INVESTIGATION ON HOW RAW WATER QUALITY ABSTRACTED FROM VON BACH DAM AFFECTS THE WATER TREATMENT PROCESS

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February 2013

DECLARATION

I hereby declare that this work is the product of my own efforts, undertaken under the supervision of Mr Lineekela Kandjengo and has not been presented elsewhere for the award of a degree or certificate. All sources have been duly and appropriately acknowledged.

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20th February 2013

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CERTIFICATION

This is to certify that this report has been examined and approved for the award of the degree of Bachelor of Science (Honours) in Fisheries and Aquatic Sciences of the University of Namibia.

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DEDICATION

This work is dedicated to my family, especially my mom Joséf Virginia and my sister Gaudencia Haushona who taught me to love school and science, and also my brother Volker Sikongo for his endless support and for believing in me. Even though I won't be able to pay back everything they did for me, they should know that the support they had for me was a great investment and I will always make them proud.

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ABSTRACT

The Von Bach Dam which is used for water supply for human consumption undergoes water quality changes. These could be a result of natural processes in the water body and the quality of water which is entering the reservoir. Such short term water quality changes are impacted by extreme events like floods, intense rain or seasonal changes. The purpose of the study was to determine how the treatment or chemical dosage is influenced by such water quality changes. This involved a correlation of raw water with chemicals used for treatment and analysed with simple linear regression analysis of Genstat and presented with Microsoft Excel. The results revealed a significant relationship between changes in raw water quality and the specific chemicals used for treatment; manganese and iron are oxidised by potassium permanganate, turbidity is treated using U3000, the results suggest the chemicals are influenced by the changes in raw water quality. As such, the significant difference in water quality changes has a positive correlation on chemicals used for manganese and iron. The results indicated that U3000 dosage was negatively correlated with turbidity. High concentrations of manganese (0.26 mg/l) and turbidity (4.3 NTU) were found in raw water and iron occurred in low concentrations. This implies that more chemicals would be needed to treat water accordingly.

CHAPTER ONE

1. INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

Drinking water is the most important natural resource for human consumption and therefore it must be free from pathogenic organisms and it should not possess health related risk to human beings. The term water quality refers to the suitability of water for a particular purpose (Boyd, 2000). The water quality requirements depend on its intended use, for example water intended for livestock does not have to be as high in quality as water for human consumption. Throughout human history, there were limited ways for evaluating water quality beyond sensory perception and observations of the effects that certain waters had on living things (Boyd, 2000).

Land use activities such as agriculture, mining, water transfers and wastewater discharge affects water quality. Water absorbs both natural and man-made pollutants, making it unsuitable for drinking if not treated (Gray, 2008). The problems associated with global warming leading to regional changes in climate and water availability are affecting sustainability of supplies as well as impacting on the water quality (Gray, 2008).

Water quality problems are also a concern to Namibia, the driest country in Sub-Saharan Africa. The only perennial rivers are located at the border regions of the country and more than 700 km from Windhoek, the capital city, which is centrally located. With a population of over 300 000, boreholes would be insufficient and high demand for water therefore puts a lot of strain on the supply. The Namibia Water Corporation (NamWater) is the entity assigned with the task of providing water to the Namibian population. This is primarily done through the purification plant system which supplements the existing supply of water from other sources such as the Municipality's treatment plants. The purification system involves treating water which is transferred from Swakoppoort and Omatako Dams to Von Bach Dam, before it is distributed.

Drinking water reservoirs such as Von Bach Dam predominantly guarantee long-term storage for drinking water supply. Due to seasonal changes as well as increasing additional demands on drinking water reservoirs, water suppliers are permanently facing raw water quality changes. Regardless of the numerous conflicts of interest in managing multipurpose reservoirs such as Von Bach Dam, raw water has to be provided not only at an adequate amount, but must also be of a high quality. To deal with changes in the nature of reservoir water within the process of drinking water treatment and supply, commonly used treatment technologies have to be optimized or new technologies have to be developed (Slavik and Uhl, 2009). Increasing concentrations of organic substances deteriorate the coagulation of water contaminants. The disinfection by-product formation potential and the microbial contamination within the supplying system will increase with decreasing treatment efficiencies (Slavik and Uhl, 2009).

There are concerns about possible effects on water quality of Von Bach Dam from catchment areas and water transferred from Swakoppoort and Omatako Dams, and other factors such as natural ageing of the dam which are causing changes in the water quality of Von Bach Dam over-time. These affect both the water quality in Von Bach Dam and the treatment process. Since the raw water quality of Von Bach Dam is dynamic, it may cause some differences in the amount of chemicals used for treatment. Thus the effect of the raw water quality on the treatment process is not well understood, the aims of this study is to bring knowledge and generate an understanding on how raw water quality abstracted from Von Bach Dam affects the water treatment process.

1.2. LITERATURE REVIEW

1.2.1. The effects of raw water turbidity in the water treatment process

Turbidity is the cloudiness of water caused by individual particles (suspended solids or materials) which may scatter and absorb light (Adlan *et al*., 2002). Turbidity is usually caused by the presence of clay, silt, soil particles and other impurities such as algae and other organic materials (Barnes *et al.*, 1981; Linsley *et al.*, 1992). In water treatment, the dosage of chemicals for coagulation and flocculation is much depended on the jar test, which is carried out when there is a variation in the turbidity of raw water (Adlan *et al*., 2002). The variation in turbidity is not only a function of rainfall but also on the pollution from human activities within the catchment areas either in the forms of point or non-point sources (Adlan *et al*., 2002). Non-point sources of pollution are pollution discharged over a wide land area, not from one specific location as do point sources of pollution (Kresic, 2009). A study by Adlan *et al*., (2002) suggests that when the raw water turbidity increases, the dosage of Poly Aluminium Chloride (PAC) would also be increased. PAC is used as flocculants in water treatment processes to remove dissolved organic matter and colloidal particles. Normally the higher the amount of PAC used due to the increase in raw water turbidity, the end product will be acidic (the pH reduces) and this will require more lime to be added which is used for pH correction (Adlan *et al*., 2002).

1.2.2. Sources of pollution and contamination of raw water

Non-point sources of pollution include forms of diffuse pollution caused by sediment nutrients and organic and toxic substances originating from land use activities such as agriculture or urban development (Kresic, 2009). Rainwater, snow melts or irrigation water can wash off these substances together with soil particles and carry them with surface run off to surface streams, contaminating water.

The effects of nitrogen and phosphorus runoff on fresh water systems can be severe and could possibly cause further problems at the water treatment plant (Gleick, 1993). According to Kimbrell (2002), worldwide, about 25 percent of all insecticides and 10 percent of all pesticides are applied to farming fields. In addition to pesticides, industrial monoculture techniques for cotton typically involve heavy applications of chemical fertilizers. These synthetic fertilizers contaminate drinking wells, lakes and dams, therefore posing long-term threats to both water treatment plants and aquatic life (Kimbrell, 2002). Fertilizers are also linked to amphibian declines, eutrophication and hypoxia, changes in aquatic food web and changes in benthic communities (Diaz and Rosenberg, 1995). In a study by Kimbrell (2002), leaching from soils has contaminated local rivers, and subsequent water-mediated transport has resulted in toxaphene contamination of coastal lagoons and fisheries.

1.2.3. Globalization and its impacts on raw water quality

A study by William *et al*. (2007) revealed that there is a direct connection between water quantity, water quality and the dynamics of the people sharing the same water basin. Some population lives downstream of another, so the water quality of one community is affected by unchecked economic development and associated pollution discharges of another. Population growth, urbanization, and industrialization have resulted into major impacts directly on water quality via increased volumes and spatial distribution of sewage and manufacturers' discharges (William *et al*., 2007).

Brown (2002) illustrated that the globalization of goods, services, labour, capital and technology has a strong influence on water quality. The growing population and economics associated with a global food market have led to intensification of agriculture, and an increase in demand for protein resulted into more animals and their wastes being produced, and this could end up in the reservoirs or dams used for water supply purposes.

Kimbrell (2002) stated that the increase in population and energy needs has influenced the climate via release of greenhouse gases. This climate change results in changes in precipitation and temperatures as well as the effectiveness and duration of droughts, storms and other extreme events that directly and indirectly influence raw water quality (Kimbrell, 2002). Purification costs are usually high depending on the extent of purification required, the cleaner the water, the lower the purification costs.

1.2.4. Water treatment operations

Treatment operations choice depends on the quality and variability of the raw water source and the treatment objectives, which may vary for industrial and community needs (Droste, 1997). Before designing a water supply process, the first and most important step is a thorough survey of the quality and quantity of all possible sources of raw water. Water treatment operations must be designed to handle the extremes in raw water quality variation to provide an acceptable product water at all times (Droste, 1997). The purification costs depend on the raw water characteristics.

1.3. STATEMENT OF THE PROBLEM

Changes in raw water quality affect the efficiency of the treatment processes. Depending on seasonal situations, the Von Bach Water Treatment Plant encounters different ranges of raw water quality. As a consequence of increasing concentrations of particles, algae, organic matter and temporary changes in iron and manganese concentration within the raw water, more chemicals are needed. Therefore, water supplying companies are increasingly confronted with rising costs of operation as well as sudden and long-term changes in raw water quality.

1.4. OBJECTIVES OF THE STUDY

The general objective of the study is to determine how the treatment or chemical dosage is influenced by the changes in raw water quality; by comparing raw water and product water, and correlation of the chemicals used for effective water treatment and its assigned water quality parameters.

1.5. RESEARCH QUESTIONS AND HYPOTHESIS OF THE STUDY

The research questions of the study are:

Is the chemical dosage influenced by the changes in the raw water quality?

How is the chemical dosage influenced by changes in raw water quality?

Hypothesis of the study:

H_0: Changes in raw water quality does not affect the amount of chemicals used in the treatment process.

H_1: Changes in raw water quality affect the amount of chemicals used in the treatment process.

CHAPTER TWO

2. MATERIALS AND METHODS

2.1. Study area

To investigate differing quality of raw water in the reservoir, Von Bach Dam was chosen as source of raw water. Von Bach Dam is located on the Swakop River, 10 km south of Okahandja town (See Fig. 1 and 2 below). The Von Bach Water Treatment Plant produces potable water for Windhoek, as well as for a number of other consumer points in the central part of the Khomas Region (e.g. Okahandja). The Von Bach treatment plant is the biggest in Namibia, capable of producing up to 130 000 m^3 of water per day and sourced mainly by S. Von Bach Dam, Swakoppoort and Omatako Dams. The dam also serves as a recreational facility and it is popular for most of its water recreational activities such as water skiing, wind surfing, boating as well as angling. The dam has a capacity of 50 million cubic meters. The catchment area of Von Bach Dam has seasonal rivers which cut off the villages such as Ovitoto during the rainy season when they are in flood. The catchment area is dominantly used for livestock farming, while crop production is practiced on a small scale for family consumption.

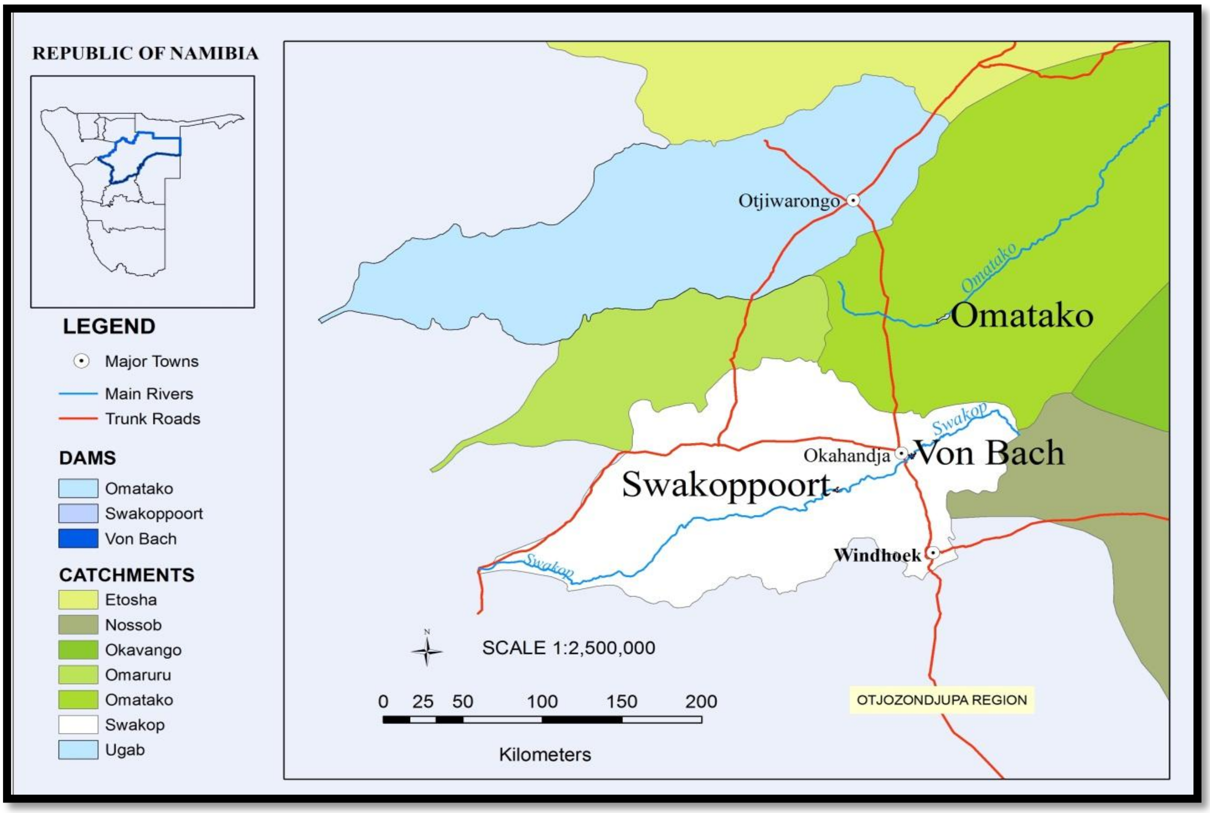

Figure 1: Von Bach catchment

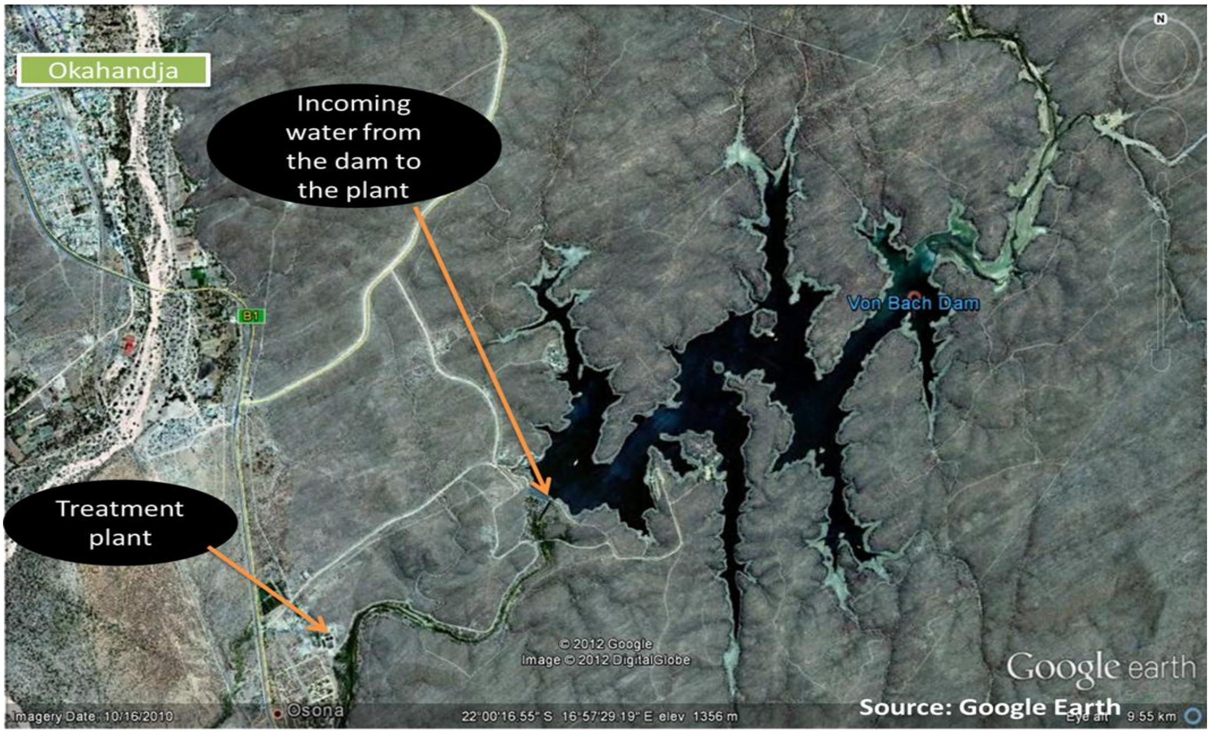

Figure 2: Von Bach Dam. *Source: Google Earth*

2.2. Data collection

The raw data used in the study was collected by NamWater. Samples were collected before and after treatment of water on hourly basis. Completely Randomised Design sampling techniques were used, in which the treatments are assigned to experimental units completely at random. Every experimental unit has an equal probability of receiving a treatment. Water samples were collected on the raw water pipeline tap before treatment. Samples were examined for turbidity, temperature, pH, manganese, iron and ammonia. Product water (in the storage tank) were sampled and examined for the same water quality parameters as well. However for this study, only three water quality parameters were used; manganese, iron and turbidity.

2.3. Statistical analysis

The data for all concerned water parameters were recorded before and after treatment, simple linear regression analysis of Genstat software was used to define the interrelationships between raw water quality parameters and chemicals used for treatment. The graphs were presented using Microsoft Excel.

CHAPTER THREE

3. RESULTS AND DISCUSSION

3.1. TURBIDITY

Turbidity may vary in its nature and composition from season to season and day to day depending on the presence of suspended matter in water. The influence of turbidity on drinking water treatment was examined, where a trend in raw water turbidity shows intense variations from the beginning of the experiment, with a decrease on the second day and a rise from the third day on (Figure 3). This indicates the increasing inputs of organic matter into raw waters where the treatment capacity is described as a function of organic load and turbidity. A highest peak of raw water turbidity of about 4.3 Nephelometric Turbidity Unit (NTU) was encountered on day 16 where it was reduced to <0.5 NTU using U3000.

Potable water turbidity (on Figure 3) indicates that there were no irregularities, and all days of treated water turbidity were below the region of 0.5 NTU, whereas the NamWater standard limit for product water (group A) turbidity is 1 NTU (Appendix 3). This shows efficient treatment of turbidity, but may also mean too much of chemicals (U3000) were used. At this point, the amount of sodium hydroxide (not included in the results) which is used for pH correction is not yet taken into account. The higher the amount of coagulants (U3000) used, indicates that the end product will be acidic (pH reduces) and this will require an addition of more sodium hydroxide to neutralise the pH. Thus, the dosage of coagulants have an effect on other chemicals, as such, the dosage of coagulants should be carefully regulated. Coagulant dosage management is a universal problem that is critical for achieving low turbidity in any treatment plant (Murat *et al*., 2011).

The relationship between turbidity and U3000 was determined by a correlation of different turbidity values at different concentrations of added U3000 values. As shown on figure 4 and by determining the degree of linear relationship between U3000 and turbidity, the results in figure 4 indicates a negative correlation. As one variable increases, a negative correlation coefficient indicates that the other decreases, and vice versa. This illustrates that when raw water turbidity increases, U3000 decreases and vice versa. The percentage variation in U3000 is determined by the coefficient of determination, the R^2, which indicates that the chemicals (U3000) changes by 14% either increasingly or decreasingly depending on the changes of raw water turbidity.

On a contrary, figure 3 shows that as turbidity increases, the amount of coagulant would have been increased, due to the increase of suspended particles in water. Since the graph indicates that there is a negative correlation between raw water turbidity and the dosage of U3000, a further research can be carried out on the estimation of the amount of U3000 required to treat certain raw waters with different turbidity levels. High turbidity increases the treatment cost. If organic solids are present, pathogens may be wrapped in the particles and escape the action of chlorine during disinfection and will be a hazard to human health. A previous research concerning the effects of turbidity on drinking water quality has associated coliforms in the distribution system (LeChevallier *et al.*, 1981). According to NamWater Drinking water guidelines, a turbidity of 1 NTU is recommended and up to 5 NTU are allowed, but this would only be accepted if the supplier could indicate that turbidity did not interfere with disinfection (chlorination).

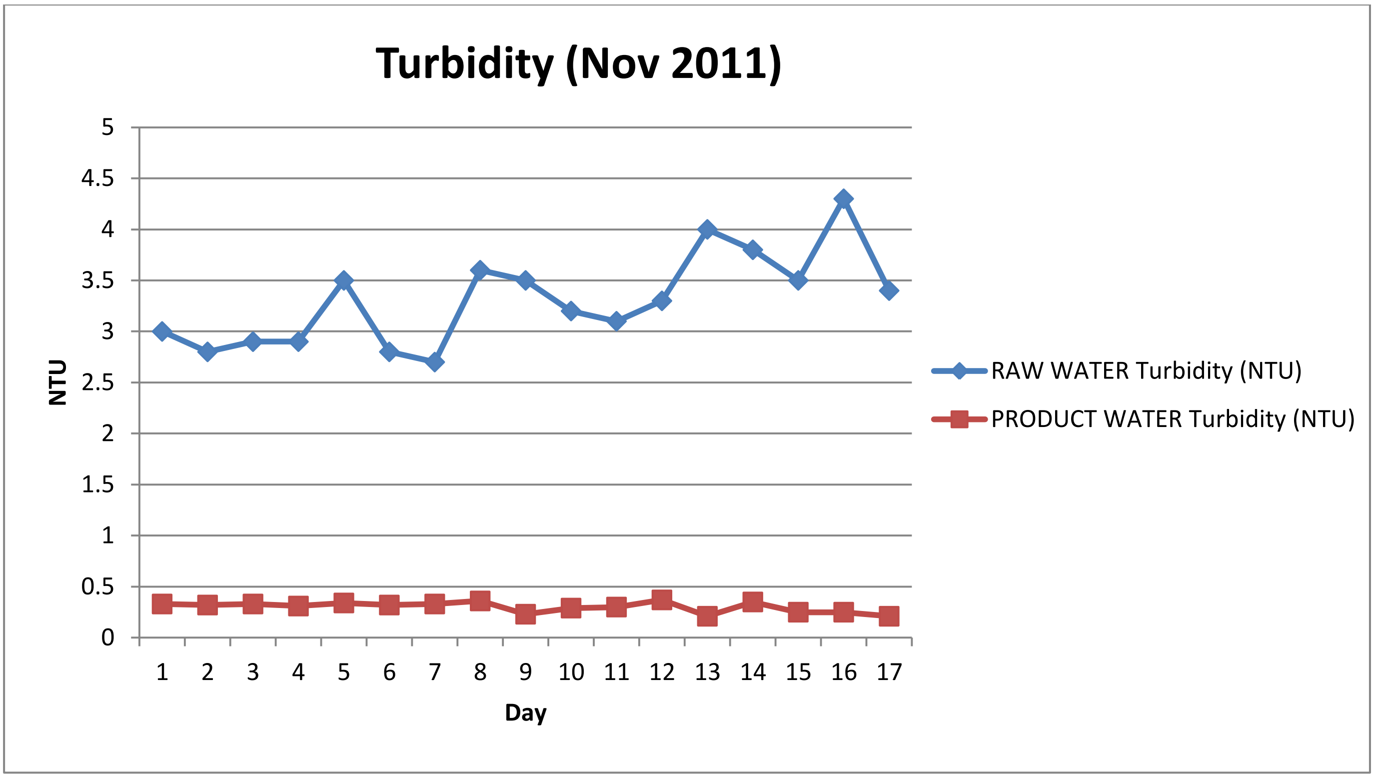

Figure 3: Variations in turbidity before treatment (raw water) and after treatment of water (product water) over a period of 17 days.

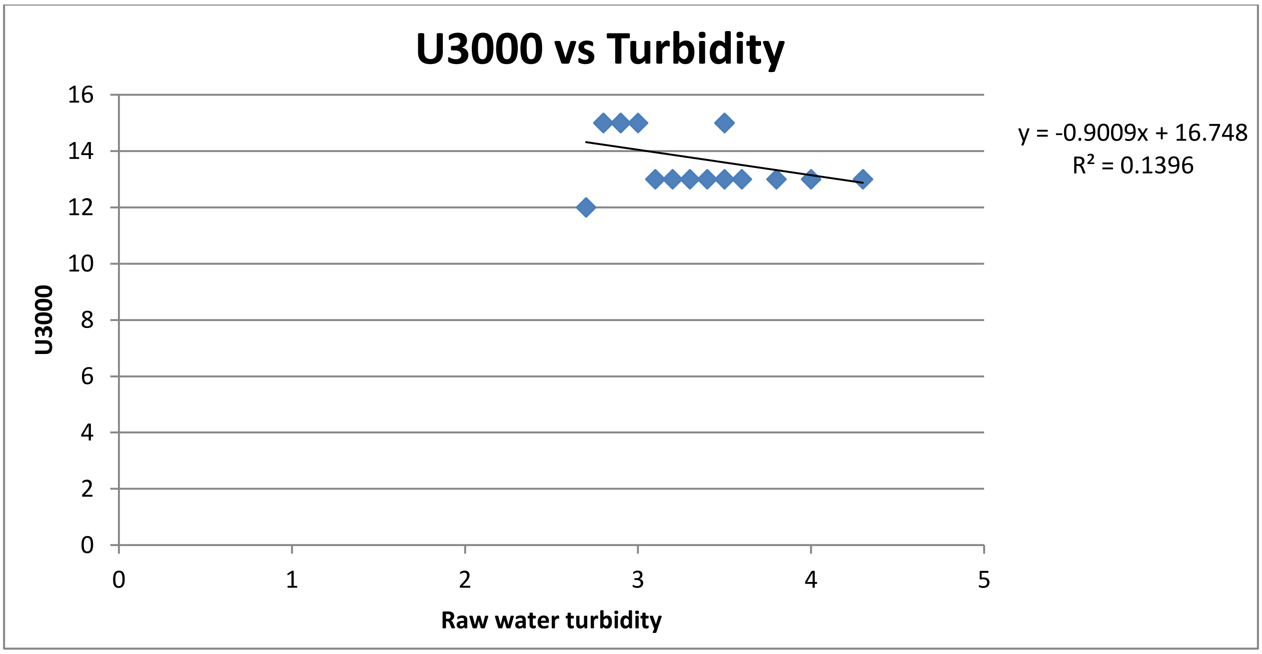

Figure 4: The correlation between raw water turbidity and the coagulant (U3000)

3.2. MANGANESE

Manganese is a mineral that naturally occurs in rocks, soil and as small particles in water (Cleasby *et al.*, 1964). As run-off water percolates in the soil, it dissolves different minerals. During run off, manganese is carried along with other minerals and nutrients to the reservoirs (water bodies). Results from the trend on (figure 5), indicating variations in manganese before and after treatment of water shows a gradual increase in raw water manganese concentration until day 6 where 0.23 mg/l of manganese was recorded. Although there were irregular variations in raw water manganese, a highest peak was recorded on day 11 with 0.26 mg/l. An increase in manganese concentration means chemicals used for oxidation of manganese in raw water has to be increased. Product water manganese is delimited below 0.05 mg/l as NamWater secondary drinking water standard (Product water, group A).

Manganese may become noticeable in tap water at concentrations greater than 0.05 mg/l by imparting a colour, odour, or taste to the water. Figure 5 shows the variation in product water manganese which falls below 0.05 mg/l. However, these variations show inconsistencies with the highest peaks attaining the maximum limit of about 0.05 mg/l. High levels of manganese in product water can impart a bittersweet or metallic taste to drinking water, thus effective manganese regulation is required. The relationship between manganese and potassium permanganate was determined by a correlation of manganese values with potassium permanganate ($KMnO_4$) values. Figure 6 indicates a positive correlation between potassium permanganate and manganese although it does not have a stronger degree of linear relationship. The positive correlation coefficient indicates that as raw water manganese changes, potassium permanganate may also change; when manganese increases, the chemical dosage (potassium permanganate) also increases, and when manganese decreases, potassium permanganate decreases as well. The percentage at which potassium permanganate changes due to changes in raw water manganese is 2.32%, whether it is increasing or decreasing. Potassium permanganate is a strong oxidizing chemical which also adds a fresh coating of manganese oxide to the medium surface and improves its capacity to remove both iron and manganese. Potassium permanganate is used both for iron and manganese oxidation because manganese is often found in water that contains iron and they are similar metals which cause similar problems. Potassium permanganate being a strong chemical oxidant, the iron and manganese particles are allowed to grow until they are large enough to be filtered or removed by flocculation. A coagulant is sometimes added to ensure that the smaller particles grow into larger ones. Therefore, if the raw water contains high levels of manganese and iron, more oxidant is required.

An increase in manganese concentration in raw water affects the efficiency of the treatment process and also the quality of treated water if the potassium permanganate dosage is not adjusted. Manganese may occur in different forms in water, such as manganese chloride or manganese dioxide; the treatment of these minerals depends on the form in which they occur in the raw water. Therefore, accurate testing of the water supply is important before selecting treatment options, as chlorine can also be used to remove manganese but with certain limitations of pH 6.5-7.5 (Bruce *et al*., 2007). In general, based on the limited results from the study, changes in manganese have an effect on the chemicals and effectiveness of potassium permanganate increases with decreasing pH. Potassium permanganate works better under acidic conditions than under alkaline conditions. Alkaline conditions enhance the capability of potassium permanganate to oxidize organic matter (Cleasby *et al*., 1964). This may suggest that potassium permanganate would be dosed after the addition of coagulants (especially alum or poly aluminium chloride and U3000) which reduces the pH of water.

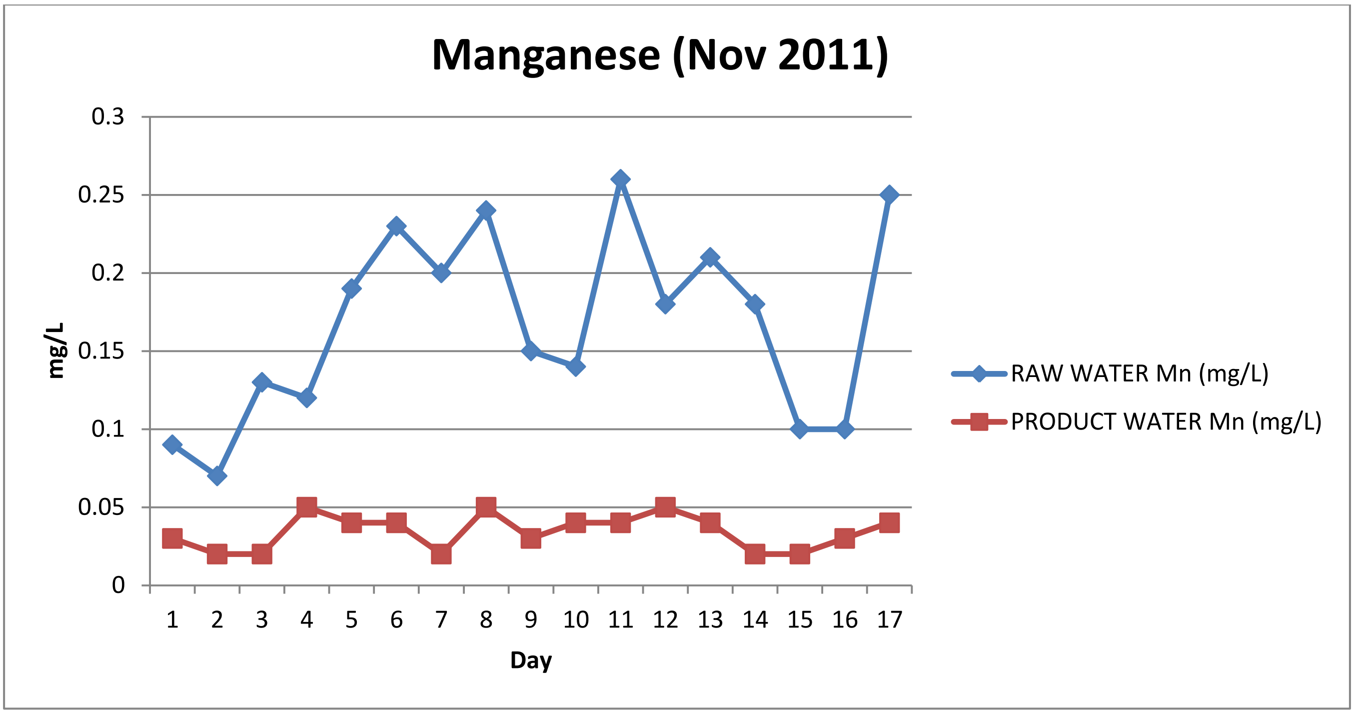

Figure 5: The variations in Manganese before treatment (Raw water) and after treatment of water (product water) over a period of 17 days.

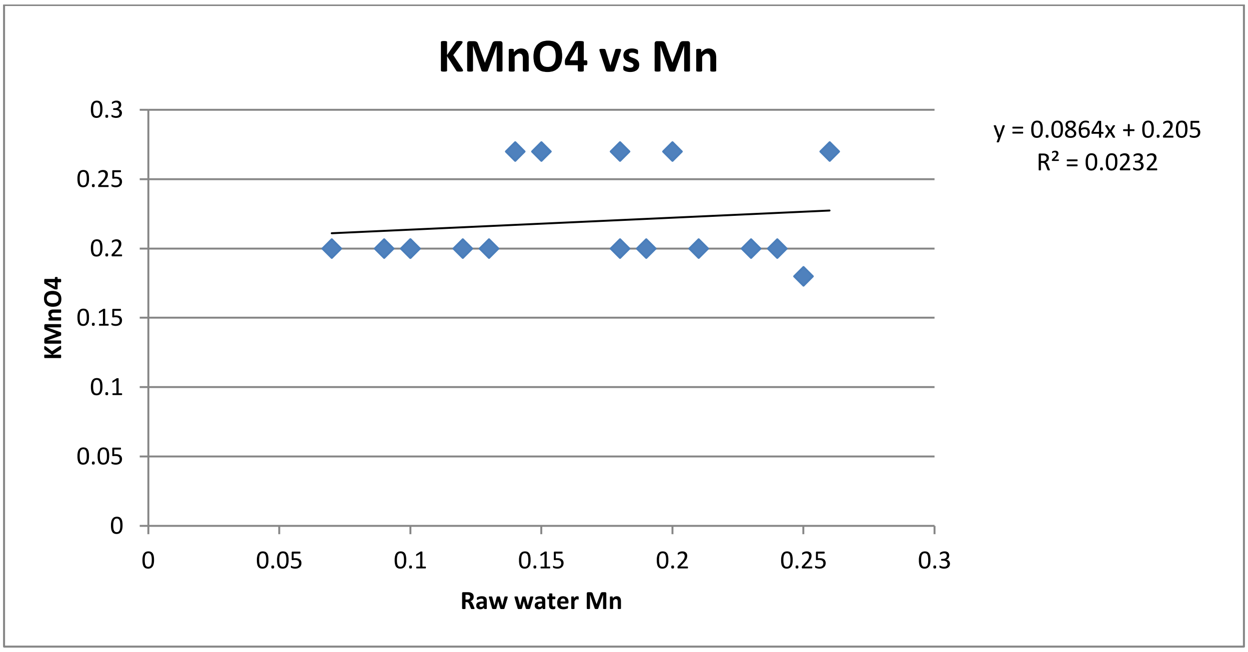

Figure 6: The correlation between raw water manganese and KMnO4

3.3. IRON

Iron as do manganese, occur naturally in water, especially in groundwater. Reservoir water supplies may have a little iron or extremely high amounts of iron. It may be naturally soft or so hard that it is almost unusable for potable purposes. Iron can be the most troublesome for water use and considered to be one of the most unstable minerals in water supply. A trend on Figure 7 indicates spiral variations in raw water iron as well as product water iron, with only one occasion where raw water iron was constant for two days, day 4 and 5. Iron in raw water has a peak of 0.1 mg/l on day 10, whereas product water has a peak of iron with 0.04 mg/l on day 13. However, these variations significantly fall within the standard limits of NamWater drinking water guidelines (Appendix 3, group A) for iron which is 0.1 mg/l. Only iron in quantities greater than 0.3 mg/l in drinking water would cause an unpleasant metallic taste and rusty colour.

The results show a low iron concentration in water, both in raw and product water. This indicates that even if there were no chemicals added (potassium permanganate) to remove or oxidise it, iron would still be in the range of drinking water standards. But due to the fact that potassium permanganate is used for oxidation of manganese, iron is also oxidised or removed in the co-process since manganese is often found in waters containing iron and a similar metal to iron. However, simple changes to the water supply such as temperature or even a change in pH can promote the change of iron from soluble to insoluble form. The addition of oxygen and potassium permanganate to a water supply easily cause this conversion. Generally, the higher the pH, the faster this reaction can take place. Iron will convert to a solid particle much faster at a pH of 8 than at a pH of 6 (Edward, 2004). Thus, the pH of the water supply has a major impact on iron conversion.

How iron and manganese are removed depends on the type and concentration, and this helps determine the best procedure and treatment system to use. Iron and manganese can be present in water in one of three basic forms: dissolved, particulate and colloidal. The predominance of one form over another is dependent on the water's pH. When soluble ferrous iron is exposed to oxygen or to potassium permanganate during water treatment, it oxidizes to the relatively insoluble iron (i.e. suspended colloidal and particulate iron) that is responsible for discoloured water. Successful reductions of iron start with proper identification of iron and have a good understanding of the water characteristics that may affect the iron reduction process. Proper testing and analysis of a water supply may accomplish this.

There is a weak correlation between raw water iron and potassium permanganate (figure 8), which could be caused by a low iron concentration in water and the use up of potassium permanganate by manganese. The rate of change in chemicals (potassium permanganate) associated with the change in raw water iron either increasingly or decreasingly is 0.32% and this shows a very weak correlation. Since iron and manganese co-exists and the same chemicals are used to oxidise these water quality parameters, there should be a careful investigation in raw water, calibration of potassium permanganate dose, and monitoring of equipment to ensure that there is no excess potassium permanganate in the product water, which may indicate a faint pink drop as evidence if potassium permanganate is present in the water. As such, careful attention is needed mostly on manganese than iron.

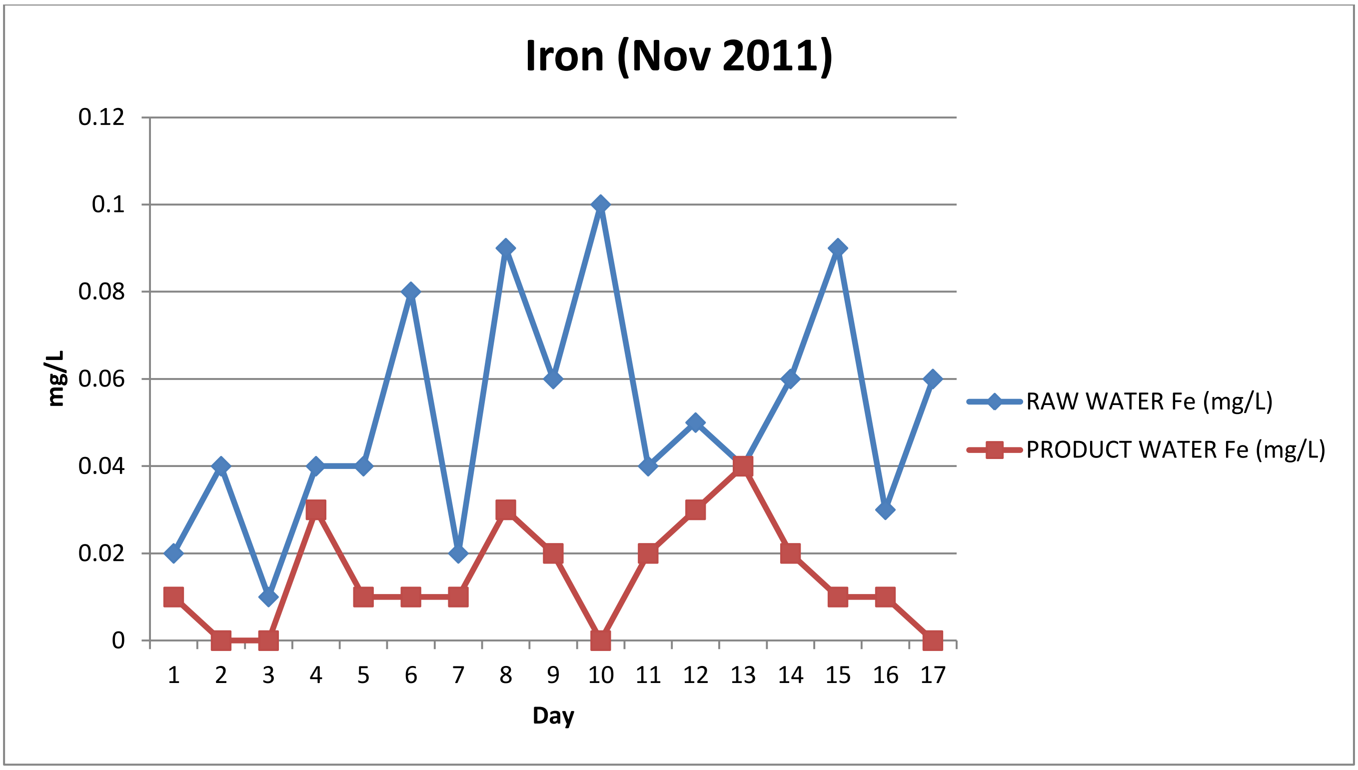

Figure 7: Variations in Iron before treatment (Raw water) and after treatment of water (Product water) over a period of 17 days.

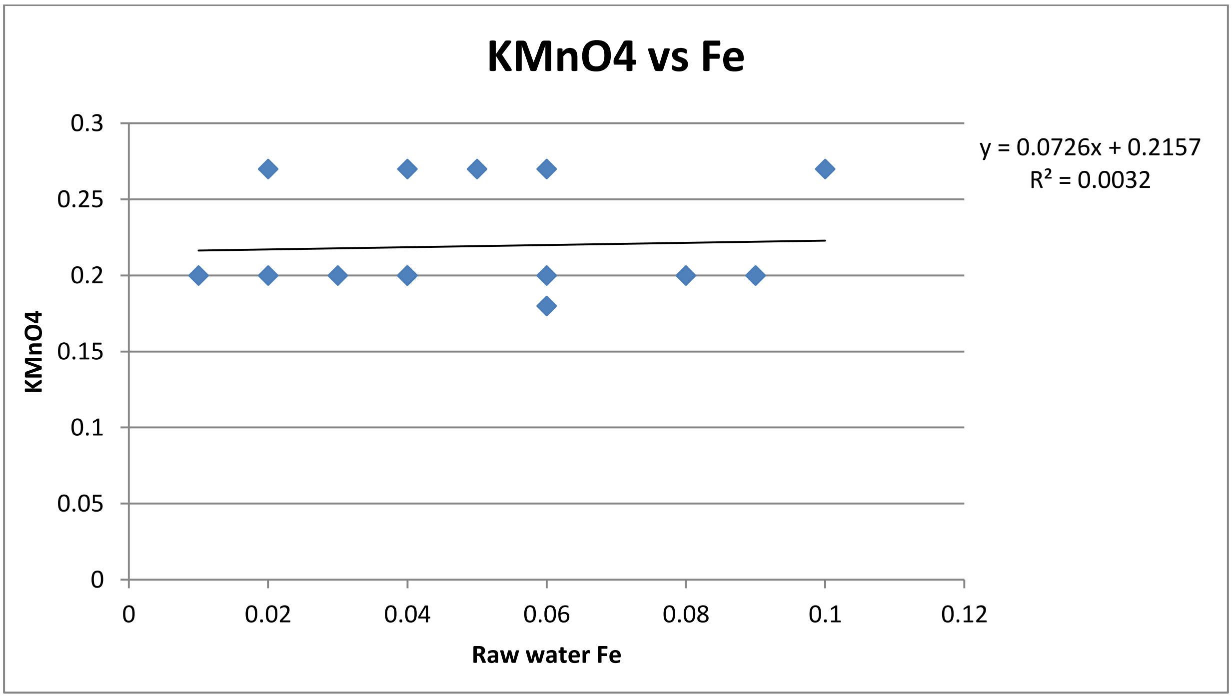

Figure 8: The correlation between raw water Iron and KMnO4

CHAPTER FOUR

4. CONCLUSION AND RECOMMENDATIONS

4.1. CONCLUSION

Investigation on how raw water quality changes affect the treatment process was done. Based on the overall results obtained, the study has revealed that there is a significant relationship between changes in raw water quality and the specific chemicals used for treatment; the chemical dosage is influenced by the changes in raw water quality in such a way that as raw water quality increases, the findings predict that chemical dosage would also increase. On the other hand, there seems to be a high amount of U3000 used as it indicates efficient treatment of turbidity, which is 50% of the allowed standard limit for turbidity (1 NTU) of group A. A subsequent study can be carried out to deduce information on the amount of U3000 to be used.

However, data from December (Appendix 2) which were not used in the study as they were incomplete shows that on several occasions product water manganese was above the secondary standard limit of manganese in product water of group A (0.05 mg/l). It was determined that the high manganese in raw water affected the treatment efficiency and also the quality of treated water, as manganese can be unpleasant in water even if present in smaller concentrations. The results also show that the treatment process does not really purify water or adjust the chemical dosage according to raw water quality changes, as the data obtained indicates a constant chemical dosage. This would lead to excess use of chemicals in situations where water quality parameters are low in water, in this case turbidity, manganese and iron. Therefore, the determination of the amount of chemical dosage prior to the treatment process is very important, which can be used as a cost reduction tool.

4.2. RECOMMENDATIONS

- Iron and manganese exists in several forms, which might pose a challenge when selecting treatment options. Laboratory testing is important to determine the concentrations and specific forms of iron and manganese in the water supply.

- Iron and manganese react with dissolved oxygen to form insoluble compounds. Therefore, they are usually not found in waters that contain high amounts of dissolved oxygen. This means surface water does not contain large amounts of iron or manganese since it is exposed to atmospheric oxygen, thus it can be abstracted for water purification if water containing less iron and manganese is desired.

- Limitations encountered during the study; based on the objectives of the study, samples were to be collected from the beginning to the end of the year, January to December or atleast one month per season. Therefore, time to carry out the project was limited since the University opens February and I had to apportion most of the time attending lectures for theoretical modules, as well as studying for tests and examinations. NamWater required a well written proposal before they could give me a go ahead, and this had to go through a channel of various personnel and was only given a go ahead in October. Therefore, raw data from the Von Bach Treatment Plant was used in the study. The data was lacking some of the water quality parameters that I had to use in the study and it was not thoroughly collected as desired, i.e. before and after treatment, and the data was missing on some of the days, as such only November month was used in the study. This must have affected the results as the data was limited for effective deductions. More samples over a long period of time are needed in a study like this to yield sufficient results.

5. REFERENCES

Adlan, M.N., Aziz, H.A. and Hasan, R. (2002). *The effects of raw water turbidity in water treatment process at SG Kampar treatment plant*. Perak: University Sains, Perak Branch Campus, Malaysia.

Barnes, D., Bliss, P. J., Gould B. W. and Vallentine, H. R. (1981). *Water and Wastewater Engineering Systems.* London: Pitman Books Ltd.

Boyd, C.E. (2000). *Water Quality: an introduction*. Norwell: Kluwer Academic Publishers.

Brown, K. (2002). *Water Security: forecasting the future with spotty data.* Science **297**: 926-927.

Bruce, L.D., Gyanendra, P., Sharon, O.S. and Wayne, W. (2007). *Drinking Water: Iron and Manganese*. Nebraska: University of Nebraska-Lincoln Extension.

Cleasby, J.L., E.R. Baumann, and C.D. Black. (1964). *Effectiveness of Potassium Permanganate for Disinfection*. Iowa State University: American Water Works Association. **56**:466-474.

Diaz, R.J. and Rosenberg, R. (1995). *Marine Benthic Hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna.* Oceanography and Marine Biology **33**: 245-303.

Droste, R.L. (1997). *Theory and Practice of Water and Wastewater Treatment*. New York: John Wiley & Sons, Inc.

Edward, T. M. (2004). *Iron in Your Water Supply*. Waunakee: Hellenbrand Inc.

Gleick, P. (1993). *Water in Crisis: A Guide to the World's Fresh Water Resources*. New York: Oxford University Press.

Gray, N.F. (2008). *Drinking Water Quality (2nd ed.): Problems and Solutions*. Cambridge: Cambridge University Press.

Kimbrell, A. (2002). *Fatal Harvest: The Tragedy of Industrial Agriculture*. Washington DC: Island Press.

Kresic, N. (2009). *Ground Water Resources: Sustainability, Management and Restoration*. New York: McGraw-Hill Companies, Inc.

LeChevallier, M.W., Seidler, R.J. and Evans, T.M. (1981). *Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water*. Applied Environmental Microbiology. **42**: 159–167.

Linsley, R.K., Franzini, J.B., Freyberg, D.L. and Tcbobanoglous, G. (1992) *Water Engineering*, Singapore: McGraw-Hill, Inc.

Murat, E., Tugrul, S.A., Ebubekir, Y. and Mete, A.S. (2011). *Effects of intermittent polyelectrolyte addition on water quality in direct filtration*. Istanbul: IWA Publishing

Slavik, I. and Uhl, W. (2009). *Analysing water quality changes due to reservoir management and climate change for optimization of drinking water treatment*. Dresden: IWA Publishing.

William, W.T., Michael, G.S. and Lois, G.W. (2007). *Globalization: Effects on Fisheries Resources*. New York: Cambridge University Press.

6. APPENDICES

Appendix 1

VON BACH WATER TREATMENT PLANT - MONTHLY PERFORMANCE LOG

Nov-11	RAW WATER						PRODUCT WATER						CHEMICAL DOSAGE (mg/L)	
Day	Turbidity (	pH	Temp (°C)	Mn (mg/L)	Fe (mg/L)	NH3	Turbidity (N	pH	Free Cl2 (m	Mn (mg/L)	Fe (mg/L)	NH3	U3000	KMnO4
1	3	8.04	21	0.09	0.02	0.04	0.33	7.84	0.65	0.03	0.01	0.1	15	0.2
2	2.8	8.1	22	0.07	0.04	0.02	0.32	7.87	0.51	0.02	0	0.03	15	0.2
3	2.9	7.99	21	0.13	0.01	0.1	0.33	7.89	0.64	0.02	0	0.03	15	0.2
4	2.9	7.97	20	0.12	0.04	0.03	0.31	7.78	0.67	0.05	0.03	0	15	0.2
6	3.5	8.01	21	0.19	0.04	0.03	0.34	7.84	0.75	0.04	0.01	0.01	15	0.2
7	2.8	7.93	22	0.23	0.08	0.11	0.32	7.9	0.85	0.04	0.01	0.02	15	0.2
9	2.7	7.84	22	0.2	0.02	0.04	0.33	7.77	0.64	0.02	0.01	0	12	0.27
14	3.6	7.82	21	0.24	0.09	0.05	0.36	7.85	0.8	0.05	0.03	0.05	13	0.2
15	3.5	7.8	21	0.15	0.06	0.01	0.23	7.89	0.9	0.03	0.02	0	15	0.27
17	3.2	7.84	21	0.14	0.1	0.06	0.29	7.96	0.51	0.04	0	0.03	13	0.27
18	3.1	7.8	22	0.26	0.04	0.03	0.3	7.91	0.59	0.04	0.02	0	13	0.27
19	3.3	7.77	22	0.18	0.05	0.05	0.37	7.85	0.8	0.05	0.03	0.05	13	0.27
23	4	7.73	21	0.21	0.04	0.06	0.21	7.65	0.47	0.04	0.04	0.02	13	0.2
24	3.8	7.72	22	0.18	0.06	0.04	0.35	7.63	0.64	0.02	0.02	0.01	13	0.2
25	3.5	7.75	23	0.1	0.09	0.03	0.25	7.69	0.48	0.02	0.01	0.01	13	0.2
26	4.3	7.78	22	0.1	0.03	0.01	0.25	7.85	0.6	0.03	0.01	0	13	0.2
30	3.4	7.71	23	0.25	0.06	0.06	0.21	7.78	0.58	0.04	0	0.01	13	0.18

Table 1: Raw data for November 2011.

Appendix 2

VON BACH WATER TREATMENT PLANT - MONTHLY PERFORMANCE LOG

Dec-11	RAW WATER						PRODUCT WATER						CHEMICAL DOSAGE (mg/L)	
Day	Turbidity (N	pH	Temp (°C)	Mn (mg/L)	Fe (mg/L)	NH3	Turbidity (N	pH	Free Cl2 (mg/L	Mn (mg/L)	Fe (mg/L)	NH3	U3000	KMnO4
1	3.4	8	23	0.23	0.14	0.07	0.2	7.81	0.58	0.04	0	0.04	13	0
2	3.7	8	24	0.18	0.12	0.07	0.21	7.84	0.62	0.03	0.01	0.01	13	0.18
7	5.5	8	22	0.36	0.14	0.05	0.27	7.62	0.51	0.09	0	0	13	0
9	5.8	8	23	0.24	0.11	0.06	0.22	7.59	0.59	0.01	0.01	0.04	13	0
11	5.1	8	23	0.2	0.06	0.04	0.29	7.62	0.5	0.01	0	0	13	0
13	5.5	8	23	0.09	0.03	0.03	0.28	7.74	0.47	0.02	0.03	0	13	0.18
14	4.7	8	23	0.1	0.03	0.02	0.28	7.22	1.11	0.01	0.02	0	13	0.2
15	4.2	8	22	0.19	0.1	0.05	0.26	7.95	0.38	0.06	0.09	0.01	13	0.26
16	4.3	8	23	0.17	0.05	0.04	0.25	7.91	0.46	0.07	0.01	0.03	13	0.18
17	3.4	7	24	0.08	0.04	0.03	0.32	7.47	0.68	0.01	0.02	0	13	0
18	3.5	7	24	0.17	0.05	0.04	0.29	7.27	0.66	0.03	0.02	0.01	13	0.18
19	3.2	7	23	0.2	0.04	0.02	0.26	7.45	0.51	0.02	0	0.01	13	0.18
20	3.8	7	23	0.19	0.02	0.04	0.29	7.47	0.52	0.03	0.01	0.01	13	0.18
21	3.7	7	23	0.37	0	0.08	0.3	7.25	0.68	0.11	0	0	13	0.18
22	4	7	23	0.38	0.01	0.09	0.3	7.24	0.46	0.1	0	0.02	14.8	0.36
23	4.4	7	23	0.33	0.03	0.05	0.27	7.44	0.42	0.08	0	0.02	15	0.45
24	4.3	7	23	0.07	0	0.03	0.27	7.44	0.49	0.12	0	0.01	15	0.45
25	3.4	7	23	0.08	0.01	0.03	0.28	7.39	0.5	0.02	0	0	15	0.45
26	4	7	23	0.12	0.04	0.18	0.28	7.35	0.55	0.06	0	0.03	15	0.45
27	3.8	7	24	0.18	0.1	0.02	0.28	7.33	0.47	0.03	0	0	15	0.4
28	3.6	7	23	0.23	0.03	0.02	0.35	7.39	0.63	0.07	0	0.01	15	0.35
29	3.9	7	23	0.22	0	0.04	0.3	7.33	0.57	0.04	0	0.01	15	0.35
30	3.8	7	24	0.22	0	0.01	0.29	7.25	0.59	0.02	0	0	15	0.35
31	3.6	7	24	0	0	0	0.28	7.25	0.6	0.02	0	0	15	0.35

Table 2: Raw data for December 2011.

Appendix 3

NAMWATER

Namibia Water Corporation Ltd.

GUIDELINES FOR THE EVALUATION OF DRINKING-WATER FOR HUMAN CONSUMPTION WITH REGARD TO CHEMICAL, PHYSICAL AND BACTERIOLOGICAL QUALITY

2. CLASSIFICATION OF WATER

2.1 The concentration of and limits for the aesthetic, physical and inorganic determinants define the group into which water will be classified. See TABLE 3 for these limits.

GROUP A: Water with an excellent quality

GROUP B: Water with good quality

GROUP C: Water with low health risk

GROUP D: Water with a higher health risk, or water unsuitable for human consumption

2.2 Water should ideally be of excellent quality (Group A) or good quality (Group B), however in practice many of the determinants may fall outside the limits for these groups.

2.3 If water is classified as having a low health risk (Group C), attention should be given to this problem, although the situation is not critical yet.

2.4 If water is classified as having a higher health risk (Group D), urgent and immediate attention should be given to this matter. Since the limits are defined on the basis of average lifelong consumption, short term exposure to determinants exceeding their limits is not necessarily critical, but in the case of extremely toxic substances such as cyanide, remedial procedures should immediately be taken.

2.5 The group in which the water is classified is determined by the determinant which complies the least with the guidelines for the quality of drinking-water.

TABLE 3	DETERMINANTS WITH AESTHETIC/PHYSICAL IMPLICATIONS

DETERMINANTS	UNITS	LIMITS FOR GROUPS			
		A	B	C	D*
Colour	mg/ℓ Pt**	20	-	-	-
Conductivity	mS/m 25^{0}C	150	300	400	400
Total hardness	mg/ℓ $CaCO_3$	300	650	1300	1300
Turbidity	N.T.U.***	1	5	10	10
Chloride	mg/ℓ Cl	250	600	1200	1200
Chlorine (free)	mg/ℓ Cl	0.1-5.0	0.1-5.0	0.1-5.0	5.0
Fluoride	mg/ℓ F	1.5	2.0	3.0	3.0
Sulphate	mg/ℓ SO_3	200	600	1200	1200
Copper	µg/ℓ Cu	500	1000	2000	2000
Nitrate	mg/ℓ N	10	20	40	40
Hydrogen Sulphide	µg/ℓ H_2S	100	300	600	600
Iron	µg/ℓ Fe	100	1000	2000	2000
Manganese	µg/ℓ Mn	50	1000	2000	2000
Zinc	mg/ℓ Zn	1	5	10	10
pH****	pH-unit	6.0-9.0	5.5-9.5	4.0-11.0	4.0-11.0

Table 3: NamWater drinking water guidelines

* **All values greater than the figure indicated.**

** **Pt = Platinum Units.**

*** **Nephelometric Turbidity Units.**

**** **The pH limits of each group exclude the limits of the previous group.**