IMPACT OF THE DABERAS SLIMES DAM IN SOUTHERN NAMIBIA ON THE WATER QUALITY OF THE ORANGE RIVER.

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DECLARATION

I declare that this research report is my own, unaided work with the exception of using previous data collected by the Safety Health and Environment officer at NAMDEB. This report is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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ABSTRACT

Daberas slimes dam has been seeping since 2004. As a result, seepage leachate could have been passing through a permeable layer of gravel from the slimes dam to an international river. This was a major concern especially from department of Water Affairs and the Ministry of Mines and Energy in Namibia. The main concern was the possible water contamination of the Orange River, which of course leads to the Orange River mouth, which is a Ramsar protected site and the other concern was that the trees along the riverbank section that is adjacent to the Daberas tailings dam were dying.

This study has however revealed that the seepage leachate from the Daberas slimes dam is actually reaching the Orange River. Given limited available results, a minor impact on the water quality of the river has been recorded. All parameters that were studied are well within the limit of excellent water quality, with respect to the current water guidelines in Namibia. Iron and manganese which are components of ferrosilicon which is used as Dense Medium Separation (DMS) material at Daberas remains well within the limit of excellent water quality as per Namibian water guidelines. Most interestingly, the latest sample analysis confirms that iron concentration in water is actually declining near the Daberas mine section, meaning that iron concentration is higher in the upstream section in the latest samples taken in July 2007.

The water quality in the Orange River section downstream of Daberas mine is A-rated, characterising water with excellent quality, as per Namibian water guidelines. Despite that, an effective integrated water management plan and concise water-monitoring plan is recommended for the Daberas mine.

Dedication

To my mother

Hertta Tuakulilua Ailonga

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List of abbreviations and acronyms

AMD, Acid Mine Drainage

at%, Atmospheric Percentage

DMS, Dense Medium Separation

FeSi, Ferrosilicon

NWGL, Namibia Water Guidelines Limit

ORM, Orange River Mines

TDS, Total Dissolved Solids

N.W.G.L , Namibia Water Guidelines Limit for the Excellent Water category A

GIS, Geographical Information Systems

SHE, Safety Health and Environment

SPSS, Statistical Package for the Social Sciences

CHAPTER 1

1.1 Problem

The death of riparian vegetation along the Orange River (also referred to as Gariep River, Groote River or Senqu River) section adjacent to the Daberas tailings dam has raised suspicion of water contamination. The water quality of the Orange River downstream of Daberas mine was suspected to be deteriorating and suspicion was directed to the seepage from the Daberas slimes dam into the Orange River. The impact of the Daberas slimes dam on the water quality of the Orange River was unknown at the time. Water quality monitoring was then done to determine if the Daberas slimes dam seepage has an impact on the water quality in the Orange River.

To determine the impact of Daberas slimes dam on the water quality of the Orange River, parameters that could be traced back to Daberas slimes dam were compared to downstream chemical values. However, contaminant load could not be modelled as the data used in this research is not sufficient to model the contaminant load from source to the receiving body .e.g no sediment samples were taken.

1.2 Key Question

Does the Daberas mine slimes dam pose an adverse threat to the quality of the water in the Orange River?

1.3 Aims & Objectives

This study serves to determine the water quality impact on the Orange River by the Daberas mine slimes dam seepage and to discuss the previous studies done at Daberas.

A desktop study of hydrological and geotechnical reports of consultants previously hired by Namdeb will be used to determine the impact of the Daberas slimes dam seepage on the water quality of the Orange River. They are as follows:

- Botha P. (2004), *Orange River Mines: Environmental recommendations,* Geo Pollution Technologies Namibia, Windhoek.

- Cooper R., (2004), *Daberas Fine Residue Deposit: Seepage below southern outer wall,* Ref: 9087, Jones & Wagener Consulting Civil Engineers, South Africa.

- Ellmies R., Shipapo M, Iyambo J. Katjimune M, Beukes H, Kulobone N, Mufenda M, and Amkongo A.,(2006), *Impact of Daberas mine on the vegetation on the banks of Orange River, Environmental monitoring series no 2*, Ministry of mines and Energy, Namibia, March 2006.

- Braam A.F. (2004), Geotechnical Risk Review, Part II: Seepage from the new Daberas Tailings Dam, Geotec Africa cc Consultants, Namibia.

1.4 Justification of study

Pollutants monitoring is part of the environmental management system and forms basis of decision making and ultimately finding management strategies. Monitoring was directed towards surface waters in close proximity to the Daberas slimes dam (Ntengwe and Maseka, 2006).

The Orange River is an international water body that runs through various countries (Lesotho, South Africa, Botswana and Namibia). The Orange River mouth site is considered as a Ramsar site, and it is jointly managed by South Africa and Namibia (http:// www.met.gov.na/dea/international/conventions/ wetlands.htm).

It includes sensitive wetlands that harbour 57 wetland bird species of which 14 are considered either to be rare or endangered. The Ramsar site also supports 33 mammal species and the Namaqua barb, a red data species fish found only in the lower Orange River (http://www.waterinformation.co.za/misc/Wetlands /defaultorangemouth.htm)

The main Namibian and international legal statutes that cover legal aspects relating to deterioration of the water quality due to seepage from the Daberas slimes are as follows:

Namibian statutes:

- *Water Resources Management Act No. 24 of 2004 (Namibia)* - This Act concerns the management, development, protection, conservation and use of water resources.
- *Environmental Management Act No. 7 of 2007 (Namibia)* - aims to promote the sustainable management of the environment and the use of natural resources by establishing principles for decision making on matters affecting the environment
- *Minerals (Prospecting & Mining) Act No.33 of 1992 (Namibia)* - States that the course of any mining operations or any prospecting operations which may be carried on in lieu of' such mining operations appropriate measures will be taken to minimize or prevent any pollution of the environment.
- *Environmental Assessment Policy, 1996 (Namibia)* - This policy places high priority on maintaining ecosystems and related ecological processes, in particular those important for water supply, food production, health, tourism and sustainable development.

Other water related policies that may apply to pollution of water in Namibia are as follows (Hetherington, 2007):

- *Water and Sanitation Policy* - Promotes water conservation
- *Integrated Water Resource Management and Water Demand Management Policy* - Promotes water resources management

International conventions:

- *Convention on Biological Diversity of 1992* - Promotes the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings
- *The Ramsar Convention on Wetlands of 1971*, which Namibia signed in 1995 - The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. The Orange River mouth is regarded as a Ramsar site.

The principal authorities administering these Acts, Conventions and water-related policies in Namibia are the Department of Water Affairs (Ministry of Agriculture, Water and Forestry), Ministry of Mines and Energy and the Ministry of Environment and Tourism. Legal compliance is compulsory and can be expedited by keeping an up-to date legal register, gazettes and standards and complying with them.

Namibia and South Africa share the lower Orange River basin. These two countries jointly manage the water resources of the Orange River under the Orange-Senqu River Commission Agreement, which was established on the 3rd November 2000 (Turton, 2005).

1.5 Profile of the Daberas mine operation

Daberas mine is an open pit diamond mine that mines shallow alluvial diamonds along the Orange River in Namibia. The mine draws water from Orange River for its operation, and it supplements it with groundwater found in the mining areas. Namdeb has not done any rehabilitation of mined out areas, but have a rehabilitation plan in place that will need to be carried out.

Daberas mine is one of the Orange River Mines (ORM) that is within the diamond-licensed area; Namdeb Diamond Corporation (Pty) Ltd (Namdeb) operates this mine. The diamond-bearing gravels found in this area are extracted by means of dense medium separation (DMS) to reclaim alluvial diamonds, and ferrosilicon (FeSi) is used as the DMS material. The composition of FeSi was determined to be Fe (76.1 %), Si (20.3 %), Mn (1.5 %), Al (1.5 %) and Cr (0.6 %) (Waanders and Rabatho, 2005).

Ferrosilicon was reclaimed from the process during the operation, this was achieved by using magnetic separators and it was then recycled. However, FeSi can be lost as a result of attrition, adhesion to the separation products, density changes and changes to the magnetic properties, leaving some FeSi in the tailings (Waanders and Rabatho, 2005). No other chemicals are used in the process other than flocculants.

The mine had to build a slimes dam where fines were disposed. The Daberas slimes dam was commissioned in August 2003 and seepage was noticed on the southern outer wall in January 2004 (Cooper, 2004). The slimes dam was constructed as an impoundment. The outer wall is an engineered wall consisting of 95% compacted selected overburden material. A cut-off wall was provided below the outer wall to reduce the potential for seepage below the wall. A filter drain is provided at the upstream toe of the wall to control the phreatic level within the residue adjacent to the wall. Residue is deposited using spray bars in order to ensure a free draining zone above the filter drain (Cooper, 2004).

The depth slimes dam floor was specified to bedrock. The backfill to the dam floor consisted of compacted selected clay from the mine pit. A portion of the southern wall is located over an ancient riverbed and the depth to bedrock is in order of 10 m. A 1.5 m thick clay layer is located at approximately 1.5 m below surface. A portion of the slimes dam was not excavated to bedrock, instead excavation took place at the base of the key to 2 m. (See appendix D for the detailed design).

In spite of all the engineering and technical input, the modifications did not meet the requirements. The slimes dam started leaking four months after it was commissioned.

1.6 Description of the Area

1.6.1 Orange River Basin

The Orange River Basin has a total catchment of approximately 1 000 000 km^2, of which 600 000 km^2 is in South Africa and the rest in Namibia, Lesotho and Botswana (http://www.dwaf.gov.za/orange/intro.htm). The Orange River originates in the Lesotho Highlands and it stretches for 2300 km to the mouth at Alexander Bay (http://www.dwaf.gov.za/orange/intro.htm). The Orange River has three main storage reservoirs, which are the Gariep Dam and Vanderkloof Dam in South Africa and the Katse Dam in Lesotho (http://www.dwaf.gov.za/orange/intro.htm). No storage reservoirs are present in Namibia.

1.6.2 Climate, Rainfall and Temperature

The study area is located in the succulent Karoo biome. Rainfall at Oranjemund, located west of the project area, averages 51 mm per annum. Monthly rainfall data of Alexander Bay (approximately 75 km from the Daberas mine) is presented in Figure 12, Springbok's rainfall data was used because it is the closest weather station to the study site. The weather at Alexander Bay is not the same as that at Daberas mine.

Temperatures in the Orange River valley can be high, with an average daily maximum of 33 °C for the hottest month and frosts are uncommon (Burke, 2002). Coastal fog often protrudes inland along the Orange River and provides an important moisture source for plants and animals inhabiting slopes and gullies facing the river (Burke, 2002). Steady and strong southwesterly winds occur throughout the year, while northeasterly, warm "bergwinds" occur during the winter months (Burke, 2002).

1.6.3 Geology and hydrogeology

This section presents the geology and hydrogeology of the Daberas mine surroundings. Figure 1 shows a water filled sinkhole in Zone 8 at Daberas mine. Figure 2 and 3 indicates groundwater potential for southern Namibia, including the Daberas mine. The Daberas mine is situated in the area with low potential primary aquifers with some patches falling in the low-medium potential primary aquifers (Carr and Louw, 2000).

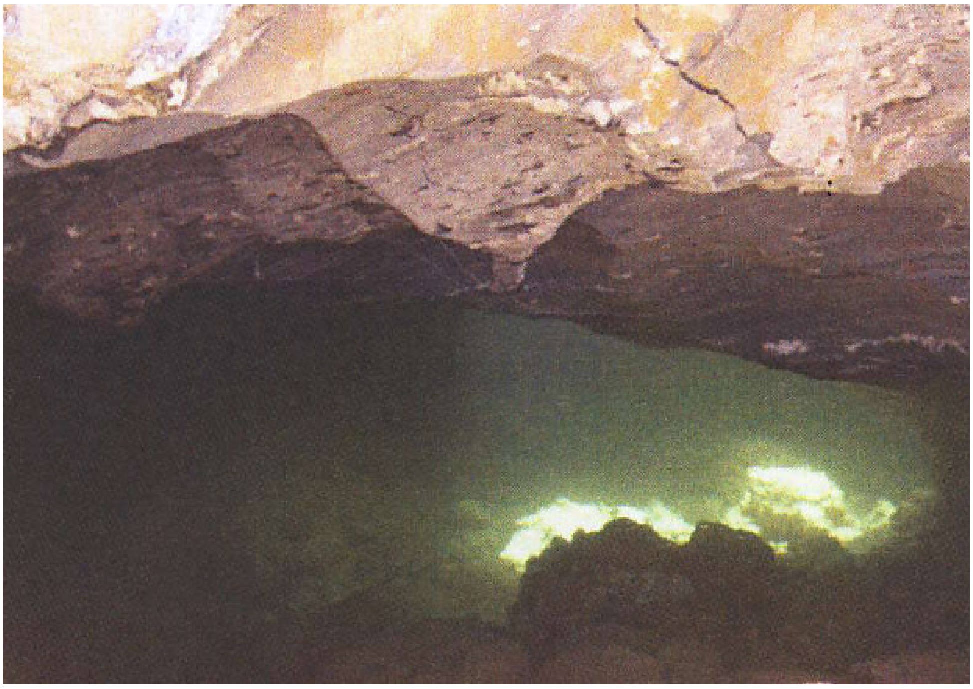

Figure 1: Dolomitic water filled cavity in Zone 8 at Daberas mine

Fountains/seeps are found north of the tailings dam, with another further north in the Obib dunes (Carr and Louw, 2000). The Daberas slimes dam is sandwiched by two low potential aquifers, with the Schakalberg on the west and the Obibberge on the east, near Sendelingsdrift (Carr and Louw, 2000). Deducing from Figure 2 the aquifers in the Daberas area are well developed.

The study area falls under the Gariep belt or complex that stretches over Namibia and South Africa. The Gariep belt makes up the immediate environs of the Daberas mine, characterised by lenticular bodies of meta-sediment with dolomite, shale, schist, green schist, ortho-/para-amphibolite, quartzite, intraformational and basal mixtite, grit, which belongs to the Namibian geological age (Botha, 2004). The raised river terraces along the Lower Orange River consist of gravel deposits that have formed between Late Tertiary and Quaternary times. These fluvial sequences lie across the regional strike of the country rocks on the Hilda formation of the Precambrian Gariep Group (Enkara, 2004). Figure 3 indicates the bedrock type of the immediate environs of the Daberas slimes dam.

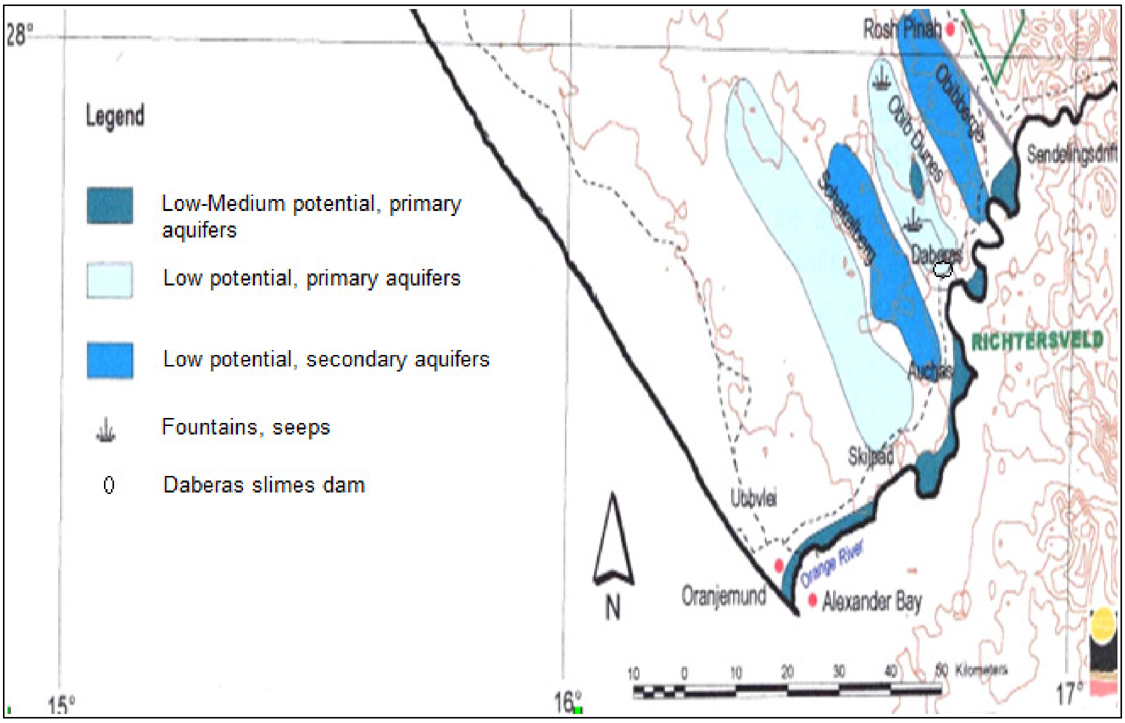

Figure 2: Groundwater potential (Modified from Carr and Louw, 2000)

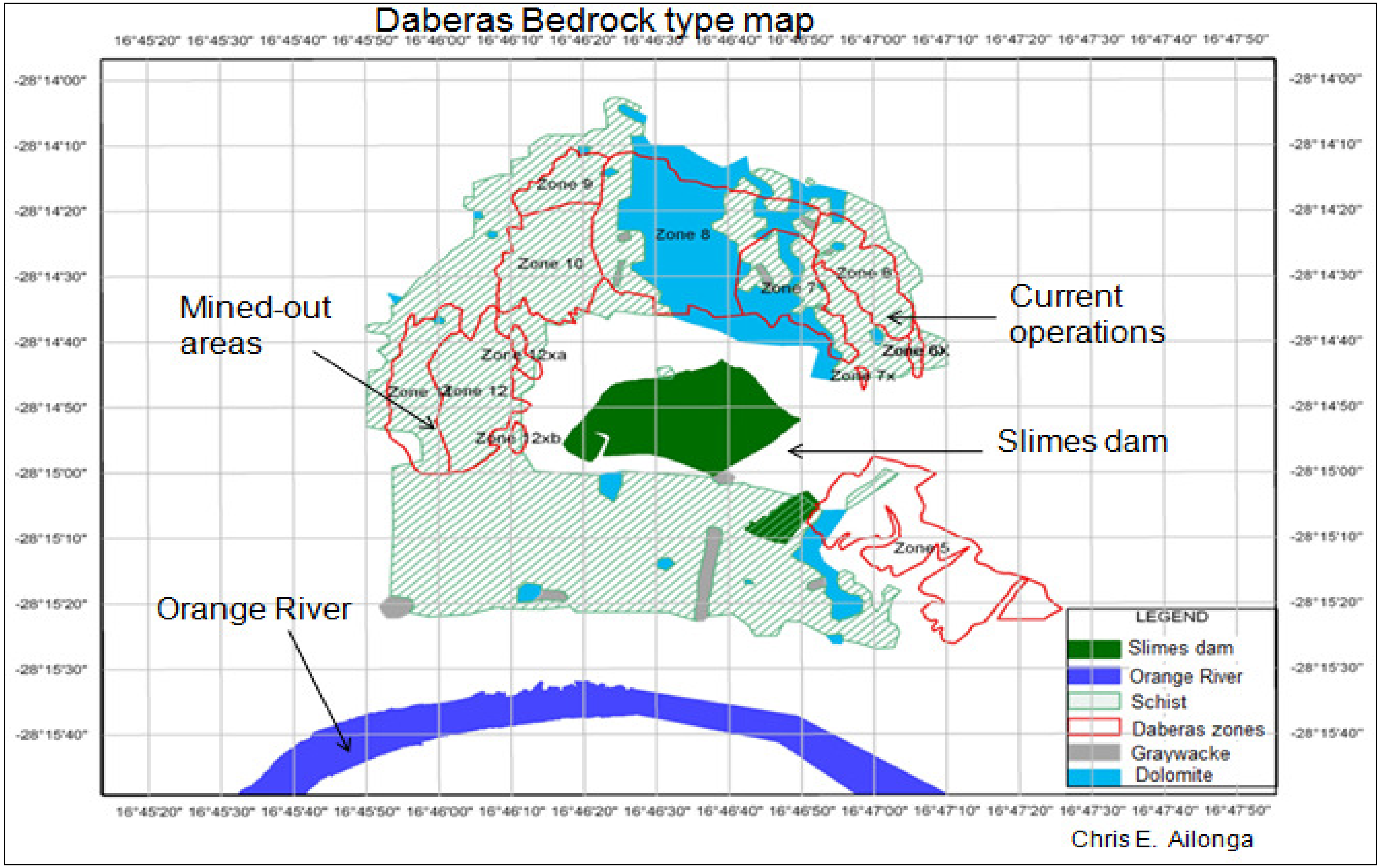

Figure 3: The bedrock type of the immediate environs of the Daberas slimes dam and the Orange River.

1.6.4 Mining along the Lower Orange River basin

There are several mines along the Orange River in Southern Namibia and the North-western South Africa. There are three mines in Namibia that are close to the Orange River: Scorpion Zinc mine, Rosh Pinah Zinc mine and Namdeb diamond mines (including the Daberas mine, Auchas mine, Elizabeth Bay mine, Mining Area 1, Pocket Beaches, and Bogenfels). The Baken and the Oena mines are mining alluvial diamonds on the South African side. Dense medium separation is used by all these mines, utilising FeSi as DMS material. All the mines along the Orange River draw water from it to sustain their operations (Lange *et al*, 2007). Figure 4 indicates the location of diamond mines along the Orange River, in Namibia and South Africa.

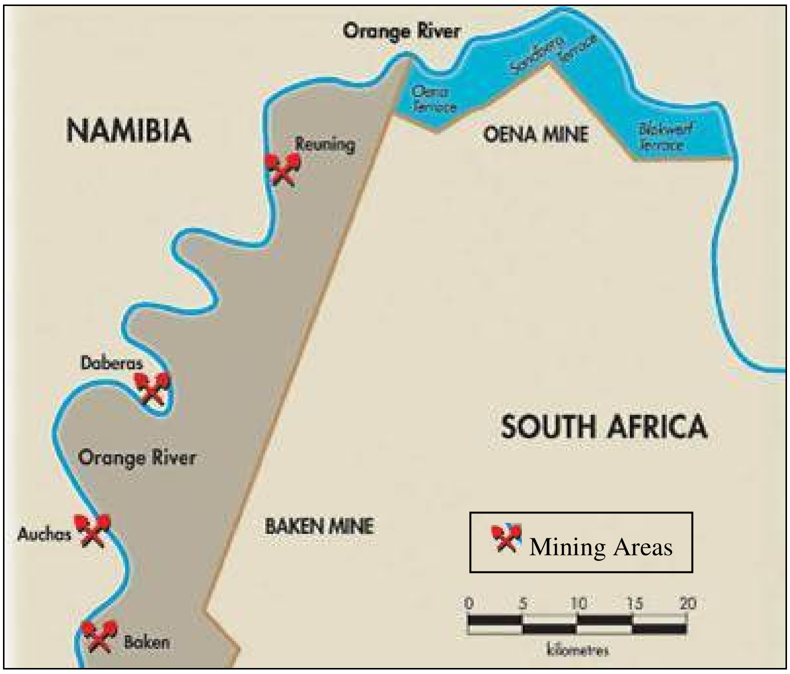

Figure 4: Diamond mines along Orange River (http://www.firestonediamonds.com/oena)

According to Lange *et al.* (2007) South Africa uses most of the water in the Orange River Basin, amounting to 77 % in the upper Orange River Basin and 20 % in the Lower Orange River Basin, whereas Botswana, Lesotho and Namibia uses <1 %, 1 % and 2 % respectively. Mining accounts for 7 % of the whole water supply in Namibia (Lange *et al.,* 2007).

1.6.5 Population and agriculture along the Lower Orange River basin

The Lower Orange River Basin runs through arid land, which is sparsely populated both in Namibia and Botswana, as low as 163 903 and 47 661 people respectively (Hall and Jennings, 2007). The only residential towns in the area are those that were developed as mining villages or towns. The Lower Orange River basin serves to supply irrigation water to farms along the Orange River on both the Namibian and the South African side. Many farms along the Orange River are involved in grape farming and a lot of fertilisers are used to enhance production, therefore possibly increasing the risk of impacting the water quality of the Orange River e.g. runoffs from the vineyards would consist of high phosphates, nitrates and potassium (Van Vuuren, 2006).

CHAPTER 2

LITERATURE REVIEW

2.1 Environmental impacts from diamond mining

Diamond mining uses water, rather than chemicals, for extraction, but of course, water is scarce in many parts of Africa, where diamond mining companies often operate (http://www.diamondfacts.org/pdfs/media/media_resources/fact_sheets/Diamond_Mining_Environment_Fact_Sheet.pdf). This makes it even more important that the diamond mining process does not pollute natural water sources and that it uses as little as possible (http://www.diamondfacts.org/pdfs/media/media_resources/fact_sheets/Diamond_Mining_Environment_Fact_Sheet.pdf).

Diamond mining impacts the environment in many ways. Alluvial diamond mining is known to affect water quality (Gordon, 2008). Many rivers are diverted so that mines can be exposed and, although they can be returned to their natural state, they typically are left how they are. To do this, canals are created and short sections of the river are dammed (Gordon, 2008). Soil deposits are also affecting the water quality as the land is being unearthed (http://en.wikipedia.org/wiki/Mining_industry_of_Angola#cite_note-10).

According to Meeuwis (2006), water pollution, biodiversity depletion, and waste generation are the main environmental problems encountered by diamond mines, mostly artisanal miners.

A typical example would be mining in Congo River headstreams in Katanga Province, via Congo River starting point in Kisangani (Eastern Province), to the Atlantic Ocean in Bas-Congo Province (Kirongozi, 2003). The majority of Congolese Mines are connected to Congo River waters (Kirongozi, 2003). Regarding Gold and Diamond, almost all mines are located along Congo River and its streams, rivers and terraces (Kirongozi, 2003). Any spill or disposal of any pollutant could end up in the Congo River. The major environmental impacts caused by mining activities into Congo River are water pollution and the degradation of riverbanks (Kirongozi, 2003).

2.2 Water quality

Water quality is referred to as the measure of the suitability of the water for a particular use based on selected physical, chemical and biological characteristics (Cordy, 2001). According to Chapman (1996), water quality is defined as the overall quality of the aquatic environment, which describes the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses.

The quality of water is determined by analyzing the characteristics of water e.g. pH, number of bacteria, temperature and dissolved salts. Selected characteristics of interest are then compared to numerical standards and guidelines to determine if the water is suitable for a particular use (Cordy, 2001). Water standards and guidelines are there to protect the water for designated use such as drinking, recreation, irrigation and ecosystem maintenance (Cordy, 2001). Natural water quality varies from place to place, depending on the climate, season, rock and soil type in which the water moves (Cordy, 2001).

Chemical aspects of water- The health concerns associated with chemical constituents of drinking-water differ from those associated with microbial contamination and arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure (WHO, 2006). There are few chemical constituents of water that can lead to health problems resulting from a single exposure, except through massive accidental contamination of a drinking-water supply (WHO, 2006). Exposure of humans to some chemical constituents like manganese can have long term effects on their health e.g. iron deficiency anaemia and kidney failure. Concentrations of some chemicals could be increased collectively in all the countries that are within the Orange River Basin, and since Namibia is on the lower end of Orange River, most pollutants are likely to accumulate in the wetlands near the river mouth.

2.2.1 Global water quality

Access to safe drinking water is essential to health, a basic human right and a component of effective human health protection (WHO, 2006). The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums (WHO, 2006). Access to safe drinking water is important as a health and development issue at a national, regional and local level (WHO, 2006). In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions to properly manage water sources and prevent contamination (WHO, 2006).

The WHO guidelines for drinking-water quality explains requirements to ensure drinking-water safety, including minimum procedures and specific guideline values, and how those requirements are used (WHO, 2006). The report also describes the approaches used in deriving the guidelines, including guideline values (WHO, 2006). It includes fact sheets on significant microbial and chemical hazards, which describes acceptable and critical levels of chemical concentrations and microbes in drinking water (WHO, 2006).

The latest edition of WHO Guidelines for drinking-water quality incorporates and addresses the following components which were not addressed in previous editions (WHO, 2006): Microbial safety, revision of many chemicals that were not considered previously and consideration of stakeholders in drinking water safety and the recognition of few chemicals that can cause large scale health effects through contaminated water.

The guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers and/or derive numerical “guideline values” for constituents of water or indicators of water quality (WHO, 2006). In order to define mandatory limits, it is preferable to consider the guidelines in the context of local or national environmental, social, economic and cultural conditions (WHO, 2006). The guidelines provide a scientific point of departure for national authorities to develop drinking water regulations and standards appropriate for their national situation (WHO, 2006).

The nature and form of drinking-water standards may vary among countries and regions. There is no single approach that is universally applicable (WHO, 2006). Typically, comparing a water sample against drinking water quality guidelines or standards assesses drinking water quality. Used rigorously, drinking water quality guidelines and standards can provide for the protection and promotion of human health (Aggarwal et *al*: 2005). It is essential in the development and implementation of standards that the current and planned legislation relating to water, health and local government are taken into account and that the capacity to develop and implement regulations is assessed (WHO, 2006). Approaches that may work in one country or region will not necessarily transfer to other countries or regions (WHO, 2006). Although the guidelines describe a quality of water that is acceptable for lifelong consumption, the establishment of these guidelines, including guideline values, should not be regarded as implying that the quality of drinking water may be degraded to the recommended level (WHO, 2006). The same principle applies to mining companies as well, whereby it is unacceptable to dispose or release pollutants into natural environment in spite of being within recommended levels.

2.2.2 Water quality in Southern Africa

This section covers general water quality and management in countries within southern Africa. Water is generally a scarce resource in southern Africa. A few countries like Zambia have abundant water resources but are facing problems of proper distribution and management. Generally natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves (http://www.dwaf.gov.za/Dir_WQM/wqm.htm).

South Africa. South Africa is very rich in mineral resources ranging from gold, platinum and diamonds etc but the same cannot be said for water resources. South Africa's average rainfall is 500 mm a year, with the western part of the country receiving 200 mm a year; it is thus regarded as a semi-arid country (http://www.wrc.org.za/downloads/education/Water%20in%20SA.pdf).

In South Africa, most water is used for agriculture and irrigation (52 %), forestry (4 %), industry (4 %), and domestic use (10 %) whereas about 19 % of water is protected for the survival of the environment (http://www.wrc.org.za/downloads/education/Water%20in%20SA.pdf). Most of the water consumed by South Africa is tapped from Lesotho or directly from the Orange River. The Gauteng province is densely populated with high water consumption, whereas the Northern Cape region has vineyards along the Orange River which consumes river water. Vineyards are also present on the Namibian side of the Orange River.

The Department of Water and Environmental Affairs (DWEA) is the regulating body that enforces the water-related legislation to protect the water and maintains the acceptable water quality and regulates the 'polluter pay practice' (http://www.dwaf.gov.za/Dir_WQM/wqm.htm). The legal statutes protecting water resources and managing water related pollution are highlighted in Appendix A.

Botswana. Botswana is a land locked country bordered by Namibia, South Africa, Zambia and Zimbabwe. The climate is arid and semi-arid, with low rainfall and high evapotranspiration rates (Matlock, 2008). The average annual rainfall of Botswana is 416 mm, ranging from 650 mm in the north to 250 mm in the southwest of the country (Matlock, 2008). Rural areas depend heavily on groundwater resources and supplemented by water from dams, rivers and other surface water sites (Matlock, 2008).

Botswana has five major drainage basins which are as follows (Matlock, 2008):

- The Limpopo basin occupies about 14% of the country in the east;
- The Orange basin occupies about 12% in the south;
- The Zambezi basin occupies a small area (2%) in the north;
- The Okavango basin occupies about 9% in the northwest;
- The South Interior basin occupies the remaining area (about 63%) and includes the Kalahari Desert and the Makgadikgadi Pans.

Botswana's economy is not agricultural based, it is heavily dependent on mining, specifically diamond mining. Kimberlite diamonds in Botswana are processed using dense medium separation, and using ferrosilicon as the medium.

Mining accounts for 11% of water use in Botswana (Lange *et al*, 2007). Botswana manages its water resources and quality very well, and they have policies and regulations that govern water in Botswana. Botswana's management goals are to reserve sufficient water to maintain natural ecosystems, avoiding groundwater depletion and minimising water pollution (Arntzen *et al*, 2000). Activities such as mining that could impact the water resources and its quality are managed and regulated accordingly.

Zambia. Water availability in Zambia is not a problem, but efficient water supply and distribution has not been implemented (Sievers, 2006). The Government of the Republic of Zambia has recognised the following issues as serious drawbacks and challenges and launched a process, which consists of institutional, legal and regulatory reform of the Water Resource Management sub-sector (Sievers, 2006).

Most of the copper mines in Zambia are sited on top of large sources of groundwater, and these mines use the groundwater for their mining operations (Luanga, 2008). Very few mines in Zambia draw water from rivers for mining operations (Luanga, 2008). Mining related effluent has entered the waterways of the Copperbelt for the past 70 years, resulting in extensive environmental impacts detected as far downstream as the Kafue

Hook Bridge, 700km from the mining area (Bäckström and Jonsson, 1996). The Orange River is not impacted in any way by mines in Zambia,

The government of Zambia faces challenges of poor and inadequate infrastructure and systems for management of water resources, lack of funds and funding mechanisms generally to sustain the activities of water resources management, lack of an integrated approach to water resources management, inadequate institutional and legal framework and lack of regulation of groundwater (Sievers, 2006).

2.2.3 Water quality in Namibia

Namibia receives average rainfall of 400 mm a year, making Namibia an arid country (Lange and Hassan, 2006). In the past, mining was the cornerstone of the Namibian economy, producing 41% of GDP in 1980 (Blackie and Tarr, 1999). Due to growth in other sectors this has declined to below 20% during the 1990s (Blackie and Tarr, 1999). The main mining areas of the country are in the south and west where diamonds and uranium are the major contributors (Blackie and Tarr, 1999).

Namibia used the Water Act No. 54 of 1956 until the introduction of the Water Resources Management Act No. 24 of 2004 in 2004 (Blackie and Tarr, 1999), which is therefore the current applicable legislation that governs water management in the country (Water Resources Management Act No. 24 of 2004). Ownership of water resources in Namibia below and above the surface of the land belongs to the State, and the same applies in South Africa, Botswana and Zambia (Water Resources Management Act No. 24 of 2004).

The main objective of the Water Resources Management Act No 24 of 2004 is to ensure that Namibia's water resources are managed, developed, protected, conserved and used in ways that are consistent with or conducive to the following fundamental principles (Water Resources Management Act No. 24 of 2004):

- Harmonisation of human needs with environmental ecosystems and the species that depend upon them, while recognising that those ecosystems must be protected to the maximum extent;
- Integrated planning and management of surface and underground water resources, in ways which incorporate the planning process, economic, environmental and social dimensions;
- Management of water resources so as to promote sustainable development; and
- Prevention of water pollution, and the polluter's duty of care.
- Promoting respect for Namibia's rights with regard to internationally shared water resources and, in particular, to the abstraction of water for beneficial use and the discharge of polluting effluents.

2.2.4 Water quality of the Orange River

Based on baseline studies done for Namdeb Diamond Corporation (Pty) Ltd by O'Keeffe et al (1994), the water quality in the Orange River was suitable for all uses, with low salinity and nutrient concentrations, relatively high dissolved oxygen, and high turbidity, as would be expected in the downstream reaches of a large river (O'Keeffe *et al*, 1994).

The Orange River section of concern at Daberas mine is located between the Sendelingsdrif and Arisdrif section of the Orange River. The baseline studies done by O'Keeffe *et al* (1994) reveal that salinity from Sendelingsdrif to Arisdrif is generally low (around 30 mS/m) with only rare occurrences of medium salt concentrations (>50 mS/m). Nutrient concentrations are similarly low, as might be expected in a desert environment. The water was generally neutral to alkaline and therefore it was well buffered against changes in pH, which in most cases when polluted turns acidic (O'Keeffe *et al*, 1994).

The baseline report further emphasised that water quality may deteriorate locally during periods of low flow in terms of salinity, some metals and dissolved oxygen, and that seepage from Auchas diamond mine (downstream of Daberas mine, now abandoned) may have contributed to that deterioration. It was assumed that the tailings seepage leachate from

Auchas mine contaminated the river water with tailings containing FeSi (O'Keeffe *et al*, 1994).

It is reported that high water tables and salinisation have been a problem in irrigated areas along the Orange River in the northern Cape and southern Namibia since 1948 (Van Vuuren, 2006). The Lower Orange River water is located in an arid region characterised by high evaporation losses and low or limited rainfall (Van Vuuren, 2006). The presence of high water tables promotes salinisation of these soils under conditions of high evaporative demand that are typical for the Lower Orange River region (Van Vuuren, 2006). Previous water quality investigations showed that the water quality of the Lower Orange River between Boegoeberg and Onseepkans was still good, with limited potential for salinity and sodicity problems (Van Vuuren, 2006). The potential for salinity problems increased from Onseepkans to Alexander Bay where the water quality was influenced by tidal flows (Van Vuuren, 2006). According to Coleman and Van Niekerk (2007) the water quality of the Lower Orange River is affected by upstream activities in the Vaal and Orange River Catchments.

Due to an inefficient integrated Orange River basin management with co-operation of all stakeholder countries, it is likely that countries will have different approaches to managing the water resources in the Orange River basin. Due to the Highlands water scheme in Lesotho, periods of no flow are likely to be expected and isolated pools will become important refuge areas and will be extremely vulnerable to the effects of seepage from the slimes dam (Pallett, 1995). Coupled with local droughts in the area the situation can become worse (Pallett, 1995). However, this did not happen over 15 years.

Salinity tends to be low if the flow is high and vice versa (Van Vuuren, 2006). Volschenk *et al* (2005) confirmed that water quality and quantity are interrelated and need to be tackled jointly in an integrated water resource management. There is limited continuous monitoring of water quality in the Orange River Basin and lack of information on discharge volumes, quality and quantities from sewage treatment works, mines and industries (Coleman and Van Niekerk, 2007). Attempts have been made in the to install electrical conductivity probes and data logging systems at key points in the system but theft and vandalism has limited the life of the installations and precluded extensive use of these systems (Coleman and Van Niekerk, 2007).

2.3 Tailings storage facilities

In order to obtain the gem stones needed for jewellery, large quantities of rock or earth are mined, crushed and processed to recover the gem diamonds. In the process, enormous quantity of fine-grained waste called tailings or slimes are produced (U.S. Environmental Protection Agency, 1994).

Tailings consist of ground rock and process effluents that are generated in a mine processing plant. They are waste products that provide no financial gain to a mineral operator at that point in time (http://www.tailings.info/tailings.htm). Tailings storage is essentially a concentration process as evaporation and precipitation occurs. Tailings are different from most naturally occurring soils, because their density is initially low and increase relatively slowly with time (Jewell, 1998).

A dewatering process is often used to thicken the tailings to a consistency at which they can be pumped to the tailings storage facility (Jewell, 1998). However, the metallurgical treatment process also has a direct bearing on the nature of the tailings and other effluents (Digby Wells and Associates, 2008). The treatment process determines the characteristics of the tailings, e.g. water content in tailings.

The unrecoverable and uneconomic metals, minerals, chemicals, organics and process water are discharged, normally as slurry, to a final storage area commonly known as a tailings management facility (TMF), tailings storage facility (TSF) (http://www.tailings.info/tailings.htm) or impoundment. The ultimate purpose of a tailings impoundment is to contain fine-grained tailings, often with a secondary or co-purpose of conserving water for use in the mine and mill (U.S. Environmental Protection Agency, 1994). The outer walls of tailings storage facilities are normally built out of material consisting of natural soils, mine overburden, other mine waste or tailings from pre-existing tailings deposits (Blight, 1998). The Daberas slimes dam walls are built with overburden soil.

A study done by Ntengwe and Maseka (2006) concluded that effluent from mining operations was a danger to the surrounding environment dependent on streams and rivers. They further stressed that discharge from Tailings dam 6 that belongs Chimbishi Metals Plc has contaminated the water in Chimbishi and Mwambashi streams in Zambia with nickel and zinc (Ntengwe and Maseka, 2006). Water downstream of Tailings dam 6 was found to be polluted with zinc and nickel, and the number of fish and plankton downstream of the tailings dam decreased as well (Ntengwe and Maseka, 2006). This is a clear sign of the effect of the pollution of the river with heavy metals.

Historically, tailings around the world were disposed of where convenient and most cost-effective, often in flowing water or directly into drainage systems (U.S. Environmental Protection Agency, 1994). As concerns over water quality and sedimentation arose, mining companies started impounding tailings behind earthen dams, which were often constructed out of tailings and other waste materials (U.S. Environmental Protection Agency, 1994).

Tailings dams built with tailings or mine waste are unstable, as they are likely to seep or fail because tailings particles are so fine that they cannot withstand heavy rain, wind or continual seepage.Past tailings storage dam failures have claimed lives and may have caused considerable environmental damage (Balkau, 1998). In the Mazowe District of Zimbabwe, sulphate contaminated (Acid Mine Drainage) water seeped from the Iron Duke iron mine's evaporation ponds and waste rock dump. This polluted the nearby Yellow Jacket River, with recorded elevated levels of sulphate, conductivity and total dissolved solids and a decrease in pH. This situation liberated immobile metals from the soil and caused AMD polluting the Yellow Jacket River (Nyamadzawo *et al*, 2007).

Due to increased demand for minerals, it has become economical to mine large lower-grade deposits by utilizing advances made by mining equipment manufacturers and developments in mining and milling technology (U.S. Environmental Protection Agency, 1994). This has greatly increased the amount of tailings and other wastes generated by individual mining projects and by the mining industry as a whole (U.S. Environmental Protection Agency, 1994).

Climatic and operating conditions of tailings storage facilities are of great importance, as they may cause tailings storage systems to generate either a water surplus or deficit. In the case of a surplus, excess water must be discharged periodically into an adjacent water body (river, lake or sea) or reused (Blight, 1998). The discharge must meet acceptable quality standards and, in many cases, must be treated to remove deleterious or toxic substances (Blight, 1998). Figure 5 shows an example of typical Tailings Storage Facility. The Clemows Valley tailings dam is vegetated on the walls to reduce erosion of the dam by water and wind.

Figure 5: A typical tailings storage facility, Clemows Valley Tailings Dam
(http://www.cantabkent.co.uk/projectphotos/image_clemows.jpg)

Tailings dams are designed to have a number of functions (Environment Canada, 1987), namely.

- Removal of suspended solids by sedimentation, whereby solids are allowed to settle in the tailings dam.
- Permanent containment of settled tailings, whereby tailings are stored in the dam permanently.
- Stabilisation of wastewater quality, whereby water is stabilized and stored in the dam.

- Stabilisation of some oxidizable constituents (e.g., thiosalts, cyanides, flotation reagents) by neutralizing them.
- Storage waste water that can be decanted and reused or recycled.

Tailings storage facilities have a number of disadvantages that may require attention during the design phase. Achieving good tailings flow distribution and segregating drainage from uncontaminated areas is very important on tailings dams, thus it needs careful consideration (Environment Canada, 1987). Tailings dams should be designed in such a way to cater for treatment of seepage and to withstand wind dispersion of fine materials e.g. by re-vegetation of tailings dam walls or rock cover (Environment Canada, 1987).

Releases of supernatant water from a tailings storage facility, whether in normal operations or as the result of failure or seepage, have the ability to change the quality of the receiving waters to which they flow (Balkau, 1998). Most of the tailings storage facilities seep at some point, and this may have a deteriorating impact on the water quality of surface and groundwater in the vicinity (Balkau, 1998).

Tailings dam stability is a major issue in tailings storage facility management, if poor designs of the tailings dam leads to catastrophic failure the contents may impact water quality, waterways, wildlife, natural ecosystems and people (Bruce, 1998). Some recent examples of tailings dam failures in the world include: Merriespruit in South Africa (1994), Omai in Guyana (1995), Marcopper in Philippines (1996) and Los Frailes in Spain (1998) (Bruce, 1998). The environmental and socio-economic impacts caused by failures of tailings dams have prompted people to start questioning the design and stability of tailings dams (Bruce, 1998). The following figure 6 illustrates the number of dam failures around the world. This figure shows that there were more tailings dam failures than water supply dam failures in recent years. Such statistics highlights the need to manage tailings dam better these days.

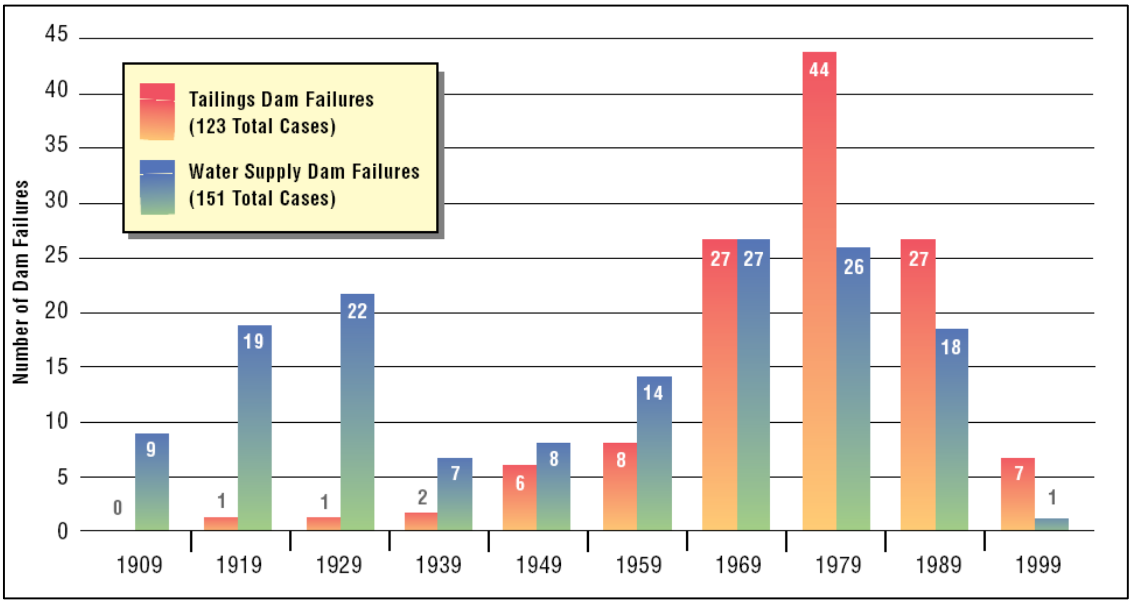

Figure 6: The number of dam failures around the world between 1909 and 1999 (Bruce, 1998).

According to Bruce (1998), the existence of undocumented tailings dams could explain the low number of tailings dam failures in the 1940s. The rise in the number of dam failures in the 1950s to 1960s (see Figure 6) might have been caused by the increasing size and weight of earthmoving equipment used in the mining industry, that led to an increase in production which led to the development of larger tailings dams (Bruce, 1998).

The major causes of tailings dam failures all over the world are reported to be as follows; seepage/piping whereby contaminated water from the tailings dam seepage through the walls of the dam, ultimately eroding the walls and this may result in a failure of the dam (Benito *et al*, 2007). The bad designs of tailings dam are also known to have caused failures of the dams, which may be related to dam foundation failure, slope instability, seismic movements or structural failure (Benito *et al*, 2007). Unusual weather patterns have also contributed to the failure of tailings dams, e.g. unusual high rainfall and snow melt could increase the water in the dam and ultimately putting too much pressure on the dam walls and causing it fail (Benito *et al*, 2007). General poor management of tailings dams has also caused tailings dam failures in the past e.g. failure to manage and account for all the water on site. The peak in the failure of tailings in the 1960's and 1970's are proportional to the increase in mining activities in during this period.

The common methods used to control seepage are cut-off trenches, grout curtains, sheet-pile walls and other thin cut-offs, impermeable upstream blankets, thin sloping membranes and reducing the amount of water discharged and stored on tailings storage facilities (Simons and Simons, 1998). Other measures taken to control seepage from tailings storage facilities are methods that primarily aim at controlling water that enters the facility; they are embankment zoning, longitudinal drains and blankets, chimney drains extending upward into embankments, partially penetrating toe drains and relief wells (Cedergren, 1977).

The main problem that is always linked to tailings storage facilities is water management. The more water there is on top of the tailings, the more likely it is to increase the chances of seepage through the walls (Cedergren, 1977). Some measures that may be implemented to reduce the amount of water ending on the tailings storage facility are dewatering of tailings or thickening and paste thickening, use of decanting systems to remove the supernatant water on top of the tailings dams etc (Cedergren, 1977).

2.3.1 Tailings failure or seepage around the world

Tailings dams all around the world that are built with earth are known to leak at some point in the in their existence (U.S. Environmental Protection Agency, 1994). In this context, seepage is regarded to be the movement of water through and around a dam or impoundment regardless of its quality, be it contaminated or not (Balkau, 1998).

Supernatant water from tailings storage facilities can impact on the quality of surface and groundwater, when this water seeps through permeable sections of the slimes dams to the water bodies e.g. underlying aquifers, river etc (Callcott, 1989). Water bodies supports fauna and flora, thus seepage from tailings dam into rivers can consequently have an impact on these habitats.

Mines around the world tend to contaminate water bodies in areas where they are operating. Some pollution of water bodies is done on purpose while some are mere accidents or caused by engineering design problems and inefficient tailings management.

Direct tailings discharge into water bodies is a typical example of polluting water bodies on purpose. It happened at Tolokuma gold mine located about 100 km north of Port Moresby in Papua New Guinea (Tingay and Tingay, 2006). The gold mine commenced in 1994 and has since been discharging its tailings into the nearby Auga River, and pollution was detected in the Auga River as well as the Angabanga River which 90 km downstream of the mine (Tingay and Tingay, 2006).

Elevated levels of turbidity, copper, arsenic, zinc, lead and mercury was observed in the downstream section of the Auga River. The metals observed in the downstream section are impurities found in the tailings. The Auga and Angabanga River are now highly disturbed ecosystems, although they were relatively undisturbed before mining activities commenced in the area north of Port Moreby (Tingay and Tingay, 2006). Below are a few important case studies of tailings dam seepage or failures around the world. The case studies studies cover the causes of the failures and the damage or pollution caused.

Los Frailes tailings dam failure, Spain

Los Frailes tailings dam is located near the town of Aznalcóllar in southwestern Spain and approximately 40 km west of the large city of Seville (http://www.tailings.info/losfrailes.htm). The Agrio and then Guadiamar Rivers drain the mine site. This river system extends to the south-southwest, under a road bridge near the town of Sanlúcar la Mayor, and into Doñana National Park (http://www.tailings.info/losfrailes.htm). The Aznalcóllar tailings dam was commissioned in 1978 and failed in April 1998, at the height of 27 m (Penman, 2001). Acidic tailings (pH 2-4) ended up in the Agrio and the Guadiamar River, and consequently altering water quality (http://www.tailings.info/losfrailes.htm). Boliden mining company removed the tailings extending downriver to the bridge near Sanlúcar la Mayor followed by remedial measures to clean up the polluted area, and government cleaned up the section below that bridge (http://www.tailings.info/losfrailes.htm).

Baia Mare, Romania

The Aurul gold mine is located in the town of Baia Mare, in northern Romania (Greenspace, 2005). On the 30th January 2000, a change of wind direction brought heavy rain and a sudden increase of temperature (Penman, 2001). Water liberated from the ice and snow, supplemented by the rainfall raised the water level in the tailings dam until it overflowed, part way up one of the long sides where dam construction was quite low, cutting a breach 20 to 25 m wide permitting a spill of about 100 000 m^3 of heavily contaminated water (Penman, 2001).

According to Csagoly (2000), 100 000 cubic meters of toxic cyanide and heavy metal containing waste water was released into the rivers Sasar, Lapus, Somes, Tisza and Danube Rivers before reaching the Black Sea within four weeks. Some 2,000 kilometres of the Danube's water catchment's area were affected by the spill. More than 1.400 tons of fish died and the livelihood of some hundred fishermen along the Tisza in Hungary was negatively impacted, and commercial fishing was halted, however in 2005 the fish had recovered but there were fewer species (Greenspace, 2005). It was still not a commercial proposition to fish in the Tisza River by 2005.

The spill ran through villages, contaminating drinking water sources and the whole environment in general. Drinking water supply had been impacted both in Romania and Hungary at that time (Greenspace, 2005). Figure 7 shows the spread of pollution across Europe, from the Baia Mare tailings failure.

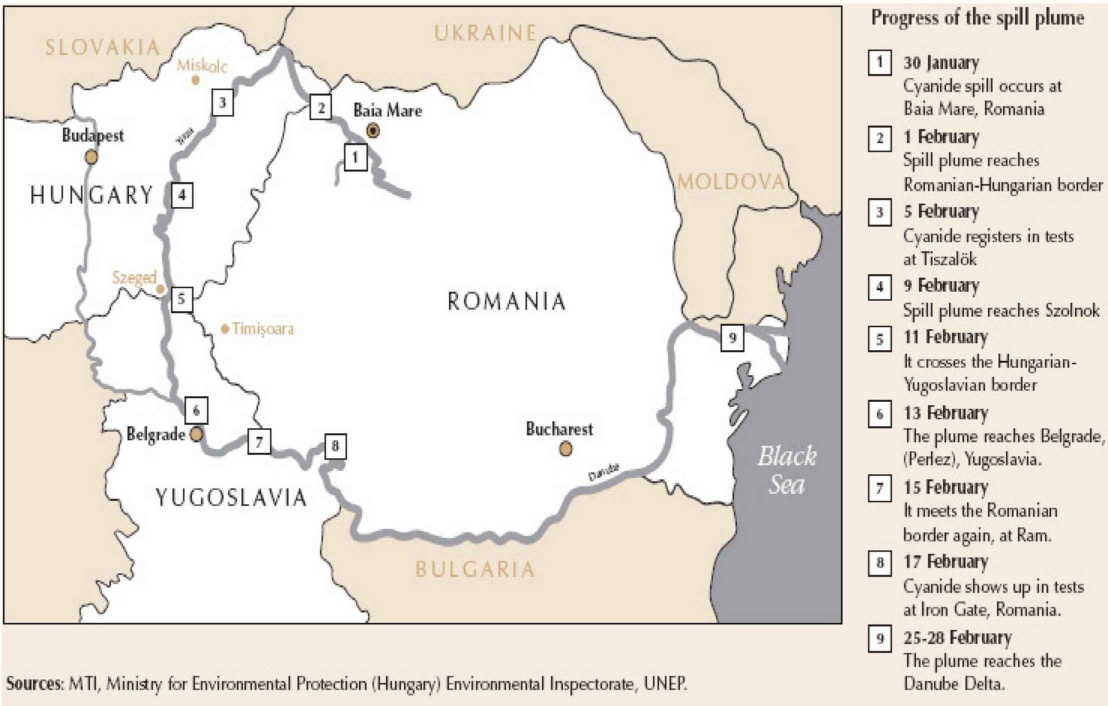

Figure 7: The spread of the cyanide spill from Baia Mare, Romania (Csagoly, 2000)

The reasons for this accident were identified later on to be a combination of mistakes in the construction of the dam, poor risk management and extreme weather conditions (Greenspace, 2005).

Rimac River Basin Contamination, Peru

The polymetallic deposits of zinc, copper, silver and lead have been mined continuously in Lima and Hurichirí provinces since the 1940's (Mendez, 2005). The mining companies which were in the basin before 1997 were, Los Quenuales S.A, Peru Bar and S.A and Casapalca S.A (Mendez, 2005).

Studies done by Mendez (2005), revealed heavy metal contamination along the Rimac River Basin. High concentrations of copper, lead, zinc, arsenic, cadmium, chromium, nickel, and mercury were analyzed in the samples taken along the Rimac River (Mendez, 2005). The study further indicates that pollution of the Rimac River is caused by runoffs and possible seepage from mining tailings dams in the Rimac River Basin (Mendez, 2005).

Omai tailings dam, Guyana

The Omai Gold mine in Guyana is one the largest gold mines in South America (Bayah, 1998). The mine is located close to the Omai River, a tributary of the Essequibo River (Bayah, 1998). Gold mining at Omai commenced in 1993, and gold was extracted using cyanide (Bayah, 1998). Tailings were deposited on the Omai tailings dam which was made out of earth fill (Bayah, 1998). The Omai tailings dam failure happened on the 19th August 1995, and approximately 2.9 million cm^3 of tailings containing diluted cyanide ended up in the Omai River and ultimately reaching the Essequibo River (Bayah, 1998 and Davies, 2002). Fish kill and suspended clay plume were the only documented environmental impacts (Bayah, 1998).

Marcopper Talings Dam failure, Phillipines

The Tapian Pit and San Antonio mine is located in Marinduque, Philippines. It was operated by the company called Marcopper Mining Corporation, and operated from 1969 to 1996 (Coumas, 2002). From 1975 to 1991, Marcopper mine dumped more than 200 million tons of mine tailings into shallow waters of the Calancan Bay covering corals and sea grasses and the bottom of the bay with 80 square kilometres of tailings (Coumas, 2002). The tailings also leached metals into the bay and are suspected to be the cause of lead contamination found in children from villages around the bay. Fish died and food security among the fishing villages was heavily impacted (Coumas, 2002).

The mined out pit, high in the central mountains of Marinduque, had been used as storage place for tailings from the adjacent San Antonio mine since 1992 (Coumas, 2002). On March 24, 1996, another massive tailings spill at the Marcopper Mine filled the 26-kilometer-long Boac River on the island of Marinduque with 3-4 million tons of metal enriched and acid generating tailings (Coumas, 2002). The spill happened when a badly sealed drainage tunnel at the base of the Tapian Pit burst. Tailings where forced out of the containment dam ending up the immediate environment.

It was later discovered that, no risk assessments or environmental impact assessment were conducted before using the impoundment for tailings deposition.

Merriespruit tailings dam failure, South Africa

Merriespruit Tailings dam was part of the mine operated by Harmony Gold, in South Africa (Davies, 2002). The mine was located near the town Merriespruit and dwellings were located below the tailings dam wall (Davies, 2002). Merriespruit tailings dam failed in 1997, and it was regarded as one of the world's major catastrophic tailings disasters (Blight *et al*, 2002).

According to (Davies, 2002), the Merriespruit tailings dam failure occurred on the 22nd of February, 1994 in the evening. A massive failure of the north wall occurred after a heavy rainstorm (Davies, 2002). Overtopping due to inadequate freeboard was ample trigger for static liquefaction once enough toe material was eroded away (Davies, 2002). More than 600,000 m^3 of tailings and 90,000 m^3 of water were released into the environment, and 17 people lost their lives during this event (Davies, 2002). This was due to the close proximity of the dwellings below the tailings dam.

2.3.2 Lessons learned from tailings dam failures around the world

Incidents of tailings dam failure all around the world have awakened people to the dangers of tailings dams. Deducing from previous case studies of tailings dam failures and seepage, failures are known to be mainly caused by inefficient water management on tailings dams coupled with unpredicted precipitation (rainfall, snow etc) patterns.

It is evident from the tailings dam failure case studies that tailings dams are also known to fail when they are used for activities other than their intended purpose e.g. using a tailings dam to store sewage. Foundation and stability of the tailings dams plays a major role, because the dams can fail when the stability and foundations are compromised by seepage, unstable geology and unpredicted precipitation.

These incidents have taught us that careful construction and management of tailings dams around the world is essential. Tailings dams built nowadays should be able to withstand unpredicted precipitation, have efficient monitoring programmes, concise water balance, sealed or lined to prevent groundwater contamination and conduct regular geotechnical assessments to ensure the safety of the dams and emergency structures to deal with unexpected failure.

2.3.3 Daberas tailings dam seepage and contamination of the Orange River

The present study focuses on the impacts of the Daberas slimes dam seepage on the water quality of the Orange River, thus the case studies discussed relate to this study. Tailings dam failure case studies share common causes of failure or seepage and provide information on how to manage them.

The Daberas slimes dam was commissioned in August 2003 (Cooper, 2004). On the 4th of January in 2004, seepage was noticed on the outer south wall of the new slimes dam at Daberas mine. Assessments were made to determine whether the seepage was coming from the slimes dam or not (Cooper, 2004).

Cooper (2004) stated that that a portion of the southern outer wall of the slimes dam is located over an ancient riverbed and the depth to the bedrock is in order of 10 m. A 1.5 m thick clay layer is located 1.5 m below surface (Cooper, 2004). Excavation was done approx 2.0 m below the underside of the clay layer as planned (Cooper, 2004). The slimes dam wall is not based on the bedrock (Cooper, 2004). However, the section through the soil shows three layers, a clay lens layer, a porous layer and the bedrock (Cooper, 2004).

The trenches that were excavated as a remedial action to intercept seepage from the tailings dam are 7 m deep and do not reach the bedrock and seepage water can pass underneath and through the trench walls towards the Orange River (Cooper, 2004). The water in trenches moves towards the Orange River which is about 1.4 km away from the first trench. Groundwater flow direction in the area is unknown but local surface drainage is perceived to flow towards the Orange River.

CHAPTER 3

METHODS

This section of the research report describes the methods of water sample collection, location of the study area and detailed methods of data analysis.

3.1 Location of the study area

The study site is near the Namibia-South Africa border, but it is within Namibia. This site is near the Orange River and it lies within the mining licensed area Orange River Mines (ORM), operated by Namdeb. The nearest town to this site is Oranjemund, which is a closed mine town.

The slimes dam of concern is located at 16°46’30”S, 28°14’50”E, and it is 1.4 km north of the Orange River and 80 km north-east of Oranjemund (Botha, 2004). Figures 8 and 9 show the location of the study site including the whole footprint of the Orange River and the location of the Daberas slimes dam in Namibia.

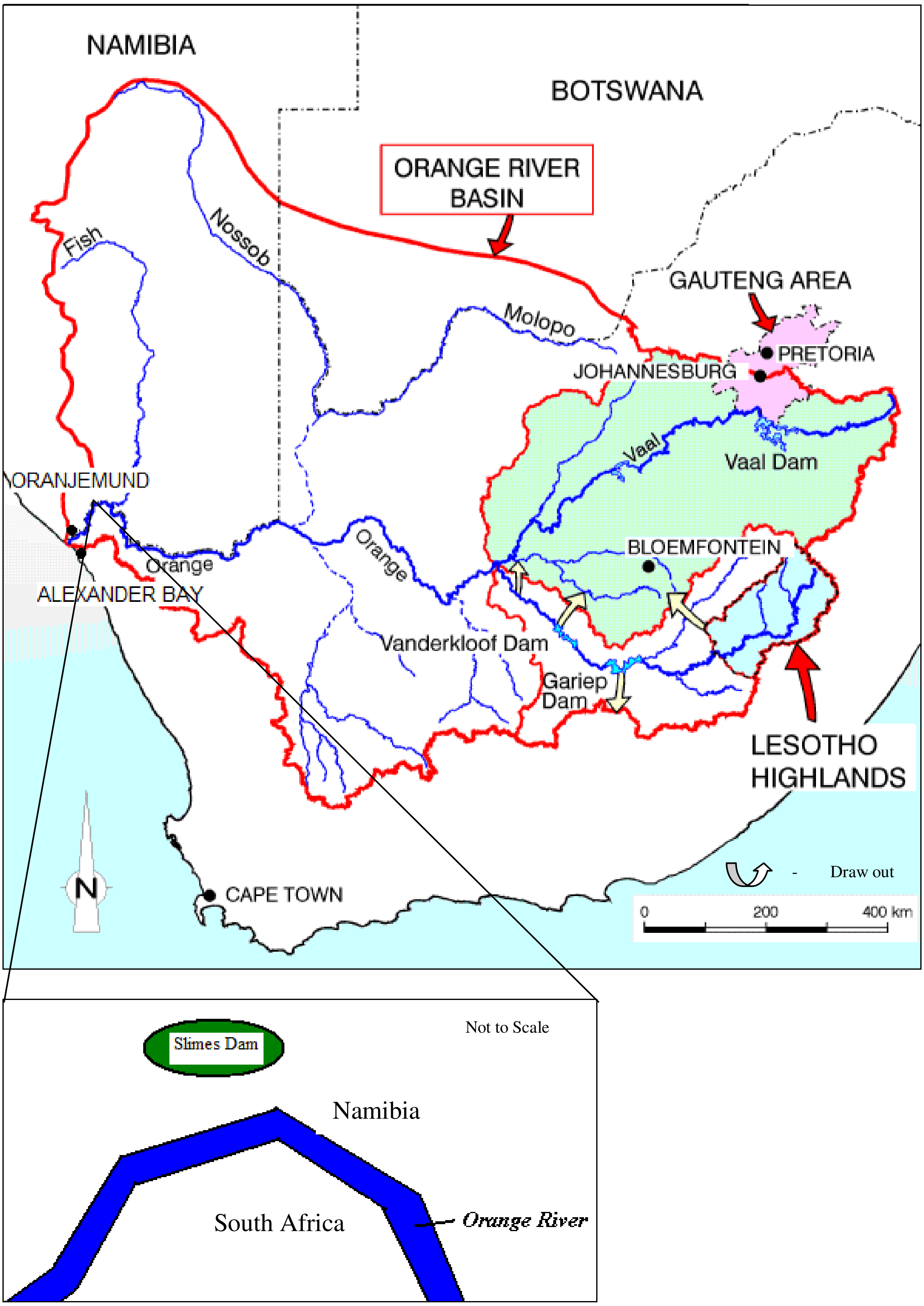

Figure 8: The location of the Orange River and the Daberas slimes dam (The study site). Source: (http://www.dwaf.gov.za/orange/)

Figure 9: The location of Daberas slimes dam (Source: Google Earth 2009)

Namdeb commissioned the investigations on the impact of the Daberas slimes dam seepage on the water quality of the Orange River and the sudden death of riparian vegetation. Water quality analysis that was done by NAMWATER (a national water supply utility corporation) was used in this study (See Appendix B). Samples were taken from upstream, downstream of the slimes dam and from trench 1, 2 & 3 (see Figure 10 below for locations) by the Safety, Health and Environment officer at Daberas mine and chemical analysis were done by NAMWATER to determine the chemical constituents in all samples collected. The samples were collected on 4 different occasions from 2005 to 2007

(12/01/2005, 23/11/2006, 11/04/2007 and 25/07/2007). Only one sample per site was collected during each of the sampling periods. The samples were collected and preserved in ice before they were sent to the NAMWATER Laboratory in Windhoek, a certified commercial laboratory for the water utility company NAMWATER.

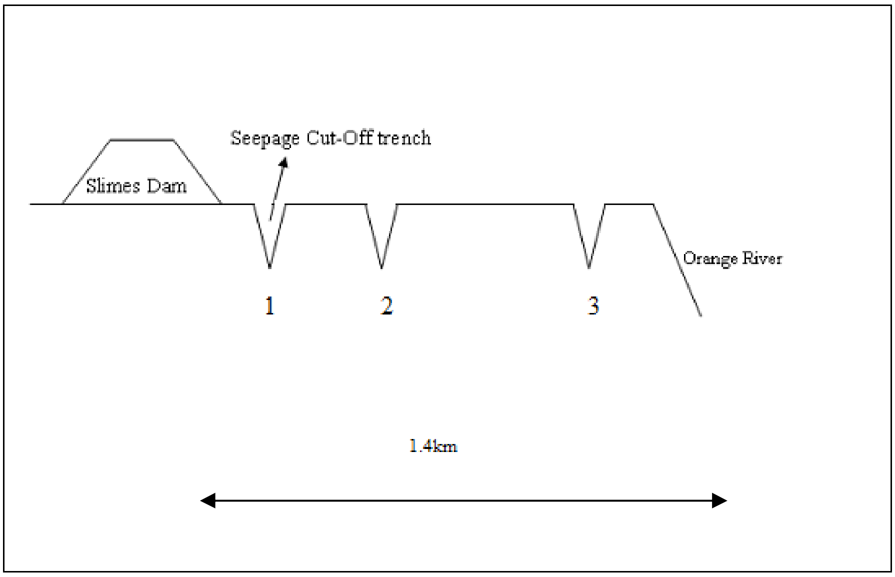

Figure 10: Positions of sample points relative to the Daberas slimes dam

The distance between the slimes dam and the Orange River is 1.4 kilometres, and cut-off trench 1 is about 10 m from the slimes dam and cut-off trench 2 is about 30 m away from the slimes dam. Cut-off trench 3 is about 1.3 km away from the slimes dam (40 m away from the river). The river upstream sample point is 5 km before the section of the river that is perpendicular to the slimes dam whereas the downstream sample point is two kilometres further downstream of the river.

The coordinates of the sample sites are as follows. Trench 1 and 2 were very close to each other, thus only one GPS coordinate was taken in between the two trenches. The two smaller slimes dams were used in the feasibility stage but have dried up. The following map shows the exact locations of the sample areas relative to the Daberas slimes dam in question:

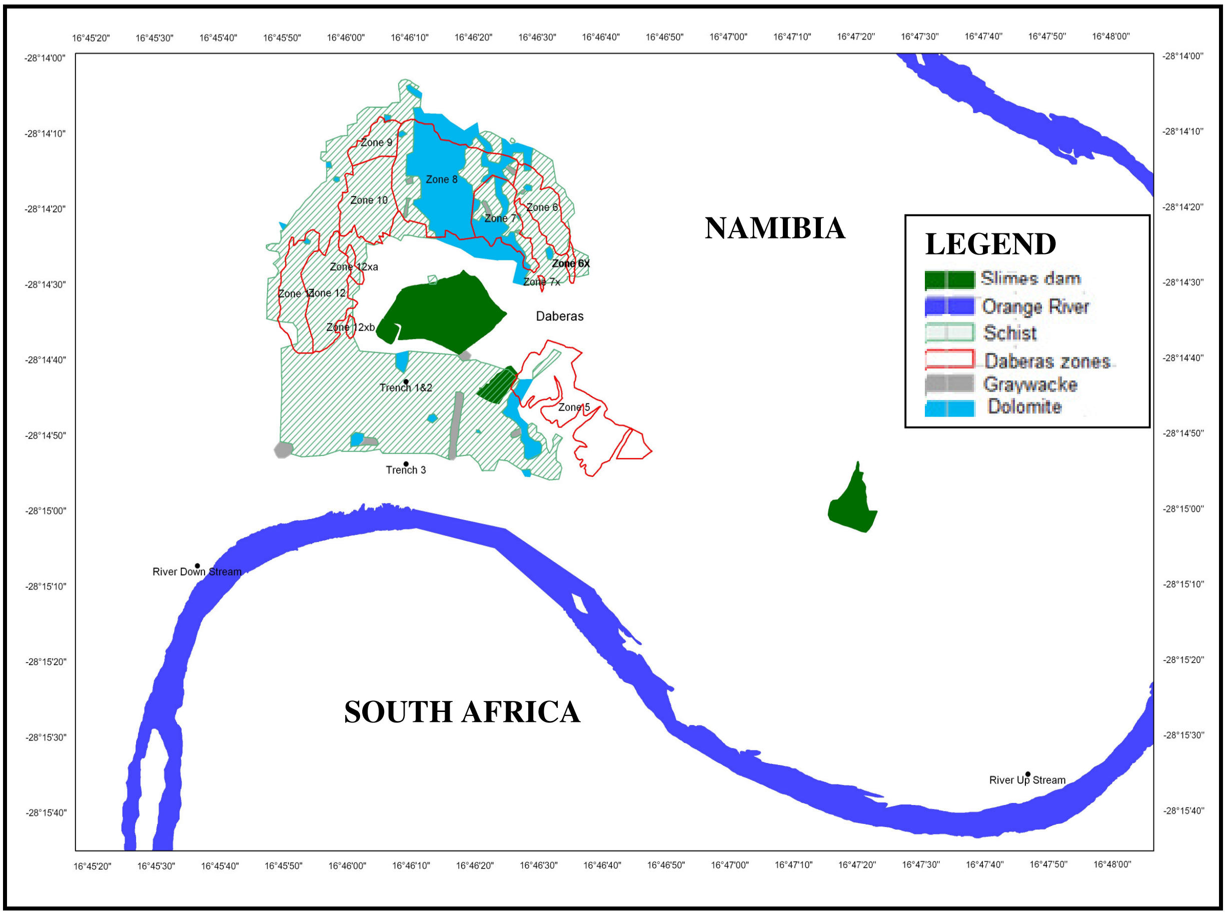

Figure 11: The positions where samples were taken (Chris E. Ailonga)

Table 1: Coordinates of sample sites

Name	**Latitude**	**Longitude**	**Elevation**
Trench 1&2	28º15´06.16˝	16º46´24.67˝	72.592 m
Trench 3	28º15´23.47˝	16º46´24.65˝	60.137 m
River Up Stream	28º16´28.94˝	16º48´59.39˝	54.326 m
River Down Stream	28º15´44.80˝	16º45´32.65˝	53.211 m

Assumptions: The trends in the change of parameter concentrations amongst sample points will enable one to determine the impact of Daberas slimes dam on the water quality of the Orange River. It is assumed that the water quality along the river does not vary between the upstream and downstream sampling point in the Orange River for any reason other than slimes dam seepage. An increase in certain chemicals constituents, from upstream to downstream of Daberas can be used to point out that the seepage from Daberas slimes dam has a direct impact on the water quality of the Orange River.

3.2 Methods of analysis

The samples were analysed for a wide range of parameters including pH, iron and manganese. However, aluminium, chromium and silicon which make up FeSi used at Daberas mine were not analysed at all sampling periods. The analysis included the comparison of chemical constituents and concentrations in the Orange River, upstream and downstream and within the cut-off trenches. The metals and non-metals were analysed using the Perkin Elmer ICP Spectrometer (OES) at the NAMWATER Commercial Lab. Samples were not filtered nor digested, but only acidified with nitric acid before analysis with the ICP (Communication with Conradie, 21/02/2011) .

3.3 Statistical analysis

Water quality data obtained from NAMWATER was analysed using a statistical program called, Statistical Package for the Social Sciences (SPSS) Version 15.0 and Microsoft Excel 2003 spreadsheet (See appendix C for SPSS output). Since the data used in this study is not normally distributed, one-way analysis of variance (ANOVA) could not be used to test the variance. A non-parametric test Kruskal-Wallis was instead used to test for significant differences between the means of samples over time. Water chemical constituents and concentrations were compared in all sample sites.

3.4 Technical reports desk top study

Four technical reports of consultants who worked on the Daberas slimes dam seepage issue, is discussed in the discussion section in chapter 5. The primary focus was on the recommendations made in this reports and how relevant they are to solving the seepage issue. Some reports were mainly focused on the engineering aspects of the Daberas slimes dam rather than the impact of seepage on the water quality of the Orange River.

CHAPTER 4

RESULTS

This section serves to present the results of the chemical parameters and to discuss the variations of metal concentrations with respect to the suspected contaminant source, the Daberas slimes dam. The section discusses and illustrates the water quality of each sample site and compared it to the Namibia water guidelines.

The first part of the results consists of the assessment of parameters and their possible connection to the Daberas slimes dam.

4.1 Limitations

This study was limited to the available data in the possession of Namdeb Management. There was no proper monitoring procedure in place, thus there is no consistency in sampling periods. The Namdeb management made the decision to take samples at some points and omit others on some of sampling dates.

Immediately after the seepage in 2004, no concise chemical analysis was carried out until 2005. Amongst the chemicals analysed in all the samples, iron and manganese are the only parameters of concern that could be related to the Daberas Slimes dam. pH which is a field parameter was analysed in the laboratory as well.

No rainfall data is available for the Daberas mine or the nearest Auchas mine. Rainfall data of Alexander Bay and that of Springbok will be used for this project, as it is the nearest weather station close to Daberas mine. Rainfall data of Alexander Bay is not necessarily compared to that of Daberas due to its location at the coast. There is generally a lack or no information on any continuous consistent monitoring in the Orange River Basin, discharge volumes and quantities from sewage treatment works, mines and industries (Coleman and Van Niekerk: 2007).

4.2 River flow

Table 2 indicates the river flow at Viooldrif station (above the Daberas mine) in South Africa. This station is the closest station to Daberas mine that recorded river flow during the study period. The sampling months are highlighted in the table in grey.

Table 2: River flow at Viooldrif Station near Daberas, South Africa (DWEA Database)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2005	132	127	136	133	121	138	131	132	116	120	124	113	**127**
2006	126	117	122	183	236	2039	2127	1061	679	286	261	512	**645.8333**
2007	293	740	676	564	141	150	134	141	81.4	#	#	3.36	**243.6467**

4.3 Rainfall

Daberas is generally an area that receives low rainfall all around the year. Since no rainfall data is available for Daberas, data from Springbok and Alexander Bay was used in this study.

Monthly rainfall data of Springbok (approximately 190 km from the Daberas mine) is presented in Figure 12, Springbok's rainfall data was used because it is the closest weather station to the study site. Rainfall data will help us determine the impact of rain on the water quality of the Orange River.

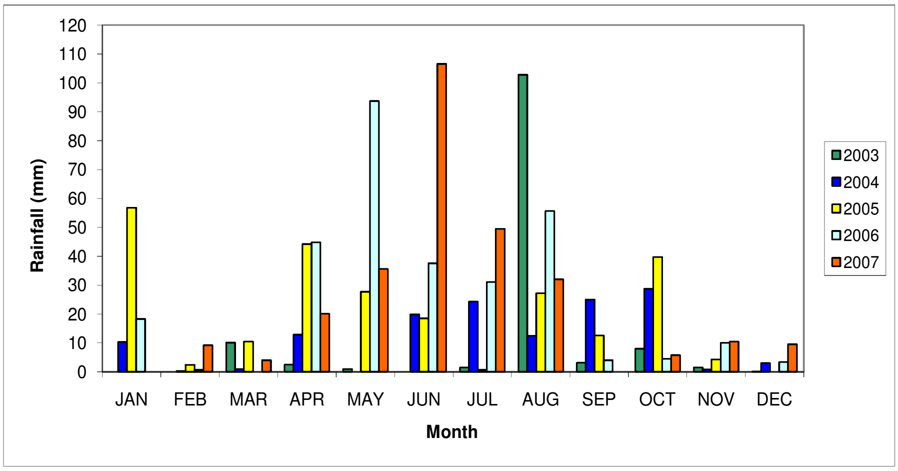

Figure 12: Monthly rainfall of Springbok, from 2003 to 2007.

Monthly rainfall data of Alexander Bay is presented in Figure 13. An average of about 10 mm rainfall per month was recorded in Alexander Bay from April to October as from 2003 to 2007. The highest rainfall recorded at Alexander Bay was in the period of 2003 to 2007 was 28mm. As from 2003 to 2007, these years were generally dry, this amount of rainfall did not have any major impact on the water quality of the Orange River.

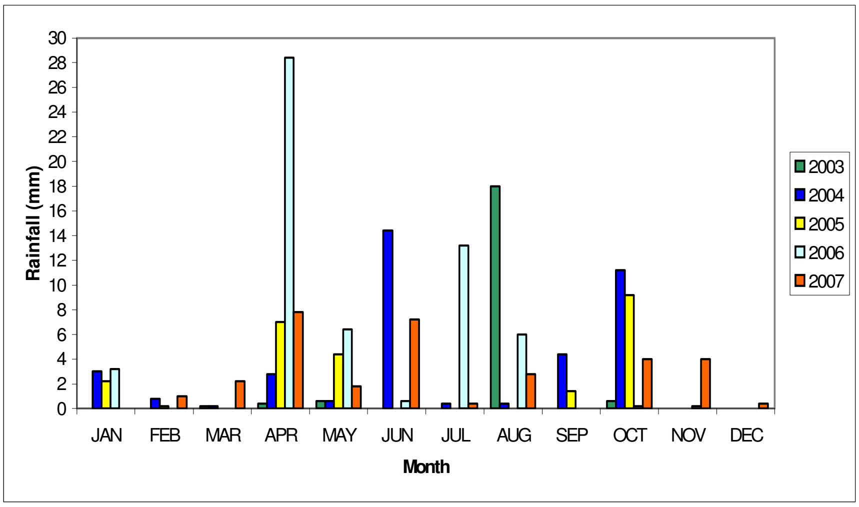

Figure 13: Monthly rainfall of Alexander Bay, from 2003 to 2007.

4.4 Parameters

Parameters that could be related to the Daberas slimes dam were chosen. Other parameters were chosen due to concerns raised by the Ministry of Mines and Energy and the Department of Water Affairs in Namibia. Concerns raised by the two ministries are river pollution, death of riparian vegetation and continual seepage from Daberas slimes dam. The raw data obtained from the laboratory are attached in the appendix C. Table 2 shows the water guidelines for Namibia, subdivided into four standards of water quality. The parameters of concern are highlighted in blue.

Table 3: Water guideline values for Namibia (NAMWATER, 1996).

ID	Standard	**pH**	**EC**	**K**	**Na**	**Cl**	**Mg**	**Ca**	**SO_4**	**NO_3**	**Fe(II)**
			µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
A	Water with an excellent quality	6.0-9.0	1500	200	100	250	70	150	200	40	0,1
B	Water with acceptable quality	5.5-9.5	3000	400	400	600	100	200	600	88	1
C	Water with low health risk	4.0-11.0	4000	800	800	1200	200	400	1200	176	2
D	Water with a high health risk or water unsuitable for human consumption.	11	4000	800	800	1200	200	400	1200	176	2
	Livestock Watering										10

ID	Standard	**Al**	**As**	**B**	**Ba**	**TDS**	**Br**	**Cd**	**Co**	**Cr**	**Cu**	**F**
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
A	Water with an excellent quality	0,15	0,1	0,5	0,5	500	1	0,01	0,25	0,1	0,5	1,5
B	Water with acceptable quality	0,5	0,3	2	1	1500	3	0,02	0,5	0,2	1	2
C	Water with low health risk	1	0,6	4	2	-	6	0,04	1	0,4	2	3
D	Water with a high health risk or water unsuitable for human consumption.	1	0,6	4	2	-	6	0,04	1	0,4	2	3
	Livestock Watering	0-5	0.-0.5			-		0-0.01	0-1	0-1	0-5	6

4.5 Summary of results

Table 4 below presents a summary of the results of chemicals of concern obtained from the laboratory during the sampling period from December 2005 to July 2007. The values that do not comply with the Namibian water guidelines are highlighted in pink while those that are within the guideline limits of excellent water in Namibia are highlighted in green.

Table 4: Summary of results

Sample Site	12/1/2005	23/11/2006	11/4/2007	25/07/2007	Mean	Mean±SE
pH						
Upstream	8.7	8.4	8.3	8.4	8.45	0.0866
Slimes drain 1		7.8		8	7.9	0.1
Slimes drain 2		8		8.1	8.05	0.05
Slimes drain 3		8.4	8.3	8.1	6.2	0.0882
Downstream	8.7	8.4	8.3	8.4	8.45	0.0866
Fe (mg/l)						
Upstream	0.34	1.3	0.03	0.09	0.44	0.29442
Slimes drain 1		0.01		0.02	0.015	0.005
Slimes drain 2		0.01		0.01	0.01	0
Slimes drain 3		0.46	0.01	0.02	0.1225	0.14836
Downstream	0.32	1.6	0.03	0.07	0.505	0.3706
Mn (mg/l)						
Upstream	0.12	0.05	0.03	0.03	0.0575	0.02136
Slimes drain 1		0.01		0.01	0.01	0
Slimes drain 2		0.03		0.01	0.02	0.01
Slimes drain 3		0.04	0.01	0.01	0.015	0.01
Downstream	0.11	0.05	0.03	0.03	0.055	0.01893
EC (ms/m)						
Upstream	62.4	23.1	50.2	62.3	49.5	9.2543
Slimes drain 1		955		2480	1717.5	742.5
Slimes drain 2		1783		1259	1521	262
Slimes drain 3		592	1630	1326	887	308.0959

Table 5: Summary of results (continued)

Downstream	70.8	24.1	57.6	67.3	54.95	10.6556
TDS (mg/l)						
Upstream	418	155	336	417	331.5	61.89
Slimes drain 1		6399		16616	11507.5	5108.5
Slimes drain 2		11946		8435	10190.5	1755.5
Slimes drain 3		3966	10921	8884	5942.75	2064.355
Downstream	474	161	386	451	368	71.471

4.5.1 pH

The measurements of pH along the Orange River show that water is slightly alkaline. pH in the Orange River has remained more or less constant upstream and downstream of Daberas mine during the investigative period of this study The highest pH amongst all samples was recorded in 2005, both upstream and downstream. The pH recorded in the cut-off trenches (slimes drains) remained between 7.8 and 8.4. The overall pH results show that the river water and the water in the cut-off trenches are both alkaline, although the alkalinity in the cut-off trenches is lower than that of river water. Slimes drain 3 that is close to the Orange River showed a decreasing trend from 2006 to 2007.

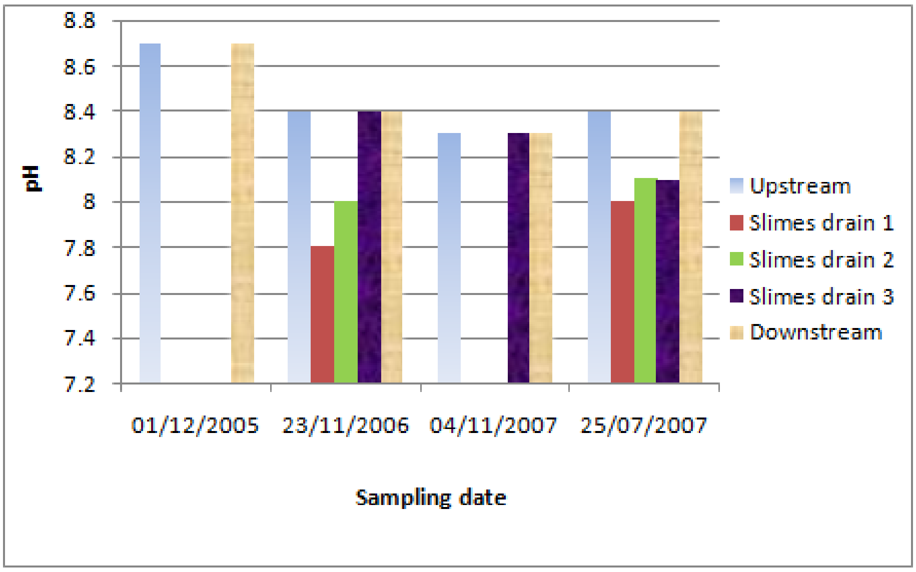

Figure 14: pH of water along the Orange River and within cut-off trenches

The pH of excellent drinking water according to the Namibian water guidelines ranges between 6 and 9. It is very evident from Figure 14 that pH along the river portion near Daberas mine has been within the limit of excellent drinking water in Namibia. The highest pH of 8 was recorded in 2005 along the Orange River. The pH within the cut-off trenches has also remained within the limit of drinking water in Namibia.

The null hypothesis for pH assumes that there is no significant difference in the mean pH readings for all sample sites over time. A Kruskal Wallis one way ANOVA analysis was performed at 0.05 level of significance. The significant P-value = 0.045, therefore we reject H_0 and accept the H_a, which means that there is sufficient evidence to indicate that there is a difference amongst the mean pH readings. The test for pH was significant at 5% confidence level.

4.5.2 Conductivity

The results indicate that there has been a trend in conductivity along the Orange River, whereby minor increases in conductivity in downstream river water have been recorded from 2005 to 2007. It is evident from Figure 14 that conductivity in the Orange River has always been within the limits of excellent safe drinking water as per Namibian water guidelines. However, conductivity is very high within the trenches and it is beyond the drinking water limit in all trenches during all sample times. This could be linked to minor increases in conductivity downstream in Orange River.

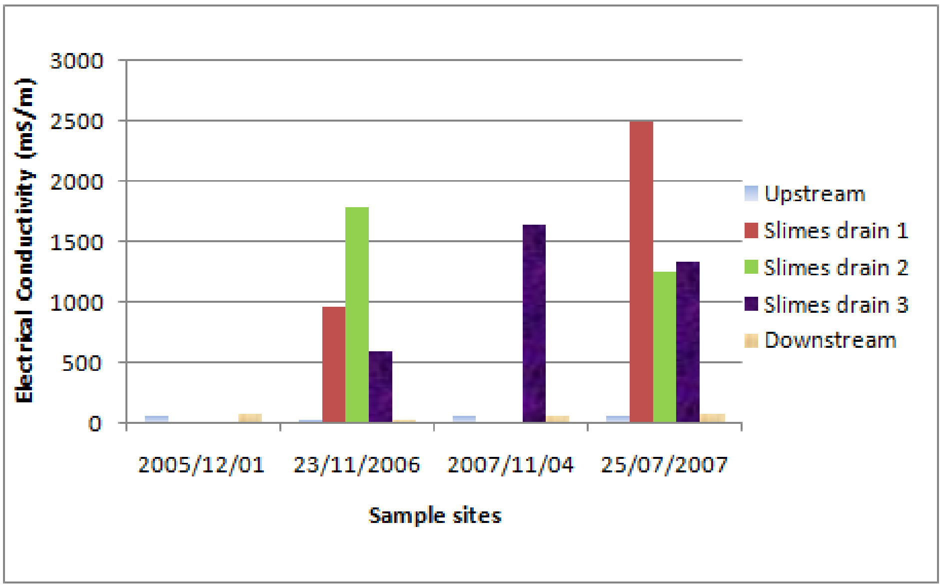

Figure 15: Conductivity of the water along the Orange River and within cut-off trenches

The null hypothesis for conductivity assumes that there is no significant difference in the conductivity readings for all sample sites over the sampling period. A Kruskal Wallis one way ANOVA analysis was performed. The test was done at 0.05 level of significance. The significant P-value = 0.028 which is less than 0.05; therefore we reject the null hypothesis and accept the Ha, which means that there is sufficient evidence to indicate that there is a difference amongst the mean conductivity readings. The Kruskal-Wallis test for conductivity was significant at 5% confidence level.

4.5.3 Total dissolved solids,

More or less the same trend occurred with respect to total dissolved solids in all sample sites, whereby higher TDS was recorded in the trenches and the TDS along the river remaining the same or fluctuating slightly. Figure 16 clearly shows minor fluctuations in total dissolved solids along the Orange River, and the concentrations remain within the limits of the excellent water as per Namibian water guidelines. However, TDS remain high within the trenches at all sample times, exceeding the limits of excellent water category as per Namibia water guidelines showing signs of seepage from the slimes dam.

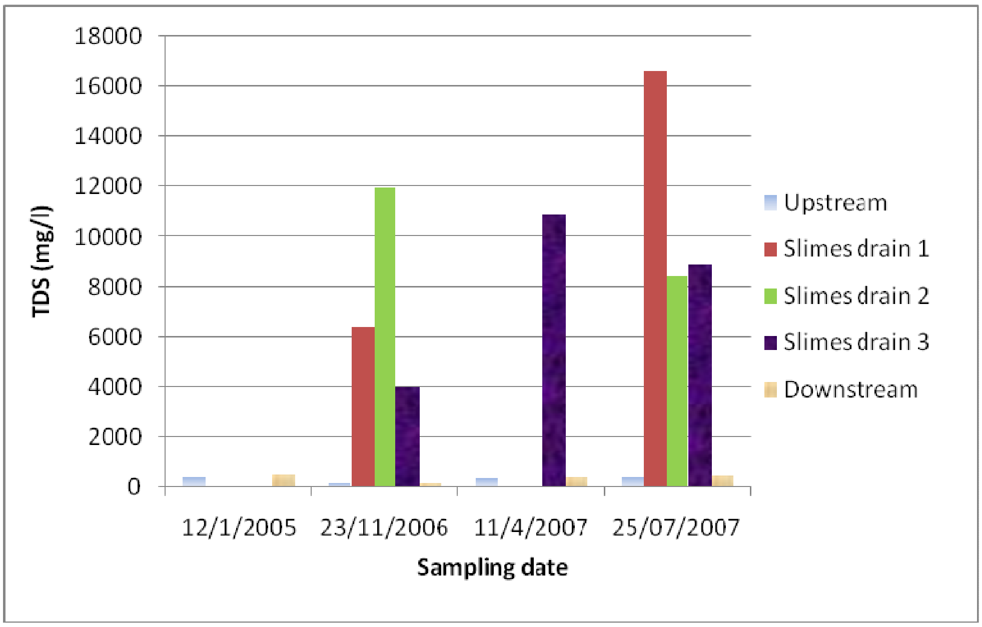

Figure 16: Total dissolved solids in the water along the Orange River and within cut-off trenches

The null hypothesis for TDS assumes that there is no significant difference in the mean iron readings for all sample sites over time. A Kruskal Wallis one way ANOVA analysis was performed at 0.05 level of significance. The test revealed that the significant P-value = 0.028 which is less than 0.05, therefore we reject the null hypothesis and accept the Ha, which means that there is sufficient evidence to indicate that there is a difference amongst the mean TDS readings. The Kruskal-Wallis test for TDS was significant at 5% confidence level.

4.5.4 Iron

Iron is one of the components of the dense medium separation material, ferrosilicon, which is used at Daberas mine to extract diamonds, and it is present in the Daberas slimes dam. Deducing from Figure 17 below, Iron concentration was higher than the Namibian drinking water limit for excellent water (0.1 mg/l) in the upstream and downstream section of the river in 2005 and 2006. This finding can be attributed to the low rainfall that was experienced in 2005 or perhaps leachate from diamond mines along the Orange River in South Africa or from the upper Orange River. In spite of the general increase in the iron concentration along the river, iron concentration was higher in the downstream section of the river in 2006. The iron concentration in within the trenches was generally lower than that recorded in the river, this clearly shows impacts from upstream section the Orange River, which could be from diamond mines in South Africa.

The iron concentration has since declined and remained within the Namibia water guidelines limit of iron concentration in drinking water, following good rain in the year 2007. 2005 and 2006 instances could be linked to the seepage through outer wall of the Daberas slimes dam that occurred on the 4th of January 2004. The highest iron concentration was recorded downstream in 2006 when the river flow and rainfall was higher than the previous year

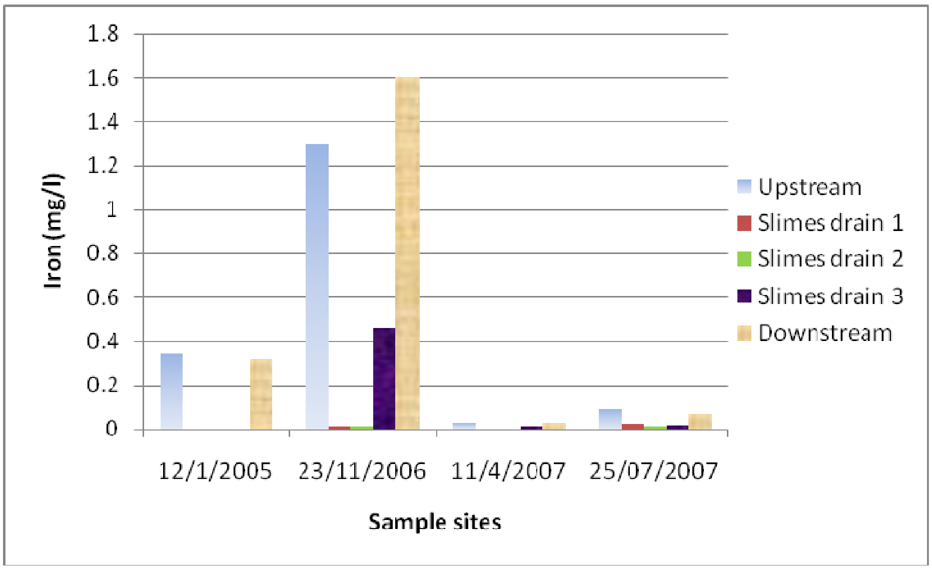

Figure 17: Concentration of iron along the Orange River and within cut-off trenches

The latest results show that iron concentration in the Orange River and trenches is still within the limit of excellent drinking water in Namibia as per water guidelines.

The null hypothesis for iron assumes that there is no significant difference in the iron concentrations for all sample sites over time. A Kruskal Wallis one way ANOVA analysis was performed at 0.05 level of significance. The test revealed that the significant P-value = 0.092, therefore we accept the null hypothesis and reject the H_a, which means that there is no sufficient evidence to indicate that there is a difference amongst the mean iron readings. The test did not agree with the mean concentrations which in fact differ, but this could be as a result of abnormal distribution of the results caused by insufficient sampling and replicates. The test for iron was not significant at 5% confidence level.

4.5.5 Manganese (N.W.G.L = 0.05 mg/l)

Manganese is one of the components of ferrosilicon. Deducing from Figure 18, there has never been much of a difference between manganese concentration in upstream and downstream sections, and in fact, manganese concentrations remained well within the limit of drinking water during all sample times except in 2005.

Concentrations of manganese in the river were always high in the upstream section, with little or no significant changes in the downstream section. It is evident from Figure 18 that there has been a decreasing trend recorded at most sites over time.

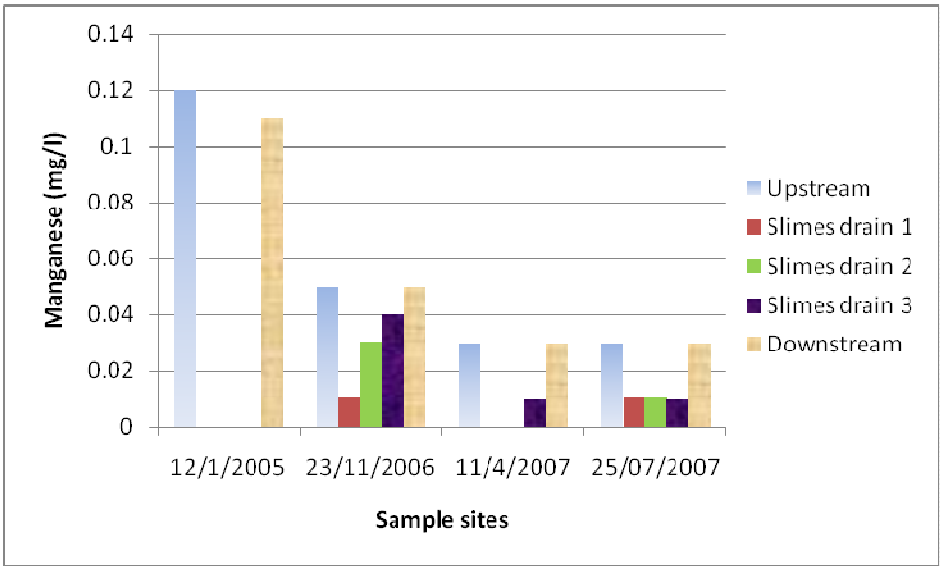

Figure 18: Concentration of manganese along the Orange River and within cut-off trenches

The null hypothesis for manganese assumes that there is no significant difference in the mean manganese readings for all sample sites over the sampling period. A Kruskal Wallis one way ANOVA analysis was performed at 0.05 level of significance. The significant P-value = 0.111 which is more than 0.05, therefore we accept the null hypothesis and reject the H_a, which means that there is no sufficient evidence to indicate that there is a difference amongst the mean manganese readings, even if the differences are visible from Figure 18. The test for iron was not significant at 5% confidence level.

CHAPTER 5

DISCUSSION

The main problem of this study revolves around the seepage from the Daberas mine slimes dam which was suspected to have caused the deterioration of the water quality of the Orange River and the death of trees along the riverbank.

The primary purpose of this study was to determine the water quality impact on the Orange River by the Daberas mine slimes dam seepage and to discuss the previous studies done at Daberas. The study assumes that the water along the river is uniform and water quality will be more or less the same and any significant change in chemicals along the river would show signs of external impacts. Chemicals that could be traced to the Daberas slimes dam are iron and manganese, as they are components of ferrosilicon, which is used in the dense medium separation method of processing alluvial diamonds. The other parameters like pH, electrical conductivity and total dissolved solids are indicators of pollution, as they are sensitive to changes in water.

The pH along the river would most probably differ significantly due to an introduction of external chemicals. In this case, minor changes were recorded along the Orange River. Minor fluctuations in the overall pH of the Orange River water can be accounted for by seasonal effects of rainfall (see rainfall data in Chapter 4, sub-section 4.2). Coleman and Van Niekerk (2007) also support the theory that concentration could be higher when the water volume is low and vice versa. The water in the river and within trenches is generally slightly alkaline, showing no signs of any acidic pollution. The soil at Daberas mine has less sulphur content, which would normally cause acid mine drainage. Acid mine drainage lowers the pH (Nickanor, communication in 2007).

Electrical conductivity and total dissolved solids (TDS) within the Orange River had minor fluctuations as well and were well within the guideline limit for excellent water in Namibia during all sample times. All the samples taken from the cut-off trenches during the sampling period, showed higher electrical conductivity and TDS that was above the Namibia Water Guidelines limit. These increases may also be impacted by diamond activities in the upstream section of the river in South Africa. Minor changes in conductivity and TDS along the river can be attributed to seepage of the Daberas slimes dam, and fluctuations in rainfall and river flow. Conductivity could have dropped in 2006 due higher river flow and rainfall which could have had a dilution effect, while it could have increased in July 2007 due to low river flow along at the time of sampling or due to diamond mining activities in South Africa that are located upstream of Daberas.

Given the arid nature of the Lower Orange River and high potential evaporation, the evaporative losses results in an increase in concentrations along the length of the Lower Orange River (Coleman and Van Niekerk, 2007).

Iron was beyond the Namibia Guidelines limit for excellent water in 2005 and 2006, this could have been caused by the initial seepage which might have washed out chemicals from soil to the river or due diamond activities in the upstream section of the river in South Africa. The highest iron concentration was recorded downstream in 2006 when the river flow and rainfall was higher than the previous year; iron concentration could have been affected by upstream water in the Orange River and probably worsened when it passed the Daberas section of the Orange River. Most interestingly, iron concentration has declined in the downstream section of the river compared to higher concentrations recorded upstream during the sampling period of July 2007. All parameters of concern were well within the limit of excellent water quality standard. However, this study assumes that water has seeped from Daberas slimes dam towards the Orange River as shown the conceptual model below.

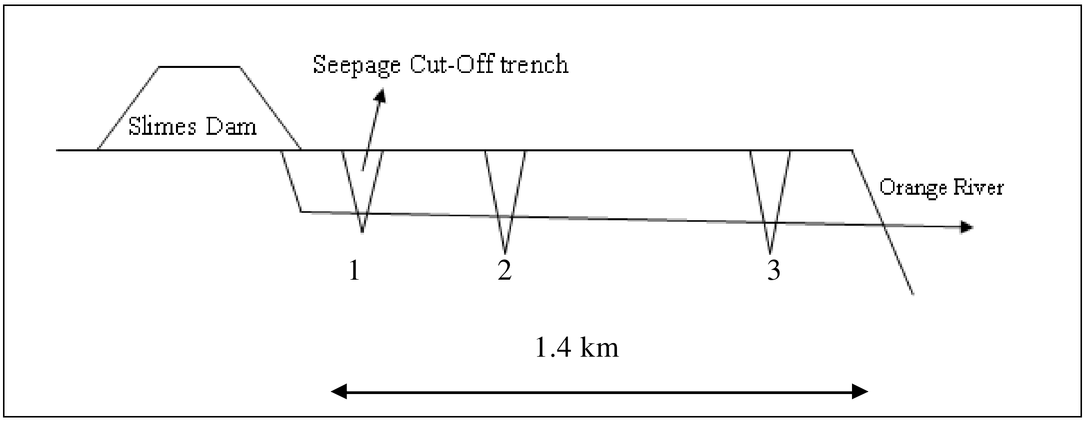

Figure 19: Conceptual model of seepage from the Daberas Slimes dam into the Orange River

Manganese was above the Namibian water guideline limit for excellent water in 2005, with concentrations being slightly higher in the upstream section of the river compared to the downstream section of the river. The results indicate no pollution of Orange River from manganese, as the concentrations of manganese in the river are constant. Minor flactuations in manganese concentrations in 2006 could be accounted for by high river flow, which might have had a dilution effect on the concentration of manganese. Higher rainfall in 2007 could explain the lower manganese concentrations recorded that year. Lower concentrations of Mn in the river could also be attributed to changes in diamond mining activities in the upstream section of the Orange River. It was noticeable the Fe and Mn from the slimes dam did not impact on the concentrations below the dams.

5.1 Technical reports review

After it was observed that the Daberas slimes dam was seeping, Namdeb mine tried hired a couple of consultants to advice management on how to address to seepage and avoiding the contamination of the Orange River. Part of the study was to scrutinise the consultant's reports and point out relevance of these studies and recommendations made in these reports. Since the technical report review was part of the main aims and objective, it was found necessary to discuss them futher in separate section under the discussion chapter. The consultants had different ideas and recommendations about the seepage from daberas slimes dam.

Studies by Ellmies *et al* (2006) were able to demonstrate the impact of the seepage on the death of vegetation along the Orange River banks, but these results might have resulted due to initial seepage that carried all contaminants with it.

Such incidents occur when water/seepage washes out minerals in the soil (http://www.environment.nsw.gov .au/mao/stormwater.htm). This might have occurred at Daberas. The riparian vegetation along the Orange River banks section at Daberas has recovered and still growing. Studies by Ellmies *et al* (2006) cannot be used to extrapolate the impacts of the Daberas slimes dam seepage on the water quality of the Orange River. Ellmies *et al* (2006) took the samples from upstream and downstream of the tailings dam, and not in the river. To determine the impact of seepage on the water quality of the Orange River, representative samples were supposed to be taken in the river to determine changes amongst parameters of concern.

Studies by Botha (2004) revealed minor increases in calcium, sodium, magnesium and chloride from upstream to downstream of the Orange River. Only sodium can be traced back to the mine, as it is one of the elements that make up Yangfloc, a flocculant that was used by the mine in the early stages of the commissioning process.

Seepage normally happens for a number of reasons, but in the case of tailings dams, it is mainly due to the settling of too much water (supernatant water) on top of the dam (Blight *et al*, 2002). Too much water in the tailings dam may result in seepage through the dam walls and in worse cases causing a dam failure. Spray bars used at the dam are effective and but fines settle very slowly, as tailings seepage is still visible in the trenches. The walls of the tailings dam can be at risk if the water in the dam settles too close to the walls, gradually eroding the walls.

According to Braam (2004), strong seepage has been observed in the cut-off trenches. He further states that continual seepage underneath the tailings wall may lead to dam failure. It is clear from the above mentioned account that seepage has been observed into the trenches. Minor increases have generally occurred amongst the parameters of concern in the Orange River.

The set-up and methodology of these studies were not exactly same, nor had the same aims and objectives as that of this study. These reports mainly focused on confirming seepage and its causes. It was only Botha (2004) who focused on the impact of seepage on the water quality of Orange River, but had different parameters of concern that did not include iron or manganese.

CONCLUSIONS

Determining the water quality impact on the Orange River by the Daberas mine slimes dam seepage were the main task of this study. Minor increases of some parameters of concern downstream in the river could be traced back to the mining project at Daberas. Iron and manganese, which forms part of ferrosilicon that is used as DMS material by the mine, remained within the limit of excellent water quality downstream of Daberas as from 2006 onwards.

The results from this study have indicated low levels of contamination from the Daberas slimes dam. The water quality of the Orange River section, downstream of Daberas is currently A-rated, characterising water with excellent quality as per Namibian water guidelines.

The four studies conducted by the consultants concludes that the Daberas slimes dam is in fact seeping, with Elmies *et al* (2006) confirming seepage from the dam as the cause of death of riparian vegetation of the Orange River banks after monitoring water samples upstream and downstream of the tailings dam. These studies did not really cover the aspects of impacts on the water quality. Botha (2004) has however done some water quality analysis in the river, but did not focus on the chemicals that could be traced to the mine. The present report has a section of recommendations that proposes the way forward on how to tackle the river pollution problem at Daberas.

RECOMMENDATIONS

Botha (2004) recommended that water be intercepted in the cut-off trench to prevent river pollution. This may be a good idea but it may not solve to the seepage problem, it will be costly to continually be pumping water out of the cut-off trench for the rest of the mine life. Continual seepage of tailings through the tailings dam walls could result in the dam collapsing. Cooper (2004) suggested that the amount of water on the dam available for seepage should be highly reduced. Recommendations made by Cooper (2004) and Ellmies *et al* (2006) to continually pump back seepage water to the dam, wait for fines to settle and seal the dam after 4 years is a good measure but there is still more to be done to address continual seepage. The walls of the dam might be eroded which would result in a catastrophic failure of the dam. There is still no tangible evidence that the dam has sealed, however the mine came up with a solution of using the water in the tailings dam in the operation and no seepage water is collected in the trenches (Nickanor, communication on 21/02/2011).

To prevent damage of the dam wall, it is highly recommended that the supernatant pond must be kept as small as possible and it should remain at the centre of the slimes dam. This can be achieved by different ways or a combination of mechanisms.

The most reliable method of achieving a small and centred supernatant pond is by paste or tailings thickening. Thickened tailings are defined as tailings that have been significantly dewatered to a point where they will form a homogeneous non-segregated mass (http://www.tailings.info/thickened.htm). Paste thickening is very expensive but very effective. However, paste thickening has a lot of safety and environmental advantages, by not having or reducing the supernatant pool on the dam, reducing seepage and saving water. It is economical and feasible not to go as far as paste, but thickening performance should be improved. Improved thickening involves the application thickeners to tailings slurry, reducing the amount of water in the tailings before they are disposed on the dam.

Currently, the seepage collected in the trench is pumped to zone 12 for evaporation instead of being pumped back on the dam. This is a good idea, provided the mined out zone 12 is engineered as an evaporation pond e.g. erected with liners and having a large surface area.

The quality of the seepage leachate seem to be improving, this might be due to the dilution with dolomitic water that is suspected to be below the tailings dam. Presence of aquifers below the tailings dam might wet the clay liner beyond dampness and this might cause instability. Further studies regarding the groundwater should be done to determine the risks posed to groundwater and the likely impact it might have on the dam wall.

River water contamination is not a critical concern at the moment in the light of positive indications of these studies; continual seepage might erode the wall and cause piping. Excessive piping may result in local or general failure of the tailings dam. An efficient decant system should be installed to remove the water that is settling in the dam and possibly reuse or recycle this water.

A concise mine water balance should be implemented to account for all the water at the mine, whereby water supply should ideally be equal to the water used and disposed. This tool will serve to help to anticipate the amount of water the mine used, lost, disposed or stored. This tool can be very beneficial as it alerts the tailings management about signs of water loss or gain, which can be used to account for seepage or overflow and can also be used as a measure of water use in the mine. Erection of Piezometers in the drains and around the mine would help to monitor the groundwater (seepage) levels and this will contribute greatly to a concise water balance of the mine.

Daberas mine is surrounded by seeps and primary potential aquifers, thus it is recommended that the mine draw up an effective surface and groundwater quantity and quality monitoring plan. The monitoring plan should incorporate all the chemicals that are likely to be sourced at the mine. Specifically with the Daberas mine, all components of ferrosilicon which is used as DMS material at the mine should be monitored to determine efficiency of mitigating measures in place. The present study could only base these conclusions on the two of the five components of ferrosilicon, which were iron and manganese. Other components of ferrosilicon, which are chromium, aluminium and silicon, should also be incorporated in the monitoring plan. Water quality monitoring should be conducted every 3 months, whereby samples should be taken upstream and downstream of the Orange River, and within trenches. 3 replicate samples should be collected at every sample site. Boreholes can be erected between the tailings dam and the Orange River, to monitor water quality, water level and groundwater flow direction.

Should NAMDEB be planning to erect another slimes dam within their mining area in future, a concise environmental impact assessment and site selection study must be done before construction. It should incorporate geotechnical assessments, groundwater and surface water investigation, fatal flaw assessment, monitoring plans and seepage control measures. An integrated water management plan should be guiding mine planners on how to manage water at the mine.

In conclusion, it would be very good to conduct a strategic environmental impact assessment that includes mining activities and irrigation schemes in the Lower Orange River Basin in Namibia and South Africa.

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APPENDICES

APPENDIX A

Water guidelines: aquatic natural environment for South Africa

Parameters	Target Water Quality Range (µg/l)	Chronic Effect Value (µg/l)	Acute Effect Value (µg/l)
pH	pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by > 5 %, and should be assessed by whichever estimate is the more conservative.		
Chromium	12	24	340
Iron	The iron concentration should not be allowed to vary by more than 10 % of the background dissolved iron concentration for a particular site or case, at a specific time.		
Manganese	180	370	1300
Conductivity	250 mS	250 mS	250 mS
TDS	TDS concentrations should not be changed by > 15% from the normal cyclesof the water body under unimpacted conditions at any time of the year; and .The amplitude and frequency of natural cycles in TDS concentrations should not be changed		
Silicon	*	*	*
Aluminium	5	10	100
* = No guideline values			

Legal framework of other Southern African countries

Legal framework of other Southern African countries		
South Africa	**Botswana**	**Zambia**
National Environmental Management Act, 1998 (Act No.107 of 1998)	Public Health Act (CAP.63:01 of 1981)	Water Act of 1948
National Water Act, 1998 (Act No.36 of 1998)	Water Act (CAP.34:01 of 1968)	Environmental Protection and Pollution Control Act 1990
	Waterworks (Cap.34:03 of 1962)	Water and Sanitation Act 1997
		Public Health Act of 1978

APPENDIX B

Statistical analysis

Ranks

Sample size	N	Mean Rank
Upstream	4	10.88
Slimes drain1	2	1.75
Slimes drain 2	2	3.50
Slimes drain 3	3	7.50
Downstream	4	10.88
Total	15	

Test Statistics(a,b)

	pH
Chi-Square	9.745
df	4
Asymp. Sig.	.045

a Kruskal Wallis Test
b Grouping Variable: Sample size

Descriptives

Sample site			Statistic	Std. Error
Upstream	Mean		8.450	.0866
	95% Confidence Interval for Mean	Lower Bound	8.174	
		Upper Bound	8.726	
	5% Trimmed Mean		8.444	
	Median		8.400	
	Variance		.030	
	Std. Deviation		.1732	
	Minimum		8.3	
	Maximum		8.7	
	Range		.4	
	Interquartile Range		.3	
	Skewness		1.540	1.014
	Kurtosis		2.889	2.619
Slimes drain1	Mean		7.900	.1000
	95% Confidence Interval for Mean	Lower Bound	6.629	
		Upper Bound	9.171	
	5% Trimmed Mean		.	
	Median		7.900	
	Variance		.020	

	Std. Deviation		.1414	
	Minimum		7.8	
	Maximum		8.0	
	Range		.2	
	Interquartile Range		.	
	Skewness		.	.
	Kurtosis		.	.
Slimes drain 2	Mean		8.050	.0500
	95% Confidence Interval for Mean	Lower Bound	7.415	
		Upper Bound	8.685	
	5% Trimmed Mean		.	
	Median		8.050	
	Variance		.005	
	Std. Deviation		.0707	
	Minimum		8.0	
	Maximum		8.1	
	Range		.1	
	Interquartile Range		.	
	Skewness		.	.
	Kurtosis		.	.
Slimes drain 3	Mean		8.267	.0882
	95% Confidence Interval for Mean	Lower Bound	7.887	
		Upper Bound	8.646	
	5% Trimmed Mean		.	
	Median		8.300	
	Variance		.023	
	Std. Deviation		.1528	
	Minimum		8.1	
	Maximum		8.4	
	Range		.3	
	Interquartile Range		.	
	Skewness		.935	1.225
	Kurtosis		.	.
Downstream	Mean		8.450	.0866
	95% Confidence Interval for Mean	Lower Bound	8.174	
		Upper Bound	8.726	
	5% Trimmed Mean		8.444	

	Median	8.400	
	Variance	.030	
	Std. Deviation	.1732	
	Minimum	8.3	
	Maximum	8.7	
	Range	.4	
	Interquartile Range	.3	
	Skewness	1.540	1.014
	Kurtosis	2.889	2.619

Ranks

Sample size	N	Mean Rank
Upstream	4	10.88
Slimes drain 1	2	4.00
Slimes drain 2	2	2.50
Slimes drain 3	3	7.00
Downstream	4	10.63
Total	15	

Test Statistics(a,b)

	Fe
Chi-Square	7.977
df	4
Asymp. Sig.	.092

a Kruskal Wallis Test
b Grouping Variable: Sample size

Descriptives(a)

Sample size			Statistic	Std. Error
Upstream	Mean		.4400	.29442
	95% Confidence Interval for Mean	Lower Bound	.4970	
		Upper Bound	1.3770	
	5% Trimmed Mean		.4150	
	Median		.2150	
	Variance		.347	
	Std. Deviation		.58884	
	Minimum		.03	
	Maximum		1.30	
	Range		1.27	
	Interquartile Range		1.02	
	Skewness		1.709	1.014
	Kurtosis		2.869	2.619

Slimes drain 1	Mean		.0150	.00500
	95% Confidence Interval for Mean	Lower Bound	.0485	
		Upper Bound	.0785	
	5% Trimmed Mean		.	
	Median		.0150	
	Variance		.000	
	Std. Deviation		.00707	
	Minimum		.01	
	Maximum		.02	
	Range		.01	
	Interquartile Range		.	
	Skewness		.	.
	Kurtosis		.	.
Slimes drain 3	Mean		.1633	.14836
	95% Confidence Interval for Mean	Lower Bound	.4750	
		Upper Bound	.8017	
	5% Trimmed Mean		.	
	Median		.0200	
	Variance		.066	
	Std. Deviation		.25697	
	Minimum		.01	
	Maximum		.46	
	Range		.45	
	Interquartile Range		.	
	Skewness		1.729	1.225
	Kurtosis		.	.
Downstream	Mean		.5050	.37060
	95% Confidence Interval for Mean	Lower Bound	.6744	
		Upper Bound	1.6844	
	5% Trimmed Mean		.4706	
	Median		.1950	
	Variance		.549	
	Std. Deviation		.74119	
	Minimum		.03	
	Maximum		1.60	
	Range		1.57	
	Interquartile Range		1.24	
	Skewness		1.829	1.014
	Kurtosis		3.349	2.619

a Fe is constant when Sample size = Slimes drain 2. It has been omitted.

Ranks

Sample size	N	Mean Rank
Upstream	4	10.88
Slimes drain 1	2	3.00
Slimes drain 2	2	5.50
Slimes drain 3	3	5.67
Downstream	4	10.63
Total	15	

Test Statistics(a,b)

	Mn
Chi-Square	7.524
df	4
Asymp. Sig.	.111

a Kruskal Wallis Test
b Grouping Variable: Sample size

Descriptives(a)

Sample size				Statistic	Std. Error
Upstream	Mean			.0575	.02136
	95% Confidence Interval for Mean		Lower Bound	.0105	
			Upper Bound	.1255	
	5% Trimmed Mean			.0556	
	Median			.0400	
	Variance			.002	
	Std. Deviation			.04272	
	Minimum			.03	
	Maximum			.12	
	Range			.09	
	Interquartile Range			.07	
	Skewness			1.728	1.014
	Kurtosis			2.919	2.619
Slimes drain 2	Mean			.0200	.01000
	95% Confidence Interval for Mean		Lower Bound	.1071	
			Upper Bound	.1471	
	5% Trimmed Mean				
	Median			.0200	
	Variance			.000	
	Std. Deviation			.01414	
	Minimum			.01	
	Maximum			.03	
	Range			.02	
	Interquartile Range			.	
	Skewness			.	.
	Kurtosis			.	.

Slimes drain 3	Mean		.0200	.01000
	95% Confidence Interval for Mean	Lower Bound	.0230	
		Upper Bound	.0630	
	5% Trimmed Mean		.	
	Median		.0100	
	Variance		.000	
	Std. Deviation		.01732	
	Minimum		.01	
	Maximum		.04	
	Range		.03	
	Interquartile Range		.	
	Skewness		1.732	1.225
	Kurtosis		.	.
Downstream	Mean		.0550	.01893
	95% Confidence Interval for Mean	Lower Bound	.0052	
		Upper Bound	.1152	
	5% Trimmed Mean		.0533	
	Median		.0400	
	Variance		.001	
	Std. Deviation		.03786	
	Minimum		.03	
	Maximum		.11	
	Range		.08	
	Interquartile Range		.07	
	Skewness		1.659	1.014
	Kurtosis		2.615	2.619

a Mn is constant when Sample size = Slimes drain 1. It has been omitted.

Ranks

Sample size	N	Mean Rank
Upstream	4	3.75
Slimes drain 1	2	12.50
Slimes drain 2	2	2.50
Slimes drain 3	3	11.33
Downstream	4	5.25
Total	15	

Test Statistics(a,b)

	EC
Chi-Square	10.842
df	4
Asymp. Sig.	.028

a Kruskal Wallis Test
b Grouping Variable: Sample size

Descriptives

Sample size			Statistic	Std. Error
Upstream	Mean		49.500	9.2543
	95% Confidence Interval for Mean	Lower Bound	20.049	
		Upper Bound	78.951	
	5% Trimmed Mean		50.250	
	Median		56.250	
	Variance		342.567	
	Std. Deviation		18.5086	
	Minimum		23.1	
	Maximum		62.4	
	Range		39.3	
	Interquartile Range		32.5	
	Skewness		1.488	1.014
	Kurtosis		1.847	2.619
Slimes drain 1	Mean		1737.500	742.5000
	95% Confidence Interval for Mean	Lower Bound	7696.857	
		Upper Bound	11171.857	
	5% Trimmed Mean		.	
	Median		1737.500	
	Variance		1102612.50	
	Std. Deviation		1050.0536	
	Minimum		995.0	
	Maximum		2480.0	
	Range		1485.0	
	Interquartile Range		.	
	Skewness		.	.
	Kurtosis		.	.
Slimes drain 2	Mean		1521.000	262.0000
	95% Confidence Interval for Mean	Lower Bound	1808.026	
		Upper Bound	4850.026	
	5% Trimmed Mean		.	
	Median		1521.000	
	Variance		137288.000	
	Std. Deviation		370.5240	
	Minimum		1259.0	

	Maximum		1783.0	
	Range		524.0	
Slimes drain 3	Mean		1182.667	308.0959
	95% Confidence Interval for Mean	Lower Bound	142.963	
		Upper Bound	2508.297	
	5% Trimmed Mean		.	
	Median		1326.000	
	Variance		284769.333	
	Std. Deviation		533.6378	
	Minimum		592.0	
	Maximum		1630.0	
	Range		1038.0	
	Interquartile Range		.	
	Skewness		1.121	1.225
	Kurtosis		.	.
Downstream	Mean		54.950	10.6556
	95% Confidence Interval for Mean	Lower Bound	21.039	
		Upper Bound	88.861	
	5% Trimmed Mean		55.783	
	Median		62.450	
	Variance		454.163	
	Std. Deviation		21.3111	
	Minimum		24.1	
	Maximum		70.8	
	Range		46.7	
	Interquartile Range		37.5	
	Skewness		1.617	1.014
	Kurtosis		2.534	2.619

Ranks

Sample size	N	Mean Rank
Upstream	4	3.75
Slimes drain 1	2	12.50
Slimes drain 2	2	12.50
Slimes drain 3	3	11.33
Downstream	4	5.25
Total	15	

Test Statistics(a,b)

	TDS
Chi-Square	10.842
df	4
Asymp. Sig.	.028

a Kruskal Wallis Test
b Grouping Variable: Sample size

Descriptives

Sample size				Statistic	Std. Error
Upstream		Mean		331.50	61.890
	95% Confidence Interval for Mean		Lower Bound	134.54	
			Upper Bound	528.46	
		5% Trimmed Mean		336.50	
		Median		376.50	
		Variance		15321.667	
		Std. Deviation		123.781	
		Minimum		155	
		Maximum		418	
		Range		263	
		Interquartile Range		218	
		Skewness		1.486	1.014
		Kurtosis		1.834	2.619
	Slimes drain 1	Mean		11507.50	5108.500
		95% Confidence Interval for Mean	Lower Bound	53402.15	
			Upper Bound	76417.15	
		5% Trimmed Mean		.	
		Median		11507.50	
		Variance		52193544.5	
		Std. Deviation		7224.510	
		Minimum		6399	
		Maximum		16616	
		Range		10217	
		Interquartile Range		.	
		Skewness		.	.
		Kurtosis		.	.
	Slimes drain 2	Mean		10190.50	1755.50
		95% Confidence Interval for Mean	Lower Bound	12115.24	
			Upper Bound	32496.24	
		5% Trimmed Mean		.	
		Median		10190.50	
		Variance		6163560.50	

	Std. Deviation		2482.652	
	Minimum		8435	
	Maximum		11946	
	Range		3511	
	Interquartile Range		.	
	Skewness		.	.
	Kurtosis		.	.
Slimes drain 3	Mean		7923.67	2064.355
	95% Confidence Interval for Mean	Lower Bound	958.54	
		Upper Bound	16805.87	
	5% Trimmed Mean		.	
	Median		8884.00	
	Variance		12784686.3	
	Std. Deviation		3575.568	
	Minimum		3966	
	Maximum		10921	
	Range		6955	
	Interquartile Range		.	
	Skewness		1.121	1.225
	Kurtosis		.	.
Downs tream	Mean		368.00	71.471
	95% Confidence Interval for Mean	Lower Bound	140.55	
		Upper Bound	595.45	
	5% Trimmed Mean		373.61	
	Median		418.50	
	Variance		20432.667	
	Std. Deviation		142.943	
	Minimum		161	
	Maximum		474	
	Range		313	
	Interquartile Range		251	
	Skewness		1.621	1.014
	Kurtosis		2.547	2.619

APPENDIX C

Laboratory Raw Data Sheets

NAMWATER

Namibia Water Corporation Ltd

Private Bag 13389, Windhoek Namibia
Tel (+264 - 61) 71 2257 Fax (+264 -61) 71 2097

CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS21788
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Up Stream -
COMMENTS	:	EW 4386
DATE SAMPLE TAKEN	:	7/25/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	7/25/2007
DATE SAMPLE ANALYSED	:	8/2/2007

DETERMINANT :	**Value**	**Units**	**Classification**
pH	8.4		A - Excellent
Conductivity mS/m	62.3	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	417	mg/l	
Sodium as Na	61	mg/l	A - Excellent
Potassium as K	2	mg/l	A - Excellent
Sulphate as SO_4	74	mg/l	A - Excellent
Nitrate as N	1.8	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	4	mg/l	
Fluoride as F	0.4	mg/l	A - Excellent
Chloride as Cl	57.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	150	mg/l	
Total Hardness as $CaCO_3$	192	mg/l	A - Excellent
Calcium as $CaCO_3$	100	mg/l	A - Excellent
Magnesium as $CaCO_3$	92	mg/l	A - Excellent
Iron as Fe	0.09	mg/l	A - Excellent
Manganese as Mn	0.03	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	11.3	NTU	Above recommende

REMARKS :

Namibia Water Corporation Ltd

Private Bag 13389, Windhoek Namibia
Tel (+264 - 61) 71 2257 Fax (+264 -61) 71 2097

CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS21787
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Slimes River Point -
COMMENTS	:	EW 4385
DATE SAMPLE TAKEN	:	7/25/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	7/25/2007
DATE SAMPLE ANALYSED	:	8/2/2007

DETERMINANT :	Value	Units	Classification
pH	8.1		
Conductivity mS/m	1326.0	mS/m	
Total dissolved solids calculated from conductivity	8884	mg/l	
Sodium as Na	2000	mg/l	
Potassium as K	18	mg/l	
Sulphate as SO_4	2050	mg/l	
Nitrate as N	<0.5	mg/l	
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	39	mg/l	
Fluoride as F	1.2	mg/l	
Chloride as Cl	2600	mg/l	
Total Alkalinity as $CaCO_3$	184	mg/l	
Total Hardness as $CaCO_3$	1917	mg/l	
Calcium as $CaCO_3$	875	mg/l	
Magnesium as $CaCO_3$	1042	mg/l	
Iron as Fe	0.02	mg/l	
Manganese as Mn	<0.01	mg/l	
Copper as Cu	0.01	mg/l	
Zinc as Zn	0.02	mg/l	
Cadmium as Cd	<0.01	mg/l	
Lead as Pb	<0.02	mg/l	
Turbidity	0.96	NTU	

REMARKS :

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS21789
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Down Stream -
COMMENTS	:	EW 4387
DATE SAMPLE TAKEN	:	7/25/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	7/25/2007
DATE SAMPLE ANALYSED	:	8/2/2007

DETERMINANT :	**Value**	**Units**	**Classification**
pH	8.4		A - Excellent
Conductivity mS/m	67.3	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	451	mg/l	
Sodium as Na	68	mg/l	A - Excellent
Potassium as K	2	mg/l	A - Excellent
Sulphate as SO_4	84	mg/l	A - Excellent
Nitrate as N	2.2	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	4	mg/l	
Fluoride as F	0.4	mg/l	A - Excellent
Chloride as Cl	70.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	152	mg/l	
Total Hardness as $CaCO_3$	211	mg/l	A - Excellent
Calcium as $CaCO_3$	115	mg/l	A - Excellent
Magnesium as $CaCO_3$	96	mg/l	A - Excellent
Iron as Fe	0.07	mg/l	A - Excellent
Manganese as Mn	0.03	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	8.4	NTU	Above recommende

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS21784
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Trench 2 -
COMMENTS	:	EW 4382
DATE SAMPLE TAKEN	:	7/25/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	7/25/2007
DATE SAMPLE ANALYSED	:	8/2/2007

DETERMINANT :	Value	Units	Classification
pH	8.1		
Conductivity mS/m	1259.0	mS/m	
Total dissolved solids calculated from conductivity	8435	mg/l	
Sodium as Na	2000	mg/l	
Potassium as K	32	mg/l	
Sulphate as SO_4	1950	mg/l	
Nitrate as N	<0.5	mg/l	
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	1	mg/l	
Fluoride as F	1.7	mg/l	
Chloride as Cl	2500	mg/l	
Total Alkalinity as $CaCO_3$	98.0	mg/l	
Total Hardness as $CaCO_3$	1546	mg/l	
Calcium as $CaCO_3$	750	mg/l	
Magnesium as $CaCO_3$	796	mg/l	
Iron as Fe	0.01	mg/l	
Manganese as Mn	<0.01	mg/l	
Copper as Cu	0.01	mg/l	
Zinc as Zn	0.01	mg/l	
Cadmium as Cd	<0.01	mg/l	
Lead as Pb	<0.02	mg/l	
Turbidity	0.70	NTU	

REMARKS :

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS21783
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Trench 1 -
COMMENTS	:	EW 4381
DATE SAMPLE TAKEN	:	7/25/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	7/25/2007
DATE SAMPLE ANALYSED	:	8/2/2007

DETERMINANT :	**Value**	**Units**	**Classifica**
pH	8.0		
Conductivity mS/m	2480.0	mS/m	
Total dissolved solids calculated from conductivity	16616	mg/l	
Sodium as Na	4300	mg/l	
Potassium as K	58	mg/l	
Sulphate as SO_4	3200	mg/l	
Nitrate as N	<0.5	mg/l	
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	6	mg/l	
Fluoride as F	2.6	mg/l	
Chloride as Cl	5700	mg/l	
Total Alkalinity as $CaCO_3$	160	mg/l	
Total Hardness as $CaCO_3$	2667	mg/l	
Calcium as $CaCO_3$	1625	mg/l	
Magnesium as $CaCO_3$	1042	mg/l	
Iron as Fe	0.02	mg/l	
Manganese as Mn	0.01	mg/l	
Copper as Cu	0.02	mg/l	
Zinc as Zn	0.02	mg/l	
Cadmium as Cd	<0.01	mg/l	
Lead as Pb	<0.02	mg/l	
Turbidity	0.73	NTU	

REMARKS :

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS20844
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	River down stream -
COMMENTS	:	EW4207
DATE SAMPLE TAKEN	:	3/28/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	3/29/2007
DATE SAMPLE ANALYSED	:	4/11/2007

DETERMINANT :	**Value**	**Units**	**Classificatio**
pH	8.3		A - Excellent
Conductivity mS/m	57.6	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	386	mg/l	
Sodium as Na	52	mg/l	A - Excellent
Potassium as K	3	mg/l	A - Excellent
Sulphate as SO_4	57	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	19	mg/l	
Fluoride as F	0.3	mg/l	A - Excellent
Chloride as Cl	60.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	136	mg/l	
Total Hardness as $CaCO_3$	180	mg/l	A - Excellent
Calcium as $CaCO_3$	105	mg/l	A - Excellent
Magnesium as $CaCO_3$	75	mg/l	A - Excellent
Iron as Fe	0.03	mg/l	A - Excellent
Manganese as Mn	0.03	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	0.02	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	51.8	NTU	Above recomr
Colour	10.0	mg/l Pt	Within recomr
Total Kjehldahl as N	0.90	mg/l	
Ammonia as N	0.02	mg/l	
Dissolved Oxygen as O2	4.9	mg/l	
Oxidation Reduction Potential in mV	+148	mg/l	
Total Phosphate (Unfiltered) as P	0.07	mg/l	
Oxygen Absorbed	1.00	mg/l	
Chemical Oxygen Demand as COD	11.7	mg/l	
Biochemical Oxygen Demand as BOD	<1.00	mg/l	

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS20845
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	River up stream -
COMMENTS	:	EW4208
DATE SAMPLE TAKEN	:	3/28/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	3/29/2007
DATE SAMPLE ANALYSED	:	4/11/2007

DETERMINANT :	Value	Units	Classificatioı
pH	8.3		A - Excellent
Conductivity mS/m	50.2	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	336	mg/l	
Sodium as Na	41	mg/l	A - Excellent
Potassium as K	3	mg/l	A - Excellent
Sulphate as SO_4	47	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	19	mg/l	
Fluoride as F	0.3	mg/l	A - Excellent
Chloride as Cl	37.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	136	mg/l	
Total Hardness as $CaCO_3$	157	mg/l	A - Excellent
Calcium as $CaCO_3$	90	mg/l	A - Excellent
Magnesium as $CaCO_3$	67	mg/l	A - Excellent
Iron as Fe	0.03	mg/l	A - Excellent
Manganese as Mn	0.03	mg/l	A - Excellent
Copper as Cu	0.02	mg/l	A - Excellent
Zinc as Zn	0.02	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	46.3	NTU	Above recomı
Colour	13.0	mg/l Pt	Within recomı
Total Kjehldahl as N	0.40	mg/l	
Ammonia as N	0.02	mg/l	
Dissolved Oxygen as O2	5.8	mg/l	
Oxidation Reduction Potential in mV	+157	mg/l	
Total Phosphate (Unfiltered) as P	0.07	mg/l	
Oxygen Absorbed	1.00	mg/l	
Chemical Oxygen Demand as COD	39.0	mg/l	
Biochemical Oxygen Demand as BOD	2.0	mg/l	

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	:	DS20841
SENDER	:	Namdeb
SAMPLE POINT NAME	:	Daberas
AREA DESCRIPTION	:	-
LOCATION DESCRIPTION	:	Slimes -
COMMENTS	:	EW4204
DATE SAMPLE TAKEN	:	3/28/2007
TIME TAKEN	:	-
DATE SAMPLE RECEIVED	:	3/29/2007
DATE SAMPLE ANALYSED	:	4/11/2007

DETERMINANT :	**Value**	**Units**	**Classification**
pH	8.3		A - Excellent
Conductivity mS/m	1630.0	mS/m	D - Unsuitable for stockwatering
Total dissolved solids calculated from conductivity	10921	mg/l	
Sodium as Na	2300	mg/l	D - Unsuitable for stockwatering
Potassium as K	20	mg/l	A - Excellent
Sulphate as SO_4	2100	mg/l	D - Unsuitable for stockwatering
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	20	mg/l	
Fluoride as F	1.1	mg/l	A - Excellent
Chloride as Cl	3500	mg/l	D - Unsuitable for stockwatering
Total Alkalinity as $CaCO_3$	200	mg/l	
Total Hardness as $CaCO_3$	2650	mg/l	D - High risk
Calcium as $CaCO_3$	1275	mg/l	D - High risk
Magnesium as $CaCO_3$	1375	mg/l	D - High risk
Iron as Fe	<0.01	mg/l	A - Excellent
Manganese as Mn	<0.01	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	0.02	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	2.4	NTU	B - Good
Colour	10.0	mg/l Pt	Within recommended limit
Total Kjehldahl as N	0.90	mg/l	
Ammonia as N	0.02	mg/l	
Dissolved Oxygen as O2	4.6	mg/l	
Oxidation Reduction Potential in mV	+137	mg/l	
Total Phosphate (Unfiltered) as P	0.01	mg/l	
Oxygen Absorbed	1.6	mg/l	
Chemical Oxygen Demand as COD	8.0	mg/l	
Biochemical Oxygen Demand as BOD	<1.00	mg/l	

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS19937
SENDER	: Namdeb
SAMPLE POINT NAME	: Daberas
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Up Stream -
COMMENTS	: -
DATE SAMPLE TAKEN	: 21/11/2006
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 22/11/2006
DATE SAMPLE ANALYSED	: 23/11/2006

DETERMINANT :	Value	Units	Classification
pH	8.4		A - Excellent
Conductivity mS/m	23.1	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	155	mg/l	
Sodium as Na	12	mg/l	A - Excellent
Potassium as K	3	mg/l	A - Excellent
Sulphate as SO_4	19	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	0.1	mg/l	
Silicate as SiO_2	16	mg/l	
Fluoride as F	2.1	mg/l	C - Low risk
Chloride as Cl	7.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	94.0	mg/l	
Total Hardness as $CaCO_3$	104	mg/l	A - Excellent
Calcium as $CaCO_3$	63	mg/l	A - Excellent
Magnesium as $CaCO_3$	42	mg/l	A - Excellent
Iron as Fe	1.3	mg/l	C - Low risk
Manganese as Mn	0.05	mg/l	A - Excellent
Copper as Cu	0.02	mg/l	A - Excellent
Zinc as Zn	<0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	107	NTU	Above recommended limit
Colour	496	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class C : Low risk water
Stockwatering : Suitable

FLUORIDE: Protracted intake of water with fluoride concentrations greater than 2.0 mg/l causes mottling of teeth and from 3-6 mg/l skeletal fluorosis can occur.
IRON: High iron concentration in water is aesthetically undesirable, gives rise to discolouration, staining and taste problems.
TURBIDITY: Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS19936
SENDER	: Namdeb
SAMPLE POINT NAME	: Daberas
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Down Stream -
COMMENTS	: -
DATE SAMPLE TAKEN	: 21/11/2006
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 22/11/2006
DATE SAMPLE ANALYSED	: 23/11/2006

DETERMINANT :	Value	Units	Classification
pH	8.4		A - Excellent
Conductivity mS/m	24.1	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	161	mg/l	
Sodium as Na	12	mg/l	A - Excellent
Potassium as K	3	mg/l	A - Excellent
Sulphate as SO_4	20	mg/l	A - Excellent
Nitrate as N	0.4	mg/l	A - Excellent
Nitrite as N	0.1	mg/l	
Silicate as SiO_2	16	mg/l	
Fluoride as F	0.2	mg/l	A - Excellent
Chloride as Cl	9.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	92.0	mg/l	
Total Hardness as $CaCO_3$	102	mg/l	A - Excellent
Calcium as $CaCO_3$	60	mg/l	A - Excellent
Magnesium as $CaCO_3$	42	mg/l	A - Excellent
Iron as Fe	1.6	mg/l	C - Low risk
Manganese as Mn	0.05	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	<0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	104	NTU	Above recommended limit
Colour	459	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class C : Low risk water
Stockwatering : Suitable

IRON: High iron concentration in water is aesthetically undesirable, gives rise to discolouration, staining and taste problems.
TURBIDITY : Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS19932
SENDER	: Namdeb
SAMPLE POINT NAME	: Daberas
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Slimes Drain 1 -
COMMENTS	: -
DATE SAMPLE TAKEN	: 21/11/2006
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 22/11/2006
DATE SAMPLE ANALYSED	: 23/11/2006

DETERMINANT :	Value	Units	Classification
pH	7.8		A - Excellent
Conductivity mS/m	955.0	mS/m	D - Unsuitable for stockwatering
Total dissolved solids calculated from conductivity	6399	mg/l	
Sodium as Na	1720	mg/l	D - High risk
Potassium as K	14	mg/l	A - Excellent
Sulphate as SO_4	3240	mg/l	D - Unsuitable for stockwatering
Nitrate as N	3.1	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	20	mg/l	
Fluoride as F	2.5	mg/l	C - Low risk
Chloride as Cl	1520	mg/l	D - High risk
Total Alkalinity as $CaCO_3$	80.0	mg/l	
Total Hardness as $CaCO_3$	1763	mg/l	D - High risk
Calcium as $CaCO_3$	1400	mg/l	D - High risk
Magnesium as $CaCO_3$	363	mg/l	B - Good
Iron as Fe	0.01	mg/l	A - Excellent
Manganese as Mn	<0.01	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	<0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	0.85	NTU	A - Excellent
Colour	2.0	mg/l Pt	Within recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class D : Unsuitable for human consumption
Stockwatering : Unsuitable

CONDUCTIVITY: Conductivity is a function of the total dissolved solids in the water. A conductivity of 300 mS/m corresponds to approximately 2000 mg/l total dissolved solids.
SODIUM: Guideline values for sodium are based on taste considerations. High sodium levels can give high blood pressure.
SULPHATE: Guideline values for sulphate are based on taste considerations. Water containing high concentrations of sulphate can have a laxative effect which is enhanced when consumed in combination with magnesium. Metal corrosion and degradation of concrete and asbestos cement may be increased by high sulphate levels.
FLUORIDE: Protracted intake of water with fluoride concentrations greater than 2.0 mg/l causes mottling of teeth and from 3-6 mg/l skeletal fluorosis can occur.
CHLORIDE: Guideline values for chloride are based on taste considerations. High concentrat.ons give rise to corrosion of metals.
TOTAL HARDNESS: Guideline values for total hardness are based on taste and household considerations. Depending on the calcium and magnesium salt combination, high levels can cause scaling. In addition, hard water results in excessive soap consumption and subsequent scum formation.
CALCIUM: Guideline values for calcium are based on taste and household consideration. High calcium concentrations cause scaling problems and excessive soap consumption.

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS19933
SENDER	: Namdeb
SAMPLE POINT NAME	: Daberas
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Slimes Drain 2 -
COMMENTS	: -
DATE SAMPLE TAKEN	: 21/11/2006
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 22/11/2006
DATE SAMPLE ANALYSED	: 23/11/2006

DETERMINANT :	Value	Units	Classification
pH	8.0		A - Excellent
Conductivity mS/m	1783.0	mS/m	D - Unsuitable for stockwatering
Total dissolved solids calculated from conductivity	11946	mg/l	
Sodium as Na	2670	mg/l	D - Unsuitable for stockwatering
Potassium as K	31	mg/l	A - Excellent
Sulphate as SO_4	3550	mg/l	D - Unsuitable for stockwatering
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	29	mg/l	
Fluoride as F	1.2	mg/l	A - Excellent
Chloride as Cl	3700	mg/l	D - Unsuitable for stockwatering
Total Alkalinity as $CaCO_3$	184	mg/l	
Total Hardness as $CaCO_3$	2867	mg/l	D - Unsuitable for stockwatering
Calcium as $CaCO_3$	1325	mg/l	D - High risk
Magnesium as $CaCO_3$	1542	mg/l	D - High risk
Iron as Fe	0.01	mg/l	A - Excellent
Manganese as Mn	0.03	mg/l	A - Excellent
Copper as Cu	0.01	mg/l	A - Excellent
Zinc as Zn	<0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	1.5	NTU	B - Good
Colour	21.0	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class D : Unsuitable for human consumption
Stockwatering : Unsuitable

CONDUCTIVITY: Conductivity is a function of the total dissolved solids in the water. A conductivity of 300 mS/m corresponds to approximately 2000 mg/l total dissolved solids.
SODIUM: Guideline values for sodium are based on taste considerations. High sodium levels can give high blood pressure.
SULPHATE: Guideline values for sulphate are based on taste considerations. Water containing high concentrations of sulphate can have a laxative effect which is enhanced when consumed in combination with magnesium. Metal corrosion and degradation of concrete and asbestos cement may be increased by high sulphate levels.
CHLORIDE: Guideline values for chloride are based on taste considerations. High concentrations give rise to corrosion of metals.
TOTAL HARDNESS: Guideline values for total hardness are based on taste and household considerations. Depending on the calcium and magnesium salt combination, high levels can cause scaling. In addition, hard water results in excessive soap consumption and subsequent scum formation.
CALCIUM: Guideline values for calcium are based on taste and household consideration. High calcium concentrations cause scaling problems and excessive soap consumption.
MAGNESIUM: Magnesium concentrations greater than 420 mg/l give rise to an unpleasant taste. Magnesium, in association with sulphate, may have laxative properties, but the human body can adapt to this effect in time.
COLOUR Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS19938
SENDER	: Namdeb
SAMPLE POINT NAME	: Daberas
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Slimes Dam -
COMMENTS	: -
DATE SAMPLE TAKEN	: 21/11/2006
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 22/11/2006
DATE SAMPLE ANALYSED	: 23/11/2006

DETERMINANT :	Value	Units	Classification
pH	8.4		A - Excellent
Conductivity mS/m	592.0	mS/m	D - High risk
Total dissolved solids calculated from conductivity	3966	mg/l	
Sodium as Na	1080	mg/l	D - High risk
Potassium as K	5	mg/l	A - Excellent
Sulphate as SO_4	830	mg/l	C - Low risk
Nitrate as N	1.0	mg/l	A - Excellent
Nitrite as N	0.1	mg/l	
Silicate as SiO_2	12	mg/l	
Fluoride as F	2.1	mg/l	C - Low risk
Chloride as Cl	1070	mg/l	C - Low risk
Total Alkalinity as $CaCO_3$	108	mg/l	
Total Hardness as $CaCO_3$	263	mg/l	A - Excellent
Calcium as $CaCO_3$	188	mg/l	A - Excellent
Magnesium as $CaCO_3$	75	mg/l	A - Excellent
Iron as Fe	0.46	mg/l	B - Good
Manganese as Mn	0.04	mg/l	A - Excellent
Copper as Cu	0.02	mg/l	A - Excellent
Zinc as Zn	<0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	612	NTU	Above recommended limit
Colour	99.0	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class D : Unsuitable for human consumption
Stockwatering : Suitable

CONDUCTIVITY: Conductivity is a function of the total dissolved solids in the water. A conductivity of 300 mS/m corresponds to approximately 2000 mg/l total dissolved solids.
SODIUM: Guideline values for sodium are based on taste considerations. High sodium levels can give high blood pressure.
SULPHATE: Guideline values for sulphate are based on taste considerations. Water containing high concentrations of sulphate can have a laxative effect which is enhanced when consumed in combination with magnesium. Metal corrosion and degradation of concrete and asbestos cement may be increased by high sulphate levels.
FLUORIDE: Protracted intake of water with fluoride concentrations greater than 2.0 mg/l causes mottling of teeth and from 3-6 mg/l skeletal fluorosis can occur.
CHLORIDE: Guideline values for chloride are based on taste considerations. High concentrations give rise to corrosion of metals.
TURBIDITY : Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

M.Conradie **Pr.Sci.Nat.**
Senior Technician : Water Quality Services

E.Honga
Manager : Water Quality Services

DS19938

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS18514
SENDER	: Namdeb
SAMPLE POINT NAME	: Orange River
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Upstream -
COMMENTS	: -
DATE SAMPLE TAKEN	: 28/11/2005
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 30/11/2005
DATE SAMPLE ANALYSED	: 1/12/2005

DETERMINANT :	Value	Units	Classification
pH	8.7		A - Excellent
Conductivity mS/m	62.4	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	418	mg/l	
Sodium as Na	81	mg/l	A - Excellent
Potassium as K	4	mg/l	A - Excellent
Sulphate as SO_4	69	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	2	mg/l	
Fluoride as F	0.5	mg/l	A - Excellent
Chloride as Cl	77.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	162	mg/l	
Phenolphthalein Alkalinity as $CaCO_3$	4.0	mg/l	
Total Hardness as $CaCO_3$	177	mg/l	A - Excellent
Calcium as $CaCO_3$	73	mg/l	A - Excellent
Magnesium as $CaCO_3$	104	mg/l	A - Excellent
Iron as Fe	0.34	mg/l	B - Good
Manganese as Mn	0.12	mg/l	B - Good
Copper as Cu	0.02	mg/l	A - Excellent
Zinc as Zn	0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	44.8	NTU	Above recommended limit
Colour	54.0	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class B : Suitable for human consumption
Stockwatering : Suitable

TURBIDITY : Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

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DS18514

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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER	: DS18515
SENDER	: Namdeb
SAMPLE POINT NAME	: Orange River
AREA DESCRIPTION	: -
LOCATION DESCRIPTION	: Downstream -
COMMENTS	: -
DATE SAMPLE TAKEN	: 28/11/2005
TIME TAKEN	: -
DATE SAMPLE RECEIVED	: 30/11/2005
DATE SAMPLE ANALYSED	: 1/12/2005

DETERMINANT :	Value	Units	Classification
pH	8.7		A - Excellent
Conductivity mS/m	70.8	mS/m	A - Excellent
Total dissolved solids calculated from conductivity	474	mg/l	
Sodium as Na	81	mg/l	A - Excellent
Potassium as K	4	mg/l	A - Excellent
Sulphate as SO_4	73	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	1	mg/l	
Fluoride as F	0.5	mg/l	A - Excellent
Chloride as Cl	84.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	164	mg/l	
Phenolphthalein Alkalinity as $CaCO_3$	4.0	mg/l	
Total Hardness as $CaCO_3$	188	mg/l	A - Excellent
Calcium as $CaCO_3$	80	mg/l	A - Excellent
Magnesium as $CaCO_3$	108	mg/l	A - Excellent
Iron as Fe	0.32	mg/l	B - Good
Manganese as Mn	0.11	mg/l	B - Good
Copper as Cu	0.02	mg/l	A - Excellent
Zinc as Zn	0.01	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	64.7	NTU	Above recommended limit
Colour	58.0	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class B : Suitable for human consumption
Stockwatering : Suitable

TURBIDITY : Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

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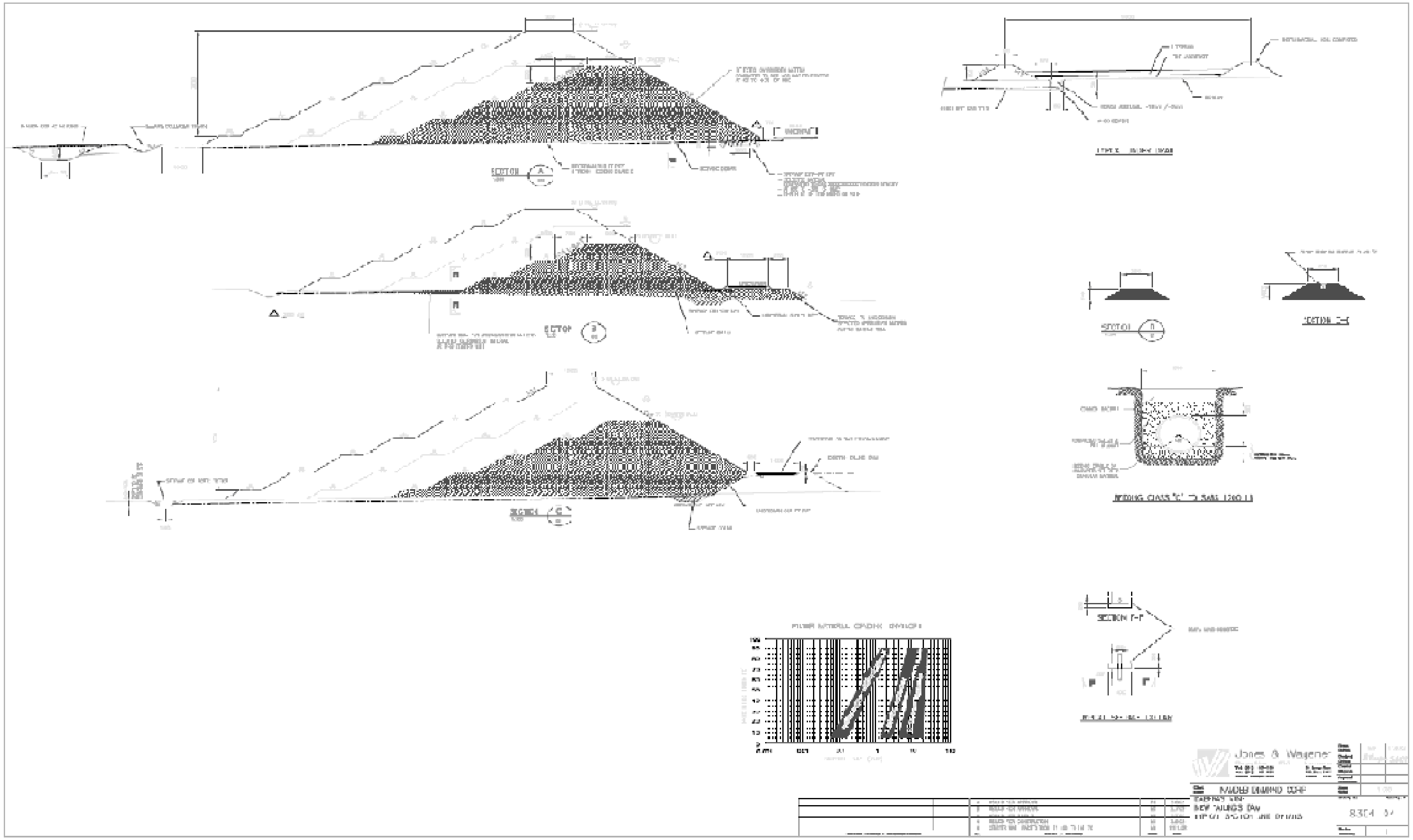
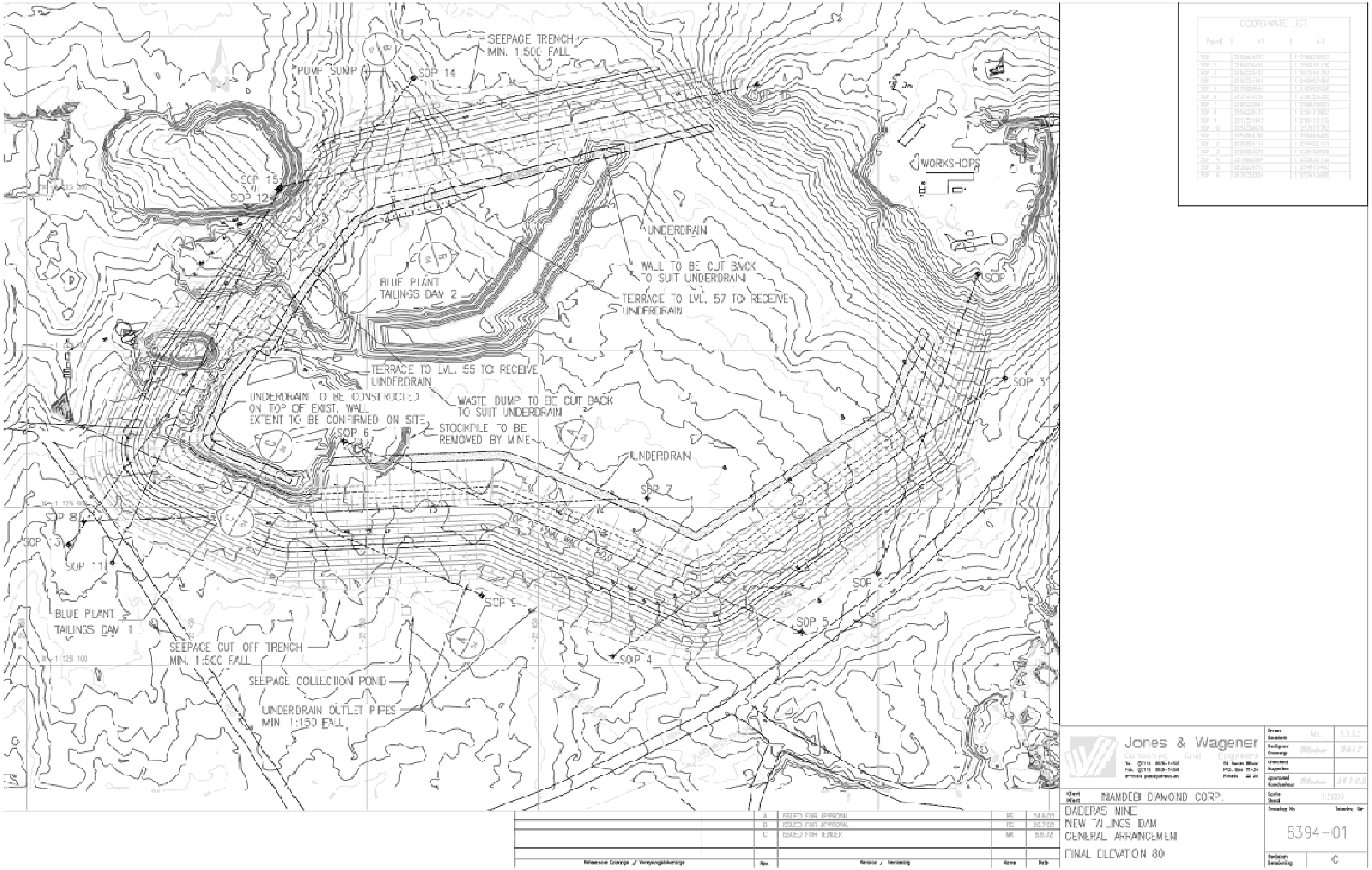
DS18515

APPENDIX D
Slimes dam Engineering designs




SEEPAGE TRENCH
MIN. 1:500 FALL
PUMP SUMP
SOP 14
SOP 13
SOP 12
WORKSHOPS
UNDERDRAIN
WALL TO BE CUT BACK
TO SUIT UNDERDRAIN
TERRACE TO LVL. 57 TO RECEIVE
UNDERDRAIN
BLUE PLANT
TAILINGS DAM 2
TERRACE TO LVL. 55 TO RECEIVE
UNDERDRAIN
UNDERDRAIN TO BE CONSTRUCTED
ON TOP OF EXIST. WALL
EXTENT TO BE CONFIRMED ON SITE
WASTE DUMP TO BE CUT BACK
TO SUIT UNDERDRAIN
STOCKPILE TO BE
REMOVED BY MINE
SOP 6
SOP 3
SOP 7
SOP 8
SOP 11
BLUE PLANT
TAILINGS DAM 1
SEEPAGE CUT OFF TRENCH
MIN. 1:500 FALL
SOP 5
SOP 4
SEEPAGE COLLECTION POND
UNDERDRAIN OUTLET PIPES
MIN. 1:150 FALL
COORDINATE LIST
Jones & Wagener
Consulting Civil Engineers
ISSUED FOR APPROVAL
ISSUED FOR APPROVAL
ISSUED FOR TENDER
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