. ozone
8. ultraviolet light (UV)

Spellman, 1999 describe in detail the consideration on choosing the above disinfection alternatives which I think is very informative and offer good resource to decision in choosing disinfection alternatives.

Subsequent are some important facts on the above disinfection alternatives

**CHLORINE**

The use of chlorine as a potable water disinfectant was introduced early in the 20 century and still remains the major chemical in use today. This is due to its excellent bactericidal properties requiring short contact times. In water, hypochlorous acid (HOCl) is formed which is a strong disinfectant can disassociates to form hypochlorite ion (OCl) at higher pH, a less effective disinfectant. Chlorine is widely used because of its suitability and easy applicability for all sizes of plant in the form of gas or as hypochlorite (calcium hypochlorite powder or sodium hypochlorite solution). The contact time for chlorine is usually 30 minutes depending again on the pH, temperature,
dosage and quality of treated water. Drinking water guidelines usually recommends a residual level of 0.2mg/l in the distribution system. However maintaining residual chlorine level is not easy and usually ammonia is added for this purpose (ADWG Procedures Sheet 1.2)

The main drawback of chlorine is the formation of disinfection-by-products especially trihalomethanes (THM) and its toxicity-ness when in contact. Usually big plants are installed with fail-safe devices and scrubber to neutralize any chlorine gas leak.

**CHLORAMINATION**

Chloramines are formed when chlorine and ammonia are added to water. The reactions are

\[ \text{NH}_3 + \text{HOCl} \rightarrow \text{NH}_2\text{Cl} \text{ (monochloramine)} + \text{H}_2\text{O} \]

\[ \text{NH}_2\text{Cl} + \text{HOCl} \rightarrow \text{NHCl}_2 \text{ (dichloramine)} + \text{H}_2\text{O} \]

\[ \text{NHCl}_2 + \text{HOCl} \rightarrow \text{NCl}_3 \text{ (nitrogen trichloride, trichloramine)} + \text{H}_2\text{O} \]

Dichloramine is a stronger disinfectant than monochloramine, but is less stable with a strong odour. Trichloramine has even more offensive odour. Chloramines are not as strong as chlorine as a disinfectant but it is better in maintaining a residual in distribution than chlorine. Like Chlorine, it is easy to apply and suitable for all sizes of plants. The ratio of chlorine to ammonia is usually between 3:1 to 5:1 and pH of 7.5 to 8 ensuring the formation of chloramines. The contact time is longer and requires up to 1.5mg/l concentration to be effective as it is a weaker disinfectant than chlorine.
Chloramines produces considerably lower concentrations of THMs and other chlorinated byproducts than chlorination. (ADWG Procedures Sheet 1.3)

**CHLORINE DIOXIDE**

Chlorine dioxide is usually generated on site by acid treatment of sodium chlorite and is more effective than chlorine. Its excellent oxidizing ability reduces taste, colour and oxidizes iron and manganese complexes. It is suitable for small to medium size plants and mainly use as a preoxidant to control taste and odour, remove iron and manganese and more recently to remove THM and TOX precursors. Contact time and dosage is similar to chlorine and is a moderately persistent residual. Byproducts include chloride ions, chlorate ions and residual chlorine dioxide (ADWG Procedures Sheet 1.4)

**OZONATION**

Ozone is generated by passing an electric discharge through clean dry air or oxygen and is a very strong biocide and oxidizing agent, very effective in reducing colour, iron, manganese, taste and odour. It is suitable for medium to large plants and is more expensive than chlorine with low solubility in water. The technology involved for ozonation is complex and still developing. Above pH 8, ozone is unstable and coupled with its low solubility in water residual ozone cannot be maintained in the system. The byproducts generated are brominated THMs but usually in lower concentrations than chlorinated THMs (ADWG Procedures Sheet 1.5).
ULTRAVIOLET IRRADIATION

Ultraviolet light (UV) is generated by low-pressure mercury lamps and has a minimal effect on the chemical composition of water, thus no danger of overdosing and is sometimes contrived as a safety factor. It is suitable for small to medium plants and technology required is fairly simple and controls for this process are being developed. The quality of water to be irradiated is important as turbid water reduce the effectiveness of UV radiation. The units need to be maintained regularly and byproducts are minor due to the low intensities required. The major draw back is no residual disinfection (ADWG Procedures Sheet 1.6).

Bromine chloride and Potassium permanganate are not used in large-scale plants. They can be use in small-scale installations and are less commonly used in water treatment plants as a disinfectant.

Recommendations

Chloramines disinfection is recommended in lieu of chlorine. Even though the disinfection power of chlorine is better than chloramines, the properties are similar however chloramines are more stable at higher pH (treated water have pH of 7.8 to 8.5) and have far superior residual retention in the distribution system. Chlorine at higher pH forms hypochlorite ions which is weak and have less residual level.

The dosing of chloramines is recommended to be just before the filter thus giving longer contact times with a ratio chlorine to ammonia of 4:1. This is the practice of
Kuching Water Board in an effort to have better residual disinfection level in distribution and reduce the risk of DBPs (esp. THMs).
2.6 DISINFECTION BY-PRODUCTS

Chlorination of drinking water to prevent disease became one of the most widely practiced public health measures in the twentieth century until the discovery of disinfection by-products (DBPs) in the mid 1970s, which affected the confidence in chlorine. Research into DBPs is complex and expensive and thus a balance is required in controlling DBPs without incurring excessive cost. Of utmost importance is striking a balance of controlling DBPs without compromising on disinfection and the meeting of standards. With continued development in treatment techniques, it may be possible to renew the standards set to be more stringent taking into account of costs.

Chlorine appears to produce the largest number of halogenated by-products. Chloramine produced the same types of halogenated by-products as chlorine, but fewer in number and lower in concentration than chlorine. Ozone produced no halogenated by-products, and chlorine dioxide very few. Non-halogenated DBPs are quite similar for ozone, chlorine, chlorine dioxide and chloramines indicating a similar mechanism of oxidation, with regard to the formation of these by-products (Richardson et al., 1999).

Haley, 1999, did an investigation into replacement of chlorine with chloramine and overall results were encouraging. The concern was infringements of nitrite Prescribed Concentration or Value (PCV), which could be minimized by the careful control of ammonia to chlorine ratio. The objective of achieving reduced microbiological activity with limited impact in terms of compliance with the nitrite standard was successful.
Advanced water treatment process (AWT) developed by Thames Water Utilities Ltd., incorporating the use of ozone and granular activated carbon (GAC) into the conventional process were used to reduce background organics and DBPs. The filters use the patented GAC sandwich™, which consisted of inserting a layer of GAC within a slow sand filter sandwiched between layers of sand. The filter operates in the same manner except the GAC is periodically removed, regenerated and re-laid. This gives the benefits of a biological slow sand filter as well as the adsorption of the GAC. Chloramine was use in the final disinfection to limit the amount of free chlorine in the distribution (in the absence of free chlorine THMs should not form). The findings are

- GAC sandwich has proved to be more effective at organics removal than conventional slow sand filters even after six years of operation
- Ozonation has been shown to reduce concentrations of complex organics by forming simpler compounds which are removed by a further biological step that in turn reduce formation of total trihalomethanes
- Ozonation results in formation of predominately brominated THMs as opposed to chlorinated THMs at conventional plant. Dichlorobromomethane has the greatest health risk, but its formation is more limited after ozonation
- The combination of ozone and GAC sandwich in the AWT process is effective at meeting customer demands and legislation by reducing pesticide, organics and TTHM concentrations

(Shurrock et al, 1999)
The findings by Cable, 1999 indicate that ozonation combined with slow sand filtration does have a significant effect on reducing THMs in distribution.

The study by Littlejohn, 1999 conclude that nanofiltration is a viable method for the effective control of THM concentrations in small coloured water supplies.

The Dutch after many years and strategies finally developed the treatment strategy for the 21st century, which can be summarized as,

- Total avoidance of chlorination,
- Disinfection by a combination of process that is ozonation (balancing the risk of pathogens and DBPs) and membrane (biological and physical) processes.

(Kruithof, 1999)

It seems that to have zero DBPs is not quite possible unless disinfection is not used. However there must be a balance between water free from pathogenic micro-organism and DBPs. In fact from customer’s point of view, safe, pleasant and affordable water free of pathogenic organisms are the highest priority and not DBPs, probably due to public’s level of knowledge on DBPs (Breach, 1999).

**Recommendations**

I support the Dutch treatment strategy of avoidance of chlorine, using a combination of ozone and membrane filtration. However for the State of Sarawak, this process is quite costly and thus more study is required to investigate the level of THMs in our treated
water before any recommendations can be made. The replacement of chlorine by chloramines is however highly recommended in view of its obvious lower concentration of DBPs and effective residual level in distribution system.
CHAPTER 3

3.0 METHODOLOGY

3.1 Introduction

The methodology chosen for this dissertation is desktop study and on-site investigation. There are 17 water treatment plants in Sarawak using peat water source and 4 using groundwater source (Water Supply Branch, JKR Sarawak). This represent approximately 23.3 % of the total treatment plants in Sarawak (total treatment plants in Sarawak is 90) using peat and ground water source. Most of the violation in the National Drinking Water Quality Standards 2000 (NDWQS 2000) comes form these treatment plants. This is in view of the difficulty in treating this type of water in which the dosage of chemicals is very sensitive and requires more precise jar testing and control.

The methodology is designed in such a way to answer the objectives of this dissertation, and to test the hypothesis in chapter 1.

3.2 Desktop Study

3.2.1 Literature Review

Literature review for basic water characteristics to appreciate what are the constituents in water and what are the significant of them is compiled. Review would cover the physical, chemical and biological characteristics of peat and groundwater; and the treatment process used by the water treatment plants under study in this dissertation. Besides this, literature review on water quality standards, the local water sampling protocols, the emerging best practice in water treatment
suited for peat and ground water, disinfection by-products and optimization of water treatment plant operations would be done too.

3.2.2 Performance of Water Treatment Plants

Water quality data from Water Supply Branch would be used to assess the performance of the treatment plant under study. The performance criteria would be comparison of the quality of the raw water and treated water with the National Drinking Water Quality Standards 2000 (NDWQS 2000). The parameters for the comparison would be the Biological, group 1, 2, and 3 parameters. Biological parameters consisted of Coliform and E.Coli. Group 1 parameters consisted of turbidity, colour, pH, and residue chlorine. Group 2 parameters consisted of total dissolved solids (TDS), chloride, ammonia (as N), nitrate (as N), iron, fluoride, aluminium and manganese. Group 3 parameters consisted of arsenic, silver, cadmium, chromium, silver, copper, zinc, magnesium, sodium, selenium, and sulphate. These parameters are under the monitoring program set out by the Ministry of Health, Malaysia. In view of time constraints and availability of raw data, analysis would be done for year 2000 and 2001 only.

The result of these groups of parameters would be tabled. From there, the maximum value, minimum value, standard deviation, mean and confidence interval would be computed. These values would then be compared to the NDWQS 2000 for raw and treated water. The violated parameters would be tabled for each individual water treatment plants. This would give an indication of which parameters have more frequency of violations and also which treatment plant has the most parameters violated.
Besides the data from water supply branch, data from the public health section of Ministry of Health would also be investigated.

### 3.2.3 Performance Assessing - Statistics

The performance of the water supply system under study is assessed by following the Australian Drinking Water Guidelines (ADWG) because it is simple and straightforward and is internationally recognized. In the ADWG, there are three methods of assessment, however the assessment by measuring performance against a percentile (95%) is chosen. This is in view that this method allows statistical procedures to estimate with a known degree of confidence on how well the results of sampling represent the quality of water at other times. This method is also consistent with the requirement of the upper control limit of control chart be equal to or less than the guideline value. This means that if the upper control limit is the same as or less than the guideline value, than 95% or more of the data should be below the guideline value.

As in procedures sheet 3.2 of the ADWG, the uncertainty in the estimated percentile or mean can be measured by the confidence interval. The confidence interval specifies upper and lower limits, so that within a known probability, the interval covers the true percentile or the true mean. This confidence interval for a normal distribution can be calculated from the number of samples, the mean and the standard deviation. Thus the $95^{th}$ percentile is $z \pm D$, where $z$ is the mean, and $D$ is the precision, which is half the width of the confidence interval. The formula for $D$ is:

$$D = \left[ t(a) \times s \right] / \left( \sqrt{n} \right)$$
where: \( t(a) \) is the student’s t statistic with \((n-1)\) degrees of freedom corresponding to a single tail probability of \(a\),

\( s \) is the standard deviation,

\( n \) is the number of independent random samples

Therefore the performance can be quoted as \( z \pm D \) (with 95% confidence). The performance is satisfactory if the upper bound of \( z + D \) is below the guideline value. This method is chosen for parameters that are non-health related. For health-related parameters like trihalomethanes (THMs), a more stringent method would be used, in which the 95 percentile is the mean + 1.64 x \( s \) and thus

\[
D = \frac{[t(a) \times s \times 1.64]}{\sqrt{n}}
\]

This would give a higher mean and \( D \).

### 3.2.4 Outliners

In most raw data, there bound to be some outliers. They can be due to malfunction of equipment or transcript errors, which would be discarded. The handling of exceptional high/low values is a bit tricky, which would definitely affect the 95\(^{th}\) percentile. The high/low values would be kept if they are within the limits of detection and makes sense (e.g., a pH value of more than 14 does not make sense) as the results would have an impact on the quality of water. Only those data that have been clearly shown to be in error should be ignored. For the less than (<) values, this dissertation ignored the symbol <, as this gives the worst case scenario.
From all these, conclusion on the performance of the treatment plants under study should be taken into account of raw water quality, treatment processes, coagulants used, and competency of staff.

3.3 On-site Investigation

The on-site investigation involves field visits to the selected water treatment plants and carrying out some in-situ water quality measurements, interviewing of plant attendants and supervisors, assessment on the standard of water treatment plant operation and maintenance and general house-keeping. The assessment of water treatment plants would use the standard forms used by the Water Supply Branch. The sampling protocols would be investigated and assessed on whether the protocols are followed, and the sampling consumables required are available or otherwise. The on-site investigation is important as it can act as an affirmation for the findings done from desktop study. The on-site visits can gather valuable observations that are useful in drawing recommendations for improvement and enhancement.

The desktop study and the on-site findings would then be correlated and compared. These findings would form a basis for the development of recommendations for the enhancement and improvement of the water treatment plants so that the existing facilities can be optimized.
3.4 Limitation of Study

The performance of the water treatment plants would be computed from the data of raw and treated water quality obtained from the records of Water Supply Branch. The assumptions are that the records are correct and reliable and the attendants who did the sampling follow the sampling protocols. Only year 2000 and 2001 would be examined and the results and findings would be based on these two years only.
CHAPTER 4

4.0 RESULTS

4.1 SUMMARY OF RESULTS

Violations for raw and treated water for each treatment plant for year 2000 and 2001 are summarized in tables. The parameters are recorded in the table only if the average value exceeds the National Drinking Water Quality Standards 2000 (NDWQS 2000). For parameters within the recommended standards of the NDWQS 2000, the values are not summarized in the table and the complete details can be accessed in CD provided and Appendix B. The format of summary is raw water violations for 2000 and 2001 and treated water violations for 2000 and 2001 for the 21 treatment plants. The format of display uses the 95th percentile format, which is the average ± D, where D is the precision as described in the chapter 3(Methodology).

4.2 RAW WATER

Unit of measurement for colour is hazen, otherwise all units in mg/l

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>PANTU</td>
<td>COD 27±9.4, 14.8, [10] Al 0.24±0.08, 0.1, [0.2]</td>
<td>COD 22±15, 22.5, [10]</td>
</tr>
<tr>
<td>LINGGA</td>
<td>pH 4.06±.3, 0.5, [5.5-9.0] Colour 534±41, 134, [300] COD 145±25, 39.5, [10] Fe 1.0±0.3, 0.5, [1.0] Al 0.25±0.15, 0.2, [0.2]</td>
<td>pH 4.0±0.04, 0.06, [5.5-9.0] Colour 459±96, 143, [300] COD 118±40, 63, [10] Fe 8.21±16.8, 26.4, [0.3]</td>
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</tr>
<tr>
<td></td>
<td>BOD 6.1±9.8, 11.7, [6]</td>
<td>Fe 1.22±0.52, 0.56, [1.0]</td>
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<tr>
<td></td>
<td>Fe 1.6±0.02, 0.2, [1.0]</td>
<td>Al 0.2±0.11, 0.15, [0.2]</td>
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<td>Colour 655±148, 221, [300]</td>
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## Chapter 4 - Results

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<td>Colour 502±39, 50, [300]</td>
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<td>Fe 2.2±0.57, 0.91, [1.0]</td>
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<td>PH 4.7±0.06, 0.1, [5.5-9.0]</td>
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<td>Al 2.14±3.78, 3.6, [0.2]</td>
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Note:

Colour, pH, turbidity are measured by plant attendants of the respective treatment plants. They are not measured by accredited laboratory. For Beluru (2000) and Kuala Tatau (2000) and Sebangan (2001), the results are not available. This could be due to no samples being send to the laboratory for analysis. For Kuala Balingian (2001), only one sample was sent to the laboratory and thus the standard deviation is not available. Beluru (2001), Kuala Lawas (2001), Kuala Tatau(2001) do not have a value for pH and colour and as such do not mean that the parameters are not violated. Aluminium is not a parameter in the NDWQS 2000 for raw water; however, it is an important parameter in JKR’s standard and a good comparison to treated water results in view of the high percentage of violations of aluminium in treated water. The standard of 0.2mg/l is adopted following the NDWQS 2000 for treated water. This would give a comparison on residue aluminium in treated water to raw water.
Majority of the raw water sources have violations in pH, colour, COD, iron, and aluminium, although a few have manganese problem. These violations are not surprising as the raw water source of peat and ground water has these types of characteristics.

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<td>BOD</td>
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<td>ALUMINIUM</td>
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<td>NN</td>
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The ranking in percentage violations are COD, aluminium, colour, pH, manganese, BOD and chloride, NH₃ and NN.
### 4.3 TREATED WATER

Unit of measurement for colour is hazen, otherwise all units in mg/l

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<td>AL 1.25±0.9, 1.34, [0.2]</td>
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<td>AL 3.05±0.54, 0.81, [0.2]</td>
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<td>Fe 0.45±0.24, 0.26, [0.3]</td>
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<td><strong>SPAOH</strong></td>
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### Water Supply Authority

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<td>Al 0.81±0.60, 0.84, [0.2]</td>
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<td>Al 3.75±1.83, 2.56, [0.2]</td>
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<td>Al 0.30±0.27, 0.39, [0.2]</td>
<td>Al 0.95±0.1, 0.1, [0.2]</td>
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<td>ASAJAYA</td>
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<td>Al 220±0.84, 0.8, [0.2]</td>
</tr>
<tr>
<td>SEBANGAN</td>
<td>Colour 5.4±, 1.06, [5]</td>
<td>Al 1.93±2.0, 1.26, [0.2]</td>
</tr>
<tr>
<td></td>
<td>Al 0.96±1.12, 1.21, [0.2]</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The NDWQS 2000 for colour for treated water is 15TCU. The standards used in table 4.3 for colour violation is JKR’s standard which 5 Hazen Units. True Colour Units (TCU) uses identical numerical values; which is Hazen Units.
From table 4.3, it is observed that all the treatment plants have residue aluminium in the treated water for 2000 and 2001 except for Kabong. Iron violation is not as consistent as aluminum in which the violation is not for both 2000 and 2001. As for manganese, it is a consistent violation for Kabong. Colour is the other violated parameter (JKR’s standard). It seems that the residue aluminium in treated water is very high in majority of treatment plants. Kabong has violation in manganese due to the nature of its water source, which is ground water.

**TABLE 4.5 PERCENTAGE OF PARAMETER VIOLATED BY THE TREATMENT PLANT UNDER STUDY**

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>2000 % OF WSA VIOLATED</th>
<th>2001 % OF WSA VIOLATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLOUR</td>
<td>38</td>
<td>28.6</td>
</tr>
<tr>
<td>IRON</td>
<td>33</td>
<td>9.5</td>
</tr>
<tr>
<td>MANGANESE</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>ALUMINIUM</td>
<td>90.5</td>
<td>95</td>
</tr>
</tbody>
</table>

The ranking in violations for treated water is aluminium, colour, iron, and manganese and that aluminium violation is 90% in 2000 and 95% in 2001.
Figure 4.1 Residue Aluminium of treated Water for 2000 for WTP under study
Figure 4.2 Residue Aluminium in Treated Water for 2001 for Water Treatment Plant Under Study
Figure 4.3 Manganese in Treated Water 2000 for Water Treatment Plant Under Study

Chang, 2003
Figure 4.4 Manganese in Treated Water 2001 For Water Treatment Plant Under Study
Chapter 4 - Results

Iron in Treated Water 2000

Figure 4.5 Iron in Treated Water 2000 For Water Treatment Plant Under Study
Figure 4.6 Iron in Treated Water 2001 for Water Treatment Plant Under Study
Figure 4.7 Colour Of Treated Water (2000) For Water Treatment Plant Under Study
Figure 4.8 Colour In Treated Water (2001) For Water Treatment Plant Under Study
Microbiological

Table 4.6 Percentage of Microbiological Violation for Year 2000 and 2001

<table>
<thead>
<tr>
<th>Water Treatment Plant</th>
<th>% Coliform Violation 2000</th>
<th>% Coliform Violation 2001</th>
<th>% E. Coli Violation 2000</th>
<th>% E. Coli Violation 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pantu</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lingga</td>
<td>2.2</td>
<td>4.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maludam</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stumbin/Bijat</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spaoh</td>
<td>0</td>
<td>2.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beladin</td>
<td>2.1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pusa</td>
<td>2.1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kabong</td>
<td>1.1</td>
<td>2.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Igan</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kut</td>
<td>1.1</td>
<td>1.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kuala Balingian</td>
<td>2.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oya</td>
<td>0</td>
<td>2.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beluru</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kuala Lawas</td>
<td>0</td>
<td>4.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Daro</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kpg. Tian</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Matu</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kuala Tatau</td>
<td>5.2</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asajaya</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sebuyau</td>
<td>6.6</td>
<td>0</td>
<td>3.3</td>
<td>0</td>
</tr>
<tr>
<td>Sebagan</td>
<td>0</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** These results are for water treatment plant only and exclude the distribution system. (Source: Medical Department).
Chapter 4 - Results

Majority of the microbiological violations is for Coliform. E. Coli violation occurs only once in the two years of analysis and that is for Sebuyau for year 2000. The percentage of violations is measured by number of samples with violation divided by number of samples analyzed. The results are for treatment plants only and do not include distribution system as performance is on treatment process only. The microbiological sampling is taken every week. The violations are a concern as water from treatment works should be free from bacterial contamination. The violation ranges from 0.8% to 6.6%. However these violations cannot conclude that it is actual violation or contamination during sampling or bacteriological analysis in the laboratory. Furthermore it is unsure if samples are collected after chlorine dosing or before dosing.

From field visits, majority of the bacteriological violation could be due to contamination for not following the sampling protocol. The samples are collected 24 hours earlier and in most cases are not kept at the recommended temperature. The sampling uses Thiobags and some are leaking during transportation to the laboratory. The percentage violations could be higher in view of the poor sampling method.

It is of utmost importance that the sampling protocol is complied with; otherwise there is not much reliability in the data and as such could jeopardize the monitoring effort. However a general trend can still be observed from the results.
CHAPTER 5

DISCUSSION-PERFORMANCE OF WATER TREATMENT PLANT

5.1 WATER QUALITY

5.1.1 RAW WATER SOURCE

There are ten (10) parameters that violated the NDWQS 2000 for raw water. These parameters do not include those parameters not under the monitoring program. From Table 4.3, the highest violated parameter is COD (100% for both 2000 and 2001) followed by aluminium, iron, colour and pH. Parameters like BOD, chloride, manganese, NH$_3$ and NN are violated by small percentage. However manganese has an unusual high percentage of violation (21%) for 2000 and then subsequent year drop to 5%.

Lingga, Beladin, Pusa, Kabong, Spaoh, Oya, Daro, Sebuyau and Sebangan have above five parameters that violated the NDWQS 2000. Stubim/Bijat, Igan, Kut, Kuala Balingian, Lawas, Beluru, Maludam, Kpg. Tian, Matu, Kuala Tatau, Asajaya have between 3 and 4 parameters and Pantu only 2 parameters violated.

The raw water source of the 21 water treatment plants under study are characterized generally by low pH, high colour, high COD, aluminium, iron, manganese content. A point to note here is that most of the location of these treatment plants is along the coast and thus some are affected by salt intrusion. In the analysis of result, chloride content is occasional but most plants do have alternative source like groundwater and pond water. The salt intrusion period is short and thus the groundwater and pond water can sustain the requirement. The
salt intrusion is most severe during dry season and last from a week to almost a month (personal communication with attendants).

The high COD could be due to the amount of chemicals and organics that require oxygen for the chemical reaction like iron, manganese and other organic matters, typical of peat water. This suggest requirement of primarily treatment of raw water by oxidation.

5.1.2 TREATED WATER QUALITY
There are only three parameters that violated the NDWQS 2000; which are, iron, manganese and aluminium. The colour parameter under JKR’s more stringent standard of 5 hazen has 38% violation in year 2000 and 28.6% in year 2001. Majority of the treated water quality have only one parameter violated, which is aluminium.

There is an alarming high percentage violation of above 90% for aluminium. In year 2000, 19 out of the 21 plants under study and in year 2001, 20 out of 21 plants under study have aluminium residue above the NDWQS 2000. Iron percentage is 33% in year 2000 and only 9.5% in year 2001. From the result in chapter 4, it can be concluded that aluminium residue in treated water is the major problem. Iron and manganese are minor compared to aluminum. Colour parameter meets the NDWQS 2000.
In view of the overall poor quality of raw water source for the treatment plants under study, the general result of treated water is acceptable except for relatively high residue aluminium. This could be due to a number of reasons, namely,

- Over dosing of aluminum sulphate/sodium aluminate due to improper jar testing or faulty/wrong setting of dosing equipment,
- In-correct point of dosing resulted in ineffective mixing of coagulants,
- pH condition is not ideal for the complete reaction of the aluminium salt,
- wrong choice of coagulant,
- retention time too short,

In my visits to treatment plants, the general comments on jar testing are

- Jar test is done once per shift\(^5\), that is only three times per day. The jar test is carried out immediately after change of shift. Raw water being dynamic need more frequent jar testing or as soon as there is changes in raw water quality, usually after rain. The concept of carrying out jar test during change of shift is incorrect and should be done when the raw water quality changes.
- Wrong techniques in jar testing. This could be due to faulty jar tester, stirring manually by hand, wrong speed setting of jar tester, different sequence of coagulants dosing in jar testing and actual dosing in plant, and concentration of chemicals used is different from the actual feed tanks.

There is generally a misunderstanding on performing jar test, the general idea is that it is part of the duty during change of shift and that jar testing is a waste of time as the result is the same in every test. Thus there is no trial of other dosages to minimize aluminium residue as the idea is already accepted that high aluminium

\(^{5}\)Treatment plant that operates 24 hours runs on three shifts of eight and half hours each with an overlap of 15 minutes before and after each shift.
residue is associated with treating peat water. Sometimes the result of the jar test is not use and the adopted dosage is different. The reason given is that if the jar test dosage is adopted, the quality of the water is worse. This could be due to a number of reasons, like different chemical solution strength of the solution feed tank and that used for jar testing or the volume of raw water flow used is incorrect. Most raw water flow is via V-notch and the setting could be out.

The pH of peat water is low and is outside the pH range for aluminium salts to be effective. Trail should be carried out to raise pH by dosing lime (pH of 6.0-6.8) before dosing of aluminium salts. Otherwise alternative coagulants should be used.

From personal communication with Lim, 2003⁶, horizontal flow sedimentation can handle peat water better than up-flow clarifier. This has prompted new design and extension projects to be based on horizontal flow. The disadvantage is bigger space requirement but is offset by easier operation.

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⁶ Ir. Lim Yiam Sui is the senior engineer in charge of operation and maintenance of water supply for Sarawak, office at JKR headquarters in Kuching, email:sui@sarawaknet.gov.my
Microbial Indicators

Microbiological examination provides the most sensitive, although not the most rapid, indication of pollution of drinking-water supplies. It is a search for very small numbers of viable organisms and not for a defined chemical entity or physical property (WHO, 1993).

*Escherichia coli* (E. Coli) is used as an indication of faecal pollution due to the abundant in human and animal faeces. In water monitoring, the presence of E. Coli and Coliform bacteria suggest that the water is contaminated and treatment has been ineffective. However in Sarawak context, the usual procedure on detection of contamination would be immediate re-sampling and flushing of the affected distribution mains, investigation on possible source of contamination (leak in the system, etc) and checking of sampling procedure. Result of any bacterial contamination is notified after a few days from date of sampling done. In most cases, re-sampling result is negative and does not serve much purpose as the time when the suspected contamination is detected (result from laboratory) and of sampling is too long. There is always a benefit of doubt that the contamination occurs due to improper sampling or laboratory contamination although the latter is quite unlikely. The usual case is to ignore the contamination and classify poor sampling procedure as the probably cause, of which is a bad practice. To overcome this, on-site bacterial testing should be made available.
5.2 TREATMENT PLANT OPERATIONS

The following comments are made from observations of the treatment plants under study and represent the author’s own opinion only. They do not represent the situations/conditions of the all water treatment plants in Sarawak though there are some which are applicable in general. In fact the water treatment plants under study ranked lowly compared to the rest of the plants in Sarawak.

5.2.1 LEVEL OF COMPETENCY OF PLANT ATTENDANTS

Majority of the plant attendants have limited level of education; some attendants do not have any formal education and the highest level of education is form five. Currently the requirement for engagement of plant attendant is standard six. I believe their duties were to assist in the general housekeeping of the treatment plant. However due to shortage of technical supervisors, the plant attendants are thus required to carry out water treatment. They can perform jar-test and other duties but lack the competency when the raw water quality changes. Jar-test records tend to be similar and to be fair standard six-education level is not expected to operate a water treatment plant. Having mentioned that, some attendants who have higher level of education are relatively good in water treatment and have managed to obtain grade 1 plant attendant’s certificate. These attendants are entrusted to oversee the general operations of the plant with occasional supervision from the technical supervisors. However the percentage of these experienced attendants is very low and thus at times incompetent attendants operate the plant. They should not be blamed for poor quality water production but immediate arrangement should be made to provide competent staffs to operate the treatment plant.
Chapter 5 Discussion

The attitude of attendants is important as well and some of the attendants are ignorant of the hazards of over-dosing and the handling of water treatment chemicals. Most plants operate 24 hours and in most cases the water quality in the morning is usually of poorer quality than other times. This is due to lack of monitoring of water quality over night. Of major concern is the handing of hazardous chemical like chlorine, which is very toxic and if a leak is to occur due to poor operations or maintenance, the result could be catastrophic with extensive damage to environment and loss of lives. However only the bigger plants (above 5MLD) use chlorine gas and the rest uses calcium hypochlorite powder.

### 5.2.2 WATER TESTING EQUIPMENTS

Equipments to measure pH, colour, residue aluminium, and chlorine are provided at every treatment plants but most of them are not functioning and urgent replacement is required. Turbidity and fluoride meters are only provided at some plants. Flocculators are provided at most plants. The condition of the water testing equipment/apparatus is far from adequate and maintenance of existing equipment is unsatisfactory.

There is no turbidity meter for most plants; pH, colour, residue chlorine, aluminium is tested by comparator. The comparator’s discs are discoloured and correct ranges of disc are not available. The pH disc is the most obvious as the pH of raw water is beyond the range of the disc provided (peat water usually has low pH). The comparator disc supplied are same with the rest of water treatment plants that is of normal surface water however, peat water characteristics are extreme.
compared to other surface water and hence disc are out of range (especially pH and colour). The data records of the pH are guesswork for value beyond the comparator disc. The other observation is the use of wrong tablet with the wrong disc. For example, Lovibond tablets should be use with Lovibond disc and Palintest tablet with Palintest disc. Sometimes this is not the case.

Most of the flocculators are old and in need of servicing or replacement of worn parts, especially the drive bands for the speed control of the paddle. Some plants do not have flocculator and use manual hand to do jar test, which is not satisfactory.

Colour test kit (Lovibond Nessleriser) is spoilt in most plants but the result of colour is recorded.

The presence of recorded data even though the equipment to measure the parameter is not functioning suggests unreliability of in-situ data.

The present practice of only ISO plants provided with full range of water testing equipments is not desirable. All water treatment plants should have the ability to measure pH, turbidity, residue chlorine, colour, and residue aluminium as they are essential in monitoring treatment process as well as the quality of treated water. Any faulty or discoloured disc should be replaced immediately and care for these should be the responsibility of the attendants.
Physical parameters like pH, colour, turbidity, residue chlorine (in-situ parameters of monitoring program) becomes unreliable and incomplete if the equipment to measure them are faulty, unavailable or incorrectly used.

Comparator disc are very handy provided that the correct range of disc is provided with the matching tablets/reagent. They are effective especially for pH, colour, residue aluminium and chlorine as they give fast indicative value. In water supply monitoring, this is sufficient. However, for highly coloured water, comparator disc for pH are not suitable and alternative direct reading meter should be provided.

5.2.3 RECORDS KEEPING

Records of the plant operations are recorded in hardcover books. Records on the daily chemical usage, water levels of reservoirs, pumps running hours, backwashing of filters, raw and treated water pumping quantity, repairs and breakdown logs, jar test records and shift duty rooster are typical record kept in the plant. However these plant records are not kept and archived properly; depending on the initiative of the attendants, some of the old records are kept in cabinet, while others tend to be lost as soon as a new book is made available. All records are manual hand written and the data seems to be identical each day. In some plants the daily reports are a few days behind at time of visit and thus there is high percentage that the data would be fabricated to complete the records before submission.
5.2.4 MAINTENANCE OF DOSING EQUIPMENTS

Dosing equipments for coagulants, coagulants aids, polymers, pH adjustment, and disinfection are either metering pumps or gravity dosers. For metering pumps, calibration needs to be done frequently to ensure accuracy. However not all plants using metering pumps have calibration columns. For gravity dosers, dirty and partially blocked dosers due to lack of maintenance are common. The accurate dosing of coagulants is essential for good quality water. Cleaning of the dosers should be a routine and becomes part of weekly chore for the operators.

5.2.5 MAINTENANCE OF FILTERS

Filters are the final physical process of removing impurities from the settled water. Most of the treatment plants under study use polyelectrolyte and over-dosing and wrong dosing point cause a thin film of deposit on the filters. This not only reduces the efficiency of the filters but also damage the filter media. From field observation, it is noticed that most filters are not maintained properly and cracks are observed in the media of most plants. In some plants the media need to be replaced urgently. Some of the filter media have never been replaced since commissioning of the plants, while others have suspected damaged lateral pipes under the media. The poor condition of filters in most plants under study is alarming as filters are the last line of process and as such should be in good condition. Bad backwashing procedures could have resulted in formation of cracks and damaged filter media.
Figure 5.1
Poorly maintained filter with suspected broken lateral pipe

Figure 5.2
Satisfactory maintained filter.

5.3 WATER QUALITY MONITORING

5.3.1 WATER SAMPLING

Water sampling protocol titled Water Sampling and Preservation of water Sample, Drinking Water Monitoring Program 2002 is very detail and describes objectives, procedures, and sampling apparatus and can be referred to in appendix A3. However it seems that most personnel involved in water sampling are not aware of this protocol and thus resulted in poor sampling using outdated format of request. This prompted the Chemistry Department for a dialog session on 4 April 2003 on poor sample submissions. Problems touched on and shortcomings of water sampling including use of correct containers, labeling, preservatives and sampling points.

Logistic of the treatment plant pose a problem for the samples to be sent to the laboratory on time within 24 hours. Some samples were collected one day earlier resulted in non-compliance of the protocol. There were even cases of specially
prepared samples for analysis. Untrained sampler could have negative implications and might result in contamination of samples. The volume of samples to be collected, preservatives not added, wrong sizes, type of sampling containers, and labels, are some of the non-compliance of the protocol. The cooler box temperature control at 4°C and a sample temperature control were not complied.

In my opinion it seems that the water quality-monitoring program is not getting the attention that it should be (plants under study only). The samples were sent just because it had to follow the schedule and there is no person to coordinate the sampling. Either the engineer does not realize the importance of proper sampling or he/she is just too short-handed to see the program through.

5.3.2 WATER QUALITY DATA
The Water Supply Branch receives results of water samples analysis in hard copy from the Chemistry Department with a copy extended to the Ministry of Health. The data are then re-entered into spreadsheet format. This transfer of data from hard copy to soft copy can be a source of error. The data should be in soft-copy with the format suitable for analysis to avoid data entry error. At time of writing, developments are being made to handle this by the Chemistry Department and in future data would be electronic on line.

The data were not analyzed to check and monitor the performance or the quality of treated water of the treatment plants. The raw data are not very useful in the present format. Water Supply Branch do keep tabs on violations and every violations are send to the respective treatment plant to comment on the probably
cause. However there is no other follow up to rectify the problem and most treatment plant do not reply the violations query at all.

5.4 IMPROVEMENT OF TREATMENT PROCESSES
Peat and groundwater being more complex in nature compared to other surface water should have enhanced treatment process rather than just conventional. The enhancement could be use of spray aerators, dual media filtration and use of other coagulants. In Beluru, a tower aerator and GAC media were used and have significant improvements to treated water (personal com. with attendants).

5.5 EMERGING TECHNOLOGIES
The major points to consider in treating peat water are the low pH, low turbidity, high colour, DOC content and DBP.

The undeniable upcoming technologies in water treatment are membranes filtration and ion exchange (resin) technology. These are discussed under literature review in chapter 2.5. Membrane technology is safe and produces quality water and as such more effort should be put to incorporate its uses especially to treat peat water. Ion exchange is also environmentally friendly and can overcome the DOC problem in peat water. The efficient pre-treatment using ion exchange coupled with membrane separation would be the ultimate or premium treatment solutions for peat water. This would overcome the DOC and DBP problem in peat water and thus can continue to use chlorine as disinfection.
Other cheaper and less efficient combination probably uses coagulation/flocculation process or large off-river storage pond as pre-treatment to using membrane separation, use of alternative new coagulants, polymeric flocculants, dual filter media (GAC and sand) and other disinfection.

There are no cheap ways to treat peat water effectively; even looking for alternative source is costly too. The principle should be to produce safe and reliable water for the public.

5.6 DISINFECTION ALTERNATIVES/DBPs

Peat water contain higher amount of organic matter and as such care should be taken against the formation of disinfection by-products especially when using chlorine. At the moment no study has been done to measure the level of THMs in treated water. However, it is recommended that chlorine should be substituted with chloramines as discussed in chapter 2.5.7, otherwise removal of the precursors should be done.
CHAPTER 6

6.0 RECOMMENDATIONS AND CONCLUSION

6.1 RECOMMENDATIONS

The recommendation in this chapter is based on the findings of chapter 4 and 5. These recommendations are confined to the 21 treatment plants under study only. However some of the recommendations can be applied to water supply operations in general. The recommendations are divided into subject matters of treatment plant operations, treatment process, water quality monitoring and regionalization of treatment plants. The recommendations are the author personal views.

6.1.1 TREATMENT PLANT OPERATIONS

Competency of Staff

The Treatment plant operations need to be supervised by a competent personnel full time in the treatment plant in view of the limited automation. The present situation in which the supervisor only visits the plant once a while and for a short time is bad practice and should be avoided. One supervisor has to oversee a few treatment plants and the plant attendants’ limited education and competency in water treatment further aggravated the problem. The engineers down to the technicians are principally civil engineering based and have no formal specialized training in water treatment plant operations. In view that water treatment plant operations are very specialized, declared hazard areas, safe and reliable potable water is a health concern, the followings are recommended
Chapter 6 – Recommendations And Conclusion

Recommendation 1 - Certification of Competency in Treatment Plant Operations

Formal training of attendants, supervisors and engineers in water treatment plant operations, handling of hazardous chemicals in treatment plant, first-aid, mechanical and electrical equipments maintenance and brief course in chemistry and statistic for water quality monitoring. Certification would only be given to those achieving the required competency and all staff involved in the production of potable water especially at the treatment plant has to be certification.

Recommendation 2 – Upgrade the level of education of future intake for plant attendants

The level of education of plant attendant is recommended to be minimum form five and salary scale adjusted accordingly. This would increase the operational efficiencies as they can perform much of the monitoring and operational duties so required.

NOTE:

Back in 1993, there were courses in operations of water treatment plant and sanitary survey conducted by IKRAM in Selangor. The courses were divided into modules and were supposed to be compulsory for all level of water treatment plant staffs. Certifications were given and there were talks that only the personnel duly certified could operate the treatment plant. IKRAM was subsequently privatized and the shift to privatization of treatment plant operations requires the operator to guarantee the quality of the treated water cease this program. The competency
levels rest on the privatized plant operator. However only the bigger capacity treatment plants were privatized and this did not solve the problem of staff competency in many of the smaller treatment plant still under the public sector.

**Blame Culture**

Blame culture is an initiative killer; a staff is blamed for the mistake even though it is an initiative taken to improve the current practice or system. The management should investigate why the idea does not work and together to find a solution. It could be a worthwhile effort. In most cases this is not done and if the idea works, it just go unnoticed and probably is used locally in the staff work place only.

**Recommendation 3 – Setting up of a Smart Idea Committee (SIC)**

The SIC would consist of staffs in the Water Supply Circle may not necessary from Government Department only but also of expertise from private sector too. The important criteria for a member of SIC are to have an open mind and a genuine caring nature to improve and contribute to the society in the field of water supply. The background or expertise in water supply industry is an added advantage in understanding an idea being put up. This would eradicate the blame culture and hopefully revive initiative from all levels of staff to improve the work culture, and system resulting in maximum team effort producing a highly efficient work environment. A good idea should be rewarded not in monetary term but recognition in the *Achievement’s Log of the Water Supply Branch* (yet to be set up). A reward that benefits the family of the staff is more meaningful rather than just a pat on the back in the office, which is soon forgotten.
NOTE:

The present Water Treatment Plant competition does have a little similarity to the SIC in promoting teamwork and is reward based; however the criteria for judgment is not very clear. Usually the new plants have an added advantage over the old plants. The Department has to be commended for this effort. However SIC searches for ideas and provides an avenue for them to be presented and investigated. The reward of family based benefit is recognition given to the highest level.

Streaming Current Monitor (SCM)

This instrument is very useful in the automated achievement of coagulation efficiency. The SCM perform real-time jar testing ensuring that the dosing of coagulant is accurate with real time adjustment of the metering pump. This is especially useful when the raw water quality fluctuates.

Recommendation 4 – Installation of a Streaming Current Monitor (SCM)

The SCM would ensure continuous monitoring of the charges in water and adjust the metering pump of the coagulant so as to have a net zero charge thus ensuring the coagulant reaction is complete. This result in high efficiency of coagulation process and in turn save chemical coupled with low residue aluminum in treated water. For a modest investment, the most difficult and sensitive part of treatment process is handled automatically. However the choice of coagulant and dosing point(s) together with ideal hydraulics are important for the SCM to work properly.
6.1.2 TREATMENT PROCESS

Coagulants

The drawback of the current double coagulation process is the high usage of sodium aluminate and high residue aluminium. During my visit to Daro, Kampung Tian and Balingian, the treated water meets the NDWQS 2000. However it must be noted that most of the time the residue aluminium exceed the NDWQS 2000. The Water Supply Branch continual efforts in trying other type of coagulants with their limited manpower are commendable.

There is some success in using ACH and PAS coagulants. However trail run for longer period of time is needed to confirm the suitability of the coagulants. The dosing points of the coagulants are also important. The use of ferric chloride should be tried even though the anticipated result might be ferric precipitation.

**Recommendation 5 – Smart-partnership with private specialist firms to conduct trail experiment with other types of coagulants working in the pH range of 4.5 to 5.5**

The smart-partnership with private company dealing with different types of chemicals would be an added advantage in view of the shortage of staff of the Water Supply Branch This smart partnership can be extended to include new water supply technologies in which the private sector can try their products and assessment can be done on the suitability of the technology.
**Filter Media**

The current filter media consist of different sizes of pebbles and a top layer of river sand. Sand media is satisfactory for normal surface water; however for peat water, granular activated carbon (GAC) is highly recommended in view of it’s capabilities to absorb the organic impurities of peat water. Dual media filters should incorporate surface washing where the separation between the GAC and sand are installed with lateral pipes to wash the GAC only. The frequency of surface washing should be 2:1 to full back washing. Backwashing water flow should have a constant flow regulator control to regulate the flow of backwash water so as to be effective.

**Recommendation 6 – Usage of dual media filter of sand and granular activated carbon (GAC) with surface washing capabilities and constant flow backwashing.**

**Water Testing Apparatus**

Water testing equipments are pH meter, turbidity meter, meter to test colour, residue aluminium, manganese, iron, conductivity and chlorine. Direct reading meter is recommended instead of comparative method. Real time monitoring of pH (raw, settled, filtered), turbidity (settled and filtered), residue aluminium (settled, filtered) and chlorine (filtered) are recommended..

**Recommendation 7 –Replacement spoilt and availability of water testing equipments especially pH, turbidity, conductivity, residue aluminium, iron manganese and chlorine meters.**

Chang, 2003
These basic meters for testing pH, turbidity, conductivity, residue aluminium, iron, manganese and chlorine must be make available and replaced if spoilt. Real time monitoring of pH, turbidity and residue aluminium would be advantages especially in archiving.

Membrane filtration as a secondary process

Membrane filtration can reduce colour and organic content of peat and groundwater significantly. For groundwater membrane filtration can be use without pre-treatment. Use of membrane filtration also reduces risk of disinfection by-products too.

**Recommendation 8 – Membrane filtration as secondary treatment to existing treatment plant**

Membrane filtration could solve the existing problem of high residue aluminium when used as a secondary treatment. Although currently membrane filtration involves high capital investment, this cost would reduce in time to come with new manufacturing methods.

Spray aerators

The existing aerator for groundwater is tower type and is not as efficient and effective as spray type. Spray aerators are cheap and easy to construct and should be incorporated as this would help to oxidize some of the organic compounds in the raw water.
Alternative Disinfections

In view of the higher content of organic matter in peat water, reducing the risk of formation of DBPs should be looked at. The method can be removal of precursors or use alternative disinfectant. The use of chloramines is recommended in view of its lower concentration of DBPs. Chloramines is similar to chlorine except that it requires higher concentration and longer contact time but is more stable at higher pH and possess good residual value.

Recommendation 10 – Use of Chloramines as a disinfectant

6.1.3 WATER QUALITY MONITORING

Bacteriological Test

Simple, cheap and reliable bacteriological test should be made available to verify the contamination. The H₂S paper strip method developed by Pillai et al is best suited as it is cheap, reliable and simple to use. With the H₂S test kits, attendants can also check for contamination without relying on the laboratory test reports, which would take longer time.

Recommendation 11 – Availability of simple, cheap and reliability bacteriological test kits (H₂S paper strip method).
This test kit would provide an effective monitoring of bacteriological contamination of treated water in the plant and the distribution system.

**Collection of water samples**

Currently the attendants collecting the water samples are unaware of the sampling protocol and were not trained. Training in sample collection and the procedures of the protocol is essential for the water quality monitoring to be meaningful. The public health section of the Ministry of Health Malaysia is suitable to lead training of staffs for water sample collection.

**Recommendation 12 – Water samples are to be collected only by certified staffs trained in water sampling**

Collecting water samples is not straightforward as there are a lot of procedures to follow, different types and shape of containers, different type of hand-held meters and preservatives. A training program would immediately to overcome this shortcoming.

**Recommendation 13 – Procurement of all water sampling apparatus and preservatives as required in the water sampling protocol.**

The availability of all apparatus and preservatives is important for successful sampling, especially after the staffs have been trained and certified to collect water samples.
Results of water analysis

The Water Supply Branch re-entering the hardcopy results into soft copy for archiving purpose is a source of error and time consuming. Soft copy should be provided in a format acceptable to all parties for easy analysis.

**Recommendation 14 – useful format of e-results of water analysis**

This ensure that monitoring the performance of water treatment plant can be easily done.

Format for compilation of water analysis results

Control chart is recommended for monitoring the quality of treated water of each individual plant.

**Recommendation 15 – Formation of a water quality monitoring unit (WQMU) in Water Supply Branch**

The WQMU task would be to set up water quality control charts for all the parameters being monitored including monitoring of chemicals used and number of samples sent for analysis. This unit would also be looking at the choice of sampling points and number of samples collected according to the guideline. Non-conformance report would be issued by WQMU to the water engineer whose plants are not performing. If problems persist, a team from Water Supply Branch would be dispatched to investigate the problem. If negligence were the case, disciplinary action should be taken.
6.1.4 REGIONALIZATION OF TREATMENT PLANT

There are many water treatment plants located in the remote region of Sarawak operated and maintained by the Water Supply Branch. Some of the plants are close to each other and are road linked. Instead of operating and maintaining many small plants close to each other, it would be better to link them up and set up a regional water supply by expanding one plant which has reliable source and thus supply the rest by pipeline. Staffs can be consolidated and thus shortage is eliminated. Water supply engineers then need only to concentrate on a few plants. However one draw back is that in case of shut-down, bigger population is affected.

Recommendation 16 – Regionalize of Water Treatment Plants to reduce number of small treatment plants.

This would consolidate the present staffs’ strength and better monitoring due to fewer plants.

Note:

Shortage of staffs does not mean the overall compliment of the Department is low. It is the shortage of qualified staffs in the field of water treatment, M & E, skilled technicians in operating and maintenance of equipments in the water supply industry.
6.2 CONCLUSION

**Peat water source**

The treatment plant employs conventional process using double coagulation (sodium aluminate and aluminium sulphate) with flocculants aid. There is noted aluminium violation of treated water, 90% in year 2000, and 95% in year 2001 of the 21 treatment plants under study.

**Ground water source**

The treated water quality using groundwater source has violation in manganese and iron. Manganese is violated in year 2000 and 2001.

The hypothesis of treated water from existing conventional water treatment plants using peat and groundwater source do not meet the NDWQS 2000 is true.

The use of emerging technologies should be able to produce treated water that meets the NDWQS 2000, however such application of technologies involves major refurbishments of all the existing plants making it uneconomical. It would be more viable to regionalize the water supply by refurbishment of a treatment plant and linking the supply by pipeline. The new plant should incorporate emerging technologies to ensure production of affordable quality treated water that meet the NDWQS 2000 with thoughts on the level of operation and maintenance suitable for Sarawak. The concept should be cost-effective management of water quality involving all aspects, from raw water catchments through to the customer’s tap, including active control of the distribution networks.
6.3 Future Research

The recommended future researches are

1. Suitability of membrane filtration (CMF) in treating peat water in Sarawak with emphasis on keeping operation and maintenance cost to the minimum.

2. Choosing the correct disinfection alternatives for water supply in Sarawak taking into account of cost, DBPs and ease of operation and maintenance.

3. The level of THMs in drinking water of Sarawak

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A1 CHARACTERISTICS OF WATER

A1.1 WATER CHARACTERISTICS

Natural water inevitable contains some form of impurities. Normally the states of impurities are either in the suspended, colloidal or dissolved states. The method of treatment or removal of these impurities or the reduction to an acceptable standard like potable water depends on the states of impurities. The finer the impurities, the more costly and sophisticated the method of removal. Sometimes the method of removal involves addition of chemicals, which could adversely alter the chemical properties and further add pollutants to the water.

The characteristics of water can be divided into physical, biological and chemical characteristics. These characteristics generally can qualify a particular water sample, however analysis can be costly and thus only certain characteristics are investigated in water supply monitoring.

Physical Characteristics

These are generally easily measured and some can be observed by naked eye. Examples of physical characteristics are temperature, taste and odour, colour, turbidity, solids (Total dissolved solids, TDS) and electrical conductivity. These characteristics would be further explained under key water quality parameters.

Biological Characteristics

Microorganisms play different roles in the treatment of wastewater and drinking water. In wastewater, microorganism assist in the treatment whereas in drinking
Appendix A1- Characteristics Of Water

water is a hazard to health. For drinking water the bacteria, *coliform* and *Escherichia Coli (E. coli)* are monitored as a form of fecal contamination.

**Chemical Characteristics**

These characteristics are more specific and defined and thus are useful in assessing the properties of a water sample. Some important chemical characteristics are pH, alkalinity, hardness, dissolved oxygen, nitrogen, chloride and organics. Some important characteristics are described in key water quality parameters.

**Suspended Matter**

This is usually associated with fast flowing river in which the velocity is fast enough for the water to transport solid particles greater than its own density. During flood, rivers carry high quantities of suspended solids. However when the velocity is reduced, the quantity of suspended solid is also reduced.

**Colloids**

Colloids are fine particles that do not settle and are electrically charged (Binnie *et al.*, 2002). The charged particles have similar charge, usually negative. The colloids are invisible to the naked eye but usually affect the colour and turbidity of the water.

**Dissolved Solids**

A wide variety of chemicals in the ground can be dissolved by water when it comes in contact. Common cations are aluminium, calcium, sodium, potassium, iron and manganese while common anions are bicarbonate, chloride, sulphate and
nitrate (Binnie et al., 2002). Groundwater usually contains higher total dissolved solids (TDS) that surface water. Water may also dissolve pollutants from agricultural activities like pesticides and herbicides which can be expensive to detect not to mention to remove.

**Organic Pollution**

Water from peaty catchments can have high levels of organic colour from humic and fluvic acids. These waters not only have high levels of colour, but also much more acidic in comparison with normal surface water. These types of water are usually difficult to treat and chlorination can lead to harmful disinfection by products (DBP).

Fecal pollution from humans and animals is often of great concern due to the risk of disease transmission.

**Tastes and odours**

The presence of algae can result in objectionable tastes and odours in treated water. The removal of algae is essential and often difficult. Other substances may cause taste even at very low concentrations of 0.1µg/l, for example phenols may give rise to taste from chlorophenols when present in concentrations down to as low as 0.01µg/l (Binnie et al., 2002).

**Hardness**

Hardness is due to soluble salts of calcium and magnesium in water. Hardness forms insoluble precipitates with soap and requires more soap to be used to form
lather. Besides this, it also causes boiler scales. Hardness includes other divalent and trivalent cations.
A1.2 KEY WATER QUALITY PARAMETERS

This chapter describes the key water quality parameters monitored by water supply authority. It is broadly divided into microbiological, physical and chemical parameters and the units used are in brackets.

**Microbiological Parameters**

The greatest short-term threat to human health from drinking water derives from pathogenic microorganism (Binnie *et al.*, 2002). Thus it is of utmost importance that potable water is free from such organism and water treatment should remove them. However there are a lot of difficulties in detecting and tracing such disease-causing organism. The approach is therefore to detect the presence of easily identified bacteria that are known to be present in human faeces, and to treat their presence as an indication of possible faecal contamination (Binnie *et al.*, 2002).

**Coliform Bacteria** (MPN per 100ml)$^1$

These are rod shaped bacteria, which are widely found in the natural environment. The unit used is most probable number (MPN) per 100ml. A number of techniques can be used to detect *Coliform bacteria*, namely,

- by multiple dilution of sample and incubation of the sample for 48 hours and then counting the number of positive tubes,
- membrane techniques that filter out bacteria and then growing colonies of coliform bacteria, allowing a direct estimate of the number of *coliforms* present in a sample,
- enzyme substrate method

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$^1$ MPN per 100ml stands for Most Probably Number per 100 milliliters, and is used for bacteriological count.
Escherichia Coli (E. coli) (MPN per 100ml)

The E.coli test is used as a confirmation that the coliform are of faecal origin. Their presence is used as a confirmation of faecal contamination. The presence of E. coli is unacceptable and should not be detectable in potable water.

Physical Parameters

Turbidity (NTU)

Turbidity is caused by the presence of fine suspended solids in water. It is a measure of the amount of scattering that occurs when light passes through water. It is an optical effect, measured in turbidity units (NTU), which also reflects the fineness, colour, and shape of the dispersed particles. In water supply, turbidity is used, as an indication on how effective is the treatment process in removing solids from the source water.

Colour (Hazen)

Colour is a measure of light absorbed by the water. True colour excludes the effects of any scattering of light due to turbidity. Colour in drinking water is usually measured by a comparison method against a standard colour chart. Colour is pH dependent and usually the pH value is also reported.

Pure water is not colourless but has a pale green-blue tint in large volumes. Natural yellow colour in water from upland catchments is due to organic acids, which are not harmful, similar to tannic acid in tea, however consumers object highly coloured water due to aesthetic reason (Tebbutt, 1998).
pH

The intensity of acidity or alkalinity of water is measured on the pH scale which actually indicates the concentration of hydrogen ions present. The pH scale range from 1 to 14 with 7 being neutral, below 7 being acidic and above 7 being alkaline. Many chemical reactions are dependent on pH and for water treatment, the coagulation and flocculation process is most effective between pH 6 to pH 6.8.

TDS (Total Dissolved Solids) (mg/l)

Total dissolved solids and dissolved solids are terms generally associated with freshwater systems and consist of inorganic salts, small amounts of organic matter and dissolved materials (Train, 1979). The principal inorganic anions dissolved in water include the carbonates, chlorides, sulphates, and nitrates (in ground waters), the principal cations are sodium, potassium, calcium, and magnesium.

Chemical Parameters

Iron (mg/l)$^2$

Iron may be present in water in varying quantities depending on the geology of the area and other components of the waterways. Iron is an essential trace element for plants and animals. However iron is an objectionable constituent in water supplies as it affects the taste of beverages and can stain laundered clothes and plumbing (Train, 1979). Thus iron concentration in potable water is lowered due to desirable.

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$^2$ mg/l represent milligram per litre.
**Manganese (mg/l)**

Manganese does not occur naturally as a metal but is found in various salts and minerals, frequently in association with iron compounds (Train, 1979). Consumer complaints arise when manganese exceeds a concentration of 150 ug/l in water supplies primarily due to brownish staining of laundry (Griffin, 1960). Manganese is rarely found in surface water at concentrations of above 1mg/l and at concentrations of about 10 to 20 ug/l is acceptable to most consumers.

**Aluminium (mg/l)**

Aluminium presence in water could be through leaching of the soil or from the use of aluminium salts in coagulation process in water treatment. Aluminium concentrations in natural water sources can be 0.014 to 1.2 mg/l but can be higher up to 18mg/l depending on the nature of the soil (clay minerals). Residual aluminium in potable water depends on the concentration in water source, the alum dose, pH, coagulation process and filtration efficiency. Aluminium is usually associated with Parkinson disease. Higher concentrations of aluminium have been found in autopsied brains of people who had suffered Alzheimer’s disease. There have been a number of epidemiological studies to determine if aluminium in drinking water is related to Alzheimer’s disease. Although some studies indicated that a tentative link may exist, but more recent evidence suggests that aluminium in drinking water is not associated with increased risk of Alzheimer’s disease (ADWG 2000). The intake of aluminium through food intake is much higher than through water intake.
Appendix A1- Characteristics Of Water

Chloride (mg/l)

According to Tebbutt, 1998, Chlorides are salts of hydrochloric acid or metals combined directly with chlorine. They are responsible for the brackish taste in water and can be an indicator of sewage pollution because of chloride content of urine. Besides that, present of chloride can also be an indicator of saline intrusion in some water source. The threshold level for chloride taste is 250 to 500mg/l.

Nitrogen

This element exists in four main forms in the water cycle and is important as biological reactions can only take place with sufficient nitrogen. The four main forms are,

- organic nitrogen – in form of proteins, amino acids and urea.
- ammonia (NH₃) nitrogen – ammonium salts
- nitrite (NO₂) nitrogen – an intermediate oxidation stage
- nitrate (NO₃) nitrogen – final oxidation product

A water containing high levels of organic and ammonia nitrogen with little nitrite and nitrate nitrogen would be considered unsafe because of recent pollution while no organic and ammonia nitrogen and some nitrate nitrogen would be relatively safe because pollution could not have been recent (Tebbutt, 1998).
A2 WATER TREATMENT PROCESSES

A2.1 INTRODUCTION

Water treatment involves physical, chemical and biological changes that transform raw water into potable water (Cox, 1973). Arguably it is possible to produce potable water from virtually any source of water (Binnie et al., 2002). However in practice, the choice of a water source is usually determined by the cost involved and more recently, ecological and environmental consideration. The direct treatment of sewage to potable water is still not very readily acceptable by most people.

The selection of treatment processes depends on the nature of the raw water, the space available for the construction of the plant, considerations of operating and capital costs, and often-personal preference of the designer or in some instance political and policy preferences. There is no right or perfect treatment processes, but a combination of treatment processes options. In choosing a particular option, there is a need to consider future upgrading capability and compatibility and not forgetting deterioration of the raw water. In practice, the trend is towards what is perceived to be the most economic treatment process within the existing physical constraints, taking into account of risks and reducing them to an acceptable level (Binnie et al., 2002). Acceptable risks vary from country to country.

For many unpolluted sources and protected catchments, treatment could be by simple sand filtration to remove trace physical impurities or even by disinfection alone.
Protection of catchments involves restriction of activities within the catchments. However total protection and restriction of activities in a catchment is quite impossible for economic reasons.

It is always essential to approach water treatment with an open mind, looking at the particular problems of the water to be treated, the budget available, other plants treating similar water, and where a plant is to be upgraded, the performance of the existing plant (Binnie et al., 2002). The choice of raw water source is very important for long-term sustainable use (quality and quantity).

**Conventional Water Treatment**

According to Binnie et al., 2002 the following processes can be termed as conventional treatment for surface water,

- Catchment’s control
- raw-water storage
- removal of coarse solids by screening
- sedimentation
- aeration
- chemical dosing
- coagulation and flocculation
- clarification
- slow sand filtration
- rapid gravity filtration
Appendix A2 – Water Treatment Processes

- pressure filtration
- chlorination
Appendix A2 – Water Treatment Processes

Typical Water Treatment Process

River

Preliminary Treatment

Screening

Off-River Storage

Addition of Oxidants (Chlorine, Ozone, etc)

Aeration

Cascade, spray type

Air stripping

Chemical Mixing

Main Treatment Process

Flocculation

Clarification

Filtration

pH Adjustment

Disinfection

Enhanced Treatment Process

DAF

GAC Membrane

FIGURE A2.1 Typical Water Treatment Process
For ground water, special processes would be required to treat higher levels of iron and manganese presence. Formerly, the main processes of water treatment are settlement, clarification and filtration. With the recent development of membrane-based technology, these processes become less significant. However membrane-based technologies are not cost effective in treating surface water but more suited to treat highly coloured water with very fine solids in which conventional treatment have difficulties.

Conventional treatment might have produced water that was considered as potable before, but with the growing concern of colour, organics and the formation of THM, the process is fast becoming obsolete in layman terms.

Enhanced Water Treatment

With the development of more stringent water quality standards, the conventional water treatment processes also underwent what can be called enhanced processes. The enhanced processes are to meet the more stringent standards. The enhanced processes include

- improved coagulation control (by use of automation and microprocessors)
- dissolved air floatation (DAF – for fine floc)
- advanced clarifiers (lamella separators and advanced ‘sludge-blanket’ system)
- ozonation
- granular activated carbon (GAC) adsorption
- membrane-based processes
- air stripping of volatile organic chemicals
• ion exchange
• advanced disinfection (ultraviolet, ozonation and chlorine dioxide)

The above processes were developed mainly to cater for organic chemicals present in water which give rise to colour, taste, disinfection-by-product (DBP) or other impurities due to human activities (mainly agriculture). The above enhanced processes effectiveness can be further improved with consistency using advanced electronic monitoring devices and automation.

It is always essential to approach water treatment by looking at the quality of the raw water to be treated. Sometimes if the raw water quality requires the combination of advanced treatment processes, it might be more logical and economical to look for alternative raw water source. However more often alternative sources of raw water in today’s environment are limited and if available could be as bad. Thus water treatment plant designers are left with looking at the particular raw water problems and select the processes to cater to the problems balancing economics and water quality. In the designing of water treatment plants, budget constraints, performance of treatment plants with similar source, upgrading capabilities, and skills and level of competency of the workforce available so that the designed plant can performed and maintained to its full capabilities.
A2.2 PRELIMINARY TREATMENT

Preliminary Treatment is the process prior to the main treatment process and is important as this preliminary process reduce the stress on the main process. It also gives consistency of raw water quality (off-river storage) to the main process, which is an important factor to successful treatment (making the job of water treatment easier). A good water treatment plant design should incorporate effective preliminary treatment process, which is as important as the main process itself. However, in older plant, this preliminary process is neglected. The processes in preliminary treatment are

- raw/off-river water storage
- screening
- pre-chlorination
- pre-ozonation
- aeration

Raw or Off-River Storage

The provision of raw or off-river storage on river intake is good practice. This is so because storage can provide raw water of a more consistent quality, which is an important factor to successful treatment. Furthermore, storage alone can improve the quality of raw water especially in the reduction of turbidity, ammonia, bacteria and many other pollutants (Binnie et al., 2002).

Storage can also act as a buffer to pollution. It provides a buffer to accidental pollution. This reduces the risk of drawing contaminated water into the treatment plant, which
could result in plant shut down to clean the contaminants. If storage capacity is large, the plant can continue to run without shutdown. A minimum of 7 days storage is recommended if intake is located downstream of effluent discharges (Binnie et al., 2002). Off-river storage also provides buffer against drought or low river flows. Larger storage periods can be a solution to seasonal variation in river flows thus providing consistent quantity to treatment works. The recommended minimum storage capacity should be 7 days. In current situation, it is quite impossible to provide 7 days storage due to many factors besides economics. Thus design of treatment process usually incorporates advanced process to cater for contamination but have limitations for seasonal flow. However large storage can also lead to problems like algae, thermal stratifications (deep reservoirs), and built up of nutrients, manganese, iron and sediments.

**Screening**

Screens are normally located at the raw water intake and are the first form of barrier to prevent weeds, grass, small debris and larger life forms of the river entering the pumps and treatment works. These screens protect the pumps by preventing large debris or weeds from entering the intake and can be static or mechanized. Static screens are cheap and need to be cleaned regularly by manual labour. Mechanized screens are expensive but are cleaned automatically.

In considering screen design, the variation in water level, and type and size of solids loading are to be looked at. At the downstream of the intake, a weir is usually
constructed to give a minimum water level independent of river flows. Screens even though might look simple, is an important aspect to pump maintenance and reduce the risk of shut down of treatment works due to suction problem of pumps.

**Pre-Chlorination**

Pre-chlorination is usually done to control algae and slime but most importantly to oxidize iron and manganese in raw water. However in view of the risk of THM formation, pre-chlorination is not the usual practice except for groundwater source where there is very little risk of THM formation. A chlorine dose of 0.8mg of free chlorine per mg of iron or manganese is recommended for its removal. For oxidation of ammonia, recommended dose is eight to ten times the NH$_3$-N concentration (Binnie *et al.*, 2002).

**Aeration**

Aeration can be used to improve taste and odor in raw water. This process can also removes iron, manganese, hydrogen sulphide, and partial removal of carbon dioxide and oxygenate the raw water. Aeration is a cheap and important process to control tastes and odor due to hydrogen sulphide, and it is common to treat ground water and water drawn form deep reservoirs. Water from other surface source is generally in equilibrium with the atmosphere and thus not necessary. For the process to be effective, the area of contact between atmosphere and water should be maximized. There are different types of aerators, namely spray aerators, cascade aerators, tray and slatted tower aerators.
Spray aerators – employ nozzles, which produce thin jets of water, often directed against hard surfaces giving rise to a fine spray exposing the droplets of water to the atmosphere. Spray aerators are highly efficient. This type of installation has to be sheltered against wind, or the spray may be blown away from the collecting trays.

Cascade aerators – these depend on the turbulence created in a thin stream of water flowing swiftly down an incline and impinging against fixed obstacles. They are not very efficient due to the limited exposed surface of the water.

Tray aerators – typically consist of up to five trays, shape like a Christmas tree in which the bottom tray is the biggest. The water falls from tray to tray through a height of about 0.5m per tray. This type of aerator is simple and cheap to construct.

Diffused air aerators – consist of tanks in which air is bubbled upwards from diffusers laid on the floor. The bubbles have to be fine and depth adequate for the process to be efficient. Advantages of this system are minimal head loss and lesser space requirement.

Packed tower aerators – these consist of tower packed with media. Water passes through the media while air is blown upwards. These are highly efficient for gas transfer and are used for removal of volatile organic chemicals as well as for pre-treatment.

In ranking the efficiency, packed tower aerators would be most efficient followed by sprays, trays and cascades.
A2.3 COAGULATION AND FLOCCULATION

Coagulation and flocculation can be considered as the main water treatment processes. It involves the destabilization of fine solids present in water and thereafter creating a condition optimum for the formation of easily removed flocs. The solids present in water can be in the form of suspended particles, colloids and dissolved solids. Suspended particles are relatively easy to remove compared to colloids or dissolved solids. Dissolved solids can only be removed by reverse osmosis. The removal of colloids is the main objective of conventional water treatment. Colloids consist of hydrophilic and hydrophobic colloids. Hydrophobic colloids are unstable and thus can be removed by coagulation and flocculation. Hydrophilic colloids cannot be destabilized and thus can only be removed by chemical precipitation, filtration or adsorption. Thus to remove hydrophobic colloids, it is necessary to overcome the forces keeping the particles apart. Once this has been done, the particles coalesce into larger particles. This destabilization process is called coagulation. Coagulation occurs quickly. Flocculation is the process of further gently mixing after coagulation, which result in formation of relatively large particles that can be easily removed. The aim of coagulation and flocculation is to produce particles of a size that can be removed by settlement, floatation, or filtration.

The coagulation process involves very rapid mixing to speedily disperse the coagulant(s) being dosed. Weirs of flumes, paddle or propeller mixers, turbine mixer or static mixer can achieve this rapid mixing. Flocculation is the gentle mixing to further coalesce the particles so that they grow bigger. This process has to be gentle so that the
flocs formed by coagulation do not break up. Common flocculators are paddle flocculator and baffled channels. The later are more widely used due to simplicity and involves no moving parts. However they are inflexible and cannot be adjusted to differing flow rates.

**Coagulants**

Aluminium and ferric salts are most suitable for the destabilization of colloids. The correct dosage of coagulant is important and is pH sensitive. Overdosing can lead to charge reversal and re-suspension of the colloidal material leading to poor filtered water quality. This also leads to high chemical usage and probable health effects. Common coagulants are aluminium sulphate, ferric sulphate, ferric chloride, and polyaluminium chloride (PAC). The detailed chemistry of the reaction would not be illustrated in this dissertation. However it is important to note that for the process of coagulation to be formed efficiently, pH control is most important. For aluminium salt, the reaction is

\[
\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O} + 3\text{Ca(}\text{HCO}_3\text{)}_2 \Leftrightarrow 2\text{Al(OH)}_3 + 3\text{CaSO}_4 + 6\text{CO}_2 + 14\text{H}_2\text{O}
\]

For Ferric salt, the reaction is

\[
\text{Fe}_2(\text{SO}_4)_3 + 3\text{Ca(}\text{HCO}_3\text{)}_2 \Leftrightarrow 2\text{Fe(OH)}_3 + 3\text{CaSO}_4 + 6\text{CO}_2
\]

The symbol \(\Leftrightarrow\) indicates reversible reaction.

*Aluminium sulphate* are most commonly used in water which has high pH buffer and usually requires adjustment of pH using hydrated lime or Soda Ash.
Ferric Sulphate is gaining importance as a coagulant due to its wider pH range for minimum solubility compared to aluminium sulphate and thus more suitable to be used in wider range of raw water. The other advantage is the possible associated link of Alzheimer's disease with aluminium level. Ferric sulphate are also better in decolourization of water with low pH value, removal of manganese and clarification of water with low temporary but high permanent hardness (Binnie et al., 2002).

Ferric Chloride is very corrosive and is difficult to handle, store and dose. It has similar properties to Ferric Sulphate.

Polymerized aluminium and iron salts are more recent coagulants, which have high molecular weights and sold under various trade names. More widely known is poly-aluminium chloride (PAC). These coagulants are more expensive but offset by its low dosage. They are highly efficient and may greatly improve flocculation and overall treatment efficiency. They are known to be more effective at low temperature, faster floc formation, lower dosage rates, savings in pH adjustment’s chemicals and possibly more effective with algae.

Polyelectrolyte is a generic term for high molecular organic polymers used in coagulation and flocculation. They are normally synthetic chemicals such as polyacrylamides or polyamines. Low dosage and pH adjustment chemical savings offset their higher cost. However care has to be taken for their usage and understanding of the chemical reaction is desired. In some countries, the dosage rates and the chemical
composition are regulated. A particular advantage of polymers is that they can be relatively high pH values on waters containing iron and manganese resulting in single efficient single-stage removal by filtration of both metals.

**pH Control**

pH control in coagulation with iron and aluminium salts is most important as pH controls the precipitation of metal hydroxides and also the charges on the intermediate products arising from dosing of metal salts. Thus effective and economic coagulation is determined by the correct pH. The determination of the optimum pH can be done using jar test. However for river water in Sarawak, the pH value for coagulation using aluminium salts is in the range of 6.1 to 6.8.\(^1\)

Jar Test is the trail and error dosing of chemicals in a series of either 500ml or 1000ml beakers, usually 6 numbers. The test is performed using a jar tester or a flocculator. The stirring simulates the actual treatment plant process of coagulation and flocculation. The dosage of aluminium salt and soda ash (pH correction) is on a series of trials and the result is measured for the pH and turbidity, the rate and size of floc formation. The faster rate and biggest floc formation give an indication of the correct dosage, which would be further confirmed with pH and turbidity, measured.

Aluminium salt has a minimum solubility at a pH of approximately 7 (Binnie *et al.*, 2002). Thus at pH value of above and below 7, the solubility of aluminium salt decreases. In the destabilization process, the objectives are to create a condition for the

\(^1\) Based on experienced by the author. This narrow range is valid for surface water in Sarawak.
coalescing of the colloids and with minimum dissolved aluminium salts so that the filters can remove them. However most of the time in practice, the pH value by jar test might not be the minimum solubility pH value, in which case carried over aluminium need to be considered.

For ferric salts, the minimum solubility range is between pH 7-10 (Binnie et al, 2002). Thus in this respect, is not as sensitive as aluminium salts and hence require less precise pH control.

pH control is also affected by the nature of raw water. Water with high dissolved salts and alkalinity are generally well buffered against pH changes arising from coagulant dosing. In this sense, are easier to treat and most preferred by plant operators. However, for water with high organic content, colour and acidic, which have little buffering capacity and are thus sensitive to strong acids, alkalis and metal salts coagulants. It is difficult to control the pH in this narrow range and thus aluminium salts are not suitable. Examples of this type of water are peat water.

**pH Correction**

Lime and Soda Ash are commonly used for pH correction. Lime can be quicklime (CaO) or hydrated or slaked lime (Ca(OH))₂. Soda Ash is more expensive but easier to mix and dose thus is more preferred than quicklime. The problem associated with this type of pH correction is blockage of the dosing lines. For this reason, it is always good practice to have standby lines.
Coagulation and Flocculation Optimization

This process can be considered the most important part of the overall water treatment process, thus its optimization is of utmost importance. Failure to optimize the coagulation and flocculation process would lead to overdosing and poor water quality entering the filter (overloading of filter). This overdosing not only is a health concern but also increase the cost of operation not to mention overloading of the filters.

Jar testing is used to chart the optimal dosage and can give a good indication for optimal dosage of coagulants. However this jar testing requires some analytical skill of the operators. Usually the recommendation is to carry out jar testing when raw water changes but in practice is rarely done. A more up to date way of optimizing dosage is by using an instrument called the streaming current monitor (SCM). This instrument is then connected to control the dosing pumps to adjust dosage for optimization. The advantage of this instrument is that the dosage is monitored continuously and adjusted as required. The experience of the operators and historical data can greatly assist the operators to adapt the ‘close’ to optimal dosage. Raw water being dynamic in nature is thus quite impossible to have optimal dosage continuously but once the nature of raw water changes, the operators should respond quickly and accordingly too. The way to monitor optimal dosage is by monitoring the pH, turbidity, colour and residue coagulants downstream of the coagulation and flocculation process.
The correct choice of coagulants is very important which is governed by the nature of raw water. This together with some instrumentation to continuously monitor the residue coagulants, colour, pH and turbidity would result in close to optimal dosage. The attitude and responsiveness of the operators are also important criteria’s for successful operations.

A2.4 CLARIFICATION

Clarification is the process whereby the water heavily laden with flocs after the successful coagulation and flocculation process are separated and clarified. The process works on a simple principle that as the velocity of the water slows down in the clarifier (almost to zero velocity), its capacity to transport the flocs (suspended solids) disappear and hence the flocs would either settle or float depending on whether their density is greater or less than of water. There are a few types of clarifier design, all of the structures are designed to operate under quiescent condition to enhance the process of separation or termed clarification. Most of the designs incorporate the formation of sludge-blanket (for upward flow) to compliment the process of clarification. For the flocs that are lighter than water, dissolved air floatation (DAF) method is employed. In designing clarifier, one has to consider the following points as illustrated by Binnie et al., 2002

- ensuring equal hydraulic loading of tanks
- coincidence of peak output with peak turbidity
- low temperature
- excessive suspended solids
• proper pre-treatment
• liability to streaming
• persistent wind
• overturn of water in the basin

Types of Clarifier

*Horizontal Flow Settlement Basins*

Horizontal flow basins clarifier consists of rectangular and redial-flow type. Horizontal flow clarifiers are extremely reliable and work well with little trouble even with inexperienced plant operators. They are easy to construct and can be covered in countries which experience cold temperature. They are less susceptible to shock loads and process upset due to their considerable size. Another prime advantage of horizontal flow basin is that it allows for easy upgrade by adding plate settler modules. The rectangular shape allows for economic construction. Cleaning of this rectangle basin is easy with mechanical scrappers. The only disadvantage is that they take up large space. In Sarawak, rectangular horizontal flow settling basin is becoming more popular due to their ease of operation and good performance. They are virtually left to operate by themselves. Even streaming does not really affect their performance as the design incorporates buffer structure.

There is no fundamental difference in hydraulic design with rectangular tanks and circular-shaped tanks. However in my opinion, radial flow tanks are not as versatile and independent as rectangular tanks.
**Vertical Flow Clarifiers**

Vertical flow clarifiers are usually shaped like a cone or more commonly known as hopper type. The mechanism of function is the maintaining of the layer of sludge blanket in which the flocculated water has to pass through. Maintaining this blanket at a particular depth is quite delicate and needs experience. This blanket provides inter-particle collisions and entraps the ‘floc’ and thus only clear water passes through. Above this sludge blanket is a layer of clarified water, which is then collected by decanting channels to the next step of the treatment process, which is filtration. The advantage of this design is that under ideal conditions, vertical clarifiers provide both flocculation and settlement thus producing settled water of high clarity. Furthermore the sludge can be removed easily using only the available hydraulic head without the need of a mechanical scraper. The drawback of this type of clarifier is the cost of construction, and due to the conical shape size and depth is limited thus is suitable for small and medium capacity works only. Furthermore, in tropical weather, the increase in temperature causes the sludge blanket to be unstable due to ‘boiling effect’. This can be minimized with the provision of shade over the clarifier. The performance also decreases with the treatment of high silt loads, which need frequent and often delicate and carefully de-sludging of the extra sludge.

**Dissolved Air Floatation (DAF)**

This type of system is applicable to water characterized with the formation of very light ‘flocs’. The process is reversed compared to the conventional clarifiers in which the flow
is downwards. In DAF system, the flocs are floated by mixture of air and water. The clarified water is taken form the bottom of the tanks instead of the top.

There are other types and designs of clarifiers but the working principle is quite similar. The suitability and appropriateness of the design needs carefully considerations.

A2.5 FILTRATIONS

In the water treatment process, filtration is the final physical treatment process. This process is very important as it ‘compensate’ all the inefficiencies of the other earlier process and makes the water portable (with disinfection). However if the clarified water were of high quality, then the filters would not be unduly loaded. Filters need to be maintained properly and backwashed frequently. This is because it is the last line of treatment. In conventional filtration, the water is passed through granular material. The granular material can be sand, gravel and activated carbon or a combination of all. A good and well maintained filter should produce a filtrate of less than 0.1 NTU (Binnie et al., 2002).

Filtration is usually after clarification, thus the particles are usually fine and small amount of carried-over flocs. In some treatment works where the water is very clear especially raw water from mountain stream, the raw water is directly filtered without clarification. This is often referred to as direct filtration. However in U.K. direct filtration is considered unacceptable as the sole main treatment process due to risk of Cryptosporidium contamination (Binnie et al., 2002).
According to Tebbutt, 1998, the removal of suspended matter in a porous media bed is not simply a straining action. The mechanism and processes are complex such as

- **interception** (where streamlines pass close enough to bed grains so that particles come into contact with bed grains)
- **diffusion** (random Brownian movements can bring colloidal particles into the vicinity of a bed grain)
- **sedimentation** (gravitational forces can move particles across streamlines into quiescent areas on upward facing surfaces of bed grains, an analogy with tray concept in Hazan’s sedimentation theory)
- **hydrodynamic** (particles in a velocity gradient often develop rotational movements which produce lateral forces capable of moving them across streamlines and providing flocculation)

Suspended matter once transported into the pores of a media is held there by attachment mechanism due to physico-chemical and intermolecular forces similar to those, which operate in coagulation (Tebbutt, 1998). A bed of porous media is thus able to remove particles considerably smaller than the voids within the bed.

**Backwashing**

Backwashing is the term given to cleaning the filters. It usually involves passing water through the filter media in the reverse direction. Sometimes air is used combined with water for more effective backwashing. Depending on the quality of clarified water, filters usually run continuously for a few days without backwashing. The frequency of backwashing depends on the performance of the filters. This is monitored by observing
the turbidity of the filtrate or the differential head loss. However in most cases, the filters are backwashed at a fixed period; say 24 or 48 hours as a standing practice.

Backwashing is an important part of filter maintenance. For effective backwashing the bed of media need to be fluidized and usually expand up to 20%. The fluidization of the filter bed is achieved by air scouring the filter media and followed by water in the reverse direction. Initially the filter bed is air scoured for a short period of time (2-3 minutes) and then water is pushed through the filter at slow rate. The water can be from a high-level backwash tank in which the head and volume are fixed. After about 5 minutes, air scouring is stopped and the backwash flow is increased to maximum until the volume of the backwash tank. It is important that the procedures for effective backwashing are adhered as formation of mud balls can happen if backwashing is not done properly. This would eventually lead to changing of the filter media, which is costly, and having to shut down the filter. Signs of ineffective filter maintenance are observation of cracks in the filter beds, formation of mud balls and shrinkage of the filter media form the walls of the filters.

There are basically three types of granular filter, slow sand filters, rapid gravity filters, and pressure filters (Binnie et al. 2002).

**Slow Sand Filters**

Slow sand filters are the oldest form of filters. They operate at low loading rates and uses fine sand as the media. The process is of two types, physical straining and biological
action. A layer of biological growth (known as *schmutzdecke*) on top of the sand and in the uppermost part of the sand bed is vital to effective operation. The *schmutzdecke* is a slime layer, which contributes to the removal of fine suspended matter and often provides oxidation of organic contaminants in raw water (Tebutt, 1998). These filters are cleaned at periods of between several weeks and several months, by scraping off the top layer of sand and biological growth (Binnie *et al.* 2002).

According to Cox, 1973, the advantages of slow sand filters are

- there is no need for coagulation facilities
- equipment is simple
- readily available of sand media
- supervision is minimal and simple
- the effluent is less corrosive and more uniform in quality than chemically treated waters
- effective bacterial removal

and the disadvantages are

- large area required, with correspondingly large structure and volume of sand and high construction costs
- less flexibility in operations
- not economical for raw waters above 30 NTU for prolonged periods – needs preliminary treatment
- less effective in colour removal
- poor results with water of high algal content, unless pretreatment is done
Thus in general this type of filters are use for small works in which the raw water is less than 20 NTU. In Sarawak, some rural treatment works use this type of filters where the source is mountain stream (less than 10 NTU) and no chemicals are added. The process is simple and minimal supervision is required.

**Rapid Gravity Filters**

Rapid gravity filters uses coarser media and thus operates at higher-loading rates. Filtration is by physical process alone. With the use of granular activated carbon (GAC), some chemical absorption takes place. Coagulation is normally required to ensure that the smaller particles can be removed more effectively. Simple filters use single medium. Normally sand is the main media, but multimedia filters are common. Filters are cleaned by reversing the flow of water through the filters, to wash out the dirt (Binnie *et al.* 2002). For more effective cleaning, backwashing is achieved with water and compressed air. However some modern rapid sand filter incorporates the use of mechanical agitators in the backwashing process.

Most treatment plants uses rapid sand filters although the design can vary in shape and sizes, but the principle is the same. Nowadays it is common to use multi media with the top layer being granular activated carbon (GAC).

**Pressure Filters**

Pressure filters are a form of rapid gravity filters but operate under pressure in a large closed vessel. Traditionally they have been used on groundwater sources where water is
pumped directly through the filter into distribution, without any need for re-pumping. They are sometimes used for surface sources, normally on small plants (Binnie et al., 2002). Cox, 1973 summarized the weakness of pressure filters as below

- the treatment of water under pressure seriously complicates effective mixing, coagulation, and sedimentation of the water to be filtered
- it is more difficult to apply chemicals to water under pressure
- it is difficult to inspect, clean, and replace the sand, gravel and underdrains of pressure filters

The advantage of pressure filters is the convenient of factory installation and easily shipped to site for smaller works.

A2.6 DISINFECTION

The treatment process of coagulation, flocculation, clarification and filtration cannot completely remove small size microorganism (Tebutt, 1998). Thus the presence of viruses and bacteria contamination is a risk without disinfection. Disinfection is the last treatment process in a treatment plant to produce safe potable water (Binnie et al., 2002).

It is important to differentiate between disinfection, which is the killing of potentially harmful organism, and sterilization, which means the killing of all organisms (Tebutt, 1998). Potable water supplies are normally disinfected and sterilized waters are only used for medical or pharmaceutical purposes (Tebutt, 1998). The disinfectant used must kill the organisms of concern while not being harmful or toxic to humans (Binnie et al., 2002). The disinfection of potable water is almost universally accomplished by the use of
gaseous chlorine or chlorine compounds (Cox, 1973). However there are other disinfectant such as ozone, ultraviolet (UV) and bromine.

It is believed that chemical oxidants kill bacteria by rupturing cell membranes and destroying enzymes. There are many variables in the disinfection process, like the organisms to be killed, nature of the disinfectant, concentration of the disinfectant, contact time, temperature and quality of the water. Chlorination can kill essentially all bacteria and viruses, although some are more resistant than others. *E.Coli* is considered more resistant than most pathogenic bacteria and viruses and hence is used as an indicator organism (Binnie *et al*., 2002).

**Chlorination**

Chlorination is the most common form of disinfection because it

- is readily available as gas, liquid, or powder
- is cheap
- is easy to apply due to relatively high solubility (700mg/l)
- leaves a residual in solution which are not harmful to humans, provides protection in the distribution system
- is very toxic to most microorganisms, stopping metabolic activities

(Tebutt, 1998)

Although chlorine is widely used as a disinfectant, it has its shortcomings too. Chlorine gas is a poisonous gas and requires careful handling and can produce disinfection-by-
products (DBPs) which may give rise to tastes and odours and long-term health hazards (Tebutt, 1998). To reduce the leakage hazard, there has been development of on-site electrolytic chlorine (OSEC) generation. Electrolysis of 3 percent brine will produce a 1 percent solution of sodium hypochlorite (Tebutt, 1998).

There are two alternatives of chlorination, by use of gaseous chlorine (which dissolve in carrier water before being added to the water to be treated) and by use of solution of sodium hypochlorite. Chlorine gas is usually supplied as a liquefied gas in cylinders or drums. The gas is extracted by vacuum created by pump and dose via a chlorinator. Sodium hypochlorite is in the form of powder and dissolved in water as a chlorine solution. Dosing is by gravity doser (small works) or more commonly by metering pumps.

When added to water chlorine reacts to form hypochlorous acid and hypochlorite (Smethurst, 1988).

\[
\text{Cl}_2 + \text{H}_2\text{O} \leftrightarrow \text{HClO} + \text{H}^+ + \text{Cl}^-
\]

The hypochlorous acid (HClO) and hypochlorite (ClO⁻) together represent the ‘free available chlorine’, which is a very powerful bactericide (Smethurst, 1998). Hypochlorous acid is the more effective disinfectant. The disassociation of HClO is suppressed at low pH value and at below pH 5, the residual being all HClO, half HClO at pH 7.5 and all ClO⁻ at pH 9 (Tebutt, 1998). Thus the most effective disinfection occurs at acidity conditions. pH adjustments purely for disinfection is however not common.
If ammonia is present, either naturally or because it has been added, chloramines will be formed as follows

\[ \text{NH}_4 = \text{HClO} \leftrightarrow \text{NH}_2\text{Cl} + \text{H} + \text{H}_2\text{O} \quad \text{(monochloramine)} \]

\[ \text{NH}_2\text{Cl} + \text{HClO} \leftrightarrow \text{NHCl}_2 + \text{H}_2\text{O} \quad \text{(dichloramine)} \]

\[ \text{NHCl}_2 + \text{HClO} \leftrightarrow \text{NCl}_3 + \text{H}_2\text{O} \quad \text{(trichloramine)} \]

(Smethurst, 1988).

The formation of the three types of chloramines depends on pH and concentration of NH\(_4\). Trichloramine can only form at very low pH thus dichloramine and monochloramine prevail and is referred to as ‘combined available chlorine’ (Smethurst, 1998). The addition of ammonia to intensify the effect of disinfection is fairly common, however the current trend is in favor of ‘break-point’ chlorination. Break-point chlorination is simply the increase in dosage of chlorine until free residue chlorine is formed. Beyond the break point, free residue chlorine is proportional to the dose (Tebutt, 1988).

**Superchlorination** (Binnie et al., 2002)

Superchlorination is the most effective and safe form of chlorination. This is because breakpoint chlorination is affected by various factors and thus tedious to determine. Break point for most water should not exceed 0.3mg/l but can be much higher depending on quality and other factors. In superchlorination, sufficient chlorine is dosed to ensure breakpoint is passed\(^3\). This method is most preferred as it is the safest method of disinfection. The disadvantage of superchlorination is that consumers can smell and taste

---

\(^3\) In Sarawak chlorine is usually dosed between 1.5-2.0 mg/l at the treatment plant.
the chlorine. One way to overcome this is to allow sufficient contact time to ensure full disinfection and then dechlorinate. This can be done by dosing sulphur dioxide, which reduced the chlorine to chloride, lowering the free chlorine to around 0.5mg/l.

**Ozone** (Tebutt, 1998)

Ozone (O₃) is an allotropic form of oxygen produced by passing dry oxygen or air through an electrical charge (5000-20000V, 50-500Hz). It is unstable, highly toxic blue gas with a pungent odour. Ozone is a powerful oxidizing agent and efficient disinfectant. It is unstable and thus leaves no residual. Because of this, small dose of chlorine is usually added after ozonization. Ozonization is an expensive process due the high energy required to produce and is a very efficient disinfectant and useful in removal of colour, odour and taste. Ozone is more powerful disinfectant than chlorine and a typical requirement is 0.4 mg/l residual after 4 minutes contact. *Cryptosporidium* oocysts are inactivated at 0.2 mg/l ozone after 10 min contact and *Giardia* cysts are inactivated after 1 min at 0.5 mg/l.

**Ultraviolet Radiation**

The disinfection action of UV at wavelength of around 254nm is quite strong provided that the organisms are actually exposed to the radiation. Thus low turbidity is essential for effective disinfection by UV. The water to be disinfected flows between mercury arc discharge tubes and polished metal reflector tubes which give efficient disinfection with a retention time of a few seconds. UV disinfection leaves no taste or smell and requires minimum maintenance, easy automatic control with no danger of over dosing. The
disadvantages are lack of residual, high cost and the need for high clarity in water. The strongest point is that UV disinfection has no disinfection-by-products (DBP).

**Disinfection By-Products (DPB) and other Hazards**

Chlorination is widely used disinfection but there are hazards to its uses. The formation of trihalomethanes (THM) associated with dosing chlorine in water with high organic content is of great concern. THMs are formed by reaction between halogens and organic matter in water, in particular the humic and fluvic acids found in peaty-coloured water. (Binnie *et al.*, 2002). Beside this, there is also hazards associated with the transportation of cylinders and drums of chlorine and the dosing facilities at treatment plants. Treatment plants that uses chlorine gas are labeled hazard area and must have safety facilities and for some bigger works, a scrubber system.

Ozone is a highly toxic gas and thus care has to be taken on the facility that produces it. Ozone will react with organic matter to form ozonides in certain conditions and the significance of the presence of these products in water is not fully understood (Tebutt, 1998). Any bromine in the water will be converted by ozonization to bromate which is potentially a long-term health risk (tebutt, 1998).

UV radiation seems to be the safest form of disinfection with no known DBPs and non-toxic to humans. However as discussed earlier, the water needs to be of high clarity for the effective disinfection.

**Other Disinfectants** (Tebutt, 1998)

- heat
• silver- 0.05mg/l is toxic to most microorganisms.

• Bromine- similar properties to chlorine and sometimes used in swimming pools where it is less irritating to the eyes

• Iodine- similar to bromine but is not used for public water supplies

• Membranes- microfiltration and ultrafiltration are capable of removing particles in the range of $10^{-2}$ to 5µm, which covers the size of most microorganisms of importance in water quality.
A3 WATER SAMPLING PROTOCOLS (Ministry of Health, Malaysia)

A3.1 SAMPLING METHODS

The following water sampling protocol is extracted, compiled and translated from the Drinking Water Quality Monitoring Program prepared by the Public Health Branch, Engineering Services Division of the Health Ministry with the cooperation from the Water Section, Public Health Division of the Malaysian Chemistry Department¹.

The Drinking Water Quality Monitoring Program (DWQMP) was first introduced in 1984. In 1996 the Health Ministry introduced the ‘Multiple Sampling’ protocol with the objective to ensure that the samples send for analysis by the chemistry department contain the correct preservatives and sampled using the correct sampling techniques in order to obtain actual and reliable analysis results.

A3.1.1 Preservation of Water Sample

The aim of preservation of the water sample is to ensure that the sample is ‘original’ and to stabilize the parameter to be tested. In practice, complete preservation is impossible. Preservation techniques involved addition of chemicals to delay and slow down the chemical and biological reaction after sampling. In most cases, cooling the water samples (4°C) would retard and reduce the reaction and assist in preservation. Water, naturally would change through physical, biological and chemical process with ease from the time sample was taken to the time it was analyzed in the

¹ The sampling protocol is in Bahasa Malaysia and applies for Malaysia. The following protocol was compiled and translated into English (relevant topics applicable to the State of Sarawak).
Appendix A3 – Water Sampling Protocols

laboratory. Thus parameters like temperature, pH, colour, turbidity, dissolved oxygen, residue chlorine and conductivity would change quickly through physical activities need to be analyzed in-situ.

<table>
<thead>
<tr>
<th>Bottle</th>
<th>Type/Size</th>
<th>Parameter</th>
<th>Preservatives</th>
<th>colour sticker</th>
<th>storage temp.</th>
<th>Holding Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2 oz (60ml)</td>
<td>Chemical Group 2 and 3</td>
<td>5 Drops (1+1) HNO₃ to pH less than 2</td>
<td>Blue</td>
<td>4-10 °C</td>
<td>6 months</td>
</tr>
<tr>
<td>B</td>
<td>2 oz (60ml)</td>
<td>F, Cl, SO₄</td>
<td>no preservatives</td>
<td>White</td>
<td>4-10 °C</td>
<td>28 days</td>
</tr>
<tr>
<td>C</td>
<td>500 ml round plastic</td>
<td>BOD</td>
<td>no preservatives fill bottles completely</td>
<td>White</td>
<td>4-10 °C</td>
<td>48 Days</td>
</tr>
<tr>
<td>D</td>
<td>2 oz (60ml) amber glass</td>
<td>TOC</td>
<td>5 Drops (1+1) HCl to pH less than 2</td>
<td>Red</td>
<td>4-10 °C</td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>2 oz (60ml) amber glass</td>
<td>NH₃, NO₂+NO₃</td>
<td>3 Drops (1+1) H₂SO₄ to pH less than 2</td>
<td>Yellow</td>
<td>4-10 °C</td>
<td>28 Days</td>
</tr>
<tr>
<td>E2</td>
<td>2 oz (60ml) amber glass</td>
<td>COD</td>
<td>3 Drops (1+1) H₂SO₄ to pH less than 2</td>
<td>Yellow</td>
<td>4-10 °C</td>
<td>7 Days</td>
</tr>
<tr>
<td>G</td>
<td>2 oz (60ml) amber glass with TFE-lined cap</td>
<td>THM</td>
<td>5 Drops (1+1) HCl to pH less than 2</td>
<td>Red</td>
<td>4-10 °C</td>
<td>14 Days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Add 5 drops 10% Sodium Thiosulphate (Chlorinated water)</td>
<td>Oren</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>2 oz (60ml) plastic</td>
<td></td>
<td>3 Drops 10% sodium hydroxide (NaOH)</td>
<td>Purple</td>
<td>4-10 °C</td>
<td>14 Days</td>
</tr>
<tr>
<td></td>
<td>Sterile plastic thiobag 100ml</td>
<td>Total Coliform Faecal Coliform</td>
<td>Sodium Thiosulphate for chlorinated water</td>
<td>White Tag</td>
<td>4-10 °C</td>
<td>6- 24 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>no preservatives for raw water</td>
<td>Yellow Tag</td>
<td>4-10 °C</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>1 litre amber glass bottle with TFE lined Cap</td>
<td>Pesticide</td>
<td>Add 1000mg Ascorbic Acid if there is residue chlorine</td>
<td>Green</td>
<td>4-10 °C</td>
<td>7 Days</td>
</tr>
</tbody>
</table>

Table A2.2 Water Sampling Preservatives Protocol

Chang, 2003
A3.1.2 Sampling Consumables

<table>
<thead>
<tr>
<th>Container</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B, H</td>
<td>2 oz (60ml) plastic square bottle with leak proof stopper</td>
</tr>
<tr>
<td>C</td>
<td>500ml round plastic bottle with stopper</td>
</tr>
<tr>
<td>D, E1, E2</td>
<td>2 oz (60ml) amber glass with stopper</td>
</tr>
<tr>
<td>Sterile Thio bag</td>
<td>100 ml thiobag, plastic with sodium thiosulphate (treated water) and without sodium thiosulphate (raw water)</td>
</tr>
<tr>
<td>G</td>
<td>2 oz (60ml) amber glass with Teflon-lined cap</td>
</tr>
<tr>
<td>K</td>
<td>1 litre amber glass bottle with Teflon-lined cap</td>
</tr>
<tr>
<td>Acid preservative stock solution</td>
<td>500ml Wheaton bottle, amber glass, narrow mouth with Teflon-lined cap</td>
</tr>
<tr>
<td>Acid preservative for in-situ use</td>
<td>60-100 ml polypropylene bottle with stopper</td>
</tr>
</tbody>
</table>

Table A2.3 Water sampling bottles and preservatives bottles specification

Chemical Analysis Sampling

Colour sticker

- The usage of colour sticker is to ensure correct usage of preservatives to the sampling bottles
- The colour sticker must be of water resistant and of permanent label for easy identification
- Ensure that the sticker is stuck on properly and not easily ‘peeled-off’
Appendix A3 – Water Sampling Protocols

<table>
<thead>
<tr>
<th>Preservatives</th>
<th>Sticker Colour</th>
<th>Water Sample Bottle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitric Acid (HNO₃)</td>
<td>Blue</td>
<td>A</td>
</tr>
<tr>
<td>Hydrochloric Acid (HCl)</td>
<td>Red</td>
<td>D</td>
</tr>
<tr>
<td>Sulpuric Acid (H₂SO₄)</td>
<td>Yellow</td>
<td>E1 and E2</td>
</tr>
<tr>
<td>Ascorbic Acid</td>
<td>Green</td>
<td>K</td>
</tr>
<tr>
<td>Sodium Hydroxide 10%</td>
<td>Purple</td>
<td>H</td>
</tr>
<tr>
<td>Sodium Thiosulphate (Na₂S₂O₃)+HCl</td>
<td>Red/Orange</td>
<td>G</td>
</tr>
<tr>
<td>No Acid preservatives</td>
<td>White</td>
<td>B and C</td>
</tr>
</tbody>
</table>

Table A2.4 Sticker colour and sampling bottle

Note: Sample bottle G use two types of preservatives

Bactological Water Sampling

Use 100ml sterile thiobag for both raw and treated water

- Sterile 100ml thiobag with yellow tag without sodium thiosulphate is used for raw water
- Sterile 100ml thiobag with white tag with sodium thiosulphate preservative is used for treated water

Cool-Box

The specifications for cool box are as follows

1) Water resistant
2) Chemical resistant
3) Corrosion resistant

Chang, 2003
Appendix A3 – Water Sampling Protocols

4) Robust

5) The cover must be air tight to prevent warm air to get into the cool-box

6) The construction must be of double wall and have good insulation

7) Ensure that the ice-pack is clean and freezed prior to collection of water samples

8) Wash the cool-box with water and disinfect with 0.5% Sodium Hypochloride if necessary

A3.1.3 Collection of Water Sample

Procedure before sample collection

Plan the collection to be in the morning to ensure that the collected samples can arrive at the laboratory at the required time.

Prepare the following consumables to bring to site

1) Water sampling bottles and sterile thiobag

2) Correct preservatives

3) S1, S2 and S3 forms and complete the required information

4) Colour sticker

5) Cool-Box which is clean with ice packs

6) Plastic bags for water sample bottles

7) Reference temperature bottle containing tap water for laboratory record of the samples temperature

8) Equipments required for testing physical parameters

Chang, 2003
Procedure for field sampling

1) The storage and sending of the water samples and the preservatives are required to be at the correct temperature to ensure reliable analysis results

2) Collection of field samples is the responsibility of the health inspector and his assistant\(^2\)

3) Collect the samples from the designated sampling points using the correct ‘clean’ sampling container

4) Ensure that the sampling protocol is followed closely to avoid obvious changes in the composition of the samples prior to sending to laboratory

5) Avoid any contamination arises from the sampler, sampling container and cross contamination

6) For chemical analysis, rinse the bottles 2-3 times with the water samples before collection to avoid contamination and to get rid of any dust form the container

7) Let the water flow for 2-5 minutes to flush out the sediments from the pipe (10 minutes for pipe which is seldom used)

8) Ensure that the water flow into the bottles without touching the ‘mouth’ of the bottle

9) Fill the bottle with flow running in a ‘gentle stream’ to avoid turbulence and air bubbles

---

\(^2\) In the State of Sarawak, due to shortage of medical staff, the staff of the Public Works Department collects the water samples. This gives rise to some problems and shortcomings for the sampling protocol.
Collection of Water samples for Physical Analysis (Group 1)

1) Carry out the physical parameter analysis immediately in-situ. The parameters are pH, residue chlorine, turbidity, colour, dissolved oxygen, and conductivity.

2) The required test kits for physical parameter analysis are as follows

<table>
<thead>
<tr>
<th>Physical Parameter</th>
<th>Water Quality Field Test Kits</th>
<th>Calibration Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>pH meter</td>
<td>pH 4.0 and 7.0</td>
</tr>
<tr>
<td>Residue chlorine</td>
<td>Pocket chlorimeter</td>
<td>For accuracy check:</td>
</tr>
<tr>
<td></td>
<td>Spectrophotometer DR2000</td>
<td>Chlorine standard bet 2.0 and 5.0 mg/l as Cl₂</td>
</tr>
<tr>
<td>Colour</td>
<td>Lovibond comparator</td>
<td>-</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Turbidimeter</td>
<td>Formazin primary standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stabcal and Gelex secondary standard</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>DO meter</td>
<td>Dilute to half a saturated solution of reagent grade KCl</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Conductivity/TDS meter</td>
<td>Sodium solution standard 1000 mg/l</td>
</tr>
</tbody>
</table>

Table A2.5 Physical parameter field test kits

3) The water quality field test kits needed to be calibrated prior to their uses at site

4) Fill in the readings form the test kits to Form S1 before sending the water samples to the laboratory
Water sampling for Bacteria parameter

1) Use antiseptic condition for the collection and handling of water samples for bacteria analysis

2) Avoid any contamination to water sample during collection from the atmosphere, ground, hands or contaminated thiobags

3) For treated water, disinfect the pipe with heat using a blow-torch/70 % alcohol

4) Take the physical reading first, ie. pH, residue chlorine (treated water) and turbidity and fill them into form S1

5) Water sample for bacteria analysis is to be collected from service pipe/main and not from tanks or storage tanks

Use of thiobag

1) Use thiobag which is clean, sterile and not expired

2) For treated water, use thiobag with white tag with sodium thiosulphate to neutralize the chlorine

3) For raw water, use thiobag with yellow tag without sodium thiosulphate

4) Carefully open the cap of the thiobag. Avoid contact and place thiobag under water pipe

5) Fill the thiobag until the level marked ‘FILL LINE’ 100 ml without rinsing. Close the lid, with at least 3 turns and tied up

6) Ensure there is air space on the top part to allow mixing during bacteria inoculation analysis in laboratory
7) Label the thiobag with all the required information: station number, time sample taken, date and reference number.

Procedure to avoid contamination of sterile thiobag

1) Avoid thiobag exposed to the atmosphere for long periods

2) Avoid
   a. Form hands contact to opening of thiobag
   b. Placing thiobag on dirty surface
   c. Getting thiobag wet on the outside

Collection of Water Sample from Service Pipe

1) Clean the pipe of any dirt sticking

2) Let the water from pipe runs for 2-5 minutes before collecting the sample. For pipe with low water pressure, allow water to run for at least 5 minutes to get rid of sediments in pipe

3) For metal pipe, disinfect with heat by using a blow-torch or wipe using cotton wool with 70% alcohol and heat

4) For plastic pipe and UPVC pipe, wipe with 70% alcohol

5) Allow water to run for 1-2 minutes with medium flow before collecting sample

6) Ensure the alcohol bottle is closed tight after use
Collection of Water Sample from river/well/pond/lake

1) Clean the metal pail form any dirt

2) Pour a little alcohol (70%) to the pail, ignite and let the alcohol burn and disinfect the pail

3) Pour 70% alcohol into a tray, and place the pail in the tray. Burn the wall of pail to disinfect the outside of the pail

4) Lower the pail into the river/well/pond/lake and ensure that the rope does not touch the inside of the pail. When the pail is full carefully lift the pail

5) Open the thiobag carefully and fill the thiobag with the sample form the pail. Close the thiobag and tie it tightly

6) Clean the pail before storage

Note: alcohol used- ethyl or methyl alcohol

Collection of Water Sample for Chemical Analysis

Water sample for chemical analysis is collected by various containers (plastic, amber glass) and different types of preservatives depending on the parameter to be analyzed.

Containers for chemical water samples

The correct type of containers for chemical parameters analysis of water samples is important.

1) Use plastic bottle for water samples for inorganic analysis

2) Use glass bottle for water samples for organic and total organic. For organic sampling, avoid plastic bottles except polytetrafluorethylene (TFE).
3) The bottle cap make of plastic lined with foil or TFE is to be avoided for organic samples.

Collection of water sample for chemical analysis

1) Prepare and ensure enough sampling bottles for the various chemical tests and stations.

2) Use the correct bottles, preservatives and colour sticker.

3) Use new and clean bottles. To avoid contamination, do not use recycle bottle.

4) For all water samples except organic matter, rinse the new bottles and the cap with the water samples 2-3 times to minimize contamination, dust and ‘residue packing material’. This would assist the sample to be ‘balanced’ and minimize ‘container effect’.

5) For organic matter samples, ensure that the bottles are clean. Rinse the bottle once only to avoid accumulation concentration on the walls of the containers due to adsorption.

6) While carrying out sampling for vapour organic mixture and THM, tilt the bottle a little and fill in the sample slowly to avoid bubbling.

7) Fill the bottle until full and do not have any air space on top so that the water sample do not shake during transportation to laboratory especially for organic water sample which easily vaporize. This also prevents any changes of CO₂, pH, and colour due to dissolved gas oxidation, sediments, etc.
8) Add acid preservative into the bottles after the water sample has been filled. Ensure that the correct preservative is added into the bottle. (Do not add acid preservatives into an empty bottle).

9) Close the cap and overturn the bottle to mix the acid preservative and water sample.

10) Ensure the cap is closed tightly to avoid spillage during transportation.

11) Place the correct sticker on the sampling bottle. Fill in the required information on the sticker.

12) Place the water sample bottles from one station into a plastic bag before putting them in the ‘cool-box’.
A3.1.4 Transportation of Water Samples to Laboratory

- All water samples send to Chemistry Department for analysis should reach the laboratory at a temperature between 4-10°C.

- The ice-box can be cooled by using ‘freeze ice pack’ to the required temperature.

- Frozen water samples would be rejected for analysis.

- Place the temperature reference bottle in the ‘cool-box’ before sampling activities proceed.

Transportation of Bacteria Water Sample

1) Bacteria Water samples have to reach the laboratory within 24 hours.

2) Avoid exposing the water samples to sunlight.

3) Separate the raw water thiobag from the treated water thoibag in the ‘cool-box’ to avoid cross contamination.

4) Place the thiobag vertically in the ‘cool-box’. Do not place the thiobag horizontally and use appropriate rack if necessary.

5) Ensure the thiobags are not broken in the ‘cooler-box’ during transportation. Torn thiobags would be rejected.

6) Send the bacteria water samples to the laboratory within the same day or within 24 hours.

7) Ensure that the samples reached the receiving counter of Chemistry Department before 3.30pm. This is because the laboratory staffs need to carry out the analysis on the same day.
Appendix A3 – Water Sampling Protocols

Transportation of Chemical Water Sample

1) Send the water samples for chemical group 2 and 3 analysis straight to branches of Chemistry Department.

2) Close the cap of the bottles tightly to ensure no spillage of the samples during transportation and when receiving at the counter of Chemistry Department.

3) Water samples can be sent using enough ‘freeze icepacks’ in the ‘cooler-box’. ‘Freeze icepacks need to be placed at the bottom, side and on the top to ensure that the temperature is between 4-10°C when received at the counter.

4) For any samples that could not be sent on the same day, store the samples in a refrigerator (not in the freezer compartment).

5) Handle the ‘cool-box’ with care during transportation and handing over to the receiving counter to avoid breakage of the bottles. Ensure that the ‘cool-box’ is not shaken too much.

Handing of Water Samples at Receiving Counter of Chemistry Department

1) The samples need to hand in to the receiving counter before it closes (1530 hours).

2) Check the number of samples with the information written on the request form.

3) Arrange the water samples following the arrangement in the request analysis form as S1/S2/S3/S4.

4) The staff of Chemistry Department would measure the temperature of the temperature reference bottle and record it on the request analysis form.

5) Take the copy of the request analysis form after it has been certified by the staff at the receiving counter.
6) Check whether the results of previous analysis have been completed and if so take a copy of the results.

Sending of Special Water Samples to Chemistry Department

- This request needs to be discussed with the Chemist of the Chemistry Department on the sending schedule prior to sending, i.e. how many samples, who would be sending the samples, and what time the samples would arrive at the Chemistry Department.

- Prepare an official letter containing information of the samples including the justification and need for the special sampling.

- Coordination with the different agencies at State level need to be done to avoid repeated sampling and following of wrong protocol.

- Provide summary to appropriate parameter in crises case, thus information need to send to the Chemistry Department.

- Sampling to follow protocol.

- Ensure the samples are marked specially to allow for easy identification.

- Inform the Chemistry Department immediately if the samples would be late arriving.

- Ensure that the bottle label and the request analysis contain the same information.

- Only health inspector/assistant can send the samples

- Obtain certified copy of request form as prove.
A3.1.5 Using and Filling of Forms

1) Use the correct analysis request form together
   - Form S1- Bacteria analysis request form.
   - Form S2- Chemical analysis request form (Group 2 only).
   - Form S3- Chemical analysis request form (Group 2 and 3).
   - Form S4- Pesticide analysis request form.

2) Fill in the reading of the in-situ test for the physical parameters in Form S1 for residue chlorine, pH, turbidity, and colour. Leave the total coliform and faecal coliform column blank. The bactological laboratory of the Chemistry Department would fill this.

3) Form S2 is only for chemical analysis request for parameters in group 2 and Form S3 is for chemical request for parameters in group 2 and 3.

4) All forms are required to be completed in duplicate.

5) All forms must be completed correctly, clearly with readable writing.

6) Use waterproof pen (ballpoint).

7) Fill in the station code.

8) Fill in the section code in ascending order. Mark the code on the water sample bottle. Do not replace section code of old sampling point no longer in use with new sampling point.

9) The analysis request forms have to be completed with signature of the sampler, name, telephone and fax number for easy contact if there is any enquiries.

10) Ensure the analysis request forms are kept properly and do not get in contact with the ice-pack, torn or crumple.
11) Ensure that the number of water sample bottles correspond to the analysis request form.

**A3.1.6 Water Sample Analysis Results**

**Bacteria Analysis Result**

1) For bacteria analysis result, violation of the mandatory standard would be notified within 4 days and the results would be faxed to the station concerned.

2) Full monthly analysis results in batches would be available within 7 days of the following month.

3) Follow up action should be taken with the Chemistry Department if the result of analysis were not available within the set time frame.

**Chemical Analysis Result**

1) For chemical analysis, violation of the standard would be notified within 14 days by fax after the samples have been sent.

2) If there were no violation, the result of the analysis would be sent by batches within 14 days of the following month.

3) Follow up action should be taken with the Chemistry Department if the result of analysis were not available within the set time frame.

4) For serious crisis cases, the result would be available as soon as the analyses are completed.
A3.1.7 Water Sampler

Under the drinking water quality monitoring program (DWQM), medical staff that carry out the duties of water sampling should be trained Health Inspector or General Health Assistant. All medical staff handling the water samples and water sample preservatives under the DWQM program must comply with the guidelines or manual of the Health Ministry. If there were any amendments in the guidelines, the Engineering Division would notify through circulars. New medical staffs are encouraged to undergo continuous training in order to improve their skills for the DWQM program.
A3.2 ANALYTICAL METHODS

The water samples are all tested in the laboratory of the Chemistry Department in Kuching and Bintulu branches. The laboratories are ISO 2000 accredited lab. The following informations are obtained from the Department on the methods and techniques for testing the water samples.

<table>
<thead>
<tr>
<th>TYPE OF TEST</th>
<th>STANDARD TEST METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>APHA 4500 – CL B</td>
</tr>
<tr>
<td>Total Dissolved Solids Dried at 180°C</td>
<td>APHA 2540 C</td>
</tr>
<tr>
<td>THM</td>
<td>APHA 6232 B</td>
</tr>
<tr>
<td></td>
<td>Liquid – Liquid Extraction and Gas Chromatography</td>
</tr>
<tr>
<td>THM</td>
<td>EPA 502.2</td>
</tr>
<tr>
<td></td>
<td>Purge and Trap Gas Chromatography</td>
</tr>
<tr>
<td>Ammonia</td>
<td>APHA 4500 – NH3F</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>APHA 5220 C</td>
</tr>
<tr>
<td>Anions : Chloride, Flouride, Nitrate and</td>
<td>APHA 4110 B</td>
</tr>
<tr>
<td>Sulphate</td>
<td>Ion Chromatography with chemical suppression of Eluent Conductivity</td>
</tr>
<tr>
<td>Total Coliform and Faecal Coliform</td>
<td>Methods for the Examination of Waters and Associated Materials, 3rd Impression 1984, Multiple Tubes Method ID. JKM- M2032 Membrane Filter Test Method for</td>
</tr>
<tr>
<td>Parameter</td>
<td>Method/Technique</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Detection and Identification of Coliform Bacteria and Eschericha Coli in water</td>
<td>APHA 5210 B</td>
</tr>
<tr>
<td>BOD</td>
<td>APHA 5220 B</td>
</tr>
<tr>
<td>COD</td>
<td>APHA 5310 B</td>
</tr>
<tr>
<td>Metals: Cd, Cr, Cu, Fe, Mn, Mg, Pb, Zn</td>
<td>APHA 3111 B</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>APHA 5310 B</td>
</tr>
<tr>
<td>Total Solids</td>
<td>APHA 2540 B</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>APHA 2540 D</td>
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<tr>
<td>Total Dissolved Solids</td>
<td>KEC 009 (Calculated From Difference of Total Solids and Suspended Solids)</td>
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<tr>
<td></td>
<td>APHA 4500-H+B</td>
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<tr>
<td></td>
<td>AIR 007</td>
</tr>
<tr>
<td></td>
<td>Determination of TDS in raw and treated water by TDS/Conductivity Meter</td>
</tr>
<tr>
<td>pH</td>
<td>APHA 3112 B</td>
</tr>
<tr>
<td>Hg</td>
<td>Cold Vapour Atomic Absorption Spectrometry</td>
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<tr>
<td>Colour</td>
<td>APHA 2120 B</td>
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<tr>
<td></td>
<td>Visual Comparison</td>
</tr>
<tr>
<td>Pb</td>
<td>KES 005- Analyst, Vol 109, 1994 Pg. 507-510 AAS</td>
</tr>
</tbody>
</table>

Table A2.6 Methods and techniques for testing water samples

APHA-American Public Health Association
### WATER TREATMENT PLANT STATISTICS (as at 2002)

<table>
<thead>
<tr>
<th>Water Treatment Plant</th>
<th>Source Type</th>
<th>Source Name</th>
<th>Treatment Type</th>
<th>Design Capacity (MLD)</th>
<th>Production (MLD)</th>
<th>Estimated Population Served</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pantu</td>
<td>Peat</td>
<td>Sg. Sterap</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.153</td>
<td>1326</td>
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<tr>
<td>2 Lingga</td>
<td>Peat</td>
<td>Sg. Stugok</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.23</td>
<td>1492</td>
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<tr>
<td>3 Spaoh</td>
<td>Peat</td>
<td>Sg. Pakasi</td>
<td>Conventional</td>
<td>1.32</td>
<td>1.016</td>
<td>4597</td>
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</tr>
<tr>
<td>4 Beladin</td>
<td>Peat</td>
<td>Sg. Dumit</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.621</td>
<td>3188</td>
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<tr>
<td>5 Maludam</td>
<td>Peat</td>
<td>Sg. Maludam</td>
<td>Conventional</td>
<td>1.62</td>
<td>0.547</td>
<td>4285</td>
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<tr>
<td>6 Pusa</td>
<td>Peat</td>
<td>Sg. Undai</td>
<td>Membrane</td>
<td>2.10</td>
<td>1.115</td>
<td>4924</td>
<td>Micro membrane Filter</td>
</tr>
<tr>
<td>7 Kabong</td>
<td>Ground Water</td>
<td>Ground Wells</td>
<td>Enhanced</td>
<td>0.66</td>
<td>0.645</td>
<td>4945</td>
<td>Tower aerator</td>
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<tr>
<td>8 Stumbin/Bijat</td>
<td>Peat</td>
<td>Sg. Stumbin</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.49</td>
<td>3567</td>
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<tr>
<td>9 Igan</td>
<td>Ground Water</td>
<td>Sg. Lasai Dagan</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.403</td>
<td>2324</td>
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<tr>
<td>10 Oya</td>
<td>Ground Water</td>
<td>Btg. Benutus</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.716</td>
<td>5122</td>
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<td>11 Kut</td>
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<td>Sg. Lasai Dagan</td>
<td>Conventional</td>
<td>0.66</td>
<td>0.137</td>
<td>993</td>
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<td>12 Kuala Balingian</td>
<td>Peat</td>
<td>Btg. Balingian</td>
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<td>0.119</td>
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<td>13 Beluru</td>
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<td>Sg. Bakong</td>
<td>Enhanced</td>
<td>0.66</td>
<td>0.946</td>
<td>1721</td>
<td>Tower aerator</td>
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<td>14 Kuala Lawas</td>
<td>Peat</td>
<td>Btg. Lawas</td>
<td></td>
<td>0.80</td>
<td>0.238</td>
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<tr>
<td>15 Kampung Tian</td>
<td>Peat</td>
<td>Sg. Mabun</td>
<td>Conventional</td>
<td>0.82</td>
<td>0.267</td>
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<tr>
<td>17 Matu</td>
<td>Peat</td>
<td>Btg. Jemorong</td>
<td>Conventional</td>
<td>1.31</td>
<td>1.783</td>
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<td>0.151</td>
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<td>20 Asajaya</td>
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<td>Enhanced</td>
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<td>Sg. Sebuyau</td>
<td>Enhanced</td>
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<td>Cascade aerator</td>
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<td>22 Sebangan</td>
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<td>0.66</td>
<td>0.437</td>
<td>1799</td>
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</tbody>
</table>

**SOURCE:** WATER SUPPLY BRANCH, JKR SARAWAK
Water Supply Statistics – JKR Sarawak

- At present there are 88 gazetted water supply authorities under the jurisdiction of JKR Sarawak. This compares with 82 gazetted water supply authorities at the beginning of 1996.
- The total production and consumption as at the end of 2000 are 120MLD and 95MLD respectively. This compares with the total production and consumption of 90MLD and 70MLD respectively at the beginning of 1996.
- The design capacity has increased from 153MLD to 185.55MLD.
- The recurrent expenditure and revenue for year 2000 are RM43,109,900 and RM19,996.25 respectively. This compares with the total recurrent expenditure and revenue of RM35,974,600 and RM21,062,180 respectively for the year 1996.
- The development expenditures for 1995 were RM63,427,585 and for 2000 was RM93,597,770.
- The total number of meter connections has increased from 71,967 as at the beginning of 1996 to 94,747 as at the end of 2000.
- The above are summarized in the table below:

<table>
<thead>
<tr>
<th>Items</th>
<th>Year 1996</th>
<th>Year 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nos. of gazetted water supply authorities</td>
<td>82</td>
<td>88</td>
</tr>
<tr>
<td>Total production (MLD)</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>Total consumption (MLD)</td>
<td>70</td>
<td>95</td>
</tr>
<tr>
<td>Total design capacity (MLD)</td>
<td>153</td>
<td>186</td>
</tr>
<tr>
<td>Total recurrent expenditure (RM)</td>
<td>35,974,600</td>
<td>43,109,900</td>
</tr>
<tr>
<td>Total revenue (RM)</td>
<td>21,062,180</td>
<td>19,996.25</td>
</tr>
<tr>
<td>Total development expenditure (RM)</td>
<td>63,427,585</td>
<td>93,597,770</td>
</tr>
<tr>
<td>Total number of meter connections</td>
<td>71,967</td>
<td>94,747</td>
</tr>
</tbody>
</table>

Development Expenditures (3rd Malaysia Plan to 7th Malaysia Plan)

<table>
<thead>
<tr>
<th>Items</th>
<th>State</th>
<th>Federal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>RM1,145,772,762</td>
<td>-</td>
</tr>
<tr>
<td>Rural Water Supplies</td>
<td>RM40,876,262</td>
<td>RM126,187,573</td>
</tr>
<tr>
<td>% Rural Water Supplies</td>
<td>3.57%</td>
<td></td>
</tr>
</tbody>
</table>

- The population served are as in the tables below:

A) Piped and treated water supply

<table>
<thead>
<tr>
<th></th>
<th>End of 6MP</th>
<th>End of 7MP</th>
<th>End of 8MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Overall (% of total population)</td>
<td>57%</td>
<td>65%</td>
<td>70%</td>
</tr>
<tr>
<td>2) Urban Area (% of urban population)</td>
<td>Almost 100%</td>
<td>Almost 100%</td>
<td>100%</td>
</tr>
<tr>
<td>3) Rural Area (% of rural population)</td>
<td>45%</td>
<td>47%</td>
<td>52%</td>
</tr>
</tbody>
</table>

B) Untreated but safe water supply

<table>
<thead>
<tr>
<th>Rural Area (% of rural population)</th>
<th>End of 6MP</th>
<th>End of 7MP</th>
<th>End of 8MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.5%</td>
<td>48%</td>
<td>46%</td>
<td></td>
</tr>
</tbody>
</table>

C) Coverage in rural areas

<table>
<thead>
<tr>
<th></th>
<th>End of 6MP</th>
<th>End of 7MP</th>
<th>End of 8MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Treated water supply</td>
<td>45%</td>
<td>47%</td>
<td>52%</td>
</tr>
<tr>
<td>2) Untreated but safe water</td>
<td>46.5%</td>
<td>48%</td>
<td>46%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>91.5%</strong></td>
<td><strong>95%</strong></td>
<td><strong>98%</strong></td>
</tr>
</tbody>
</table>

Source: Suriani M. Kameri (2000)