The Effects of Water Transfer from Swakoppoort and Omatako Dams on the Water Quality of Von Bach Dam, Namibia

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Key Words

Algal bloom

Catchment

Eutrophication

Models

Runoff

Land use activities

Water quality

Stratification

Water transfers

Water treatment

ABSTRACT

In the Otjozondjupa Region, Namibia, water is transferred from Swakoppoort and Omatako Dams into Von Bach Dam to limit evaporation losses and bring water closer to the purification plant. There is a gap in the knowledge about the effects on water quality in Von Bach Dam due to water transfer from Swakoppoort and Omatako Dams, as previous studies on such aspects in the area do not exist. The study objective was to; (a) characterise water quality of the three dams, (b) determine whether water transfers affect the water quality of Von Bach Dam, (c) determine if the treatment of water abstracted from Von Bach Dam for potable water supply has been influenced by water quality changes arising from water transfers. Four sampling locations were established in Von Bach Dam, one in Swakoppoort Dam, and one in Omatako Dam. Water samples were collected in these three dams weekly. Two senior officers responsible for water treatment were interviewed about possible water treatment problems arising from the water transfer. Descriptive statistics, ANOVA and correlation were carried out to analyse the data. The results showed that, secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a* and microcystis were statistically different in the three dams at a 5% significance level. Upstream land uses, geology of the catchment and water stratification are likely to influence the water quality in the three dams. During water transfers into Von Bach Dam, secchi disk depths, turbidity, dissolved oxygen, iron, total phosphorus, ammonia (NH_4-N) and chlorophyll *a* were statistically different at a 5% significance level at all the four sampling locations within this dam. These differences are due to the influence of water transfers. The influence of water transfers on water quality was localised at the discharge points SL4 (at the inflow of Von Bach Dam) and SL1 (at the outflow of Von Bach Dam). Water treatment problems due to high ammonia, dissolved organic carbon, and turbidity in the water abstracted from Von Bach Dam occurred during water transfers and runoff from the catchment. This view was supported by the study findings.

DECLARATION

I declare that *The effects of water transfer from Swakoppoort and Omatako Dams on the water quality of Von Bach Dam* is my own work, that it has not been submitted for any degree or examination at any university and that all the sources I have used or quoted have been indicated and acknowledged through complete references.

Johannes Jaime Sirunda November 2011

Signed……………………………………….

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CHAPTER ONE: INTRODUCTION

1.1. Background

Water quality is a term used to express the suitability of water to sustain a variety of uses and processes (Maybeck *et a*l., 1996; Oberholster *et al*., 2009). Land use activities such as agriculture, deforestation, inter-basin water transfers, mining, and wastewater discharges and natural factors such as climatic, hydrologic and geologic conditions affect water quality (Kemka *et al*., 2006; Out *et al*., 2010; Nyenje *et al*., 2010). For example, the water quality of Lake Loskop in South Africa, has been affected by acid mine drainage and high nutrient concentration from its catchment area (Oberholster *et al*., 2009). In Lake Victoria, Kenya, the water quality has been affected by the increase in temperature due to global warming by 0.9°C from 1960 to 1990 (Marshall *et al*., 2009). Water quality management at catchment level should ensure that the use of water is not adversely affected.

Water quality management aims at achieving a balance between socio-economic development and environment protection (DWAF, 1996). Socio-economic activities such as forest removal for urban development, and disposal of wastewater adversely affect water quality (Olago and Odada, 2007; Oberholster and Ashton, 2008).

Management plans for pollution control are being implemented world-wide to minimize the effects of point and non-point sources of water pollution. For example, in the Latin American region, less than 10% of point sources (sewage discharge, agricultural waste discharge and oil spills) of pollution are managed in an environmentally acceptable manner. However, the control of non-point sources (urban and agricultural runoff) has been ineffective (Biswas and Tortajada, 2006). Non-point sources of pollution are of major concern in the Organisation for Economic Co-operation and Development (OECD) countries (Biswas and Tortajada, 2006). In the Rotorua District of New Zealand, nine to twelve lakes are heavily polluted with nutrients (Burns *et al*., 2009). Management plans in New Zealand, such as the upgrading of waste treatment facilities, and dosing tributary streams with alum, have been instituted to improve the water quality in these lakes (Burns *et al*., 2009).

The Millennium Development Goal 7c of halving the proportion of people without sustainable access to safe drinking water by 2015 will not be achieved if the pollution of water is not controlled. About 17% of the world population had no access to improved drinking water sources in 2004 but the plan is to reduce this to 13% by 2015 to meet the Millennium Development Goal 7c (WHO and UNICEF, 2006). From 1990 to 2004, the world population with access to improved drinking water sources increased from 78% to 83% (WHO and UNICEF, 2006). About 30% of the people without access to improved drinking water lived in Sub-Saharan Africa, 27% in East Asia and 23% in Southern Asia (WHO and UNICEF, 2006). In Southern Africa, countries like the Democratic Republic of Congo, Zambia, and Angola will have to double their efforts in order to reach the Millennium Development Goal for their drinking water target. Access to drinking water will increase if the quality of the water is managed.

The Africa Water Vision for 2025 is, "*Water for sustaining ecosystems and biodiversity is adequate in quantity and quality*" by 2025 and "*there is a sustainable access to safe and adequate water supply and sanitation to meet basic needs of all* by 2025" (African Water Vision for 2025, n.d). The Southern Africa Development

Community (SADC) water policy of 2006, also advocates that "*SADC countries should harmonise and uphold common minimum standards of water quality in a shared watercourse" and "member states should individually and collectively adopt necessary measures to prevent and control pollution (point and non-point sources) of ground and surface waters resulting from inland, coastal, or offshore activities*" (Southern African Development Community, 2006).

Some of the countries in Southern Africa are implementing water quality management plans. For example, in South Africa, water quality management has being implemented at the catchment level as part of Integrated Water Resources Management (IWRM) (Pegram and Bath, 1995, Howard *et al*., 2000). The effect of land use practices such as agriculture and human population growth on water quality in the Mgeni River catchment was being monitored (Howard *et al*., 2000). Roles and responsibilities of the interested and affected parties in pollution identification are being clarified in the Mgeni River catchment (Howard *et al*., 2000). A Geographic Information System (GIS) has been used to determine catchment characteristics and land use impacts on water quality in the Crocodile River catchment and how this impact can be managed in an integrated manner (Ashton and Van Zyl, 2000). In Zimbabwe, stakeholders participated in water quality monitoring using their indigenous knowledge of the smell, taste, colour and odour of water (Nare *et al*., 2006). The management of water quality at catchment level is important, because this is where the land use activities which affect water quality, are found.

In some countries inter-basin water transfer for water quality improvement is practiced. In China, water transferred from the Yangtze River to Lake Taihu was observed to improve the water quality (total nitrogen, total phosphorus and chlorophyll *a*) (Hu *et al*., 2009). Water transferred from Caledon River in South

Africa through Knellpoort Dam to Modder River was found to cause a decrease in light penetration and an increase in nutrients in Knellpoort Dam (Slabbert, 2007).

There is a concern in central Namibia about the possible effects of water transfers from Swakoppoort and Omatako Dams into Von Bach Dam. Water transfers could affect the water quality in Von Bach Dam. The effects of this transfer on water quality are not well understood. This study aims to fill the gap in understanding how the water quality of Von Bach Dam is affected by water transfer from (a) Swakoppoort Dam and (b) Omatako Dam.

1.2. The statement of the problem

The three dams (Von Bach Dam, Swakoppoort Dam and Omatako Dam) in the Otjiozondjupa Region of Namibia are on ephemeral rivers and they seldom spill as they are designed to hold up to three times the mean annual runoff (3 MAR). The long retention period, evaporation losses and inflow from the catchment, affect water quality. Water is transferred by the Namibian Water Cooperation (NamWater) from Swakoppoort and Omatako Dams into Von Bach Dam to limit evaporation losses due to the small surface area of Von Bach Dam, and to bring water closer to the purification plant for water supply to the central area of Namibia. There are no previous studies conducted to show how the water quality of the recipient Von Bach Dam is affected by the transfer of water into this dam.

1.3. The research aim

The aim of the study is to create an understanding of how water transfers from Swakoppoort Dam and Omatako Dam into Von Bach Dam affect water quality in the recipient dam.

1.4. The research objectives

The study has the following specific objectives:

a. To characterise water quality in Swakoppoort Dam, Omatako Dam, and Von Bach Dam.

b. To determine the extent to which the transfer of water from either Swakoppoort or Omatako Dam contributes to changes in the water quality parameters of Von Bach Dam.

c. To determine how the treatment of water abstracted from Von Bach Dam for potable water supply has been influenced by water quality changes arising from water transfers.

1.5. The research question

To determine the effect of water transfer on the water quality parameters of Von Bach Dam, the following research questions were answered:

a. Does the quality of water in the three dams differ?

b. How is the quality of water in Von Bach Dam influenced by water transfers?

c. Is the treatment of water from Von Bach Dam affected by water transfers?

1.6. The significance of the study

This study provides information about the effect of water transfers on water quality in Von Bach Dam. This information will be used to manage water transfer into Von Bach Dam in order to minimize or eliminate adverse effects on water quality and thus reduce water treatment costs.

1.7. Outline of the thesis

The study consists of eight chapters as described below:

- Chapter Two describes the characteristics of the study area.
- Chapter Three reviews the literature on the effects of inter-basin water transfers on the water quality parameters.
- Chapter Four presents the methodology used for data collection and analyses.
- Chapter Five presents a description of the water quality in the three dams based on the monitoring done in this study.
- Chapter Six presents the analysis of the effects of water transferred from Swakoppoort and Omatako Dam on the water quality of Von Bach Dam.
- Chapter Seven presents the possible effects of water transfers on water treatment.
- Chapter Eight presents a conclusion and recommendations from the results of the study.

CHAPTER TWO: DESCRIPTION OF THE STUDY AREA

2.1. Introduction

Von Bach Dam is a southern African tropical reservoir constructed in 1978 for water supply to Windhoek, the capital city of Namibia (Slabbert, 2007). Von Bach Dam is augmented with water from Swakoppoort Dam and Omatako Dam to ensure sufficient water supply (Liputa *et al*., n.d). Von Bach, Swakoppoort and Omatako Dams are located on ephemeral rivers in the central Otjozondjupa Region of Namibia. The transfer of water from Swakoppoort and Omatako Dams to Von Bach Dam is done through concrete pipelines with booster pump stations.

Von Bach Dam has lower evaporation losses (2254 mm/a) as it has a lower surface area (4.9 km^2) compared to Swakoppoort and Omatako Dams and it is located close to the treatment plant. In this chapter, the characteristics of the study area, Von Bach Dam, Swakoppoort Dam and Omatako Dam have been described.

2.2. Location of the study area in Namibia

Swakoppoort and Von Bach Dam are on the Swakop River, while Omatako Dam is on the Omatako River in Namibia (Figure 2.1 and 2.2). Swakoppoort, Von Bach and Omatako Dams are found in the Otjozondjupa Region, in Namibia (Figure 2.2). Most of the rivers in Namibia are ephemeral. Apart from ephemeral rivers, there are five perennial rivers in Namibia which are shared with the neighbouring countries. The perennial rivers are Kwando-Linyati, Kunene, Okavango, and the Orange and Zambezi Rivers. The populated areas are located far from perennial rivers which have sufficient water. Since these rivers are shared with neighbouring countries, transferring water from them for supply to populated areas requires transboundary agreements. These challenges for water supply have resulted in groundwater being the key resource for populated areas like Windhoek and Swakopomund.

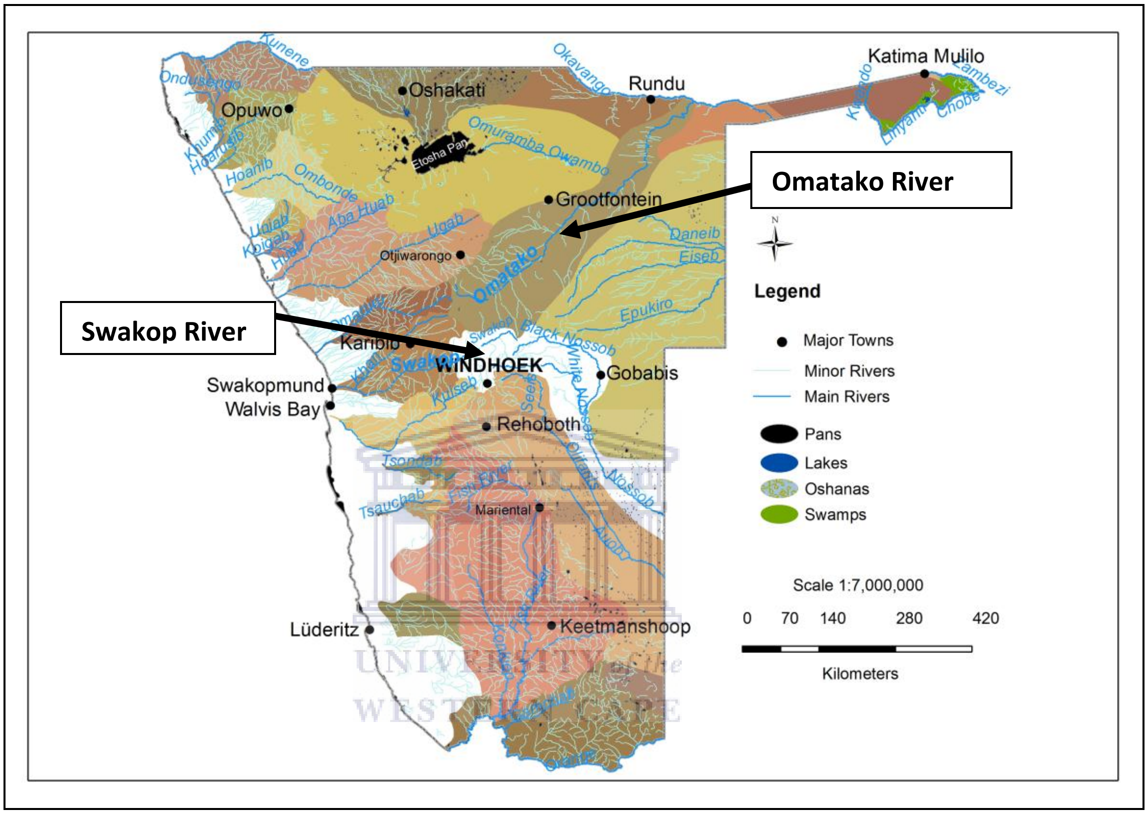


Figure 2.1: The river systems of Namibia, including Omatako and Swakop Rivers

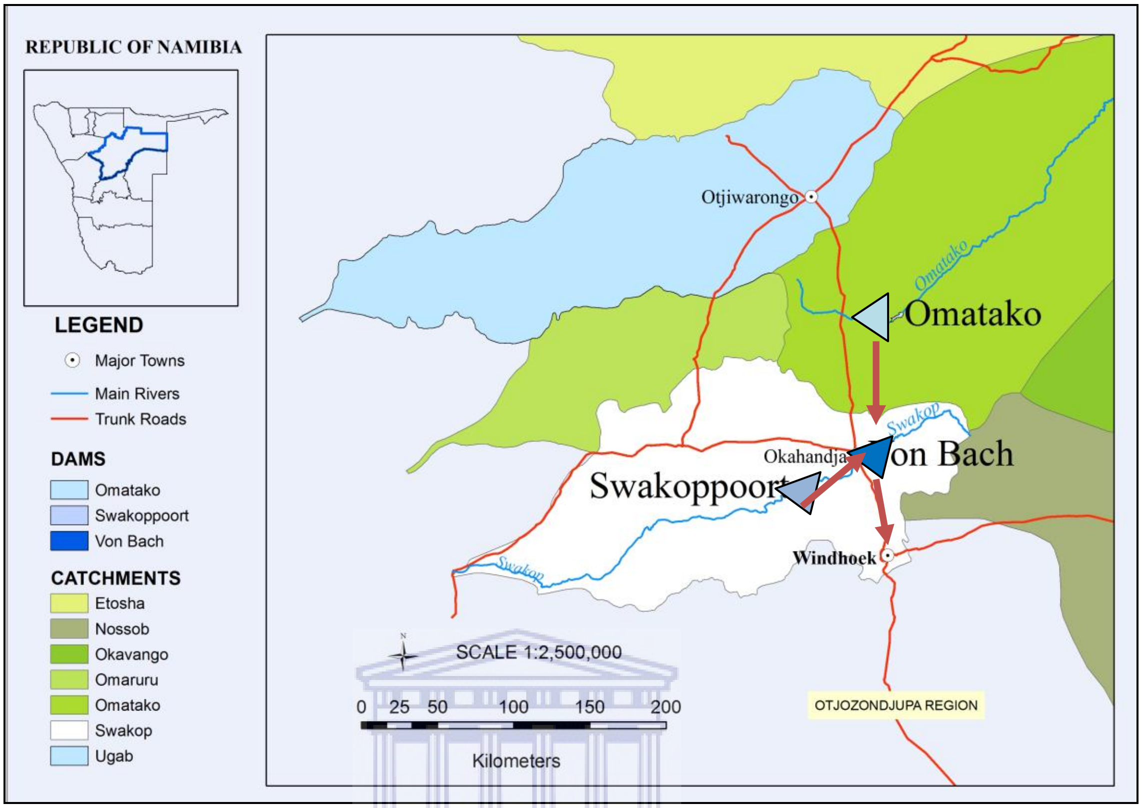
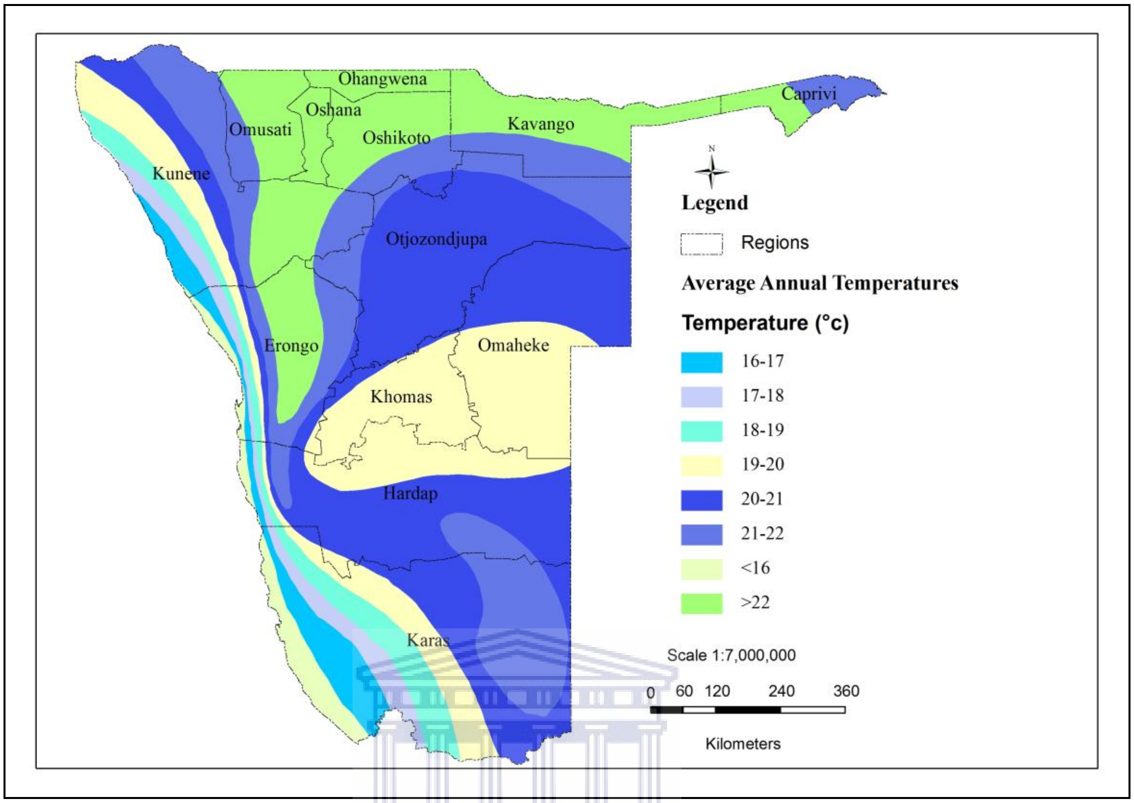


Figure 2.2: The three dams in central Namibia supplying water to Windhoek

2.3. Climate of Namibia

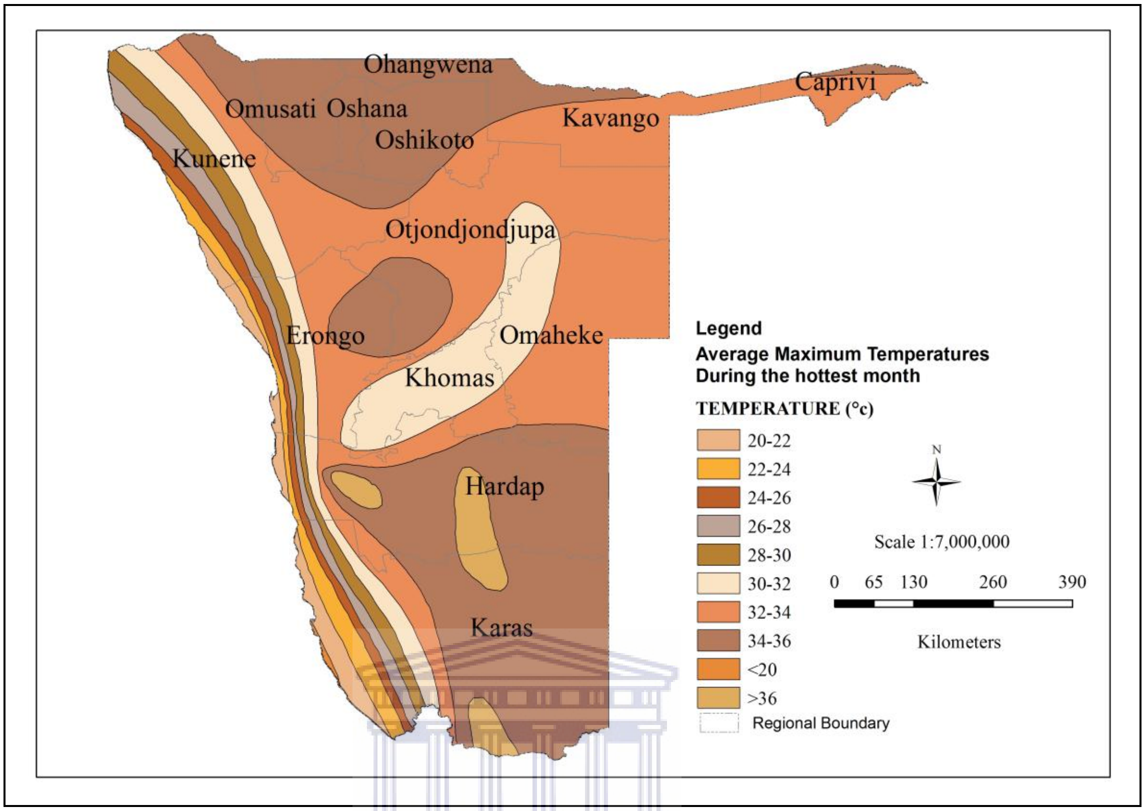
Temperature

The average annual temperature is less than 16 °C near the coast, about 18 °C to 20 °C in the central area, 20° C to 22 °C in the south, and more than 22 °C in the northern-eastern part of the country (Mendelsohn *et al*., 2002) (Figure 2.3). During the hottest months (i.e. October to February), the temperature at the coast is less than 20 °C, 30 °C in the centre, more than 36 °C in the southern part, and about 32 °C in the northern-eastern parts of the country (Figure 2.4).



Data source: Geohydrology, GIS Unit, NamWater

Figure 2.3: The spatial variation of the average annual temperature over Namibia

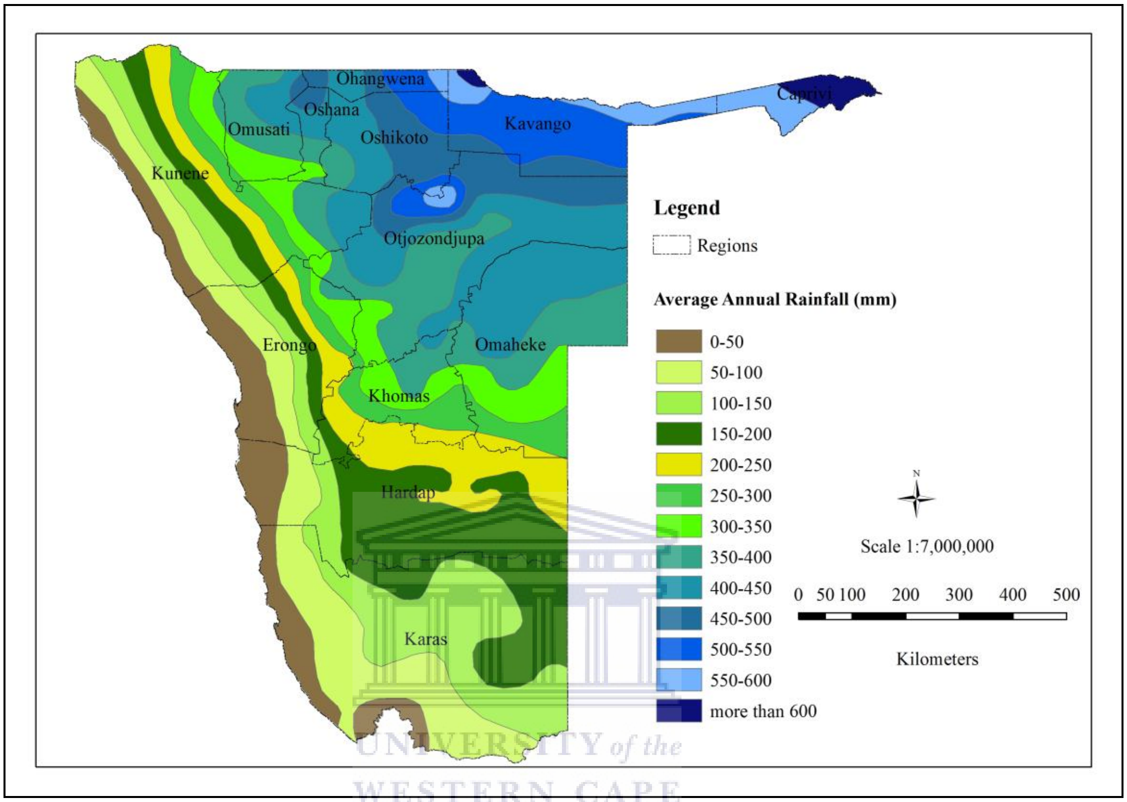


Data source: Geohydrology, GIS Unit, NamWater

Figure 2.4: The average maximum temperature of Namibia during the hottest months (October to February)

Rainfall

The annual rainfall varies across the country, where the coastal areas on average receive less than 50 mm/a, the southern part 50-200 mm/a, the central parts 200-400 mm/a and the northern part receives 400-550 mm/a (Mendelsohn *et al*., 2002). The eastern Caprivi receives the highest average rainfall in Namibia of about 650 mm/a (Figure 2.5). Areas like Tsumeb (510 mm/a), Otavi (540 mm/a), and Grootfontein (550 mm/a) also receive relatively high rainfall due to moist air being forced upward by the hills. Most of the rainfall is received during the summer, November to March, except for the winter rainfall in the southern-western corner of Namibia (Mendelsohn *et al*., 2002).

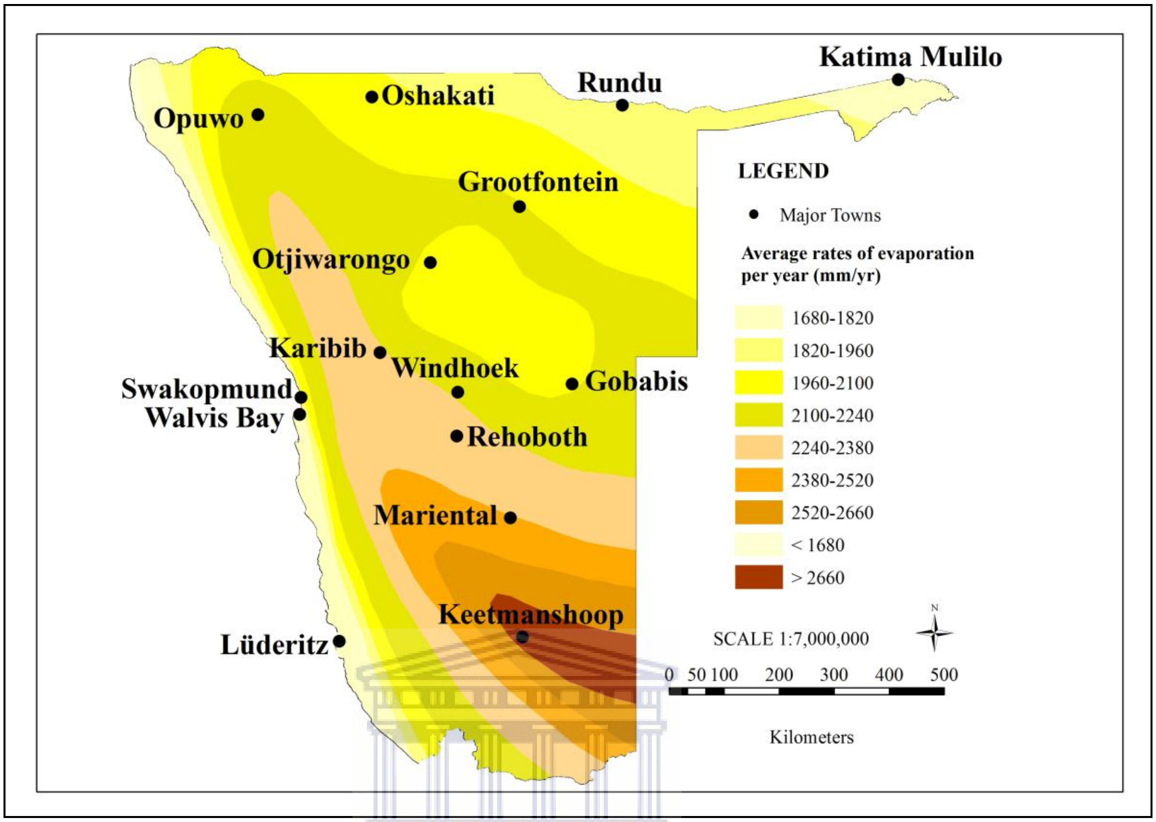


Data source: Geohydrology, GIS Unit, NamWater

Figure 2.5: The variation average annual rainfall in Namibia

Evaporation

The southern area loses 2 380-2 660 mm/a of water per annum through evaporation, about 1 680-1 820 mm/a of water is lost from the northern-eastern area and less than 1 680mm/a of water is lost along the coastal area (Figure 2.6). A high rate of evaporation occurs during October to January (Mendelsohn *et al*., 2002).



Data source: Geohydrology, GIS Unit, NamWater

Figure 2.6: The average rate of evaporation of Namibia

2.4. Population distributions of Namibia

Namibia, which has an area of 823,680 km^2 had approximately a population of 2.2 million in 2010 which is projected to increase to 2.6 million by 2020 (Mendelsohn *et al*., 2002). The population is unevenly distributed across the country. Most of the land is uninhabited and the inhabited land is sparsely populated. The majority of the people are found in urban areas and rural centers. Population distribution is influenced by the availability of drinking water, good fertile soil for crop production, and the availability of employment opportunities, education and transport. The majority of the population, about 52%, is found in the northern parts of the country in Kavango, Ohangwena, Omusati, Oshikoto and Oshana regions (Mendelsohn *et al*., 2002). Windhoek had about 314 000 people in 2007 (http://data.un.org/countryprofile.aspx?erName=Namibia).

2.5. Water supply system of Windhoek

The three sources of water supply for Windhoek are (a) the three dams (Von Bach Dam, Swakoppoort Dam, and Omatako Dam), (b) groundwater (50 municipal production boreholes), and (c) reclaimed water from both the New Goreangab Water Reclamation Plant (NGWRP) and the Old Goreangab Water Reclamation Plant (OGWRP). Von Bach Dam supplies about 20 Mm^3/a, groundwater supplies about 2 Mm^3/a, while reclaimed and reused water supplies about 7.5 Mm^3/a (Biggs and Williams, 2009). Other initiatives considered by the Municipality of Windhoek to augment future water supply to Windhoek are the Okavango River/Karst Aquifer and the artificial recharging of the Windhoek Aquifer with water from the three dams and the reclaimed water from NGWRP and OGWRP (Biggs and Williams, 2009).

2.6. Swakoppoort, Von Bach, and Omatako Dams characteristics

Table 2.1: Presents the main features of the Swakoppoort, Von Bach and Omatako Dams

Features	**Von Bach Dam**	**Swakoppoort Dam**	**Omatako Dam**
River	Swakop River	Swakop River	Omatako River
Capacity (Mm^3)	48.56	63.48	43.50
Max. Depth (m)	29	30	11
Evapo.Losses (mm/a)	2254	2275	2205
Ann.rainfall (mm/a)	370	350	380
Surface area (FSC) (km^2)	4.89	7.81	12.55
Catchment area size (km^2)	2 920	5 480	5 320
Geology of the areas	Schist and granite	Schists and granite	Sands and granite (calcrete)
Year completed	1970	1977	1982

FSC: full supply capacity

Among the three dams, Swakoppoort Dam has the largest capacity ($63.5Mm^3$), catchment area of 5 480 km^2 and a low annual rainfall of 350 mm/a (Table 2.1). Omatako Dam has a higher evaporation loss per surface area of 2 205 mm/a compared to the other two dams (Table 2.1). The geology of the Omatako Dam catchment is made up of sand and calcrete rock (Table 2.1).

2.7. Land cover and land uses of the catchment areas

The land cover of Namibia is generally dominated by tree and shrub savanna (Mendelsohn *et al*., 2002). The catchment areas of Swakoppoort, Von Bach and Omatako Dam are covered by acacia trees, shrub savanna, and broadleaved trees (Mendelsohn *et al*., 2002).

The land uses in the Omatako Dam catchment is mainly agriculture on freehold land (Mendelsohn *et al*., 2002) (Figure 2.7). The land uses in the catchment of Von Bach Dam are dominated by commercial livestock farming, game farming and villages (Mendelsohn *et al*., 2002) (Figure 2.7). In the Swakoppoort Dam catchment, land use activities are mostly cattle and game farming on a commercial scale (Figure 2.7) and urban settlements such as Okahandja and Windhoek. The capital Windhoek has sewage ponds or dams and industries that produce waste which are linked to the tributaries which flow into Swakoppoort Dam during the rainy season.

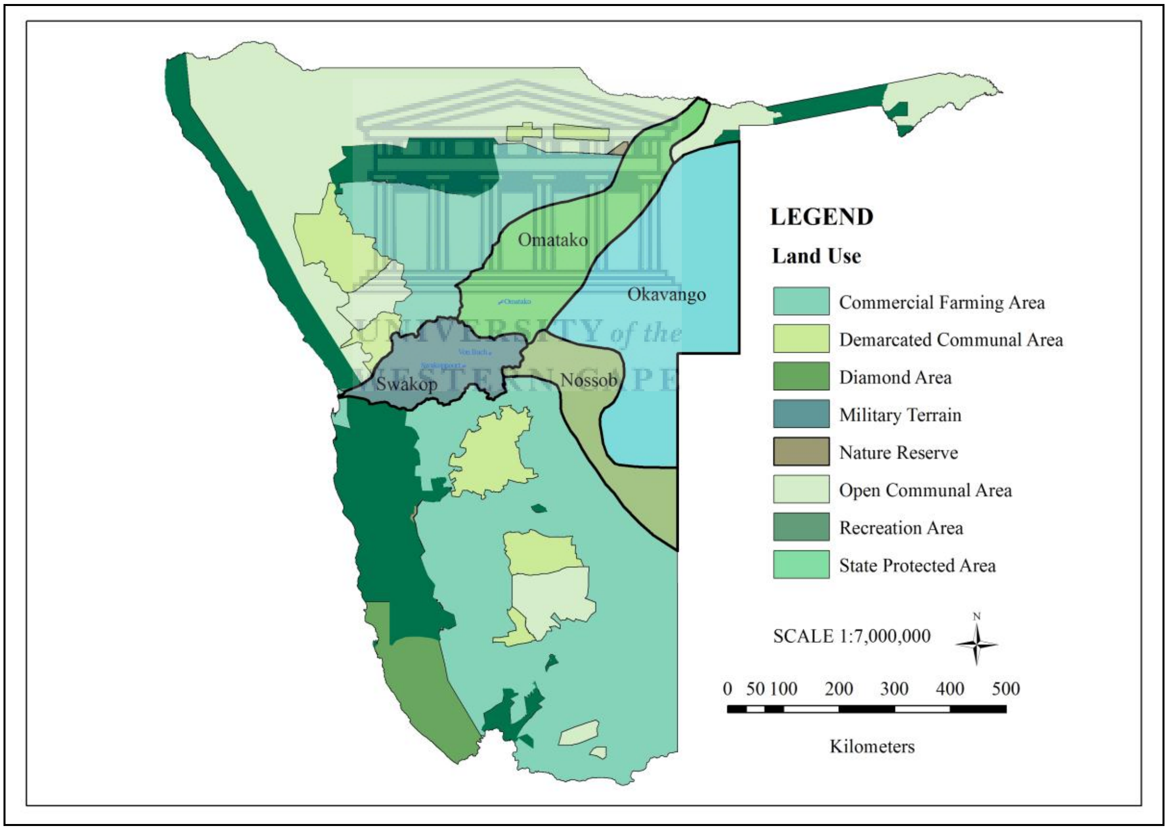
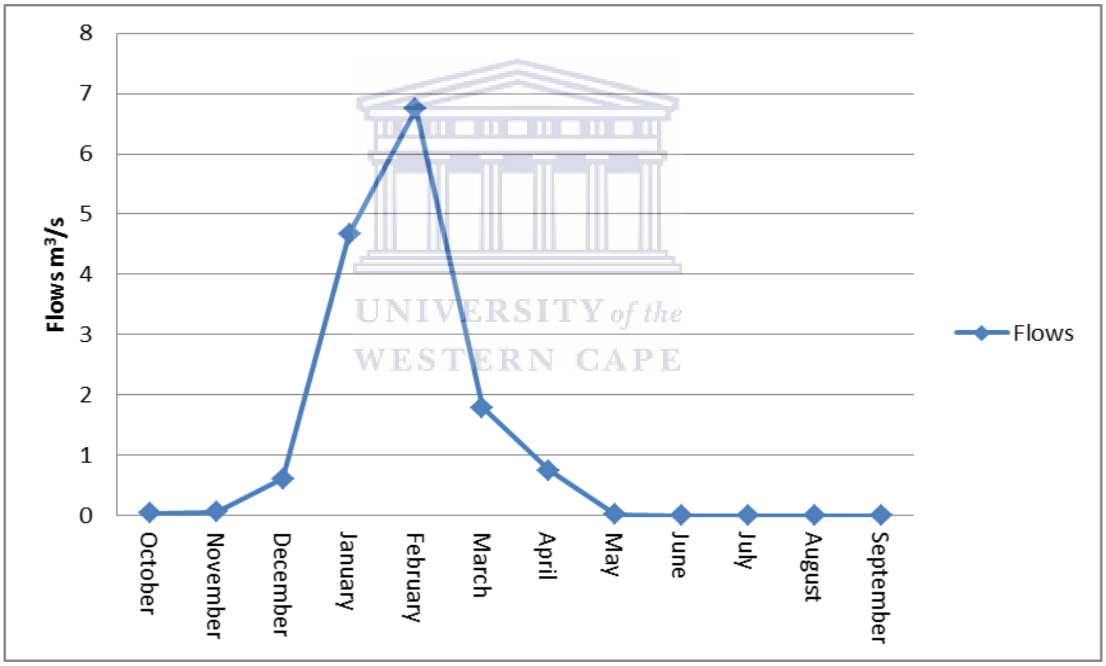


Figure 2.7: The land uses of the catchment area

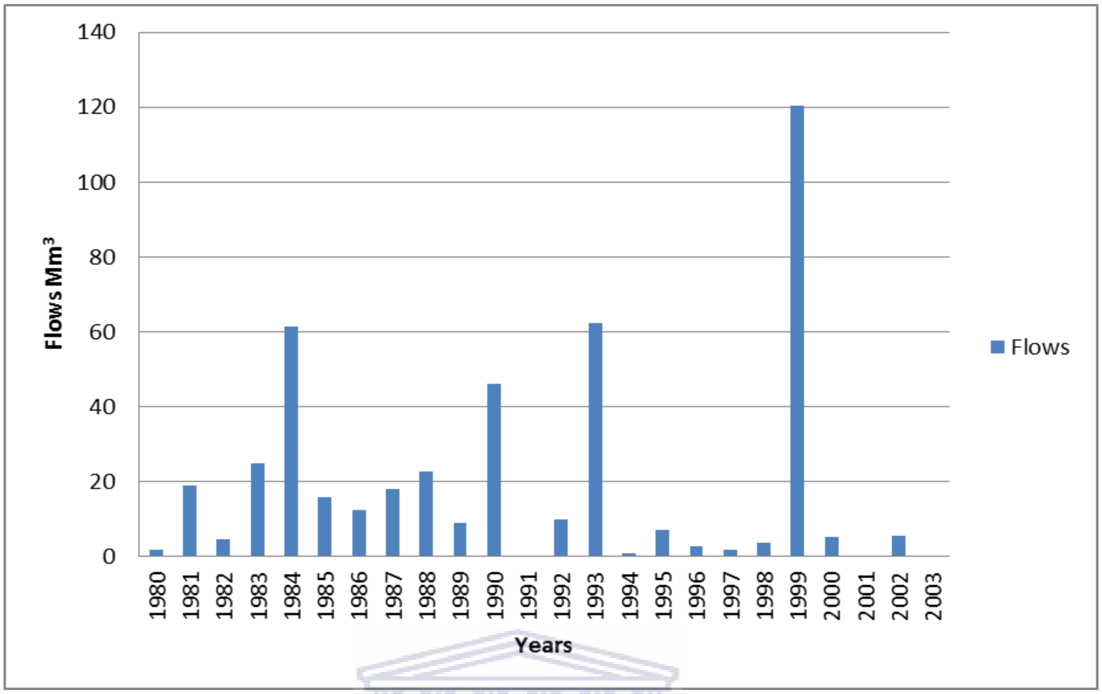
2.8. Seasonal and intra-annual variations of river flows

Flows of the Omatako River are high in January and February with the highest average flows of 6.8 m^3/s (Figure 2.8). Flows stop after the rainy season between April and May (Figure 2.8). High inflows are expected into Omatako Dam during the months of January and February. Flows were relatively low (1.2 Mm^3/a) in 1980 and relatively high (120 Mm^3/a) in 1999 (Figure 2.9). Most recent period data of Ousema site were not found in the database due to a lack of monitoring of the site (Figure 2.9).



Data source: Hydrology unit, Department of Water Affairs

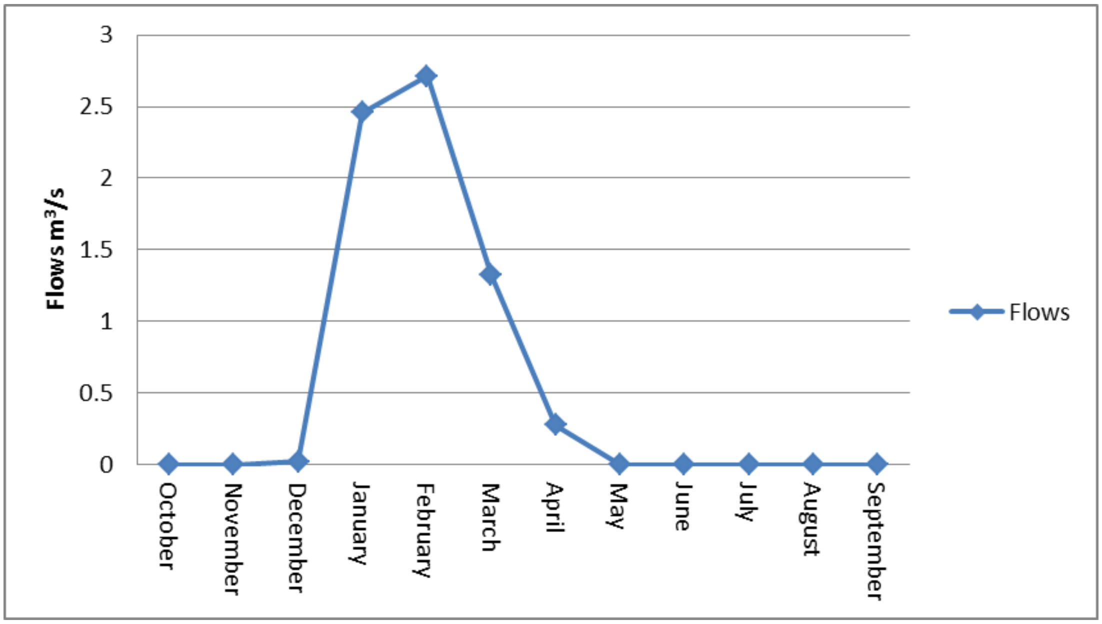
Figure 2.8: Monthly flows on the Omatako River at Ousema site upstream of Omatako Dam



Data source: Hydrology unit, Department of Water Affairs

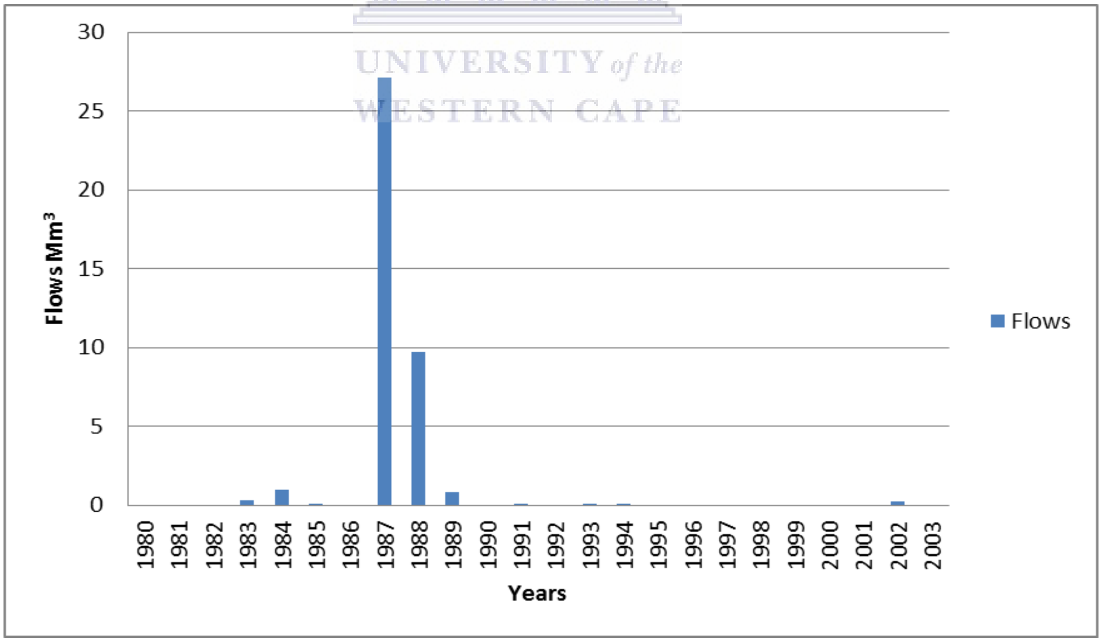
Figure 2.9: Annual flows of the Omatako River at Ousema site upstream of Omatako Dam

Flows of the Swakop River are high in January (2.5 m^3/s) and February (2.7 m^3/s), similar to that of the Omatako River in Figure 2.8 (Figure 2.10). Flows stop after the rainy season in April-May (Figure 2.10). From 1980 to 2003, the flows on the Swakop River were relatively low compared to the water flows on the Omatako River (Figure 2.11). High flows of about 27 Mm^3/a was observed in 1987 on the Swakop River (Figure 2.11). Most recent data for Westfalenhof site were not found in the database to a lack of monitoring of the site (Figure 2.11).



Data source: Hydrology unit, Department of Water Affairs

Figure 2.10: Monthly flows on the Swakop River at Westfalenof site upstream of Von Bach and Swakoppoort Dams



Data source: Hydrology unit, Department of Water Affairs

Figure 2.11: Annual flows on the Swakop River at Westfalenhof site upstream of Von Bach and Swakoppoort Dams

2.9. Summary

Swakoppoort and Von Bach Dams are on Swakop River, while Omatako Dam is on Omatako River. Swakop and Omatako Rivers are ephemeral rivers. High flows into Swakoppoort, Von Bach and Omatako Dams are expected between January and February. Swakoppoort, Von Bach and Omatako Dams are the major sources of water supplied to Windhoek. Their catchments are covered mainly by tree, shrub savanna, and the broadleaved tree. The land uses in their catchment are mainly livestock farming, game farming, villages, urban settlements and cattle farming.

CHAPTER THREE: LITERATURE REVIEW

3.1. Introduction

Inter-basin water transfers involve the transfers of water from one dam to another or from one river to another using pipelines or canals (Snaddon *et al*., 1998; Davies and Day, 1998; Gupta and Van der Zaag, 2008). Inter-basin water transfers have ecological (Snaddon *et al*., 1998), economic and social costs (Davies and Day, 1998). The ecological effect of water transfers is the effect on water quality due to mixing. The economic cost of water transfer is the cost for the electricity used in the pumping of water and the social cost, is the cost involved in the relocation of people for construction of pipelines and canals, and the decrease of water for communities located downstream of the point where water is abstracted for transfer. This chapter reviews the effects of water transfer on water quality and the models used to predict water quality changes.

3.2. Water quality

3.2.1. Factors that causes changes in water quality of lakes/dams

Water quality in lakes, rivers and groundwater is variable due to the difference in hydrological features (Chapman, 1992). During the formation of a lake the water quality undergoes changes in the early stage of their formation. Lakes are characterised by a low, average current velocity of 0.001 to 0.01 m/s (Chapman, 1992). Lakes have water residence times ranging from one month to several hundreds of years and the currents within lakes are multi-directional (Chapman, 1992; Davies and Day, 1998). Many lakes have alternating periods of stratification and vertical mixing (Chapman, 1992). Tropical lakes are mainly monimictic and stratify once a year, while temperate lakes range from polymictic to dimictic (Lewis, 1983, 1996; Kirillin, 2010). The interpretation of the water quality data of lakes should take into consideration the hydrological features.

Lakes are required to fulfill several functions including water supply for municipal and agricultural uses, and for recreation and fisheries. These uses have in some cases conflicting water quality demands (Chapman, 1992). The increases in population and industrialisation have increased the range of requirements for water together with a greater demand on higher quality water (Chapman, 1992; Rhodes *et al*, 2001). But due to low levels of industrialisation in Africa, changes in water quality of lakes does not present the same problem as in highly industialised countries (Kitaka *et al*., 2002). Land use activities in the catchments such as overgrazing, over-cultivation, and deforestation, affect the water quality of lakes particularly in Africa (Kitaka *et al*., 2002).

The geology of the catchment including land uses activities in the catchment also affect water quality in lakes. In the New England Watershed, a positive correlation was found between the percentage of the catchment area altered by human activities and the concentration of chlorine (Rhodes *et al*, 2001). Agricultural irrigation and industrial cooling require the least in terms of water quality. Water for domestic use and specialised industrial manufacturing has a high demand for water quality (Chapman, 1992; Kitaka *et al*., 2002). Effluents from these activities and inter-basin water transfers and discharge of untreated waste affect water quality. Therefore, a considerable effort has been made in controlling point sources of the pollution input of nutrients (Chapman, 1992). Non-point sources of pollution are in many cases not easy to control.

In a lake, the most important factor that influences water quality is stratification (Bartram and Balance, 1996; Chapman, 1992). Stratification occurs when the water has two different densities, one floating on the other. The difference in densities is caused by the temperature difference. Freshwater has a maximum density at 4°C, which depends on the solute concentrations (Bartram and Balance, 1996). Stratification causes the water quality to be different in the upper and bottom layers. The oxygen demand is always depleted in the bottom layer during stratification (Robarts *et al*, 1982; Bartram and Balance, 1996). When the oxygen is depleted, substances such as ammonia, phosphate, sulphide, silicate, iron, and manganese compound are released and diffuse from the sediments into the lower water layer affecting the quality of the water (Breen, 1983; Hart and Allanson, 1984; Bartram and Balance, 1996). Stratification varies depending on the lake's size. This variation affects water quality.

3.2.2. Changes in water quality of lakes and or dams

The most disturbing changes in water quality of lakes occur when the lake is enriched with nutrients such as nitrogen and particularly phosphorus from external and internal sources (Ekholm and Krogerus, 2003; Hart, 2006; Oberholster and Ashton, 2008). The enrichment of a lake/dam with nutrients is called eutrophication (Kemka *et al*., 2006) and this process has an adverse impact on the water quality of lakes (Nhapi and Tirivarombo, 2004; Oberholster and Ashton, 2008).

Eutrophication is viewed as the natural ageing of lakes, but the process is accelerated by human activities (Van Ginkel, 2004). Human activities such as the disposal of municipal wastewater and crop farming in the catchment supply nutrients to lakes, and these activities are termed as external sources of nutrients (Nhapi and Tirivarombo, 2004). The internal source of nutrients, particularly total phosphorus, is the sediment found at the bottom of the lake.

In many lakes, sediments store significant amounts of total phosphorus (Dalkiran *et al*., 2006). Dalkiran *et al*. (2006) argue that even though phosphorus is at the bottom of the lake (i.e. lake sediment) it is only released from the sediment when suitable conditions arise. Suitable conditions such as anaerobic conditions, pH, temperature, alkalinity and redox potential are needed to ensure a release of phosphorus from sediments. In Ulubat Lake, in Turkey, external sources of phosphorus were found to cause eutrophication (Dalkiran *et al*., 2006).

Even though total phosphorus was found to cause eutrophication in Lake Ulubat, in Turkey, the reduction of this external source will not guarantee an immediate recovery in water quality of a lake (Hart *et al*., 2003). To ensure a proper recovery of water quality due to total phosphorus enrichment, both external and internal sources should be reduced (Hart *et al*., 2003; Hart, 2006). Surprisingly, even though total phosphorus is released from the sediment, it may not be available for primary production to cause algal bloom in the epilimnion layer (Twinch and Breen, 1980).

Most of the total phosphorus released from the sediments during stratification is found in the hypolimnion layer below the thermocline where there are no algae available to utilize the total phosphorus (Twinch and Breen, 1980). When the stratification breaks down, phosphorus becomes fixed by an oxidizing agent in the sediment causing it once again not to be available for phytoplankton in the epilimnion (Twinch and Breen, 1980). Therefore, internal phosphorus loading contributes less to the eutrophication process of the water (Fred *et al*., 1978). The most effective way to control eutrophication in a lake is by reducing nutrients from external sources (Ekholm *et al*., 2000).

In Lake Chivero, Zimbabwe, the increase in nutrient loads of total phosphorus was found to be due to the discharge of effluent from a wastewater treatment plant (Nhapi and Tirivarombo, 2004). The Manyame River supplies a significant concentration of total phosphorus to Lake Chivero due to the sewer overflow in Chitungwiza, and the waste-stabilisation pond effluent from Donnybrook and Ruwa sewage treatment works (Nhapi *et al*., 2004). The Marimba River in the sub-catchment of Lake Chivero was also found to supply a significant amount of phosphorus, ammonia and nitrate, especially in the part occupied by informal industrial and residential areas (Mvungi *et al*., 2003).

In Lake Donghu, in China, the water quality is heavily polluted by total phosphorus (Gao *et al*., 2009). In their study to remove total phosphorus from the lake using submerged macrophytes, they found that macrophytes were effectively removing total phosphorus. In Lake Qinshan, China, freshwater algae were changing with the changes in nutrients with the season, and were not affected by temperature (Zhang *et al*., 2010). The increase in total phosphorus leads to algal bloom in lakes.

Algal blooms create health hazards for humans or animals through the production of toxins that causes the deterioration of water quality (Reynolds and Walsby, 2008). Blue-green algae cause the most detrimental algal bloom (Kirke, 2001). The most common blue green algae are microcystis and anabaena (Kirke, 2001). In Lake Victoria, Kenya, the bloom of 1986 was dominated by microcystis (Ochumba and Kibaara, 2008). Microcystis and anabaena are very efficient at utilising available nutrients and cannot usually be controlled by nutrient deprivation as they are able to fix nitrogen from the atmosphere and require only about 10µg/l of phosphate to form a bloom (Kirke, 2001), but they are however vulnerable to light limitation. Therefore, the reduction of nutrients would not prevent algal bloom, although the extent of bloom may depend largely on nutrient availability (Kirke, 2001).

Blue-green algae have vesicles inside vacuoles within their cells that they inflate with gas, thereby regulating their buoyancy in response to environmental conditions. This is an advantage over other algae as they have the ability to sink and rise at their will and move to where nutrient and light levels are at their highest, usually towards the bottom of the euphotic zone, where they encounter conditions most favouring their growth (Reynolds and Walsby, 2008). The formation of a bloom occurs when most of the algae possess excess buoyancy. Excess buoyancy is acquired when the photosynthetic rate is insufficient to develop the necessary turgor-pressure to cause collapse of the vacuoles (Reynolds and Walsby, 2008). But physical factors such as water column stability, water turbulence, and water temperature also control the occurrence of a bloom of algae (Steinberg and Hartmann, 1988). When the turbulence of the water column is low, as it is in sheltered lakes, cyanobacteria can build up a dense population (Steinberg and Hartmann, 1988). But, if the turbulence of the water column is high (mixing depth much greater than euphotic depth) cyanobacteria are outcompeted (Steinberg and Hartmann, 1988). Moreover, blue-green algae form floating scum because they are generally not eaten by other aquatic organisms due to the toxins (secondary metabolite) which they produce.

According to Kirke (2001) and Reynolds and Walsby (2008), algal blooms occur when there is a correct combination of:

1. Elevated water temperature of >20°C
2. Lack of competition and predation
3. Light
4. Long residence time
5. Low flushing rate
6. Nutrients
7. Strong vertical stratification
8. Temperature
9. Water column stability

The changes in water quality due to blooms of blue-green algae pose a problem for water treatment. The problems encountered during water treatment are identified as follows (i.e. Pitois *et al*., 2001; Heisler *et al*., 2008):

1. Unpleasant smell and taste of water.

2. Clogging of filters and pumps, and reduction in the carrying capacity of pipelines and canals.
3. Reduced oxygen level in the water, thus affecting aquatic biota.
4. Increase in the concentration of dissolved organic carbon, iron, ammonia and manganese in the water.
5. High turbidity in the water making the treatment of bacteria ineffective.

3.2.3. Models for predicting water quality changes

Water quality models are useful in describing or predicting the ecological state of a lake or river system. They are used in a situation where there are no monitoring data and in some situations they are used in combination with monitoring data to understand the changes in water quality due to different management strategies (Loucks *et al*., 2005). There are different types of water quality models such as dynamic or empirical models and statistical or steady state models (Rast *et al*., 1983; Tong and Chen, 2001; Loucks *et al*., 2005).

In Ben Chifley Dam, Bathurst, New South Wales, a conceptual model was developed to understand and to address causal factors and processes controlling blue-green algae (Rahman and Al Bakri, n.d). The model provided a basis for the cost effective management strategies to control eutrophication and minimise algal outbreaks. The model was developed on three components such as water quality, algae and sediment-water interaction.

In the East Fork Little Miami River Basin, the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) mathematical model (i.e. dynamic model) was adopted to determine the effects of land use on water quality. The statistical analyses revealed that there was a significant relationship between land use and in-stream water quality, especially for nitrogen, phosphorus and fecal coliform (Ton and Chen, 2001). Agricultural land and impervious urban lands were found to produce a much higher level of nitrogen and phosphorus than other land surfaces (Ton and Chen, 2001).

In Lake Edku, Northern Nile Delta, a water-sediment flux steady state model for total phosphorus was implemented to understand the geo-chemical behaviour of total phosphorus in the water and sediment, and to calculate its concentration in the water and sediments (Badr and Hussein, 2010). The model showed that the total phosphorus inputs into the lake were more than the outputs, which made the lake highly eutrophic (Badr and Hussein, 2010). It was recommended that, reducing 2% of total phosphorus in the lake sediment and a 15% reduction of total phosphorus from each drain could act as an important solution for the quick recovery of the lake (Badr and Hussein, 2010).

A steady state model for eutrophication control was developed for the Organisation for Economic Co-Operation and Development (OECD) countries by Vollenweider and Joseph 1982 (Rast *et al*., 1983). The model defines the relationship between phosphorus loads and eutrophication related responses of water bodies (Rast *et al*., 1983). The model is used as a management tool in the assessment and control of eutrophication in lakes. A statistical relationship is developed between annual phosphorus loadings into a lake normalised by mean depths and hydraulic residence time to predict the lake total phosphorus concentration. The model was developed using data from over 200 water bodies in 20 states of OECD. The equation for the model is written as follows:

$$P = 1.55(LTw/z)/(1+\sqrt{Tw})^{0.82} \qquad (3.1)$$

Where:

P=predicted median annual lake total phosphorus (TP) concentration (mg/l)

L= total phosphorus load (mg/m^2/year)

Z= mean depth of the lake (m)

Tw= hydraulic retention time (years)

LTw/z= average concentration of total phosphorus in the inflow (mg/l)

Tw/z= water loadings (m/y)

The OECD model was developed based on the following assumptions:

- The model assumes a steady state condition in a completely "mixed reactor"
- It is unlikely that individual loading estimates are more accurate than ± 35%.
- The nutrients loading model gives an estimation of average conditions; local conditions may deviate considerably, temporally and spatially.
- The model assumes that the basin is open and that there is an annual water surplus or outflow from the lake.

The OECD model has been applied on South African dams such as Allemanskraal, Klipfontein, Klipvoor, Vaal, and Welbedacht (Harding, 2008). The accuracy of the model was assessed by comparing the predicted total phosphorus and the observed total phosphorus, where the predicted was not varying by more than 30% of the observed (Harding, 2008).

3.3. Inter-basin water transfers

3.3.1. Inter-basin water transfers of the world

There are many inter-basin water transfer schemes planned globally, but the majority of them are never implemented (Slabbert, 2007). For example, the Grand Canal in Canada was not implemented due to a lack of agreement between the Canadians and Americans (Quinn, 1988).

In Russia, the Siberian Rivers Diversion was not implemented due to ecological concerns (Voropaev and Velikanov, 1985). In Turkey, the Peace Pipeline Project was never implemented due to economic consideration (Agnew and Anderson, 1992). While in Egypt, the Jonglei Project was not implemented due to environmental concerns (Bailey and Cobb, 1984). According to Slabbert, (2007), the following are the major inter-basin water transfers in the world:

1. The Grand Canal (Beijing-Hangzhou Grand Canal), in China.
2. Inter-basin Water Transfer to the Tokyo Metropolis, in Japan.
3. Shin-Nippon Seitetsu Kabushiki Kaisha (Kitakyushu Area), in Japan.
4. The Kagawa Irrigation Project, in Japan.
5. California State Water Project, North America.

3.3.2. Inter-basin water transfers in southern Africa

There are several inter-basin water transfers which have been implemented in southern Africa for water supply augmentation, irrigation and electricity generation (Slabbert, 2007). The following are the inter-basin water transfers implemented in Southern Africa (Slabbert, 2007):

Table 3.1: Inter-basin water transfers of southern Africa

Countries	Inter-basin water transfers schemes
Namibia	Kunene - Cuvelai, Eastern National Water Carrier (Okavango -

Countries	Inter-basin water transfers schemes
	Swakop)
South Africa-Swaziland	Komati Scheme,
South Africa	Usuthu Scheme Maputo, Usuthu-Vaal Scheme, Grootdraai Emergency Augmentation (Orange - Limpopo basin), Vaal - Crocodile, Tugela - Vaal Scheme, Mooi - Umgeni Scheme, Umzimkulu - Umkomaas - Illovo Scheme, (Umzimkulu - Umkomaas basin), Amatole Scheme (Kei - Buffalo & Nahoon basin), Palmiet River Scheme, Riviersonderend - Berg River Project, Orange River Project (Orange - Great Fish basin), Orange - Riet, Caledon - Modder, Orange - Vaal, North - South Carrier Vaal - Gamagara Scheme, Springbok Water Scheme, Vioolsdrift - Noordoewer, Turgwe - Chiredzi (Zambezi basin),
South Africa-Lesotho	Lesotho Highlands Water Project (LHWP),
South Africa-Botswana	Molatedi Dam - Gaborone,

3.3.3. Inter-basin water transfers in Namibia

The Eastern National Water Carrier (ENWC) in Namibia is one of the largest inter-basin water transfers in southern Africa (Slabbert, 2007). The ENWC was designed to transport water by canal and pipeline from the Kavango River on the north-eastern border of Namibia, pass Grootfonetin to the storage dams (Omatako, Von Bach and Swakoppoort Dams) north of Windhoek.

It was a four-phase project. Phase I was completed in 1978 which involved the Von Bach Dam on the Swakop River, the Swakoppoort Dam 55 km below Von Bach, and a pump system to Windhoek, 53 km away (Slabbert, 2007). Phase II comprising the earthfill Omatako Dam on the Omatako River, and a pump scheme, which transfers water from the Omatako River to the Von Bach Dam, was completed in 1983 (Slabbert, 2007). Construction of phase III commenced in 1981 and comprised the 263 km long Grootfontein-Omatako Canal and the Karstland Borehole System (Slabbert, 2007). Phase IV, which has not yet been implemented, will link the Kavango River to the Grootfontein/Omatoko Canal.

3.3.4. The effect of inter-basin water transfers on water quality of recipient lakes/dams

When sources of nutrients are uncontrollable in a particular dam, inter-basin water transfers may be used to lower the concentration of nutrients to acceptable levels in the recipient dam. This was successfully done in Green Lake and Moses Lake in Washington (Hu *et al*., 2009). The surface area of Lake Green and Lake Moses is less than 40 km^2 (Hu *et al*., 2009).

Inter-basin water transfer has been used in some countries as a restoration method to improve water quality. In China, inter-basin water transfers improved the water quality of Lake Taihu, by lowering the concentration of total phosphorus, total nitrogen and chlorophyll a (Hu *et al*., 2009). It was further concluded that water transfer was an effective tool for water quality improvement.

Apart from water transfers, other methods are also considered as restoration methods to improve water quality in lakes. Methods such as the reduction of nutrient loads, sediment dredging, wetland construction and bio-manipulation have been used in the restoration of aquatic ecosystems (Hu *et al*., 2009). These methods are slow at improving water quality. The transfer of water of low nutrient concentration to eutrophic small dams has a quick response in nutrient reduction. They further postulate that the method of water transfers is a cost-effective method. But the cost of water transfer as a restoration method varies from country to country.

In South Africa, water is transferred from the Caledon River through Knellpoort Dam to the Modder River. The water transfer scheme is called the *Novo* Water Transfer Scheme. Slabbert (2007) reports that, turbidity increases in Knellpoort Dam during water transfer. The increase in turbidity of the Knellpoort Dam was caused by the increase in algae (Slabbert, 2007). Apart from turbidity, nitrate increased at the surface from 56.8ug/l to 76.2ug/l and at the bottom from 64.3ug/l to 78ug/l, while ammonia concentrations did not change during the period of water transfer. Total phosphorus was found to increase at the discharge point of water transfer and the incoming water was highly turbid (Slabbert, 2007). Water transfers affect the water quality of receiving dams even though their effect is localised.

3.4. Summary

Natural factors and anthropogenic factors affect the quality of water in lakes or dams, making the water not suitable for irrigation, fisheries, recreation, and human consumption. The most significant changes in water quality are caused by nutrient input, particularly total phosphorus and orthophosphate. The increase in orthophosphate leads to algal blooms which adversely affect water quality. To improve the quality of the water in lakes or dams, models are used to predict water quality changes before implementing management measures. Inter-basin water transfers are also used to improve water quality in recipient lakes or dams.

CHAPTER FOUR: RESEARCH DESIGN AND METHODOLOGY

4.1. Introduction

Water quality can be measured using chemical, physical and biological indicators. These indicators determine the state of the water quality as to whether the water is fit for various uses. In this chapter the water quality parameters selected for the study will be discussed. The selection of the sampling sites and sampling frequency will be discussed. The method of data collection and laboratory analysis will be described and discussed.

4.2. The study approach

The study monitored water quality characteristics of the dams and the water quality of the recipient Von Bach Dam during water transfers to determine whether water transfers affect its water quality. The OECD countries model for predicting total phosphorus was adopted in this study since the model was successfully used in South African dams. The last approach was by interviewing the senior scientists responsible for water treatment at the Von Bach water treatment plant about the water treatment problems caused by water transfers.

4.3. Selection of water quality parameters

4.3.1. Physical water quality parameters

4.3.1.1. Temperature

Temperature depends on the intensity of heat stored in a volume of water (MELP, 2002). The changes in temperature affect the functioning of aquatic ecosystems (NWQMS, 2000). Temperature affects the solubility of chemical compounds and also influences the effects of pollutant on aquatic life. Increase in temperature elevates the metabolic oxygen demand, and reduces oxygen solubility in the water which affects aquatic organisms. Human activities such as discharge of cooling water into water bodies, removal of riparian vegetation, and discharge of cold hypolimnion, affects water temperature (Dallas and Day, 2004).

The increase in the water temperature increases the toxicity of chemicals such as zinc, phenol and cyanide (Dallas and Day, 2004). The temperature of water was measured in this study to determine the water quality characteristics of the three dams and the implication of water transfers on the water quality of Von Bach Dam.

4.3.1.2. Turbidity

Turbidity is a physical characteristic of water that causes light to be scattered and absorbed by suspended particles and molecules rather than to be transmitted in straight lines through a water column (EPA, 2002). Turbidity is increased by sediments, algae and aquatic weeds, humic acid and other organic compounds resulting from decay of plants and leaves (NWQMS, 2000).

The increase in turbidity reduces primary production by limiting light availability for photosynthesis and affects temperature sensitive species by reducing the water temperature as more heat is reflected at the water surface (Dallas and Day, 2004). Therefore, since turbidity affects primary production and temperature sensitive species, it was measured to determine the water quality characteristics of the three dams and how the turbidity in the transferred water affects the water quality of Von Bach Dam.

4.3.1.3. Secchi disk depths

Secchi disk is a circular disk that is lowered into water by a human observer until it disappears from view (Preisendorfer, 1986). The depth of disappearance is a visual measure of the clarity of the water (Wetzel, 1983; Preisendorfer, 1986). The depth of disappearance is inversely proportional to the average amount of organic and inorganic matter along the path of light in the water (Preisendorfer, 1986). Secchi disk depth was measured in this study to determine the water quality characteristics of the three dams and also to examine the effect of water transfers on the water quality of the recipient Von Bach Dam.

4.3.2. Chemical water quality parameters

4.3.2.1. Dissolved Oxygen (DO)

Dissolved oxygen is a measure of the amount of oxygen dissolved in the water. The concentration of dissolved oxygen in surface water is less than 10mg/l (MELP, 2002). Dissolved oxygen concentration is subject to diurnal and seasonal fluctuations caused by the variations in temperature. Moreover, dissolved oxygen also depends on processes consuming (e.g. respiration by aquatic plants during the night) and releasing oxygen (e.g. photosynthesis and the physical transfer of oxygen from the atmosphere to the water body) in the water body (NWQMS, 2000).

Dissolved oxygen is important for the respiratory metabolism of most aquatic organisms. Furthermore, dissolved oxygen affects the solubility and availability of nutrients and thus the productivity of the aquatic ecosystem. Low levels of dissolved oxygen in the bottom water facilitate the release of nutrients from the sediments. Due to the effect of dissolved oxygen on the nutrient releases from the sediments and because it is important for the respiratory metabolism of most aquatic organisms, it was selected to determine the water quality characteristics of the three dams and how it is affected in Von Bach Dam during water transfers.

4.3.2.2. pH

pH is the measurement of hydrogen ion concentration in the water. A pH below 7 is acidic and a pH above 7 is basic. Natural fresh waters have a pH range from 4.0 to 10.0 (MELP, 2002). High pH facilitates the solubilisation of ammonia, heavy metals and salts. High pH also encourages the precipitation of carbonate salts, but low pH increases the concentration of carbon dioxide and carbonic acid concentration. The lethal effect of pH on aquatic organisms occurs when the pH is below 4.5 and when the pH is above 9.5 (MELP, 2002). Anthropogenic activities such as mining, agriculture, industrial effluents and acidic precipitation cause changes to pH. Since pH facilitates the solubilisation of ammonia and salts, it was selected for measurement in this study to determine the water quality characteristics of the three dams and how the changes in pH affect water quality.

4.3.2.3. Iron

Algal growth influences the concentration of iron in the water (Wetzel, 1983). The demand for iron in the water increases during algal blooms (NWQMS, 2000). When the algae die, the iron is released back into the water column. A high concentration of iron affects the aesthetic value of the water which is a concern to water treatment.

Iron concentration was measured in this study to determine the effect of the changes on the water quality of Von Bach Dam due to water transfers and how these changes affect water treatment.

4.3.2.4. Manganese

Manganese is an essential micronutrient for aquatic plants and other organisms. When manganese is not present in sufficient quantities in the water, the photosynthetic process by aquatic plants is limited (Wetzel, 1983). The high concentration of manganese in the water affects the aesthetic value of the water which is a concern to water treatment. Manganese was measured in this study to determine the effect of the changes on the water quality in Von Bach Dam due to water transfers and how these changes affect water treatment.

4.3.2.5. Total phosphorus

Total phosphorus is a measure of both organic and inorganic forms of phosphorus (Wetzel, 1983; MELP, 2002). It is an essential nutrient for plant growth in freshwater systems and is often a limiting nutrient in water bodies. Since it is a limiting nutrient to freshwater systems, its input can cause proliferations of algal growth (Wetzel, 1983; NWQMS, 2000; MELP, 2002). It has been found as the main contributor to eutrophication in freshwater systems (Wetzel, 1983; Kirke, 2001). Major sources of total phosphorus are sewage treatment plant effluent, agriculture, urban development and industrial effluents. Therefore, it was measured in this study to determine the water quality characteristics of the three dams in terms of productivity and how water transfers and runoff from the catchment influence the eutrophication process in Von Bach Dam.

4.3.2.6. Orthophosphate (PO_4^{-3})

Orthophosphate is a measure of the inorganic oxidized form of soluble phosphorus. This form of phosphorus is the most readily available for algal uptake during photosynthesis (Wetzel, 1983; MELP, 2002). High concentration of orthophosphate causes blooms of blue-green algae (Kirke, 2001; Reynolds and Walsby, 2008). Major sources of orthophosphate are sewage treatment plant effluent, agriculture, urban development and industrial effluents (Wetzel, 1983; MELP, 2002; Dallas and Day, 2004). Orthophosphate was measured in this study to determine the water quality characteristic of the three dams in terms of productivity and to examine the effect of water transfers on the water quality of Von Bach Dam.

4.3.2.7. Total nitrogen

Total nitrogen is a measure of all forms of nitrogen (organic and inorganic). Total nitrogen is an essential plant nutrient and is often the limiting nutrient in marine systems (Wetzel, 1983; NWQMS, 2000; MELP, 2002). Major sources of total nitrogen are sewage treatment plant effluent, agriculture, urban development, paper plants, recreation, mining (blasting residuals), and industrial effluents (Wetzel, 1983; NWQMS, 2000; MELP, 2002). Total nitrogen was measured in this study to determine the water quality characteristic of the three dams and to examine the effect of water transfers on the water quality of Von Bach Dam.

4.3.2.8. Ammonia (NH_4-N)

Ammonia is a measure of the most reduced inorganic form of nitrogen in water. Although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status of bodies of water (Wetzel, 1983; MELP, 2002; Dallas and Day, 2004). Ammonia in excess concentration contributes to eutrophication which causes the growth of algae that affect water quality (NWQMS, 2000). Sources of ammonia are sewage treatment plant effluents, agriculture, urban development, paper plants, recreation, mining (blasting residuals), and industrial effluents (Wetzel, 1983; NWQMS, 2000; MELP, 2002). Ammonia was measured in this study to determine the water quality characteristics of the three dams and to examine the effects of water transfers on the water quality of Von Bach Dam and how these changes affect water treatment.

4.3.2.9. Dissolved organic carbon

Dissolved organic carbon is composed of humic substances and partly degraded plant and animal materials. It is a nutrient required for biological processes and when available in high concentration it lowers the dissolved oxygen concentration (MELP, 2002). High dissolved organic carbon in water requires a higher dosage of chlorine which results in the production of a harmful byproduct called trihalomethanes. Dissolved organic carbon was measured in this study to determine the water quality characteristics of the three dams and the effect of changes on the water quality of Von Bach Dam due to water transfers and what effect these changes have on water treatment.

4.3.3. Biological water quality parameters

4.3.3.1. Chlorophyll *a*

Chlorophyll *a* is a general indicator of plant biomass, because plants, algae, and cyanobacteria contain about 1 to 2 % chlorophyll *a* (NWQMS, 2000). A high concentration of chlorophyll *a* is a direct result of high nutrient input into the water (MELP, 2002). Measuring chlorophyll *a* in the water is a surrogate indicator of nutrient pollution (trophic status) (NWQMS, 2000). Nutrients (total nitrogen and total phosphorus) may not indicate whether a water body has a nuisance algae problem, while an increase in chlorophyll *a* (chla) in water may indicate that plant, algae or cyanobacteria are actually growing (NWQMS, 2000). Therefore, due to chlorophyll *a* being a good pollution indicator of nuisance blue-green algae, it was selected for measurement for this study to determine the water quality characteristics of the three dams and how water transfers affect the water quality of the recipient Von Bach Dam.

4.3.3.2. Blue-green algae (Anabaena and microcystis)

The most common blue green algae which cause nuisance bloom are Microcystis and Anabaena (Kirke, 2001). Microcystis and Anabaena are very efficient at utilising available nutrients and cannot usually be controlled by nutrient deprivation as they are able to fix nitrogen from the atmosphere and require only about 10µg/l of phosphate to form a bloom (Kirke, 2001), but they are however vulnerable to light limitation. Reduction of nutrients will not prevent algal bloom, although the extent of bloom may depend largely on nutrient availability (Kirke, 2001). Blue-green were measured to determine the water quality characteristics in the three dams and the effects of water transfer on the water quality of Von Bach Dam.

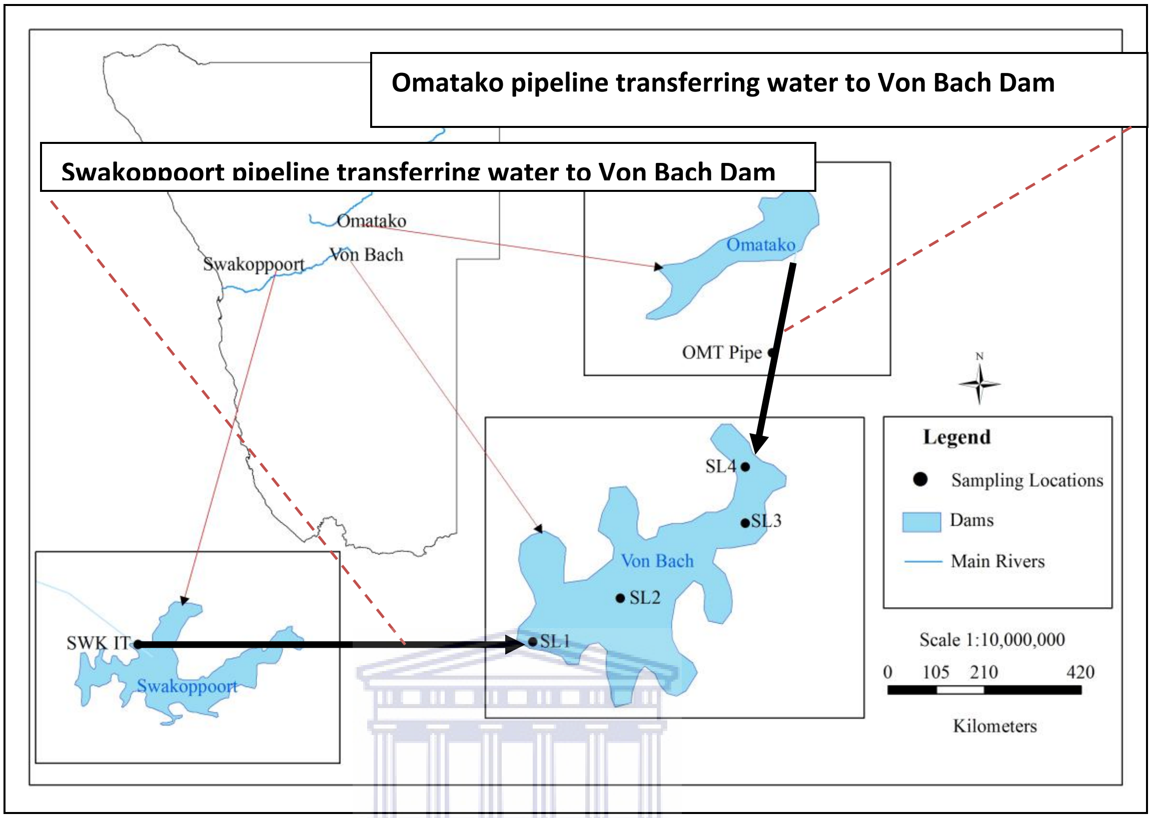
4.4. Selection of variables for qualitative analysis

Two senior officers responsible for water treatment at the Von Bach treatment plant were interviewed, (a) about the challenges faced in treating the water abstracted from Von Bach Dam, (b) what process or methods were used in treating this water, and (c) do the challenges faced in treating the water from Von Bach Dam occur during water transfers or during periods of none water transfers.

4.5. Selection of sampling sites

The first visit to the dams was used to identify a suitable sampling location. A Global Position System (GPS) was used in the establishment of the sampling location (Burns *et al*., 2000). Sampling locations were established in Swakoppoort, Omatako and Von Bach Dams to examine the difference in the water quality parameters in the three dams. One sampling location was on Swakoppoort Dam (SWK IT), one on Omatako Dam (OMT Pipe), and four locations on the Von Bach Dam (SL1 to SL4) (Figure 4.1).

Single locations were established on Swakoppoort Dam and Omatako Dam in order to determine the water quality characteristic that is transferred to Von Bach Dam. The sampling of the Omatako Dam water transferred into Von Bach Dam at a pipe was a full representative of the water quality of Omatako Dam. In Von Bach Dam, sampling location SL1, was at the point where water from Swakoppoort Dam is discharged, SL2 and SL3 where established in the middle of the dams to determine the spatial variation in the water quality due to water transfers, and SL4 was at the point where water transferred from Omatako Dam is discharged and which is also a point where runoff from the catchment area flows into Von Bach Dam.



OMT pipe: Omatako pipe; SWK IT: Swakoppoort intake tower; SL: Sampling location.

Figure 4.1: The sampling locations of the study area

4.6. Sampling frequency

Water samples were collected on a weekly basis in the three dams. Two weeks in a month on Von Bach Dam and Omatako Dam and one week in a month on Swakoppoort Dam. The differences in sampling were due to the distance between the dams. This was cost-effective for the study and it was in line with the existing sampling program used by NamWater.

4.7. Data collection

To collect a representative sample at each sampling location, a dip sampling method was used. A dip sampling method involves the dipping of the sampler into the water to retrieve the water sample which is transferred to the appropriate sample container (Burns *et al.*, 2000). The interview method was used to collect information on the effects of water transfers on water treatment. A checklist was used to collect data on the volume of water transferred from Swakoppoort and Omatako Dams into Von Bach Dam and the volume of water abstracted to the treatment plant.

To access each sampling location in the dam a boat was used. Water samples were collected at three depths (2 m, 8 m and 18 m) in Swakoppoort, Omatako and Von Bach Dams at the point where water is abstracted for transfer to Von Bach Dam and to the water treatment plant. The three depths were selected due to the higher depths of the sampling points and were based on temperature and dissolved oxygen measured in situ. In Von Bach Dam, water samples at SL2, SL3, and SL4 were collected at two (2m to 10m) depths due to the lower depths of the sampling locations. Water samples were collected using a *niskin* bottle. The collected water samples from different depths were transferred into labelled containers which were preserved in cooler boxes. The cooler boxes were transported to the laboratory and analysed within twenty four hours.

Temperature, secchi depth and dissolved oxygen were measured *in situ*. The temperature and dissolved oxygen (DO) were measured with a Yellow Springs Instrument (YSI) meter Model 54A which was calibrated before use. The water transparency (secchi depth) of the dams was measured using the secchi disc in the field. The *in-situ* measurement data were recorded on prepared sheets.

In the laboratory water samples were analysed in replicates. A blank sample without the analyte was used for quality control of the analytical processes for each analysed water quality parameter. Turbidity of the water samples was measured using the turbidity meter in the laboratory. The nephelometric method (APHA, 1998: part 2130 B) was applied during the analysis of turbidity in the water samples. The pH of the water samples was measured in the laboratory using the pH meter APHA (1998: part 4500 H B). Furthermore, the value for turbidity was reported in nephelometric Turbidity Units (NTU).

The total phosphorus and nitrogen of the water samples were also measured in the laboratory. The total phosphorus of the water samples was measured using the Ascorbic Acid method as described in APHA (1998: part 4500 P E). A spectrophotometer with infrared phototubes was used as colorimetric equipment. The total nitrogen of the water samples was measured using the Cadmium Reduction method as described in APHA (1998: part 4500 NO_3^-E). In the analysis of total nitrogen, the reduction column was used as an apparatus together with the spectrophotometer. The total phosphorus and nitrogen of the water samples were reported in mg/l. Iron and manganese were measured using the Atomic Absorption Spectrophotometry method as described in APHA (1998: part 300).

Chlorophyll *a* contained in the water samples was measured using the spectrophotometric determination method as described in APHA (1998: part 10200 H). In the analysis of the algal cell count of blue green algae (anabaena and microcystis), water samples were filtered and were analyzed by the phytoplankton counting techniques method as described in APHA (1998: part 10200 F). Dissolved organic carbon (DOC) of the water samples was measured using the carbonaceous analyzer method as described in APHA (1998: part 9060 A).

The qualities of the data were controlled and checked using test procedures as described in APHA (1998: part 1020). Calibration standards were checked to make sure that there were made up correctly. Field and laboratory generated data were recorded on a spreadsheet. The data were arranged in chronological order and sorted according to site, date, location and depths. A visual scan was made to look for possible outliers. For outliers detected, remedial action was taken, such as re-analysis.

4.8. Data analysis

Descriptive statistics were estimated for each water quality parameter measured in the three dams. The mean and standard deviation values were used to determine the elevation of each water quality parameter among the three dams. A two way-ANOVA at a 5% significance level was carried out to determine the statistically significant difference in each water quality parameter of the three dams. Box plots were generated for each water quality parameter at the four sampling locations of Von Bach Dam to show the influence by water transfers. A one way-ANOVA was carried out to determine the statistically significant difference of each water quality parameter between sampling locations. Correlation coefficient (r) between water volume transferred from Swakoppoort and Omatako Dams into Von Bach Dam and the water quality parameters at SL1 and SL4 of Von Bach Dam was determined. The correlation was done to determine the influence of water volume transferred into Von Bach Dam on the water quality parameters at SL1 and SL4. Furthermore, the correlation coefficient (r) was also determined between the water quality parameters of Swakoppoort, Omatako and Von Bach Dams to determine the influence of water transfers on the water quality of Von Bach Dam.

4.9. Summary

The physical and chemical water quality parameters such as temperature, dissolved oxygen, pH, turbidity, dissolved organic carbon, chlorophyll *a*, total nitrogen, ammonia, orthophosphate and total phosphorus were selected for the study. The biological water quality parameters involving, microcystis and anabaena, were tested. Sampling locations were selected in the three dams using a GPS. At each sampling location water samples were collected.

CHAPTER FIVE: WATER QUALITY CHARACTERSTICS OF THE THREE DAMS

5.1. Introduction

Water quality parameters such as temperature, dissolved oxygen, secchi disk depths, turbidity, pH, iron, manganese, total nitrogen, ammonia (NH_4-N), total phosphorus, orthophosphate (PO_4^{-3}), chlorophyll *a*, and blue green algae (anabaena, and microcystis) for each dam were compared between the dams and some were compared with the water quality guideline for the aquatic ecosystem of South Africa. This chapter presents and discusses the water quality of Swakoppoort, Von Bach and Omatako Dams.

5.2. Results

5.2.1. Physical water quality parameters

5.2.1.1. Temperature

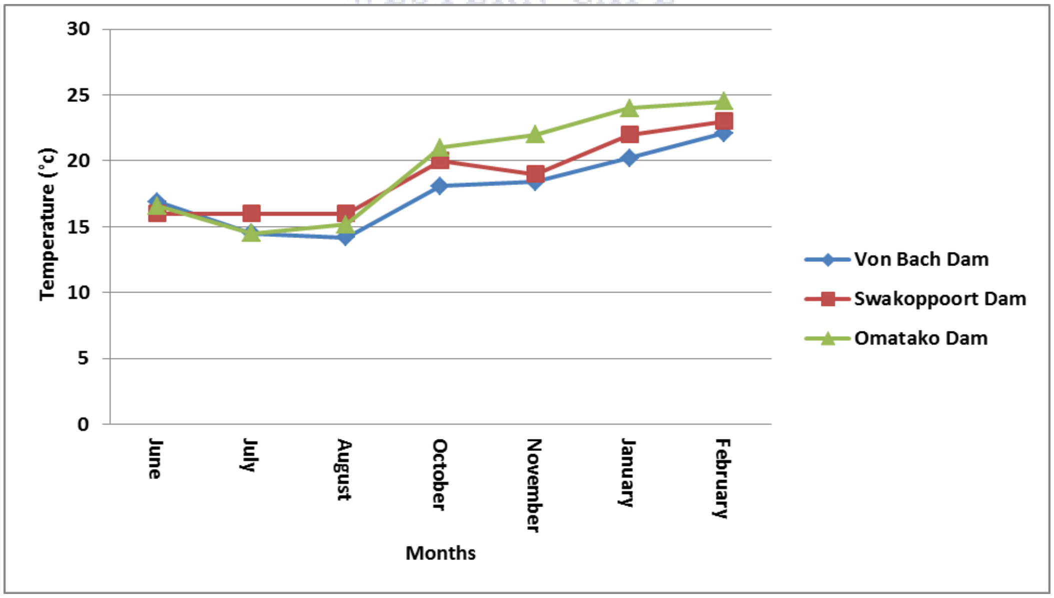


Figure 5.1: The water temperature of the three dams from June 2010 to February 2011

The water temperature in Swakoppoort, Omatako and Von Bach Dams was low in June, July and August (Figure 5.1). The water temperature of the three dams increased from August till February 2011 (Figure 5.1). The mean temperature of Swakoppoort Dam was 18.9 °C, with a standard deviation of 3.0 °C and *n* =7; Von Bach Dam was 17.8 °C, with a standard deviation of 2.9 °C and *n* =7, and Omatako Dam was 19.7°C, with a standard deviation of 4.2°C and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.500*) in the temperature of the three dams at 5% significance level. Swakoppoort Dam water stratification diminished (i.e. no thermocline) in July 2010 (Figure 5.1a) and in October 2010 the stratification developed (i.e. with a thermocline at 7.5m) (Figure 5.1b).

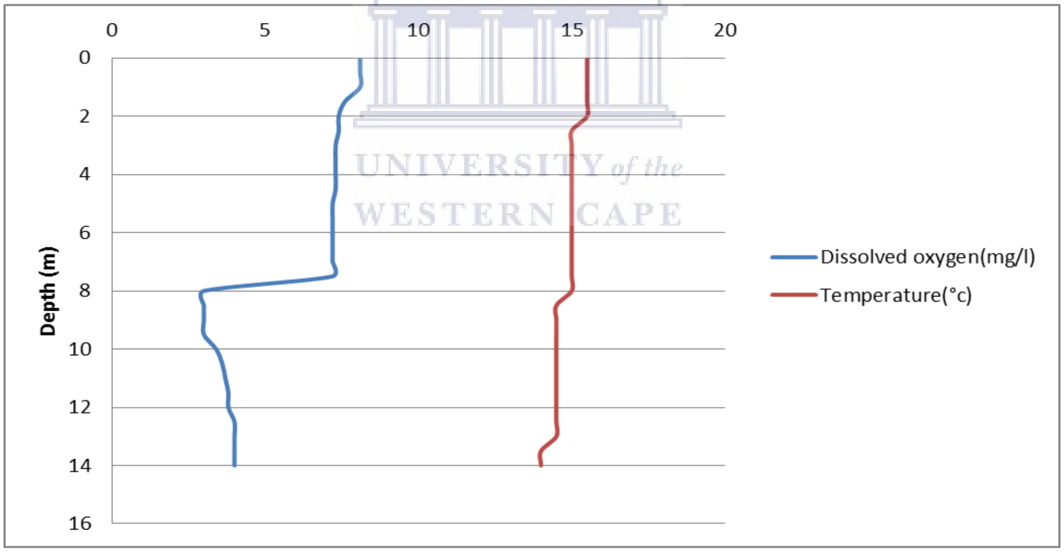


Figure 5.1a: No thermal stratification in Swakoppoort Dam in July 2010

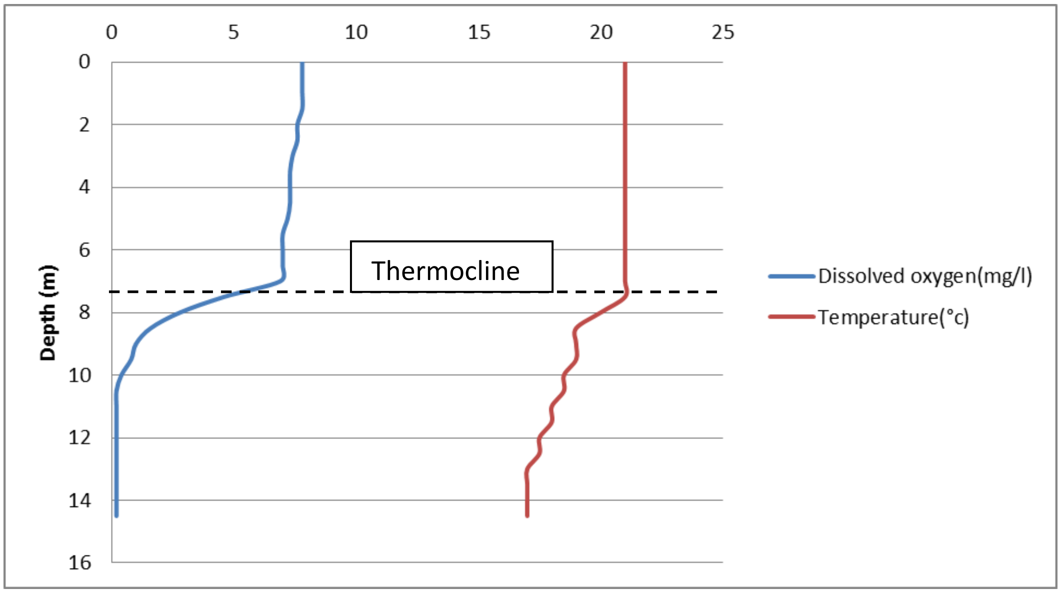


Figure 5.1b: Thermal stratification in Swakoppoort Dam in October 2010

The was no stratification of water in Von Bach Dam (i.e.no thermocline) in July 2010 (Figure 5.1c) and in October 2010 the stratification developed (i.e. with a thermocline at 6m) (Figure 5.1d).

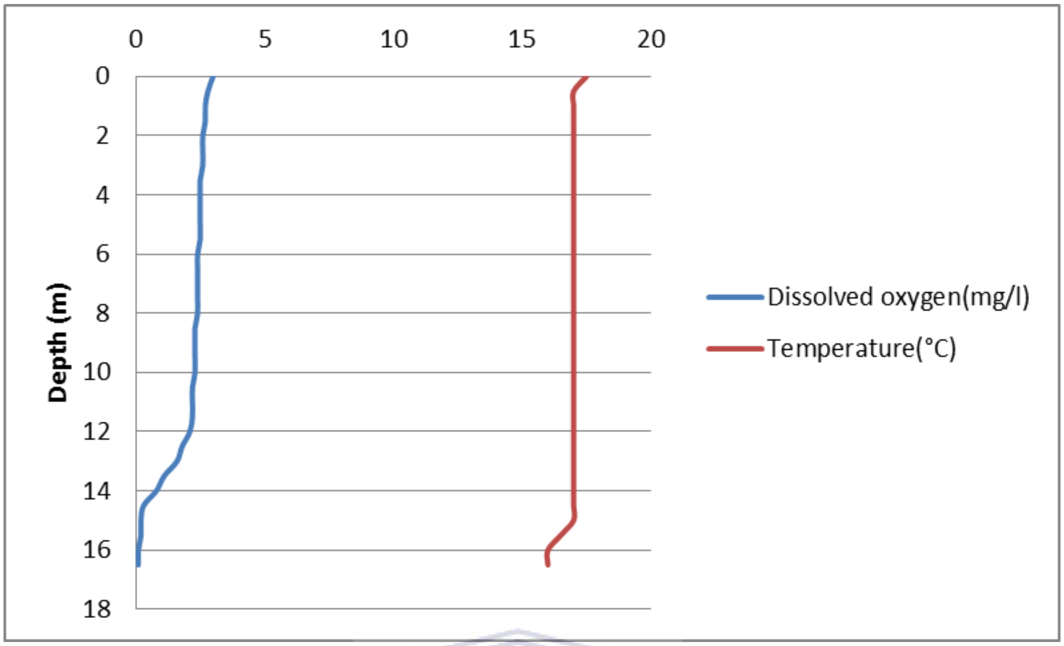


Figure 5.1c: No thermal stratification in Von Bach Dam in July 2010

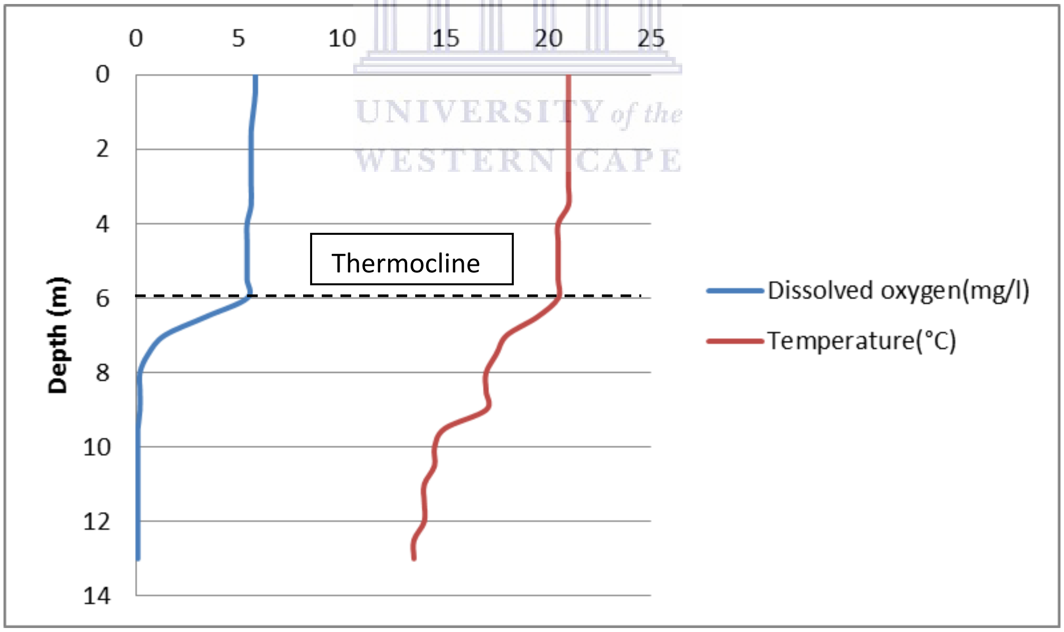


Figure 5.1d: Thermal stratification in Von Bach Dam in October 2010

5.2.1.2. Secchi disk depths

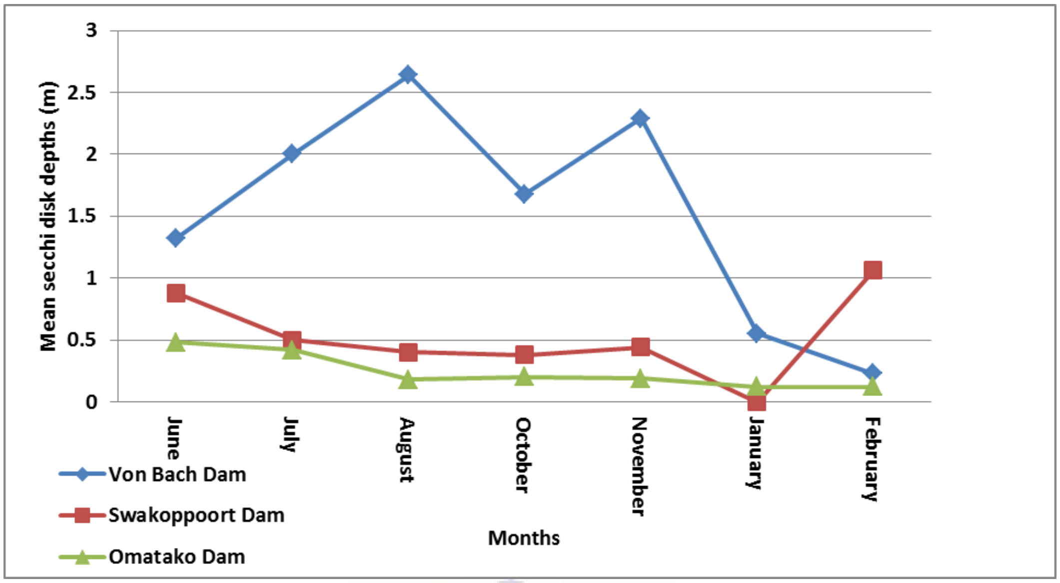


Figure 5.2: The secchi disk depths of the three dams from June 2010 to February 2011

The secchi disk depths of Von Bach Dam were greater than that of Swakoppoort Dam, except in January and February 2011 (Figure 5.2). The mean secchi disk depths were: Von Bach Dam 1.5 m with a standard deviation of 0.9 m and *n* =7; Swakoppoort Dam 0.5 m with a standard deviation of 0.4 m and *n* =7, and Omatako Dam was 0.2 m with a standard deviation of 0.15 m. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference (*p=0.016*) in the secchi disk depths of the three dams at 5% significance level.

5.2.1.3. Turbidity

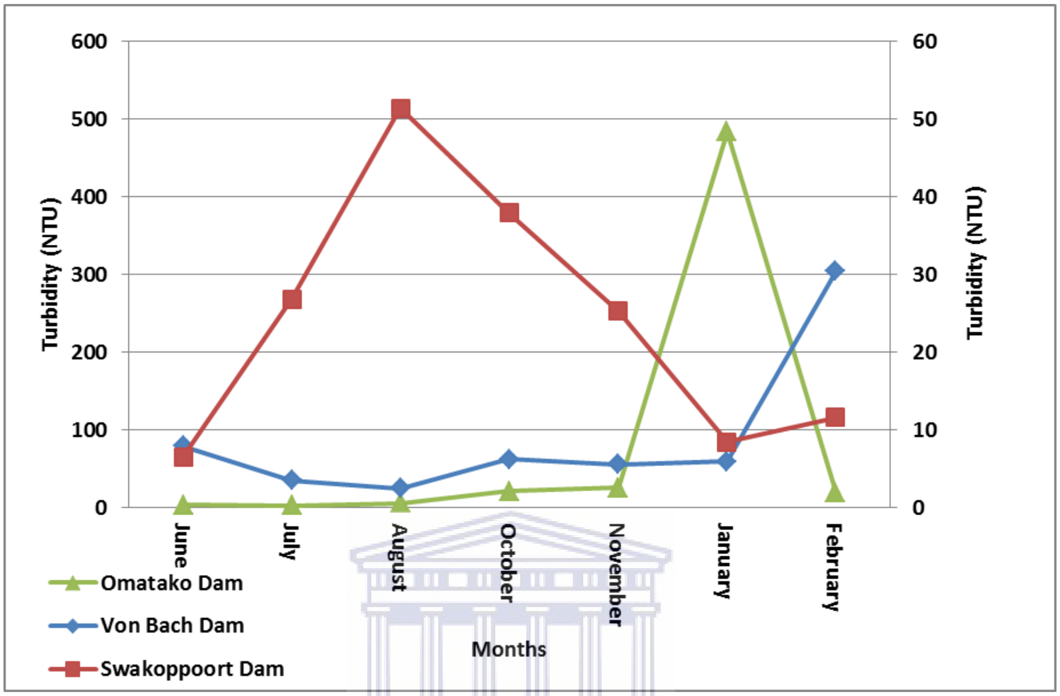


Figure 5.3: The turbidity of the three dams from June 2010 to February 2011

The turbidity of the water in Von Bach Dam was fairly stable from June until it increased from January 2011 to February 2011 (Figure 5.3). The turbidity of water in Swakoppoort Dam was highest in August 2010 while Omatako Dam was highest in January 2011 (Figure 5.3). Omatako Dam had a mean turbidity of 80.1NTU with a standard deviation of 178.4NTU and *n* =7, while Swakoppoort Dam had a mean turbidity of 24.0NTU with a standard deviation of 16.6NTU and *n* =7, and Von Bach Dam had a mean turbidity of 8.9NTU with a standard deviation of 9.7NTU and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.417*) in the turbidity of water in the three dams at 5% significance level.

5.2.2. Chemical water quality parameters

5.2.2.1. Dissolved oxygen

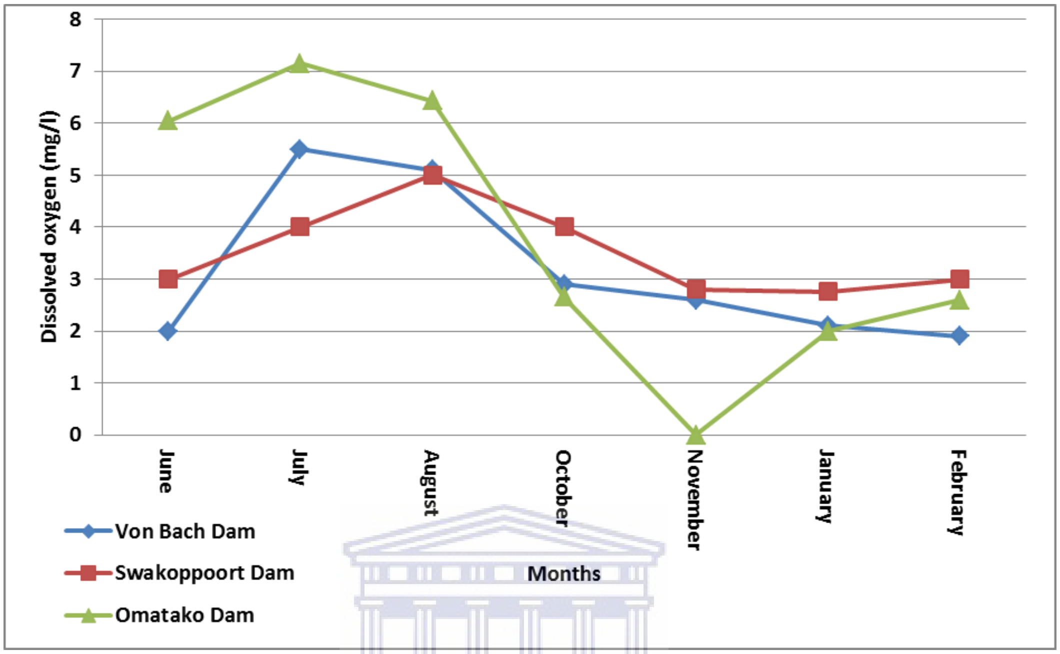


Figure 5.4: The dissolved oxygen of Von Bach and Swakoppoort Dams from June 2010 to February 2011

The dissolved oxygen concentration of Swakoppoort Dam, Von Bach Dam and Omatako Dam follow a reverse pattern as compared to temperature in Figure 5.1 (Figure 5.4). The dissolved oxygen of the three dams was highest in July and began to drop in August (Figure 5.4). The mean dissolved oxygen values of the three dams were: Swakoppoort Dam 3.5mg/l with a standard deviation of 0.9mg/l and n =7; Von Bach Dam was 3.2mg/l with a standard deviation of 1.5mg/l and n =7 and Omatako Dam was 3.84mg/l with a standard deviation of 2.70mg/l. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p=0.601$) in the dissolved oxygen of the three dams at 5% significance level.

5.2.2.2. Iron

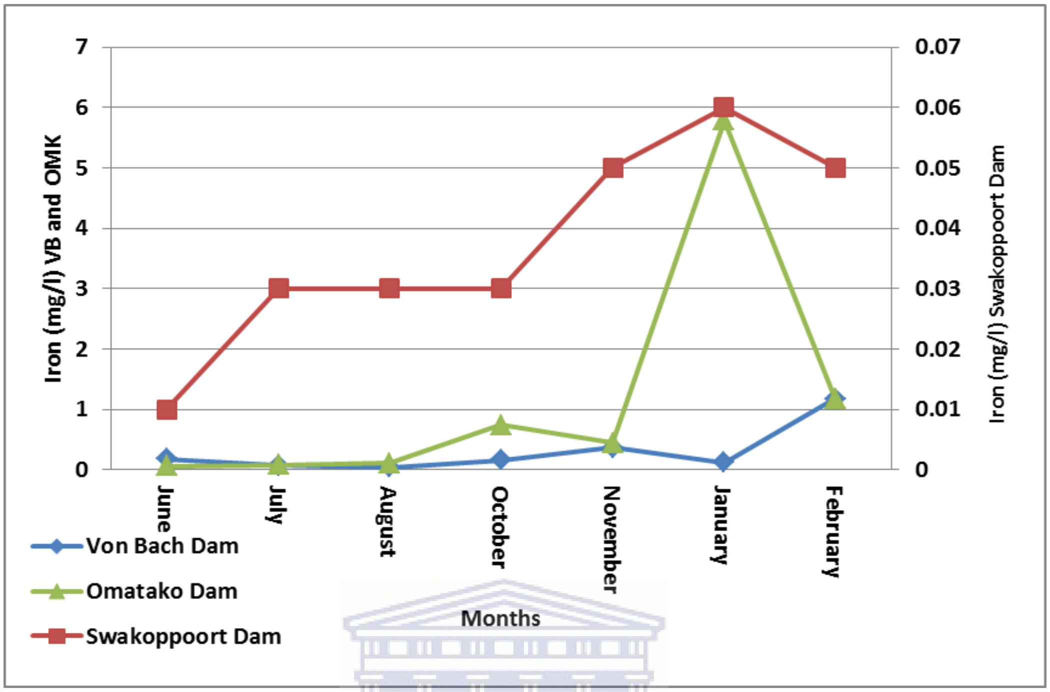


Figure 5.5: The iron concentration of the three dams from June 2010 to February 2011

The iron concentration in Von Bach and Omatako dams was fairly stable from June 2010 to November 2010 (Figure 5.5). The iron concentration in the water of Swakoppoort and Omatako Dams was high in January 2011 (Figure 5.5). The mean iron concentrations in the three dam were: Omatako Dam 1.2mg/l with a standard deviation of 2.1mg/l and *n* =7; Swakoppoort Dam 0.0mg/l with a standard deviation of 0.2mg/l and *n* =7; Von Bach Dam 0.3mg/l with a standard deviation of 0.4mg/l and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.199*) in the iron of the three dams at 5% significance level.

5.2.2.3. Manganese

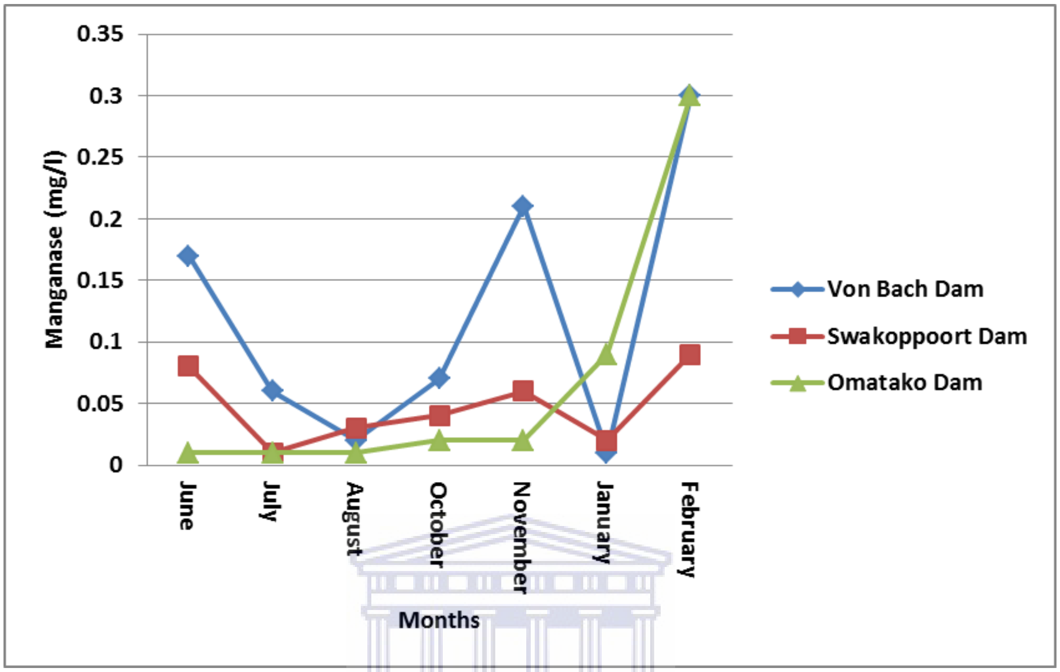


Figure 5.6: Manganese concentration of the three dams from June 2010 to February 2011

The manganase concentration was higher in Von Bach Dam than in Swakoppoort Dam water in June, November and February (Figure 5.6). While in Omatako Dam, an increase in the manganase concentration was observed in February (Figure 5.5). The mean manganase of the three dams were: Omatako Dam 0.1mg/l with a standard deviation of 0.1mg/l; Swakoppoort Dam was 0.1mg/l with a standard deviation of 0.0mg/l; Von Bach Dam was 0.1mg/l with a standard deviation of 0.1mg/l. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.301*) in the manganese of the three dams at 5% significance level.

5.2.2.4. pH

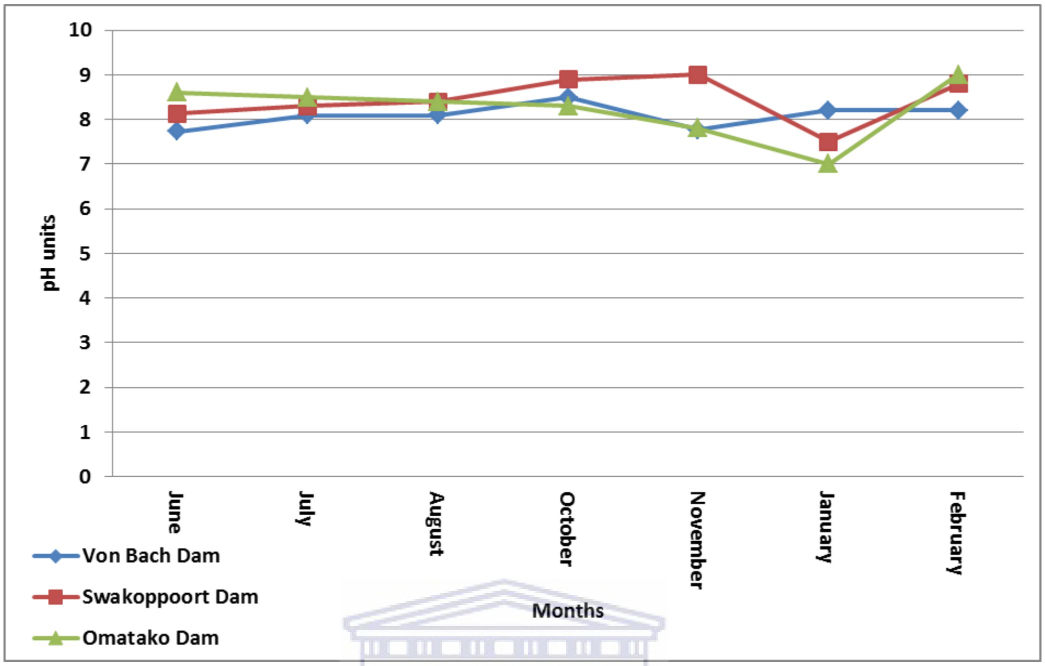


Figure 5.7: pH of the three dams from June 2010 to February 2011

The water pH in Von Bach Dam and Swakoppoort Dam was following a smilar pattern, increasing from June till October (Figure 5.7). There was a decrease in November to January in Swakoppoort and Omatako Dams (Figure 5.7). The mean pH of Omatako Dam water was 8.2 with a standard deviation of 0.7 and *n* =7; Swakoppoort Dam mean pH was 8.4 with a standard deviation of 0.5 and *n* =7 and Von Bach Dam mean pH was 8.1 with a standard deviation of 0.3 and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.452*) in the pH of the three dams at 5% significance level.

5.2.2.5. Total phosphorus

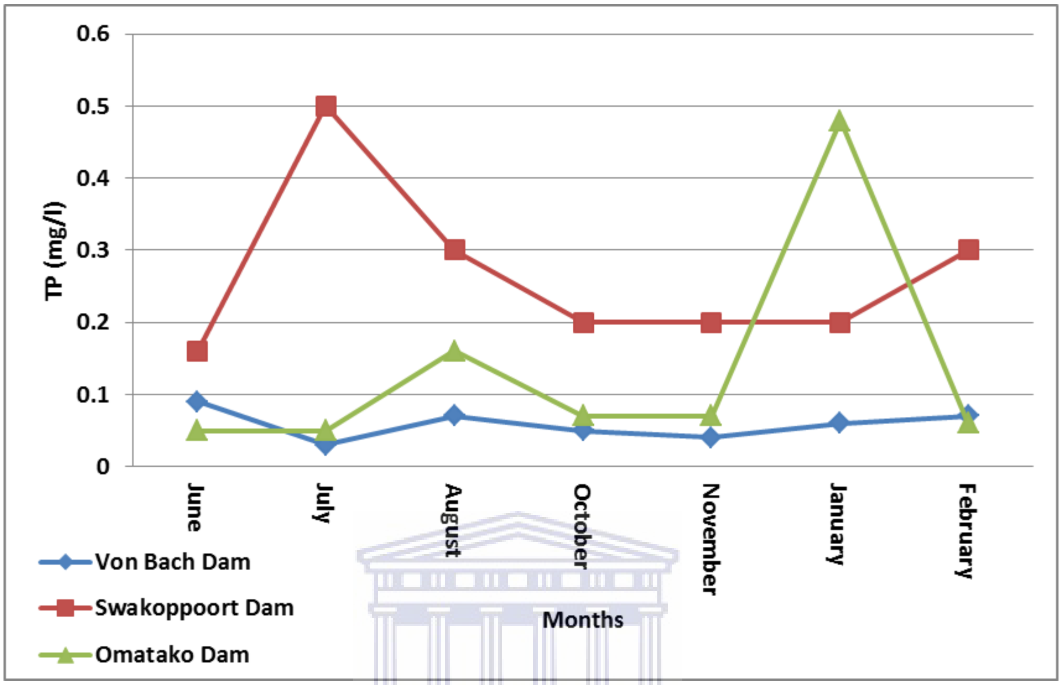


Figure 5.8: Total phosphorus of the three dams from June 2010 to February 2011

The mean total phosphorus was highest in Swakoppoort Dam and lowest in Von Bach and Omatako Dams in July (Figure 5.8). From January to February an increase in total phosphorus was observed in Swakoppoort Dam, and slightly in Von Bach Dam (Figure 5.8). Total phosphorus in Omatako was high in January and dropped drastically in February (Figure 5.8). The mean total phosphorus in the three dams were: Swakoppoort Dam 0.3mg/l, with a standard deviation of 0.1mg/l and *n* =7; Omatako Dam 0.1mg/l with a standard deviation of 0.2mg/l and *n* =7 and Von Bach Dam was 0.1mg/l with a standard deviation of 0.0mg/l and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference (*p=0.010*) in the total phosphorus of the three dams at 5% significance level.

5.2.2.6. Orthophosphate (PO_4^{-3})

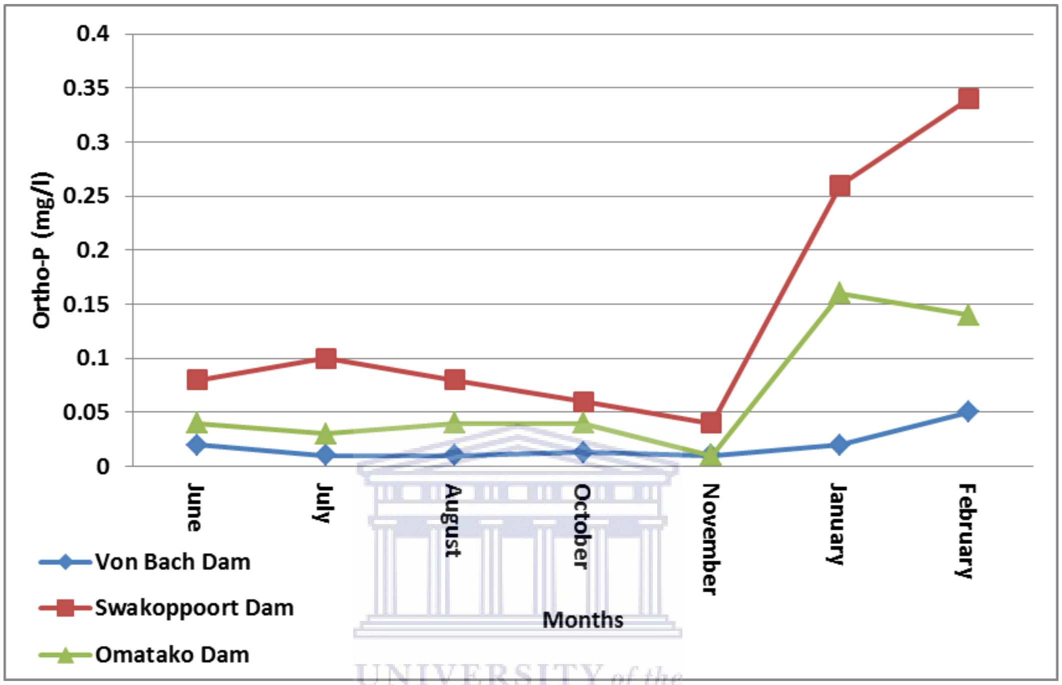


Figure 5.9: Orthophosphate of the three dams from June 2010 to February 2011

Orthophosphate was fairly stable in the three dams from June to October, and started to increase from November in Swakoppoort and Omatako Dams (Figure 5.9). The mean orthophosphate in the three dams were: Swakoppoort Dam 0.1mg/l, with a standard deviation of 0.1mg/l and *n* =7; Omatako Dam 0.1mg/l with a standard deviation of 0.1mg/l and *n* =7 and Von Bach Dam was 0.0mg/l with a standard deviation of 0.0mg/l and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p=0.028$) in the orthophosphate of the three dams at 5% significance level. Using the minimum and maximum values (**APPENDIX I**) of the measured orthophosphate concentration of the three dams, it shows that they are all in a eutrophic state with the range of orthophosphate between 0.025mg/l to 0.25mg/l (DWAF, 1996).

5.2.2.7. Total nitrogen

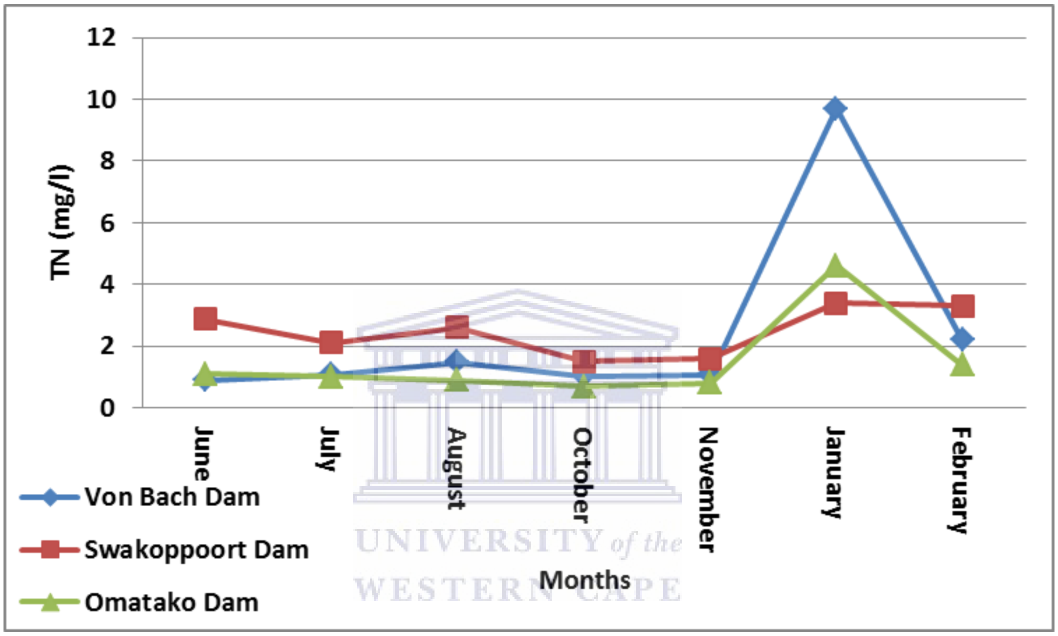


Figure 5.10: Total nitrogen of the three dams from June 2010 to February 2011

The total nitrogen concentration was fairly stable from June to November in all the three dams (Figure 5.10). In January an increase in total nitrogen was observed in all the three dams, with the highest concentration in Von Bach Dam, followed by Omatako Dam and Swakoppoort Dam (Figure 5.10). The mean total nitrogen of Von Bach Dam was 2.5mg/l with a standard deviation of 3.2mg/l and *n* =7, Swakoppoort Dam was 2.5mg/l with a standard deviation of 0.77mg/l and *n* =7 and Omatako Dam was 1.5mg/l with a standard deviation of 1.4mg/l and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences (*p=0.597*) in the total nitrogen of the three dams at 5% significance level.

5.2.2.8. Ammonia (NH_4-N)

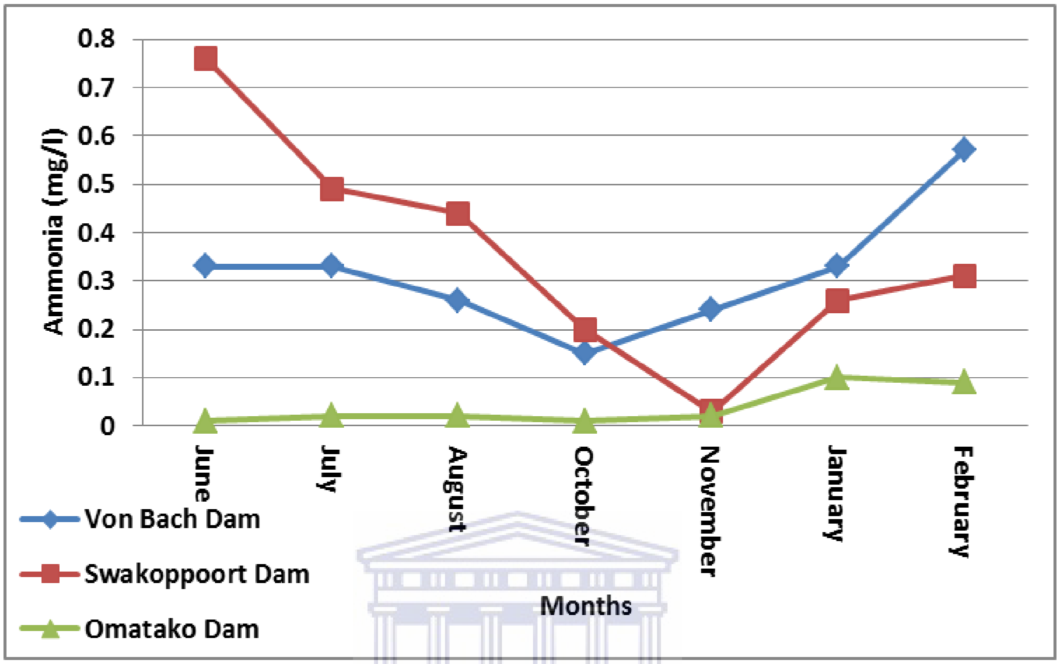


Figure 5.11: Ammonia (NH_4-N) level of the three dams from June 2010 to February 2011

Ammonia (NH_4-N) concentration was the highest in Von Bach and Swakoppoort Dams in June, July, August, January and February compared to Omatako Dam (Figure 5.11). The mean ammonia (NH_4-N) of Von Bach Dam was 0.3mg/l with a standard deviation of 0.1mg/l and n =7, Swakoppoort Dam was 0.4mg/l with a standard deviation of 0.2mg/l and n =7 and Omatako Dam was 0.0mg/l with a standard deviation of 0.0mg/l and n =7. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p=0.02$) in the ammonia of the three dams at 5% significance level. The ammonia (NH_4-N) concentration (minimum and maximum value in **Appendix I**) of the three dams was within the Target Water Quality Range (TWQR) of 7mg/l for an aquatic ecosystem (DWAF,1996).

5.2.2.9. Dissolved organic carbon

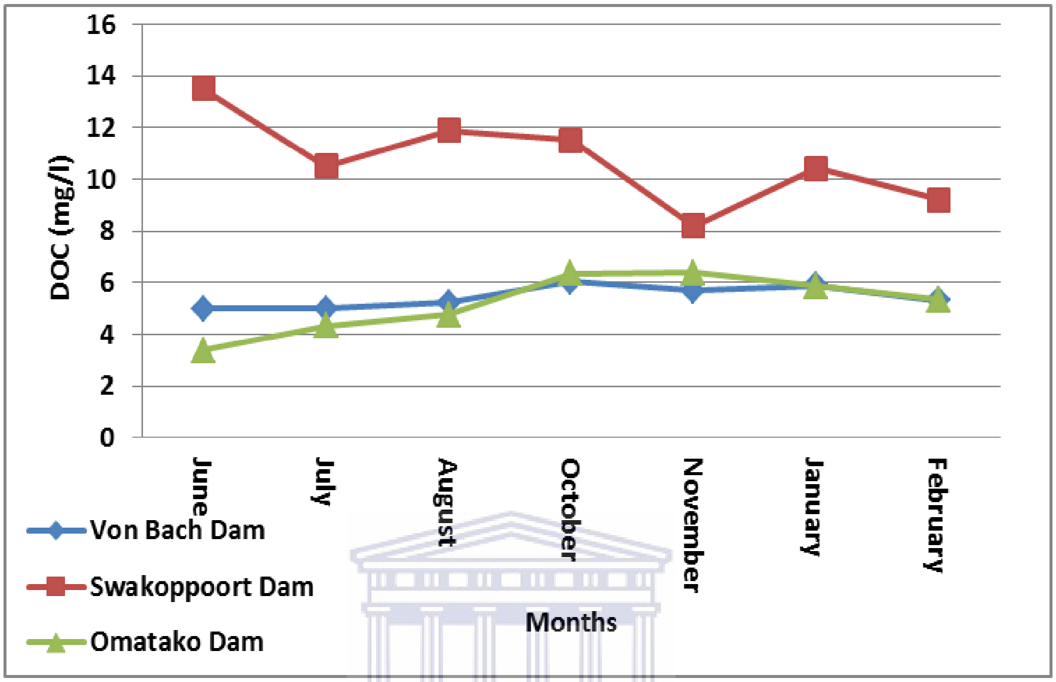


Figure 5.12: Dissolved organic carbon of the three dams from June 2010 to February 2011

The dissolved organic carbon was higher in Swakoppoort Dam than in Von Bach and Omatako Dams from June to February (Figure 5.12). The mean dissolved organic carbon of Swakoppoort Dam was 10.8mg/l with a standard deviation of 1.8ug/l and *n* =7, while Von Bach Dam was 5.5mg/l with a standard deviation of 0.4ug/l and *n* =7, and Omatako Dam was 5.2mg/l with a standard deviation of 1.1ug/l and *n* =7. Statistical analysis of the data, carried out using a two way-ANOVA, showed a significant difference (*p=0.00*) in the dissolved organic carbon of the three dams at 5% significance level.

5.2.3. Biological water quality parameters

5.2.3.1. Chlorophyll *a*

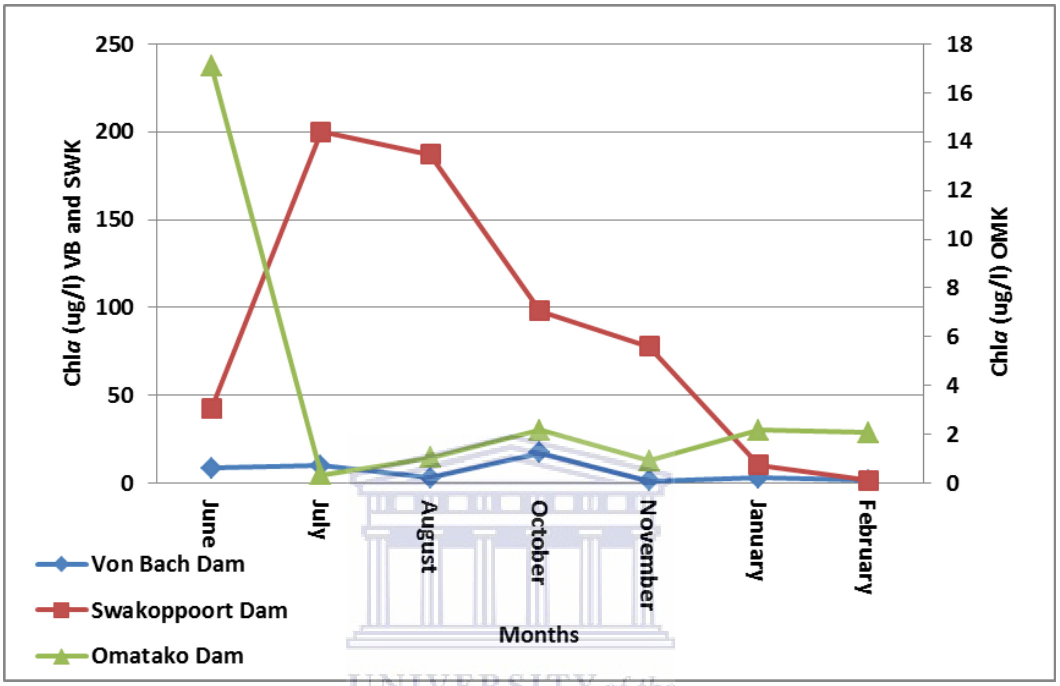


Figure 5.13: Chlorophyll *a* levels at the three dams from June 2010 to February 2011

The chlorophyll *a* concentration was higher in Swakoppoort Dam, than in Von Bach Dam and Omatako Dam in July (Figure 5.13). Chlorophyll *a* was mainly stable in Von Bach and Omatako Dams from July to February (Figure 5.13). The mean chlorophyll *a* value of the three dams were: Swakoppoort Dam 88.2ug/l with a standard deviation of 79.8ug/l and *n* =7; Von Bach Dam 6.4ug/l with a standard deviation of 5.9ug/l and *n* =7; Omatako Dam was 3.7ug/l with a standard deviation of 6.0ug/l and *n* =7. Statistical analysis of the data, carried out using a two way-ANOVA, showed a significant difference (*p=0.004*) in the chlorophyll *a* of the three dams at 5% significance level.

5.2.3.2. Blue-green algae

5.2.3.2.1. Anabaena

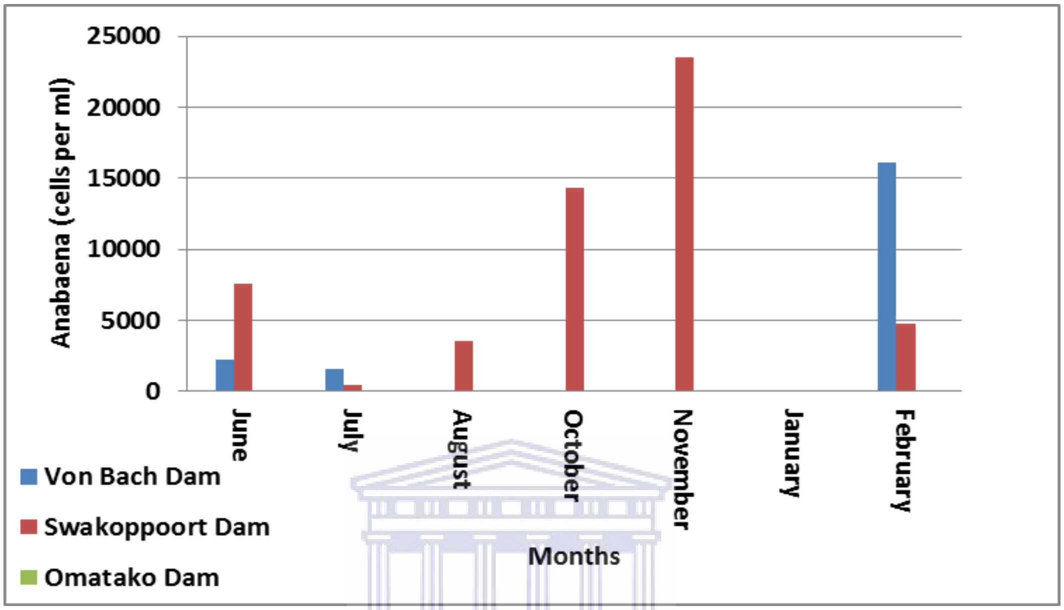


Figure 5.14: Anabaena of the three dams from June 2010 to February 2011

Anabaena cells counts were not found in Omatako Dam water from June to February, but they were found in Swakoppoort and Von Bach Dams (Figure 5.14). In November, anabaena was higher in the water of Swakoppoort Dam and in the Von Bach Dam water it was higher in February (Figure 5.14). The mean anabaena of Swakoppoort Dam was 7722.1count/ml, with a standard deviation of 8481.0count/ml and *n* =7; while in Von Bach Dam the mean anabaena was 2852.8count/ml, with a standard deviation of 5912.2count/ml and *n* =7, and in Omatako the mean anabaena was 0.0count/ml, with a standard devation of 0.0count/ml and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant difference (*p=0.075*) in the anabaena algae of the three dams at 5% significance level.

5.2.3.2.2. Microcystis

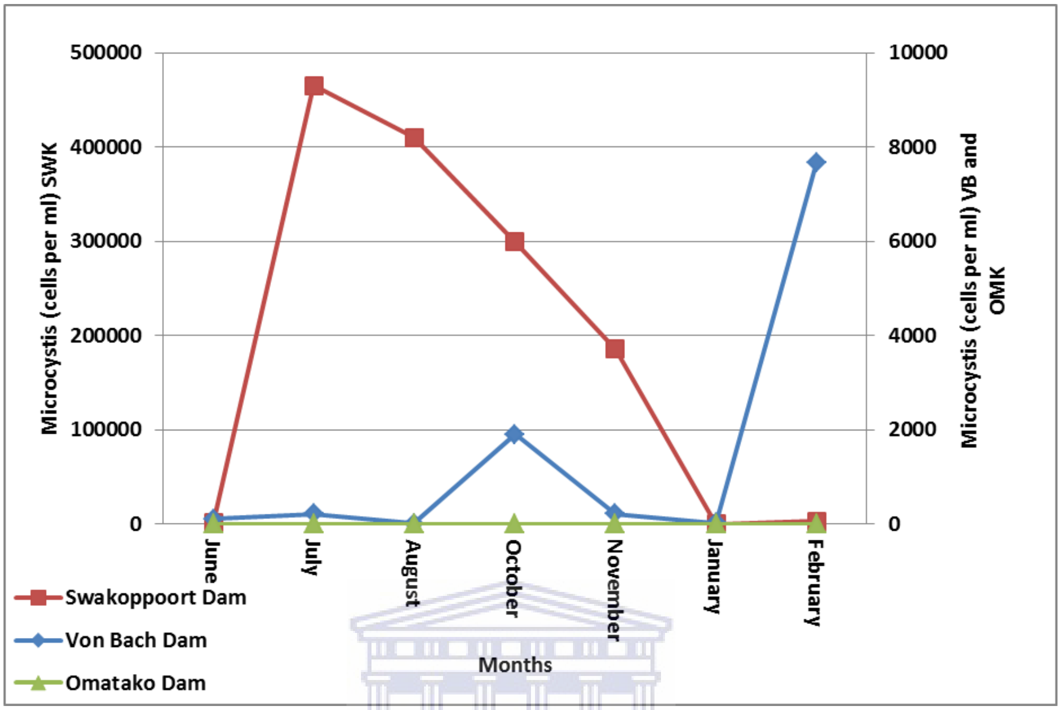


Figure 5.15: Microcystis levels at the three dams from June 2010 to February 2011

Microcystis cells were the highest in Swakoppoort Dam water, few were found in Von Bach Dam water and none in Omatako Dam water (Figure 5.15). The mean number of mycrocystis cells at Swakoppoort Dam was 194866.39 count/ml, with a standard deviation of 2.01count/ml and *n* =7, while the Von Bach Dam mean mycrocystis was 1447.1count/ml, with a standard deviation of 2821.6count/ml and *n* =7, and the Omatako Dam mean microcystis was 0.0count/ml, with a standard deviation of 0.0count/ml and *n* =7. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference (*p=0.007*) in the microcystis of the three dams at 5% significance level.

5.3. Discussions

The water temperature of the three dams was statistically similar during all the months. The temperature of the water among the three dams ranged from 14˚C during the winter months of June and July and 24˚C during the summer months of November 2010 to February 2011. Lake Midmar, South Africa, was found to have a maximum water temperature of 26˚C during November and December and a minimum water temperature of 12˚C during July (Breen, 1983). In June and July there was a higher level of dissolved oxygen in the water of the three dams, than in November and February, increased by the lower water temperature. Tropical lakes of moderate to great depth are warm, monomictic and they show great consistency in seasonal mixing (Lewis, 1996), while temperate lake are cold, polymictic and dimictic (Kirillin, 2010). The three dams are all monomictic, in that they statify once a year.

The turbidity of Von Bach Dam ranged from 2.4NTU to 30.4NTU, Swakoppoort Dam ranged from 6.5NTU to 51.4NTU, and Omatako Dam ranged from 2.4NTU to 484NTU. Von Bach Dam had high turbid water in January and February which was caused by highly turbid runoff water from the catchment area and that of water transfers from Omatako Dam. The high turbidity in the water from Omatako Dam was due to the geology of its catchment area which is made up of sand and calcrete. The shallowness of the dam which is 11m and the high evaporation losses of the water was also the factor contributing to the increase in turbidity of the water of Omatako Dam. In shallow lakes turbidity is caused by sediment resuspension while in deeper lakes turbidity is caused by chlorophyll *a* (Jackson, 2003). The turbidity in the water of Swakoppoort Dam was caused by algal bloom occurrence dominated by microcystis in July. Algal bloom increases the water turbidity by flowing with the water in any direction (Scheffer, 2004).

The high turbidity of Swakoppoort Dam was measured at the abstraction tower which has a high concentration of algae scum. Algae are pushed by wind to the shoreline of lake and the movement is also controlled by the buoyance level (Reynolds and Walsby, 2008). Land use activities such as crop cultivation and cattle and game farming, and poor land cover in the catchment area expose the soil to be removed by runoff which increases the turbidity of water in lake (Li *et al*., 2009). Since there are industries, game and cattle farming in the catchment of Swakoppoort Dam, the turbidity at the inflow point, even though it was not measured, could be influenced by these activities. Chlorophyll *a* concentration was also high in Swakoppoort Dam, which contributed to the high turbidity of the water.

Thermal stratification of water is destroyed during a period of lower temperature (Breen, 1983; Wetzel, 1983; Hart and Allanson, 1984). During thermal stratification (i.e. anoxic conditions), manganese, orthophosphate, ammonia and iron which is trapped in the sediment is released into underlying water (Wetzel, 1983). When the thermal stratification breaks, manganese, ammonia, orthophosphate and iron are released to the water column (Wetzel, 1983; Breen, 1983; Hart and Allanson, 1984; Rast and Thornton, 1996). In July, when the thermal stratification broke in Swakoppoort Dam, the manganese concentration was high. But the increase in the manganese concentration of Swakoppoort Dam in November and February could be due to runoff from the catchment area containing organic matter. While the increase in the manganese concentration of Von Bach Dam in November and February could also be due to water transfers and runoff from the catchment area. Runoff contains organic matter and humic substances which are sources of manganese (Wetzel, 1983). The measured manganese concentration of the three dams were within the Target Water Quality Range (TWQR) for an aquatic ecosystem of 0.2mg/l and they were below the Chronic Effect Value (CEV) of 0.4mg/l (DWAF, 1996).

Iron concentration in the water of Swakoppoort Dam increased from June 2010 to February 2011. The increase could be due to the iron release from the sediment (Hongve, 1997; Davison, 1993). Swakoppoort Dam had the highest concentration of dissolved organic carbon, which could be due to the decaying of organic matter in the dam from dead plants and algae, and those supplied by runoff from the catchment area. In some studies, dissolved organic carbon was found to increase in the water due to land use, rising temperature, rainfall, and acid deposition (Evans *et al*., 2004). These factors where not established in this study. The concentration of dissolved organic carbon in Swakoppoort Dam water was from 8.2mg/l to 13.5mg/l, which is too high for the Von Bach treatment plant to treat to below 4mg/l to meet the Windhoek aquifer artificial recharge requirement.

Degradation of water quality is faster in tropical lakes than in temperate lakes due to strong nutrient cycling during thermal stratification (Lewis, 2000). Total phosphorus in lakes has been found to be supplied from the catchment in many studies (Breen, 1983; Wetzel, 1983; Hart and Allanson, 1984; Sɵndergaard *et al*., 2000). In Southland, New Zealand, the increase in total phosphorus in the stream was caused by the dairy farm in its catchment (Monaghan *et al*., 2007). In the catchment of Lake Chivero, Zimbabwe, the load of total phosphorus was found to be higher from the sub-catchment containing home industries than from the sub-catchment containing residential areas (Mvungi *et al*., 2003). Tributaries of Pao-Cachinche reservoir, Venezuela, were found to introduce high orthophosphate, total phosphorus and ammonia from domestic wastewater, and from poultry and pig farms (Gonz´alez *et al*., 2004). In the catchments of the three dams, only Swakoppoort Dam has industries, domestic wastewater and residential areas on a large scale, but the load of total phosphorus from these areas was not established in this study. The higher concentration of total phosphorus and orthophosphate in Swakoppoort Dam among the three dams could be sourced from the sediment and catchment input. Total phosphorus was higher in July (0.5mg/l), which is the period when the dam had an algal bloom, but orthophosphate was very low (0.1mg/l). Orthophosphate is readily available for algal uptake and is used up by algae during this period of algal bloom (Ekholm and Krogerus, 2003).

In January and February when Swakoppoort Dam received a high runoff from the catchment area, orthophosphate increased in the water and this could be linked to the external supply from the catchment area and also from the sediment resuspension. The increase in total phosphorus in the Omatako Dam in January could be due to the external input from the catchment area. Land use activities in their catchment areas such as industry, sewage ponds, game and cattle farming, and subsistence crop cultivation increased the load of phosphorus in the dams (Kitaka *et al*, 2002; Rahman and Bakri, ud; Schindler, 2006).

Swakoppoort Dam had a bloom of blue-green algae in June 2010, which was dominated by microcystis algae. This was similar to the Lake Victoria, Kenya, bloom of 1986, which was also dominated by microcystis algae (Ochumba and Kibaara, 2008). Nhlanganzwane Dam, South Africa, also had a bloom of blue-green algae in 2007 dominated by microcystis algae and which produced microcystin followed by the biointoxication of wild animals (Oberholster *et al*., 2009). No wild animals or cattle were affected in the case of Swakoppoort Dam microcystin. But water quality for human consumption was affected as the water was not be able to be treated and as a result a water transfer to Von Bach Dam was delayed (Kirke, 2001; Oberholster *et al*., 2009).

The ammonia concentration of Von Bach Dam and Swakoppoort followed a similar pattern it was very high when the dam water was completely mixed in June and also high during the period of runoff from the catchment area. Ammonia is released from the sediment during stratification (i.e. during anoxic conditions) and thus suspended in the water column during complete mixing of the water (i.e. no thermal stability) (Beutel, 2006). But the ammonia concentrations of all the three dams were within the Target Water Quality Range for an aquatic ecosystem as prescribed in the South African Water Quality Guideline for Aquatic Ecosystems This was observed in Swakoppoort and Von Bach Dams.

Temperature, turbidity, dissolved oxygen, iron, manganese, pH, total nitrogen, and anabaena were statistically and significantly similar in the three dams. The water quality parameters which were not statistically and significantly similar in the three dams were: Secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a* and microcystis. In terms of productivity (i.e. nutrients enriched), the results showed that, the three dams are not similar. Swakoppoort is the most productive among the three dams. Therefore, since some water quality parameters were not similar among the three dams, mixing them in one dam is likely to increase their concentration which may affect water quality and water treatment.

5.4. Summary

Secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a* and microcystis were not the same in the three dams. Elevation in the water quality parameters of the three dams were linked to land use activities in their catchment areas, land covers of their catchment areas, geology of their catchment areas, and the stratification of the water.

CHAPTER SIX: EFFECT OF WATER TRANSFERS ON THE WATER QUALITY OF VON BACH DAM

6.1. Introduction

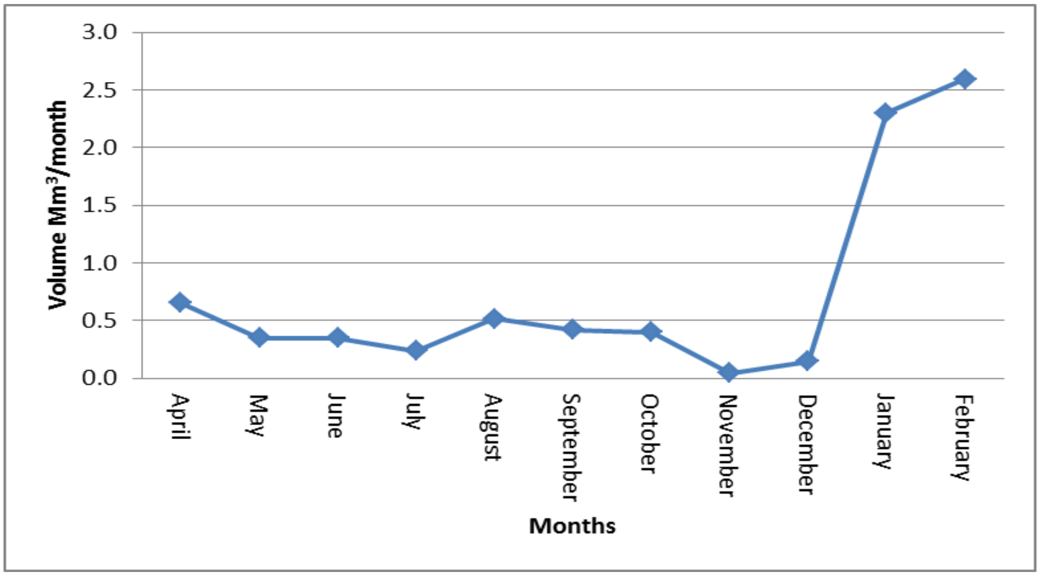
In many cases inter-basin water transfers are done for water supply augmentation and for improvement of water quality. The transfer of water for water supply augmentation could affect water quality in the recipient dam. This chapter will present and discuss the implication of water transfers from Swakoppoort and Omatako Dams on the water quality of Von Bach Dam as well as the implications of runoff from the catchment on the water quality of Von Bach Dam.

6.2. Results

The sampling of runoff from the catchment was done only once due to the unpredictability of the occurrence of river flows on an ephemeral river. This may not be representative but gives an indication of the water quality from the catchment area. The transfer of water from Swakoppoort and Omatako Dams, and runoff from the catchment happened at the same time and therefore it was not easy to separate their effects on the water quality of Von Bach Dam.

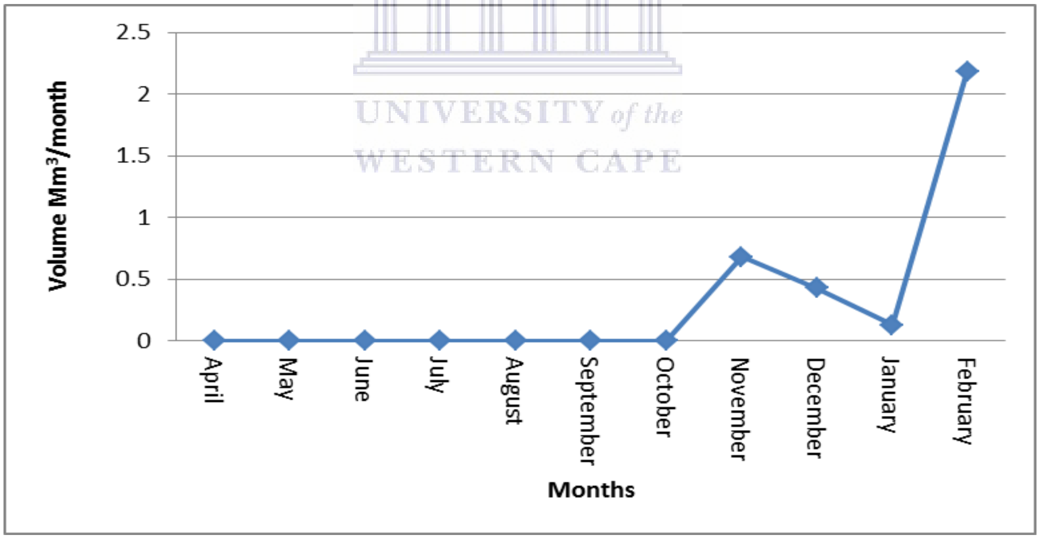
6.2.1. Inflows and storage of water in Von Bach Dam

Water transfer from Omatako Dam to Von Bach Dam was continuous except in November when it was stopped (Figure 6.1). When the transfer from Omatako Dam was stopped in November due to pump failure, the transfer of water from Swakoppoort Dam began (Figure 6.2).



Mm^3: millions cubic meters; data source: NamWater Hydrology Unit

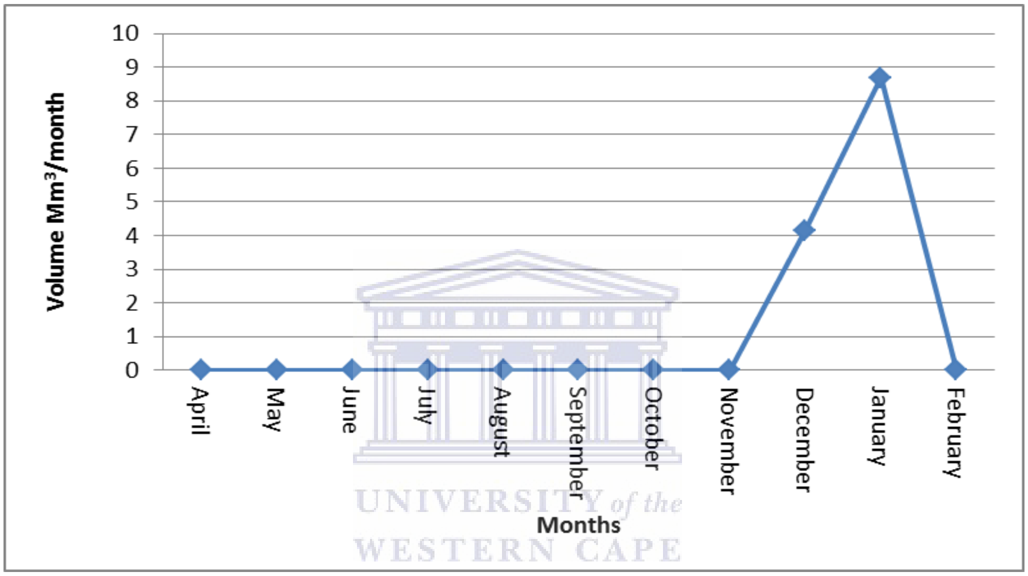
Figure 6.1: Volume of water transferred from Omatako to Von Bach Dam from April 2010 to February 2011



Mm^3: millions cubic meters; data source: NamWater Hydrology Unit

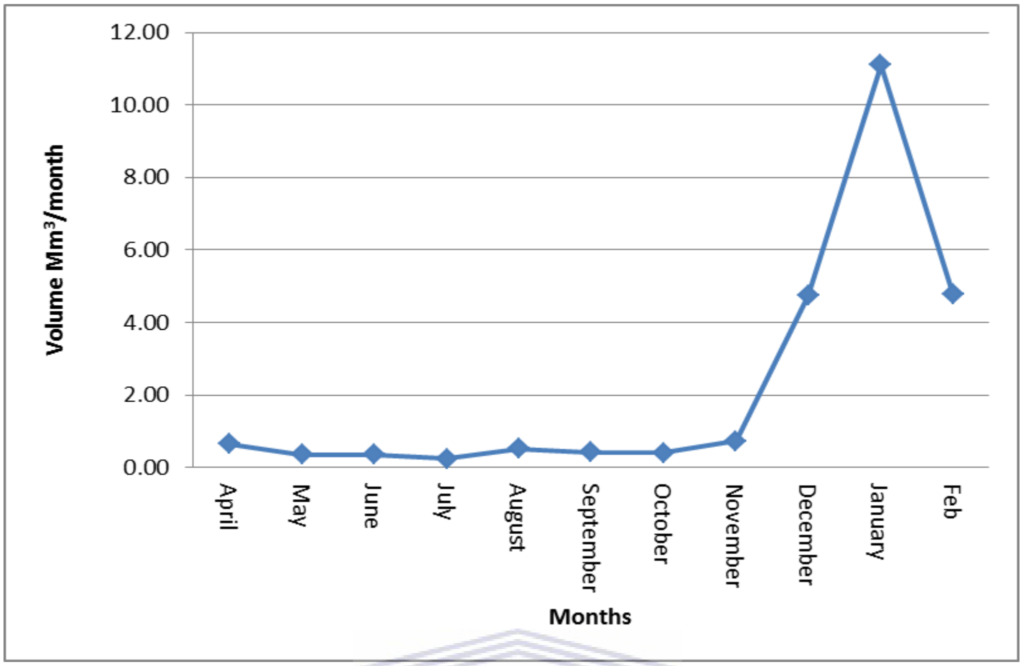
Figure 6.2: Volume of water transferred from Swakoppoort Dam to Von Bach Dam from April 2010 to February 2011

In December, the transfer of water occurred from both Swakoppoort Dam and Omatako Dam. In January 2011, there were inflows of natural runoff into Von Bach Dam (Figure 6.3). In January Von Bach Dam received water from the transfers and catchment runoff of about 11.108 Mm^3/month (Figure 6.4).



Mm^3: millions cubic meters; data source: NamWater Hydrology Unit

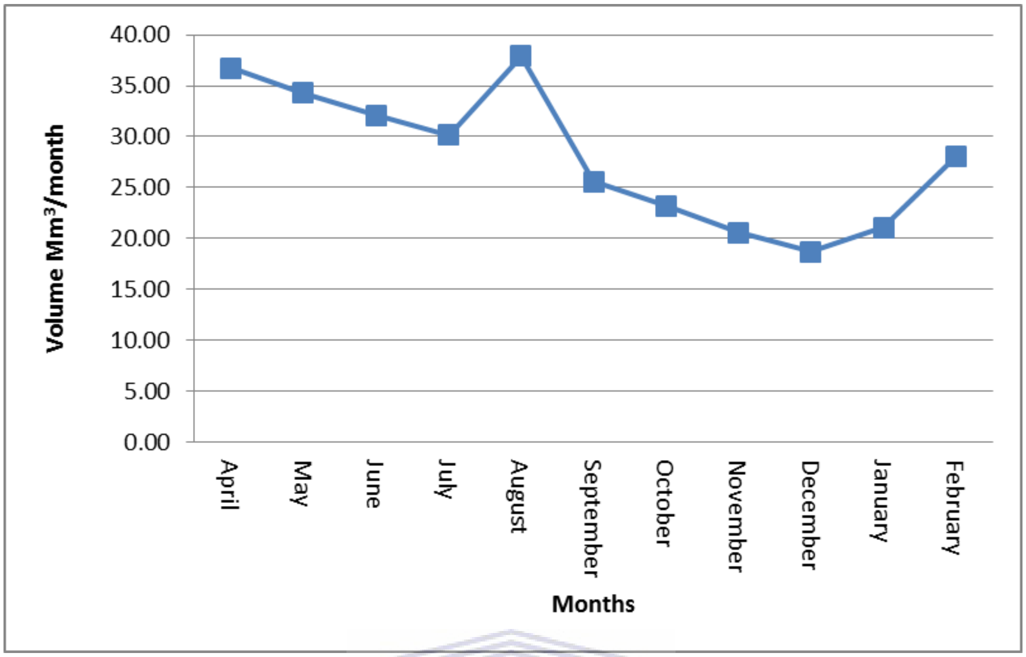
Figure 6.3: Volume of runoff from the catchment into Von Bach Dam from April 2010 to February 2011



Mm^3*: millions cubic meters; data source: NamWater Hydrology Unit*

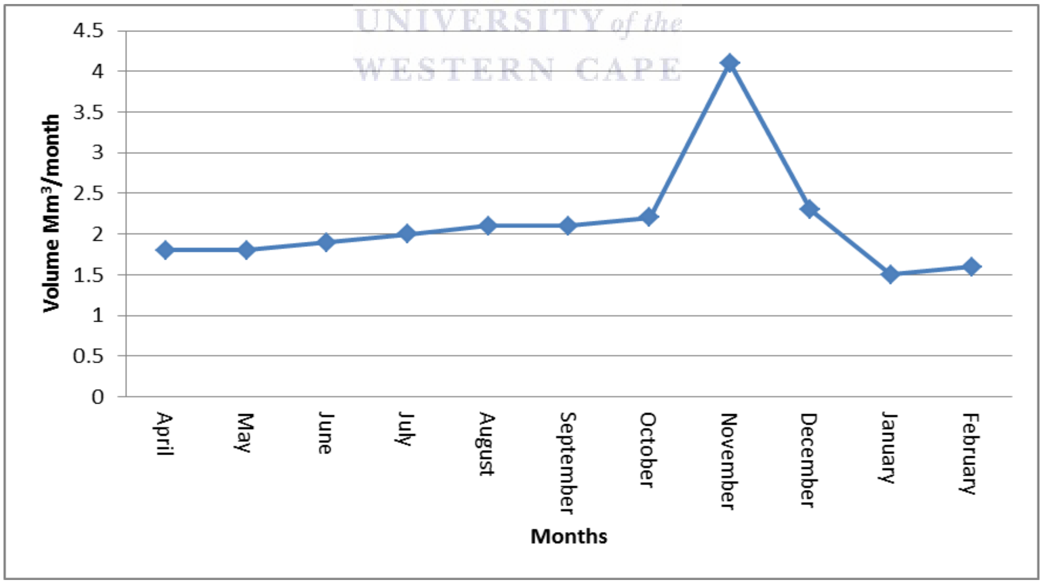
Figure 6.4: Total volume of water from Swakoppoort Dam, Omatako Dam and runoff from the catchment into Von Bach Dam from April 2010 to February 2011

In total, the inflow from the catchment and water transfers was 24.3Mm^3, and about 23Mm^3 water was abstracted for water supply to Windhoek (Figure 6.6). The storage of water in Von Bach Dam decreased from April 2010 to December 2010 (Figure 6.5 and 6.6). Therefore, without augmentation of water from the transfers and catchment runoff, Von Bach Dam can easily be depleted given the high demand of water for Windhoek. In total, most water came from the catchment runoff at about 12.9Mm^3, followed by Omatako Dam at 8Mm^3 and Swakoppoort Dam at 3Mm^3.



Mm^3: millions cubic meters; data source: NamWater Hydrology Unit

Figure 6.5: Volume of water stored in Von Bach Dam from April 2010 to February 2011



Mm^3: millions cubic meters; data source: NamWater Hydrology Unit

Figure 6.6: Volume of water abstracted from Von Bach Dam to the treatment plant from April 2010 to February 2011

6.2.2. Physical water quality parameters

6.2.2.1. Temperature

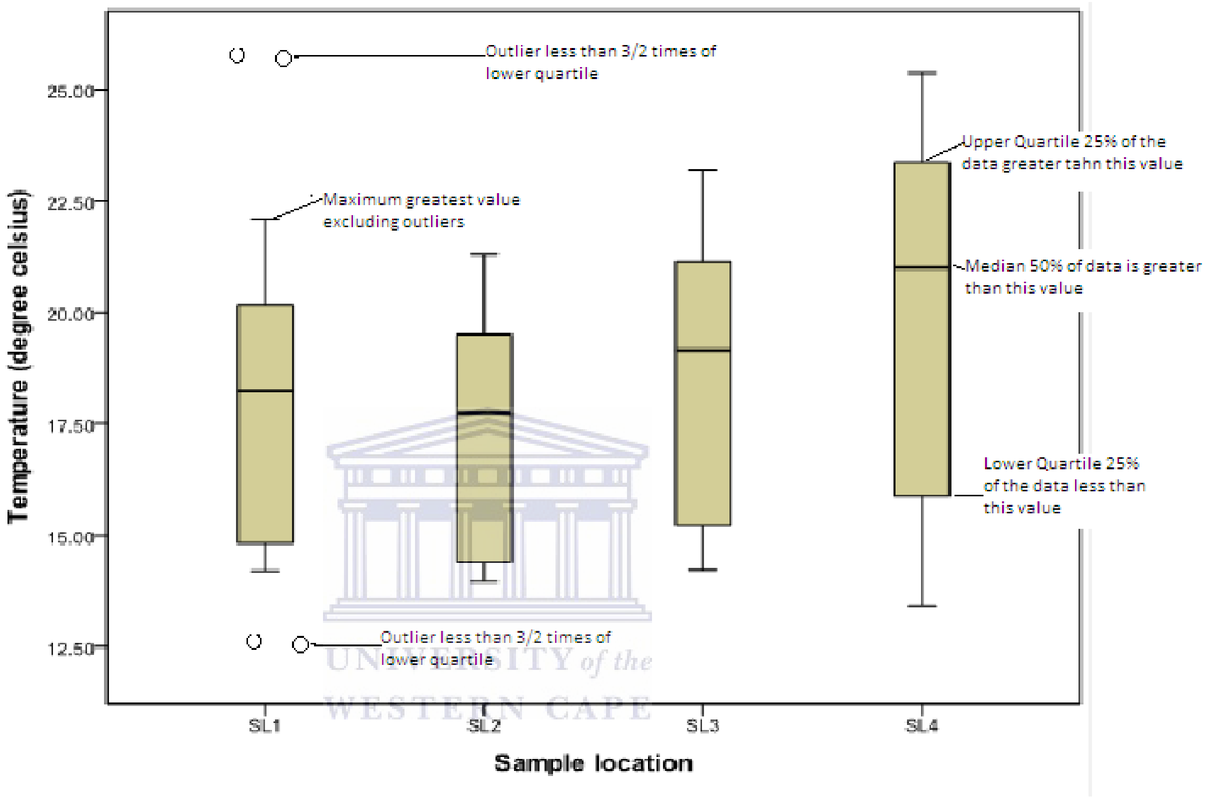


Figure 6.7: Box plots of the water temperature at different sampling locations of Von Bach Dam

The locations of the sampling points in Von Bach Dam are shown in Figure 6.8. The water temperature was higher at sampling location SL4 than at the other three locations (Figure 6.7). The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was no statistically significant difference in the water temperature at the four sampling locations at a 5% significance level with a p-value of 0.090 test value.

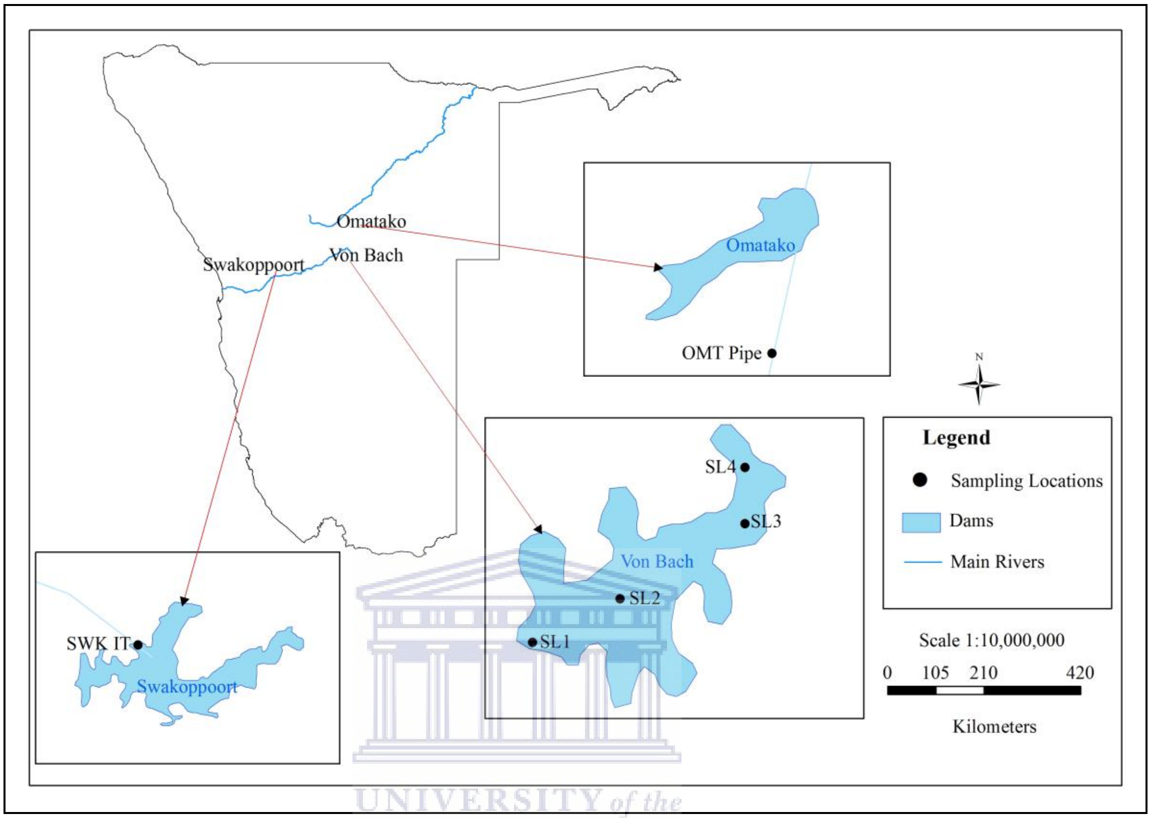


Figure 6.8: Sampling locations of Von Bach Dam

6.2.2.2. Secchi disk depths

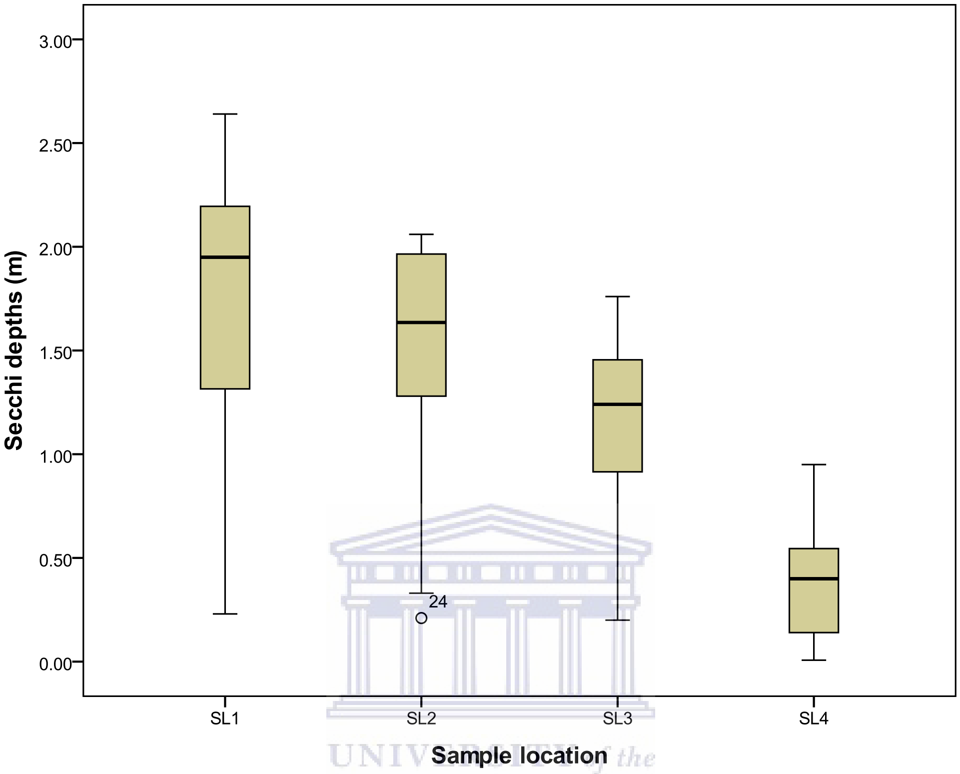


Figure 6.9: The spatial variation in the secchi depths of Von Bach Dam at different sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The secchi disk depth value was very low at SL4 and it increased toward the dam wall or toward SL1 (Figure 6.9). The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically significant difference in the secchi disk depths at the four sampling locations at a 5% significance level with a p-value of 0.00 test value.

6.2.2.3. Turbidity

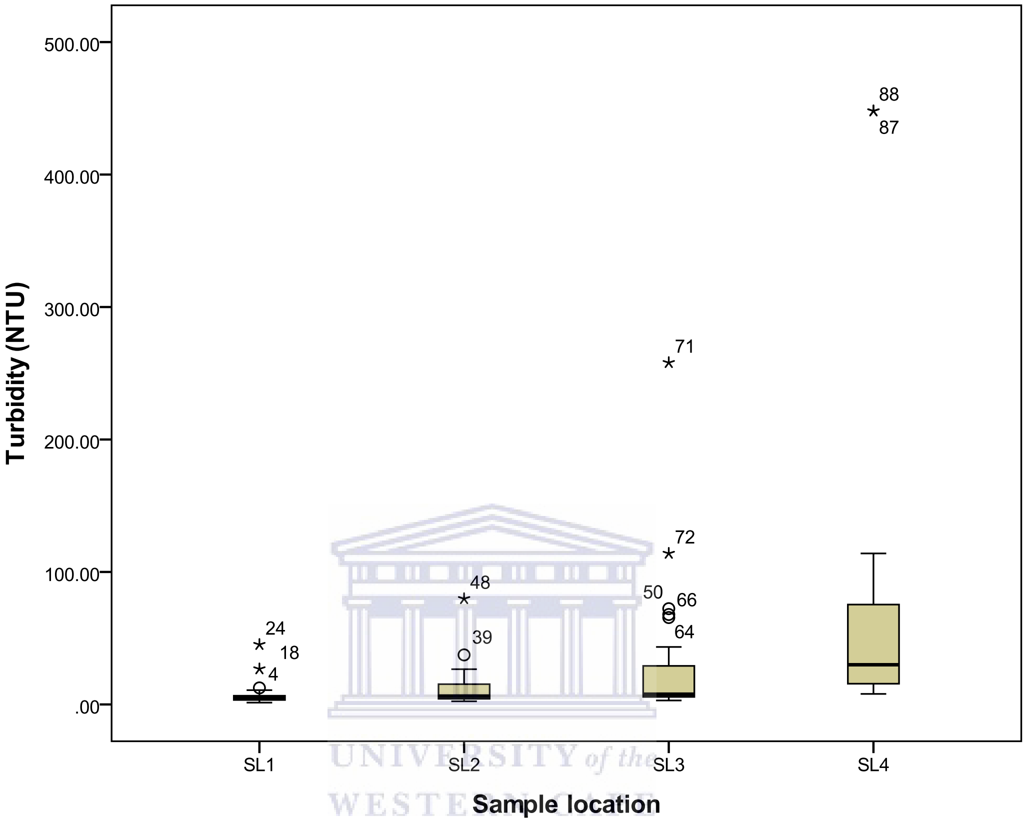


Figure 6.10: The spatial variation in the water turbidity of Von Bach Dam at different sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

SL4 had the highest turbidity and the turbidity decreased toward SL1 (Figure 6.10). A strong positive correlation of *r=0.7* was found between the volume of water transferred from Omatako Dam and the turbidity of the water at SL4. Also a strong positive correlation of *r=0.7* was found between the volume of water transferred from Swakoppoort Dam and the turbidity of the water at SL1. The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically significant difference in the water turbidity at the four sampling locations at a 5% significance level with a p-value of 0.004.

6.2.3. Chemical water quality parameters of Von Bach Dam

6.2.3.1. Dissolved oxygen

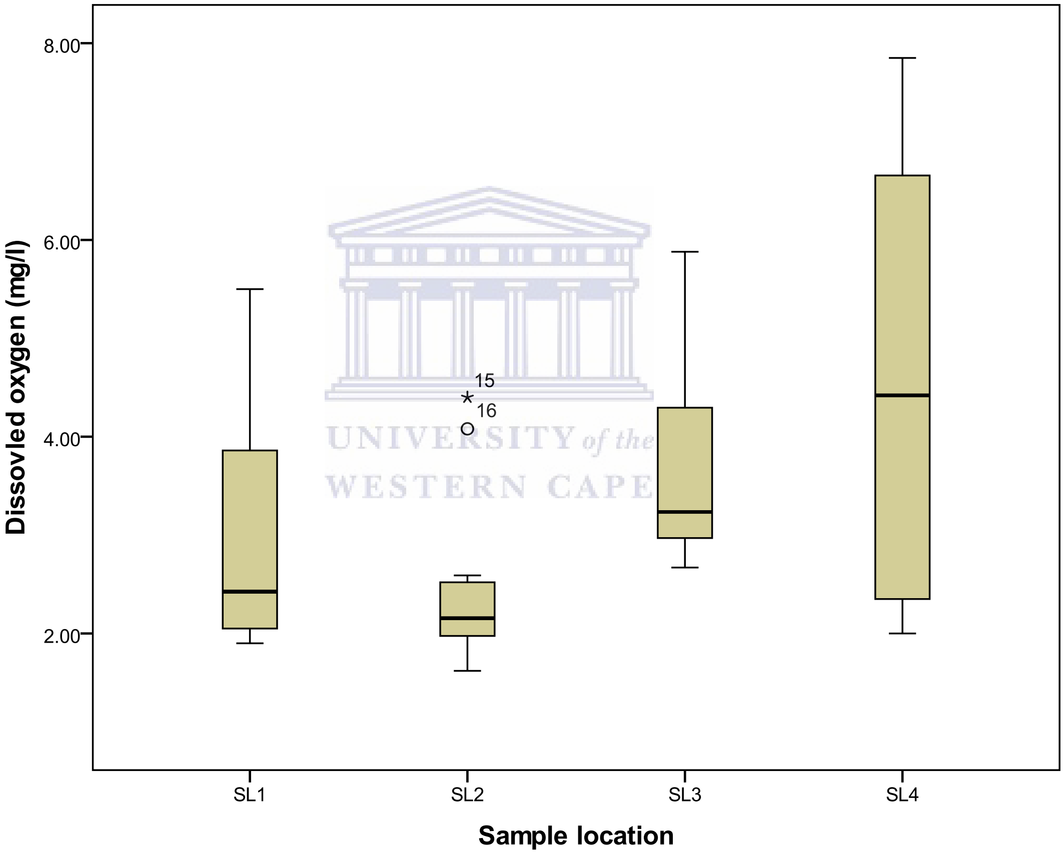


Figure 6.11: The spatial variations in the dissolved oxygen of the Von Bach Dam water at four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines

SL4 had the highest dissolved oxygen out of all the locations (Figure 6.11). The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically significant difference in the concentration of dissolved oxygen at the four sampling locations at a 5% significance level with a p-value of 0.00 test value.

6.2.3.2. Iron

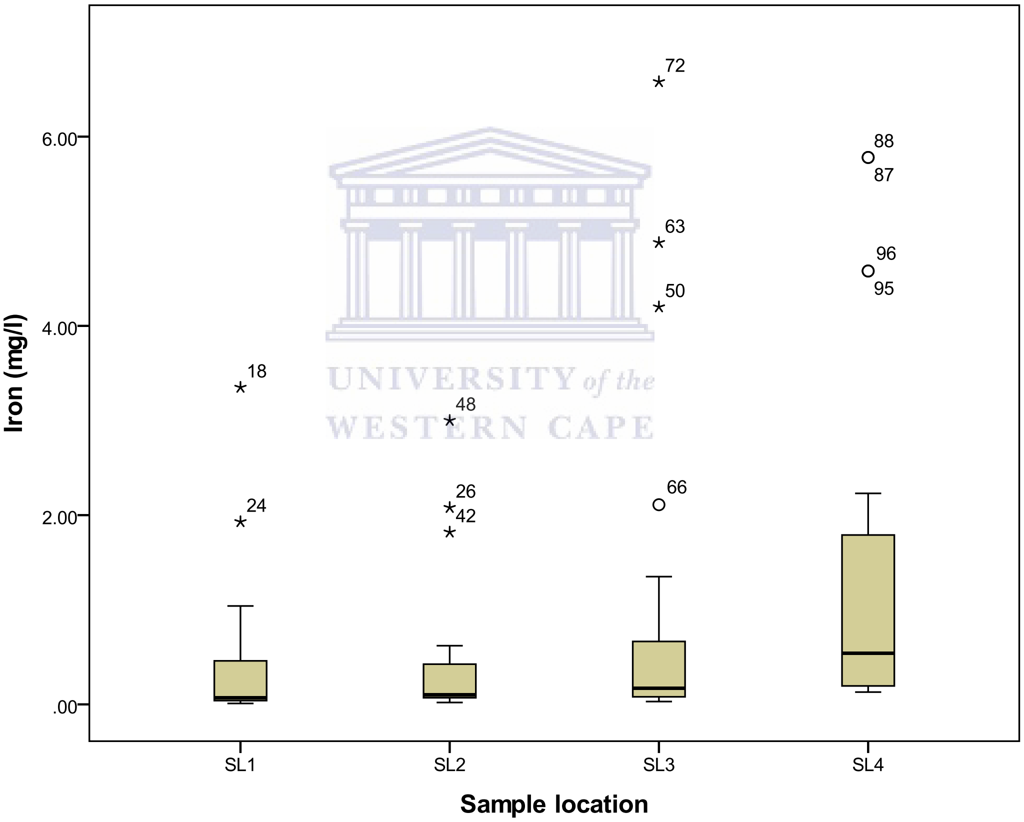


Figure 6.12: The spatial variation in the iron concentration of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

SL4 contained a higher concentration of iron than the other three locations (Figure 6.12). There was a strong positive correlation of *r=0.9* between the volume of water transferred from Omatako Dam and the iron concentration at SL4. The data was subjected to statistical analyses using a one way-ANOVA. It was found that there was a statistically significant difference in the iron concentration at the four sampling locations at a 5% significance level with a p-value of 0.045 test value.

6.2.3.3. Manganese

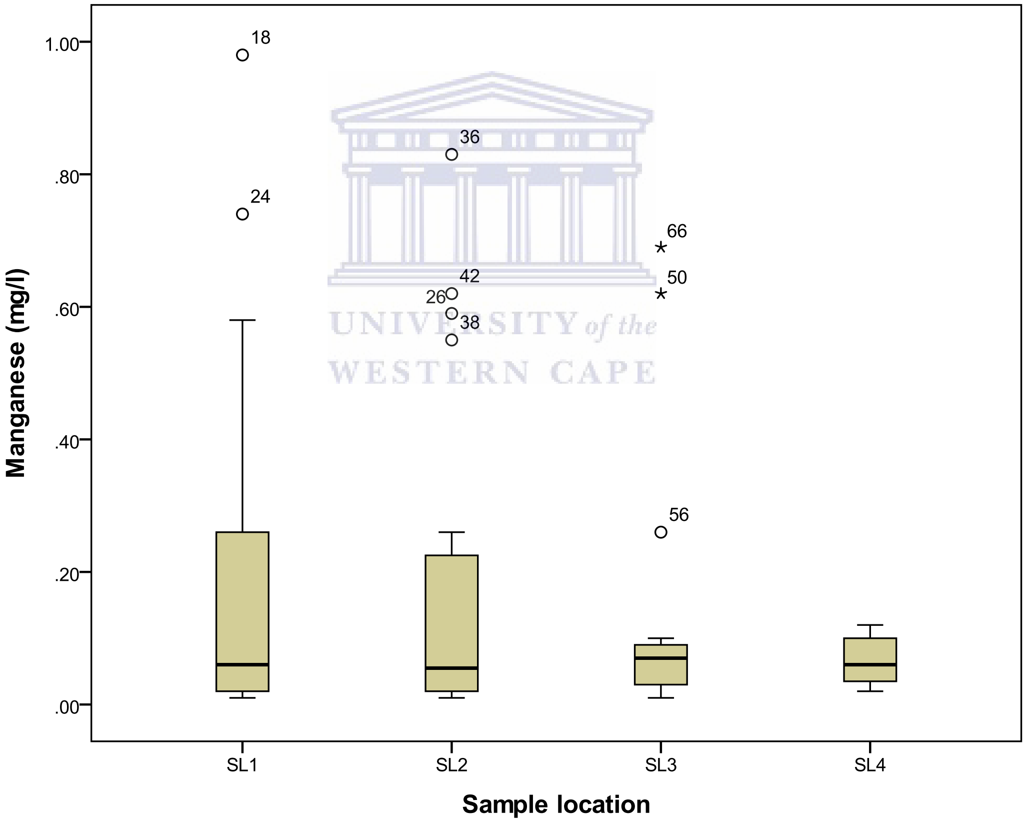


Figure 6.13: The spatial variations in the manganese concentration in the water of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was no statistical difference in the manganese concentration at the four sampling locations at a 5% significance level with a p-value of 0.125 test value.

6.2.3.4. pH

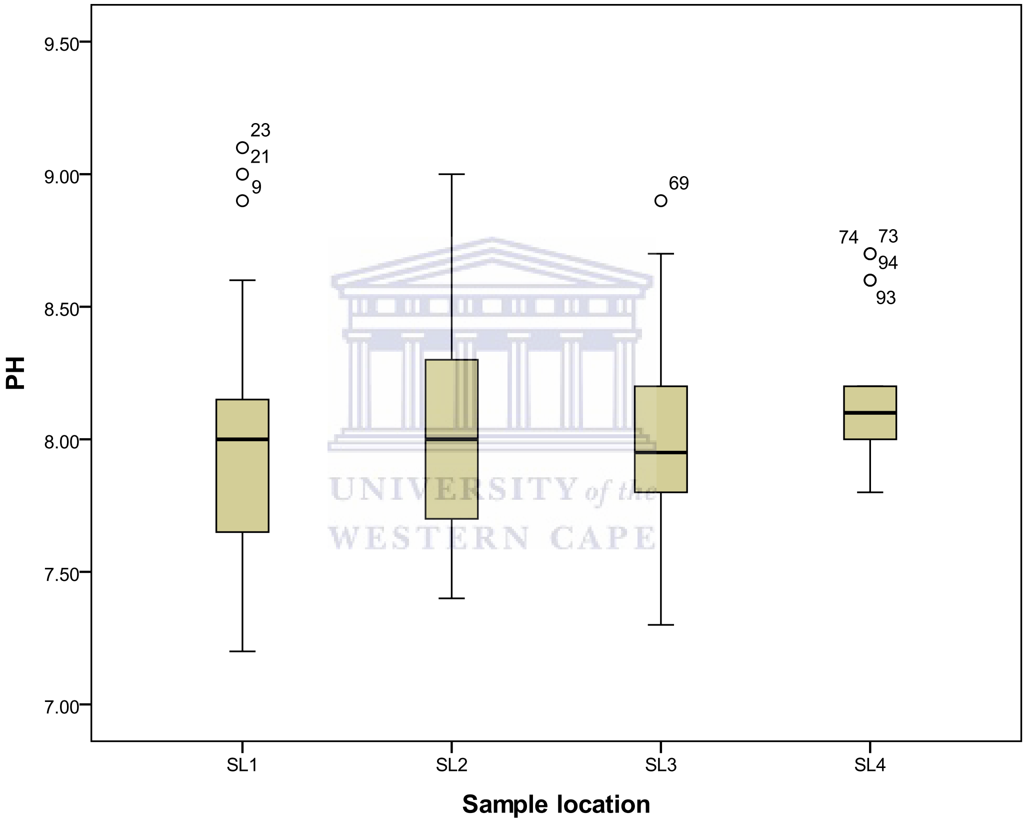


Figure 6.14: The spatial variation in pH of the Von Bach Dam water at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was no statistically significant difference in the water pH at the four sample locations at a 5% significance level with a p-value of 0.558 test value.

6.2.3.5. Total phosphorus

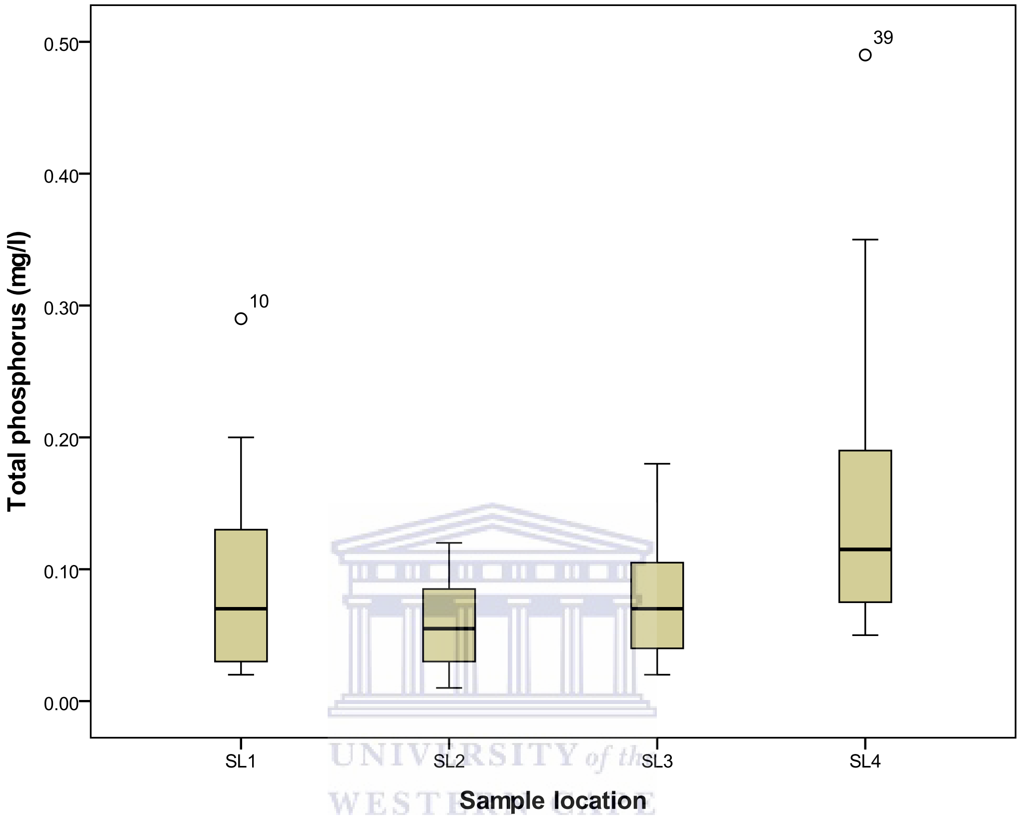


Figure 6.15: The spatial variation in the total phosphorus concentration of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The total phosphorus concentration was highest at SL4 compared to the other three locations (Figure 6.15). The total phosphorus from Swakoppoort Dam was 0.23mg/l, Omatako Dam was 0.13mg/l and catchment runoff was 0.41mg/l. The concentration of total phosphorus was highest in the catchment runoff, and thus at the discharge point (SL4) in Von Bach Dam. The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically signficant difference in total phosphorus at the four sampling locations at a 5% signficance level with a p-value of 0.039 test value.

6.2.3.6. Orthophosphate (PO_4^{-3})

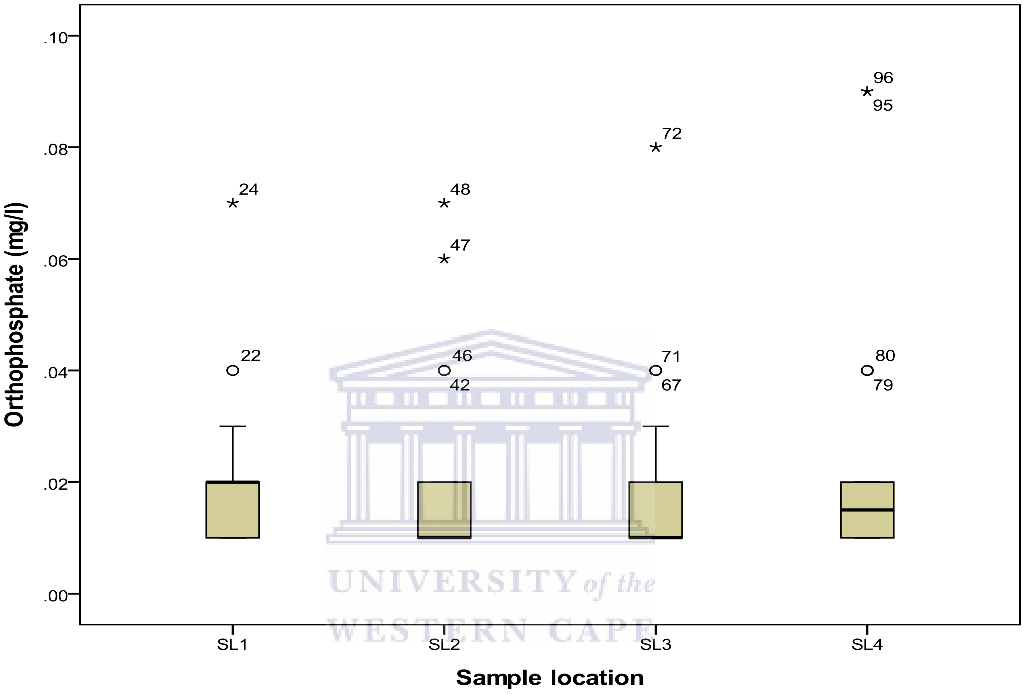


Figure 6.16: The spatial variation in the orthophosphate concentration of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

There was a postive correlation of *r=0.6* between the volume of water transferred from Omatako Dam and orthophosphate at SL4. The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was no statistically signficant difference in orthophosphate at the four sampling locations at a 5% signficance level with a p-value of 0.875 test value.

6.2.3.7. Total nitrogen

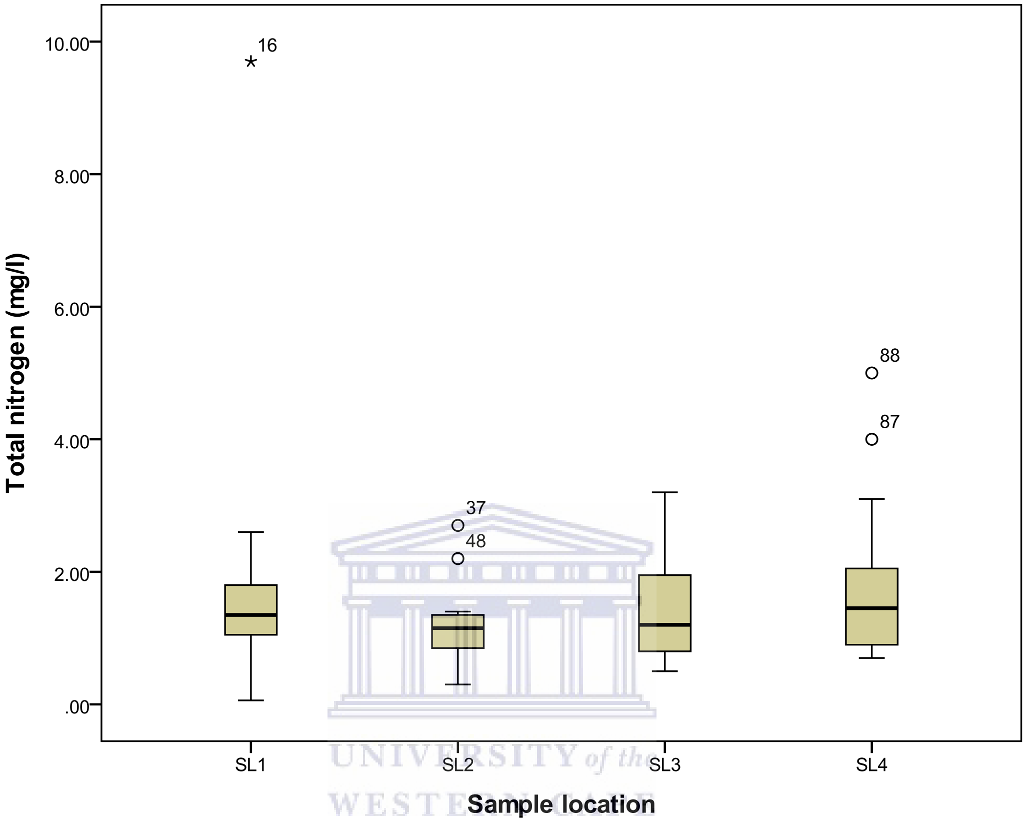


Figure 6.17: The spatial variation in total nitrogen in Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there were no statistically significant differences in the total nitrogen concetration at the four sampling locations at a 5% significance level with a p-value of 0.322 test value.

6.2.3.8. Ammonia (NH_4-N)

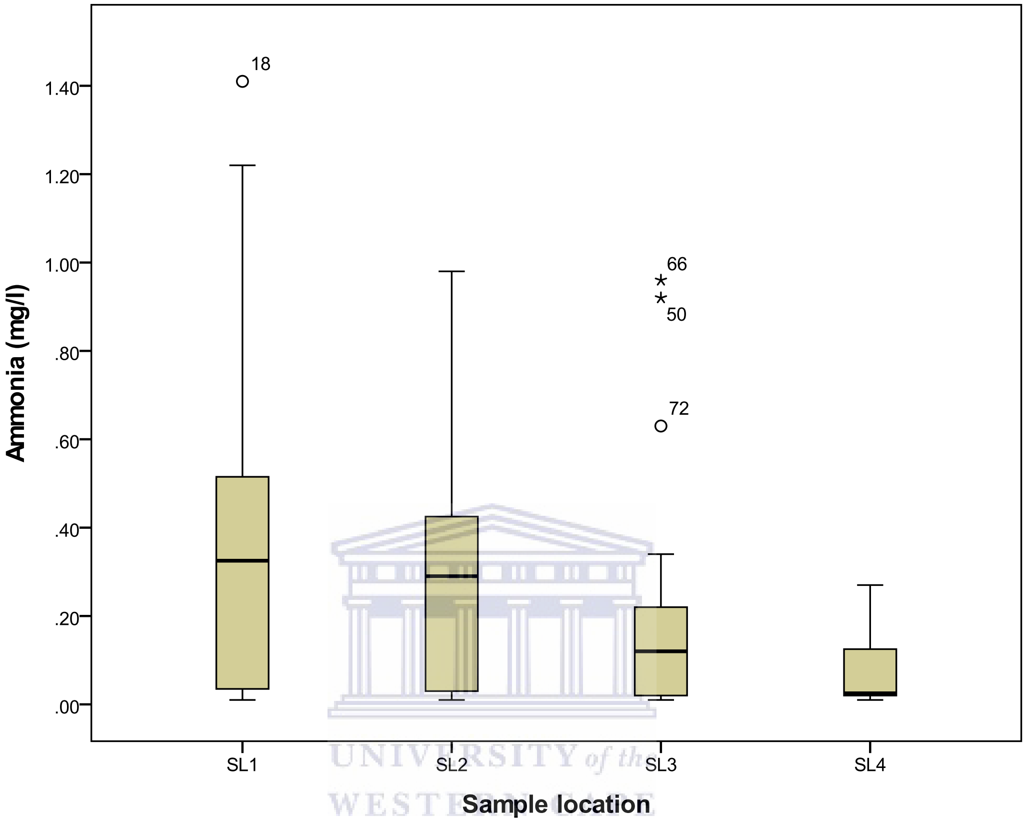


Figure 6.18: The spatial variation in ammonia (NH_4-N) in Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

Ammonia (NH_4-N) was highest at SL1 and decreased toward SL4 (Figure 6.18). The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically significant difference in the ammonia (NH_4-N) concentration at the four sampling locations at a 5% significance level with a p-value of 0.003 test value.

6.2.3.9. Dissolved organic carbon

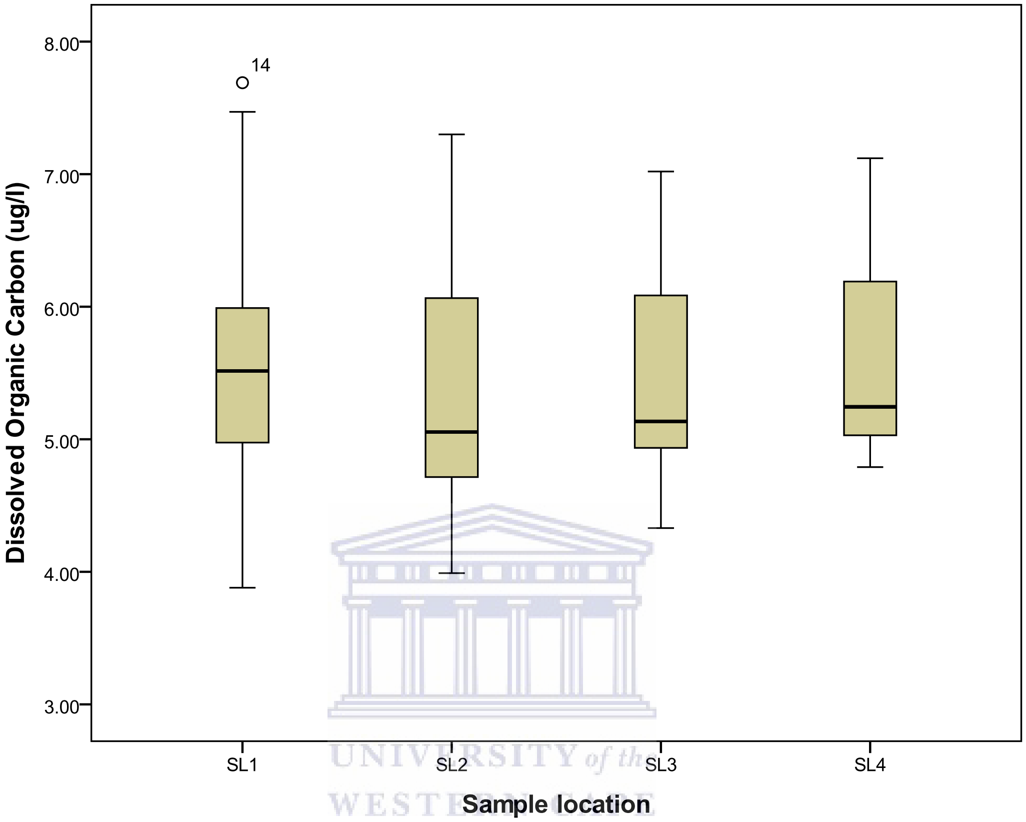


Figure 6.19: Spatial variation in the dissolved organic carbon concentration of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

The mean dissolved organic carbon in the Swakoppoort Dam water which was transferred to Von Bach Dam was 11.93mg/l and that of Omatako Dam water was 4.42mg/l. The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was no statistically significant difference in the dissolved organic carbon concentration at the four sampling locations of Von Bach Dam at a 5% significance level with a p-value of 0.659 test value.

6.2.4. Biological water quality parameters of Von Bach Dam

6.2.4.1. Chlorophyll *a*

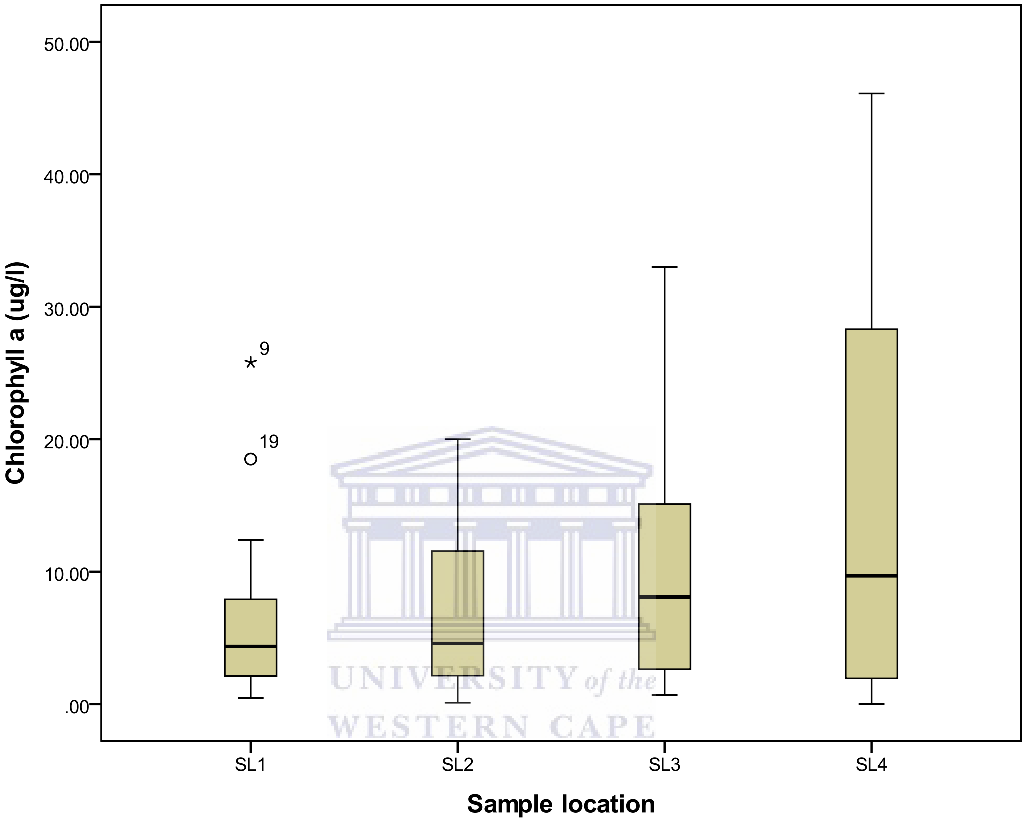


Figure 6.20: The spatial variations in the chlorophyll *a* of Von Bach Dam at the four sampling locations. Please refer to figure 6.7 for an explanation of symbols and lines.

Chlorophyll *a* concentration was highest at SL4 (Figure 6.20). The mean chlorophyll *a* in the Omatako Dam water was 3.92ug/l and catchment runoff was <0.01ug/l. The mean chlorophyll *a* in Swakoppoort Dam water transferred to Von Bach Dam was 11.7ug/l. The data was subjected to statistical analyses using a one way-ANOVA. It was found out that there was a statistically signficant difference in the chlorophyll *a* concentration at the four sampling locations at a 5% significance level with a p-value of 0.004.

6.2.4.2. Blue-green algae

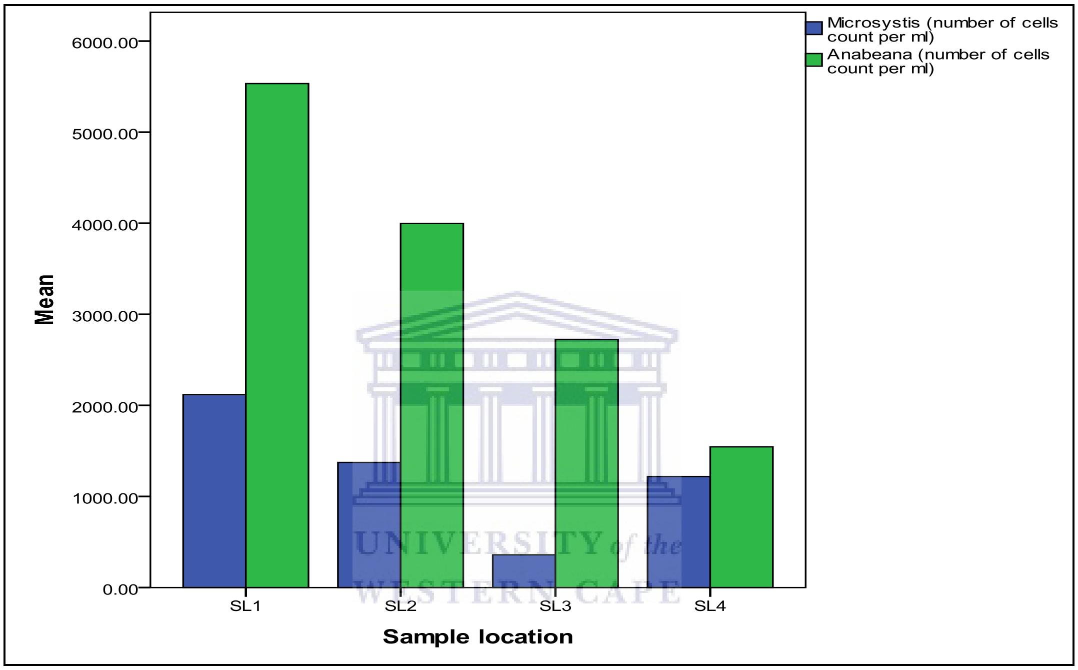


Figure 6.21: The spatial variations in the blue green algae of Von Bach Dam at the four sampling locations.

More anabaena than microcystis was found at all the sampling locations. The data was subjected to statistical analyses using a one way-ANOVA. The anabaena counts at the four sampling locations were statistically significant at a 5% significance level with a p-value of 0.605 and the microcystis count was not statistically and significantly different at the four sampling locations at a 5% significance level with a p-value of 0.575count/ml.

6.3. Total phosphorus modelling

The Organisation for Economic Co-Operation Development (OECD) countries model was used to determine the loads of phosphorus in Von Bach Dam from water transfers and catchment runoff. The model accuracy was determined by comparing the predicted versus the observed total phosphorus, where the predicted was close to the observed (Harding, 2008). The data in Table 6.2 and 6.3 was used:

Table 6.2: Hydromorphological data of Von Bach Dam

Surface area (km^2)	4.88
Average water volume (MCM/Y)	29.61
Mean depth (m)	6.06
Hydraulic retention time (Years)	1.22
Water loadings (MCM/Y)	24.26

**MCM: million cubic meters; M: meter; Km: kilometre*
**Data source: NamWater Hydrology unit*

Table 6.3: Median total phosphorus exported to Von Bach Dam

Median total phosphorus concentration in water transfers and runoff during study period	
Swakoppoort Dam	0.22
Omatako Dam	0.12
Catchment runoff	0.04
Total	**0.38**

The median total phosphorus of 0.07mg/l of Von Bach Dam was determined from 48 total phosphorus measurements obtained from four sampling locations in Von Bach Dam for the period of nine months (Table 6.4).

Table 6.4: Median total phosphorus concentration of Von Bach Dam

In-lake total phosphorus	
Median TP (mg/l)	0.07
Number of samples	48

Using equation (1) below total phosphorus was predicted at 0.06 mg/l in Von Bach Dam and the observed as shown in Table 6.4 was 0.07 mg/l. The model accurately predicted the total phosphorus concentration of Von Bach Dam as the predicted total phosphorus was close to the observed.

$$P = 1.55(LTw/z)/(1+\sqrt{Tw})^{0.82} \qquad (6.1)$$

6.4. Discussions

The transfer of water from Swakoppoort Dam into Von Bach Dam which takes place in June and July every year was delayed until November due to water quality deterioration accompanied by algal bloom (Rahman and Bakri, n.d; Kirke, 2001). Water was transferred from Omatako Dam to Von Bach Dam continuously due to higher evaporation losses of water in Omatako Dam. Von Bach Dam received more water from the runoff from the catchment than from the two dams. In total, Von Bach Dam received 24Mm^3 of water and the amount of water abstracted for treatment was 23Mm^3.

There was no statistically significant difference in temperature, manganese, pH, orthophosphate, total nitrogen, dissolved organic carbon, anabaena and microcystis between the sampling locations, thus showing that they were not influenced by water transfers and runoff from the catchment area. However, statistically significant differences were noted for secchi disk depths, turbidity, dissolved oxygen, iron, total phosphorus, ammonia and chlorophyll *a* were not statistically the same at all the sample locations during water transfers and runoff from the catchment.

The water temperature of Von Bach Dam was not affected at the discharge points during water transfers as there was no variation in temperature at the four sampling locations. Total nitrogen was also not affected at the discharge points, as there was no variation total nitrogen at the four sampling locations. But in Lake Taihu, China, water transfers affected dissolved oxygen and total nitrogen at the discharge points in the subzones (Hu *et al*., 2008). The effect on total nitrogen in Lake Taihu could be due to the higher concentration of total nitrogen in the transferred water.

The transfers of water from Caledon River into Knellpoort Dam, in South Africa, caused an increase in turbidity of water (Slabber, 2007). The turbidity of the Von Bach Dam water was influenced by runoff from the catchment and water transfers from Omatako Dam as it was shown to have high turbidity water at SL4. At SL4, fewer counts of anabaena and microcystis were recorded which could be due to light limitation by turbid water thus preventing photosynthesis. The increase in turbidity affects the penetration of light into the water column needed for photosynthesis and thus affects the aquatic ecosystem function and water quality (Wetzel, 1983; DWA, 1996). The light penetration into the water column of Von Bach Dam was not established in this study.

Chlorophyll *a* was increased at SL4 by water transfers from Omatako Dam. In some studies, chlorophyll *a* was found to be reduced by water transfers at the subzones which are discharge points (Hu *et al*., 2008). Hu *et al* (2008) found that the concentration of nitrogen and phosphorus in Lake Taihu was increased at the subzones due to water transfers. In Modder River, South Africa, the concentration of total phosphorus was decreased by water transfers from Knellpoort Dam (Slabbert, 2007). Water from Knellpoort Dam had a lower concentration of total phosphorus and orthophosphate. But total phosphorus concentration of Knellpoort Dam was increased during water transfers from Caledon River (Slabbert, 2007). Water from Caledon River was nutrient-rich in total phosphorus (Slabbert, 2007). Total phosphorus in Von Bach Dam was not statistically similar at the four sampling locations which could be due to water transfers containing a high concentration of total phosphorus.

The influence of the inflowing water into Knellpoort Dam from Caledon River was localized to the area at the inflow channel and as a result the water quality was not noticeably influenced (Slabbert, 2007). At the discharge point SL4 of water from Omatako Dam, a strong positive correlation of *r=0.9* was found between iron concentration and the volume of water transferred from Omatako Dam (**APPENDIX V**). Turbidity of the water at the discharge points SL4 and SL1 of Von Bach Dam also had a strong positive correlation with the volume of water transferred from Omatako Dam of *r=0.7* (**APPENDIX V**) and Swakoppoort Dam of *r=0.7* (**APPENDIX V**). This shows that the effects of water transfers from Swakoppoort and Omatako Dam on the turbidity and iron of Von Bach Dam was localised. Therefore, the water quality of Von Bach Dam was not greatly affected.

The influence on iron concentration of Von Bach Dam at SL1 by water transfers from Swakoppoort and Omatako Dams was not observed as there was a weak correlation of *r=0.4* and *r=0.0* (**APPENDIX IV**). This could be that the iron concentration changed in the pipeline as the water was transferred from Swakoppoort Dam and that of Omatako Dam could be diluted as the water was flowing toward SL1. On the other hand the manganese concentration of Von Bach Dam at SL1 was mainly influenced by that of Swakoppoort Dam with a strong positive correlation of *r=0.9*, rather than by that of Omatako Dam which has a positive correlation of *r=0.6* (**APPENDIX IV**). The influence on the water quality at Von Bach Dam at SL1 by Omatako Dam was affected by dilution, since the water is discharged at SL4 and flows toward SL1.

Even though the water from Omatako Dam is diluted when flowing toward SL1, ammonia and dissolved organic carbon was influenced by this water at SL1 as shown by the strong positive correlation of *r=0.7* and *r=0.9* **(APPENDIX IV)**. Orthophosphate (PO_4^{-3}) concentration was influenced by both water from Swakoppoort and Omatako Dams as shown by the strong positive correlation of *r=0.9* and *r=0.7* (**APPENDIX IV**).

Total phosphorus in Von Bach Dam was accurately predicted at 0.06mg/l close to the observed of 0.07mg/l. Therefore, if the transfer of water from Swakoppoort and Omatako Dams, and runoff from the catchment cover a longer period it could increase the amount of total phosphorus in Von Bach Dam (Badr and Hussein, 2010).

6.5. Summary

Von Bach Dam received more water from the catchment runoff, than from water transfers. Water transfers from Swakoppoort and Omatako Dams was found to influence the secchi disk depths, turbidity, dissolved oxygen, iron, total phosphorus, ammonia and chlorophyll *a* at all the sampling locations. Total phosphorus being one of the influenced water quality parameters by water transfers and runoff was modelled. The model accurately predicted the concentration of total phosphorus in Von Bach Dam arising from water transfers and runoff.

CHAPTER SEVEN: EFFECT OF WATER TRANSFERS ON WATER TREATMENT

7.1. Introduction

This chapter presents and discusses how water transfers affect the treatment of water from Von Bach Dam. Von Bach Dam is augmented with water from Swakoppoort Dam and Omatako Dam. Water from Von Bach Dam is pumped to the Von Bach treatment plant, where the water is treated for supply to Windhoek and Okahandja. Two senior officers responsible for water treatment were interviewed at the Von Bach treatment plant on water treatment challenges and processes or methods used in treating Von Bach Dam water. And on whether the challenges occur during water transfers or not during water transfers.

7.2. Results

Water treatment challenges and processes or methods at the plant

A high concentration of manganese, iron, geosmin, 2-methylisoborneol (2MIB), dissolved organic carbon and ammonia were the major challenges in treating the water from Von Bach Dam. The high concentration of these parameters requires more dosage of chemicals to treat the water to be suitable for human consumption. The chemical dosages used are: potassium permanganate for manganese and iron, Polyaluminium Chloride (PAC) for geosmin and 2-methylisoborneol (2MIB), Ultraflocs 3000 coagulant for turbidity, and enhanced coagulation for dissolved organic carbon.

The effect of water transfers on water treatment.

The senior officers responsible for water treatment at the treatment plant were of the view that the concentration of manganese, iron, geosmin, and 2-methylisoborneol (2MIB) was high in the water abstracted from Von Bach Dam when no water transfers occur. While turbidity, and dissolved organic carbon were high during water transfers and runoff from the catchment, and ammonia was high during runoff from the catchment.

7.3. Discussions

Dissolved organic carbon originates from humic substances and organic matter, and when it reaches the distribution system it causes bacterial growth which leads to the development of undesirable organisms (Servais *et al*, 1986; Joret *et al*, 1991). The senior officers responsible for water treatment were of the view that the increase in the concentration of DOC in the water of Von Bach Dam was caused by runoff from the catchment area and also by water transfers from Swakoppoort Dam. The result of the study showed that, DOC was high at SL1 where water is abstracted for treatment and had a strong positive correlation with that of Omatako, indicating the influence by water from Omatako Dam. Omatako Dam water influenced the DOC concentration of Von Bach Dam at SL1. Higher dosages of Ultrafloc 3000 were required for treating the water to a level below 4mg/l of dissolved organic carbon to meet the artificial recharge requirement for the City of Windhoek, which is a challenge at the treatment plant.

Turbidity of the water is increased by sediment resuspension and human activities in the catchment area (Wetzel, 1983; DWAF, 1996). High turbidity in the water makes the treatment of bacteria ineffective which can lead to an outbreak of cholera and diarrhea in children (Arnold and Colford JR, 2007; Luby *et al*, 2008). The respondents were of the view that runoff from the catchment area and Omatako Dam water transfers increases the turbidity in the water of Von Bach Dam which is abstracted for treatment. The results from the study showed that, the turbidity was higher at SL4 than at SL1 which are discharge points of water transfers and runoff from the catchment. The findings from the study supported the view of the respondents. To remove the turbidity in this water, higher dosages of Ultraflocs 3000 are required which are expensive and could lead to the increase of water tariffs in the future.

The respondents were of the view that high ammonia concentration in the water of Von Bach Dam is experienced during runoff from the catchment. Treating a high concentration of ammonia increases the chlorine consumption at the Von Bach treatment plant which could produce the byproduct trihalomethanes (THML). THML affects human health when it reaches the distribution system (Hua and Reckhow, 2007). The results of the study showed that, ammonia was high at the discharge point SL1 where water is abstracted for treatment. The study finding supported the view of the respondent.

The respondent stated that manganese, iron, geosmin and 2-methylisoborneol also caused water treatment problems at the plant even though their effects were not observed during water transfers and runoff from the catchment. In this study geosmin and 2-methylisoborneol were not monitored. Geosmin and 2-methylisoborneol are produced during the bloom of blue-green algae as algal metabolites (Cook *et al*., 2001). When present in the distribution system even at a lower concentration, it results in consumer complaints (Cook *et al*., 2001). But manganese in the water was statistically similar at all the sampling locations. Iron was higher at SL4 than at the other sampling locations and indicated the influence by water transferred from Omatako and runoff from the catchment area.

The study showed that the effect of water transfers were mainly at discharge points SL1 and SL4 indicating the localised effect by water transfers on some parameters. The localised effects of water transfers showed that the water quality of Von Bach Dam was not greatly affected by water transfers. Even though the effects were localised, the results of the study supported the view of the two senior scientists responsible for water treatment for DOC, that ammonia and turbidity were increased by water transfers and runoff from the catchment. But iron, which was viewed by the senior officers as not affected by water transfers, were found to be influenced by water transfers at the discharge point SL4.

7.4. Summary

The water treatment problem at the Von Bach treatment plant was mainly due to manganese, iron, turbidity, dissolved organic carbon and ammonia from the water abstracted from Von Bach Dam. The increases in ammonia, turbidity and dissolved organic carbon were caused by water transfers and runoff from the catchment area.

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

8.1. Conclusions

a. The three dams are statistically similar with respect to water temperature, pH and dissolved oxygen. High turbidity was observed in Von Bach Dam during periods of natural inflows from the upstream catchment area and water transfers from Omatako Dam. In Swakoppoort Dam, high turbidity was observed when algal blooms occurred. Among the three dams Swakoppoort Dam was found to be nutrient-rich, particularly in total phosphorus and orthophosphate. The nutrients resulted in a bloom of blue-green algae which delayed water transfers to Von Bach Dam. The bloom was dominated by microcystis algae. Furthermore within the three dams, secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a*, and microcystis algae were statistically different.

b. During water transfers and inflow of runoff from the upstream catchment into Von Bach Dam, secchi disk depths, turbidity, dissolved oxygen, iron, total phosphorus, ammonia and chlorophyll *a* were not statistically different at the four sampling locations, indicating no influence by water transferred from Swakoppoort and Omatako Dams, and runoff from the catchment area. Furthermore, iron and turbidity at the discharge points SL1 and SL4 correlated with the volume of water transferred from Swakoppoort and Omatako Dams, indicating the influence of water transfers on these parameters. The effect of water transfers and runoff from the catchment on Von Bach Dam water was localised.

c. At the Von Bach treatment plant, high turbidity, dissolved organic carbon, and ammonia (NH_4-N) resulted from water transfers and runoff from the catchment area presented problem for water treatment.

8.2. Recommendations

- Monitoring the effect of water transfer from Swakoppoort Dam, Omatako Dam and runoff from the catchment should continue and should be repeated for five years to determine any water quality changes in Von Bach Dam.

- To reduce the increase in turbidity of the Von Bach Dam water caused by water transferred from Omatako Dam and runoff from the catchment, filtration structures such as gabions should be installed at the inlet of Von Bach Dam to filter debris, humic substances, suspended solids and organic matter before the water flows into the dam. Reducing the inflow of these substances will also minimize the concentration of dissolved organic carbon and ammonia in the water which are released during the decomposition of these elements.
- The treatment plant should prepare for high turbidity, manganese, iron, ammonia, and dissolved organic carbon in the water during water transfer periods and runoff from the catchment.
- To ensure a sustainable good water quality at Von Bach Dam without a severe effect on water treatment in the future, the water quality of the three dams should be managed in an integrated manner. Pollution sources need to be identified in all the catchment areas and should be monitored to determine their effect on the water quality in the dams. Catchment management strategy or measures of land uses activities, cattle and game farming, sewage and wastewater effluent discharge, should be implemented in all the catchments.

REFERENCES

1. African Water Vision. (n.d). *The African Water Vision for 2025: Equitable and Sustainable use of water for socioeconomic development*. Economic Commission for Africa.
2. Agnew, C., and Anderson, E. (1992). *Water Resource in the arid realm*. New York, United State of America: Rouledge Taylor and Francis Group.
3. American Public Health Association. (1998). *Standard Methods for Examination of Water and Waste Water 20th edition*. New York, United State of America: American Public Health Association.
4. Arnold, B.F., and Colford JR, J.M. (2007). Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. The *American Society of Tropical Medicine and Hygiene,* 76(2), 354-364.
5. Ashton, P.J., and Van Zyl, F.C. (2000). Water quality management in the Crocodile River Catchment, Eastern Transvaal, South Africa. *Water Science and Technology,* 32 (5-6), 201-208.
6. Badr, N.B.E., and Hussein, M.A. (2010). An input/output flux model for total phosphorus in Lake Edku, a northern eutrophic Nile Delta Lake. *Global Journal of Environmental Research,* 4(2), 64-75.
7. Bailey, R.G., and Cobb, S.M. (1984). A note on some investigation carried out in the area of the Sudan plain to be affected by the Jonglei canal. *Hydrobiologia,* 110,45-46.
8. Bartam, J., and Balance, R. (1996). *Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes 1ST edition*. Great Britain: TJ Press.
9. Beutel, M.W. (2006). Inhibition of ammonia release from anoxic profundal sediments in lakes using hypolimnetic oxygenation. *Ecological Engineering,* 28(1), 271-279.

10. Biggs, D., and Williams, R. (2009). *A Case Study of Integrated Water Resource Management in Windhoek, Namibia*. Windhoek, Namibia: Department of Water Affairs.
11. Biswas, A.K., and Tortajada, C. (2006). Water management in Latin America: personal reflections before the Mexico forum. *Hydropower and Dam*, 2,2006.
12. Breen, C.M. (1983). *Limnology of Lake Midmar*. Pretoria, South Africa: National Scientific Programmes Unit, CSIR.
13. Burns, N., Bryers, G., and Bowman, E. (2000). *Protocol for monitoring trophic levels of New Zealand lakes and reservoirs*. Pauanui, New Zealand: Lake Consulting.
14. Burns, N., McItosh, J., and Scholes, P. (2009). Managing lakes of the Rotorua District, New Zealand. *Lake and Reservoir Management*, 25, (3), 284-296.
15. Chapman, D (Ed). (1992). Water quality assessment: *A guide to the use of biota, sediments and water in environment monitoring*. Great Britain: University of Cambridge Press.
16. Cook, D., Newcombe, G., and Sztajnbok, P. (2001). The application of powdered activated carbon from 2MIB and geosmin removal: Predicting PAC doses in four raw waters. *Water Research*, 35(5), 1325-1333.
17. Dalkiran, N., Karacaogˇlu, D., Dere, S., Şentürk, E., and Torunogˇlu, T. (2006). Factors affecting the current status of a eutrophic shallow lake (Lake Uluabat, Turkey): Relationship between water, physical and chemical variables. *Chemistry and Ecology*, 22(4), 279-298.
18. Dallas, H.F., and Day, J.A. (2004). *The Effects of Water Quality Variables on Aquatic Ecosystems: A Review*. Cape Town, South Africa: Water Research Commission.
19. Davies, B. and Day, J. (1998). *Vanishing waters*. Cape Town, South Africa: University of Cape Town Press.
20. Davison, W. (1993). Iron and manganese in lakes. *Earth Science Reviews,* 34(2), 119-163.

21. DWA. (1996). *South African Water Quality Guideline for Aquatic Ecosystems*. Pretoria, South Africa.
22. Ekhlom, P., Kallio, K., Salo, S., Pietilained, O.P., Rekolainen, S., Laine, Y., and Joukola, M. (2000). Relationship between catchment characteristics and nutrient concentration on an agricultural river system. *Pergamon,* 34 (15), 3709-3716.
23. Ekholm, P., and Krogeru, K. (2003). Determining algal-available phosphorus of differing origin: routine phosphorus analyses versus algal assays. *Hydrobiologia*, 492, 29-42.
24. EPA. (2002). *National recommended water quality criteria*. United States of America: Office of Science and Technology.
25. Evans, C.D., Monteith, D.T., and Cooper, D.M. (2004). Long-term increases in surface water dissolved organic carbon: Observation, possible causes and environmental impacts. *Environmental Pollutions,* 137(1), 55-71.
26. Fred Lee, G., Rast, W., and Anne Jones, R. (1978). Eutrophication of water bodies: Insight for an age-old problem. *Environmental Science and Technology,* 12,900.
27. Gao, J., Xlong, Z., Zhang, J., Zhang, W., and Obonombha, F. (2009). Phosphorus removal from water of eutrophic Lake Donghu by five submerged macrophytes. *Desalination,* 242, 193-204.
28. Gonz´alez, E.J., Ortaz, M., Peñaherrera, C., and De Infante, A. (2004). Physical and chemical features of a tropical hypertrophic reservoir permanently stratified. *Hydrobiologia,* 522, 301–310.
29. Gupta, J., and Van der Zaag, P. (2008). Interbasin water transfers and integrated water resources management: where engineering, science and politics interlock. *Physics and Chemistry of the Earth,* 32, 28-40.
30. Harding, W.R. (2008). *The determination of annual phosphorus loading limits for South African Dams*. Pretoria, South Africa: Water Research Commissions Report no 1687/1/08.

31. Hart, B., Roberts, S., James, R., Taylor, J., Donnert, D., and Furrer, R. (2003). Use of active barriers to reduce eutrophication problems in urban lakes. *Water Science and Technology,* 47. 157-163.
32. Hart, R. (2006). Food web (bio-) manipulation of South African reservoirs-viable eutrophication management prospect or illusory pipe dream? A reflective commentary and position paper. *Water SA*, 35(4).
33. Hart, R.C., and Allanson, B.R. (Ed). (1984). *Limnological criteria for management of water quality in the Southern Hemisphere*. Pretoria, South Africa: National Scientific Programmes Report no 93.
34. Heisler, J., Gilbert,P.M., Burkholder, J.M., Anderson, D.M., Cochlan, W., Dennison, W.C., Dortch, Q., Gobler, C.J., Heil,C.A., Humphries, E., Lewitus, A., Magnien, R., Marshall, H.G., Sellner, K., Stockwell, D.A., Stoecker, .D.K., and Suddleson, M. (2008). Eutrophication and harmful algal blooms: A scientific consensus. *Harmful algae*.
35. Hongve, D. (1997). Cycling of iron, manganese and phosphate in a meromictic lake. *Limnology and Oceanography*, 42(2), 635-647.
36. Howard, J.R., Ligthelm, M.E., and Tanner, A.C. (2000). The development of a water quality management plan for the Mgeni River Catchment. *Water Science and Technology,* 32 (5-6), 217-226.
37. Hu, L., Hu,W., Zhai, S., and Wu, H. (2009). Effects on water quality following water transfer in Lake Taihu, China. *Ecological Engineering,* 1576, 11.
38. Hu, W., Zhai, S.Z.Z., and Han, H. (2008). Impacts of the Yangtze River water transfer on the restoration of Lake Taihu. *Ecological Engineering,* 34, 30-49.
39. Hua, G., and Reckhow, D.A. (2007). Comparison of disinfection byproduct formation from chlorine and alternative disinfectants. *Water Research*, 41(8), 1667-1678.
40. Jackson, L.J. (2003). Macrophytes-dominated turbid states of shallow lakes: Evidence from Alberta lakes. *Ecosystem,* 6(3), 213-223.

41. Joret, J.C., Levi, Y., and Volk, C. (1991). Biodegradable dissolved organic carbon (BDOC) content of drinking water and potential regrowth of bacteria. *Water Science and Technology*, 24(2), 95-101.
42. Kemka, N., Njine, T., Togouet, H.Z., Membohan, S.T., Nola, M., Monkiedje, A., Niyitegeka, D., and Compĕre, P. (2006). Eutrophication of Lakes in urbanised areas: The case of Yaoundé Municipal Lake in Cameroon, Central Africa. Lakes and Reservoirs: *Research and Management,* 11, 41-55.
43. Kirillin, G. (2010). Modeling the impact of global warming on water temperature and seasonal mixing regimes in small temperate lakes. *Boreal Environment Research,* 15, 279-293.
44. Kirke, B.K. (2001). *Pumping downwards to prevent algal blooms*. Berlin, Germany: Poster presentation, IWA 2nd World Water Congress.
45. Kitaka, N., Harper, D.M., and Mavuti, K. (2002). Phosphorus inputs to Lake Naivasha, Kenya, from its catchment and the trophic status of the lake. *Hydrobiologia,* 488, 73-80.
46. Lewis, W.M., JR. (1983). A revised classification of lakes based on mixing. *Can. J. Fish. Aquat. Sci,* 40, 1779-1789.
47. Lewis, W.M., JR. (1996). Tropical lakes: Low latitude makes a difference. *Perspectives in Tropical Limnology,* 43-64.
48. Lewis, W.M., JR. (2000). Basin for protection and management of tropical lakes. *Lake and Reservoir: Research and Management,* 5, 35-48.
49. Li, S., Gu, S., Tan, X., and Zhang, Q. (2009). Water quality in the upper Han River Basin, China: The impact of land use/land cover in riparian buffer zone. *Journal of Hazardous Materials,* 165, 317-324.
50. Liputa, G.I., Nikodemus, K., and Menge, J. (n.d). *Strategic drinking water quality monitoring for drinking water safety in Windhoek.* Windhoek, Namibia: City of Windhoek.
51. Loucks, D.P., Van Beek E., Stedinger, J.R., Dijkman, J.P., and Villars, J.M. (2005). *Water resources systems planning and management: An introduction to methods, models and applications*. Paris, France: UNESCO publishing.

52. Luby, S.P., Mendoza, C., Keswick, H.B., Chiller, T.M., and Hoekstra, R.M. (2008). Difficulties in Bringing Point-of-Use Water Treatment to Scale in Rural Guatemala. *The American Society of Tropical Medicine and Hygiene,* 78(3), 382-387.
53. Marshall, B., Ezekiel, C., Gichuki, J., Mkumbo, O., Sitoki,L., and Wada, F.C. (2009). Global warming is reducing thermal stability and mitigating the effects of eutrophication in Lake Victoria (East Africa). *Earth and Environment.*
54. Maybeck, M., Kuusisto, E., Mäkelä, A., and Mälkki, E. (1996). *Water Quality Monitoring-A practical guide to the design and implementation of firewater quality studies and monitoring programs*. United Nations Environment Programme and World Health Organisation.
55. Mendelson, J., Jarvis, A., Roberts, C., and Robertson, T. (2002). *Atlas of Namibia: A portrait of the land and its people*. Windhoek, Namibia: Ministry of Environment and Tourism.
56. MELP. (2002). *Guideline for interpreting water quality data*. British Columbia: Resources Inventory Committee Publications.
57. Monaghan, R.M., Wilcock, R.J., Smith, L.C., Tikkisetty, B., Thorrold, B.S, Costall, D. (2007). Linkage between land management activities and water quality in the intensively farmed catchment in Southern New Zealand. *Agriculture, Ecosystems and Environment*.
58. Mvungi, A., Hranova, R.K., and Love, D. (2003). Impact of home and industries on water quality in a tributary of the Marimba River, Harare: Implication for urban water management. *Physics and Chemistry of the Earth,* 28, 1131-1137.
59. Nare, L., Love, D., and Hoko, Z. (2006). Involvement of stakeholders in water quality monitoring and surveillance system: The case of Mzingwane catchment, Zimbabwe. *Physics and Chemistry of the Earth*, 31 (15-16), 707-712.

60. NWQMS. (2000). *Water quality guideline for aquatic ecosystems: Physical and chemical stressors, volume 2*. Australian and New Zealand environment and conservation council, agriculture and resource management council of Australian and New Zealand.
61. Nhapi, I., and Tirivarombo, S. (2004). Sewage discharges and nutrient levels in Marimba River. *Water SA,* 30(1).
62. Nhapi, I., Siebel, M.A., and Gijzen, H.J. (2004). The impact of urbanisation on the water quality of Lake Chivero, Zimbabwe. *The Journal,* 18(1), 44-49.
63. Nyenje, P.M., Foppen, J.W. Uhlenbrooks, S., Kulabako, R., Muwanga, A. (2010). Eutrophication and nutrient release in urban areas of Sub-Saharan Africa - A review. *Science of the Total Environment,* 408, 447-455.
64. Oberholster, P.J., and Ashton, J. (2008). *An overview of the current status of water quality and eutrophication in South African Rivers and Reservoirs*. Pretoria, South Africa: National Report.
65. Oberholster, P.J., Myburgh, J.G., Govender, D., Bengis, R., and Botha, A. (2009). Identification of toxigenic microcystis strains after incidents of wild animal mortalities in the Kruger National Park, South Africa. *Ecotoxicology and Environmental Safety,* 3861.
66. Ochumba, P.B.O., and Kibaara, D.I. (2008). Observations on blue-green algal blooms in the open water of Lake Victoria, Kenya. *African Journal of Ecology,* 27(1), 23-24.
67. Olago, D., and Odada, E. (2007). Sediment impacts in Africa's Transboundary lake/river basins: Case study of the East African Great Lakes. *Aquatic Ecosystem Health and Management,* 10, 23-32.
68. Out, M.K., Ramlal, P., Wilkinson, P., Hall, R.I., and Hecky, R.E. (2010). Paleolimnological evidence of the effect of recent cultural eutrophication during the last 200 years in Lake Malawi, East Africa. *Journal of Great Lakes Research,* 37, 61-74.

69. Pegram, G.C., and Bath, A.J. (1995). Role of non-point sources in development of water quality management plan for the Mgeni River Catchment. *Water Science and Technology,* 32(5-6), 175-182.
70. Pitois, S., Jackson, M.H., Path, F.R., Biol, F.I., Wood, B.J.B., and Chem, C. (2001). Sources of the eutrophication problems associated with toxic algae: An overview. *Journal of Environmental Health,* 64 (5), 25.
71. Preisendorfer, S. (1986). Secchi disk science: Visual optics of natural waters. *Limnology and Oceanography,* 31(5), 909-926.
72. Quinn, F.J. (1988). Large-scale water transfers. In: *Water for the World Development Proceedings of the VIth IWRA World Congress on Water Resource, Volume 1*. R. Droste and K. Adamowski (Eds). Urbana, United State of America: International Water Resource Association.
73. Rahman, A.M., and Al Bakri, D. (n.d). *Eutrophication and Algal Blooms in Inland Reservoirs: A Case Study from Australia*. Retrieved September 8, 2011, from (http://www.eng-consult.com/C321ABCE-B947-48B3-8DEF-7726AECC2299/FinalDownload/DownloadId-E692F6D46B30A7552322E1BDE238D73A/C321ABCE-B947-48B3-8DEF-7726AECC2299/BEN/papers/Paper-mrahman.PDF).
74. Rast, W., and Thornton, A.J. (1996). Trends in eutrophication research and control. *Hydrological Processes,* 10,295-313.
75. Rast, W., Anne Jones, R., and Fred Lee, G. (1983). Predictive capability of U.S.OECD phosphorus loading-eutrophication response models. *Journal WPCF,* 55 (7).
76. Reynolds, C.S., and Walsby, A.E. (2008).Water blooms. *Biological Reviews,* 50(4), 437-481.
77. Rhodes, L.M., Newton, RM., and Putfall, A. (2001). Influences of land use on water quality of a diverse New England watershed. *Environmental Science and Technology,* 35(18), 3640-3645.

78. Robarts, R.D., Ashton, P.J., Thornton, J.A., Taussig, H.J., and Sephton, L.M. (1982). Overturn in a hypertrophic, warm, monomictic impoundment (Hartbeespoort Dam, South Africa). *Hydrobiologia,* 97(3), 209-224.
79. Scheffer, M. (2004). *Ecology of shallow lakes*. Dordrecht, Netherlands: Kluwer Academic Publisher.
80. Schindler, D.W. (2006). Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography,* 51(2), 356-363.
81. Servais, P., Anzil, A., and Ventresque, C. (1989). Simple Method for Determination of Biodegradable Dissolved Organic Carbon in Water. *Applied and Environmental Microbiology,* 2732-2734.
82. Slabbert, N. (2007). *The potential impact of an inter-basin water transfer on the Modder and Caledon River systems*. Unpublished doctoral dissertation, University of the Free State, Bloemfontein: South Africa.
83. Snaddon, C.D., Wishart, M.J., and Davies, B.R. (1998). Some implications of inter-basin water transfers for river ecosystem functioning and water resources management in Southern Africa. *Aquatic Ecosystem Health and Management,* 1(2), 159-182.
84. Southern African Development Community. (2006). Regional water policy. Infrastracture and services directorate, Gaborone, Botswana.
85. Steinberg, C.W., and Hartmann, H.M. (1988). Planktonic bloom-forming cyanobacteria and the eutrophication of lakes and rivers. *Freshwater Biology,* 20 (2), 279-287.
86. Sǿndergaard, M., Jensen, J.P., and Jeppesen, E. (2000). Role of sediments and internal loading of phosphorus in shallow lakes. *Hydrobiologia*, 506-509(1-3), 135-145.
87. Tong, S.T.Y., and Chen, W. (2001). Modelling the relationship between land use and surface water quality. *Journal of Environmental Management,* 66 (4), 377-393.

88. Twinch, A.J., and Breen, C.M. (1980). *Advances in understanding phosphorus cycling in inland waters-their significance for South African limnology*. Pretoria, South Africa: National Scientific Programmes Report no: 42.

89. United Nation Data: A world information. (n.d). Retrieved September 8, 2011, from, http://data.un.org/countryprofile.aspx?erName=Namibia

90. Van Ginkel, C.E. (2004).*A national survey of the incidence in major impoundments. Resources Quality Service Report no: 503*. Pretoria, South Africa: Department of Water Affairs and Forestry.

91. Voropaev,G.V., and Velikanov, A.L. (1985). *Partial Southward diversion of Northern and Siberian Rivers In: Large-scale transfers: emerging environmental and social experience.* New Jersey, Unite State of America: Tycooly Publishing.

92. Wetzel, R.G. (1983). *Limnology, 2th edition*. Orlando, Florida, United State of America: Saunders College Publishing.

93. WHO and UNICEF. (2006). *Meeting the Millennium Development Goals for drinking water and sanitation target: The urban and rural challenge of the decade*. Geneva, Switzerland.

94. Zhang, J., Ni, W., Luo, Y., Jan Stevenson, R., and Qi, J. (2010). Response of freshwater algae to water quality in Qinshan Lake within Taihu watershed, China. *Physics and Chemistry of the Earth*.

APPENDIX I

Descriptive statistics of the water quality parameters of the three dams

Water quality parameters	**Descriptive statistics**	**Von Bach Dam**	**Swakoppoort Dam**	**Omatako Dam**
Temperature	Mean	17.80	18.86	19.68
	95% confidence interval	(15.12, 20.42)	(16.11, 21.60)	(15.80, 23.56)
	Median	18.10	19.00	21.00
	Standard deviation	2.90	3.00	4.20
	Minimum	14.20	16.00	14.50
	Maximum	22.10	23.00	24.50
Turbidity	Mean	8.84	23.99	80.05
	95% confidence interval	(-0.12, 17.80)	(8.63, 39.35)	(-84.91, 245.01)
	Median	5.88	25.30	19.20
	Standard deviation	9.68	16.61	178.37
	Minimum	2.42	6.53	2.39
	Maximum	30.42	51.40	484.00
Secchi disk depths	Mean	1.53	0.52	0.24
	95% confidence interval	(0.71, 2.35)	(0.20, 0.85)	(0.11, 0.38)
	Median	1.68	0.44	0.19
	Standard deviation	0.88	0.35	0.15
	Minimum	0.23	0.00	0.12
	Maximum	2.64	1.06	0.48
Dissolved oxygen	Mean	3.16	3.51	3.84
	95% confidence interval	(1.80, 4.55)	(2.73, 4.30)	(1.35, 6.33)
	Median	2.60	3.00	2.65
	Standard deviation	1.51	0.86	2.70
	Minimum	1.90	2.76	0.00
	Maximum	5.50	5.00	7.15
pH	Mean	8.09	8.43	8.23
	95% confidence interval	(7.84, 8,33)	(7.95, 8.92)	(7.63, 8.83)
	Median	8.10	8.40	8.40
	Standard deviation	0.27	0.53	0.65
	Minimum	7.73	7.50	7.00
	Maximum	8.50	9.00	9.00
Iron	Mean	0.30	0.04	1.20
	95% confidence interval	(-0.07, 0.67)	(0.02, 0.05)	(-0.71, 3.12)
	Median	0.16	0.03	0.45
	Standard deviation	0.40	0.02	2.06
	Minimum	0.04	0.01	0.06

Water quality parameters	Descriptive statistics	Von Bach Dam	Swakoppoort Dam	Omatako Dam
	Maximum	1.18	0.06	5.78
Manganese	Mean	0.12	0.05	0.07
	95% confidence interval	(0.02, 0.22)	(0.02, 0.07)	(-0.03, 0.16)
	Median	0.07	0.04	0.02
	Standard deviation	0.12	0.03	0.11
	Minimum	0.01	0.01	0.01
	Maximum	0.30	0.09	0.30
Total phosphorus	Mean	0.06	0.27	0.13
	95% confidence interval	(0.04,0.08)	(0.16, 0.37)	(-0.01, 0.28)
	Median	0.06	0.20	0.07
	Standard deviation	0.02	0.12	0.16
	Minimum	0.03	0.16	0.05
	Maximum	0.09	0.50	0.48
Ortho-phosphate(PO4-3)	Mean	0.02	0.14	0.07
	95% confidence interval	(0.01, 0.03)	(0.03, 0.24)	(0.01, 0.12)
	Median	0.01	0.08	0.04
	Standard deviation	0.01	0.12	0.06
	Minimum	0.01	0.04	0.01
	Maximum	0.05	0.34	0.16
Total nitrogen	Mean	2.50	2.48	1.50
	95% confidence interval	(-0.48, 5.46)	(1.77, 3.19)	(0.22, 2.80)
	Median	1.07	2.60	1.00
	Standard deviation	3.21	0.77	1.39
	Minimum	0.90	1.50	0.70
	Maximum	9.70	3.40	4.60
Ammonia	Mean	0.32	0.36	0.04
	95% confidence interval	(0.20, 0.44)	(0.14, 0.60)	(0.00, 0.074)
	Median	0.33	0.31	0.02
	Standard deviation	0.13	0.24	0.04
	Minimum	0.15	0.03	0.01
	Maximum	0.57	0.76	0.10
Dissolved organic carbon	Mean	5.45	10.75	5.20
	95% confidence interval	(5.06, 5.84)	(9.13, 12.37)	(4.16, 6.23)
	Median	5.30	10.50	5.34
	Standard deviation	0.42	1.76	1.12
	Minimum	5.00	8.20	3.36

Water quality parameters	**Descriptive statistics**	**Von Bach Dam**	**Swakoppoort Dam**	**Omatako Dam**
	Maximum	6.03	13.50	6.37
Chlorophyll *a*	Mean	6.40	88.24	3.69
	95% confidence interval	(0.98, 11.82)	(14.45, 162.03)	(-1.82, 9.20)
	Median	2.98	77.90	2.06
	Standard deviation	5.86	79.79	5.96
	Minimum	1.34	1.70	0.34
	Maximum	17.20	200.10	17.10
Anabaena	Mean	2852.81	7722.15	0.00
	95% confidence interval	(-2615.10, 8320.72)	(-121.42, 15565.70)	(0.00, 0.00)
	Median	10.00	4714.00	0.00
	Standard deviation	5912.24	8480.94	0.00
	Minimum	0.00	0.00	0.00
	Maximum	16093.67	23493.00	0.00
Microcystis	Mean	1447.05	194866.40	0.00
	95% confidence interval	(-1162.51, 4056.61)	(8889.42, 380843.36)	(0.00, 0.00)
	Median	212.00	185702.00	0.00
	Standard deviation	2821.61	2.01	0.00
	Minimum	7.00	0.00	0.00
	Maximum	7660.33	464990.00	0.00

APPENDIX II

Descriptive statistics of the water quality parameters at the four sampling locations of Von Bach Dam

Parameters	SL	N	Mean	St deviation	St error	95% lower bound	95% upper bound	Maximum	Minimum
Total phosphorus (mg/l)	SL1	24	0.1	0.1	0	0.1	0.2	0	0.7
	SL2	24	0.1	0	0	0.1	0.1	0	0.2
	SL3	24	0.1	0.1	0	0.1	0.1	0	0.2
	SL4	24	0.1	0.1	0	0.1	0.2	0	0.5
	Total	96	0.1	0.1	0	0.1	0.1	0	0.7
Total nitrogen (mg/l)	SL1	24	1.7	1.8	0.4	0.9	2.4	0.1	9.7
	SL2	24	1.2	0.5	0.1	1	1.4	0.3	2.7
	SL3	24	1.4	0.7	0.1	1.1	1.7	0.5	3.2
	SL4	24	1.7	1.1	0.2	1.2	2.2	0.7	5
	Total	96	1.5	1.2	0.1	1.3	1.7	0.1	9.7
Chlorophyll a (ug/l)	SL1	24	6.2	6	1.2	3.7	8.8	0.5	25.8
	SL2	24	6.8	5.5	1.1	4.4	9.1	0.1	20
	SL3	24	10.5	9.6	2	6.5	14.6	0.7	33
	SL4	24	16	16.1	3.3	9.2	22.8	0	46.1
	Total	96	9.9	10.8	1.1	7.7	12.1	0	46.1
Dissolved Organic Carbon (mg/l)	SL1	24	5.5	0.9	0.2	5.2	5.9	3.9	7.7
	SL2	24	5.4	0.9	0.2	5	5.7	4	7.3
	SL3	24	5.4	0.8	0.2	5.1	5.8	4.3	7
	SL4	24	5.6	0.8	0.2	5.3	6	4.8	7.1
	Total	96	5.5	0.8	0.1	5.3	5.7	3.9	7.7
PH	SL1	24	8	0.5	0.1	7.8	8.2	7.2	9.1
	SL2	24	8	0.5	0.1	7.9	8.2	7.4	9
	SL3	24	8	0.4	0.1	7.8	8.2	7.3	8.9
	SL4	24	8.1	0.3	0.1	8	8.3	7.8	8.7
	Total	96	8.1	0.4	0	8	8.1	7.2	9.1
Turbidity (NTU)	SL1	24	7.8	9.5	1.9	3.8	11.8	1.4	45.2
	SL2	24	12.8	16.8	3.4	5.7	19.9	2.4	79.8
	SL3	24	31.2	56.4	11.5	7.4	55	3	258
	SL4	24	73.3	120	24.5	22.6	124	8	448

Parameters	SL	N	Mean	St deviation	St error	95% lower	95% upper	Maximum	Minimum
	Total	96	31.3	70.8	7.2	16.9	45.6	1.4	448
Anabaena (number of cells count per ml)	SL1	24	3495.9	7625.4	1556.5	276	6715.8	0	35044
	SL2	24	2154.2	6823.3	1392.8	-727	5035.4	0	32951
	SL3	24	1651.6	3866.8	789.3	18.8	3284.4	0	16829
	SL4	24	1545	2299.6	469.4	573.9	2516.1	0	7990
	Total	96	2211.7	5555	567	1086.1	3337.2	0	35044
Microcystis (number of cells count per ml)	SL1	24	1092	3993.4	815.1	-594.2	2778.3	0	19615
	SL2	24	697.6	2600.9	530.9	-400.7	1795.9	0	12728
	SL3	24	200.3	790.2	161.3	-133.4	534	0	3889
	SL4	24	1219.5	2651.5	541.2	99.9	2339.1	0	9192
	Total	96	802.4	2740.7	279.7	247	1357.7	0	19615
Dissolved oxygen (mg/l)	SL1	24	3	1.3	0.3	2.5	3.6	1.9	5.5
	SL2	24	2.5	0.8	0.2	2.1	2.8	1.6	4.4
	SL3	24	3.6	1.3	0.3	3.1	4.1	0	5.9
	SL4	24	4.6	2.2	0.4	3.6	5.5	2	7.9
	Total	96	3.4	1.7	0.2	3.1	3.7	0	7.9
Secchi depths (m)	SL1	24	1.7	0.7	0.2	1.4	2	0.2	2.6
	SL2	24	1.5	0.6	0.1	1.2	1.7	0.2	2.1
	SL3	24	1.1	0.5	0.1	0.9	1.3	0.2	1.8
	SL4	24	0.4	0.3	0.1	0.3	0.5	0	1
	Total	96	1.2	0.7	0.1	1	1.3	0	2.6
Temperature (Degree Celsius)	SL1	24	17.8	2.7	0.5	16.7	19	14.2	22.1
	SL2	24	17.3	2.5	0.5	16.2	18.4	14	21.3
	SL3	24	18.6	3.2	0.7	17.2	20	14.2	23.2
	SL4	24	19.5	4.1	0.8	17.8	21.3	13.4	25.4
	Total	96	18.3	3.3	0.3	17.7	19	13.4	25.4
Iron (mg/l)	SL1	24	0.4	0.8	0.2	0.1	0.8	0	3.4
	SL2	24	0.4	0.8	0.2	0.1	0.8	0	3
	SL3	24	0.9	1.8	0.4	0.2	1.7	0	6.6
	SL4	24	1.4	1.8	0.4	0.6	2.2	0.1	5.8

Parameters	SL	N	Mean	St deviation	St error	95% lower	95% upper	Maximum	Minimum
	Total	96	0.8	1.4	0.1	0.5	1.1	0	6.6
Manganese (mg/l)	SL1	24	0.2	0.3	0.1	0.1	0.3	0	1
	SL2	24	0.2	0.2	0	0.1	0.3	0	0.8
	SL3	24	0.1	0.2	0	0	0.2	0	0.7
	SL4	24	0.1	0	0	0.1	0.1	0	0.1
	Total	96	0.1	0.2	0	0.1	0.2	0	1
Ammonia (mg/l)	SL1	24	0.4	0.4	0.1	0.2	0.5	0	1.4
	SL2	24	0.3	0.3	0.1	0.2	0.4	0	1
	SL3	24	0.2	0.3	0.1	0.1	0.3	0	1
	SL4	24	0.1	0.1	0	0	0.1	0	0.3
	Total	96	0.2	0.3	0	0.2	0.3	0	1.4
Orthophosphate (mg/l)	SL1	24	0	0	0	0	0	0	0.1
	SL2	24	0	0	0	0	0	0	0.1
	SL3	24	0	0	0	0	0	0	0.1
	SL4	24	0	0	0	0	0	0	0.1
	Total	96	0	0	0	0	0	0	0.1

APPENDIX III

One way-ANOVA of the water quality parameters of the four sampling locations

		Sum of Squares	df	Mean Square	F	Sig.
Total phosphorus (mg/l)	Between Groups	0.097	3	0.032	2.895	0.039
	Within Groups	1.025	92	0.011		
	Total	1.122	95			
Total nitrogen (mg/l)	Between Groups	4.688	3	1.563	1.178	0.322
	Within Groups	122.042	92	1.327		
	Total	126.73	95			
Chlorophyll a (ug/l)	Between Groups	1462.902	3	487.634	4.687	0.004
	Within Groups	9572.038	92	104.044		
	Total	11034.94	95			
Dissolved Organic Carbon (mg/l)	Between Groups	1.095	3	0.365	0.535	0.659
	Within Groups	62.722	92	0.682		
	Total	63.817	95			
PH	Between Groups	0.349	3	0.116	0.693	0.558
	Within Groups	15.446	92	0.168		
	Total	15.795	95			
Turbidity (NTU)	Between Groups	63826.552	3	21275.517	4.74	0.004
	Within Groups	412952.91	92	4488.619		
	Total	476779.47	95			
Anabaena (number of cells count per ml)	Between Groups	57854007	3	19284669	0.617	0.605
	Within Groups	2.874E+09	92	31235976		

		Sum of Squares	df	Mean Square	F	Sig.
	Total	2.932E+09	95			
Microcystis (number of cells count per ml)	Between Groups	15153256	3	5051085.4	0.665	0.575
	Within Groups	698437530	92	7591712.3		
	Total	713590786	95			
Dissolved oxygen (mg/l)	Between Groups	56.854	3	18.951	8.634	0
	Within Groups	201.935	92	2.195		
	Total	258.788	95			
Secchi depths (m)	Between Groups	25.081	3	8.36	27.137	0
	Within Groups	28.343	92	0.308		
	Total	53.424	95			
Temperature (Degree Celsius)	Between Groups	68.575	3	22.858	2.233	0.09
	Within Groups	941.634	92	10.235		
	Total	1010.209	95			
Iron (mg/l)	Between Groups	16.04	3	5.347	2.79	0.045
	Within Groups	176.276	92	1.916		
	Total	192.316	95			
Manganese (mg/l)	Between Groups	0.229	3	0.076	1.96	0.125
	Within Groups	3.586	92	0.039		
	Total	3.815	95			
Ammonia (mg/l)	Between Groups	1.056	3	0.352	4.916	0.003
	Within Groups	6.588	92	0.072		
	Total	7.644	95			

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Orthophosphate (mg/l)	Between Groups	0	3	0	0.23	0.875
	Within Groups	0.028	92	0		
	Total	0.028	95			

APPENDEX IV

Correlation coefficient (*r*) between the three dams

Correlation coefficient (*r*) between the three dams

Iron	Von Bach Dam	Swakoppoort Dam	Omatako Dam
Von Bach Dam	1		
Swakoppoort Dam	0.4	1	
Omatako Dam	0.0	0.7	1
manganese	Von Bach Dam	Swakoppoort Dam	Omatako Dam
Von Bach Dam	1		
Swakoppoort Dam	0.9	1	
Omatako Dam	0.6	0.5	1
Ammonia	Von Bach Dam	Swakoppoort Dam	Omatako Dam
Von Bach Dam	1		
Swakoppoort Dam	0.2	1	
Omatako Dam	0.7	-0.2	1
Orthophosphate	Von Bach Dam	Swakoppoort Dam	Omatako Dam
Von Bach Dam	1		
Swakoppoort Dam	0.9	1	
Omatako Dam	0.7	0.9	1
DOC	Von Bach Dam	Swakoppoort Dam	Omatako Dam
Von Bach Dam	1		
Swakoppoort Dam	-0.3	1	
Omatako Dam	0.9	-0.7	1

APPENDIX V

Correlation coefficient (r)

Correlation coefficient (*r*) between SL4 water quality parameters and water volume from Omatako Dam

	Volume	**Ammonia**
Volume	1	
Ammonia	-0.3	1

	Orthophosphate	**Volume**
Orthophosphate	1	
Volume	0.6	1

	Manganese	**Volume**
Manganese	1	
Volume	0.0	1

	Volume	**Iron**
Volume	1	
Iron	0.9	1

	Volume	**Turbidity**
Volume	1	
Turbidity	0.7	1

Correlation coefficient (*r*) between SL1 turbidity and water volume from Swakoppoort Dam

	Volume	**Turbidity**
Volume	1	
Turbidity	0.7	1