

**A HOLISTIC HYDROGEOLOGICAL
ENVIRONMENTAL SITE RISK ASSESSMENT
METHODOLOGY FOR THE FERTILISER
INDUSTRY IN SOUTH AFRICA**

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THESIS

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DECLARATION

I, George Frederik (Ferdie) Linde, declare that the thesis hereby submitted by me for the Doctor of Philosophy degree at the University of the Free State., is my own independent work and has not previously been submitted by me at another university/faculty. I further more cede copyright of the thesis in favour of the University of the Free State.

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ABBREVIATIONS

BPD:	Barrels Per Day
BTEX:	Benzene, Toluene, Ethylbenzene and Xylenes
CTL:	Coal to Liquid
DNAPL:	Dense Non-Aqueous Phase Liquid
DWEA:	Department of Water and Environmental Affairs
EIA:	Environmental Impact Assessment
EMS:	Environmental Management Systems
GAAP (US):	General Accepted Accounting Principles
GRI:	Global Reporting Initiative
GTL:	Gas to Liquid
IAS:	International Accounting Standard
IASB:	International Accounting Standards Board
IASC:	International Accounting Standards Committee
IFAC:	International Federation of Accountants
IFRS:	International Financial Reporting Standards
IGS:	Institute for Ground water Studies
ISO:	International Standards Organisation
LAN:	Limestone Ammonium Nitrate
LLDPE:	Linear Low Density Polyethylene
MAP:	Mono Ammonium Phosphate
MCP:	Mono Calcium Phosphate
MoP	Muriate of Potash
NEMA:	National Environmental Management Act
NEMAQA:	National Environmental Management: Air Quality Act
NATREF:	National Petroleum Refiners of SA Ltd.
NWA:	National Water Act
PNS:	Plant Nutrient Sulphur
PVC:	Polyvinyl Chloride
SEC:	Securities Exchange Commission

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SAPREF: South Africa Petroleum Refinery Ltd.
SF: Storativity of the Fracture
SCI: SASOL Chemical Industries
SM: Storativity of the Matrix
SSP: Single Super Phosphate
TF: Transmissivity of the Fracture
TM: Transmissivity of the Matrix
URA: Urban Risk Assessment Tool
USEPA: United States Environmental Protection Agency
UST: Underground Storage Tank
VCM: Vinyl Chloride Monomer
WISH: Windows Interpretation System for the Hydrogeologist

ACRONYMS

Ammonia	NH_4
Ammonium Nitrate Solution	NH_4NO_3
Ammonium Sulphate	NH_4SO_4
Bicarbonate	HCO_3
Boron	B
Calcium	Ca
Calcium Nitrate	$\text{Ca}(\text{NO}_3)_2$
Chloride	Cl
Copper	Cu
Fluoride	F
Defluorinated Phosphoric Acid	P_2O_5
Iron	Fe
Mercury	Hg
Magnesium	Mg
Manganese	Mn
Molybdenum	Mo
Mono Ammonium Phosphate	$\text{NH}_4 \cdot \text{H}_2\text{PO}_4$
Mono Calcium Phosphate	$\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$
Nitrate	NO_3
Nitric Acid	HNO_3
Nitrite	NO_2
Nitro Phosphate	$\text{NH}_4\text{NO}_3 \cdot \text{NH}_3\text{H}_2\text{PO}_4 \cdot (\text{NH}_3)_2\text{HPO}_4$
Ortho Phosphate	PO_4
Phosphoric Acid	H_3PO_4
Potassium	K
Potassium Chloride	KCl
Silica	Si
Single Super phosphate	P_2O_5 (soluble)
Sodium	Na
Sulphate	SO_4

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Tetrasodium Pyrophosphate

$\text{Na}_4\text{P}_2\text{O}_7$

Urea

$(\text{NH}_2)_2\text{CO}$

Vanadium

V

Zinc Oxide

ZnO

MEASURING UNITS

CEC	Cation Exchange Capacity
Cmol/kg	Centimol per kilogram
COD	Chemical Oxygen Demand
cfu/100ml	Colony forming units per 100 millilitres
EC	Electrical Conductivity
ha	Hectares
km	Kilometre
km ²	Square kilometre
l/s	Litres per second
m	Metre
m ⁻¹	Per metre
m ²	Square metres
m ² /d	Metres squared per day
m ³ /a	Cubic metres per annum
mamsl	Metres above mean sea level
magl	Metres above ground level
mbgl	Metres below ground level
meq	Milli equivalent
mg/l	Milligram per litre
mm	Millimetre
mm/a	Millimetre per annum
Mm ³ /a	Million cubic metres
mS/m	Milli-siemens per metre
TDS	Total Dissolved Solids

CHAPTER 1: INTRODUCTION

1.1 PREFACE

“Ten years into the twenty-first century, environmental issues are prominent in people’s minds and they dominate political agendas.” (Kidd: 2011).

There is a continued increase in environmental awareness driven by legal and voluntary requirements in South Africa.

Since 1996, Environmental Management Systems (EMS’s) have been designed, developed and implemented by numerous industries to conform to the then, newly published, International Standards Organisation’s (ISO) standard for environmental management systems (ISO 14001:1996). According to the ISO, the ISO 14001 standard has been adopted as a national standard by more than half of the 160 national members of ISO. Its use is encouraged by governments around the world. Although certification of conformity to the standard is not a requirement of ISO 14001, at the end of 2007, at least 154 572 certificates had been issued in 148 countries and economies (International Standards Organisation, 2012). In South Africa, there has been a continuous evolution of environmental laws and regulations, in particular since 1998. As such, there has been an increase in awareness on environmental matters such as reduction of natural resources and environmental pollution incidents. Subsequently, an awareness of potential financial liabilities for remediation and third party liability have evolved and has increasingly been debated by organs of state, business leaders and industry themselves.

Similarly, there has been an increase in international accounting standards that seek to acknowledge and quantify, in financial reporting practises, environmental liabilities. In addition to an increase in international accounting standards on environmental liabilities, there are additional voluntary requirements that are imposed on listed companies for the inclusion of information on the impact it has on environment and society. The main intent of these so called “Integrated Reports” is to provide stakeholders with a broader spectrum of information which might influence and affect a company as going concern.

“In South Africa, King III calls for organisations to prepare an integrated report, recognising that the impact of the organisation on the environment and society, and related reputational issues, are material issues that can affect the very existence of the organisation. Following the incorporation of King III into the Johannesburg Stock Exchange (JSE) Listings Requirements, listed companies are required to issue an integrated report for financial years starting on or after 1 March 2010, or to explain why they are not doing so. Various other initiatives in the country are adding to the call for integrated reports.” (Institute of Directors, 2011). (Judge Mervyn King is a leader in integrated and sustainability reporting thinking. Mervyn King consults and advises on corporate legal issues. He is recognised internationally as an expert on corporate governance and sustainability. He sits as an arbitrator and as a mediator. He is a founding member of the Arbitration Foundation of Southern Africa and for some eight years was the South African judge at the ICC International Court of Arbitration in Paris. He has acted as an Inspector of Companies and a Commissioner of Inquiries into the affairs of companies. He has chaired many meetings for the compromise of creditors of companies and the rearrangement of shareholders’ interests. He has spoken at conferences and lectured on corporate issues in 38 countries. He is a regular speaker on radio and television talk shows and ran his own television series, “King on Governance”).

An ongoing challenge for company leadership is to identify environmental impacts, to quantify its significance in liability terms and whether there is a need to report this in a responsible way to stakeholders. A particular challenge is to apply a methodology which is appropriate and repeatable for the assessment of ground water impacts and associated liabilities.

As such, methodologies will have to be established and implemented by industry to assess environmental impacts and to translate the scientific information to acceptable financial liability statements. The quantification of ground water impacts, in particular, would be important as it provides a “footprint” of an industries’ environmental impact, which not only affects a water resource, but can be assessed and measured, in some instances, centuries after the impact has occurred.

“The requirement for listed companies to file financial reports emerged out of the Great Depression in the early 1930s with the Securities Act of 1933 requiring companies to provide potential investors with sufficient information to make an informed investment decision. Much later, in the 1990s, some leading companies voluntarily began to publish sustainability reports reflecting a growing understanding of sustainability challenges and stakeholder calls for more informed corporate disclosure. Now, in the context of the global financial crisis and amidst increasing evidence that the current economic model is socially and environmentally unsustainable and that current reporting practice is not delivering, it is time for new and more effective forms of accountability.” (Institute of Directors, 2011).

1.2 STRUCTURE OF THESIS

The development of an environmental hydrogeological site risk assessment methodology for the fertiliser industry in South Africa is the focus of this thesis. Subsequently an industrial site (Omnia Fertiliser Sasolburg) is used to develop the methodology. The thesis is therefore divided into the following sections:

- The first section (Chapter 3) provides the reader of with the background setting of the industrial site (Omnia Fertiliser). The location, history, production processes, environmental aspects and impacts, point and diffuse pollution sources, other industries in the vicinity which might impact on water resources and information generated by the formal Environmental Management System (EMS) is discussed;
- The second section (Chapter 4) provides the reader to the physical characteristics of the study area such as the geology, soil characteristics, climate, topography, hydrography and the site water balance;
- The third section (Chapter 5) provides the reader with a conceptual ground water model of the study area. The conceptual model indicates pollution risk to receptors such as Henry’s dam and evaluates ground water vulnerability for the study area;
- The fourth section (Chapter 6) provides the reader with the ground water monitoring network design, inadequacies in the ground water monitoring design and the results of the ground water sampling;

- The fifth section (Chapter 7) provides the reader with the surface water sampling network and the results of the surface water sampling;
- The sixth section (Chapter 8) considers the human and ecological health risk posed by the monitoring results for ground and surface water and associated receptors;
- The seventh section (Chapter 9) deals with the environmental regulatory framework applicable to the study area and the site;
- The eighth section (Chapter 10) provides the reader with the liability risk analysis framework under two accounting regimes the IFRS and US GAAP; and
- The ninth and last section (Chapter 11) draws the conclusion and proposed environmental site risk assessment methodology derived from this study for the South African fertiliser industry.

1.3 HYPOTHESIS

It is hypothesised that the application of a systematic methodology, which is aligned with the principles contained in formal environmental management systems thinking, such as ISO 14001:2004 could be used to reasonably inform the International Audit Standard 37 (IAS 37) on the financial reportability of the hydrogeological environmental impact and associated potential financial liability.

1.4 OBJECTIVE

No single methodology, which is used as an industry standard has been established and formalised for hydrogeological environmental site risk assessment and liability evaluation for the fertiliser industry in South Africa.

There is inconsistency in the hydrogeological environmental impact assessment approach followed by the fertiliser manufacturers in South Africa and often between different sites of the same legal entity. The results, which, based on the inconsistent approach in numerous instances is uncertain with regard to its accuracy in describing the environmental impact on ground water, both holistically and cumulatively.

The reliance that can thus be placed on the information provided to stakeholders by way of integrated reporting is thus of concern, and might not provide, a true reflection of the holistic and cumulative impact which the fertiliser industries have on ground water. The result is that numerous fertiliser companies in South Africa are unable to present to their stakeholders information on ground water impact which has been derived from the implementation of a standardised liability assessment methodology.

The objective of this thesis is to philosophise, design and test a hydrogeological environmental site risk assessment methodology which, can be applied in the fertiliser industry in South Africa, in order to inform a decision on the International Audit Standard 37 (IAS 37) on the financial reportability of the hydrogeological environmental impact and associated potential financial liability.

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This thesis is also an attempt to introduce a number of environmental management principles in the assessment and evaluation of ground water impact, the intent of which is to provide the fertiliser industry with an improved ground water impact liability and reporting risk understanding.

The methodology derived is new to the field of hydrogeology in South Africa.

CHAPTER 2: RESEARCH METHODOLOGY

An international literature review on hydrogeological environmental risk assessment methodologies returned limited results on the subject of this thesis. It is evident from the international literature study review that most research conducted is in the field of fertiliser application in agricultural use and its impact on ground water. As such, the writer of this thesis have relied on experience gained in the fields of EMS design, development, implementation and sustenance as well as environmental risk assessment and environmental audit experience gained over a career of thirteen years, to guide the approach to the development of a holistic hydrogeological environmental risk assessment methodology for the fertiliser industry in South Africa. The writer has obtained approval by Omnia Holdings (Pty) Ltd., to use their Sasolburg production operation to develop, test and apply the holistic hydrogeological environmental risk assessment methodology.

The Omnia Fertiliser Sasolburg site is deemed an appropriate site to design, test and apply the proposed hypothetical, holistic hydrogeological environmental risk assessment methodology due to its size, complexity and age. A summary is provided below of the reasons why the site is deemed appropriate:

- Omnia Fertiliser Sasolburg, a division of Omnia Holdings, is located in the complex Northern Industrial Area of Sasolburg, in the Free State Province of South Africa;
- Main production activities and products are fertiliser and explosives ingredients and fertiliser blends (solid and liquid);
- The operation has been active since the early 1960's;
- The manufacturing industries involved in the manufacturing of fertilisers and explosive ingredients are notoriously known to cause and have caused ground water impacts. This is mainly as a result of the type, quantity and toxicity of chemicals dealt with on site;
- Numerous other heavy industries operate in vicinity of Omnia Fertiliser Sasolburg, creating a cumulative ground water impact threat;
- A number of *ad-hoc* ground water monitoring activities have been performed in the study area since 1998 by numerous companies/consultants. These studies have not been linked to provide a holistic and cumulative overview of the ground water impact status of the study area;

- Limited evidence exist that that the scope of work for consultants/companies appointed for the historic ground water studies have included a requirement to consider and utilise information generated by the certified ISO 14001:2004 Environmental Management System (EMS), which could have assisted with a better and more holistic understanding of the risk associated with the ground water impact;
- There also has been inconsistency in approach by consultants/companies used on the Omnia Fertiliser Sasolburg site (and other Omnia Fertiliser operations) to assess ground water impact risk and potential liabilities;
- The Omnia Fertiliser Sasolburg site has developed and implemented an EMS to the requirements of ISO 14001:2004 and is certified;
- There is management commitment from Omnia to better understand their ground water impact, potential liabilities arising from this impact and to take all reasonable measures to prevent, mitigate and remediate the ground water impact; and
- Omnia Holdings is listed on the Johannesburg stock exchange, and integrated reporting requirements are applicable to this legal entity.

The following steps are undertaken as part of the approach to develop the hydrogeological environmental risk assessment methodology:

- Obtaining and reviewing previous ground water investigation and environmental management related reports for the study area;
- Performing an environmental site assessment of Omnia Fertiliser Sasolburg through a site visit and site and information “walk-through” based in the clauses and principles of ISO 14001:2004, and EMS audits;
- Numerous interviews with site operational managers in obtaining and understanding of the site operational and production processes including an identification and description of the main chemicals used on site;
- Identifying the type of activities taking place on the Omnia Fertiliser Sasolburg production site;
- Identifying information contained as part of the formal ISO 14001:2004 certified EMS which might assist with ground water impact quantification;

- Identifying and evaluating the environmental aspects and impacts under normal, abnormal and emergency conditions which might cause ground water and surface water impacts;
- Identifying potential historical environmental aspects which could have caused ground water and surface water impacts;
- An evaluation of historical environmental incidents which could have caused ground water and surface water impacts;
- Interacting with site employees who has invaluable knowledge on historical and current activities and processes which could/can have an impact on ground water and surface water;
- Identification and observation of the industries located close to Omnia Fertiliser Sasolburg which could have an impact on the study area and contribute as such to a cumulative impact on the ground water and surface water quality in the study area;
- Based on the information above identify and providing an overview of the point and non-point (disperse) pollution sources found on site;
- Providing an overview of the physical characteristics of the study area;
- Developing a conceptual ground water model of the study area;
- Evaluating the adequacy of the existing ground water monitoring network;
- Evaluating the ground water and surface water chemistry against the point and non-point pollution sources;
- Identifying the relevant legal requirements and its implication on the ground water impact at the Omnia Fertiliser Sasolburg site;
- Identifying and evaluating the ground water impact against existing financial accounting standard requirements with regard to recordability and reportability; and
- Evaluating the actual impact of Omnia Fertiliser Sasolburg on ground water and surface water quality and its subsequent potential financial consequences based on the Omnia risk assessment matrix.

CHAPTER 3: BACKGROUND

3.1 BACKGROUND SETTING

3.1.1 Location and history of Omnia Fertiliser Sasolburg

Omnia Fertiliser, a division of Omnia Holdings (Pty) Ltd., is located on portion 12 of stand 8031 (Sasolburg industrial zoned stand), Northern Industrial Area, Sasolburg, Free State Province.

Latitude: 26⁰48.770' South
Longitude: 27⁰51.670' East
SG 21 Digit Code: FO2500030000803100012

Omnia Holdings is a diversified, specialist chemical services company providing customised solutions in the chemical, mining and agriculture markets. Omnia's agricultural division comprises of Omnia Fertiliser and Omnia Specialities, which are marketed to farmers as a holistic agricultural nutritional product and service provider. Omnia's agricultural businesses have been built up over more than 50 years.

The Omnia Fertiliser Sasolburg operation in the Free State Province is the largest production site of Omnia, where a large number of products, chemicals and explosive intermediates are produced.

The Omnia Fertiliser Sasolburg plant was established in 1967. The first operation was mainly focussed on the manufacturing of granulated fertiliser. Manufacturing of liquid fertiliser and the introduction of ammonia application services followed in 1972 and 1974 respectively.

The construction of nitrogen manufacturing facilities started in 1982 and was operational until late 1983. **Figure 1** provides an overview of the national setting, while **Figure 2 and 3** provide more detailed information on the regional location.



Figure 1: Omnia Fertiliser Sasolburg location in South Africa satellite image (Google Earth, 2011).

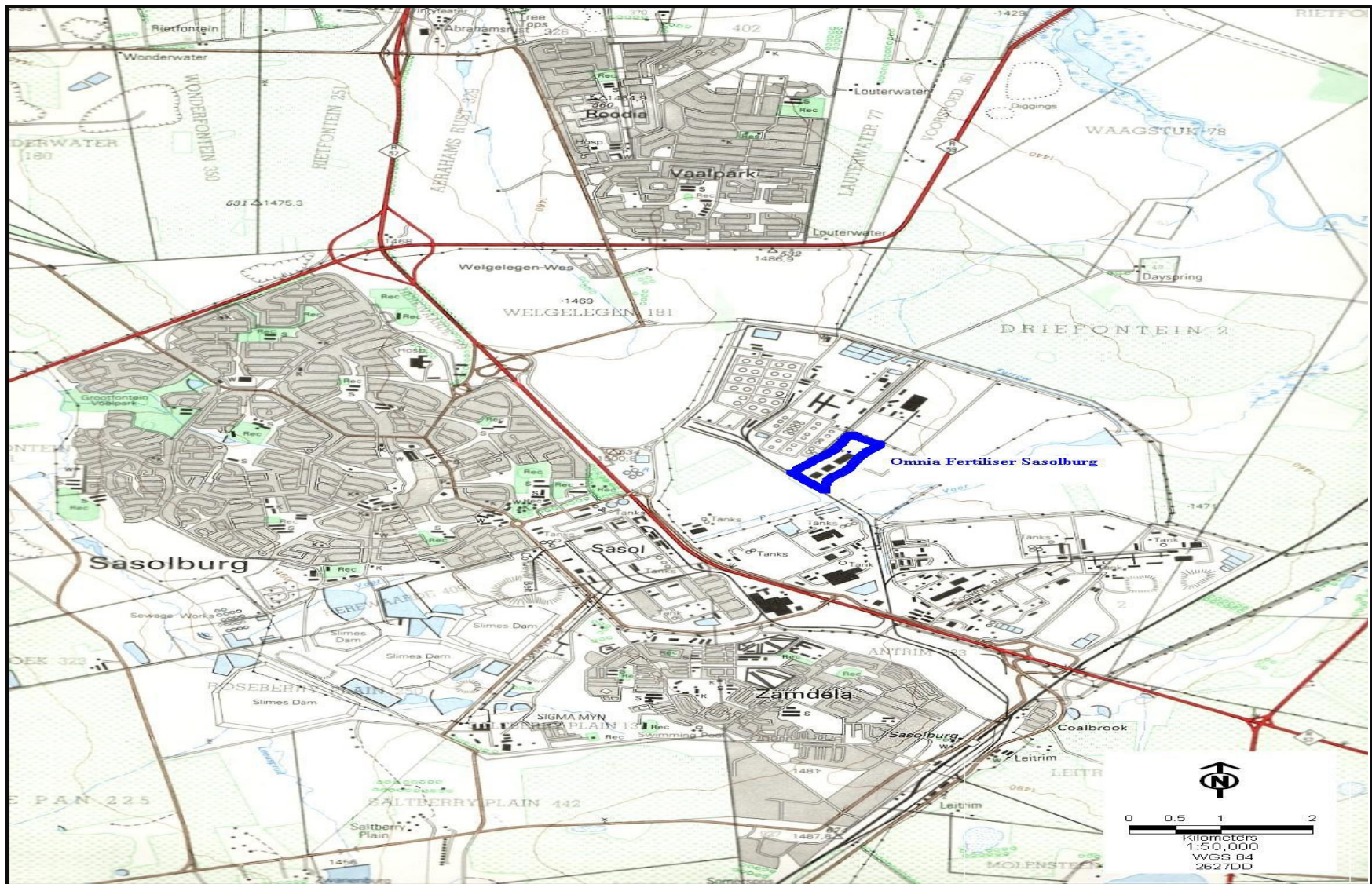


Figure 2: Omnia Fertiliser Location: 1:50000 Map.

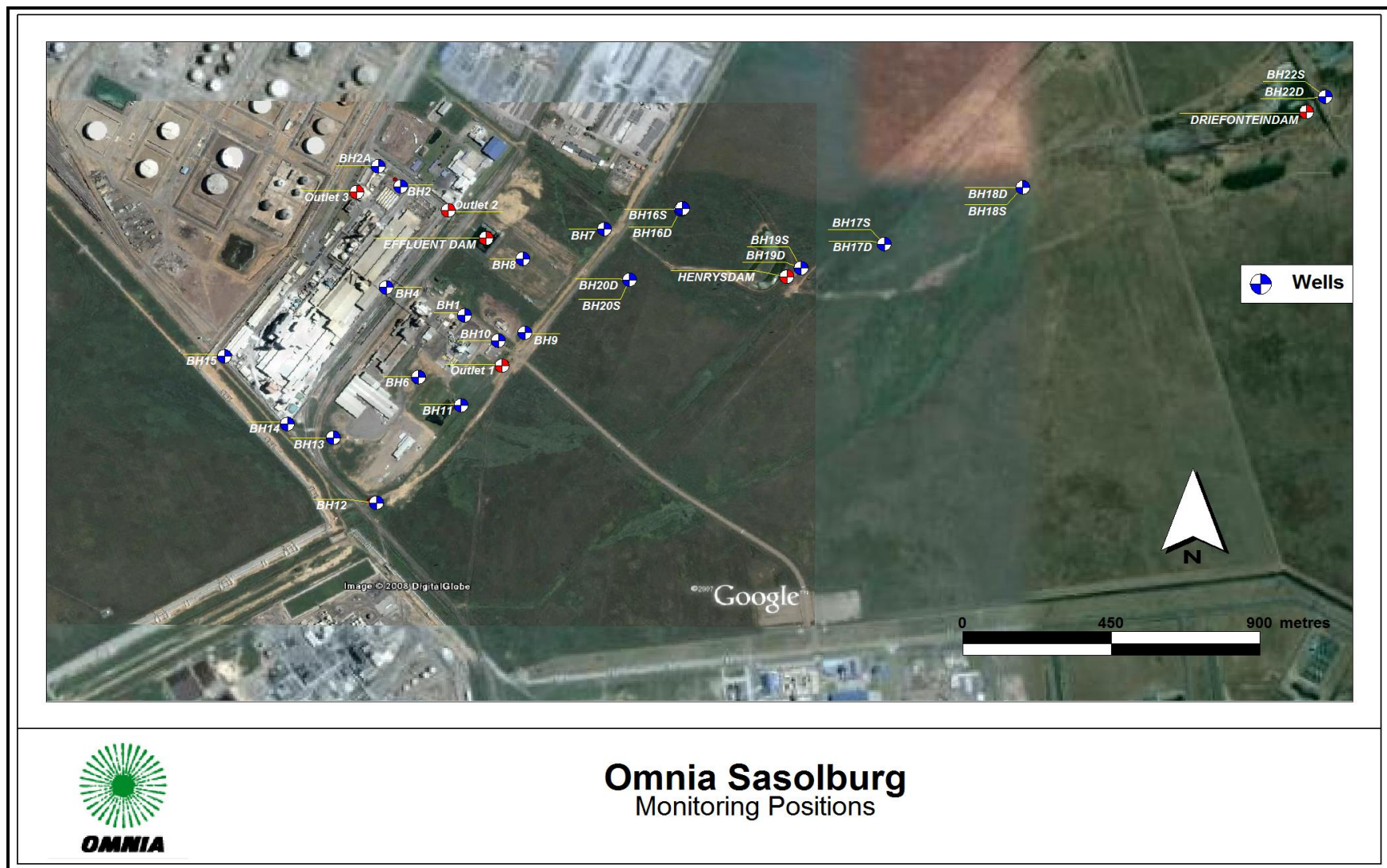


Figure 3: Ground water monitoring network in the study area, satellite image (GPT, 2008).

3.1.2 General overview of the fertiliser production processes in South Africa

Fertiliser production is structured around the three main macronutrients requirements for plant growth which are nitrogen, phosphate and potash (N, P and K). The acquisition of raw materials in the South African fertiliser industry are sought and obtained from a number of sources both locally and internationally.

Fertiliser manufacturing in South Africa has a seasonal trend to it due to the fact that the seasons in South Africa can be clearly differentiated. In general, the demand for fertiliser is at its highest during spring and summer. Omnia Fertiliser Sasolburg is a main production facility where the same production activities and quantities are conducted throughout the year. The production fertiliser volumes at this main production facility are not influenced by seasonal fertiliser demand. It should also be noted here, that the Omnia Fertiliser Sasolburg operation is also manufacturing the basic raw materials for bulk mining explosives, which has a similar production profile to nitrate based fertiliser.

It is essential to have an in depth understanding of the chemical processes on site in order to understand the potential contaminants that might be impacting on soil, surface and groundwater. This will inform the minimum requirements for element analysis and the monitoring programme design.

The following provides a generic overview of the fertiliser production process. It is summarised from Ratlabala (2003).

3.1.2.1 Phosphate

The term phosphate rock is used in industry to describe mineral assemblages with a high concentration of phosphate minerals in the Francolite (($\text{Ca}_5\text{PO}_4\text{CO}_3\text{OH}$)₃ (F,OH)) and Apatite (($\text{Ca}_5(\text{PO}_4)_3\text{F}$)) series.

Phosphate rock is the primary source of the nutrient phosphorus used in the fertiliser industry.

Phosphate sources have to be converted into a form which can be taken up by plants. This is achieved by using the integrated “Nitrophosphate” process. The result is compound fertilisers containing ammonium nitrate, phosphate and potassium salts. This process aims to produce nitrate-containing straight and compound fertilisers starting from rock phosphate and using all the nutrient components in an integrated process without solid wastes and with minimal gaseous and liquid emissions (European Fertiliser Manufacturers Association: 2000).

The main purpose of phosphate fertilisers is to stimulate root development, promote flowering and help prevent diseases and environmental stress. Phosphates in their natural state have a low solubility and need to be converted by chemical processing to a form that can be assimilated by plants. Phosphate is extracted from three main types of deposits:

- Marine phosphorites;
- Apatite-rich igneous rocks; and
- Modern and ancient guano accumulations.

All three types are developed in South Africa, but the igneous deposits are currently the only ones being exploited. The Omnia Rustenburg operation is the main production site where Phosphates are transformed to increase their solubility. The products which results from this are:

- Phosphoric acid, by reaction with an excess of sulphuric acid (by-product of the mining industry and also produced from imported and local sulphur) and filtration of gypsum;
- Single and double super-phosphate fertilisers, by acidulation with sulphuric acid and phosphoric acid, respectively; and
- Nitro phosphate fertilisers, by acidulation with nitric acid.

Other companies which are involved in the processing of Phosphate rock are:

- Sasol Agri (previously known as Fedmis); and
- Foskor Richards Bay (previously known as Indian Ocean Fertilisers).

3.1.2.2 Potash

Potash is a generic term used by industry and the farming community for commercially supplied potassium bearing ores and processed products.

The most important potassium bearing minerals are:

- Sylvite;
- Kainite;
- Carnallite; and
- Langbeinite.

Potassium (K) is present in every living cell both plants and animals, is a primary nutrient, (along with phosphorus and nitrogen) which is necessary for virtually every aspect of plant growth. Potassium is the third most widely used fertiliser nutrient after nitrogen and phosphorus.

Fertilisers account for approximately more than 95% of total potash consumption. Potassium chloride, sourced from Sylvite and also known as Muriate of Potash (MoP), is the most common source of potassium (K) for fertilisers and has a K_2O content of more than 60%. Other forms of potash include potassium sulphate with approximately 50% K_2O content and potassium magnesium sulphate with approximately 25% K_2O content.

The importance of potassium in the fertiliser industry relates to its importance for water balance regulation in plants, the activity of many enzymes, starch synthesis, nitrogen uptake and protein production. Potassium is also known to facilitate sugar movement through plants and boost resistance to stress such as drought and diseases.

South Africa has no developed potash resources. All national demand is imported.

3.1.2.3 Nitrogenous fertilisers and its downstream products

Ammonia is the basic raw material for the production of nitrogenous fertilisers. Anhydrous ammonia (NH_3) is important for direct soil application in agriculture and is also the primary raw material of all nitrogen fertilisers.

Ammonia is manufactured mainly by the well-known Haber-Bosch process which is the nitrogen fixation reaction of nitrogen gas and hydrogen gas, over an enriched iron or ruthenium catalyst. The raw materials for manufacturing ammonia are hydrogen gas (H_2), which is obtained by the

gasification of coal and coke with steam, and nitrogen gas (N_2), which is manufactured from air by means of fractional distillation.

Sasol Limited supplies more than 90% of the country's ammonia, with the balance coming mainly from Iscor. Ammonia is the basic raw material for the production of nitrous fertilisers.

3.2.2.4 Urea

Urea ($(NH_2)_2CO$) contains 46% nitrogen. The basic raw materials used in the process for the manufacturing urea are CO_2 and NH_3 .

3.1.2.5 Ammonium Nitrate

Ammonium nitrate (NH_4NO_3) contains 35% nitrogen. The raw materials used for the manufacturing ammonium nitrate are ammonia and nitrogen.

3.1.2.6 Ammonium Sulphate

Ammonium sulphate ($(NH_4)_2SO_4$) contains 21% nitrogen. It is manufactured from by products such as coal and coke gases, as well as diluted ammonium sulphate solutions from the refineries.

3.1.2.7 Limestone Ammonium Nitrate (LAN)

LAN contains 28% nitrogen. LAN is not a homogeneous salt or chemical substance but is a mixture of limestone (mainly dolomitic lime and sometimes calcitic lime is also used) and ammonium nitrate. The product consist of approximately 20% finely ground limestone and 80% ammonium nitrate.

3.1.2.8 Ammonium Sulphate Nitrate (ASN)

Ammonium sulphate nitrate contains 27% nitrogen. It is a mixture of ammonium sulphate and ammonium nitrate. The raw materials are ammonium sulphate crystals and ammonium nitrate solutions.

3.1.2.9 Agricultural lime

Limestone is known for its main application in the portland cement and metallurgical industries in South Africa. In most cases limestone is referred to as lime. The term “lime” refers to quicklime CaO, which is calcite limestone and slaked lime (Ca (H₂O)), the hydrated form. Limestone (CaCO₃) and its derivative lime (CaO) find more applications in industry than any other natural product.

3.1.2. 10 Composition of limestone/ dolomite

Pure limestone is composed entirely of CaCO₃ but usually contains a variable amount of impurities such as dolomite, quartz, silicate and iron oxides. The magnesium contents vary from 0 to 46%. There are different types of limestone, which are classified according to CaCO₃ and magnesium carbonate content.

- Dolomitic limestone: CaMg (CO₃)₂ consists of approximately 40 % MgCO₃; and
- Calcitic limestone: CaCO₃ consists of less than 15% MgCO₃.

The terminology dolomite or dolomitic limestone is used when the molecular proportion of magnesium and calcium carbonate are equal in the rock. Calcitic limestone is pure calcium carbonate with a minimum of 70% CaCO₃ content. Lime is a derivative of limestone, and is manufactured by burning limestone at 850°C to 1100°C yielding carbon dioxide as a by-product.

3.1.2.11 Sulphur

Sulphur is known as the fourth major plant nutrient after N, P, and K, because most crops require as much sulphur as phosphate.

Sulphur is generated as a nutrient in fertiliser by the use of sulphuric acid for producing phosphate fertilisers, through a reaction with phosphate rock. Sulphur performs many important functions similar to nitrate in plants. Sulphur is vital for the synthesis of proteins, oils and vitamins and promotes nitrogen fixation and nitrate reduction in plants; is also a key ingredient in the formation of chlorophyll, fights diseases, control pests and lowers the pH of saline and alkaline soils.

Sulphur is recovered in the form of elemental sulphur, and ammonium and sodium sulphates from four sources, namely:

- Pyrite;
- Metal sulphide smelter gases; and
- Coal and crude oil.

Most of the elemental sulphur is converted to sulphuric acid.

The major generators of elemental sulphur are:

- NATREF;
- SAPREF;
- Sasol Synthetic Fuels (SSF);
- Engen; and
- Caltex.

A wide variety of sulphur sources can provide plant nutrient sulphur (PNS). The major sulphur fertilisers are:

- Ammonium sulphate;
- Elemental sulphur-based materials;
- Potassium sulphate;
- Potassium magnesium sulphate; and
- Single Super Phosphate.

3.1.2.12 Magnesium compounds

Magnesium compounds are essential in both as fertilisers and animal feed additives. An adequate supply of magnesium enhances the photosynthetic activity of leaves. It also acts as a phosphorus carrier in plants and is essential for phosphate metabolism, plant respiration and the activation of several enzyme systems.

The main products used are caustic calcite magnesia and magnesium sulphate.

Caustic calcite magnesia is an affordable magnesium fertiliser, but has limited water solubility. Epsom salt (magnesium sulphate) is a fast-acting magnesium and sulphur fertiliser often used as a foliar application to crops, although its high cost is a handicap.

3.1.2.13 Gypsum

Gypsum or land plaster ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) serves similar functions as limestone both as a soil amendment that improves the structure and drainage of compacted clay soils, and it is also added to ameliorate subsoil acidity. The calcium sulphate leaches down into the subsoil where it causes a slight rise in soil pH. In addition, root growth in the subsoil is encouraged by the higher calcium concentration. Gypsum also makes available sulphate sulphur (particularly to corn, cotton, wheat and peanuts), stimulates microorganisms and neutralises sodium compounds.

3.1.2.14 Micronutrients

Micronutrients are lesser known than the macronutrients. Micronutrients can be classed as naturally occurring agricultural minerals that are essential in plant and animal nutrition, but are needed by plants in relatively small quantities. Micronutrients are typically blended with primary and secondary nutrients to make a complete nutrient package for plants and animals. There are six generally recognised elements that comprise the category of micronutrients:

- Boron (B);
- Copper (Cu);
- Iron (Fe);
- Manganese (Mn);
- Molybdenum (Mo); and
- Zinc (Zn).

Boron occurs as the Borate (B_4O_7) anion in soils. Sources of boron include borax, fertiliser borate, boric acid and Ulexite (crude borax ore). Borax is generally recovered by evaporation/crystallisation process from dry lake brines or salt beds, or by beneficiation of mined Ulexite ores. Boric acid is made by reacting borax with sulphuric acid followed by filtration and drying. South Africa has no local sources of borates. Borates are imported from the Netherlands and re-exported to other African countries.

Molybdenum occurs as an accessory mineral in various types of base mineral deposits, but is not produced in South Africa at present. The only officially declared production of molybdenum in South Africa was 22 t in 1957/8, and one ton in 1964. Presently South Africa is dependent on imports from China, Chile and United Kingdom.

South Africa has vast supplies of copper, iron, manganese and zinc which are used in the fertiliser industry.

3.2 PRODUCTS AND SERVICES OF OMNIA FERTILISER SASOLBURG

The Omnia Fertiliser Sasolburg industrial site produces chemical fertilisers, raw materials for bulk explosives and industrial chemicals. The production facilities include:

- Nitric Acid;
- Ammonium Nitrate;
- Calcium Nitrate;
- Ammonium Nitrate/Calcium Nitrate blend;
- Fertiliser granulation complex;
- Single super phosphate (SSP);
- Mono calcium phosphate (MCP);
- Liquid fertiliser blending;
- Potassium Chloride; and
- Nitro Phosphate.

Figure 4 provides an indication on the location of some of these production areas on site.

The typical chemicals that was present on site in the past and currently are:

- Ammonium Nitrate solution;
- Ammonium Sulphate;
- Boron;
- Calcium Nitrate;

- Copper;
- Defluorinated Phosphoric Acid;
- Iron;
- Manganese;
- Molybdenum ;
- MAP;
- MCP;
- Nitric Acid;
- Nitro Phosphate;
- Phosphoric Acid;
- Potassium Chloride;
- SSP;
- Tetrasodium Pyrophosphate;
- Urea; and
- Zinc oxide.

The Omnia Fertiliser Sasolburg site covers a total area of 90,000 m² on the North Factory and 70,000 m² on the South Factory. On the South Factory, only 20,000 m² of the area is currently being utilised for industrial activities. The whole of the main factory area is utilised for industrial activities. **Figure 5** provides an indication of the location of the North and South Factories. Indicative production capacities for the different products (in tons) are:

- Nitric Acid – 245,000t;
- Ammonium Nitrate – 345,000t;
- Solid Calcium Nitrate – 67,000t;
- Ammonium Nitrate/Calcium Nitrate blend – 162,000t;
- Fertiliser granulation complex – 650,000t;
- Single Super Phosphate (SSP) – 84,000t;
- Mono Calcium Phosphate (MCP) – 30,000t;
- Liquid fertiliser blending– 96,000l; and

- Nitro Phosphate – 30,000t.

3.3 CURRENT ACTIVITIES, ENVIRONMENTAL ASPECTS AND IMPACTS

The main production and operational areas on the Omnia Fertiliser Sasolburg site which can be differentiated are:

- Granulation (Plant 1 and 2);
- SSP plant;
- SCN plant;
- Bagging plant;
- Cooling towers;
- Nitrogen complex (ammonia bulk storage tanks, ammonium nitrate and nitric acid plant);
- Nitrates complex (ammonium nitrate, calcium nitrate, liquid calcium nitrate);
- Speciality liquids blending plant;
- Super Phosphate Store;
- Super Phosphate Plant;
- Tank farm;
- Liquid fertiliser plant;
- Storm water system management (including storm water dam);
- Utilities (steam, water, gas);
- Goods receiving;
- Dispatch;
- Stores;
- Warehousing;
- Workshops and offices;
- Compressed air system;
- Storm water dam;
- Effluent dam;
- Ammonia gas facility; and

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- Material control.



Figure 4: Fertiliser Sasolburg site layout and general activities (Google Earth, 2011).

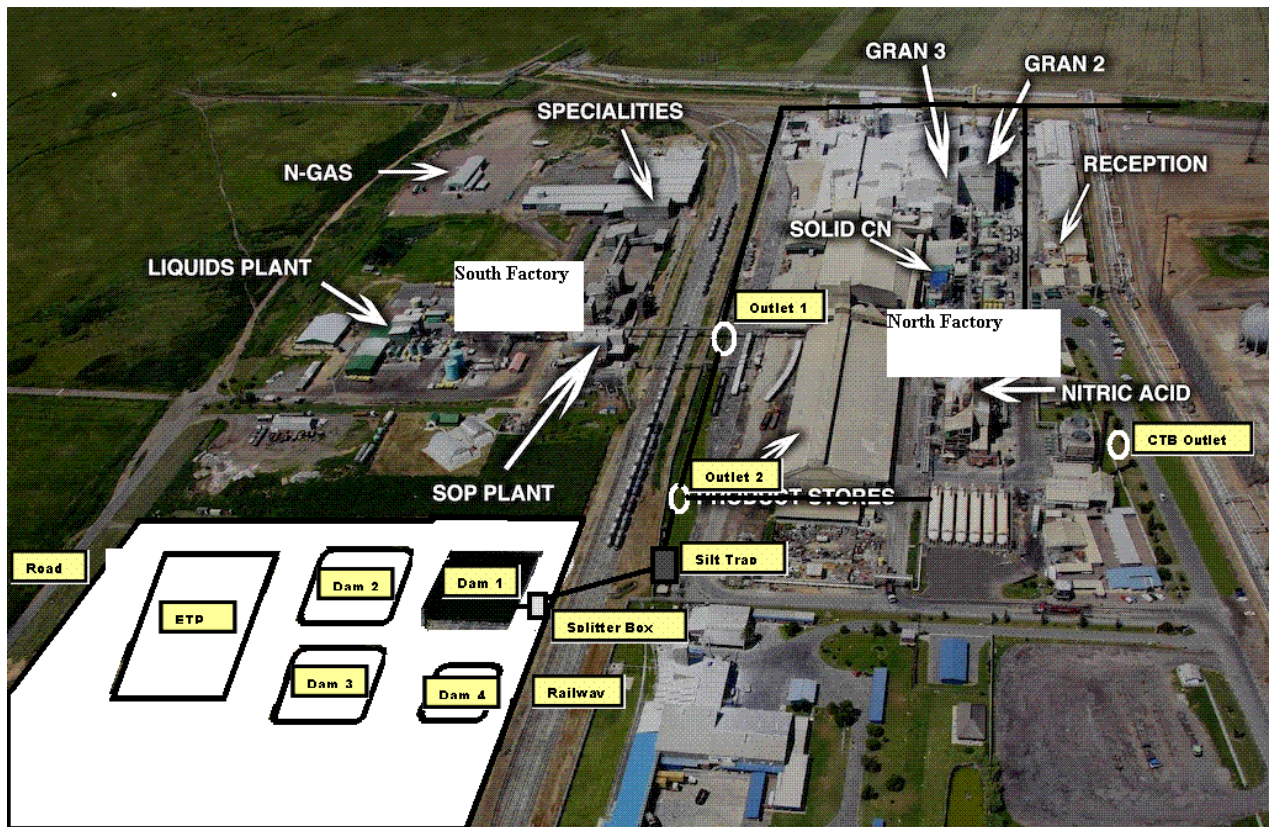


Figure 5: Omnia Fertiliser Sasolburg site layout, North and South Factory (Omnia, 2008).

An environmental site assessment was performed in early 2008 in order to identify the site processes and activities. The result was a list of environmental aspects and impacts which might cause soil, surface and ground water impacts.

Appendix A provides an overview of the areas where the associated activities whose associated environmental aspects might cause soil, surface and ground water impacts.

The conditions under which the impact might occur have been identified and three main categories are being differentiated:

- Normal – Usual day to day activities;
- Abnormal – Activities which differ from normal day to day activities but which are still controlled e.g. shutdown activities and sudden but time limited increase in production; and
- Emergency – Activities and conditions which are not controlled and cause an unforeseen impact e.g. explosions and equipment failure causing uncontrolled spillages.

3.4 HISTORICAL ENVIRONMENTAL ASPECTS AND IMPACTS

Historical environmental aspects and impacts relate to those activities performed in the past which have or have the potential to cause an impact on soil, surface and ground water.

Before the Omnia Fertiliser established the production site in the 1960's, the land was used for low intensity agricultural activities such as grazing for cattle. The Omnia Fertiliser Sasolburg site was thus established on a “green fields” location.

Results of historical activities which might/are causing impacts usually are the result of inadequate:

- Engineering design e.g. no/inadequate bund walls, wash bays, impermeable surfaces, roofing, effluent containment dams, integrity of effluent containment lining, dust elimination, spill prevention etc.;

- Elimination of pollution sources e.g. removal of practises and/or equipment responsible for causing pollution;
- Operational culture e.g. no/inadequate pollution prevention training and awareness, failure to report and clean product/chemical spillages within reasonable time;
- Environmental management system design e.g. no/inadequate design and implementation of environmental management system procedures, design and implementation of operational control procedures;
- Inadequate planned maintenance e.g. scheduling of replacing part which requires replacement and could cause pollution if the equipment fails; and
- Pro-active environmental impact monitoring e.g. no/inadequate pro-active pollution monitoring practises such as ground water monitoring network.

Table 1 provides an overview of the historical activities, aspects and impacts which might cause soil, surface and ground water impacts. It is virtually impossible to identify the number, type and significance of environmental incidents such as spillages, uncontrolled product release into the environment etc. as a formalised environmental management system has only been recently implemented.

Table 1: Historical activities and aspects which could have caused soil, surface and ground water impacts.

Historical Activity	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
Operation of the granulators.	Solid calcium nitrate, limestone and magnesium nitrate dust generation at the North Factory and windblown across	Air, soil, surface and ground water pollution.	Normal.

Historical Activity	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	site (Figure 8 and 9).		
Storage of raw and final product.	Dust and spillages generated by transport and off-load of product.	Air, soil, surface and ground water pollution.	Normal.
Process feed with liquid product.	Spillages of product.	Soil, surface and ground water pollution.	Normal.
Storm water generation from the North and South Factory.	Inappropriate and inadequate storm water channels (Figure 8).	Inappropriate and inadequate storm water channels.	Normal.
Operation of the cooling towers.	Process water release in the storm water system (Figure 8).	Soil, surface and ground water pollution.	Normal.
Release of process and storm water into the environment.	No effluent and storm water storage facilities (Figure 6).	Soil, surface and ground water pollution.	Normal.
Inadequate effluent	Storm and process	Soil, surface and ground	Normal.

Historical Activity	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
and storm water dam capacity.	water releases from storm/effluent water dams due to inadequate capacity (Figure 6).	water pollution.	
Inadequate lining of the storm water and effluent dams.	Seepage from storm water and effluent dams (Figure 6 and 8).	Soil, surface and ground water pollution.	Normal.
Use of lime to build ramps across the railway for easier conveyance of material.	Storage and handling of lime on impermeable surfaces.	Soil, surface and ground water pollution.	Normal.
Flood irrigation of the employees' vegetable garden with process water.	Irrigation of the vegetable garden with water containing high concentrations of nutrients (Figure 6 and 7).	Soil, surface and ground water pollution.	Normal.



Figure 6: Water being used from the storm water dam for the purpose of flood irrigation of the vegetable garden (Google Earth, 2011).



Figure 7: The vegetable garden as seen from the East (Aucamp, 2008).

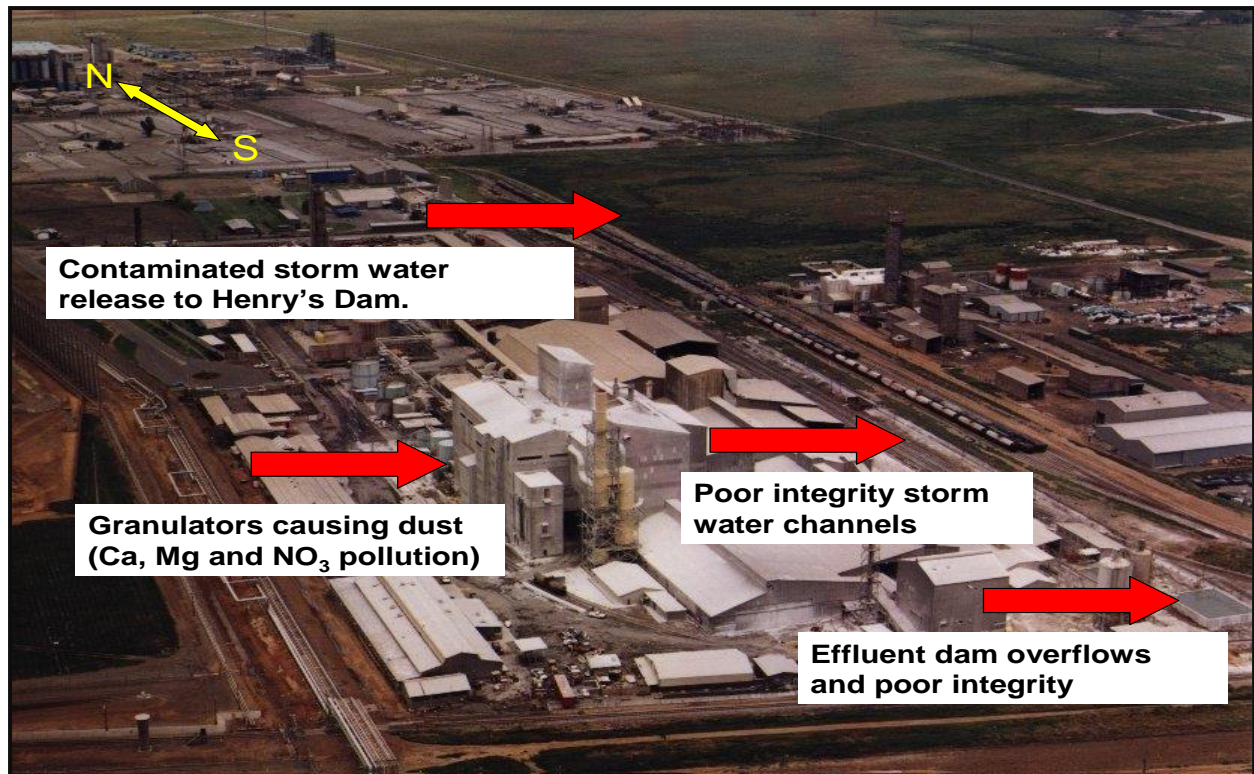


Figure 8: Summary of historical ground and surface water impacts approximately in 1990 (Omnia, 2008).



Figure 9: Examples of historical impacts approximately 1990 (Omnia, 2008).

3.5 POINT AND NON-POINT (DIFFUSE) POLLUTION SOURCES

Point pollution sources are defined as pollution from discrete or definable points, as opposed to pollution from broad areas. Point pollution can be described as pollution from a well-defined and specific source e.g. leaking storage tank, a landfill, an unlined storm water canal etc. Non-point pollution or (diffuse source pollution) can be defined as pollution from widely distributed sources instead of from a discrete or definable point. Non-point pollution can be described as pollution from activities that take place over a wide area (e.g. contaminants which are windblown over a broad area).

The following are identified as point pollution sources:

- Granulation (plant 1 and 2);
- SSP plant;
- SCN plant;
- Bagging plant;
- Nitrogen complex (ammonia bulk storage tanks, ammonium nitrate and nitric acid plant);
- Nitrates complex (ammonium nitrate, calcium nitrate, liquid calcium nitrate);
- Granulation plant and areas directly surrounding it;
- Speciality liquids blending plant;
- Liquid fertiliser plant;
- Storm water channels (including storm water dam);
- Utilities (steam, water, gas);
- Goods receiving, dispatch, stores and warehousing;
- Workshops and offices;
- Ammonia gas facility;
- Cooling towers;
- Henry's dam;
- Storm water channel leading to Henry's dam; and
- Driefontein dam.

Figure 10 provides an indication of the location of some of the point pollution sources.

The following present non-point (diffuse) pollution sources:

- Transport areas in and around the plant;
- Overflow of water from Henry's dam to Driefontein dam;
- Area beneath the storm water dam where contaminated water has been overflowing/released; and
- Area impacted by windblown dust from the granulators.

Figure 11 provides an indication of the location of the non- point pollution sources and off-site point pollution sources.

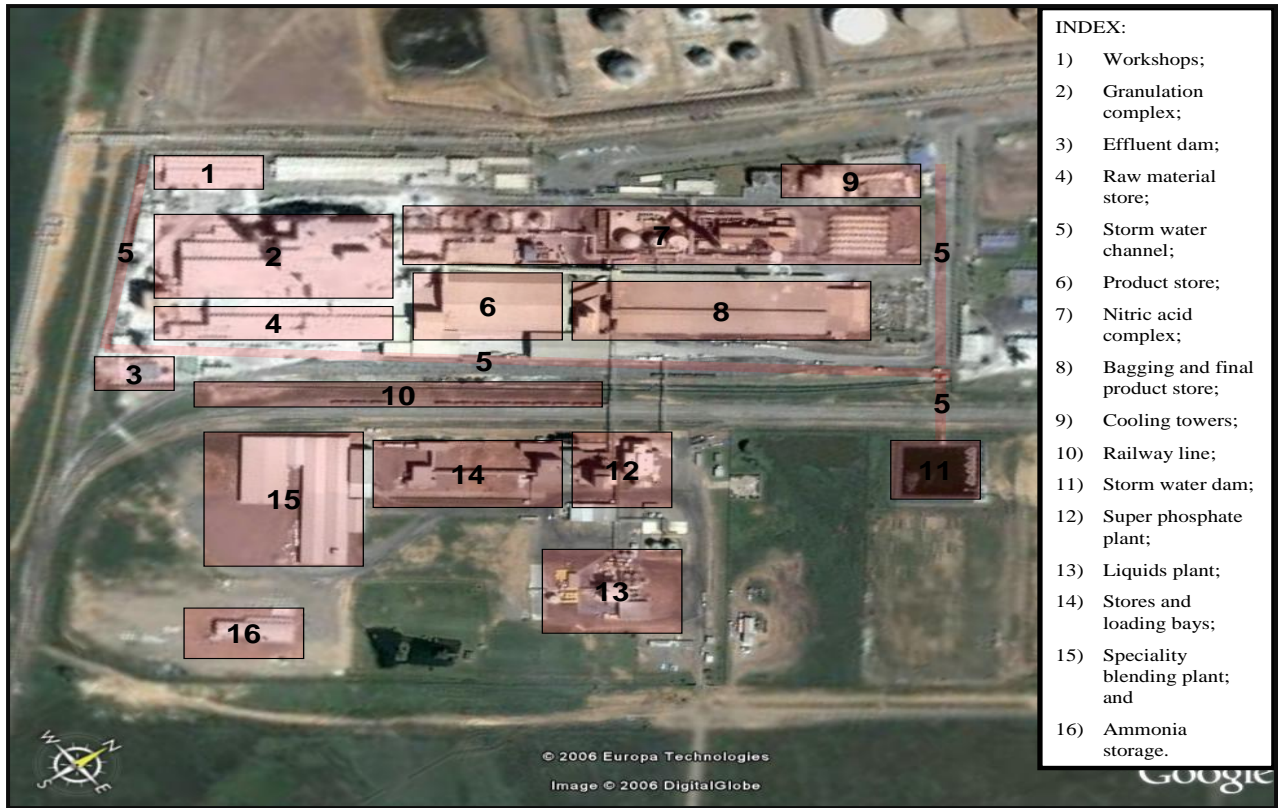


Figure 10: Point pollution sources identified on the Omnia Fertiliser Sasolburg site (Google Earth, 2011).



Figure 11: Non-point pollution sources and off-site point pollution sources (Google Earth, 2011).

3.6 EVALUATION OF INDUSTRIES LOCATED IN CLOSE PROXIMITY OF OMNIA FERTILISER SASOLBURG

Omnia Fertiliser Sasolburg is located in a heavy industrial area. The area is known to be a major chemical production area in South Africa. Typical industries located in this industrial area:

- Petrochemical refineries;
- Petrochemical manufacturers;
- Pesticide manufacturers;
- Specialised chemical manufacturers;
- Catalytic converter manufacturers;
- Plastic manufacturers and moulders; and
- Brick manufacturers.

In order to assess the potential of other inorganic pollution sources a review of the industries in the close proximity of Omnia Fertiliser Sasolburg were performed. **Figure 12** represents an overview of the industries in close proximity to Omnia Fertiliser Sasolburg. The results of cumulative contaminants are being represented in **Table 2**.

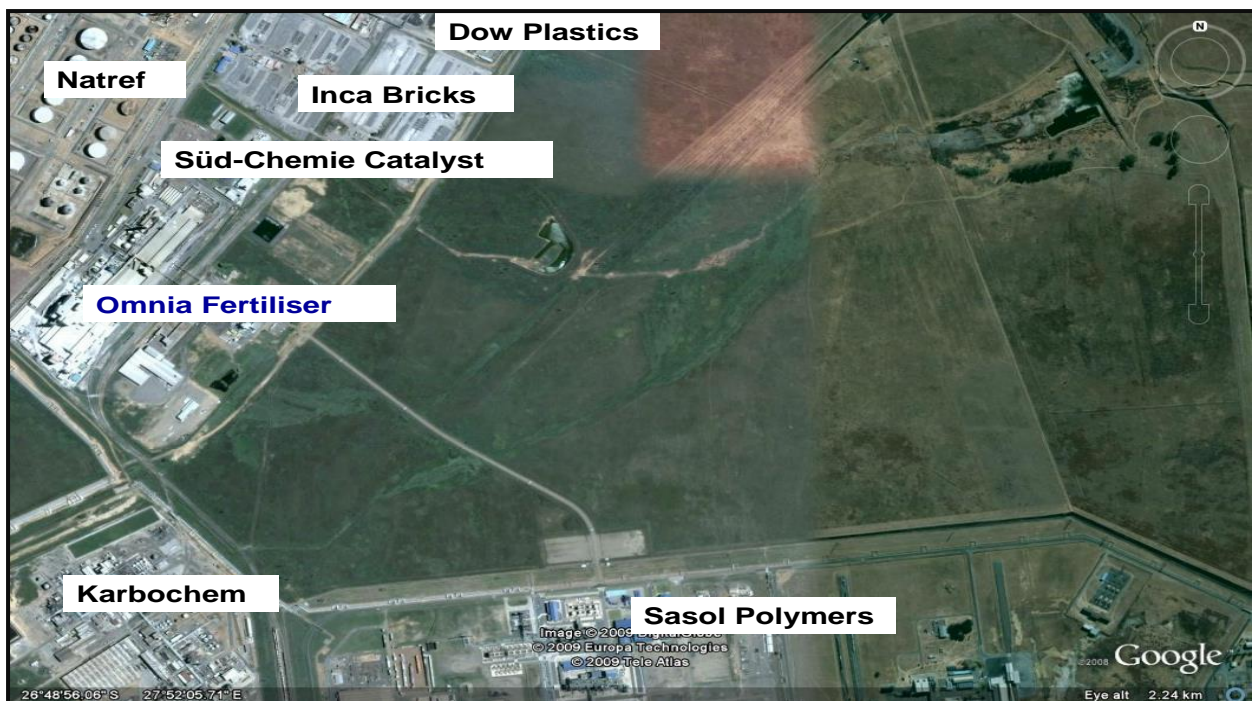





Figure 12: Industries in close proximity to Omnia Fertiliser Sasolburg (Google Earth, 2011).

Table 2: Industries located in close vicinity of Omnia Fertiliser Sasolburg and their associated production chemicals.

Industry	Description of activity	Typical chemicals used in the process	Inorganic Cumulative Pollution Risk with Omnia Fertiliser Associated Chemicals	Direct boundary distance to Omnia Fertiliser
Karbocem (Pty) Ltd.	Manufacturer of various types of synthetic rubber targeted at the tyre and retreading markets as well as industrial rubber converters and sports goods manufacturers.	Acrylonitrile, ammonia, antimony, benzene, butadiene, cadmium, carbon black, chloroform, chrome, zinc oxide, formaldehyde chromium, dichloroethylenes, lead, phenols, phthalates, sodium hydroxide, styrene, sulphur, vinyl chloride, fluoride, toluene, heptane, fuels, oil and grease (Centre for Disease Control and Prevention,	Ammonia, sulphur, zinc, sodium, and chloride.	120m

Industry	Description of activity	Typical chemicals used in the process	Inorganic Cumulative Pollution Risk with Omnia Fertiliser Associated Chemicals	Direct boundary distance to Omnia Fertiliser
		2012).		
Sasol Polymers 	Manufacturer and marketer of ethylene, propylene, low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), polypropylene, vinyl chloride monomer (VCM) and polyvinyl chloride (PVC), chloralkali chemicals and mining reagents (SASOL: 2011).	Acrylonitrile, ammonia, antimony, benzene, butadiene, cadmium, carbon black, chloroform, zinc oxide, formaldehyde chromium, dichloroethylenes, lead, phenols, phthalates, sodium hydroxide, styrene, sulphur, vinyl chloride, toluene, heptane, fuels; oil and grease.	Ammonia, sulphur and chloride.	920m
Natref	Total (2010), describes Natref as a complex oil refinery with the following	Sulphur, benzene, toluene, ethylbenzene, xylene (BTEX);	Sulphur, ammonium, sodium and fluoride.	60m

Industry	Description of activity	Typical chemicals used in the process	Inorganic Cumulative Pollution Risk with Omnia Fertiliser Associated Chemicals	Direct boundary distance to Omnia Fertiliser
	<p>production capabilities (barrel per day):</p> <ol style="list-style-type: none"> 1) Integrated atmospheric and vacuum distillation units (86,000 bpd); 2) Two catalytic de-sulphurisers (26,500 bpd); 3) Catalytic reformer (14,500 bpd); 4) Fluid catalytic cracker (18,100 bpd); 5) Hydrofluoric acid alkylation unit (3,900 bpd); 6) Butane 	<p>fuels; ammonium sulphide, hydrofluoric acid, sodium hydrogen sulphide, oil and grease.</p>		

Industry	Description of activity	Typical chemicals used in the process	Inorganic Cumulative Pollution Risk with Omnia Fertiliser Associated Chemicals	Direct boundary distance to Omnia Fertiliser
	<p>isomerisation unit (3,900 bpd);</p> <p>7) Distillate hydrocracker (10,500 bpd);</p> <p>8) Residual crude de-sulphuriser (13,000 bpd); and</p> <p>9) Two amine units and a sulphur recovery unit (130 ton per day).</p>			
<p>INCA Bricks</p> 	<p>Manufacturer of concrete based bricks and other building material.</p>	<p>Fly ash (silicon dioxide, aluminium oxide, iron oxide), silica, potassium, sodium, calcium, sulphates, phosphates and dioxins.</p>	<p>Sodium, calcium, iron, potassium, phosphates and sulphates.</p>	<p>20m</p>

Industry	Description of activity	Typical chemicals used in the process	Inorganic Cumulative Pollution Risk with Omnia Fertiliser Associated Chemicals	Direct boundary distance to Omnia Fertiliser
Süd-Chemie Sasol Catalysts (Pty) Ltd.	Catalysts are used in the gas-to-liquid (GTL) and coal-to-liquid (CTL) processes, which convert natural gas or coal into high-grade oil products such as diesel fuel, or into basic and intermediate petrochemical products (Süd-Chemie: 2012).	Silica; Iron; Cobalt; Alumina; Vanadium; Zinc; Sodium; Phosphates and Zeolite.	Iron, silica, sodium, phosphates and zinc.	20m

A number of potential cumulative inorganic contamination sources might be present at surrounding industries and could contribute to surface and ground water contamination of the area. Of particular relevance are nitrate, ammonia, calcium, magnesium, fluoride, potassium, chloride and sulphates.

3.7 OTHER POLLUTION SOURCES LOCATED CLOSE TO THE STUDY AREA

3.7.1 SASOL Explosives (SMX)

SASOL SMX Sasolburg manufactures fertiliser and explosives. According to Cowley (1999), significant concern exists on nitrate concentrations detected in the ground water around this

operation after reviewing a technical analysis report of Jones and Wagener. The study showed the impact of shallow seepage from the old effluent dam to the south of the plant to be significant, and various options to address this problem area were compiled.

A significant impact on surface water quality was observed due to decant from the dam reaching the storm water canal at the Heilbron-Vereeniging road, from where it eventually reaches the Taaibosspruit.

From the analytical results of samples taken it was clear that the ground water downstream of the old effluent dam is highly polluted with regard to:

- Nitrate;
- Calcium;
- Sodium;
- Magnesium; and
- Sulphate.

3.7.2 Schümann Catalysts

Cowley (1999) indicates that ground water quality results for Schümann Catalysts, a catalyst plant indicated conclusively that there is contamination of the soil and perched ground water table. The contaminants that were of concern included:

- Nitrate;
- Calcium;
- Magnesium;
- Bicarbonate; and
- Sodium.

3.7.3 SASOL CHEMICAL INDUSTRIES (SCI)

Cowley (1999) wrote that SCI is responsible for domestic sewage from the whole of Sasolburg including the sewage generated by the SASOL Sasolburg Complex. The ground water

monitoring results observed in this area was highly variable. Contaminants of particular concern are:

- Nitrates;
- E-coli; and
- Sulphates.

Figure 13 provides an overview of the domestic sewage works that SCI operates and manage.



Figure 13: SCI sewage treatment plant (Reddy, 2008).

Several other sources of ground water pollution have been identified at the SCI site.

- Ash disposal area;
- Old and new tar pits;
- Fertiliser dump;
- Municipal dumping site;
- Effluent dams; and
- Venco Park area.

A variety of contaminants (nitrate, sulphate, sodium, fluoride, etc.) were found at these different sites. High COD levels were also detected indicating the potential of high levels of organic contamination.

The Sasol Midlands site recently underwent a mercury remediation and Dense Non Aqueous Phase Liquid (DNAPL) investigation. The site is publicly known to be significantly impacted by mercury (Hg).

3.8 AIR POLLUTION AND ITS IMPACT ON THE STUDY AREA

The Vaal Triangle (of which the Metsimaholo Municipality forms part of) and the surrounding areas have been declared a national air pollution hotspot (or priority area) in terms of Section 18 (1) of the National Environmental Management: Air Quality Act – (NEMAQA), Act No. 39 of 2004. This is the first area of its kind in South Africa and is known as the “Vaal Triangle Air Shed Priority Area” (Department of Environmental Affairs and Tourism, Date Unknown).

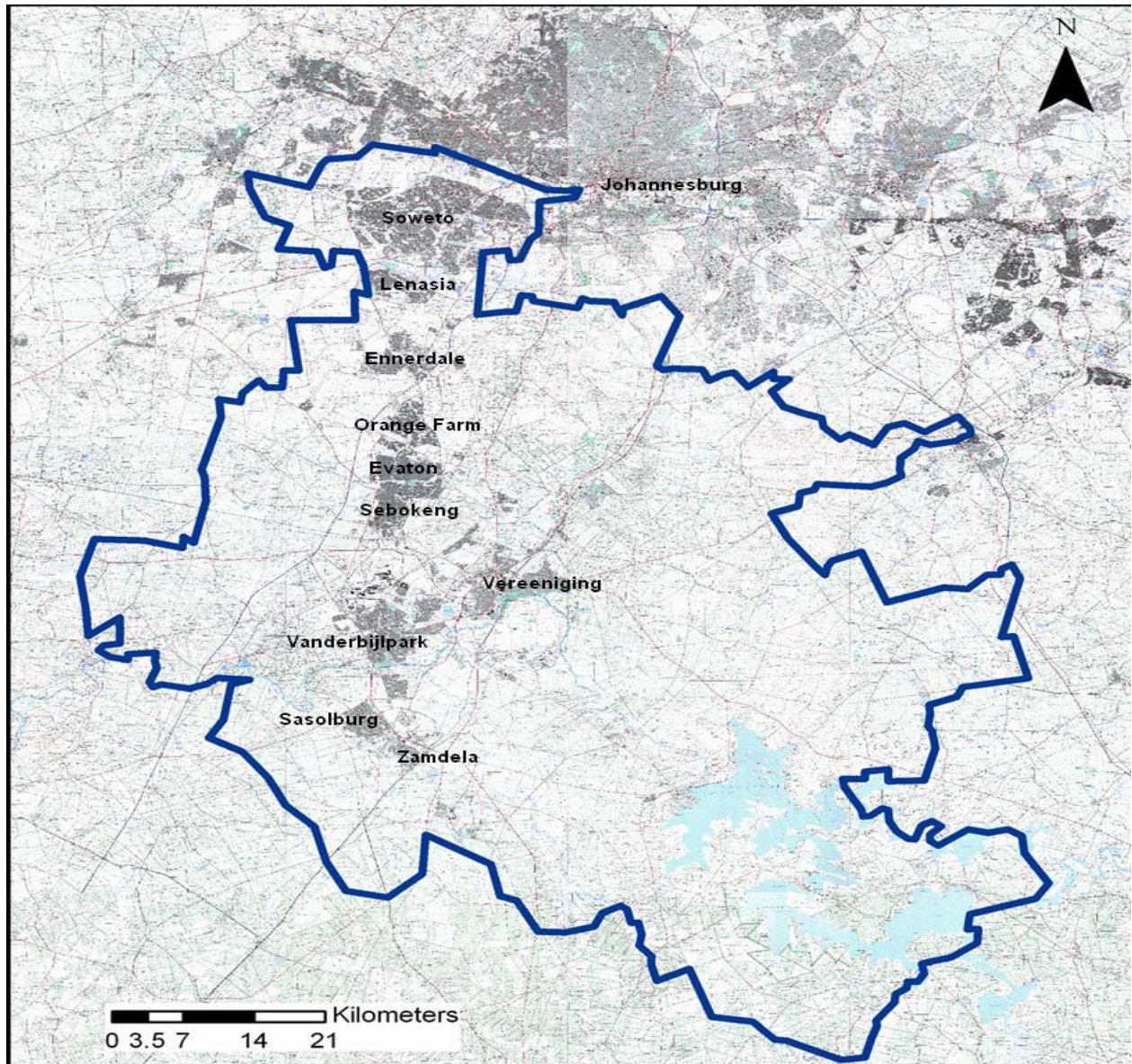


Figure 14: Vaal Triangle Air Shed Priority Area (Department of Environmental Affairs and Tourism, Date Unknown).

Investigation into the ground water quality of the Driefontein area (Jones and Wagener, 2004) provides evidence that concern existed on the air pollution impact in the Driefontein area. The area forms a natural depression and would be prone for the accumulation of air pollution contaminants that could settle in this area. An element of particular concern was vanadium (V) which was detected in the aquifer systems of the study area. **Table 3** indicates the ambient air quality limits for common pollutants as adopted to be the air quality objectives for the Vaal Triangle Air Shed Priority Area. Vanadium is not regulated.

Table 3: Ambient air quality limits for common pollutants as adopted to be the air quality objectives for the Vaal Triangle Air Shed Priority Area (DEAT, 2009).

Substance	10 minute maximum ($\mu\text{g}/\text{m}^3$)	1 hour maximum ($\mu\text{g}/\text{m}^3$)	8 hour maximum ($\mu\text{g}/\text{m}^3$)	24 hour maximum ($\mu\text{g}/\text{m}^3$)	Annual average ($\mu\text{g}/\text{m}^3$)
Sulphur Dioxide	500	350	0	0	50
Nitrogen Dioxide	0	200	0	0	40
Carbon Monoxide	0	30,000	10,000	0	0
Particulate Matter (PM10)	0	0	0	0	40
Ozone	0	200	120	0	
Lead	0	0	0	0	0.5
Benzene	0	0	0	0	5

3.9 INFORMATION GENERATED BY THE FORMAL EMS

Essential information generated by the formal EMS that was considered to assist with the assessment and quantification of ground water impact and potential financial liability are:

- Scope of application of the EMS (Clause 4.1). This provide an understanding of the scope of application of the EMS and if there are any exclusions in the EMS where there are no controls to mitigate environmental impact;
- Aspects and impacts associated with the site (Clause 4.3.1). The aspect register provides a good basis to work from in order to understand the typical activities and environmental impacts that the organisation has. The impacts are usually rated based on its significance by following a standardised significance rating criteria;
- Legal and other requirements pertaining to the site (Clause 4.3.2). The intent of an EMS is to drive environmental legal compliance. As part of this process, the relevant environmental legal requirements is identified and linked with the environmental aspects;
- Operational control procedures, standards and work instructions (Clause 4.4.6). This provides an overview of the procedures established for preventing environmental impacts that might be caused by operational activities. It also described how engineering interventions such as oil water separators should be operated, managed and maintained.
- Existing monitoring information (Clause 4.5.1). This provides impact monitoring information on environmental impacts caused such as dust, soil, water, air emissions etc. The requirement for monitoring is determined by the significance of the potential impact and permit and other regulatory requirements;
- Evaluation of compliance (Clause 4.5.2). The environmental legal compliance status needs to be assessed at regular intervals and progress tracked on continued improvement.
- Incident reporting, corrective and preventive action (Clause 4.5.3). Incidents such chemical spillages is recorded, investigated, corrective and preventive actions identified and closed out. This provide valuable information on potential incidents that might have an impact on ground water quality;
- Internal Audit (Clause 4.5.4). Internal audit reports provide information on the effective implementation of the EMS and the status of operational control within the scope of the EMS of the organisation. These reports might bring under the attention of the hydrogeologist areas where there might be ground water impacts caused by non-adherence to the EMS requirements; and
- Management review (Clause 4.6). The management review minutes provides a summary of the suitability, adequacy and effectiveness of the EMS. The minutes can provide

valuable information on specific concerns such as monitoring information concerns and furthermore, information on management concerns with regard to the effectiveness of environmental impact mitigation measures (ISO 14001, 2004).

CHAPTER 4: PHYSICAL CHARACTERISTICS OF THE STUDY AREA

4.1 REGIONAL GEOLOGY

Vorster (2009) states that the Free State is underlain by sedimentary rocks of the Karoo Super group. These constitute sandstone, shale and mudstone, which have been intruded by dolerite sills and dykes. The Karoo rocks in this area were deposited onto an erosion surface characterised by deep glacially scoured valleys or basins. Within the Vereeniging-Sasolburg area, three such glacial basins are present, namely the Sigma Basin (around Sasolburg), the Cornelia Basin (around Vereeniging) and the Coal brook Basin to the south east (Jones and Wagener, 2004). The coal seams are well developed and of economic significance and define the Vereeniging - Sasolburg Coalfield. Two major post-Karoo age dolerite intrusions (sills) are present within the area. In the southern sections of the Sigma Basin, two intrusions are present but within the northern portions around Sasolburg only the younger intrusive is present. These intrusions are each typically 40m to 60m thick (Reddy, 2008). The detailed lithology including the borehole logs is discussed in the conceptual model section of this thesis and is depicted in **Figure 15**.

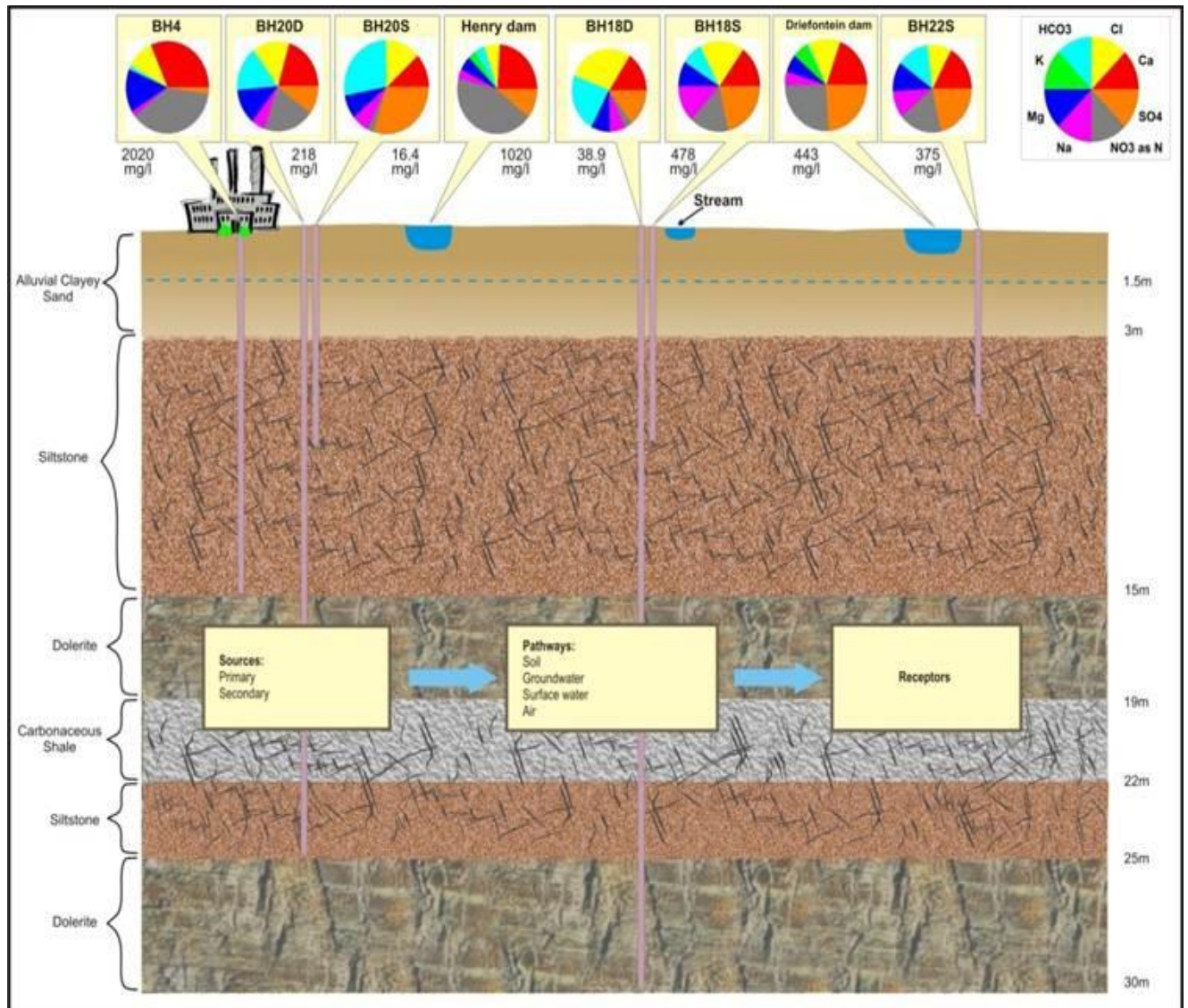


Figure 15: Lithology of the Omnia Fertiliser Site (GPT, 2011).

4.2 SOIL CHARACTERISTICS

The results of three geotechnical studies over a period of twenty years were compared with regard to soil characterisation. All three studies came to the same conclusion.

Van Wyk (1988) studied the area for the construction of the pallet production plant. He indicated the soils in the study area have the following soil characteristics:

- The upper 0,4 – 0,8m is a dry to slightly moist light brown to light grey-brown very loose silty to clayey fine sand;
- Below this to a depth of 2,1 – 5,3m follows a dry to wet profile with brown grey and yellow very stiff to soft jointed and slickenside with open joints sandy clay. This material has high expansiveness; and
- Below this to a depth of 2,5 – 6,4m follows a grey, olive and brown highly weathered to weathered very closely jointed and laminated layered very fine grained and extremely soft to medium hard mud and siltstone.

The siltstones and dolerite weathers to mixtures of silt and clay.

The general observations regarding the soil characteristics in the area are shared by the different investigations performed over a period of twenty years. It can be summarised that auger drillings have shown that silty clays and clayey sands underlie the site and form the unsaturated zone above the shallow water table. The water table is fairly shallow, varying from 2.5m to 7m below ground level and the ground water potential of the area is fairly limited. The silt and mudstone are well-fractured and generally weathered in excess of 20 metres (Grobbelaar and Usher, 2004).

Jones and Wagner (2004) indicate that the Aeolian horizon overlying most of the site is permeable and the development of a seasonal perched water table at the contact of this horizon within the underlying transitional horizon to residual horizon can be expected. Very soft rock, relict laminated siltstone was encountered at depths of between 3,5 – 4,0m.

Soil types play a significant role in the ground water regime as water seep through it to reach the aquifer systems.

Velde (1992) indicate that clay in the surface environments is critical to the passage of dissolved species in aqueous solution as the move from one medium to another. Clays are at the interface of the major surface environments. They are at the surface of the solid earth in its contact with the atmosphere. Any transfer of material between airborne and sediment or rock aqueous systems pass through soils, and hence clays are the critical materials present. The resting place of particulate matter in bodies of water, lakes and oceans is on clay dominated sediments.

Clays govern the release of chemical entities in sediments, it is the major inorganic particulate materials in river and ground water which will accept or reject ionic or molecular species in aqueous suspensions.

The understanding of soil chemistry is important, as most of the contaminants present on a fertiliser production site is produced to interact with soil in order to provide optimal nutrition for plants.

Velde (1992) is convinced that an understanding of the principles of clay-chemical (contaminant) interaction is a prerequisite for any attempt to understand ground water pollution if the pollution was induced on soil surface.

Of particular importance is Cation Exchange Capacity (CEC) in clays. CEC measures two of the fundamental properties of clays:

- The surface area; and
- The charge on this surface area.

Exchange capacity is an estimate of both the number of ions absorbed between the layers of a clay structure and those adsorbed on the outer surfaces.

In soil science, CEC is the capacity of a soil for ion exchange of cations between the soil and the soil solution. CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect ground water from cation contamination.

The quantity of positively charged ions (cations) that a clay mineral or similar material can accommodate on its negatively charged surface is expressed as milli-ion equivalent per 100g, or more commonly as milli equivalent (meq) per 100g or cmol/kg. Clays are aluminosilicates in which some of the aluminium and silicon ions have been replaced by elements with different valence, or charge. For example, aluminium (Al^{3+}) may be replaced by iron (Fe^{2+}) or magnesium (Mg^{2+}), leading to a net negative charge. This charge attracts cations when the clay is immersed in an electrolyte such as salty water and causes an electrical double layer.

The exchange isotherm can be described as follows:

$$KD = (P_{\text{clay}})(M^+_{\text{sol}})/(M^+_{\text{clay}})(P_{\text{sol}})$$

Where:

- KD = Cation Exchange Capacity (CEC);
- P_{clay} = Pollutant molecules present in clay;
- M^+_{sol} = Other ions in solution;
- M^+_{clay} = Other ions in solution; and
- P_{sol} = Pollutant molecules present in solution.

There are several factors which dominates the interaction of surface waters with rocks in the weathering process which produces clay minerals. The factors can be considered as being chemical or physical in nature.

Four geological or geomorphologic variables can be considered as part of the basic factors of weathering:

- Rock type (chemical factor);
- Climate (rainfall – chemical factor) and (temperature - physical factor);

- Topography or flow rate (chemical factor because it determines the ration of water to rock through drainage); and
- Age of a profile or weathering sequence (physical factor – time).

Clays are divided in two major groups. Swelling and non-swelling type minerals. Swelling clays are also called smectites. Non swelling clays are divided in 2 sub-categories, those associated with metamorphic minerals (illite and chlorites) and those with low-temperature geological processes (kaolinite and sepiolite-palygorskites).

The origin of clay is very closely related to the geological environment in which they form.

The soil types present in the study area have reasonably high clay contents, and as such will play a role in the ground water chemistry as the contaminants seep through the soil to the water saturated area.

Table 4: Clay Mineralogy (Velde, 1992).

Clay Type	Dominant Elements	Basal Spacing (Å)
SWELLING TYPES		
(Smectites)		
Beidellite	Al	17
Montmorillonite	Al (Mg, Fe ²⁺ minor)	17
Nontronite	Fe ³⁺	17
Saponite	Mg, Al	17
Vermiculite	Mg, Fe ²⁺ , Al (Fe ³⁺ minor)	15.5
NON-SWELLING TYPES		
Illite	K, Al (Fe, Mg minor)	10
Glauconite	K, Fe ²⁺ , Fe ³⁺	10
Celadonite	K, Fe ²⁺ , Mg, Fe ³⁺ , Al ³⁺	10
Chlorite	Mg, Fe, Al	14
Berthierine	Fe ²⁺ , Al ³⁺ (minor Mg)	7
Kaolinite	Al	7

Clay Type	Dominant Elements	Basal Spacing (Å)
Halloysite	Al	10.2
Sepiolite	Mg, Al	12.4
Palygorskite	Mg, Al	10.5
Talc	Mg, Fe ²⁺	9.6

4.2.1 Soil types

The soil types encountered on site can be classified as Hutton, Kroonstad and Clovelly soils in the higher lying areas while Willowbrook and Rensburg soil formations are dominating in the lower lying areas.

The Hutton soil form is identified on the basis of the presence of an apedal (structureless) “red” B-horizon as indicated in Figure 16 below. These soils are the main agricultural soil found in South Africa, due to the deep, well-drained nature of these soils. The Hutton soils found on the site are restricted to the midslopes of the site. The Hutton soil form is known to be well drained and allows for good infiltration of water.

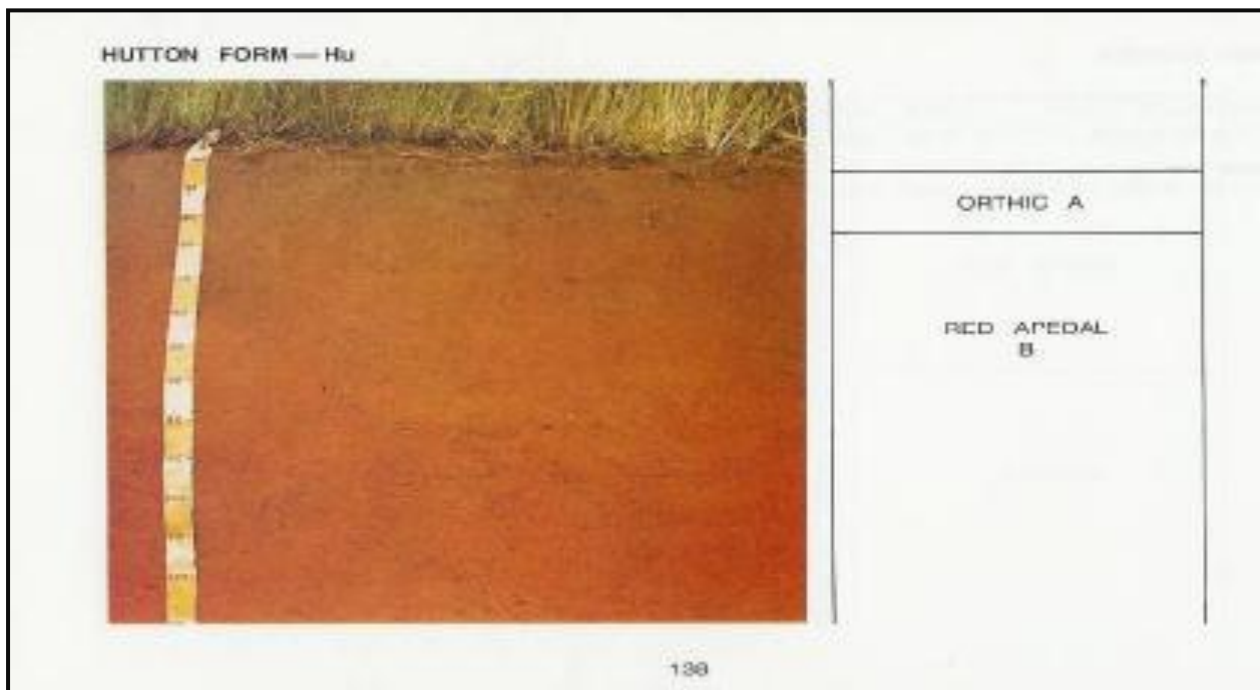


Figure 16: Hutton soil form (MacVicar *et al*, 1991).

The Kroonstad soil form is most commonly found in areas of semi-permanent wetness. The soil is made up of an Orthic A horizon over a diagnostic E-horizon over a G-horizon, as indicated in **Figure 17** below. The G-horizon has several unique diagnostic criteria as a horizon, namely:

- It is saturated with water for long periods unless drained;
- Is dominated by grey, low chroma matrix colours, often with blue or green tints, with or without mottling;
- Has not undergone marked removal of colloid matter, usually accumulation of colloid matter has taken place in the horizon;
- Has a consistency at least one grade firmer than that of the overlying horizon;
- Lacks saprolitic character; and
- Lacks plinthic character (MacVicar *et al.*, 1991).

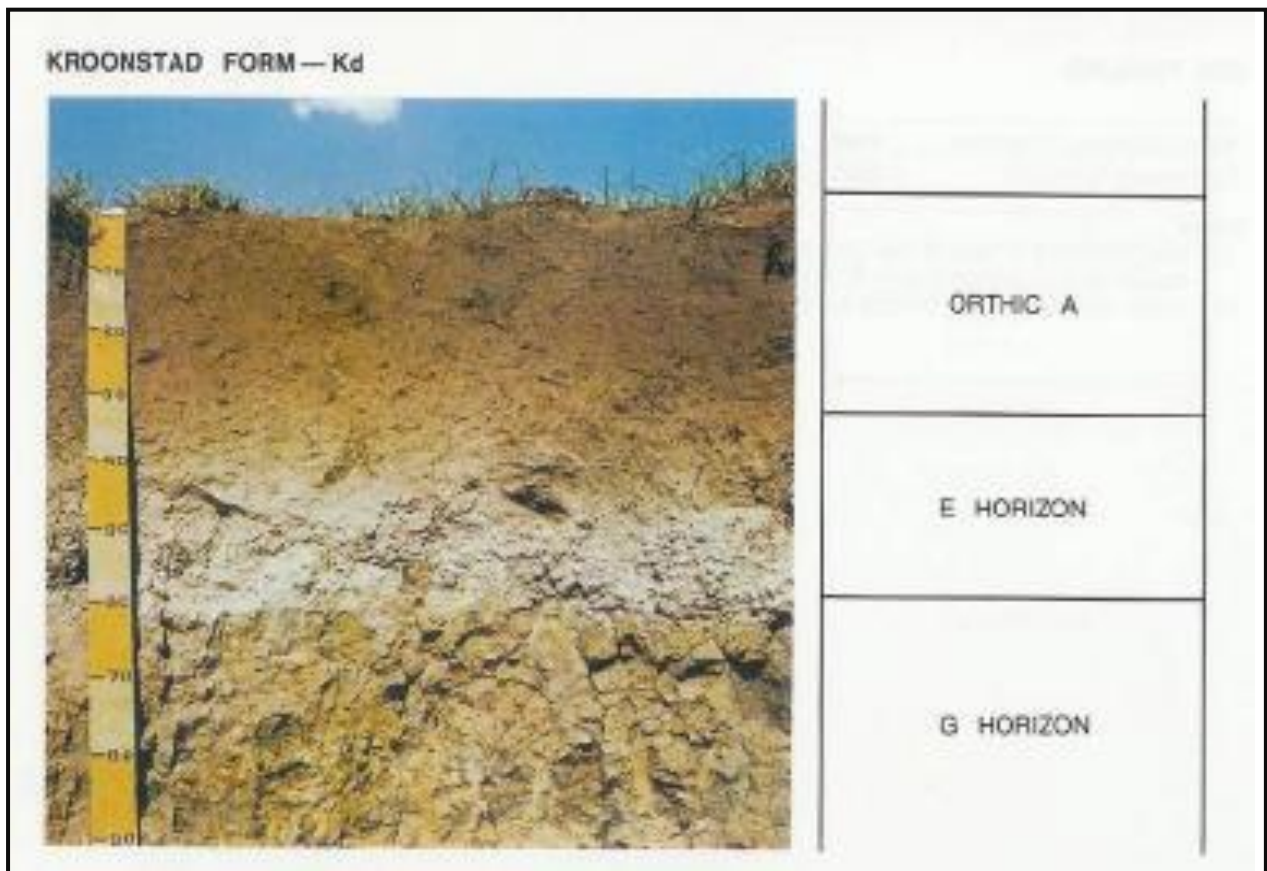


Figure 17: Kroonstad soil form (MacVicar *et al.*, 1991).

Clovelly soils can be identified as an apedal “yellow” B-horizon as indicated in **Figure 18** below.

These soils along with Hutton soils are the main agricultural soil found within South Africa, due to the deep, well-drained nature of these soils (MacVicar *et al.*, 1991).

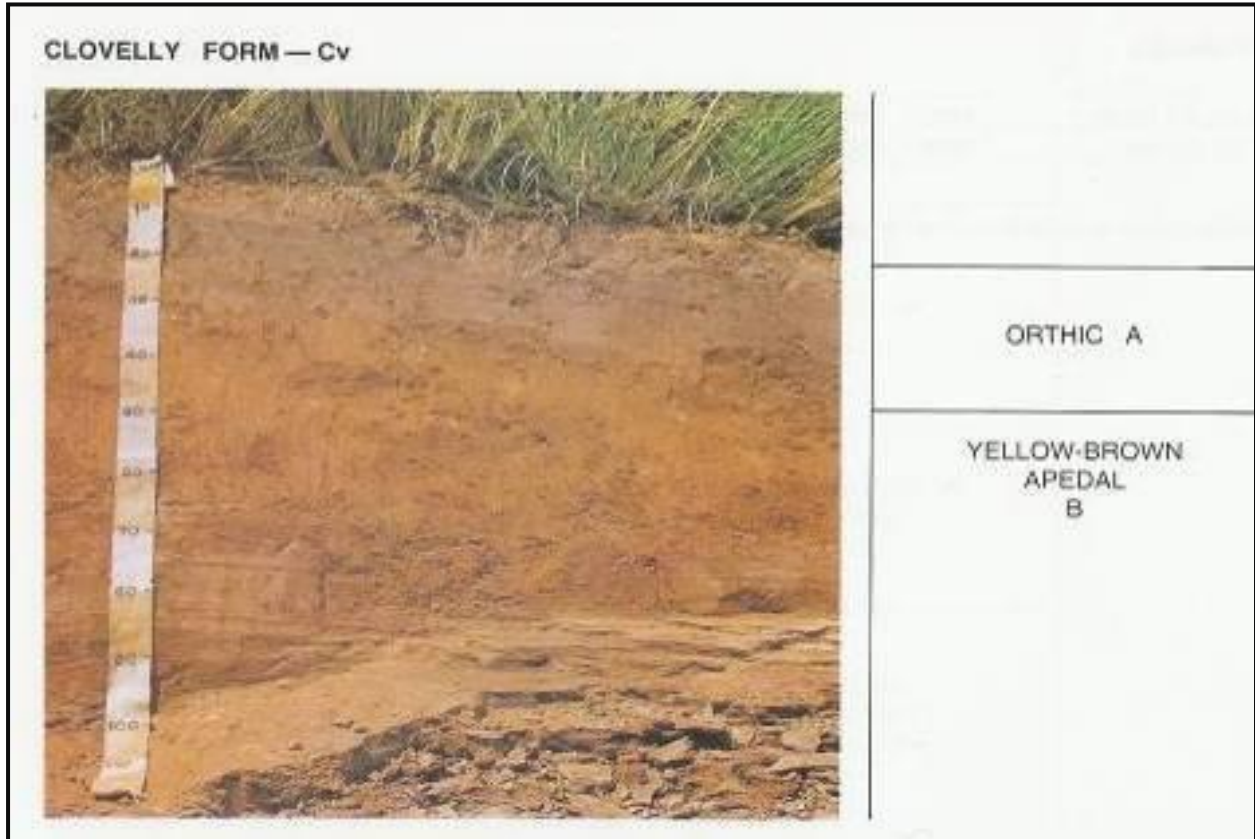


Figure 18: Clovelly soil form (MacVicar *et al.*, 1991).

Willowbrook soils are characterised by Melanic A-horizon over a G-horizon (**Figure 19**). The G-horizon is invariably firm or very firm and its characteristics are described above. The Melanic horizon has several unique diagnostic criteria as a horizon, namely:

- Has dark colours in the dry state;
- Lack slickensides that are diagnostic of vertic horizons;
- Has less organic carbon than required for diagnostic organic O horizon;
- Has structure that is strong enough so that the major part of the horizon is not both massive; and
- Hard or very hard when dry (MacVicar *et al.*, 1991)

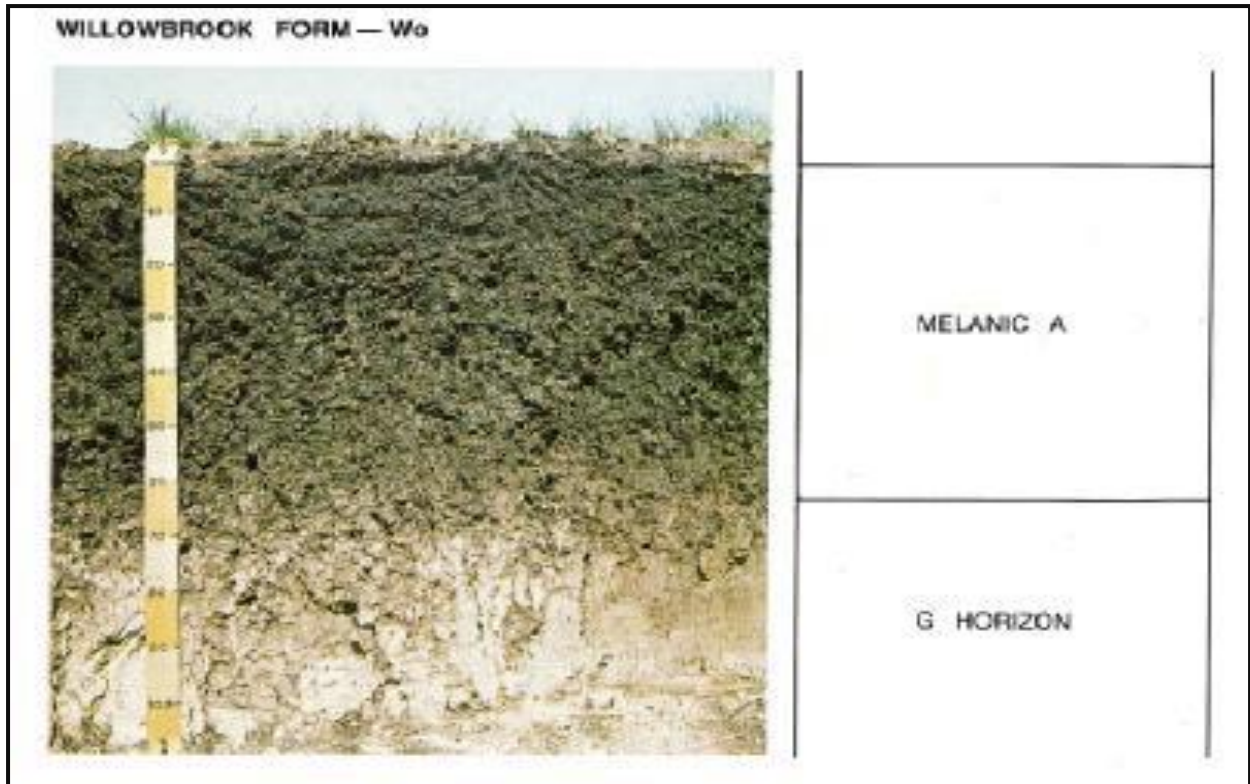


Figure 19: Willowbrook soil form (MacVicar *et al*, 1991).

Rensburg soils are characterised by a vertic A-horizon over a G horizon (**Figure 20**). The vertic A-horizon is characterised by shrinking and swelling of the soils and the G-horizon has the following characteristics:

- Is found below a vertic, melanic or ortic A horizon;
- Is usually saturated with water for long periods; and
- Usually has strong prismatic structural soil development (MacVicar *et al*, 1991).

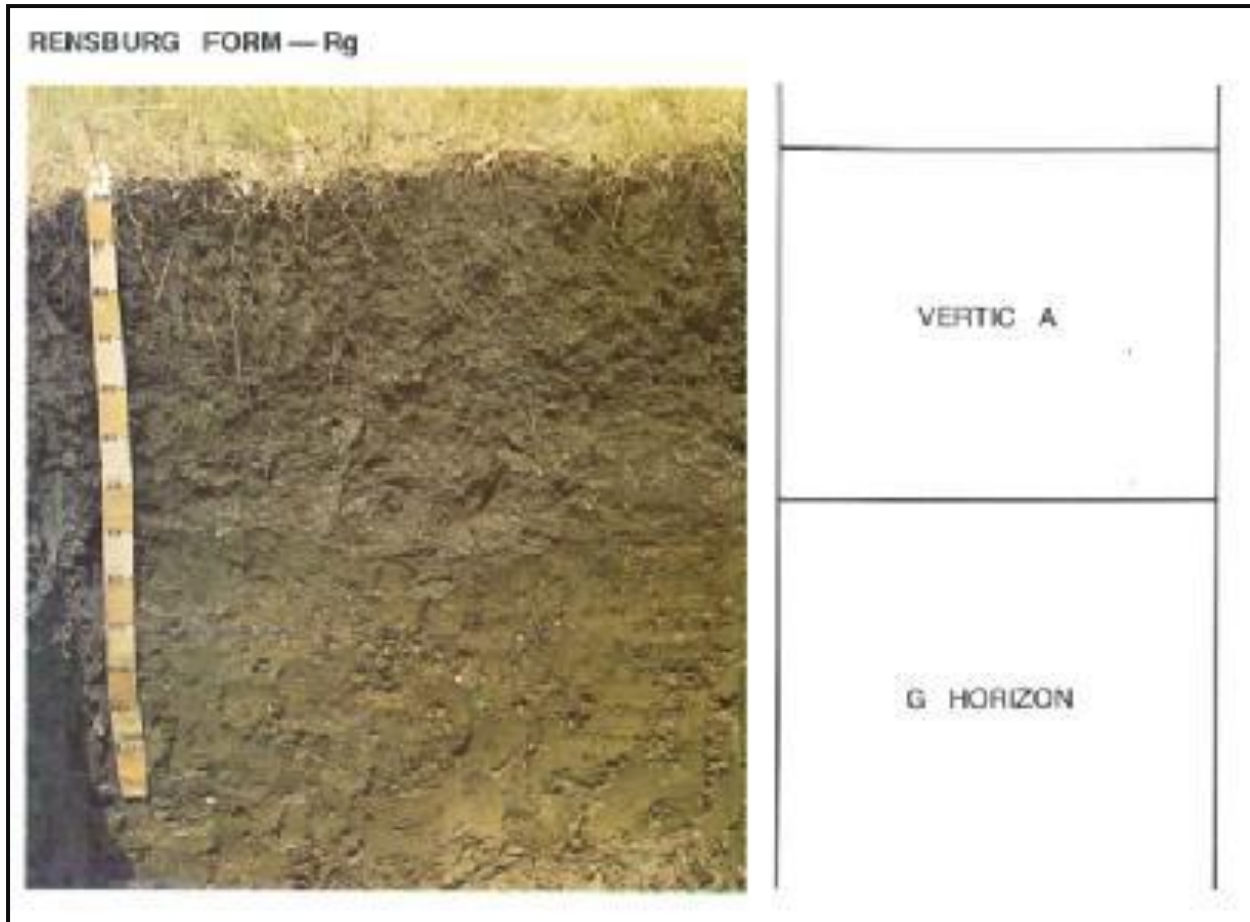


Figure 20: Rensburg soil form (MacVicar *et al*, 1991).

As indicated in **Figure 21**, the clay content of these soil types are relatively high clay content between 20 - 35%. Especially the lower lying soil types is known to have a high clay content and then in particular the 2:1 clay mineral type. This will significantly increase the sorption of cations such as Ca, Mg and K.

The cation exchange activity might influence and change the physical characteristics of the soils such as infiltration capacity, water retention capacity etc.

The CEC of clays in this study area is of particular importance as the ground water pollutant is fertiliser based a product which will readily interact with clays in soil. Furthermore, most of the pollution takes place at surface level where the pollutant first have to seep through the soil (clay) profile in order to reach the aquifer systems, and as such is provided with the opportunity to interact with the clay.

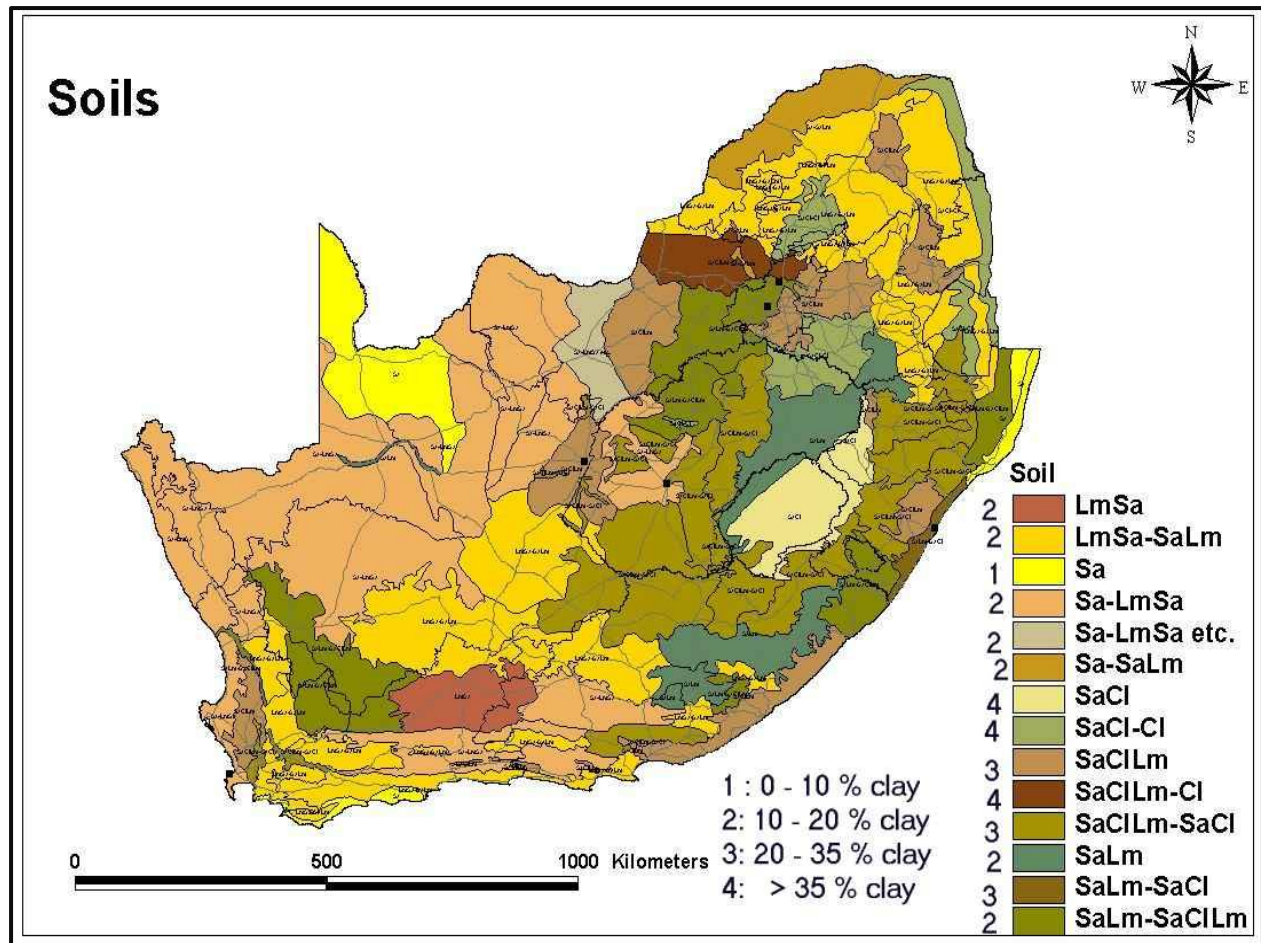


Figure 21: Soil map of South Africa (van Tonder *et al*, 2000).

4.3 CLIMATE

4.3.1 Rainfall

Rainfall statistics for the period 1961 - 1990 which are presented in **Graph 1** and **Table 5** indicate a typical summer rainfall climate (Highveld) with high rainfall (and subsequent flash floods) taking place from November to February. May to August is the period which records the lowest levels of rainfall. The average annual rainfall is 671mm/year. The maximum rainfall per 24-hour cycle is 122mm which was recorded on 20 November 1973. Thunderstorm intensity is fairly high with consequent high intensity of lightning (Aucamp, 2008). **Figure 22** provides an overview of the mean annual rainfall in South Africa.

Graph 1: Monthly maximum, minimum and mean rainfall for the Sasolburg area (Aucamp, 2008).

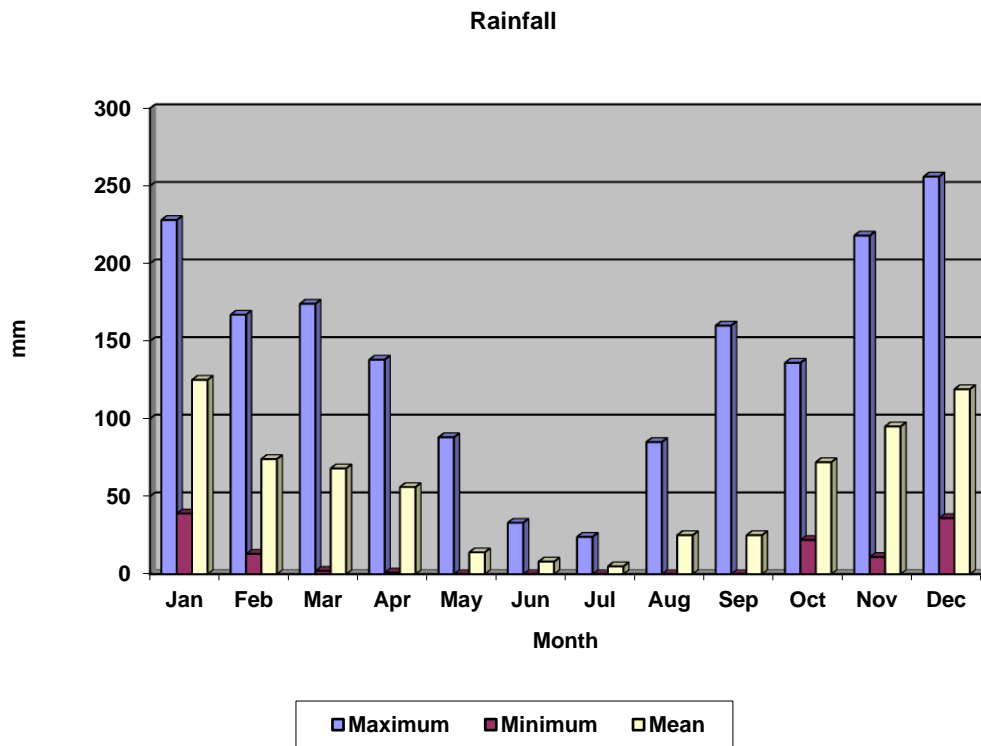


Table 5: Rainfall summary for the period 1969-1991 (Aucamp, 2008).

Month	Max mm/month	Min mm/month	Mean rainfall mm/month
January	228	39	125
February	167	13	74
March	174	2	68
April	138	1	56
May	88	0	14
June	33	0	8
July	24	0	5
August	85	0	10
September	160	0	25
October	136	22	72
November	218	11	95
December	256	36	119

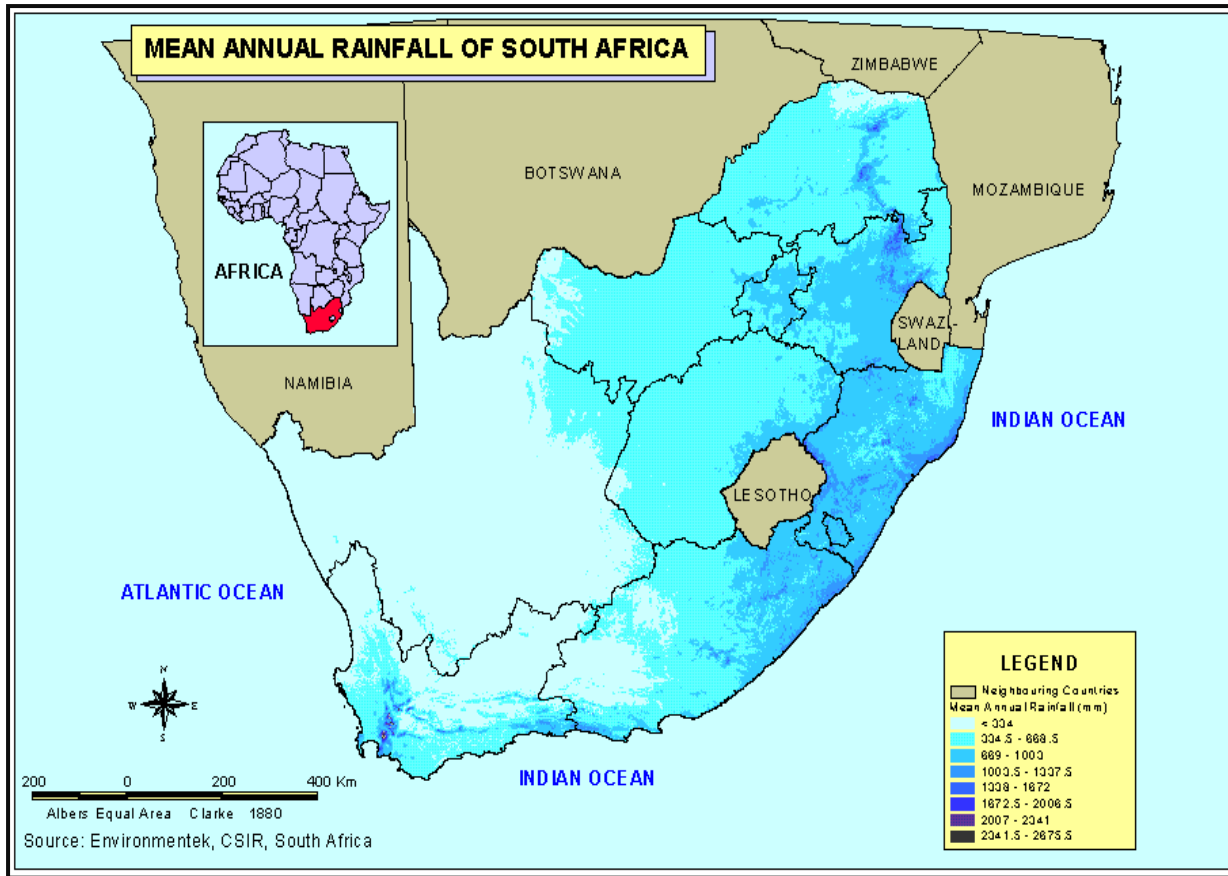


Figure 22: Mean Annual Rainfall of South Africa (Council for Scientific and Industrial Research - Environmentek, 2008).

4.3.2 Temperature

Statistics regarding the temperature are presented in **Graph 2** and **Table 6** below.

Sasolburg has a temperature profile ranging from very warm in summer to extremely cold in winter. The mean daily temperature can however be considered as moderate.

Figure 23 provides an overview of the mean annual temperatures in South Africa.

Graph 2: Maximum and minimum temperatures for the period 1961 – 1990 (Aucamp 2008).

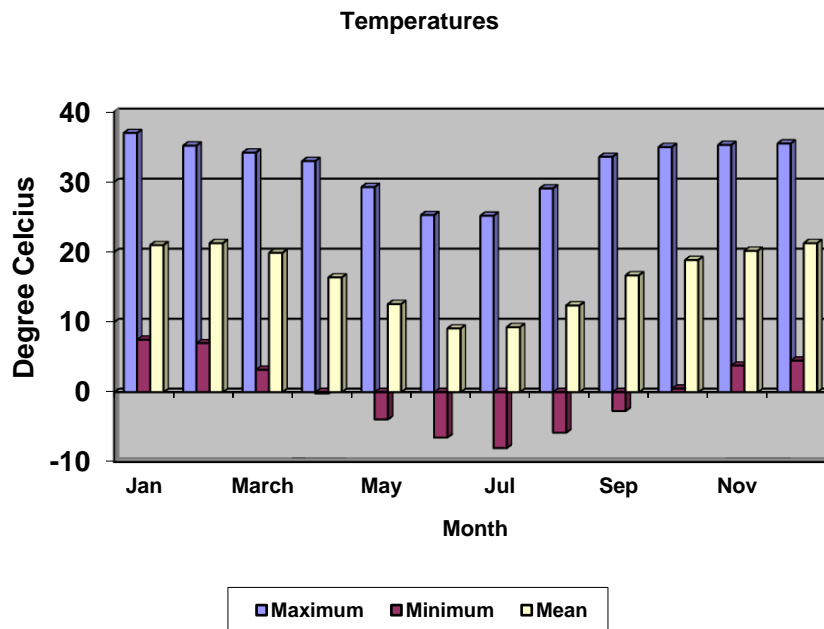


Table 6: Maximum and minimum temperatures (Aucamp, 2008).

Month	Max °C	Min °C	Mean daily temperature °C
January	37.0	7.5	21.0
February	35.2	7.0	21.3
March	34.2	3.2	19.9
April	33.0	-0.2	16.4
May	29.3	-3.9	12.6
June	25.3	-6.5	9.1
July	25.2	-8.0	9.3
August	29.1	-5.8	12.4
September	33.6	-2.7	16.7
October	35.0	0.5	18.9
November	35.3	3.8	20.2
December	35.5	4.5	21.3

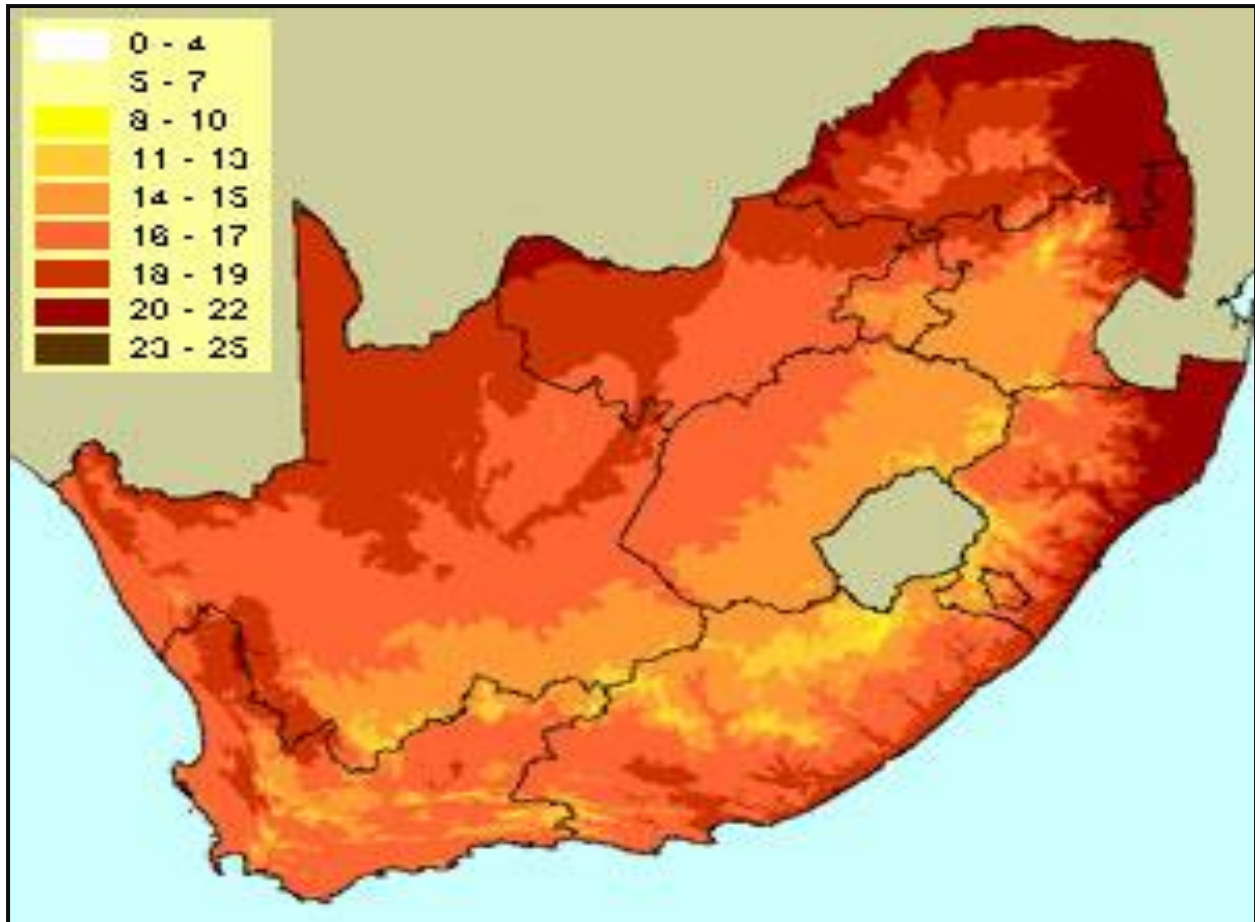


Figure 23: Mean Annual Temperatures of South Africa (Council for Scientific and Industrial Research - Environmentek, 2008).

4.3.3 Wind

Wind roses comprise 16 spokes which represent the directions from which winds blew during the monitoring period. The colours reflect the different categories of wind speeds. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. Period wind roses for the Vereeniging monitoring station is depicted in **Figure 24**. For the periods assessed, winds predominated from the north-western sector. Wind speeds are fairly low, mainly ranging between 2.1 to 3.6 m/s and rarely exceed 11 m/s. In addition, for the periods assessed the Vereeniging station experienced 8.79% calms.

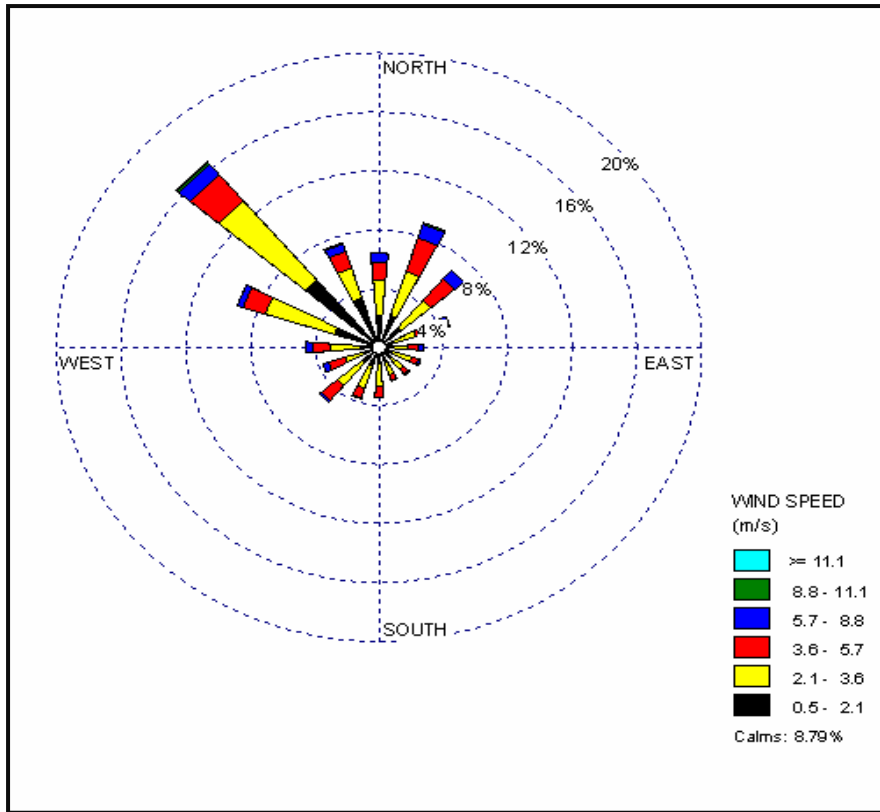


Figure 24: Period average wind rose for the Vereeniging Weather Station for 2004, Station number 0438784 3, 26.57° S, 27.95° E (South African Weather Service, 2004).

4.3.4 Evaporation

Monthly evaporation has been established at approximately 1490mm per annum. This value is based on the E-pan evaporation data for the Vaal Barrage meteorological station, which is the nearest to the study area. **Table 7** provides an overview of the average evaporation for the study area per month.

Table 7: Evaporation data for the study area (mm/m) (Aucamp, 2008).

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
178.8	148	135.2	101.4	77.7	58.8	64.3	92.1	127.9	159.8	166.9	180.4

4.4 TOPOGRAPHY

The topography in the study area is gentle with no mountain ranges and valleys. **Figure 25** provide an indication on the relative gentle topography in the study area. Elevations get lower

towards the Taaibosspuit in the north which is also the natural drainage area of the catchment. **Figure 26** provides an overview of the topography by taking the ground level elevation of the borehole monitoring network at meter above mean sea level (mamsl).

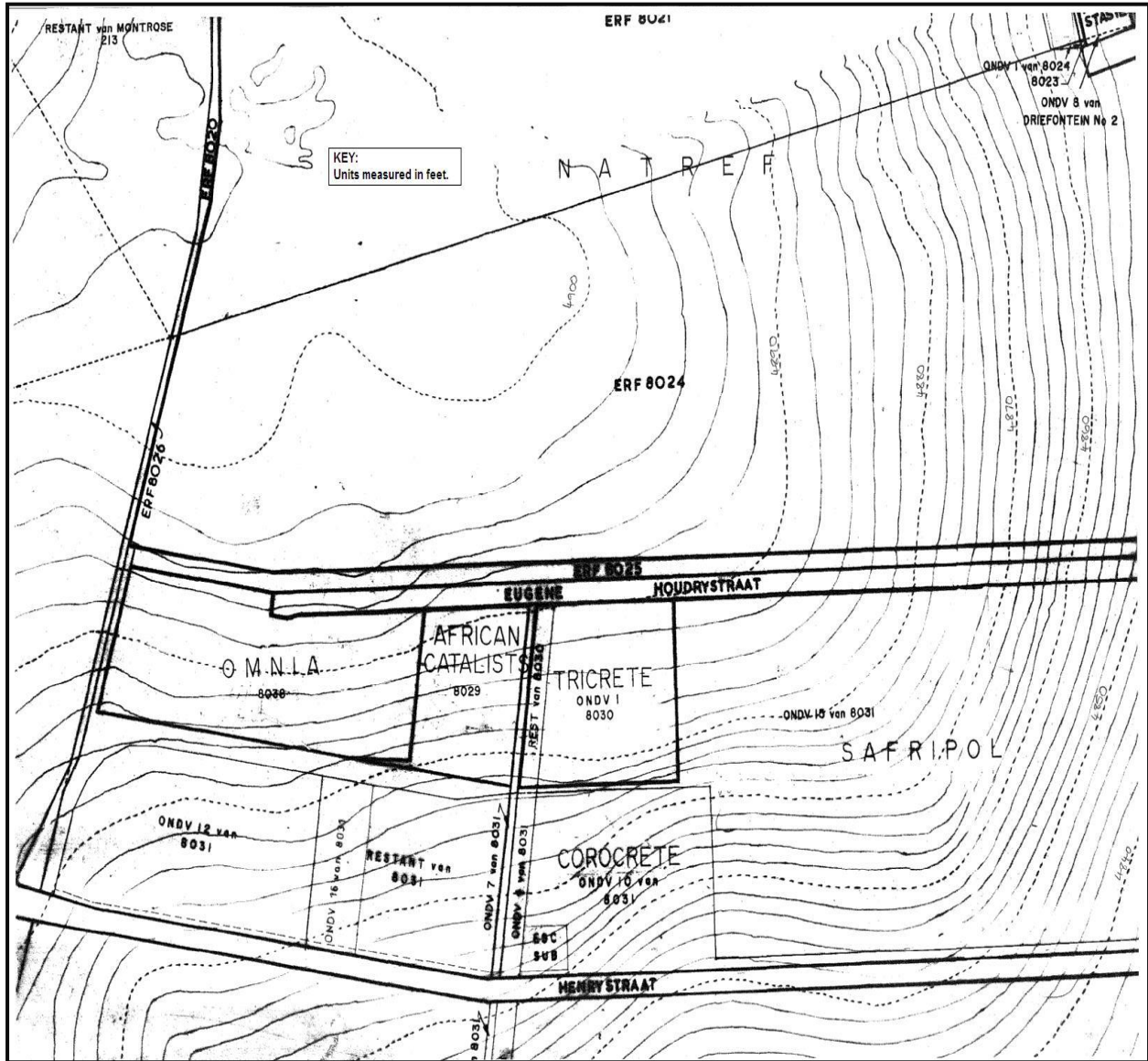


Figure 25: Topography Contour Map (Omnia, 1988).

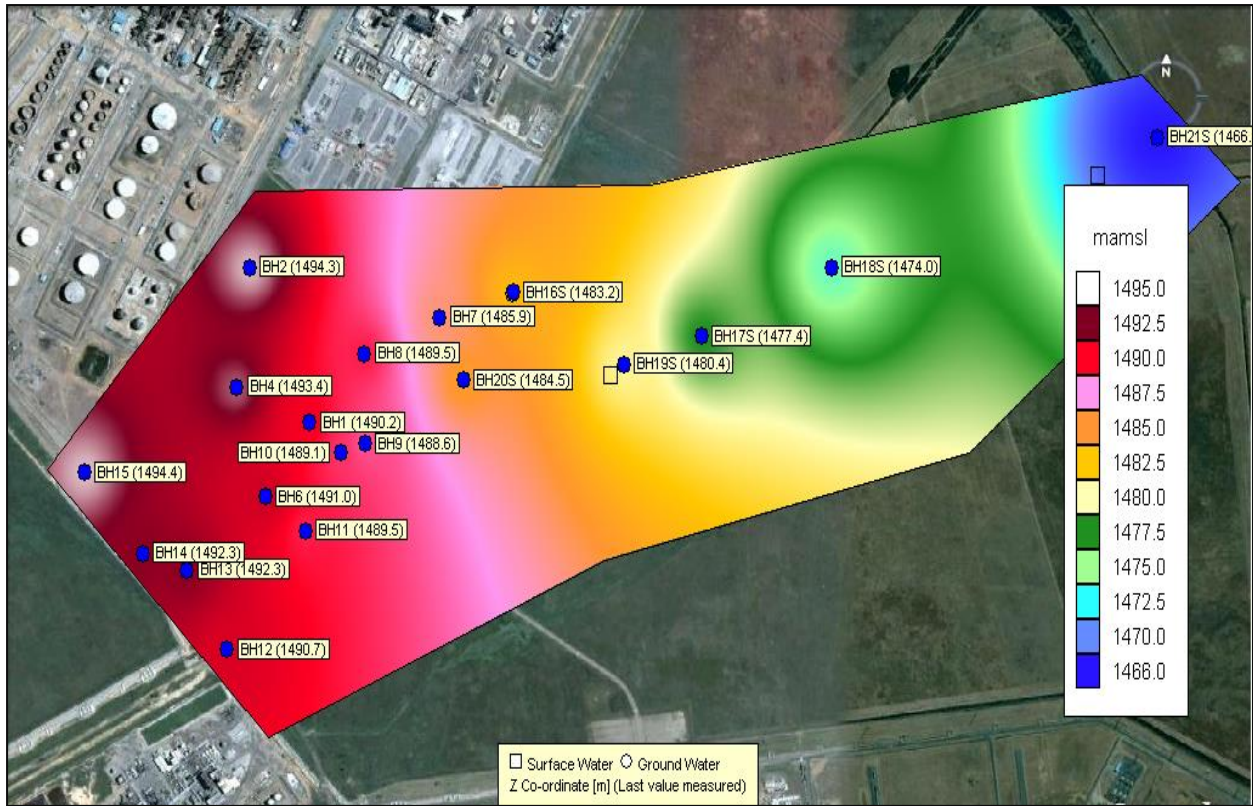


Figure 26: Topography contour map based on borehole elevation heights (mamsl).

4.5 HYDROGRAPHY

The catchment boundaries include the northerly draining tributaries of the Vaal River, the Leeu and the Taaibosspruit. The Leeuspruit is situated on the western side of Sasolburg and is approximately 15 km in length. The Taaibosspruit and its tributaries are located east of Sasolburg and are approximately 55 km in length. The Vaal River forms the northern boundary and the major surface drainage feature of the study area (Cowley, 1999). The quaternary catchment is C22G and is indicated on **Figure 27**. Storm water run-off from the Omnia Fertiliser Sasolburg site is in the direction of Henry's dam which can be seen in **Figure 28**. Before 2006 the site did not have the necessary infrastructure to contain contaminated storm water run-off from the North and South Factory areas. A single storm water containment dam was constructed during 2005 with a capacity of 5500m³ (although indicated that three dams with a capacity 5500m³ would have been constructed), mainly as an attempt to contain contaminated storm water from the north factory which is indicated in **Figure 29**. The establishment of the storm water dam was an attempt to satisfy the requirements from the then Department of Water Affairs and Forestry (DWAFF) to increase the facility's ability to contain storm water in the event of a 1:50 year 24 hour rainfall event from potentially contaminated surface areas from within the factory boundaries.

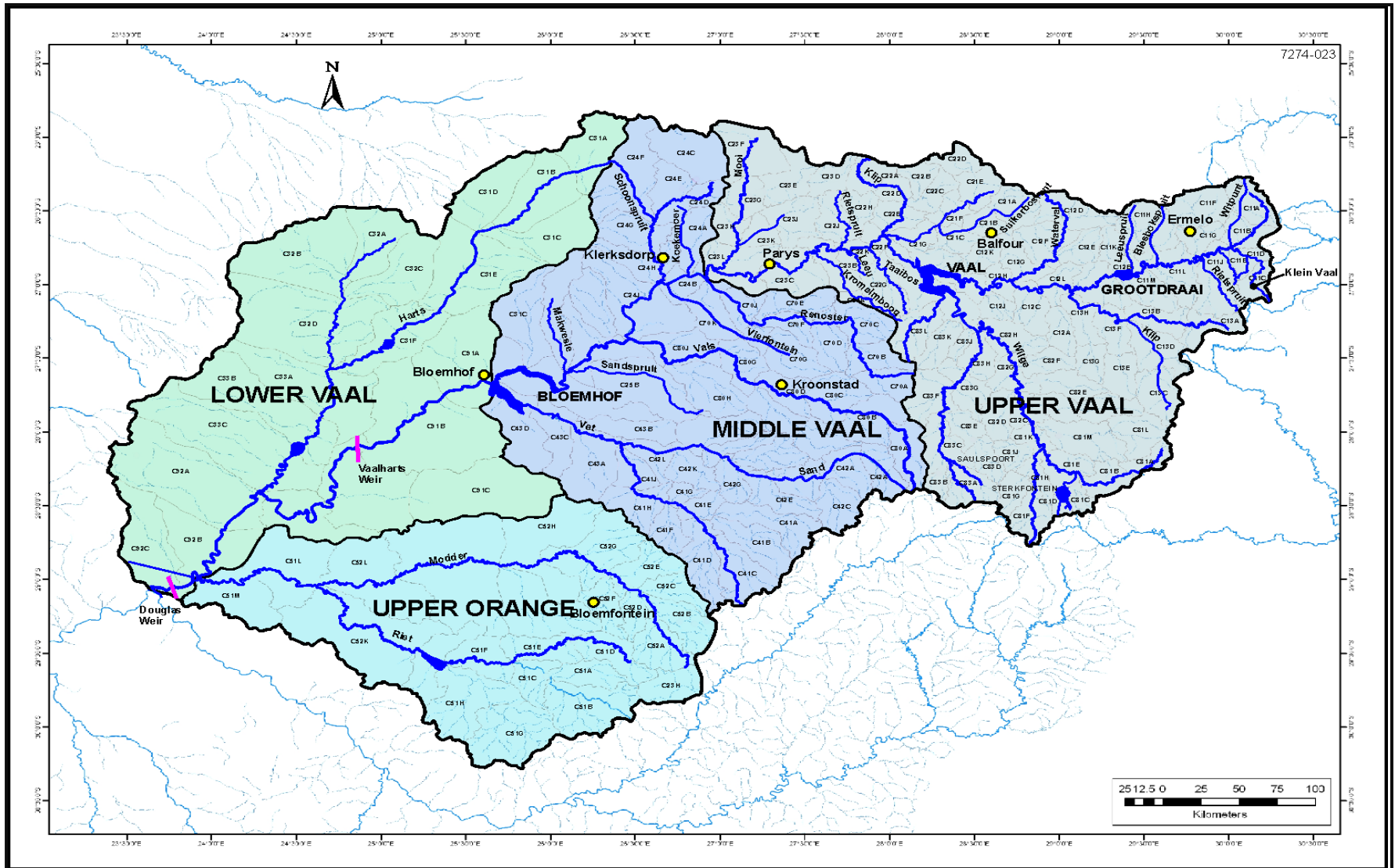


Figure 27: Quaternary Catchment in the Upper Vaal Catchment (Department of Water Affairs and Forestry, 2008).

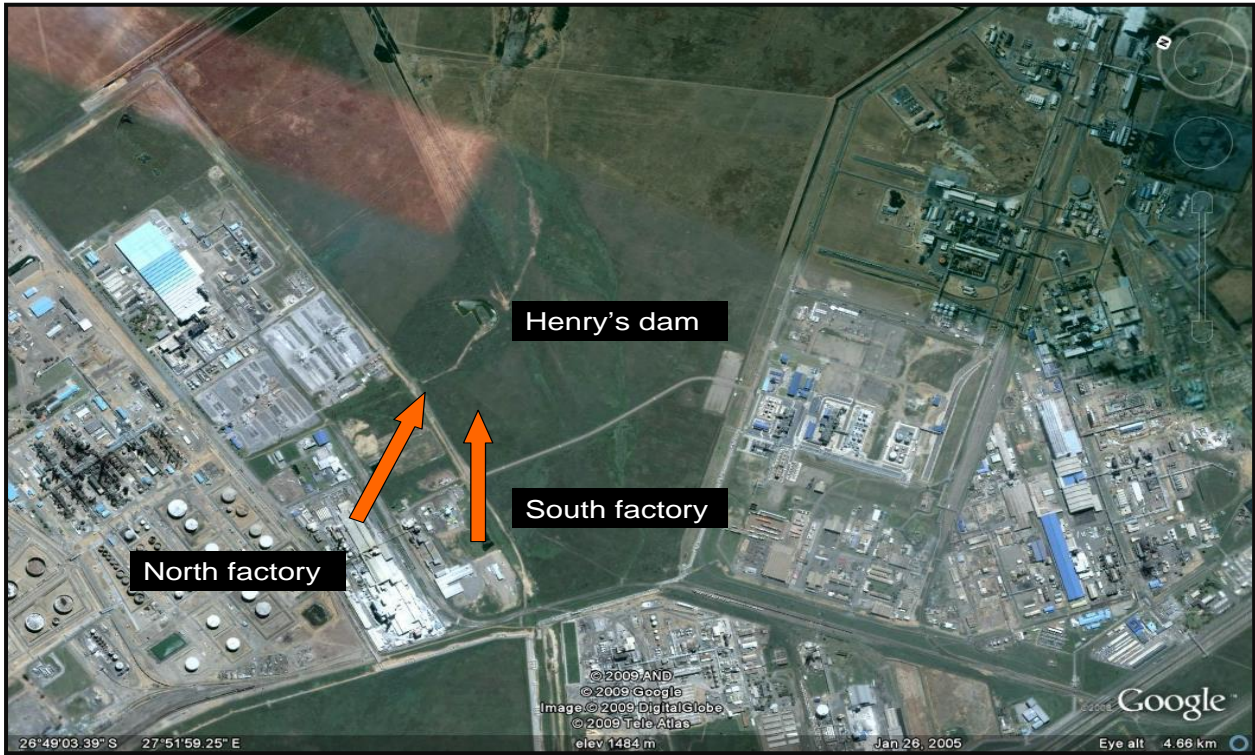


Figure 28: Storm water flow directions from the north and south factory (Google Earth, 2011).



Figure 29: The location of the storm water dam and Henry's dam (Google Earth, 2011).

4.5.1 Annual storm water volume and intensity calculation

The Omnia Fertiliser Sasolburg site covers an area of 90,000 m² on the North Factory and 70,000 m² on the South Factory.

According to Fetter (2001), a basic problem of hydrology is predicting the amount of run-off that will occur from a given storm. Structures that carry run-off such as storm water channels are usually designed on the basis of the peak run-off rate. A maximum expected rainfall rate is determined based on climatic rainfall records.

Several equations have been developed to make this prediction. The most simple and frequently used equation is the rational equation which states that if it rains long enough, the peak discharge from the drainage basin will be the average rate of rainfall times the drainage basin area, reduced by the factor to account for infiltration.

The smaller the drainage basin the higher the validity of the rational method. Fetter (2001), indicates that the rational method is particular accurate for drainage basins smaller than 100ha.

Table 8 represents the run-off factors for the rational equation.

Table 8: Run-off factors for the rational equation (Fetter, 2001)

Description of the area	C (Run-off factor)
Business	
Downtown	0.70-0.95
Neighbourhood	0.50-0.70
Residential	
Single family	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Residential, suburban	0.35-0.40
Apartment	0.50-0.70
Industrial	

Description of the area	C (Run-off factor)
Light	0.50-0.80
Heavy	0.60-0.90
Parks, cemeteries	0.10-0.30
Playgrounds	0.20-0.35
Railroad yard	0.20-0.35
Unimproved	0.10-0.30
Character of surface	
Pavement	
Asphalt and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Lawns and sandy soil	
Flat, up to 2% grade	0.05-0.10
Average, 2%-7% grade	0.10-0.15
Steep, over 7%	0.15-0.20
Lawns and heavy soil	
Flat, up to 2% grade	0.13-0.17
Average, 2%-7% grade	0.18-0.22
Steep, over 7%	0.25-0.35

The storm water volume for the North and South Factory can be calculated as follows:

$$V = A(P*C)$$

Where:

V = Volume of storm water (m³);

A = Area (m²);

C = Run-off factor; and

P = Precipitation (mm/a)

Thus for mean annual storm water volume of the North Factory the following applies:

Confidential

$$A = 90,000\text{m}^2;$$

$C = 0,75$ (mean average for heavy industry); and

$$P = 671\text{mm/a or } 0.671\text{m/a.}$$

Thus: $V = A(P*C)$

$$V = 90,000\text{m}^2 (0.671\text{m/a}*0.75)$$

$$V = 90,000\text{m}^2 (0,503\text{m/a})$$

$$V = 45,270\text{m}^3$$

It is clear from the storm water volume calculation results that the existing 5500m³ storm water dam is inadequate to contain all the annual storm water from the North Factory.

Thus for mean annual storm water volume of the South Factory the following applies:

$$A = 70,000\text{m}^2;$$

$C = 0,5$ (mean average for light industry); and

$$P = 671\text{mm/a or } 0.671\text{m/a.}$$

Thus: $V = A(P*C)$

$$V = 70,000\text{m}^2 (0.671\text{m/a}*0.50)$$

$$V = 70,000\text{m}^2 (0,336\text{m/a})$$

$$V = 23,485\text{m}^3$$

The total volume of storm water generated by the North and South Factory based on the mean annual rainfall figure is approximately 68,755m³/a.

Figure 30 represents the surface water flow vectors based on meters above mean sea level (mamsl) borehole monitoring point heights. **Figure 31** represents the surface water monitoring points.

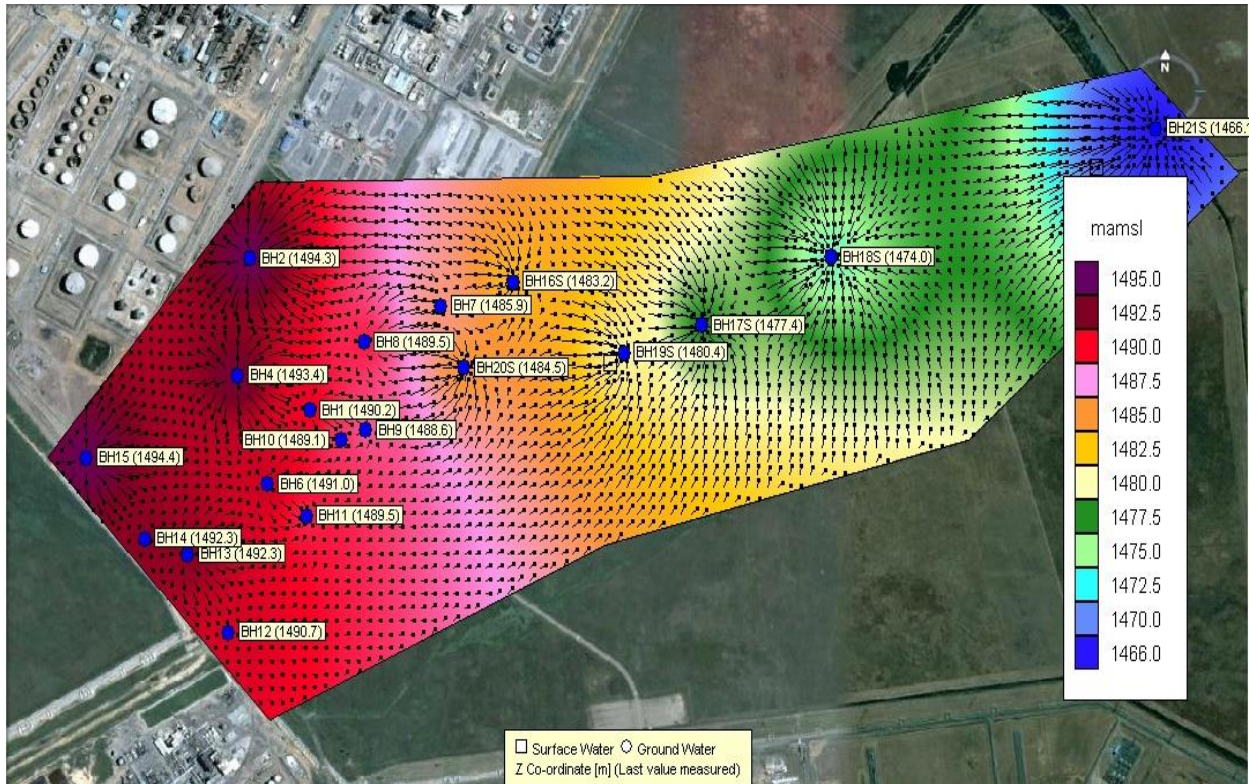


Figure 30: Surface water flow directions based on topography.



Figure 31: Surface water monitoring points.

4.5.2 Site water balance

Figure 32 presents a simplified version the Omnia Fertiliser Production site water balance. The aspects considered in the water balance is summarised below:

Incoming water to the site:

- Precipitation;
- Rand water;
- Demineralised water from Sasol Infrachem; and
- Steam and condensate.

Outgoing water from the site:

- Storm water;
- Evaporation; and
- Cooling tower blow down.

The following presents an indication of the various water users on the site.

Nitric Acid Plant

- Cooling tower;
- Steam generation at the boiler;
- Vaporisation;
- Human consumption; and
- Ablution facilities.

Granulation Complex

- Scrubbing water and recycling of it;
- Process water;
- Human consumption; and
- Ablution facilities.

Super Phosphate Complex

- Process water;
- Scrubbing water and recycling of it; and
- Human consumption.

Laboratory

- Ablution facilities;
- Cleaning of apparatus and equipment; and
- Human consumption.

Workshops

- Cleaning of equipment and work area;
- Human consumption; and
- Ablution facilities.

Nitrates Complex

- Scrubbing liquor and recycling of it;
- Plant cleaning;
- Process water and recycling of it;
- Evaporation; and
- Human consumption.

South Factory

- Plant cleaning;
- Process water;
- Ablution facilities; and
- Human consumption.

Office Blocks

- Human consumption;
- Ablution facilities; and

- Cleaning.

Other

- Wetting of grass around the lawns on site; and
- Washing of equipments and cars.

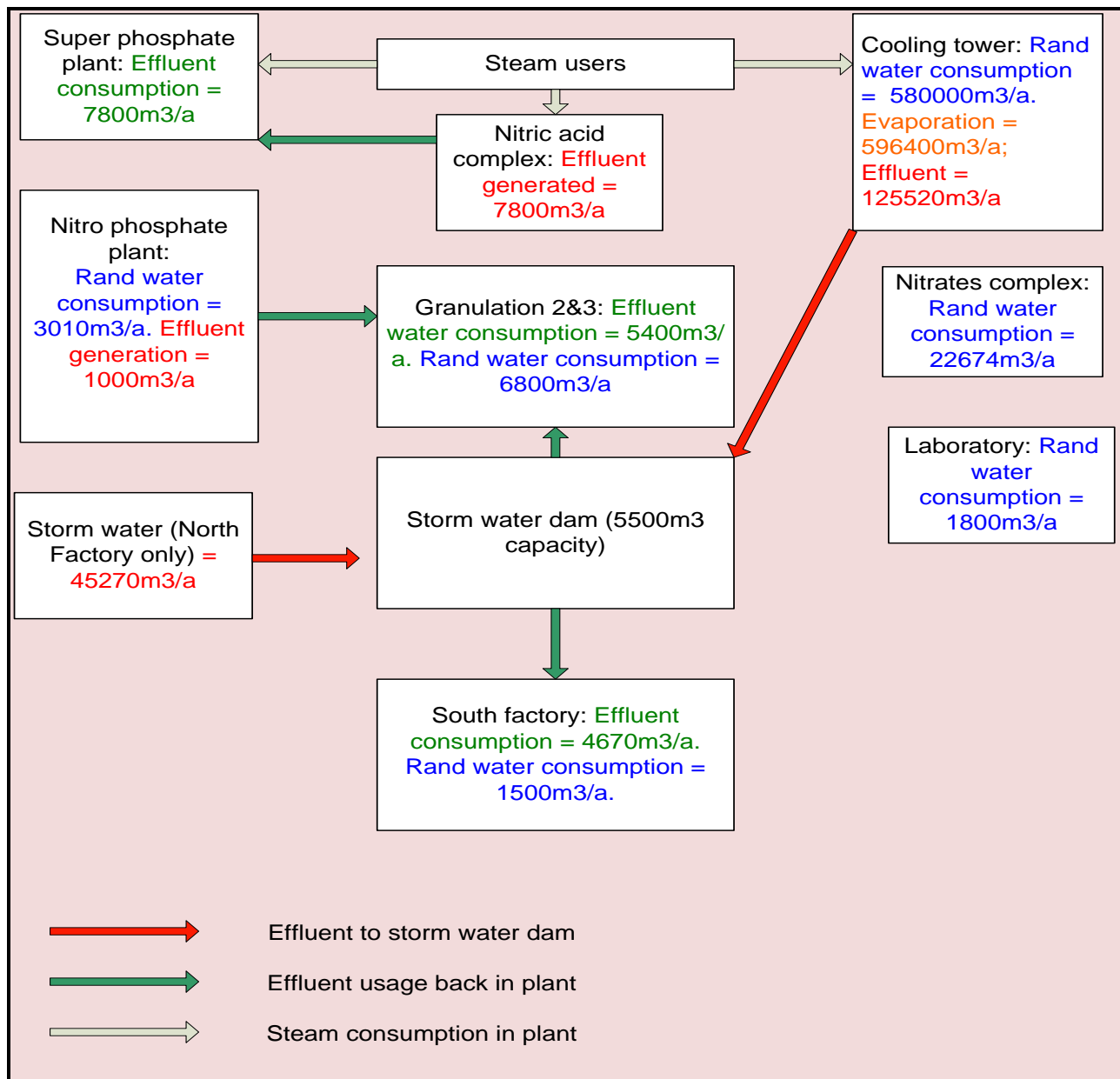


Figure 32: Simplified water balance for the Omnia Fertiliser Sasolburg operation.

Except for storm water and cooling tower water discharge, the operation is a net consumer of water. Except for the cooling towers, no water is discharged by the operation. The main water supply is potable water from Rand Water. The Rand Water system is physically separated from the process water and effluent water. This is to prevent possible contamination of drinking water and Rand Water. There is also a separate drainage system between the Rand Water system and the storm water drainage (channels, drains, trenches). The normal procedure is to recycle process water and re-use in the various processes on site.

CHAPTER 5: CONCEPTUAL GROUND WATER MODEL

5.1 GROUND WATER MONITORING NETWORK

The ground water monitoring network is represented in **Figure 33** and **Figure 34**. Differentiation between the deep and shallow aquifer monitoring boreholes is also indicated.

The adequacy of the monitoring network is discussed in Chapter 6 of this thesis.

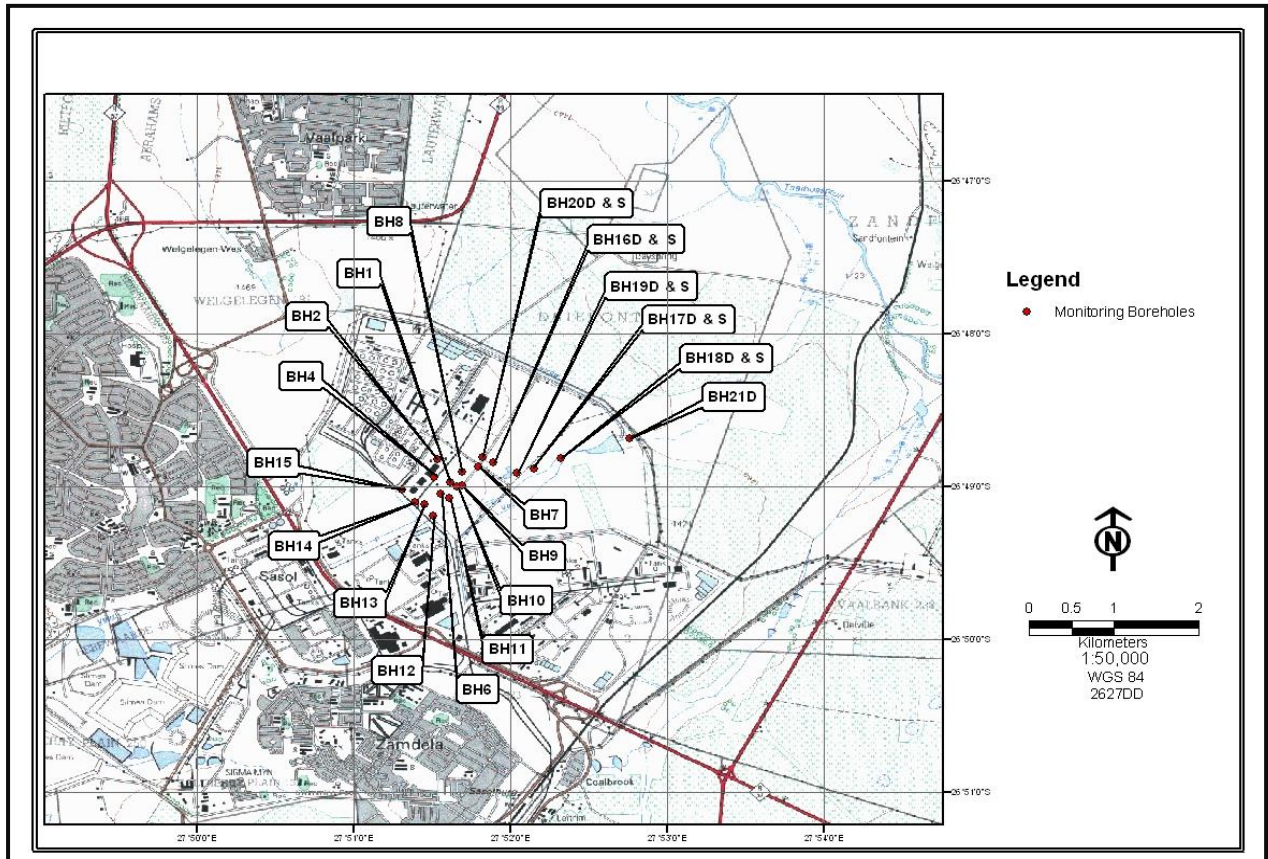


Figure 33: 1:50000 Topographic map indicating the ground water monitoring network.

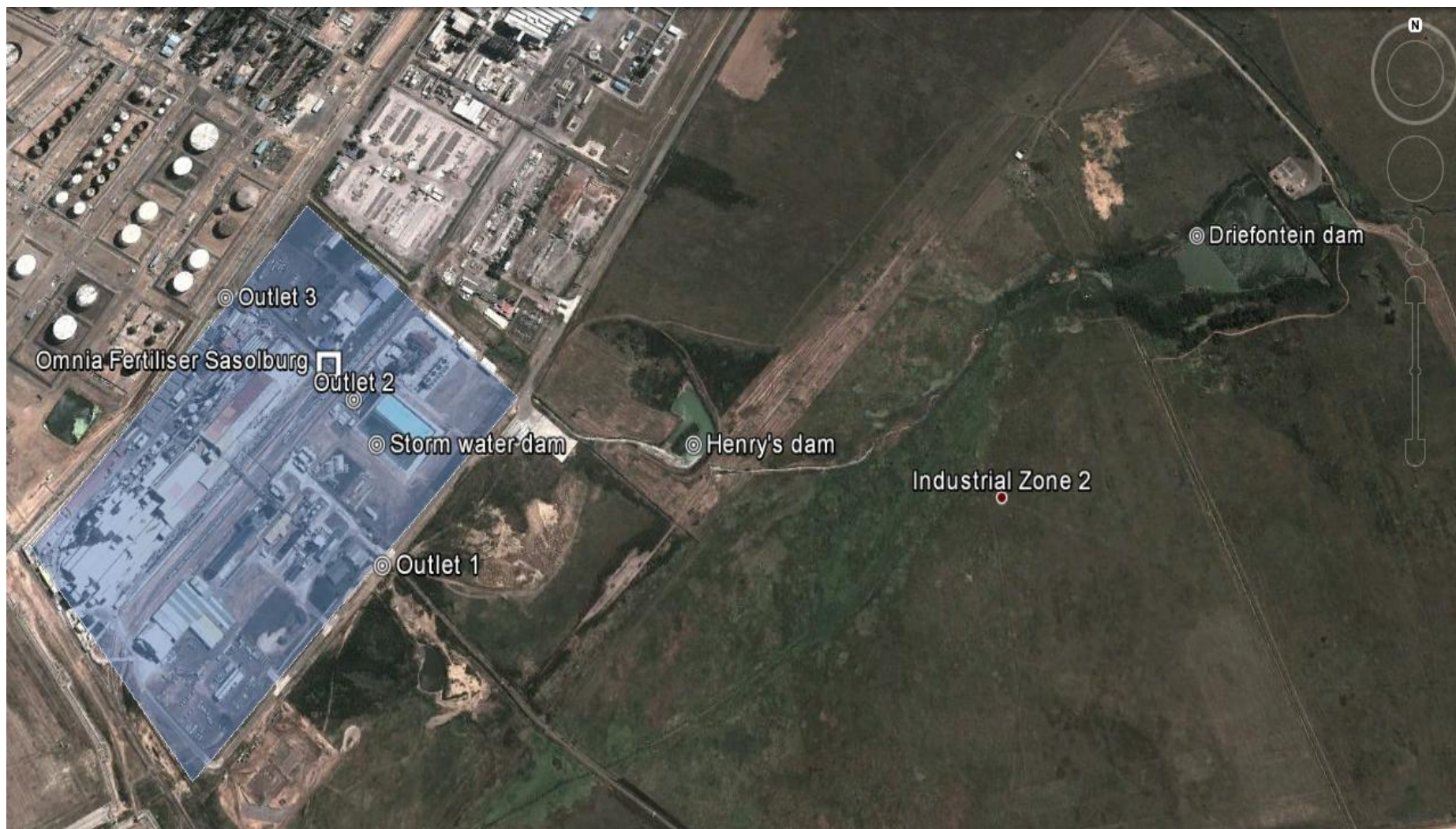


Figure 34: Satellite map indicating the surface water monitoring network.

5.2 SITE SPECIFIC GEOLOGY

The study area is located within the Vereeniging-Sasolburg Coal Field.

According to Jones and Wagner (2004) this coalfield comprises three paleo basins namely:

- Sigma;
- Cornelia; and
- Coalbrook basin.

The study area is located in the Sigma basin. Within the study area, only the younger dolerite sill is encountered to the west of Henry's dam. Two dolerite dykes have been intersected in this area according to Jones and Wagner (2004).

Monitoring boreholes have been drilled to a depth of twenty metres and thirty metres respectively. The lithology of selected boreholes is indicated in **Figures 35, 36, 37, 38, 39 and 40.**

The lithology underneath the site mainly consists of loose sand, clay layers, weathered dolerite, silt, sandstone and mudstone. Shale below the dolerite is common.

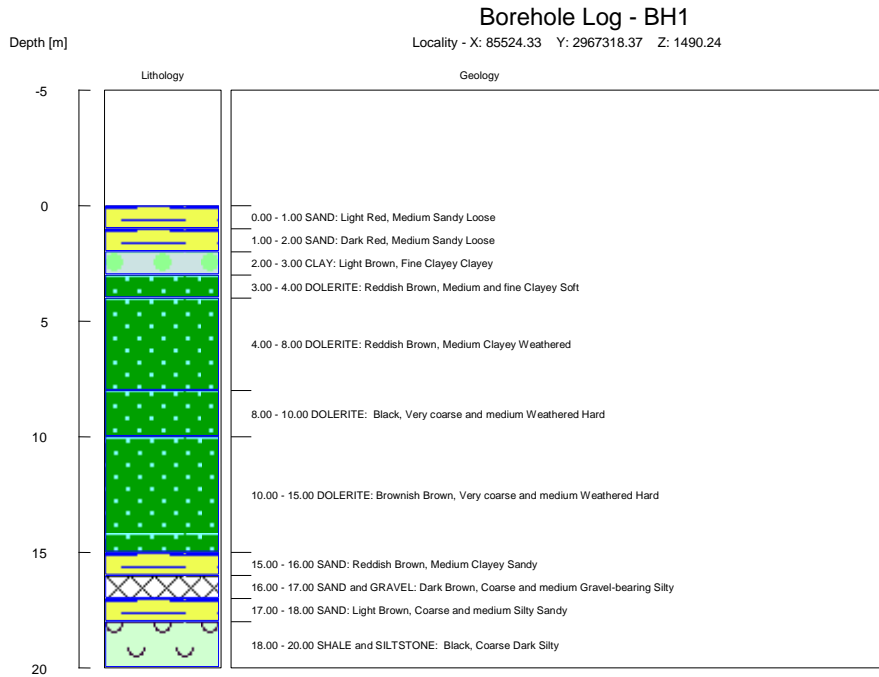


Figure 35: Lithology of Borehole 1.

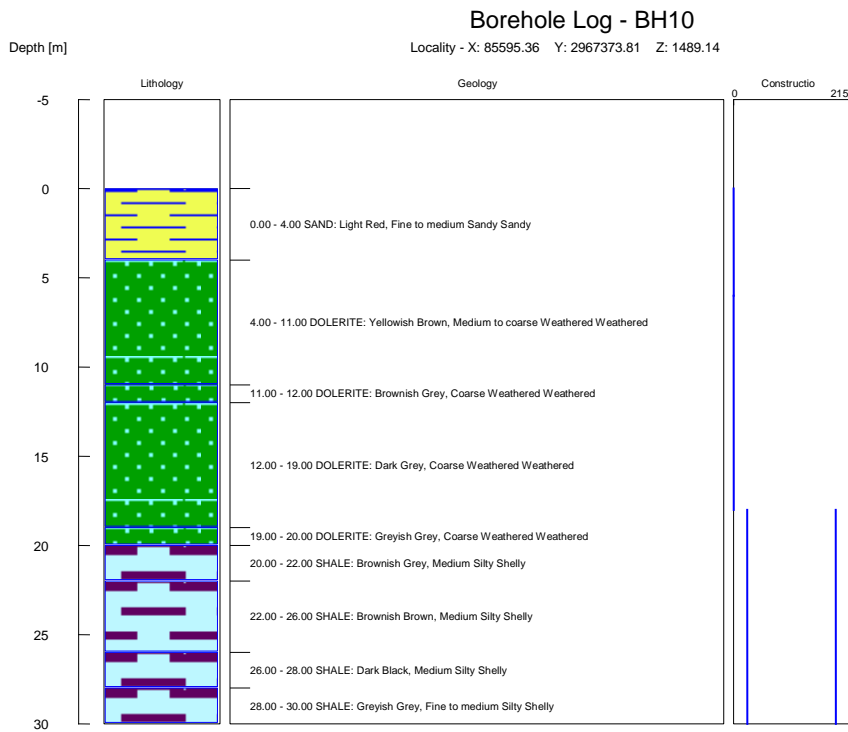


Figure 36: Lithology of Borehole 10.

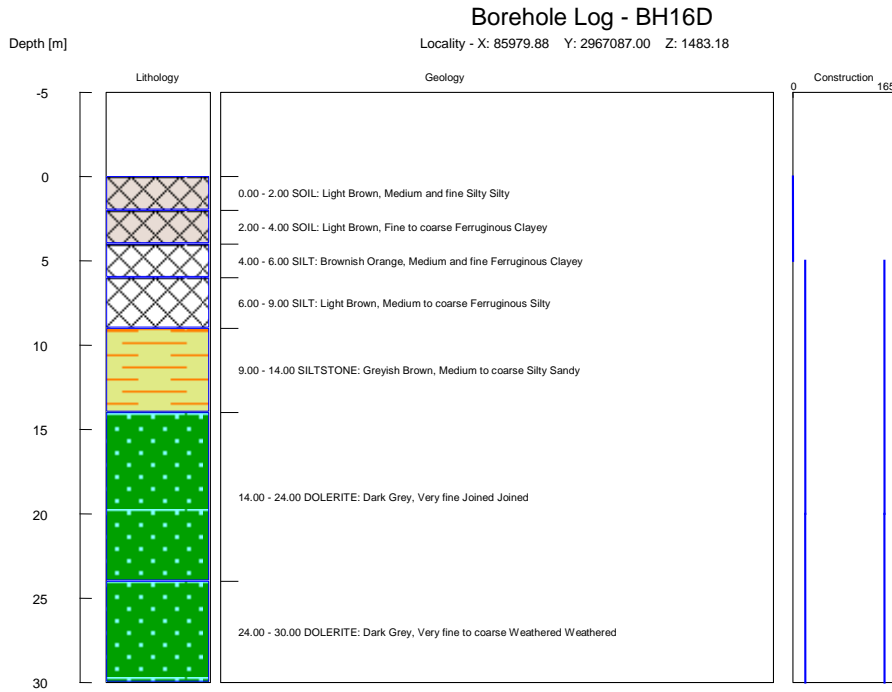


Figure 37: Lithology of Borehole 16S&D.

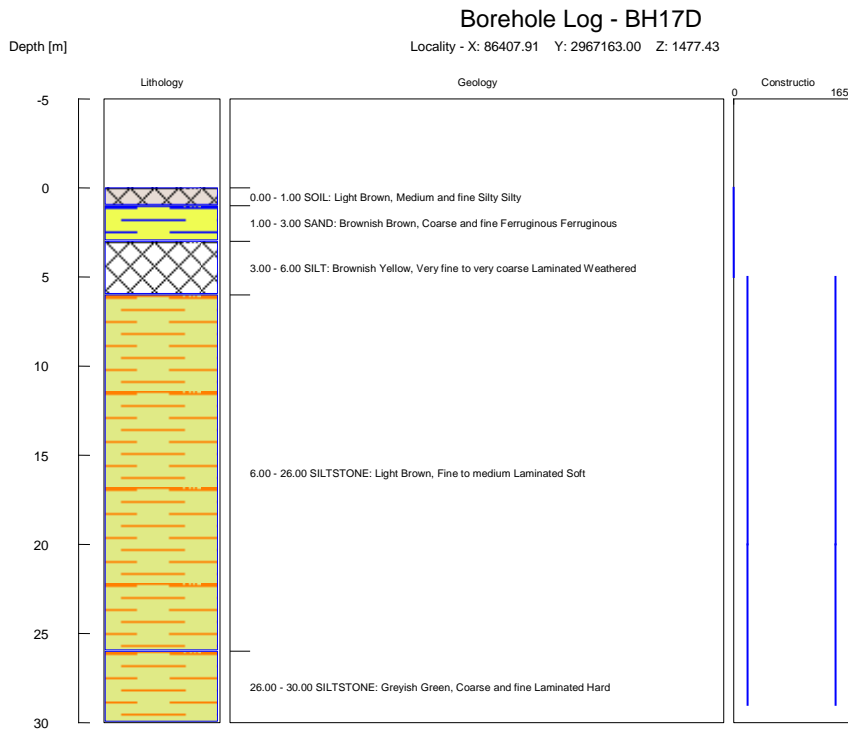


Figure 38: Lithology of Borehole 17S&D.

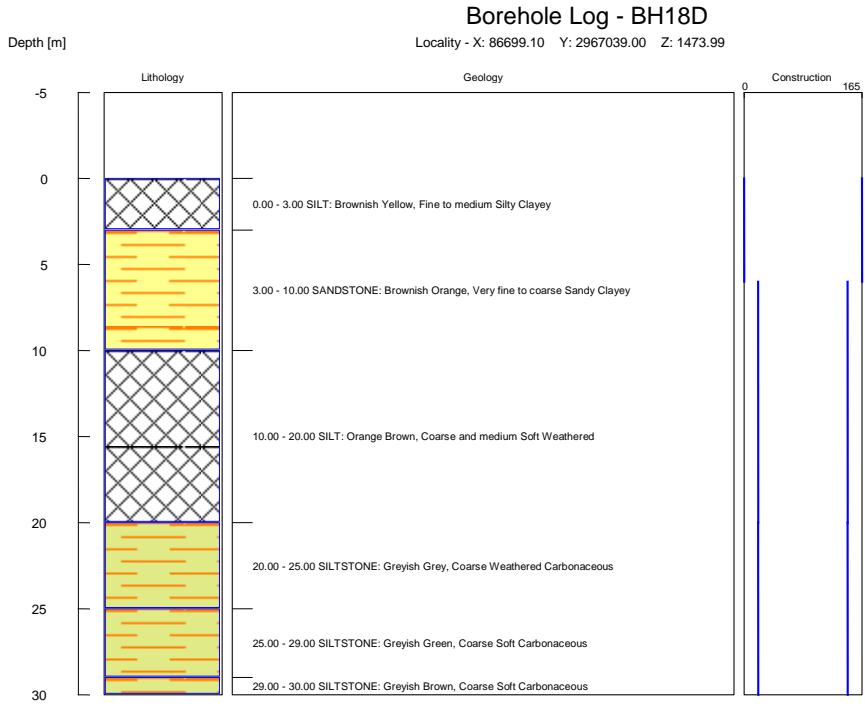


Figure 39: Lithology of Borehole 18S&D.

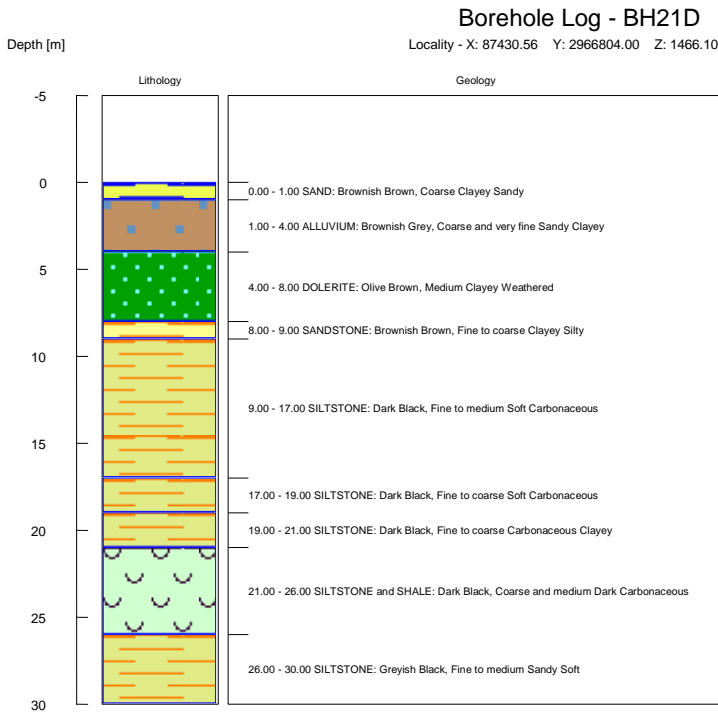


Figure 40: Lithology of Borehole 21S&D.

5.3 GEOPHYSICAL CHARACTERISTICS

Limited information is available on the geophysical characteristics of the geology underlying the Omnia Fertiliser site. Jones and Wagner (2004) performed a geophysical study of the Driefontein area in 2004. The purpose of this study was to get a better understanding of the local geology as well as the location of shallow pollution plumes in the weathered aquifer originating from both Henry's dam and Driefontein dam. A previous EM-34 investigation conducted by Jones and Wagner showed a major anomalous high conductivity trend from the southern factory areas, possibly striking towards Driefontein dam.

Jones and Wagner used EM-34 (electromagnetics), magnetics and resistivity in the investigation. Magnetics was used to map the presence of possible dykes. The EM-34 anomaly showed anomalously deep dolerite, possibly associated with a feeder dyke for the dolerite present to the west of the site (**Figure 41**). Boreholes 16 and 20 were percussion drilled (Jones and Wagner, 2004) and the results confirmed the anomaly as having originated as a result of geology (two dolerite dykes and an increase in contamination in this area).

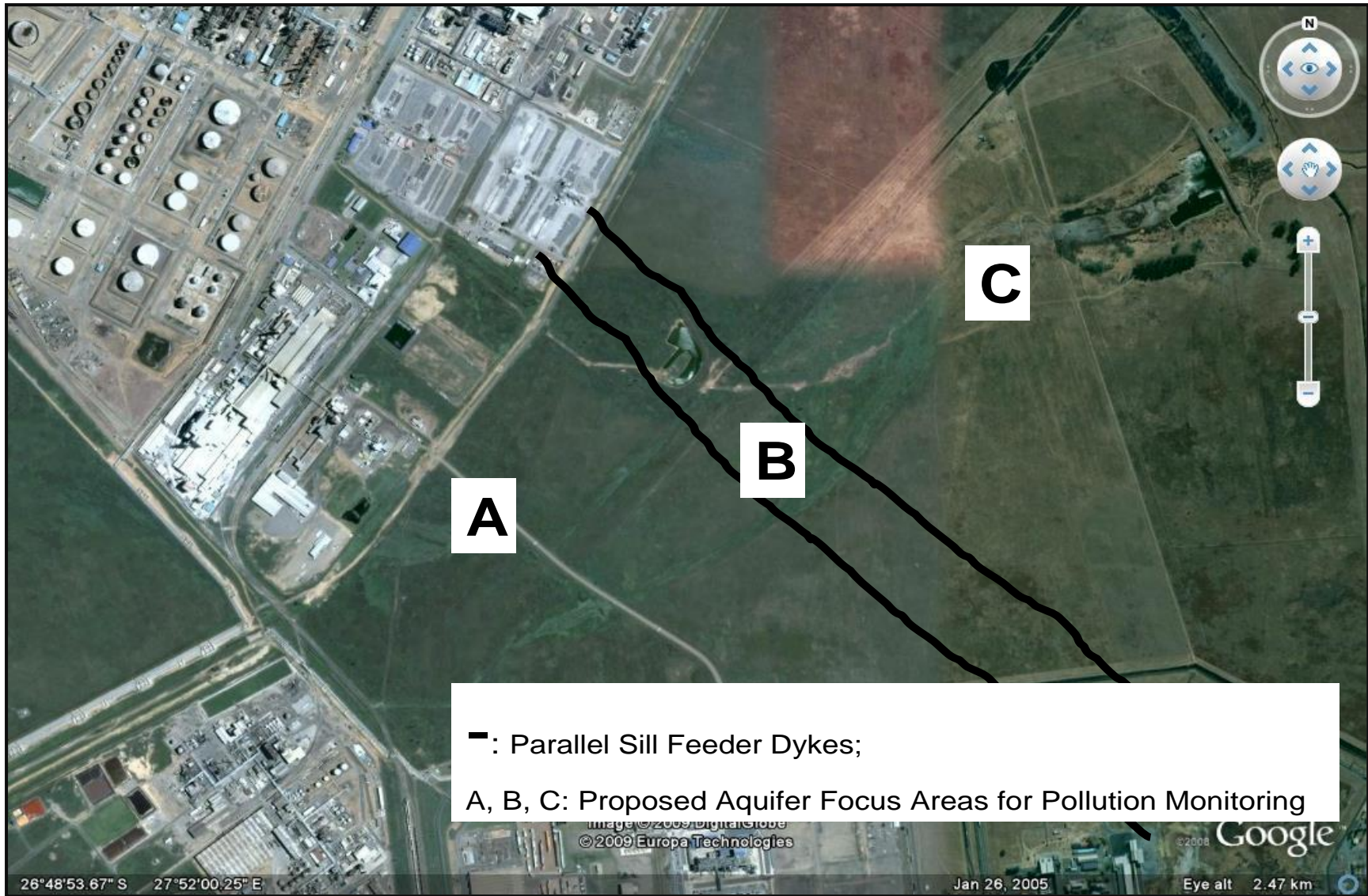


Figure 41: Representation of the approximate possible location of the encountered dolerite dykes (Google Earth, 2011).

5.4 AQUIFER CLASSIFICATION

Based on the lithology of the study area the aquifer systems within the study area can be divided in two aquifer systems:

- Shallow unconfined weathered Karoo aquifer; and
- Deeper semi-confined fractured Karoo aquifer.

This is supported by Jones and Wagener (2004) and Cowley (1999).

5.4.1 Shallow unconfined weathered Karoo aquifer

The weathered Karoo formations which are represented by the sandy clay, silty sand, residual sandstone and siltstone represent the shallow weathered Karoo aquifer.

The shallow aquifer does not have an upper confining layer of impermeable or low permeability material. The water table is exposed to the atmosphere through a series of interconnected openings in the overlying soil layers and is in equilibrium with atmospheric pressure.

According to Van Wyk and Usher (2004) the geology underlying the site mainly consists of loose sands, followed by clay layers and weathered dolerite. During drilling, shale was readily found below the dolerite. The presence of a significant impermeable layer (aquiclude) was found to be unlikely. The uppermost layers consist of unconsolidated sand which causes a high risk of infiltration. This high infiltration risk promotes the risk of pollution being transported in the shallow weathered aquifer.

The shallow aquifer generally has a low yield (less than 1l/s) and has limited opportunity for supplying large volumes of ground water on a sustainable basis (Van Wyk and Usher, 2004).

From this information it is indicative that the shallow aquifer plays the most important role in mass transport simulations from process and induced contamination sources because the lateral seepage component in the shallow weathered aquifer often dominates the flow.

5.4.2 Deep semi-confined fractured Karoo aquifer

The deep semi-confined fractured Karoo aquifer is partly confined by layers of lower permeability material (stiff laminated silt) causing this aquifer semi-confined. This aquitard separates the weathered and fractured aquifer. There is evidence that there is hydraulic connectivity between the shallow unconfined aquifer and deep semi-confined fractured Karoo aquifer.

Van Wyk and Usher (2004) indicate that the study area is situated on a typical fractured rock Karoo aquifer which consists of both a porous matrix and a system of fractures. Most of the water is stored in the matrix while most of the flow takes place in the fractures. Jones & Wagner (2004) indicates that the primary porosity of the Karoo strata is very low. The fracturing and jointing of the rock formations enhance the porosity of the deep semi-confined fractured Karoo aquifer. From studying borehole logs it can be concluded that the deep semi-confined aquifer are comprised of the typical secondary porosity fractured rock type with fissures and fractures facilitating ground water flow and mass transport in **Figures 35, 36, 37, 38, 39 and 40**. In secondary porosity fractured bedrock aquifers (**Figure 42**), ground water flow, and mass transport are virtually fully restricted to open fissures, cracks or fractures in the virtually impermeable host rock matrix. The thickness, yield and other parameters also depend on the characteristics of the fractures. Such characteristics include:

- Fracture aperture;
- Extent;
- Orientation;
- Frequency of occurrence; and
- Texture of the fracture-matrix interface.

Where no fracturing is present, bedrock matrix is impermeable and flow extremely slow.

The study area is prone to have dolerite dyke intrusions cutting through the aquifer and hence can have an influence on ground water flow (**Figure 43**). Usually when dolerite intruded the aquifer area it caused rock in the immediate vicinity to fracture. These fractures form a preferred pathway as water tend to move easier in this area.

Anisotropic aquifers characteristically have properties that vary with direction (horizontal and vertical). It is evident that the aquifers in the study area have a high level of anisotropy making it exceptionally difficult to quantify and simulate the aquifer systems. The transmissivity and storativity of the matrix (TM and SM) is illustrated with the transmissivity and storativity of the fracture (TF and SF) in **Figure 44**.

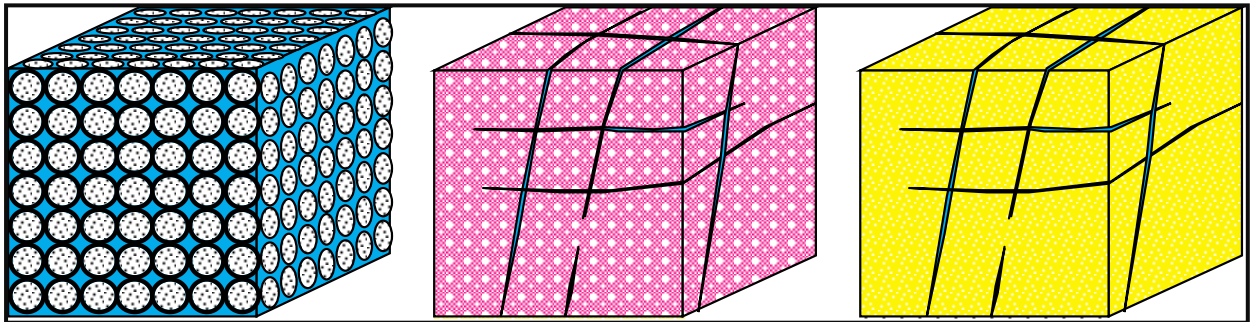


Figure 42: Primary porosity, double and secondary porosity aquifers (Kruseman and de Ridder, 1990).

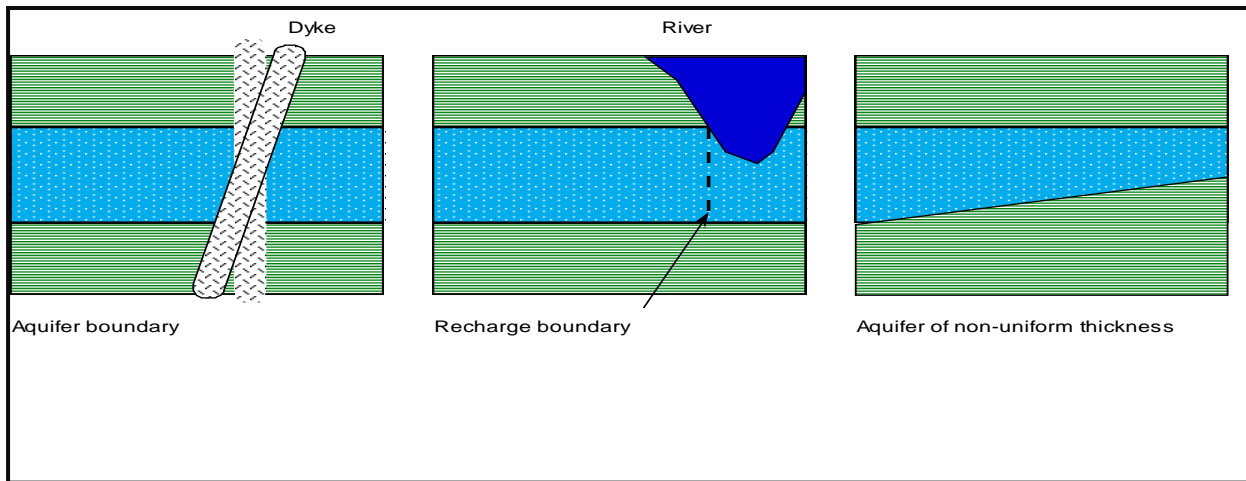


Figure 43: Dyke aquifer boundary, recharge boundary and aquifer non-uniform thickness (Van Tonder and Vermeulen, date unkown).

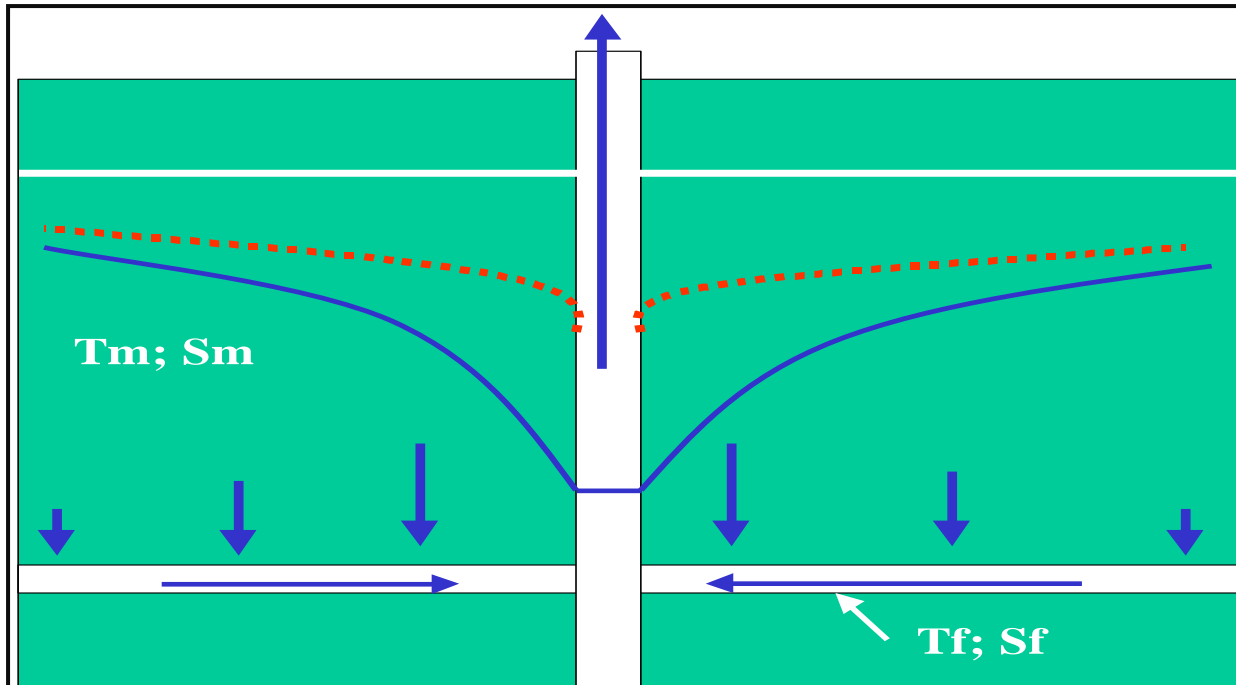


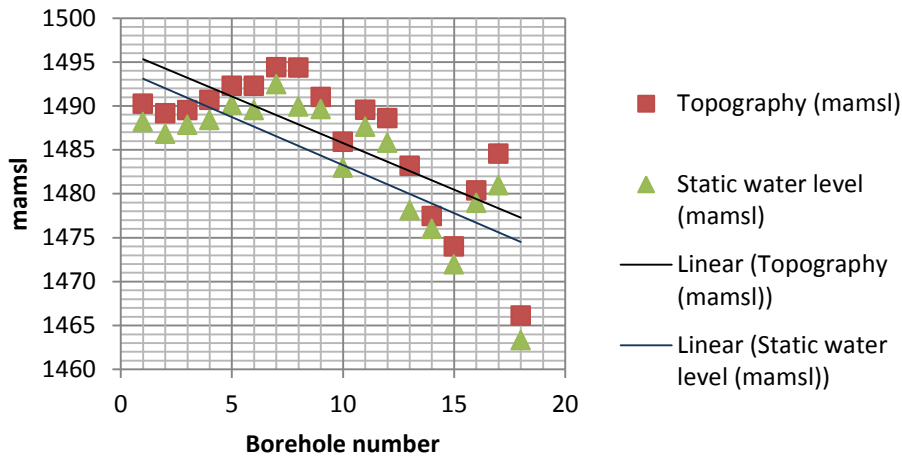
Figure 44: TM; SM; TF; SM (Van Tonder and Vermeulen, date unkown).

5.5 GROUND WATER FLOW EVALUATION

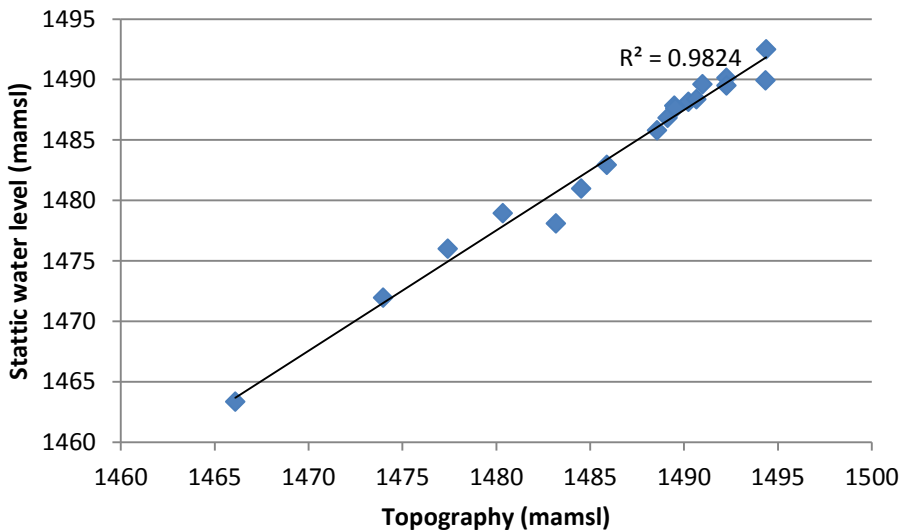
5.5.1 Depth to water level

A comparison between the static water and topography indicates a high level correlation (**Graph 3**). Correlation has been calculated at approximately 98% (**Graph 4**), indicating that the water table follow the topography and that there are few discrepancies. This information can thus be used to improve estimates of the static water levels.

Graph 3: Relation between topography and static water level.



Graph 4: Correlation between topography and static water level.



Static water level depths in the shallow unconfined weathered Karoo aquifer range between 1.0 and 4.4 mbgl (**Figure 45**) and 1471 and 1491 mamsl (**Figure 47**) while static water level depths for the deep aquifer range between 1.4 and 2.8 mbgl (**Figure 46**) and 1462 and 1480 mamsl (**Figure 48**).

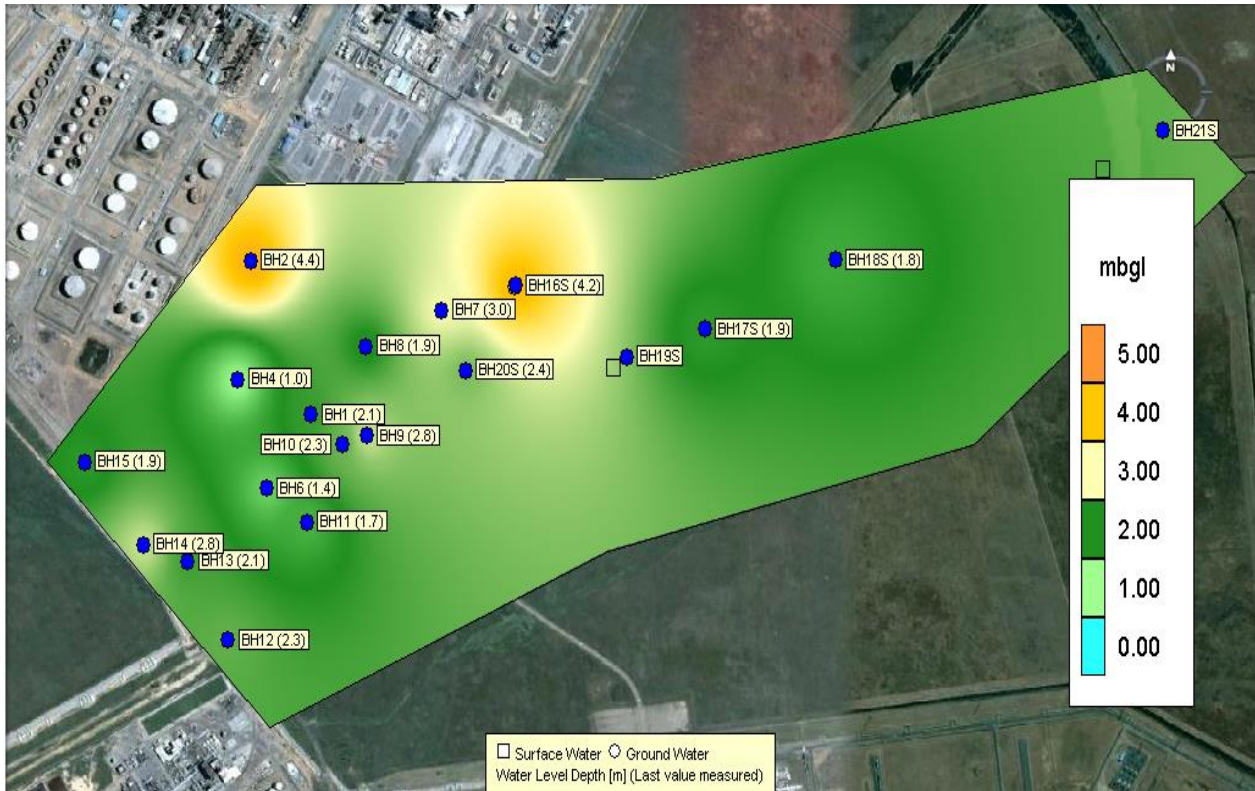


Figure 45: Static water levels in meter below ground level (mbgl) for the shallow boreholes.

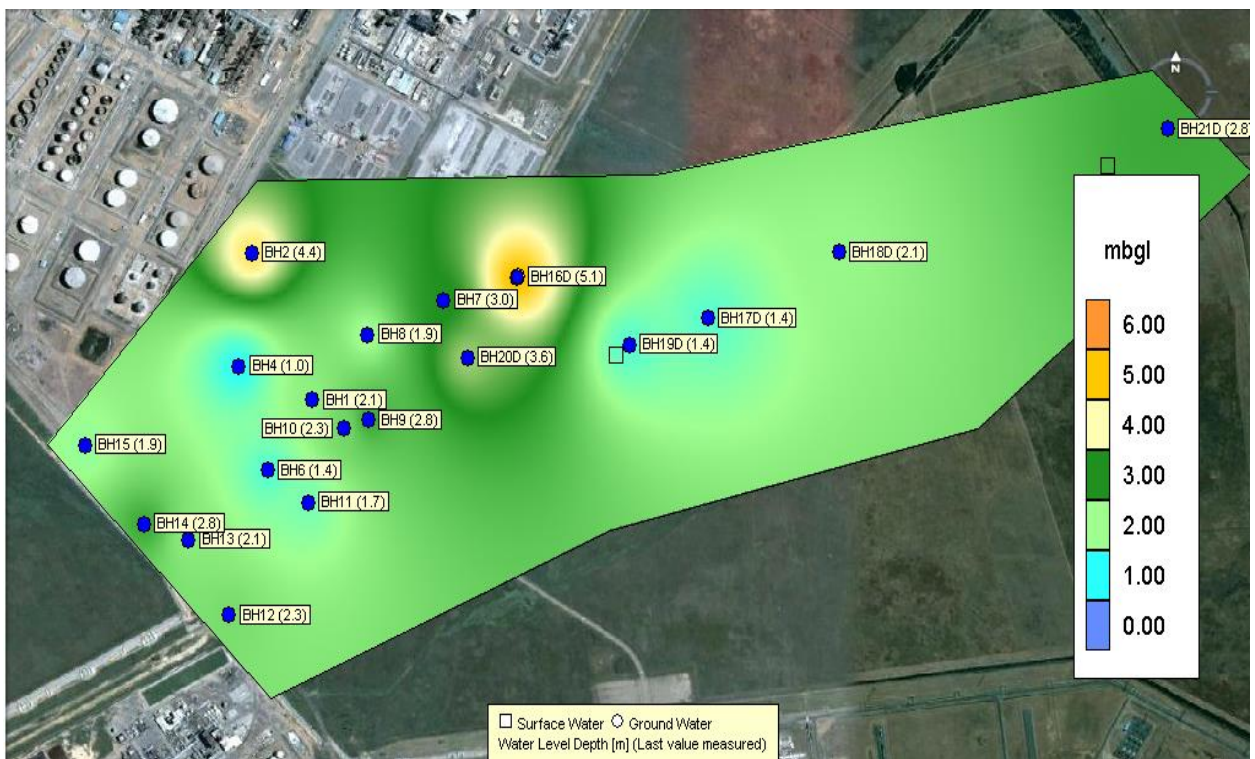


Figure 46: Static water levels (mbgl) for all deep boreholes.

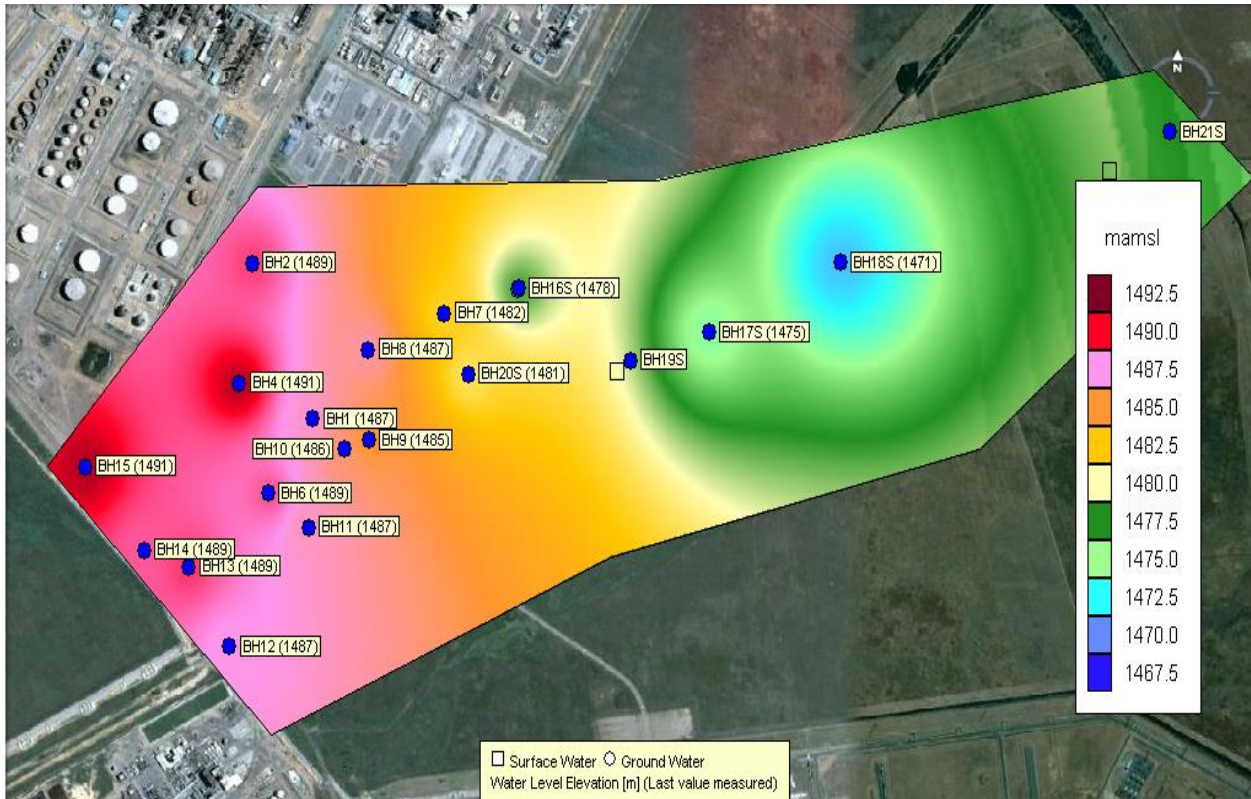


Figure 47: Static water levels in mamsl for shallow aquifer.

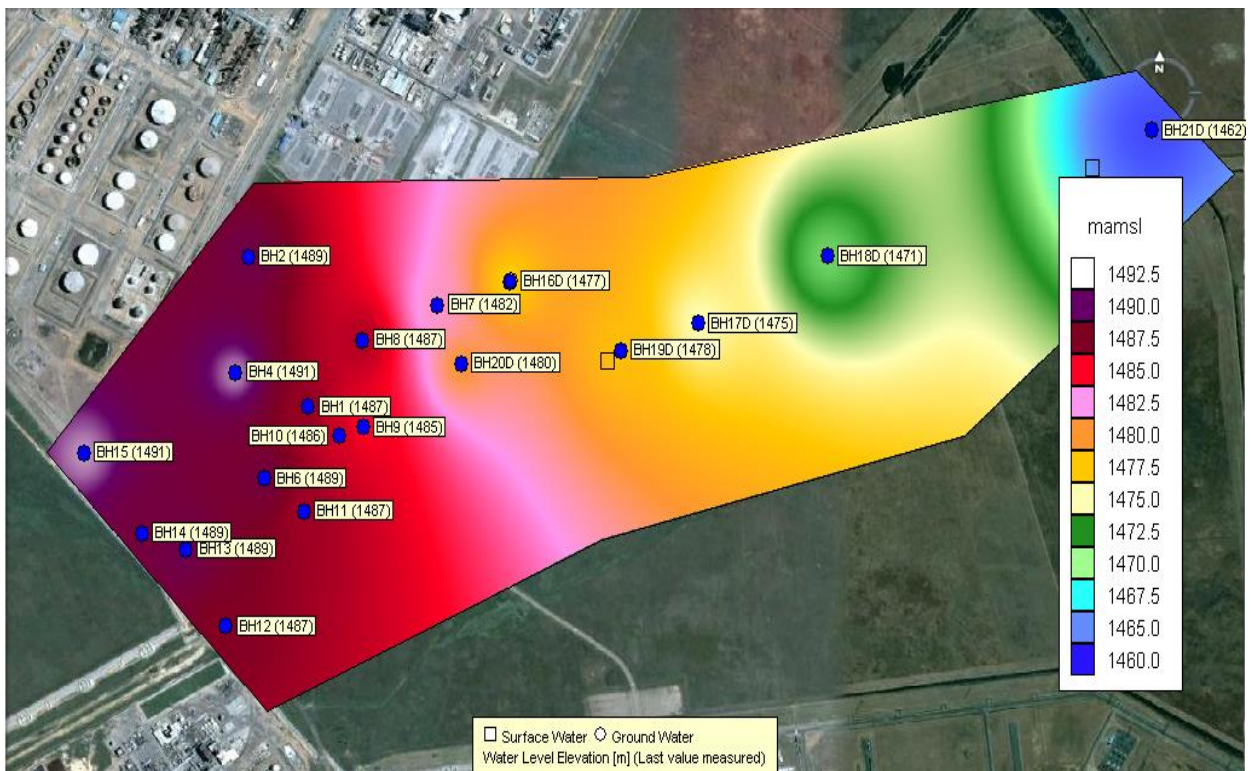


Figure 48: Static water levels in mamsl for deep aquifer.

5.5.2 Flow gradients

Flow gradients determine the flow rate and mass transport rate through an aquifer.

Darcy's law is the basic flow equation, demoted by the following equation:

$$Q = KiA$$

Where:

Q = Rate of flow through a medium;

K = Hydraulic conductivity;

A = Area; and

i = Hydraulic gradient

Flow rate distribution through the aquifer is determined through ground water gradient distribution.

The highest static water level elevation in the study area is at BH 15 (1491 mamsl) and occurs at the topographic high point of the study area (1494.3 mamsl). The lowest static water level elevation in the study area is at BH 21D (1462 mamsl) and occurs at the topographic low point of the study area (1466 mamsl). The flow direction indicated through flow vectors for the deep and shallow bore holes are indicated in **Figures 49 and 50**.

$$i = dH / L$$

Where:

i = Hydraulic gradient;

dH = Head difference; and

L = Lateral distance over which gradient is measured.

The steady state ground water gradient for the study area based on the highest (BH15) and lowest (BH21) static water level can thus be a calculated as:

$$i = dH / L$$

$$i = (1491-1462) / 2430m$$

$$i = 0.012 (1.2\%)$$

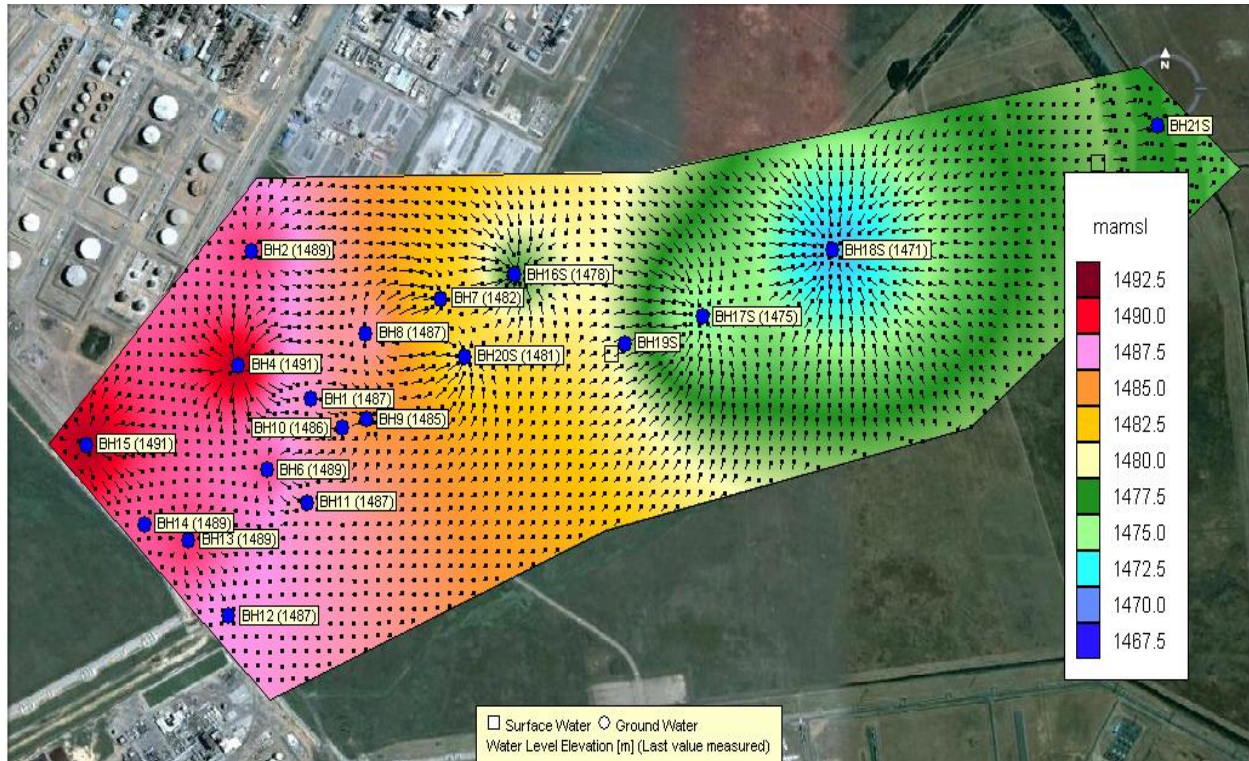


Figure 49: Flow vector indication shallow boreholes.

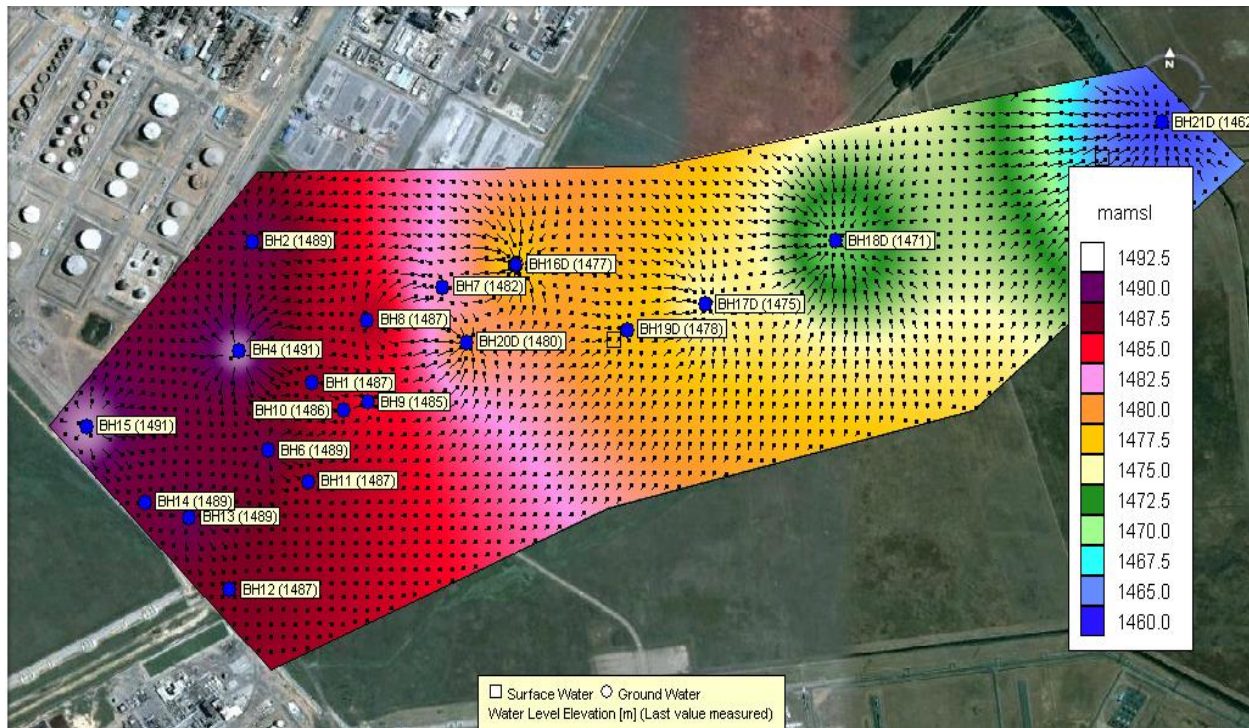


Figure 50: Flow vector indication deep boreholes.

5.6 AQUIFER PARAMETERS

Graph 5: Indicative porosity and hydraulic conductivity for different material (Allen, 1999).

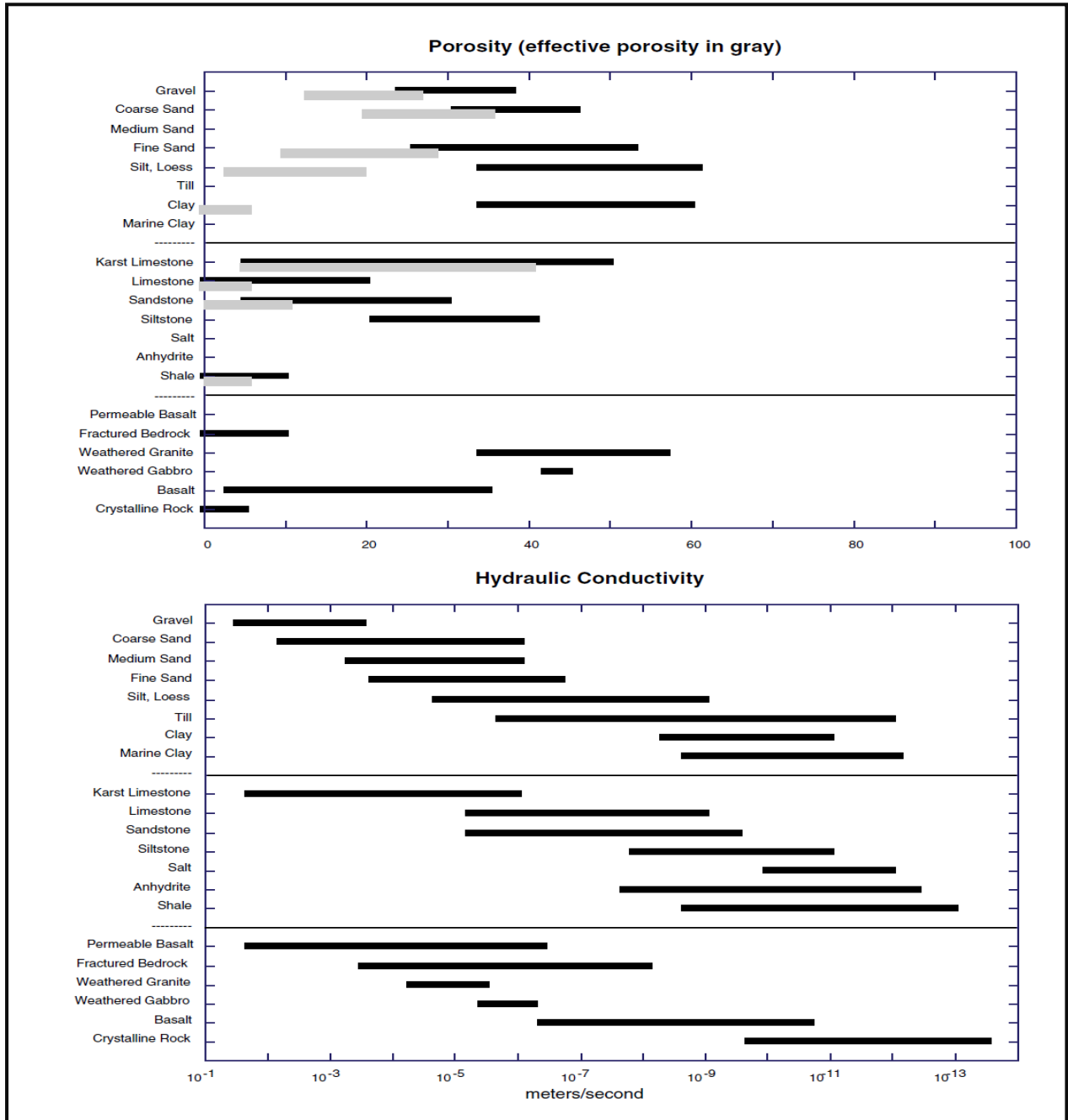


Table 9 provides an overview of typical storage coefficient values for South African rock formations.

Table 9: Storage Coefficient Values for South African Formations (Van Tonder, 2008).

Formation	Minimum Value	Maximum Value
Karoo	0,002	0,007
Table Mountain Group	0,005	0,01
Hard Rock	0,001	0,004
Dolomite	0,01	0,03
Porous	0,05	0,15

Aquifer thickness in a fractured rock aquifer is virtually impossible to determine as the actual aquifer consist of fractures with any orientation, dip strike or aperture. Only an approximation of the thickness of the aquifer can thus be made.

Table 10 and 11 provide an overview of the aquifer parameters. From these figures it is evident that the aquifer systems in the study area is highly anisotropic with hydraulic conductivities in the vertical and horizontal direction differing significantly.

Table 10: Detailed aquifer parameters $D=T/k$. ** Jones &Wagener, * IGS (Jones and Wagener, 2004) and (Van Wyk and Usher, 2004).

Borehole number	k Value (m/d)	Approximate D (m)	$T = k*D$	Comments
BH1	0.0678*			
BH2				Piezometer
BH3				Collapsed
BH4				Piezometer
BH5				Damaged
BH6	0.0620*			
BH7	0.0940*			
BH8	0.0770*			
BH9	0.0660*			
BH10	0.0890*			
BH11	0.0980*			
BH12	0.8500*			
BH13	0.0850*			

Borehole number	k Value (m/d)	Approximate D (m)	T = k*D	Comments
BH14	0.0850*			
BH15	0.1270*			
BH16D	0.0070**		0.1900**	
BH16S	0.0700**	7.143	0.5000**	
BH17D	0.0007**		0.1600**	
BH17S	0.1200**	7.583	0.9100**	
BH18D	0.0060**		0.1600**	
BH18S	0.1000**	7.400	0.7400**	
BH19D				No information**
BH19S				No information**
BH20D	0.0080**		0.2100**	
BH20S	0.2000**	7.500	1.5000**	
BH21D	0.0200**		0.5600**	
BH21S	0.1100**	7.455	0.8200**	

Table 11: A summary of the aquifer parameters (Jones and Wagener, 2004).

Parameter	Initial value	Variation	Source
Weathered aquifer			
Horizontal permeability	0.028m/day to 0.32m/day**	0.292m/day	Pump test**
Vertical permeability	0.0009m/day to 0.05m/day**	0.0491m/day	Pump test**
Storage coefficient	3×10^{-3} **		Estimate**
Rainfall recharge	2% MAP**		Estimate**
Longitudinal dispersion	40m**		Estimate**
Transversal dispersion	1m**		Estimate**
Fractured aquifer			

Parameter	Initial value	Variation	Source
Horizontal permeability	0.005m/day and 0.1m/day**	0.095m/day	Pump test**
Vertical permeability	0.001m/day to 0.009m/day**	0.008m/day	Pump test**
Storage coefficient	3×10^{-3} **		Estimate**
Rainfall recharge	0**		Estimate**
Longitudinal dispersion	40m**		Estimate**
Transverse dispersion	1m**		Estimate**

5.6.1 Pollution risk assessment Henry's dam to BH17S

The following assumptions with regard to the risk calculation were made:

- The hydraulic conductivity for BH17S is 0.12 m/d;
- The hydraulic gradient is 0.012 [(h1-h2)/d];
- Effective porosity (Ne) is 0.05 or 5% for the unconfined weathered aquifer (medium sand and silt value taken from **Graph 5**;
- Thickness of the aquifer is estimated at 7m;
- The equation used assume seepage in 1 direction;

Table 12: Seepage velocity from Henry's dam to Driefontein dam.

$v=Ki/n$			
Hydraulic Gradient	(i)	0.012	
Effective Porosity	(Ne)	0.05	
Hydraulic Conductivity	(K)	Tested at 0.12	m/d
Seepage Velocity	(v)	0.0288	m/d

From the calculation above it can be estimated that in ten years the water contained in Henry's dam would have seeped approximately 105.12 metres. In order to reach Driefontein dam (1.03km away) it would take approximately 98 years.

Based on the age of the plant (2010 - 1967 = 43 years) and assuming that Henry’s dam was operational in 1967 the plume distance can be calculated as 452.02 metres in the direction of Driefontein dam. The plume distance is visually indicated in **Figure 51**.



Figure 51: Calculated distance of pollution plume from Henry’s dam in the unconfined weathered aquifer since operation of Omnia Fertiliser Sasolburg started in 1967 (Google Earth, 2011).

Table 13: Transmissivity calculation.

T=KD			
Hydraulic conductivity	(K)	0.12	m/d
Thickness of aquifer	(D)	7	m
Transmissivity	(T)	0.84	m²/d
Q=TiW			
Gradient	(i)	0.012	
Width	(W)	105	m
Discharge	(Q)	1.06	m³/d

Table 14: Salt load in Henry's and Driefontein dam.

Existing TDS values in (mg/l)		
Driefontein dam	7254	
Henry's dam	48100	
Henry's dam current TDS load		
Concentration	48100	mg/L
Volume	15000 (Estimate)	L
Salt load	721.5	kg
Driefontein dam current TDS load		
Concentration	7254	mg/L
Volume	30000	L
Salt load	217.62	kg

From this it can be calculated that based on the discharge (Q) expected, that an additional 1.06m³ of water seeping from Henry's dam will enter Driefontein dam in 55 years (2065) adding an additional salt load of approximately 51kg/d to Driefontein dam. This relate to 18.6t/a.

5.7 RECHARGE

Recharge to an aquifer occurs from rainfall which could recharge directly in outcrop areas or percolate through soil layers. Pond forming of rain water on the surface after a rainfall event may cause recharge long after a rainfall event. Dams and streams may aid in aquifer recharge. Two main types of recharge exist:

- Diffuse recharge: piston flow type; and
- Focused recharge: there are two distinct types of focused recharge, namely:
 - Indirect recharge: preferred pathways- stream beds and cracks and fractures; and
 - Localised recharge: depression cracks (Petersen *et al*, 2012).

Piston recharge entails water passing through interconnected pores as a pulse following a rainfall event, with successive pulses occurring after closely spaced rainfall events. Piston recharge is mainly relevant and applicable to shallow unconfined aquifers in areas of relative high and frequent rainfall. A clay rich soil horizon will usually limit the piston recharge effect if it is present.

Preferred pathway recharge takes place when water enters the subsurface by via animal, insect excavations and desiccation cracks. The water will follow these preferred paths until a porous stratum or fractures enable it to penetrate downward to the aquifer. Some parts of the soil profile do not get wet in this model compared with the blanket of moisture movement through the soil profile envisaged by piston recharge.

The recharge percentage has been estimated using the recharge calculation (Van Tonder and Yongin, 2000) and the results is represented in **Table 15**.

Table 15: Summary of recharge estimations (Van Tonder and Yongin, 2000).

Method	Percentage of Rainfall
Soil	9.4
Geology	3.7
Vegter	9.7
Acru	1.5
Harvest potential	1.5
Experts guesses	5.1
Baseflow	4.5
EARTH Model	6.2
Average recharge	5.2

5.8 GROUND AND SURFACE WATER INTERACTION

The following is a summary from Winter *et al*, (1998). The interaction between streams and dams with ground water in the study area is important as the static water level of the weathered Karoo aquifer is particularly high (**Figure 45 and 47**).

The fact that most of the contamination is due to dust and other operational activities on site, which is transported to the storm water dam and then with overflows to Henry's dam create a risk scenario where the interaction between storm water and ground water is material to the impact.

Winter *et al*, (1998) provides information on the surface and ground water interaction. The following provide a summary of Winter *et al's* (1998) argument.

Differentiation is made between 2 types of streams. Those who gain water from the inflow of ground water (gaining stream) and those who lose water by outflow to ground water (losing stream) **Figure 52 A, B and C**. In many cases streams do both, gaining in some reaches and losing in other reaches.

The flow directions between ground water and surface water can change seasonally, and is in particular relevant to the study area with its typical Highveld climate. The altitude of the ground-water table changes with respect to the stream-surface altitude or can change over shorter timeframes when rises in stream surfaces during storms cause recharge to the stream bank. Under natural conditions, ground water makes some contribution to stream flow.

Losing streams are connected to the ground-water system by a continuous saturated zone (**Figure 52B**) or can be disconnected from the ground-water system by an unsaturated zone (**Figure 52C**).

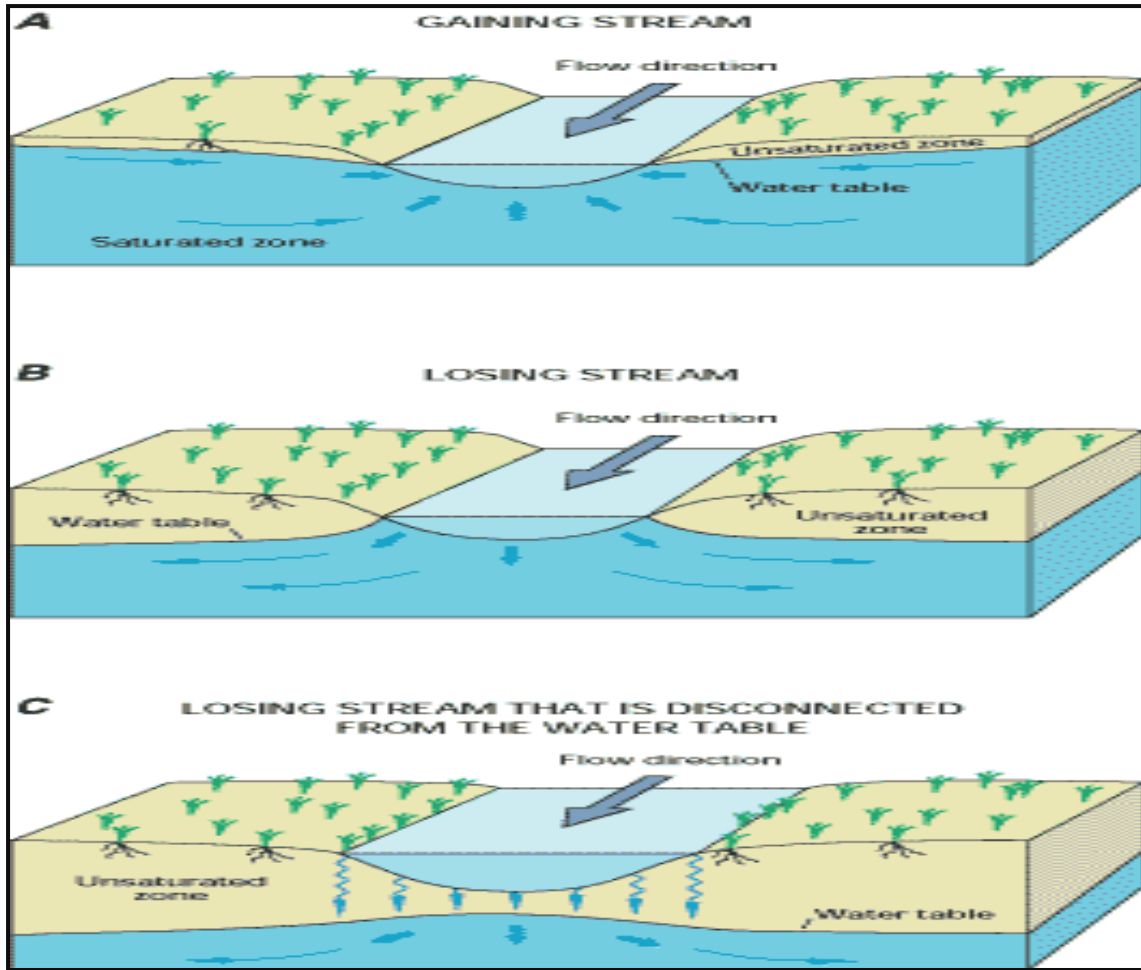


Figure 52: Gaining and losing streams (Winter *et al*, 1998).

Water and dissolved chemicals can move repeatedly over short distances in gaining and in losing streams, between the stream and the shallow subsurface below the streambed.

These resulting subsurface environments, which contain variable proportions of water from ground water and surface water, are referred to as hyporheic zones (Figure 53).

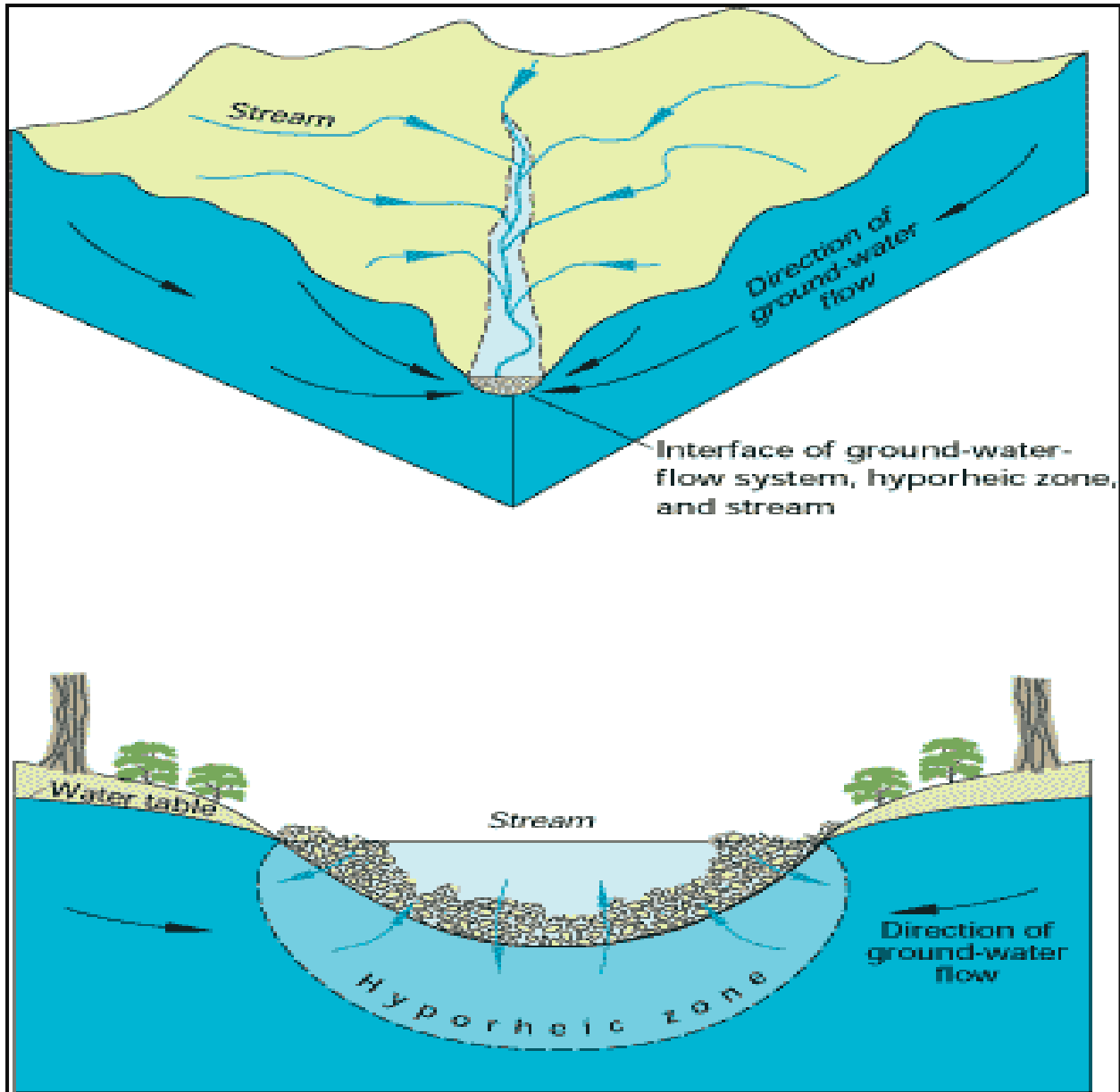


Figure 53: Hyporheic zones (Winter *et al*, 1998).

The ground and surface water interaction is particularly evident at Henry's dam where static water level of the shallow weathered aquifer is elevated due to Henry's dam losing water to the shallow weathered aquifer.

During winter (low rainfall) Henry's dam is always full with water. This might indicate that Henry's dam is gaining water from the shallow weathered aquifer. Henry's dam in this instance then fulfills a gaining and losing role. The implication regarding the interpretation of chemical

sampling results in particular the shallow weathered aquifer in the vicinity of Henry's dam is therefore seasonally dependent and should be considered as such.

A further important aspect is the quality and integrity of the storm water dam's lining. There might be ground and surface water interaction if water from the dam is seeping through the lining.

Taking into consideration how high the static water level in the study area is (particularly during winter), the release of water from the storm water dam for irrigation purposes (flood irrigation) could have caused unintended artificial recharge of the shallow weathered aquifer.

5.9 AQUIFER VULNERABILITY

The vulnerability of an aquifer system is defined as the tendency or likelihood for contamination to reach a specified position in the ground water system after introduction at some location above the uppermost aquifer (Ground Water Dictionary, Date Unknown).

According to Thirumalaivasan (2001), ground water is inherently susceptible to contamination from anthropogenic activities and remediation is very expensive and often impractical. Prevention of pollution is therefore extremely important in aquifer management.

DRASTIC is a ground water quality model for evaluating the pollution potential of large areas using the geohydrologic settings of the region. This model was developed by the Environmental Protection Agency (EPA) in the May 1987 (Environmental Protection Agency of the United States of America, 1987). DRASTIC includes various ground water settings which influence the pollution potential of a region. A geohydrologic setting is defined as a mappable unit with common geohydrologic characteristics. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative ground water vulnerability to contamination (Aller *et al.*, 1987). The geohydrologic settings which make up the acronym DRASTIC are detailed in **Table 16**.

Table 16: DRASTIC Aquifer vulnerability criteria.

Letter	Description
D	Depth to water table: Shallow water tables pose a greater chance for the contaminant to reach the ground water surface as opposed to deep water tables.
R	Recharge (Net): Net recharge is the amount of water per unit area of the soil that percolates to the aquifer. This is the principal vehicle that transports the contaminant to the ground water. The more the recharge, the greater the chances of the contaminant to be transported to the ground water table.
A	Aquifer media: The material of the aquifer determines the mobility of the contaminant through it. An increase in the time of travel of the pollutant through the aquifer results in more attenuation of the contaminant
S	Soil media: Soil media is the uppermost portion of the unsaturated / vadose zone characterized by significant biological activity. This along with the aquifer media will determine the amount of percolating water that reaches the ground water surface. Soils with clays and silts have larger water holding capacity and thus increase the travel time of the contaminant through the root zone.
T	Topography (Slope): The higher the slope, the lower the pollution potential due to higher runoff and erosion rates. These include the pollutants that infiltrate into the soil.
I	Impact of vadose zone: The unsaturated zone above the water table is referred to as the vadose zone. The texture of the vadose zone determines how long the contaminant will travel through it. The layer that most restricts the flow of water will be used.
C	Hydraulic conductivity. Hydraulic conductivity of the soil media determines the amount of water percolating to the ground water through the aquifer. For highly permeable soils, the pollutant travel time is decreased within the aquifer.

DRASTIC evaluates pollution potential based on the above seven geohydrologic settings. Each factor is assigned a weight based on its relative significance in affecting the pollution potential. Each factor is further assigned a rating for different ranges of the values. The typical ratings are from 1-10 and the weights are from 1-5. The DRASTIC Index, a measure of the pollution potential, is computed by summation of the products of rating and weights for each factor as follows:

$$\text{DRASTIC Index} = [(Dr)*(Dw)] + [(Rr)*(Rw)] + [(Ar*Aw)] + [(Sr*Sw)] + [(Tr*Tw)] + [(Ir*Iw)] + [(Cr*Cw)]$$

Where:

- Dr** = Ratings to the depth to water table;
- Dw** = Weights assigned to the depth to water table;
- Rr** = Ratings for ranges of aquifer recharge;
- Rw** = Weights for the aquifer recharge;
- Ar** = Ratings assigned to aquifer media;
- Aw** = Weights assigned to aquifer media;
- Sr** = Ratings for the soil media;
- Sw** = Weights for soil media;
- Tr** = Ratings for topography (slope);
- Tw** = Weights assigned to topography;
- Ir** = Ratings assigned to vadose zone;
- Iw** = Weights assigned to vadose zone;
- Cr** = Ratings for rates of hydraulic conductivity; and
- Cw** = Weights given to hydraulic conductivity.

The weighing factors for hydrogeologic variables are defined by Aller *et al* (1987) and are depicted in **Table 17**:

Table 17: Hydrogeologic variable and it's weighting factor (Aller *et al*, 1987).

Hydrogeologic Variable	Weighting Factors
Depth to water	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Aquifer hydraulic conductivity	3

The higher the DRASTIC index, the greater the relative pollution potential to the aquifer. The DRASTIC index can be further divided into four categories: low, moderate, high, and very high. The sites with high and very high categories are more vulnerable to contamination and consequently need to be managed more closely. The weights assigned are relative, therefore a site with a low pollution potential may still be susceptible to ground water contamination but it is less susceptible to contamination compared to the sites with high DRASTIC ratings.

Table 18: DRASTIC depth to water table (m) (Aller *et al*, 1987).

Depth (m)	Rating
0 - 5	10
5 - 15	9
15 -30	7
30 - 50	5
50 -75	3
75 - 100	2
100 +	1

The static water levels of the boreholes are indicated in **Figure 45**. The average static water level for the boreholes in the study area is 2.35m. A rating of 10 is thus allocated as indicated in **Table 18**.

Table 19: DRASTIC recharge (Percentage) (Aller *et al*, 1987).

Recharge (%)	Rating
0 - 2	1
2 - 4	3
4 - 7	6
7 - 10	8
10 +	9

The recharge percentage has been calculated in Table 16 as 5.2% of the annual rainfall. A rating of 6 is thus allocated as indicated in **Table 19**.

5.9.1 Aquifer Media

Ratings are based on the permeability of each layer of matrix. High permeability will have a high DRASTIC rating.

Table 20: Aquifer media permeability rating (Aller *et al*, 1987).

Range	Rating
Karst limestone	10
Permeable basalt	10
Fractured bedrock	10
Limestone	8
Sandstone	8
Siltstone	8
Shale	6
Weathered granite	4
Basalt	3
Crystalline rock	1

From the borehole logs (**Figures 35, 36, 37, 38, 39 and 40**) it can be seen that the geology (aquifer media is dominated by weathered dolerite, shale, sandstone and siltstone). Fractured rock is also present. For the purpose of this assessment a value of 8 is selected.

5.9.2 Soil Media

Table 21: DRASTIC soil media (Aller *et al*, 1987).

Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Aggregated Clay	7
Loam	5
Silty Loam	4
Clay Loam	3
Non Shrinking Aggregated Clay	1

At least 4 different soil profiles are present in the study area with characteristics ranging from sandy to clay loam. Loam would be the most representative of the soil profiles in the study area. A rating of 5 is thus allocated as indicated in **Table 21**.

5.9.3 Topography (% slope)

The lower the slope gradient the higher the DRASTIC rating.

Table 22: DRASTIC Topography (percentage slope) (Aller *et al*, 1987).

Range	Rating
1-5%	10
5-15%	5
>15%	1

The percentage topography slope can be calculated as:

$$i = dH / L$$

Where:

$$i = \text{Gradient};$$

$$dH = \text{Height difference}; \text{ and}$$

$$L = \text{Lateral distance over which gradient is measured.}$$

The topographic heights are indicated in **Figure 30**. The highest and lowest topographic values available have been selected to calculate the topographic slope.

$$i = (1494.4\text{m} - 1466.1\text{m}) / 2430\text{m}$$

$$i = (28.3\text{m}) / 2430\text{m}$$

$$i = 0.012 (1.2\%)$$

A rating of 10 is thus allocated as indicated in **Table 22**.

5.9.4 Vadose Zone

High permeability of the vadose zone would have a high DRASTIC rating.

Table 23: DRASTIC vadose zone ratings (Aller *et al*, 1987).

Range	Rating
High	10
Medium	5
Low	1

The permeability of the vadose zone is dependent on the soil types of the study area of which at least 4 different soil profiles are present in the study area with characteristics ranging from sandy to clay loam. Loam would be the most representative of the soil profiles in the study area and a

medium permeability rating would be the most relevant. A rating of 5 is thus allocated as can be seen in **Table 23**.

5.9.5 Hydraulic Conductivity

Relates the fractures, bedding planes and inter-granular voids which become pathways for fluid movement. The higher the hydraulic conductivity the higher the DRASTIC rating.

Table 24: DRASTIC hydraulic conductivity ratings (Aller *et al*, 1987).

Range (m/s)	Rating
$10^{-1} - 10^{-5}$	10
$10^{-6} - 10^{-9}$	5
$10^{-9} - 10^{-13}$	1

The hydraulic conductivity has been determined for some boreholes and has been recorded in **Tables 10 and 11**. The average hydraulic conductivity has been determined as 0.112m/d which translates to 0.13×10^{-5} m/s.

A rating of 10 is thus allocated as indicated in **Table 24**.

The calculation can then be performed:

$$DI = [(10) \times (5)] + [(6) \times (4)] + [(8) \times (3)] + [(5) \times (2)] + [(10) \times (1)] + [(5) \times (5)] + [(10) \times (3)]$$

$$DI = 50 + 24 + 24 + 10 + 10 + 25 + 30$$

$$DI = 173$$

The factors contributing most to the vulnerability score is the static water level and hydraulic conductivity ratings.

The highest score obtainable in this instance is 224 and the lowest score is 23. Based on the aquifer vulnerability risk quantification as indicated in **Table 25** the aquifer system in the study area has a high vulnerability.

Table 25: Aquifer vulnerability risk quantification (Aller *et al*, 1987).

DRASTIC Score	Vulnerability qualification
23-70	Limited

DRASTIC Score	Vulnerability qualification
71-120	Low
121-170	Medium
170-210	High
211-224	Very high

There are limitations to the use of DRASTIC as a vulnerability model. These relate to:

- If the contaminant is introduced at lower levels than surface level e.g. Underground Storage Tanks (UST's);
- Type of contaminant; and
- Previously disturbed areas such as construction sites etc.

CHAPTER 6: WATER CHEMISTRY - HYDROGEOLOGY

6.1 MONITORING NETWORK DESIGN

The ground water monitoring system design was conducted by a number of companies appointed. The Institute for Ground Water Studies (IGS) was involved in 2004 (BH) 1-15. The monitoring system over the past two years was extended to include BH 16-21, designed and drilled by Jones and Wagner in 2005. BH 16-21 was designed to differentiate between the weathered shallow unconfined Karoo aquifer and the deep fractured semi-confined Karoo aquifer. The differences in design can be attributed to the fact that an aquiclude was more readily visible and present at BH 16-21 which is located at a lower altitude and closer to lowest points of the study area in mamsl than BH 1-15. Finer grained material e.g. clay particles have a tendency to accumulate more readily in the lower lying areas. This trend is substantiated by differences in soil types observed in lower lying areas as compared to higher elevations. Soils in lower lying areas have higher clay content than those found at higher elevations because of the transportation of it.

Surface water bodies were also included in the water monitoring design network due the actual and potential interaction between surface and ground water in the study area and is discussed in Chapter 7 of this thesis.

The location of the ground water and surface water monitoring points can be seen in **Figure 54**.

6.1.1 Third party impact, source, pathway, receptor and ambient water quality monitoring

The design of a ground water monitoring network should have a holistic objective and each borehole should have a documented objective within the network. The following should be considered when establishing a monitoring network:

6.1.1.1 Third party impact monitoring

Monitoring boreholes are placed at the site boundaries (in particular in the direction of ground water movement) to assess any third party e.g. neighbouring companies potential impact on ground water sources. This can be done more effectively if the known point pollution sources of

neighbouring companies are known. This approach is essential in industrial areas where high environmental impact companies are located close to each other. The information generated by these monitoring results can also be used to evaluate time series chemical changes in ground water flux (movement) through the owner's premises.

6.1.1.2 Source monitoring

Monitoring boreholes are placed in the vicinity of a point or diffuse pollution source. This approach can also be used after environmental incidents have occurred (such as chemical spillages) and it is suspected that the ground water might be contaminated or to indicate that it has not impacted ground water.

6.1.1.3 Pathway monitoring

Monitoring boreholes are placed in the expected plume's migration path. The purpose being to assess migration rates, chemical changes and attenuation along the pathway.

6.1.1.4 Receptor monitoring

Monitoring boreholes are placed at specific receptors where the impact can be assessed (such as wetlands, streams or other sensitive environmental areas). The purpose is also to serve as early warning systems for contamination reaching the receptor of concern.

6.1.1.5 Ambient (background) monitoring

Ambient ground water quality is essential as ground water carries the "chemical fingerprint" of the geology in which it is stationed. It is important to compare the results of all the third party, source and pathway ground water monitoring results with ambient ground water quality to assess actual impact.

6.1.2 Ground water levels

Ground water levels are monitored to assess any changes in relation to seasonal (rain) and other abstraction and/or recharge events. The static water levels are used to determine the hydraulic gradient and flow direction within an aquifer. The shallower the static water levels the higher the vulnerability of ground water pollution.

6.1.3 Inadequacies in the monitoring network

Numerous inadequacies exist in the current monitoring design. These inadequacies are described below:

6.1.3.1 Geophysical information

Limited information is available of the detailed site specific geophysical characteristics of the study area. The largest possible shortcoming of the monitoring network is that no detailed ground water geophysical survey has been conducted for the study area. The existing monitoring has mainly been designed based on point pollution sources (source monitoring). The area is prone to have major geophysical anomalies such as dolerite dykes, sills and areas of highly weathered material. The limited understanding and information of these geophysical structures in the study area makes the estimation of mass transport rates and movement direction virtually impossible. Numerous geophysical anomalies were observed during borehole drilling by both the IGS and Jones and Wagener e.g.:

- BH 11, BH 13, BH 14 and BH 15 were observed to be of higher yielding capacity due to the intersection of dykes and their location on site (close to storm water channels) (van Wyk and Usher, 2004);
- Three possible fault/weathered/fracture zones were identified; and
- Shallow dolerite and dolerite boulders were intersected. (Jones and Wagner, 2004).

Jones and Wagner (2004) concluded that “no final correlation between geophysical and ground-truth information can be made” based on the geophysical work performed.

6.1.3.2 Monitoring network design

There are no true ambient ground water quality boreholes for the deep and shallow aquifer, as no Greenfields information gathering were conducted in the 1960's. Although the source monitoring network is well designed at the plant area, limited attention has been paid to date to design a pathway monitoring network. Disperse pollution sources such as storm water channels leading to the Henry's dam and Driefontein dam has been omitted, including areas which might be impacted

by windblown dust from the granulator and to detect third party impact on the Omnia Fertiliser Sasolburg site from industries such as Natref, SASOL Polymers and Karbochem. The monitoring network below Driefontein dam is inadequate to assess the extent of the pollution plume and the cumulative impact of all industries whose activities and particular storm water discharge might impact the ground water in the area.

6.1.3.3 Consistency in sampling frequency

The frequency of sampling and analysis for ground water and surface water has been erratic since 1998 with numerous years skipped and inadequate sampling of the monitoring network. It also could not be established that a standardised sampling standard was followed to ensure consistency and repeatability of analysis results, particular, during the changeover of monitoring consultants.

6.1.3.4 Chemical parameters

Although major cations and anions are being monitored for the following essential elements associated with the chemicals and production practises on site are not being analysed for:

- Boron (B);
- Copper (Cu);
- Molybdenum (Mo); and
- Zink (Zn).

These elements can be considered important “tracer” elements related to the fertiliser production activities and could provide additional certainty of Omnia Fertilisers’ impact on the study area.

Table 26 describes the objective of the existing monitoring boreholes.



Figure 54: Ground water monitoring network layout.

Table 26: Boreholes in the current monitoring network and their possible purpose.

Site Name	X-Coordinate	Y-Coordinate	Elevation	Possible Monitoring Purpose
BH1	-26.814040	27.860000	1490.242	Source
BH2	-26.811820	27.859186	1494.348	Source (Potential ambient and third party)
BH4	-26.813750	27.858610	1493.41	Source
BH6	-26.815080	27.858940	1490.99	Source
BH7	-26.812380	27.863160	1485.893	Source, pathway
BH8	-26.812930	27.861460	1489.543	Source
BH9	-26.814040	27.861840	1488.58	Source
BH10	-26.814490	27.860780	1489.137	Source
BH11	-26.815900	27.860170	1489.495	Source
BH12	-26.817580	27.858350	1490.662	Source (Potential ambient and third party)
BH13	-26.816460	27.857320	1492.266	Source (Potential ambient and third party)
BH14	-26.816310	27.856500	1492.267	Source (Potential ambient and third party)
BH15	-26.815040	27.855180	1494.379	Source (Potential ambient and third party)
BH16D	-26.811960	27.864900	1483.18	Pathway, source and (potential third party)
BH16S	-26.811960	27.864900	1483.17	Pathway, source and (potential third party)
BH17D	-26.812630	27.869070	1477.43	Pathway, source
BH17S	-26.812630	27.869070	1477.43	Pathway, source
BH18D	-26.811450	27.872090	1473.99	Pathway, source and (potential third party)
BH18S	-26.811450	27.872090	1473.99	Pathway, source and (potential third party)

Site Name	X-Coordinate	Y-Coordinate	Elevation	Possible Monitoring Purpose
BH19D	-26.813150	27.867320	1480.36	Source
BH19S	-26.813150	27.867320	1480.36	Source
BH20D	-26.813260	27.863850	1484.54	Pathway, source
BH20S	-26.813260	27.863850	1484.54	Pathway, source
BH21D	-26.809770	27.878660	1475.10	Source
BH21S	-26.809770	27.878660	1475.10	Source

6.2 AMBIENT (BACKGROUND) WATER CHEMISTRY

6.2.1 Risk based ground water quality monitoring and reporting.

A risk based ground water monitoring, analysis and assessment is proposed by this author in the following section. It is the opinion of this author that ground water monitoring results presented simply in terms (and mostly to drinking water standards) provide limited value to particularly environmental managers who have to interpret and include the ground water monitoring results in the formal EMS of the company/operation.

Ground water monitoring results should be compared to the end land use objectives established for site closure, which should consider the highest receptor risk, usually agriculture or human risk and the environmental legal requirements (if applicable).

The deduction of the ambient water chemistry from the ground water monitoring results provides essential information on the impact of the particular industry/activity on the ground water resource. More importantly is that it could provide essential information on the operational control effectiveness of a particular point pollution source/contaminant. This information can then be used for risk based decision making for example to focus on the effectiveness of specific operational activities.

The above mentioned concept is simplified and depicted in **Table 27**.

Table 27: Risk based ground water quality monitoring and reporting summary.

Criteria	Description	Outcome
1) End land use objective.	Determine the land end use objective. This is particularly applicable to mines and industry after operational closure and is usually include in documents such as mine closure plans, EMP's, water use license conditions etc. Where no such information is available is available the most likely scenario should be assessed and agreed upon between the hydrogeologist and the environmental manager/company management.	Most appropriate criteria against which ground water chemical analysis should be compared to.
2) Ambient ground water monitoring boreholes.	The strategic location of ambient ground water boreholes should be decided upon by the hydrogeologist based on ground water flow directions, the risk of third party contaminants to the study area and the location of point and diffuse pollution sources of the study area/company. Ambient ground water boreholes should be representative of the aquifer	Strategically positioned ambient ground water quality boreholes representative of the study area.

Criteria	Description	Outcome
	types e.g. deep and shallow etc.	
3) Presentation of ground water monitoring results.	<p>The ground water monitoring results should be described as:</p> <p>1) Ground water monitoring results minus ambient ground water quality compared to the appropriate end land use objective standard and water use license condition(s);</p> <p>2) Ground water monitoring results compared to the appropriate end land use objective water standard and water use license condition.</p>	Differentiable criteria of which the actual pollution impact of the industry/activity can be identified and its impact on the end land use objective (relevant standard) and environmental legal condition(s) such as water use license, EMP etc. conditions.
4) Risk based feedback into company's formal EMS.	<p>The pollution contribution to the ambient water quality should be assessed against the land end use and/or environmental legal requirement to assess risk e.g. if the land end use objective is drinking water which requires a maximum concentration of 600mg/l sulphates and the ambient ground water quality is 340mg/l but the analysis indicates 560mg/l it indicate that the pollution contribution of the company is 220mg/l.</p>	Risk assessment approach whereby the formal EMS is updated with the required controls to prevent the target water quality being exceeded.

Criteria	Description	Outcome
	<p>This indicates that there is probably a chance that the 600mg/l limit might be exceeded in the future. An assessment of the adequacy and effectiveness of operational control measures depicted by the formal EMS such as bund walls, spill cleaning, operational control work instructions etc., are therefore required to prevent exceeding the target/limit and to ensure continuous application of the appropriate operational controls. ISO 14001 clauses applicable will be 4.4.6 (operational control), 4.3.1 (aspect and impact identification), 4.3.3 (environmental management programmes).</p>	
<p>5) Continual follow-up using the EMS. (ISO 14001) methodology of Plan, Do, Check and Act (PDCA Cycle).</p>	<p>Apply the ISO 14001 methodology of Plan, Do, Check and Act (PDCA Cycle) by regularly assessing ground water quality, actual pollution impact and the suitability, adequacy and effectiveness of operational controls to ensure</p>	<p>Continuous risk assessment and effectiveness results pertaining to ground water impact.</p>

Criteria	Description	Outcome
	end land use objective and legal commitment ground water quality targets is not exceeded (ISO 14001, 2004).	

The natural chemistry of ground water is dependent on the rock types that the water has moved through or is contained in as indicated in **Table 28**. No ambient ground water quality information is available for the Omnia Fertiliser Sasolburg site as this principle has not been considered and applied by the Omnia Fertiliser Sasolburg. The ground water quality in BH 2 is the least affected by the site activities of Omnia Fertiliser and as such is used in this instance as the ambient ground water borehole. The ground water quality might also been affected by other industries located in the vicinity of Omnia Fertiliser, and as such cannot truly be considered as a ambient ground water quality borehole. This is only done as example for the principle depicted in section 6.1.2.

An important factor relating to the contribution of chemicals to the natural ground water qualities in the study area is that the natural background water quality, associated with the geology (matrix) of the study area is generally poor. The associated ground water quality for shale and sandstone matrixes is indicated in **Table 28**. From this it is evident that in particular ground water present in shale has elevated Calcium, Sodium, Sulphate, Chloride, Nitrate and TDS concentrations. Except the fact that the aquifers in the study have limited development potential, the natural ground water quality in the study area is also poor. Water entering the aquifer therefore does not have the same chemistry as water leaving the discharge region/area.

Residence time of water in an aquifer play a significant role in water chemistry as all chemical reactions is time dependent. Residence time in aquifers is usually very long. This provides an opportunity for water and rock reactions to take place. Weathering of rocks is also taking place during this time. Soluble salts from both congruent and incongruent dissolution of minerals increases the salt load of the water and it is possible for equilibrium between the water and the mineral components to be established.

Renewal and turnover time imply that each water has an identity and that exchange is taking place. Renewal time is not the same as residence time in most cases because of mixing. Renewal time can be explained as the time it takes for an aquifer to reach its original water quality state if the pollution source is removed. Chemical reactions which influence the concentration of solutions include:

- Lewis Acid-base reactions - a Lewis acid base reaction is a chemical reaction that forms at least one covalent bond between an electron pair donor and an electron pair acceptor (Helmenstine, 2012);
- Solid phase interactions;
- Complexation - an activated complex is any chemical species formed from the collision of energetic particles which is capable of reacting to form intermediates or products;
- Oxidation and reduction reactions - any chemical reaction in which the oxidation numbers (oxidation states) of the atoms are changed;
- Hydrolysis reactions - hydrolysis is a type of decomposition reaction where one reactant is water; and
- Isotopic reactions (Helmenstine, 2012).

Table 28: Natural chemical composition of ground water (mg/l) based on geology (Usher, Date Unknown).

Element	Rhyolite	Granite	Gabbro	Sandstone	Shale	Limestone	Dolomite	Schist
Fe	0.32	0.29	0.62	0.74	1.7	0.4	1.1	0.5
Mn	0	0.02	0.06	0.06	3.1	0.06	0.07	0.08
Cu	0	0	0	0	0.04	0	0	0
Zn	0.07	0.06	0.03	0	0.09	0.01	0	0.03
Ca	8.4	38.1	25.7	53.2	114.4	71.3	62	40.4
Mg	2.2	8	26.3	20.8	53.7	19.1	43.7	15.2
Na	20.7	51.2	14.3	51.1	194.3	12.9	27.4	22.4
K	2.3	3.7	9.1	4.3	5.3	2.2	1.8	3.1
HCO ₃	77	175	196	252	330	228	272	166
CO ₃	0	0	0	2.1	3	0	0.7	0
SO ₄	6.9	65.4	17.1	69	358.4	60.7	138.2	37.5
Cl	5.1	53.7	22.5	37.3	219	19.7	6.9	23.1
NO ₃	2.6	7.6	6.5	4.5	17.2	8.9	6.3	4.4
PO ₄	0.1	0.07	0.03	0.02	0	0.09	0	0.01
Al	0.62	0.18	0.2	0.1	3.6	0.09	0.13	0.1
SiO ₂	49	32	41	23	26	12.8	14.9	23.1
TDS	175.61	436.52	359.64	518.62	1330.43	436.55	575.8	336.52

Element	Rhyolite	Granite	Gabbro	Sandstone	Shale	Limestone	Dolomite	Schist
pH	7.2	7.1	7.5	7.5	7.2	7.5	7.7	7.1

6.3 MONITORED PARAMETERS

The samples have been analysed for the major cations and anions. The results of the analysis are represented in **Table 29a and 29b** in mg/l. The South African National Standard Specification for Drinking Water: SANS 241:2006 was used to compare the results against. This standard classifies domestic water into two classes namely:

- Class 1: Acceptable domestic water for lifetime usage; and
- Class 2: Domestic water usage for limited periods only.

Table 30a and 30b provides an overview of the ambient background water quality (BH 2) from which the water qualities of the remaining boreholes are deducted from. Although (BH 2) is not truly designed as a background water quality borehole, it is used in this thesis to demonstrate the principle.

It is currently not a requirement of the water use license (Reference No. 16/2/07C223/B306) to monitor for:

- Boron (B);
- Copper (Cu);
- Molybdenum (Mo); and
- Zink (Zn).

Monitoring these elements might however provide additional information on the footprint and mass transport characteristics of the study area as these elements are included as micro-nutrients in fertiliser, and based on the cumulative background contaminants in the study area the mentioned elements might provide a better understanding of the impact Omnia Fertiliser Sasolburg has on the aquifers.

A comprehensive overview is provided on all the main elements that has been analysed for. The reason for this is determining the potential point pollution and disperse pollution sources from the Omnia Fertiliser Sasolburg site also in an attempt to identify potential impact on the aquifer from surrounding industries.

All illustrative figures in this thesis where site data of Omnia Fertiliser Sasolburg is used, is used for illustrative purposes only in order to substantiate the proposed methodology for environmental hydrogeological site risk assessment. The Windows Interpretation System for Hydrogeologists (WISH) was used to compile the site figures.

Table 29a: Ground water laboratory analysis results evaluated against SANS 241:2006 (GPT, 2008).

SiteName	PH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l
BH1	6.4	1900.00	12350.00	1480.00	637.00	65.00	222.00	11.08	13.51	1842.27	826.88
BH2	7.0	144.00	936.00	164.00	67.70	19.50	36.20	25.08	30.56	62.45	263.04
BH4	7.2	1410.00	9165.00	1260.00	855.00	97.80	7.63	32.96	40.14	478.43	66.34
BH6	7.2	290.00	1885.00	214.00	99.40	142.30	3.90	33	40.19	56.42	4.68
BH7	7.7	698.00	4537.00	566.00	360.00	57.40	2.84	116.32	141.19	355.47	619.79
BH8	7.0	422.00	2743.00	233.00	203.00	95.70	3.96	44.04	53.67	128.04	178.79
BH9	7.0	2100.00	13650.00	1680.00	925.00	96.50	7.66	45.6	55.56	758.69	55.80
BH10	7.3	4950.00	32175.00	4610.00	3070.00	150.00	56.10	76.48	93.10	2272.81	159.77
BH11	7.6	710.00	4615.00	600.00	292.00	87.10	4.95	93.92	114.10	1160.38	87.50
BH12	7.6	500.00	3250.00	501.00	201.00	66.70	2.89	78.68	95.61	373.03	179.31
BH13	7.4	2100.00	13650.00	1036.00	486.00	96.5	4.07	93.84	114.20	489.33	1200.84
BH14	5.3	960.00	6240.00	670.00	277.00	143.90	82.5	8.04	9.81	251.43	2871.04
BH15	9.2	520.00	3380.00	404.00	223.00	41.60	203.00	315.04	338.54	131.83	865.09
BH16D	7.5	407.00	2699.00	407.00	185.00	52.00	2.80	160	194.60	299.00	124.00
BH16S	6.0	404.00	2570.00	368.00	201.00	55.00	2.50	24	29.28	223.00	51.00
BH17D	7.5	116.00	609.00	91.00	47.00	40.00	1.50	120	145.95	221.00	43.00
BH17S	6.1	574.00	3897.00	468.00	240.00	263.00	2.70	28	34.16	566.00	391.00
BH18D	7.7	228.00	1394.00	213.00	93.00	96.00	2.80	224	271.97	396.00	251.00
BH18S	6.8	836.00	5985.00	681.00	302.00	587.00	7.40	184	224.97	685.00	670.00
BH19D	7.2	135.00	826.00	123.00	56.00	38.00	1.60	104	126.68	110.00	5.00
BH20D	6.9	105.00	626.00	96.00	51.00	41.00	2.30	236	287.70	97.00	64.00
BH20S	7.0	187.00	1251.00	182.00	89.00	44.00	1.40	100	121.88	117.00	106.00
BH21S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BH21D	7.8	110.00	692.00	57.00	24.00	160.00	4.30	324.00	392.91	59.00	122.50
Drinking water classes											
Class 1		150.00	1000.00	150.00	70.00	200.00	50.00			200.00	400.00
Class 2		370.00	2400.00	300.00	100.00	400.00	100.00			600.00	600.00
Exceeds maximum											
NS = Not Sampled											

Table 29b: Ground water laboratory analysis results evaluated against SANS 241:2006 continued (GPT, 2008).

SiteName	SO4 mg/l	Balance	N_Ammonia mg/l	NO2 mg/l	NO3-N mg/l	F mg/l	PO4 mg/l	Fe mg/l	Mn mg/l	Si
BH1	826.88	-5.59	162.688	0.00	5640.40	0.42	0.00	5.250	6.920	13.20
BH2	263.04	-4.40	14.952	0.00	555.93	0.89	0.00	0.000	0.219	16.90
BH4	66.34	-4.53	0.00	0.00	8318.40	0.00	0.00	0.118	0.33	16.70
BH6	4.68	-1.37	0.00	0.00	1401.40	0.00	0.00	0.000	0.00	14.10
BH7	619.79	-3.62	0.00	0.00	2462.40	0.00	0.00	0.000	0.60	5.89
BH8	178.79	-0.67	5.453	0.00	1554.89	1.63	0.00	0.000	0.306	1.72
BH9	55.80	-0.64	0.00	0.00	8831.57	0.00	0.00	0.000	0.183	10.10
BH10	159.77	1.21	10.24	0.00	25430.80	0.00	0.00	0.000	1.45	8.27
BH11	87.50	-5.64	0.00	0.00	1740.33	0.00	0.00	0.000	0.278	8.74
BH12	179.31	-0.48	0.00	0.00	1776.89	0.13	0.00	0.000	0.34	10.20
BH13	1200.84	-3.78	0.00	0.00	3881.69	0.00	0.00	0.000	0.443	8.17
BH14	2871.04	1.25	811.24	0.00	2221.45	53.81	0.00	9.870	13.7	28.50
BH15	865.09	1.34	159.76	60.1	1170.35	0.23	0.00	0.000	0.449	5.08
BH16D	124.00	1.40	0.00	0.00	1531.62	0.20	0.00	0.000	0.360	13.80
BH16S	51.00	3.90	0.00	0.00	1651.14	1.20	2.76	0.050	0.280	18.70
BH17D	43.00	4.00	0.00	0.00	92.96	0.20	0.00	0.570	0.00	10.10
BH17S	391.00	2.30	0.00	2.63	1859.19	0.00	0.00	0.120	0.52	9.28
BH18D	251.00	3.70	0.00	0.00	208.05	0.20	0.00	0.070	0.00	6.94
BH18S	670.00	0.10	0.73	4.27	2939.29	0.20	0.00	0.120	1.09	11.50
BH19D	5.00	0.90	0.00	0.00	429.30	0.00	0.00	0.060	0.00	14.30
BH20D	64.00	0.50	0.00	0.00	132.80	0.00	0.00	0.090	0.00	20.00
BH20S	106.00	1.00	0.00	0.00	650.72	0.00	0.00	0.030	0.00	18.40
BH21S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BH21D	122.50	0.20	0.00	0.00	70.83	0.50	0.00	3.90	0.13	6.40
Drinking water classes										
Class 1	400.00		1.22	44.00	1.00		0.20	0.10		
Class 2	600.00		2.43	88.00	1.50		2.00	1.00		
Exceeds maximum										
NS = Not Sampled										

Table 30a: Ground water laboratory analysis minus background water quality (BH2) results.

Site Name	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	HCO3 mg/l	Cl mg/l
BH1	6.4	1756.00	11414.00	1480.00	569.30	45.50	185.80	0.00	0.00	1779.82
BH2	7.0	144.00	936.00	164.00	67.70	19.50	36.20	25.08	30.56	62.45
BH4	7.2	1266.00	8229.00	1096.00	787.30	78.30	0.00	7.88	9.58	415.98
BH6	7.2	146.00	949.00	50.00	31.70	122.80	0.00	7.92	9.63	0.00
BH7	7.7	554.00	3601.00	402.00	292.30	37.90	0.00	91.24	110.63	293.02
BH8	7.0	278.00	1807.00	69.00	135.30	76.20	0.00	18.96	23.11	65.59
BH9	7.0	1956.00	12714.00	1516.00	857.30	77.00	0.00	20.52	25.00	696.24
BH10	7.3	4806.00	31239.00	4446.00	3002.30	130.50	19.90	51.40	62.54	2210.36
BH11	7.6	566.00	3679.00	436.00	224.30	67.60	0.00	68.84	83.54	1097.93
BH12	7.6	356.00	2314.00	337.00	133.30	47.20	0.00	53.60	65.05	310.58
BH13	7.4	1956.00	12714.00	872.00	418.30	77.00	0.00	68.76	83.64	426.88
BH14	5.3	816.00	5304.00	506.00	209.30	124.40	46.30	0.00	0.00	188.98
BH15	9.2	376.00	2444.00	240.00	155.30	22.10	166.80	289.96	307.97	69.38
BH16D	7.5	263.00	1763.00	243.00	117.30	32.50	0.00	134.92	164.04	236.55
BH16S	6.0	260.00	1634.00	204.00	133.30	35.50	0.00	0.00	0.00	160.55
BH17D	7.5	0.00	-327.00	0.00	0.00	20.50	0.00	94.92	115.39	158.55
BH17S	6.1	430.00	2961.00	304.00	172.30	243.50	0.00	2.92	3.60	503.55
BH18D	7.7	84.00	458.00	49.00	25.30	76.50	0.00	198.92	241.41	333.55
BH18S	6.8	692.00	5049.00	517.00	234.30	567.50	0.00	158.92	194.41	622.55
BH19S	3.8	1911.00	12421.50	725.00	357.30	147.50	161.80	0.00	0.00	265.77
BH19D	7.2	0.00	0.00	0.00	0.00	18.50	0.00	78.92	96.12	47.55
BH20D	6.9	0.00	0.00	0.00	0.00	21.50	0.00	210.92	257.14	34.55
BH20S	7.0	43.00	315.00	18.00	21.30	24.50	0.00	74.92	91.32	54.55
BH21S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BH21D	7.8	0.00	0.00	0.00	0.00	140.50	0.00	298.92	362.35	0.00
Drinking water classes										
Class 1		150.00	1000.00	150.00	70.00	200.00	50.00			200.00
Class 2		370.00	2400.00	300.00	100.00	400.00	100.00			600.00
Exceeds maximum										
NS = Not Sampled										

Table 30b: Ground water laboratory analysis minus background water quality (BH2) results (Continued).

Site Name	SO4 mg/l	Balance	NO3-N mg/l	N_Ammonia mg/l	NO2 mg/l	F mg/l	PO4 mg/l	Fe mg/l	Mn mg/l	Si
BH1	563.84	-1.19	5084.47	162.688	0.00	0.00	0.00	5.25	6.70	0.00
BH2	263.04	-4.40	555.93	14.952	0.00	0.89	0.00	0.00	0.22	16.90
BH4	0.00	-0.13	7762.47	0.00	0.00	0.00	0.00	0.12	0.11	0.00
BH6	0.00	3.03	845.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BH7	356.75	0.78	1906.47	0.00	0.00	0.00	0.00	0.00	0.38	0.00
BH8	0.00	3.73	998.96	5.453	0.00	0.74	0.00	0.00	0.09	0.00
BH9	0.00	3.76	8275.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BH10	0.00	5.61	24874.87	10.24	0.00	0.00	0.00	0.00	1.23	0.00
BH11	0.00	-1.24	1184.40	0.00	0.00	0.00	0.00	0.00	0.06	0.00
BH12	0.00	3.92	1220.96	0.00	0.00	0.00	0.00	0.00	0.12	0.00
BH13	937.80	0.62	3325.76	0.00	0.00	0.00	0.00	0.00	0.22	0.00
BH14	2608.00	5.65	1665.52	811.24	0.00	52.92	0.00	9.87	13.48	11.60
BH15	602.05	5.74	614.42	159.76	60.1	0.00	0.00	0.00	0.23	0.00
BH16D	0.00	5.80	975.69	0.00	0.00	0.00	0.00	0.00	0.14	0.00
BH16S	0.00	8.30	1095.21	0.00	0.00	0.31	2.76	0.05	0.06	1.80
BH17D	0.00	8.40	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00
BH17S	127.96	6.70	1303.26	0.00	2.63	0.00	0.00	0.12	0.30	0.00
BH18D	0.00	8.10	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
BH18S	406.96	4.50	2383.36	0.73	4.27	0.00	0.00	0.12	0.87	0.00
BH19S	1045.18	-2.46	7128.14	673.88	0.00	0.00	0.00	0.37	17.48	0.00
BH19D	0.00	5.30	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
BH20D	0.00	4.90	0.00	0.00	0.00	0.00	0.00	0.09	0.00	3.10
BH20S	0.00	5.40	94.79	0.00	0.00	0.00	0.00	0.03	0.00	1.50
BH21S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BH21D	0.00	4.60	0.00	0.00	0.00	0.00	0.00	3.90	0.00	0.00
Drinking water classes										
Class 1	400.00		44	1.22	44.00	1.00		0.20	0.100	
Class 2	600.00		88	2.43	88.00	1.50		2.00	1.000	
Exceeds maximum										

NS = Not Sampled

6.3.1 Calcium (Ca)

Calcium exceeds the Class 1 drinking water standard for BH1, BH4, BH7, BH9, BH10, BH11, BH12, BH13, BH14, BH15, BH16D, BH16S, BH17S, BH18S and BH19S. The respective concentrations for the deep boreholes are reflected in **Figure 55** and for the shallow boreholes in **Figure 57**. The respective contour maps are represented in **Figures 56 and 58**. The two highest calcium concentrations are observed at BH10 and BH9 which are closely located to each other. The area surrounding BH10 and BH9 also has high calcium concentrations (e.g. BH1) indicating a clear highly impacted area where a primary source of calcium is not readily expected. This might be due from dolomitic lime dust caused by the granulators in the primary factory area and which is transported during rainfall events to the storm water dam from which water has been released to irrigate the community vegetable garden. This could have caused artificial recharge to the aquifer system. Lime has also been used by employees on site to cover the railway tracks in the past for easier conveyance of material across the railway tracks.

The area around BH9 and BH10 form a slight topographical depression against the normal topographic decline towards Henry's dam. Based on the historic design of the employees vegetable garden and the subsequent release of water from this dam for irrigation purposes, the potential presence of a dolerite dyke at BH 20 (Jones and Wagener, 2004), and the fact that BH9 and BH 10 are located close to the storm water accumulation point for the South Factory makes this specific area highly vulnerable for contaminated storm water run-off. Recharge in this area from surface water will also be higher due to tendency of pond forming after rain. As indicated previously in this document there is a 98% relationship between topography and static water levels which might also cause ground water to flow towards this slight depression.

Figure 59 indicates that the shallow aquifer is the main transporter of calcium pollution and is heavier impacted than the shallow aquifer except at BH16.

The storage and use of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and limestone (mainly CaCO_3) at the South Factory (liquids plant) are also potential sources of surface and ground water pollution in this area.

Calcium concentrations downstream of Henry's dam in the shallow aquifer are also exceeding maximum levels. It is clear in this instance the shallow Karoo aquifer is more impacted by the calcium pollution than the deep fractured Karoo aquifer (**Figure 59**). Henry's dam in this instance serves as a point pollution source.

The background water quality (where the water quality from BH2 is subtracted from the remaining BH's) and contour maps are indicated in **Figures 60, 61, 62 and 63**. The use of BH 2 for background water quality for the deep aquifer is obviously incorrect as some concentrations drop below 0mg/l for e.g. BH17D and BH19D. The comparison between calcium concentrations in the deep fractured Karoo aquifer and shallow Karoo aquifer where the background water quality have been taken in consideration shows that the shallow Karoo aquifer is mainly impacted by the calcium pollution (**Figure 64**).

Point pollution sources for calcium are solid calcium nitrate, product store, raw product store, granulation plants, speciality blending plant, loading bays, stores in the south factory, effluent dam, storm water dam, Henry's dam and Driefontein dam.

Disperse pollution sources can be regarded as dust from the granulators which is windblown off-site, storm water channels and the railway tracks that were sometimes covered with lime.



Figure 55: Calcium last measured value deep boreholes drinking water standard.

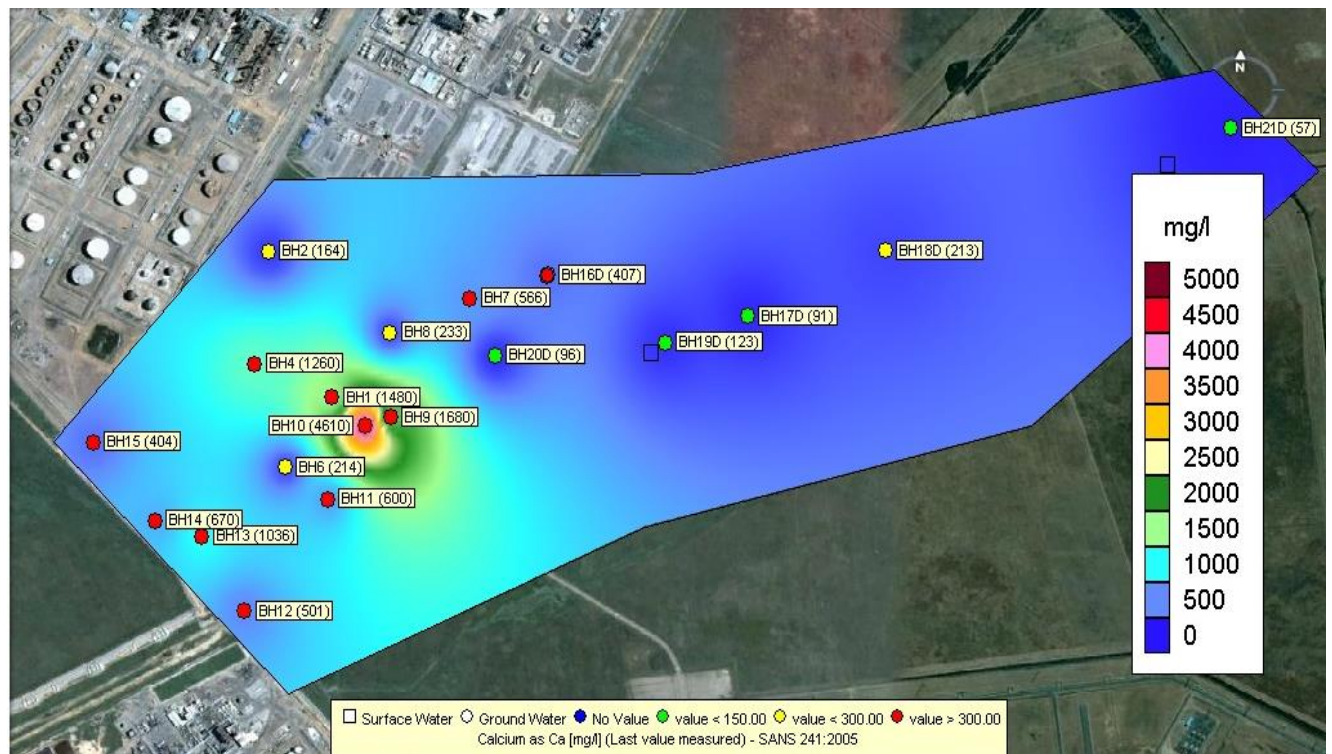


Figure 56: Calcium last measured value deep boreholes contour map.

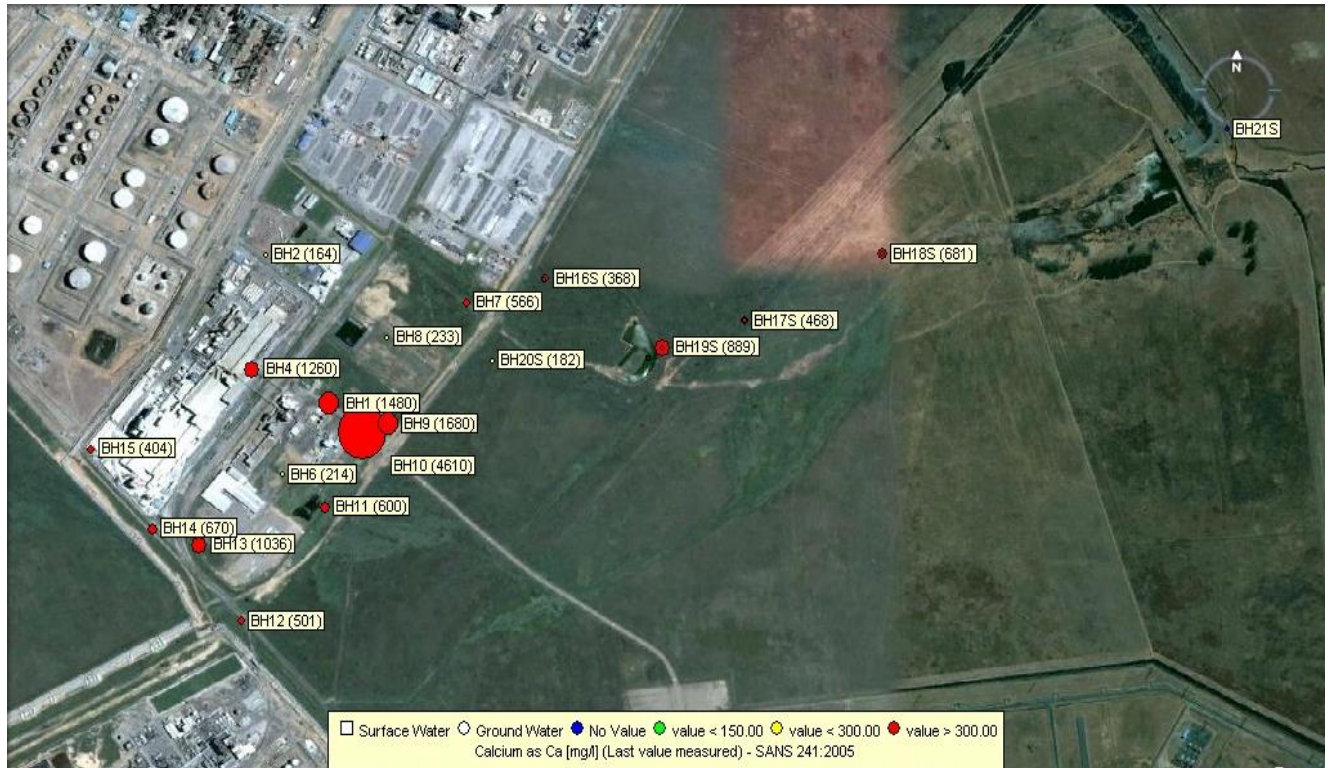


Figure 57: Calcium last measured value shallow boreholes.

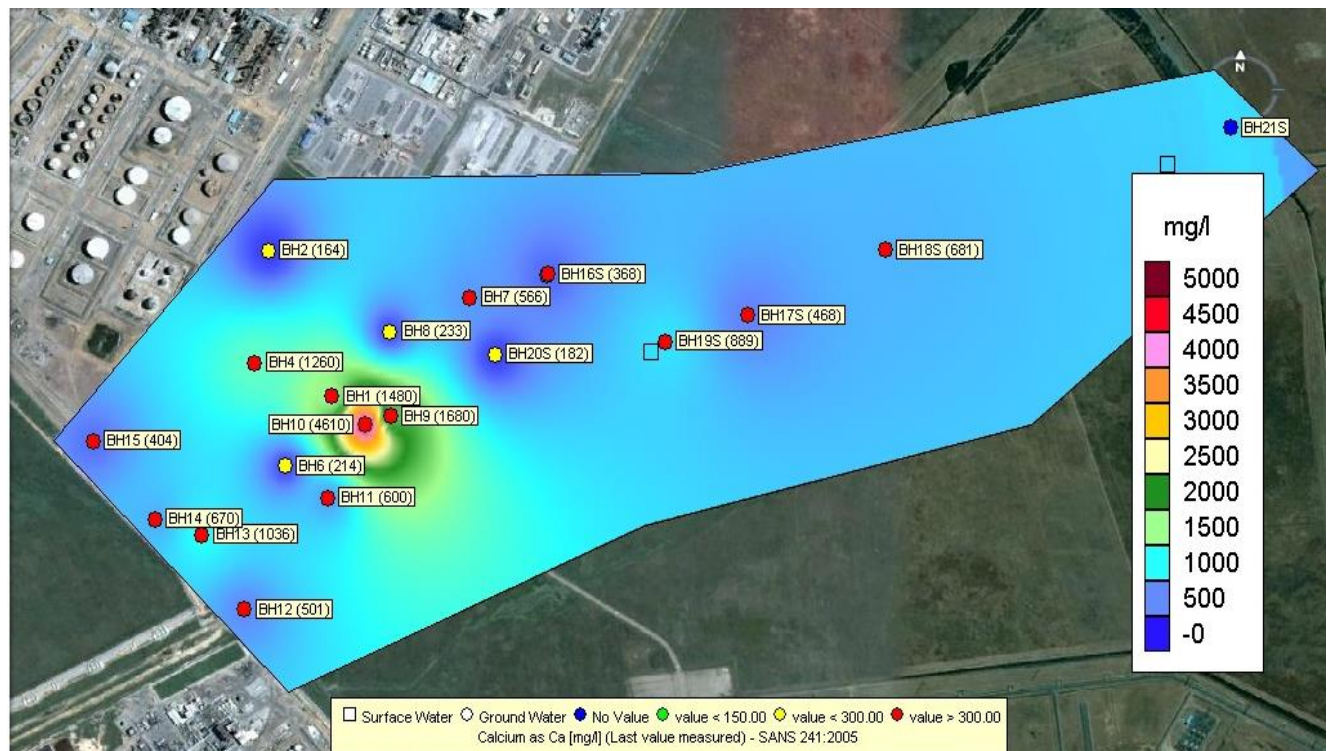


Figure 58: Calcium shallow boreholes last measured value contour map.

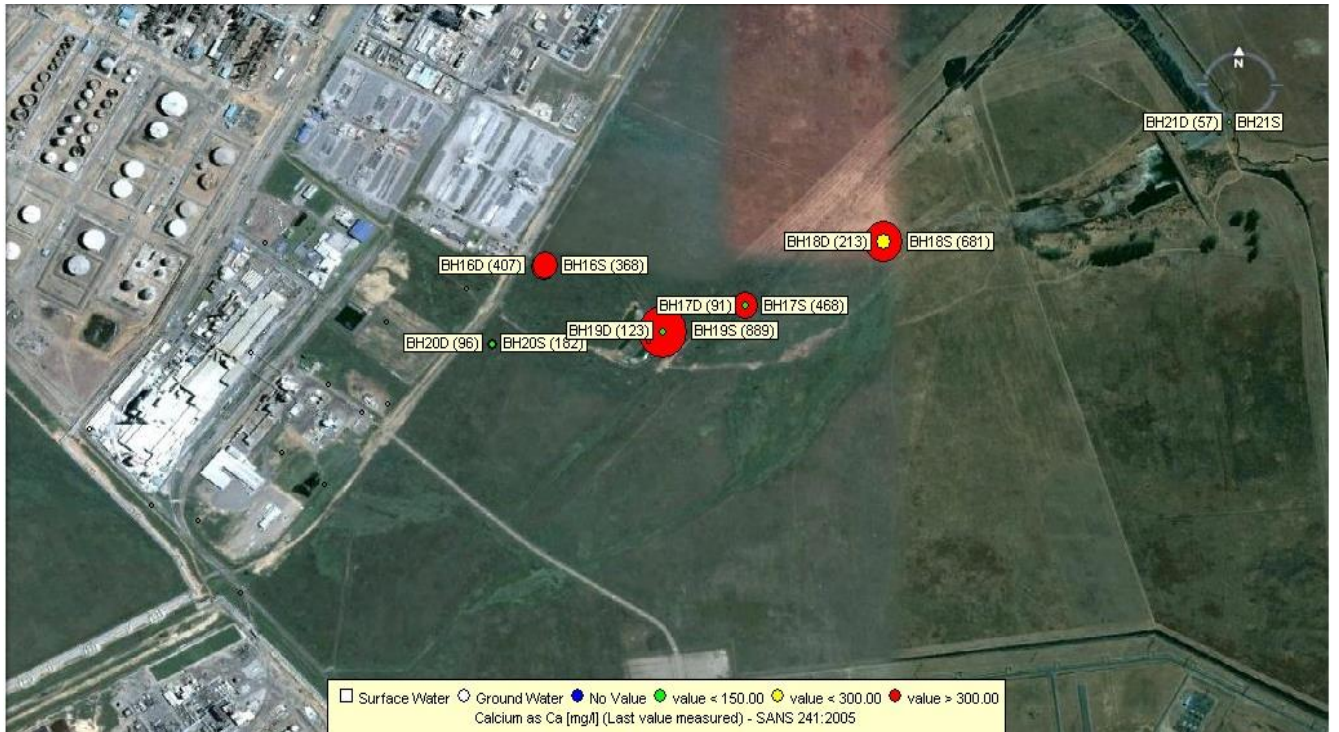


Figure 59: Calcium last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 60: Calcium last measured value deep boreholes minus background water quality compared against SANS 241:2006.

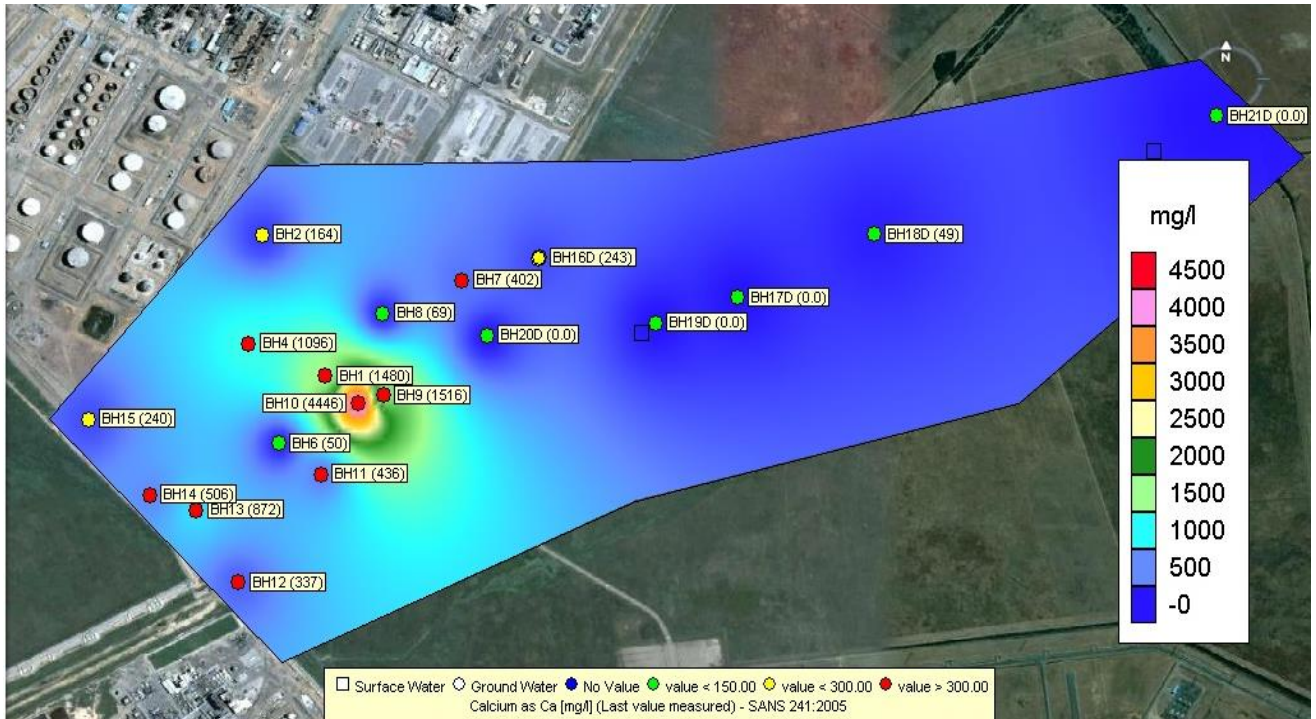


Figure 61: Calcium last measured value deep boreholes minus background water quality contour map SANS 241:2006.

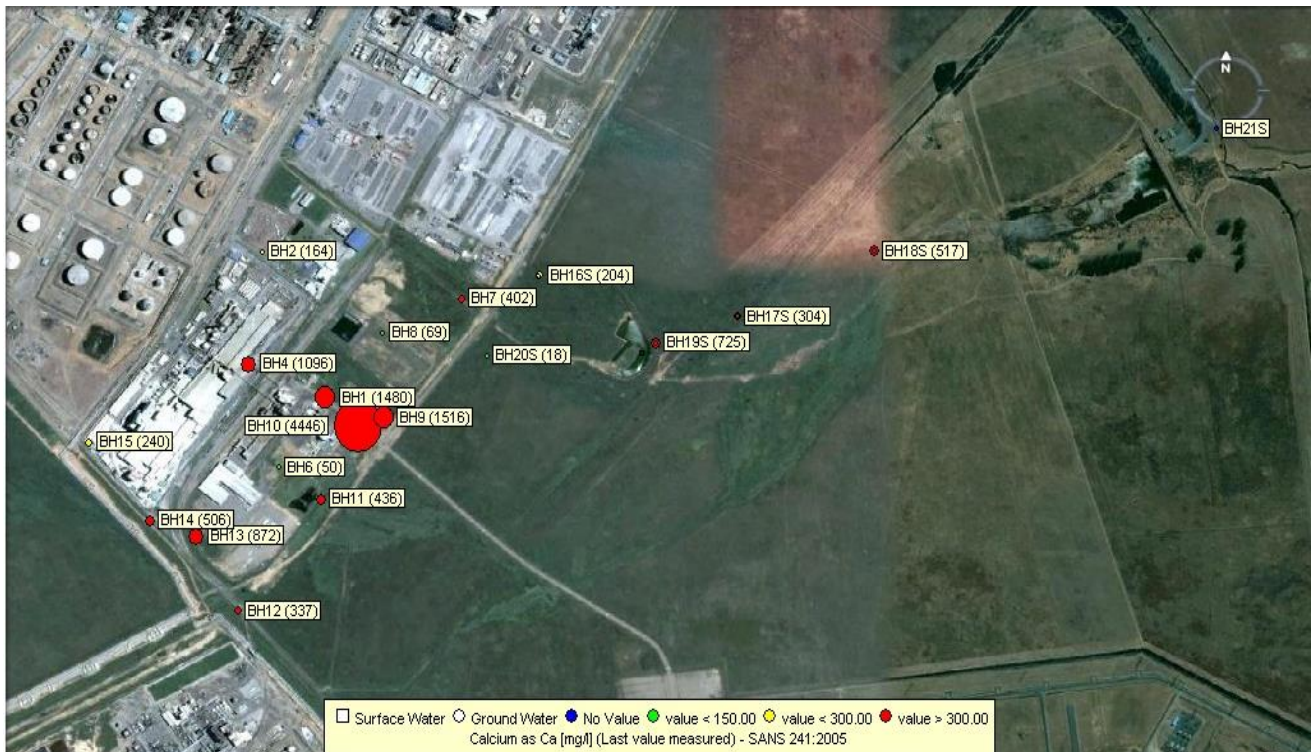


Figure 62: Calcium last measured value shallow boreholes minus background water quality SANS 241:2006.

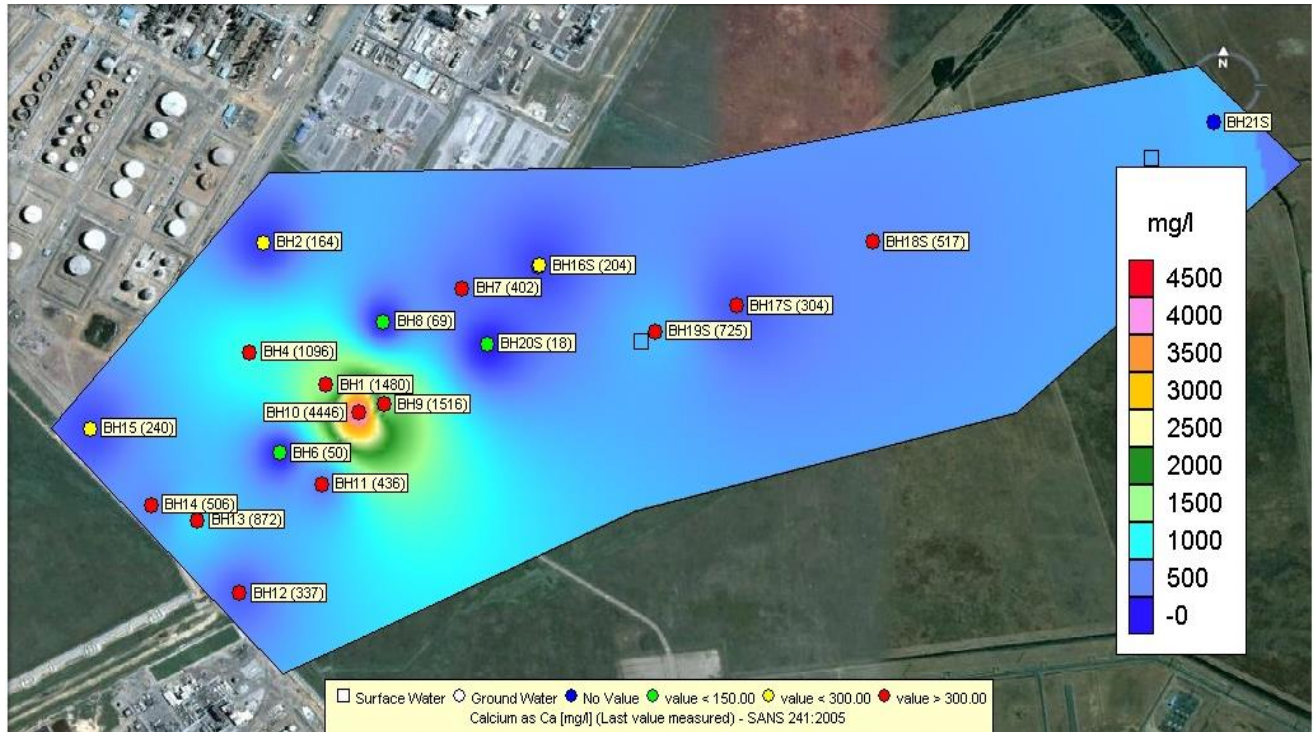


Figure 63: Calcium last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 64: Calcium last measured value shallow and deep boreholes minus background water quality compared against SANS 241:2006.

6.3.2 Chloride (Cl)

Chloride concentrations exceed the Class 1 drinking water standard for BH1, BH9, BH10, BH11 and BH18S. The respective concentrations are reflected in **Figure 65** and **Figure 67**. The respective contour maps are represented in **Figures 66 and 68**. The two highest chloride concentrations are observed at BH1 and BH10 which are closely located to each other.

The area surrounding BH1 and BH10 also has high chloride concentrations (e.g. BH11) indicating almost the same impacted area as for calcium. Chloride might be transported from the North Factory during rainfall events to the storm water dam from which water has been released to irrigate the community vegetable garden (high levels of chloride in Henry's dam). This could have caused artificial recharge to the aquifer system.

The area around BH9 and BH10 form a slight topographical depression against the normal topographic decline towards Henry's dam. Based on the historic design of the community vegetable garden and the subsequent release of water from this dam for irrigation purposes, the potential presence of a dolerite dyke at BH 20 (Jones and Wagener, 2004) and the fact that BH9 and BH 10 are located close to the storm water accumulation point for the South Factory makes this specific area highly vulnerable for contaminated surface water run-off. Recharge in this area from surface water will also be higher due to tendency of forming ponds. As indicated previously in this document there is a 98% relationship between topography and static water levels which might also mean that ground water might flow towards this slight depression.

The background water quality (where the water quality from BH2 is subtracted from the remaining boreholes) and contour maps are indicated in **Figures 70, 71, 72 and 73**. The comparison between chloride concentrations in the deep fractured Karoo aquifer and shallow Karoo aquifer where the background water quality have been taken in consideration shows that the shallow Karoo aquifer is mainly impacted by the chloride pollution (**Figure 74**).

Potassium chloride at the South Factory (liquids plant) is a potential point pollution source as well as the product store, effluent dam, bagging and final product store, stores and loading bays at the South Factory, speciality blending plant, storm water dam, Henry's dam and Driefontein dam.

Chloride concentrations downstream of Henry's dam in BH18S are also exceeding maximum levels. It is clear in this instance the shallow Karoo aquifer is impacted heavier by the Chloride than the deep fractured Karoo aquifer. **Figure 69** compares the chloride concentrations in the deep fractured Karoo aquifer and the shallow Karoo aquifer. It is evident that shallow Karoo aquifer is more impacted than the deep fractured Karoo aquifer, except for BH16 where the deep fractured Karoo aquifer is more contaminated than the shallow Karoo aquifer.



Figure 65: Chloride last measured value deep boreholes SANS 241:2006.

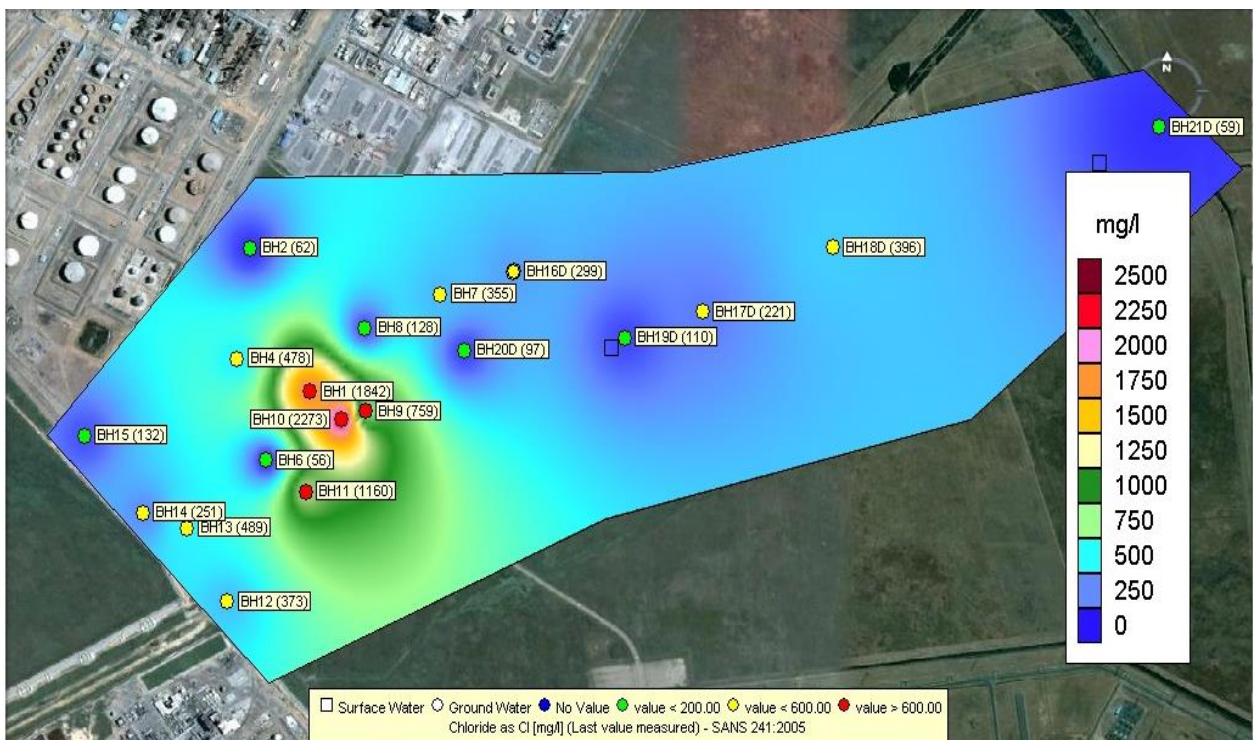


Figure 66: Chloride last measured value deep boreholes contour map.



Figure 67: Chloride last measured value shallow boreholes.

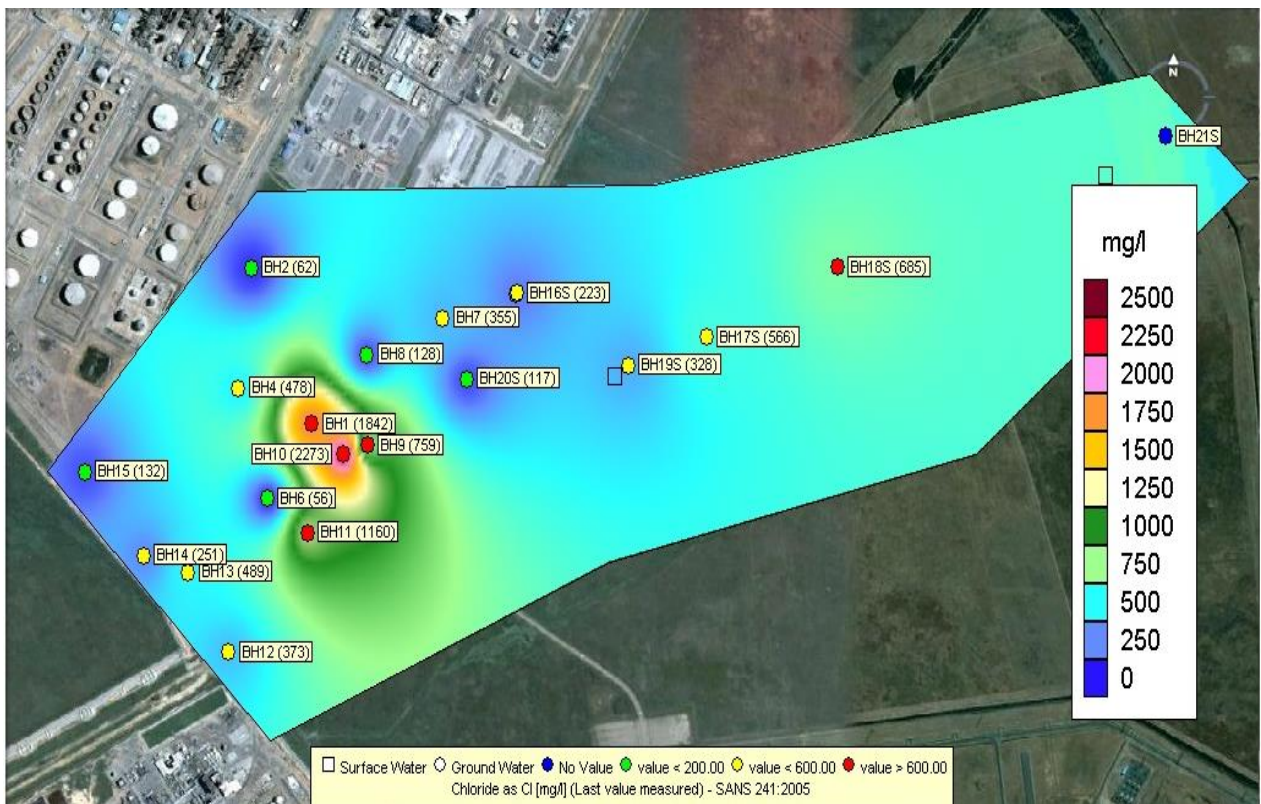


Figure 68: Chloride last measured value shallow contour map.



Figure 69: Chloride last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 70: Chloride last measured value deep boreholes minus background water quality compared against SANS 241:2006.

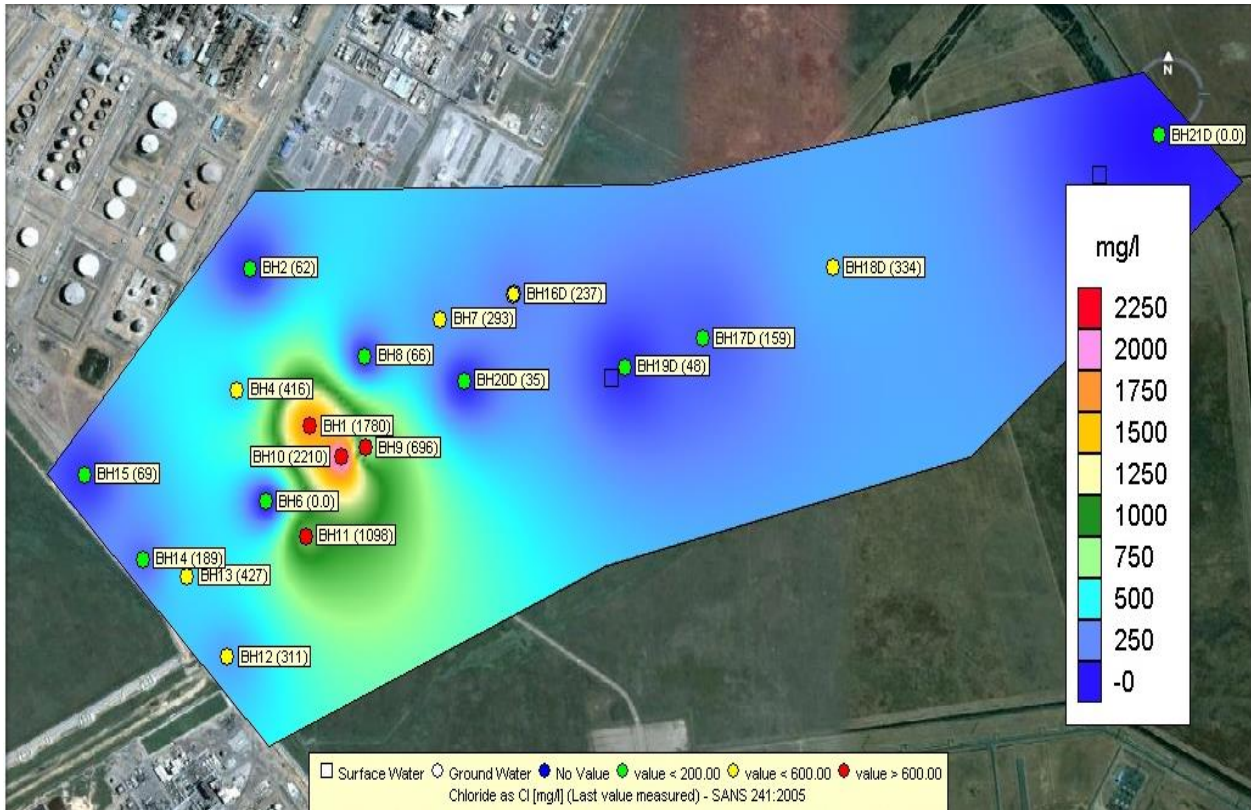


Figure 71: Chloride last measured value deep boreholes minus background water quality compared against SANS 241:2006 contour map.



Figure 72: Chloride last measured value shallow boreholes minus background water quality compared against SANS 241:2006.

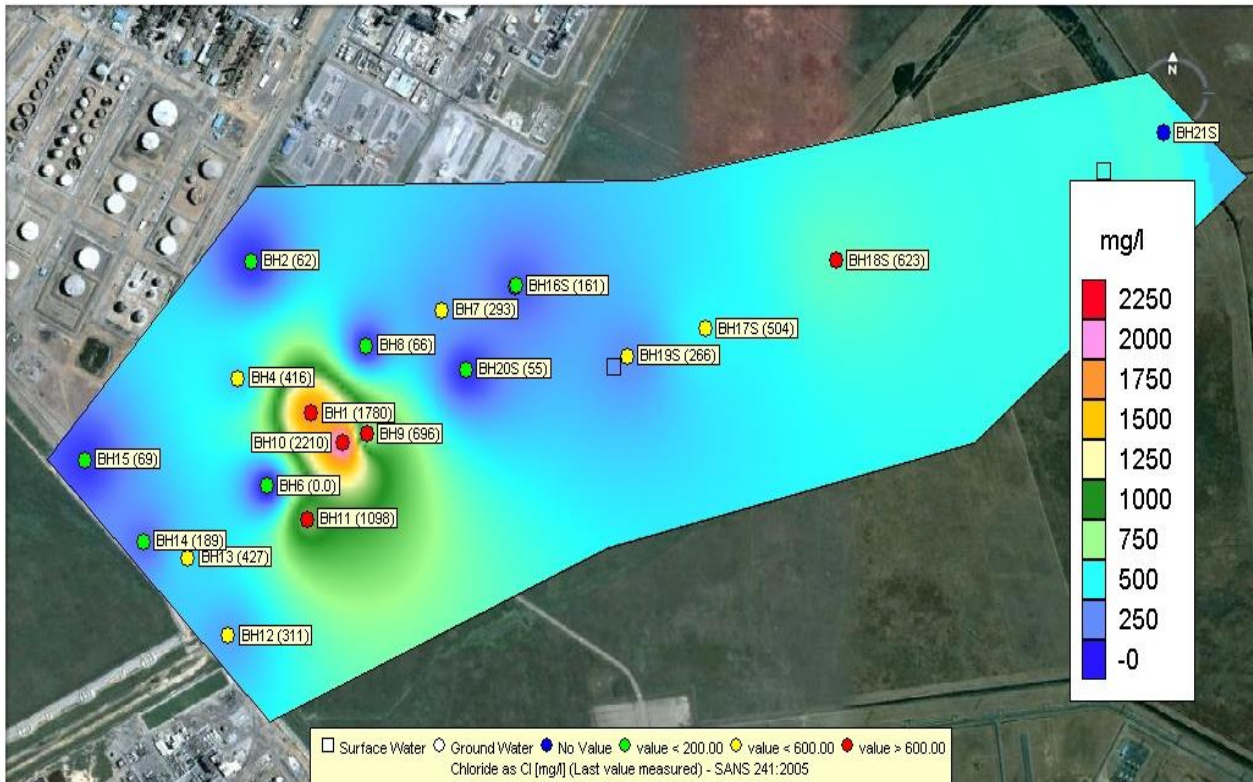


Figure 73: Chloride last measured value shallow boreholes minus background water quality compared against SANS 241:2005 contour map.

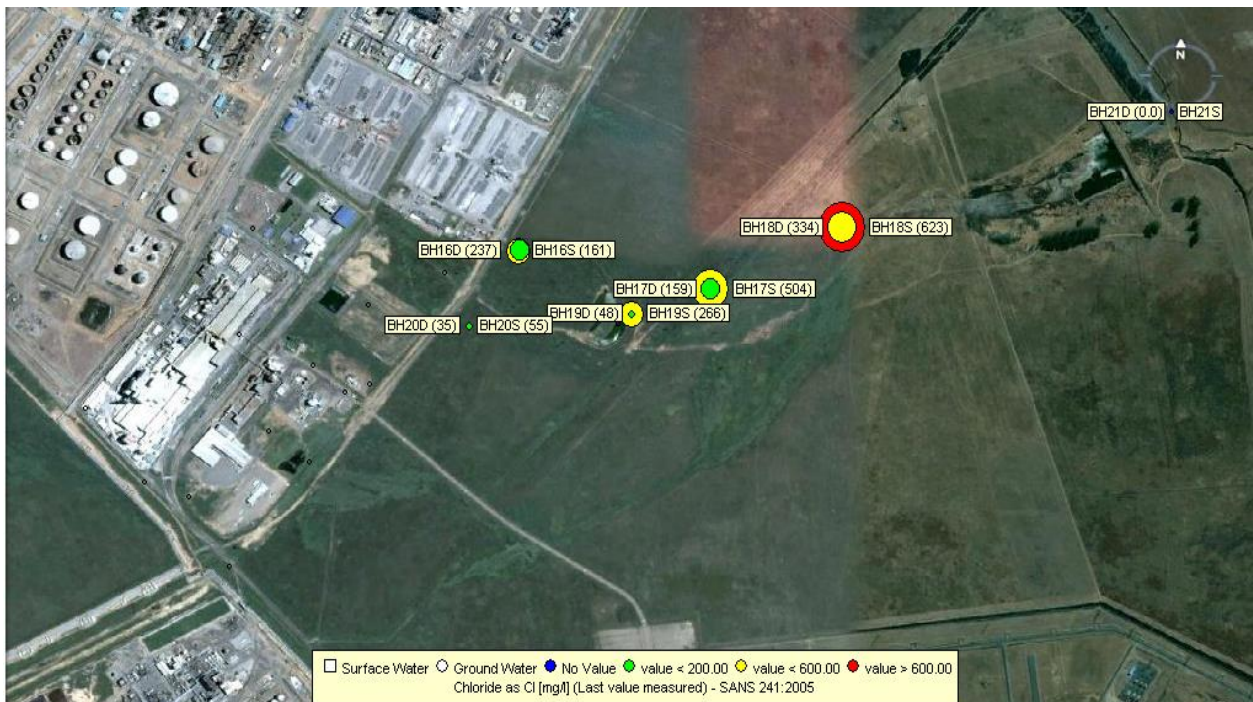


Figure 74: Chloride last measured value shallow and deep boreholes minus background water quality compared against SANS 241:2006.

6.3.3 Fluoride (F)

Fluoride exceeds the Class 1 drinking water standard for BH8 and BH14. The respective concentrations are reflected in **Figure 75** and **Figure 77**. The respective contour maps are represented in **Figures 76 and 78**. BH14 has the highest fluoride concentration and the area surrounding BH14 probably contains the fluoride point pollution source as it is closely located to the granulators where the super phosphate store is located. Natref might also be a contributor of fluorides to the ground water, refer to **Table 3**. BH8 is also impacted. This might be due to the release of water from the storm water dam. Phosphate fertilisers contain approximately 3% fluoride (Connett, 2010). Fluoride is readily mobilised at low pH. **Figure 79** indicate the comparison between fluoride concentrations in the deep fractured Karoo and shallow Karoo aquifer. BH17D shows a higher fluoride concentration than BH17S.

BH2 which is used as the background water quality borehole is impacted by fluorides with a concentration of 0.89 mg/l. This statement is made as there are a number of boreholes with no detectable fluoride concentrations. To use BH 2 as the background water quality borehole therefore has no value but the results are indicated in **Figures 80, 81, 82, 83 and 84**.



Figure 75: Fluoride last measured value deep boreholes.

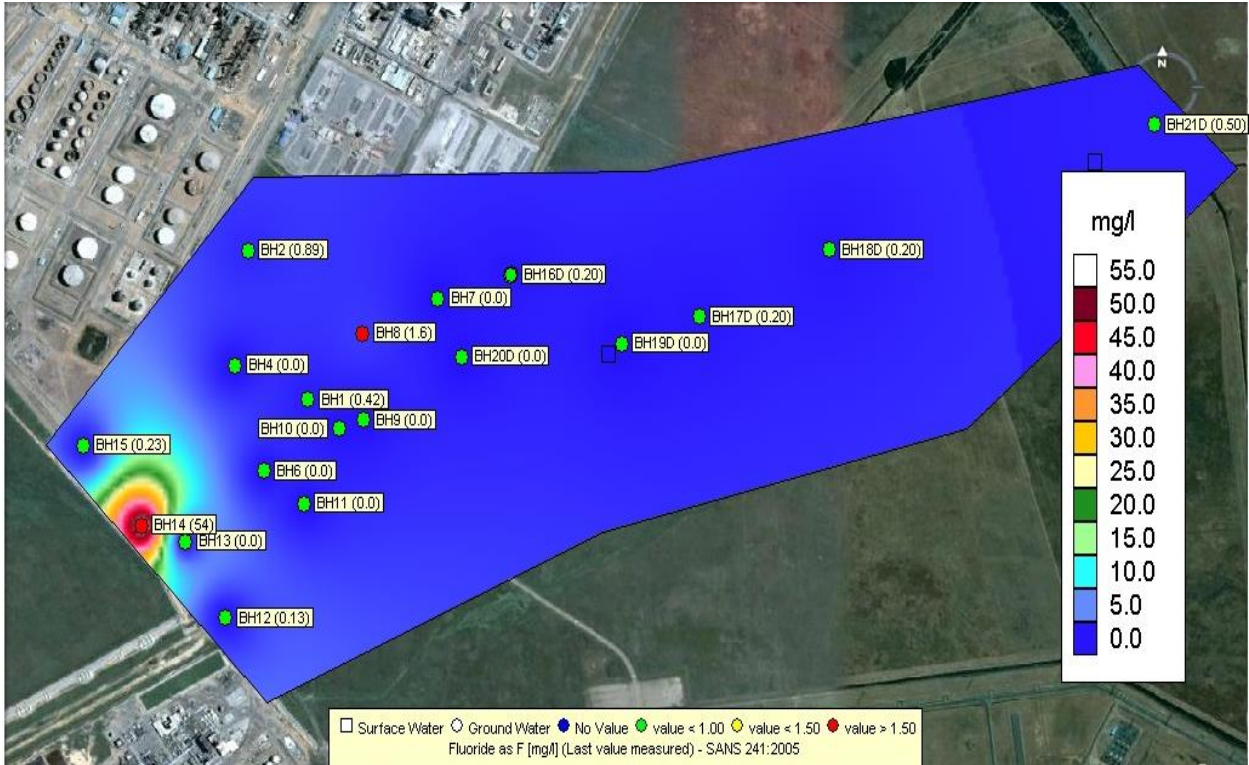


Figure 76: Fluoride last measured value deep boreholes contour map.



Figure 77: Fluoride last measured value shallow boreholes.

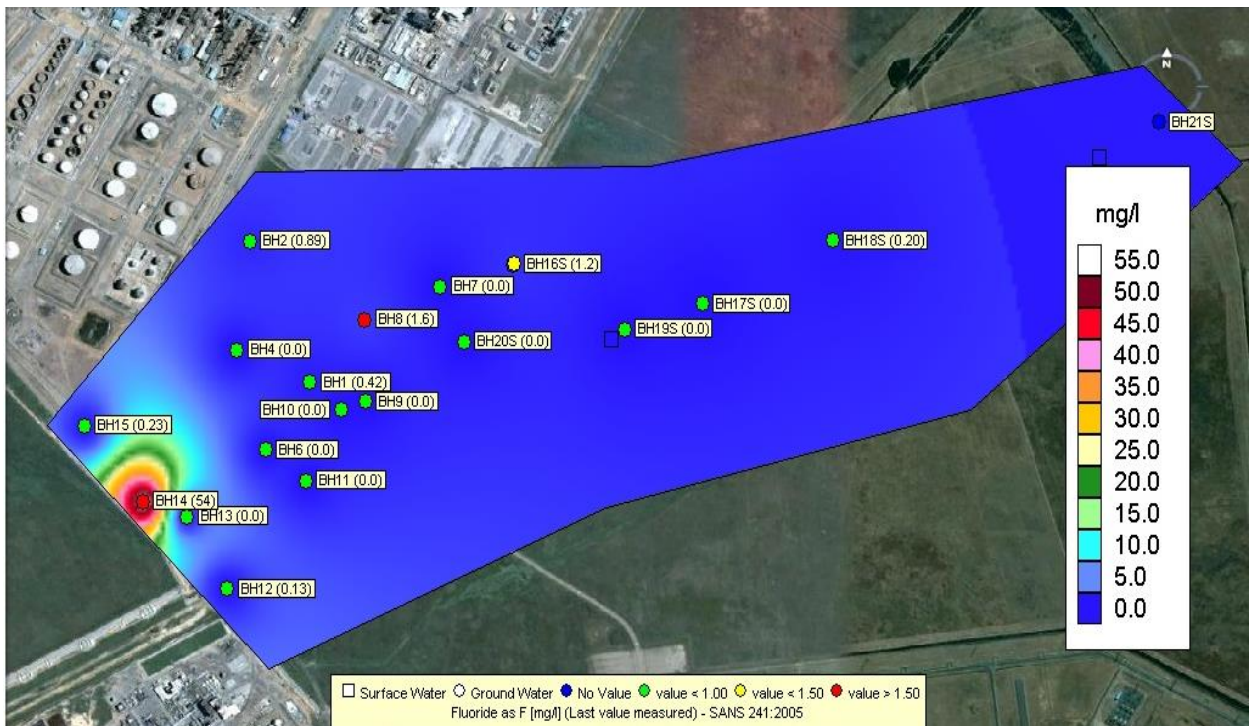


Figure 78: Fluoride last measured value shallow boreholes contour map.



Figure 79: Fluoride last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 80: Fluoride last measured value deep boreholes minus background water quality SANS 241:2006.

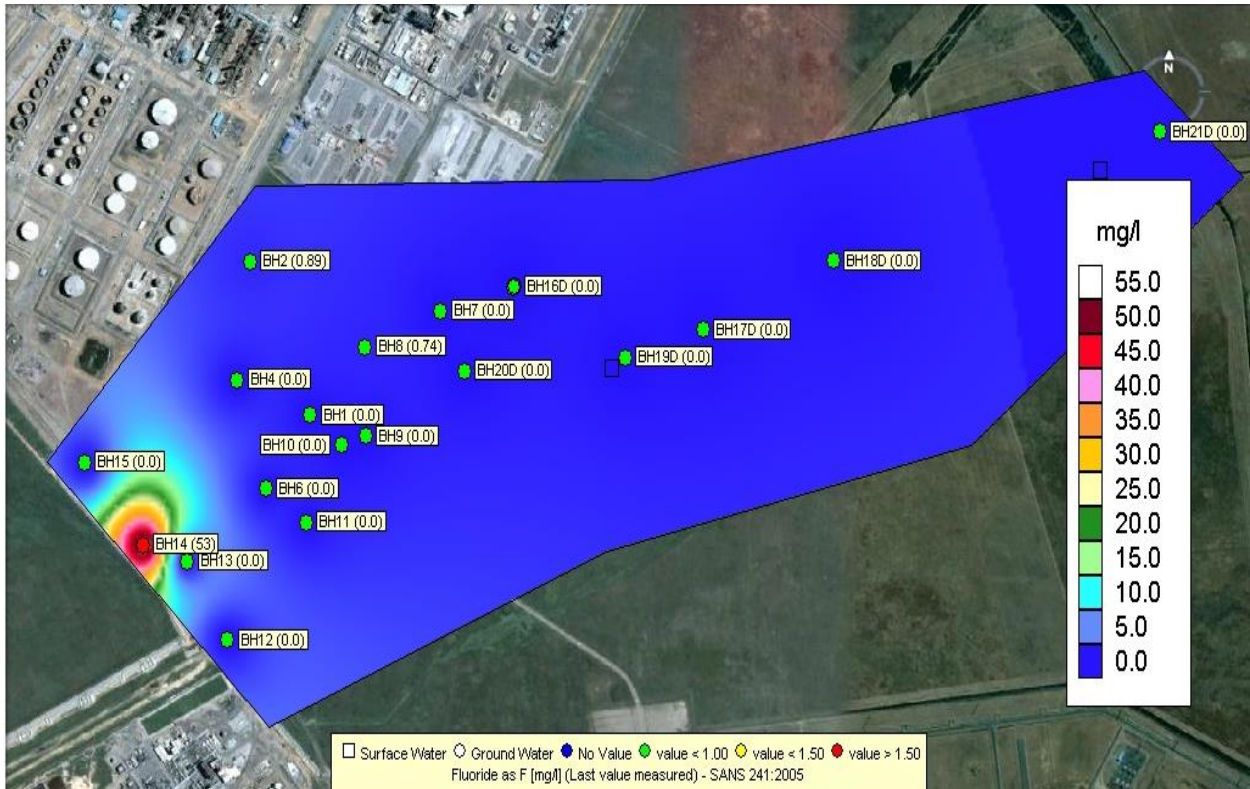


Figure 81: Fluoride last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 82: Fluoride last measured value shallow boreholes minus background water quality SANS 241:2006.

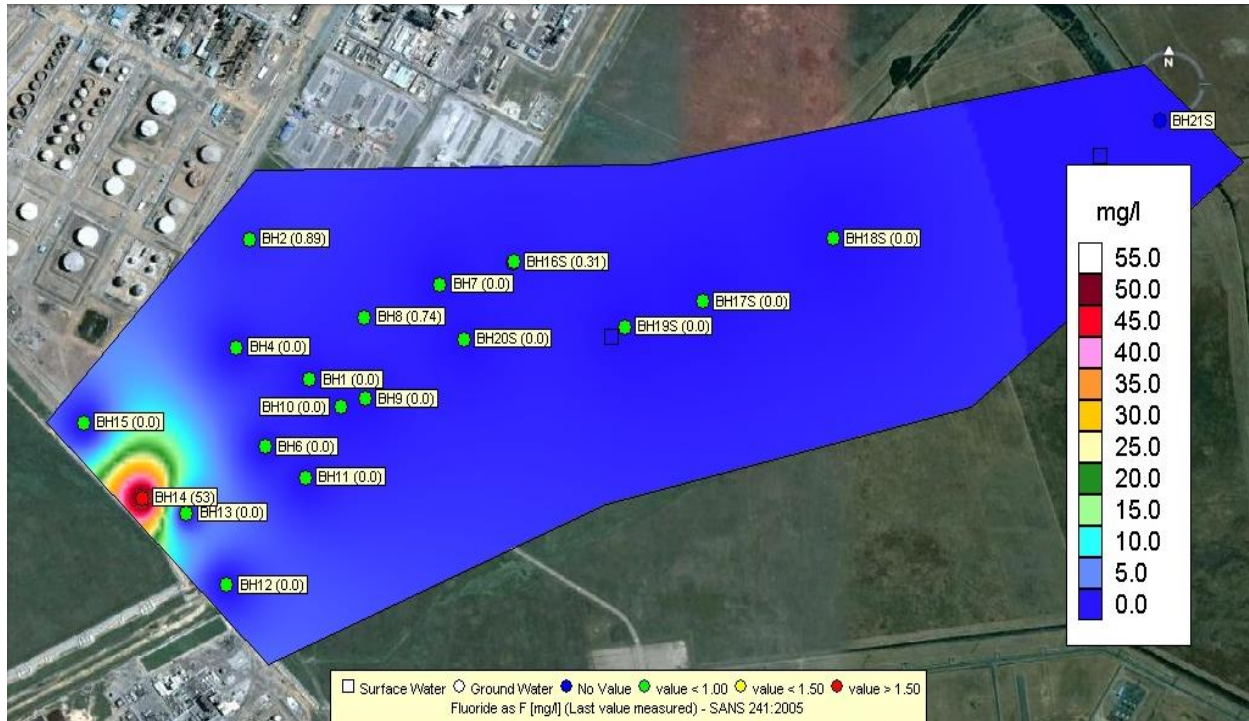


Figure 83: Fluoride last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 84: Fluoride last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.4 Iron (Fe)

Iron levels are elevated at BH14, BH1 and BH21D and exceed the Class 1 drinking water standard. BH14 contain the highest concentration iron. The respective concentrations are reflected in **Figure 85** and **Figure 87**. The respective contour maps are represented in **Figures 86 and 88**. Iron is used as a micro-nutrient in fertiliser and the effluent dam located in the South Eastern side of the North Factory seem to be the main source.

Figure 89 indicates the comparison of iron concentrations between the shallow and deep aquifer. There are fluctuations in highest concentrations between the deep and the shallow aquifer which might be indicative of natural occurring iron in the deep aquifer. No iron concentration was detected in BH2 which is used as the background water quality borehole. **Figures 90, 91, 92, 93, and 94** are thus a repeat of **Figures 85, 86, 87, 88 and 89**.

Some iron is detected in BH19S located below Henry's dam. There is however limited evidence of Iron concentration elevation in Henry's dam.

The iron concentrations observed at BH21D below Driefontein Dam might include other source(s) than Omnia such as Süd-Chemie and Inca Bricks, refer to **Table 3**.



Figure 85: Iron last measured value deep boreholes.

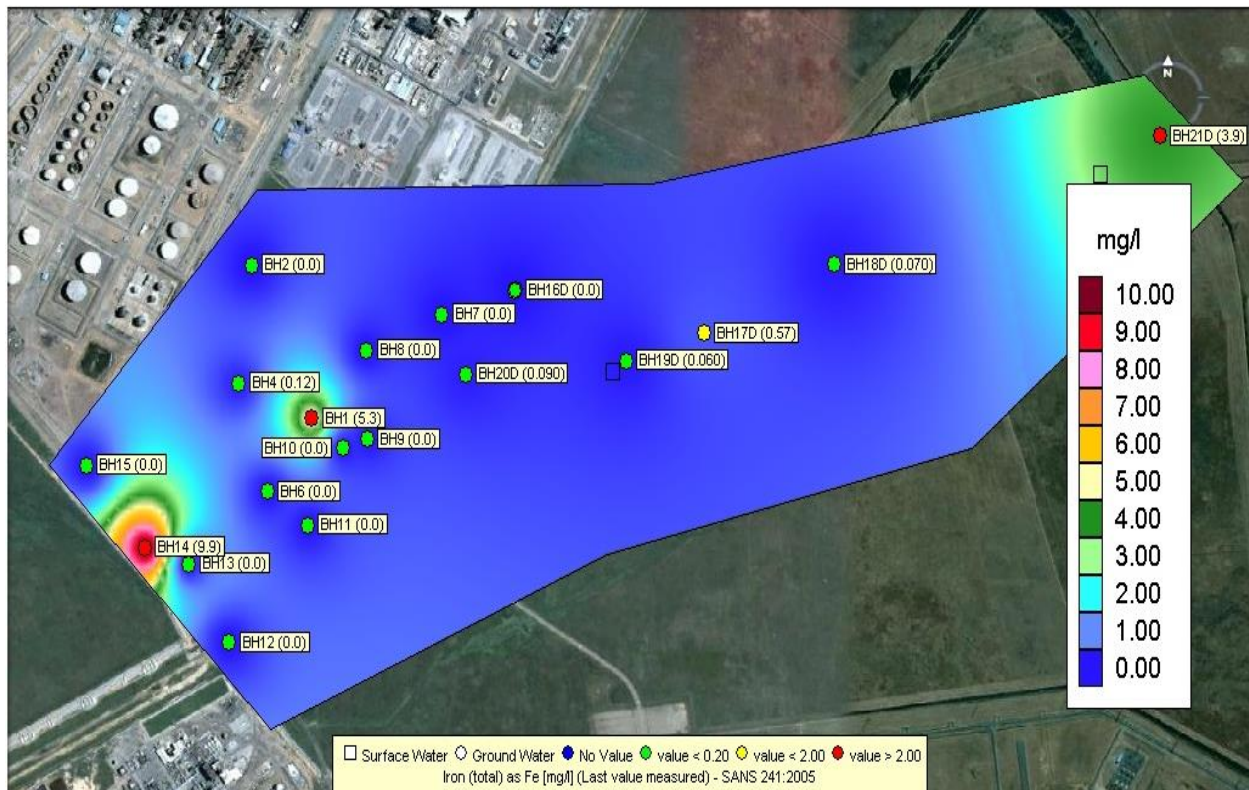


Figure 86: Iron last measured value deep boreholes contour map.



Figure 87: Iron last measured value shallow boreholes.

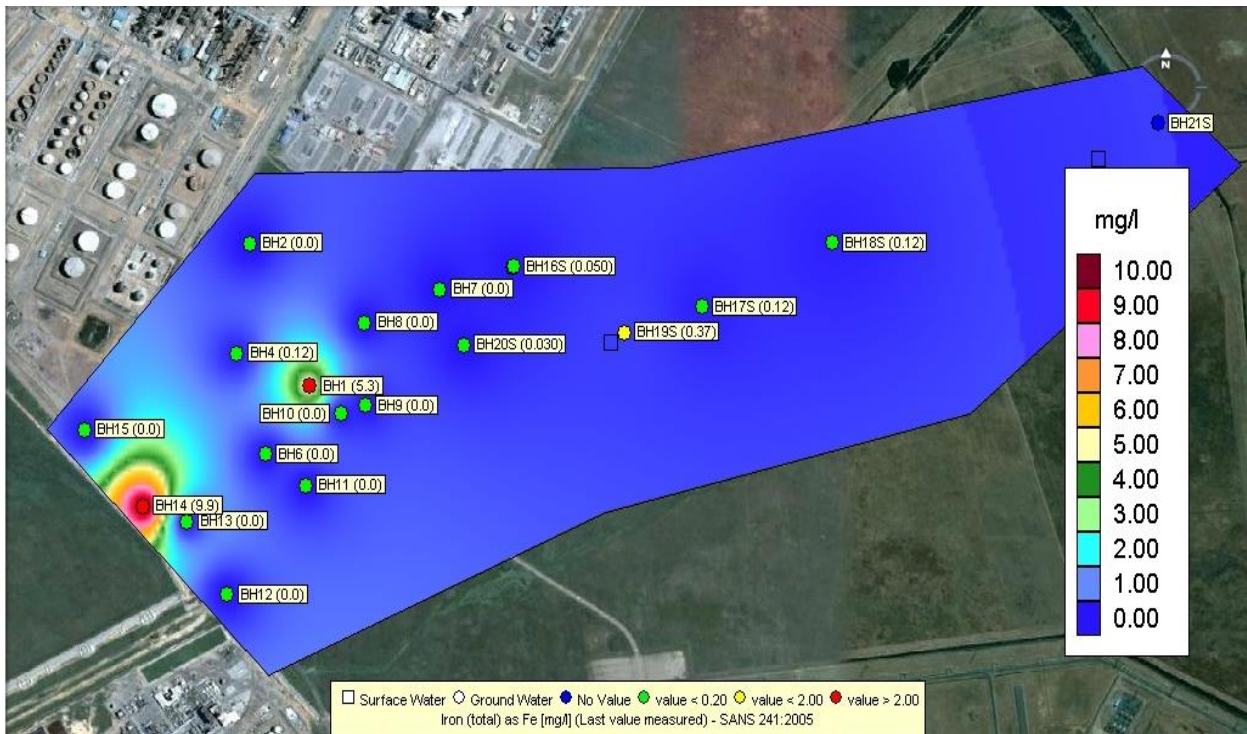


Figure 88: Iron last measured value shallow boreholes contour map.



Figure 89: Iron last measured value shallow and deep boreholes comparison SANS 241:2006.

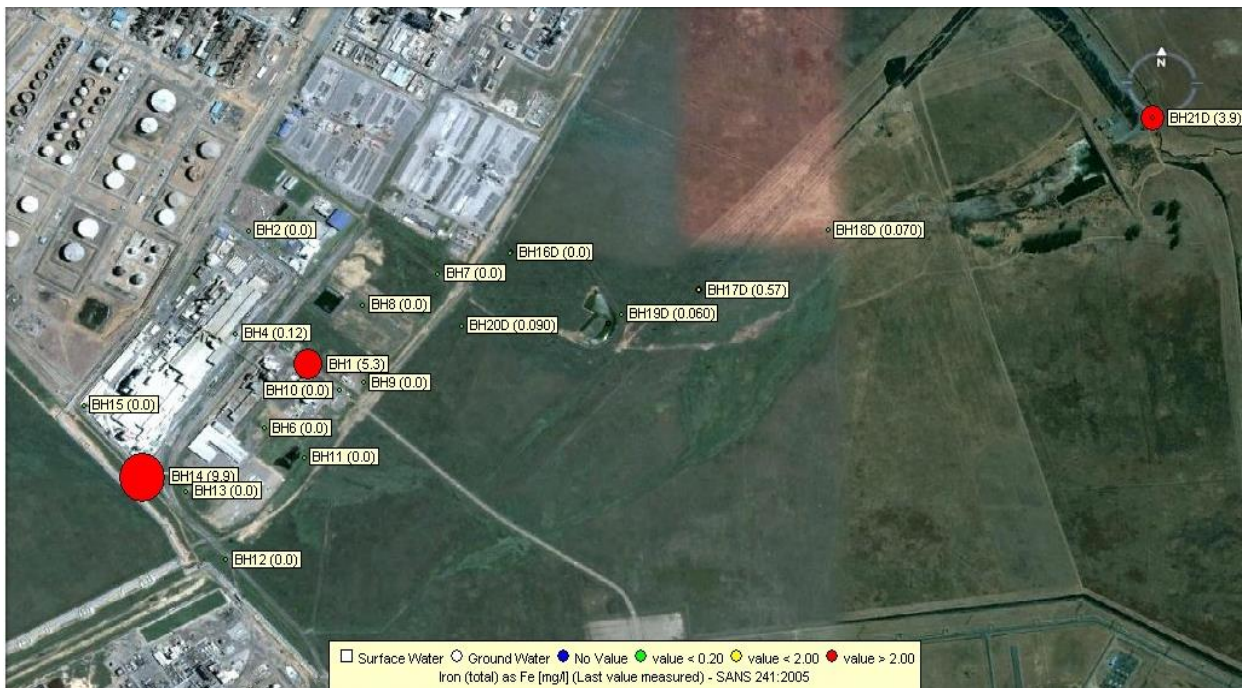


Figure 90: Iron last measured value deep boreholes minus background water quality SANS 241:2006.

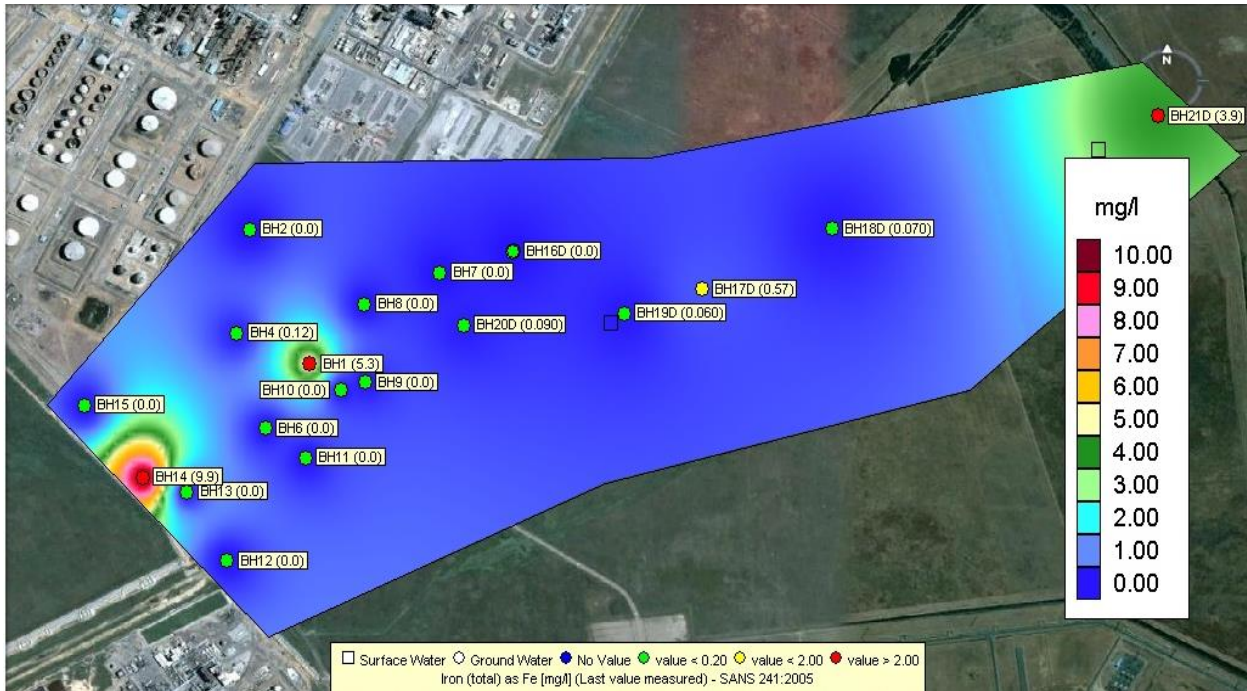


Figure 91: Iron last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 92: Iron last measured value shallow boreholes minus background water quality SANS 241:2006.

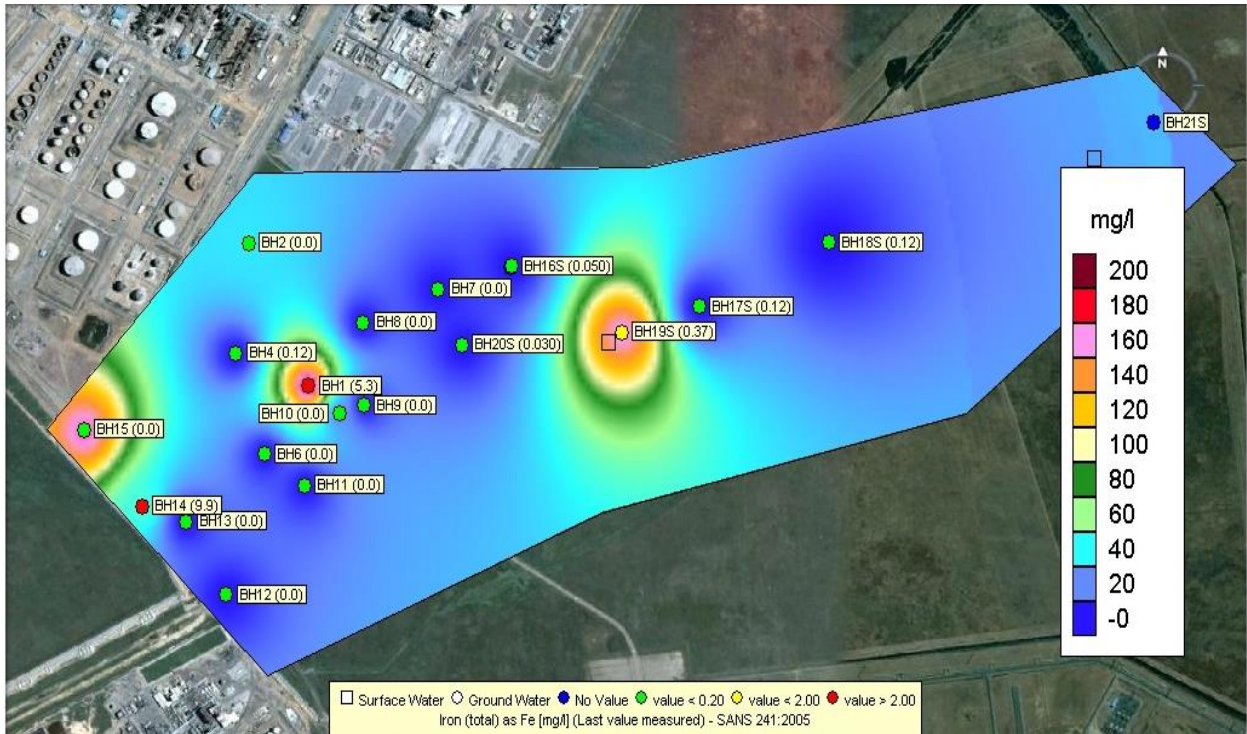


Figure 93: Iron last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 94: Iron last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.5 Potassium (K)

Potassium levels are elevated at BH15, BH1 and BH19S and exceed the Class 1 drinking water standard. The respective concentrations are reflected in **Figure 95** and **Figure 97**. The respective contour maps are represented in **Figures 96 and 98**. BH1 contain the highest concentration potassium. It is unusual that the potassium content is so elevated at BH15 and might reflect a spillage or unprotected storage incident involving a potassium source. It is expected that potassium and chloride as contaminants would be found together in the same location as potassium chloride (KCl) is used on site. This might be an historical pollution incident where potassium has been retarded in the ground water migration and chloride to lesser extent. BH1 however show the same trend in respect of potassium and chloride concentrations, close to the vicinity of the liquid fertiliser operation.

The escalated level of potassium observed in BH14 is due to dust generation at the granulation plant and potential seepage and overflow of the effluent dam in the South Eastern corner of the North Factory.

Seepage and overflows of Henry's dam is responsible for the elevated concentration of potassium in BH19S. Again it is Evident that Henry's dam is a point pollution source and the shallow unconfined aquifer is mostly impacted by the potassium pollution as indicated in **Figure 99**.

BH2 which is used as the background water quality borehole is impacted by potassium and limited reliance can be placed as such on the deduction of the background values to the remaining boreholes. The resulting concentrations are however indicated in **Figures 100, 101, 102, 103 and 104**.

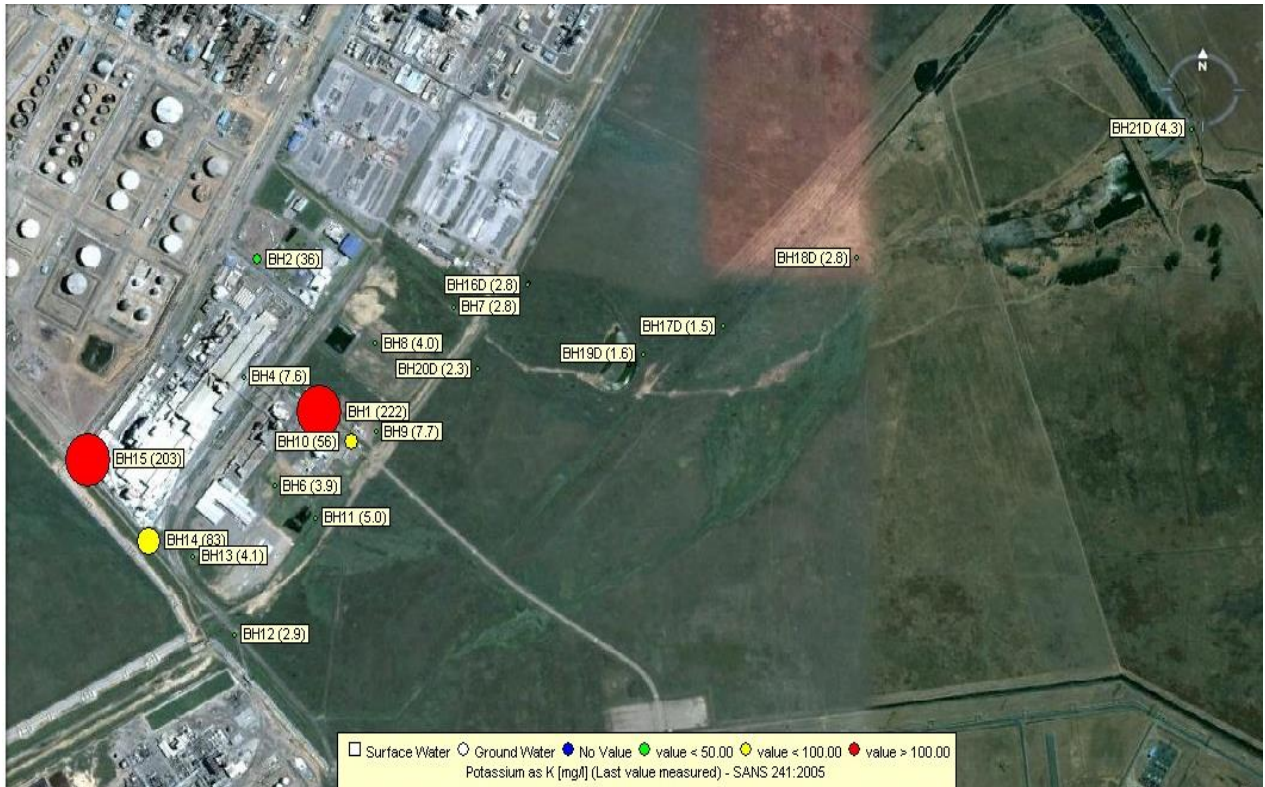


Figure 95: Potassium last measured value deep boreholes.

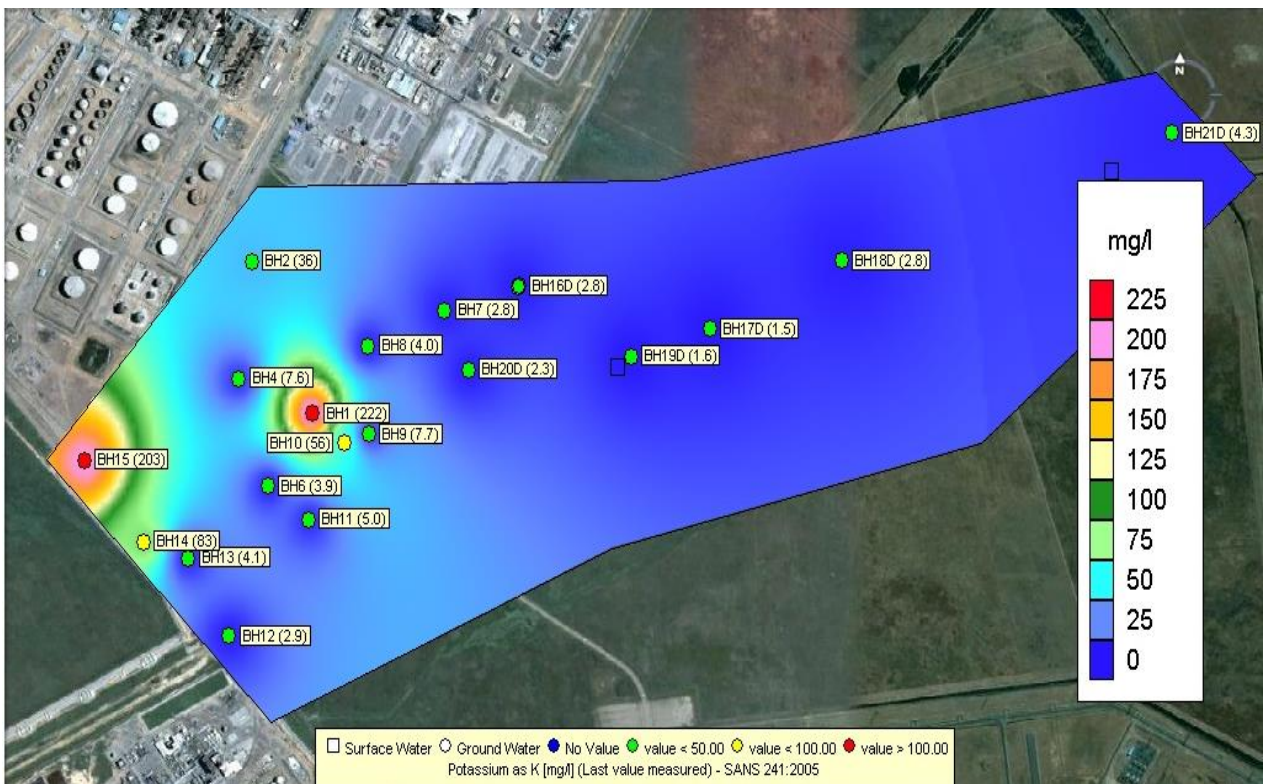


Figure 96: Potassium last measured value deep boreholes contour map.



Figure 97: Potassium last measured value shallow boreholes.

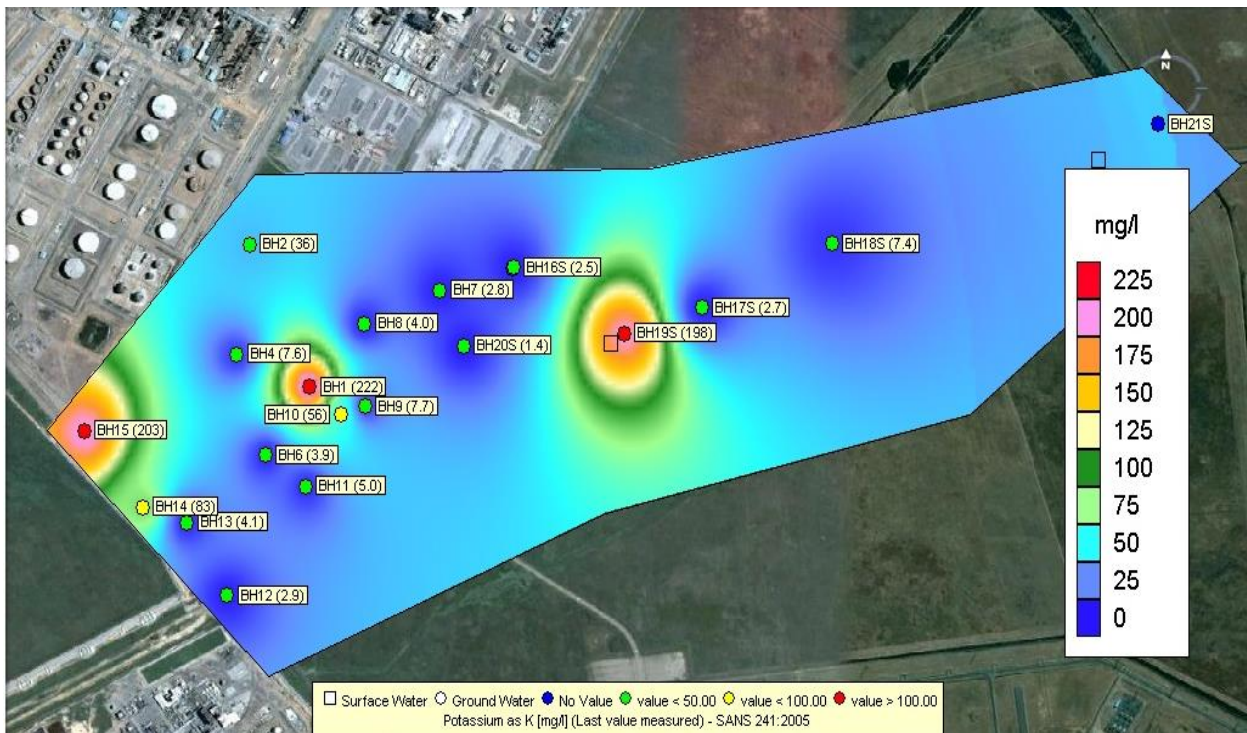


Figure 98: Potassium last measured value shallow boreholes contour map.



Figure 99: Potassium last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 100: Potassium last measured value deep boreholes minus background water quality SANS 241:2006.

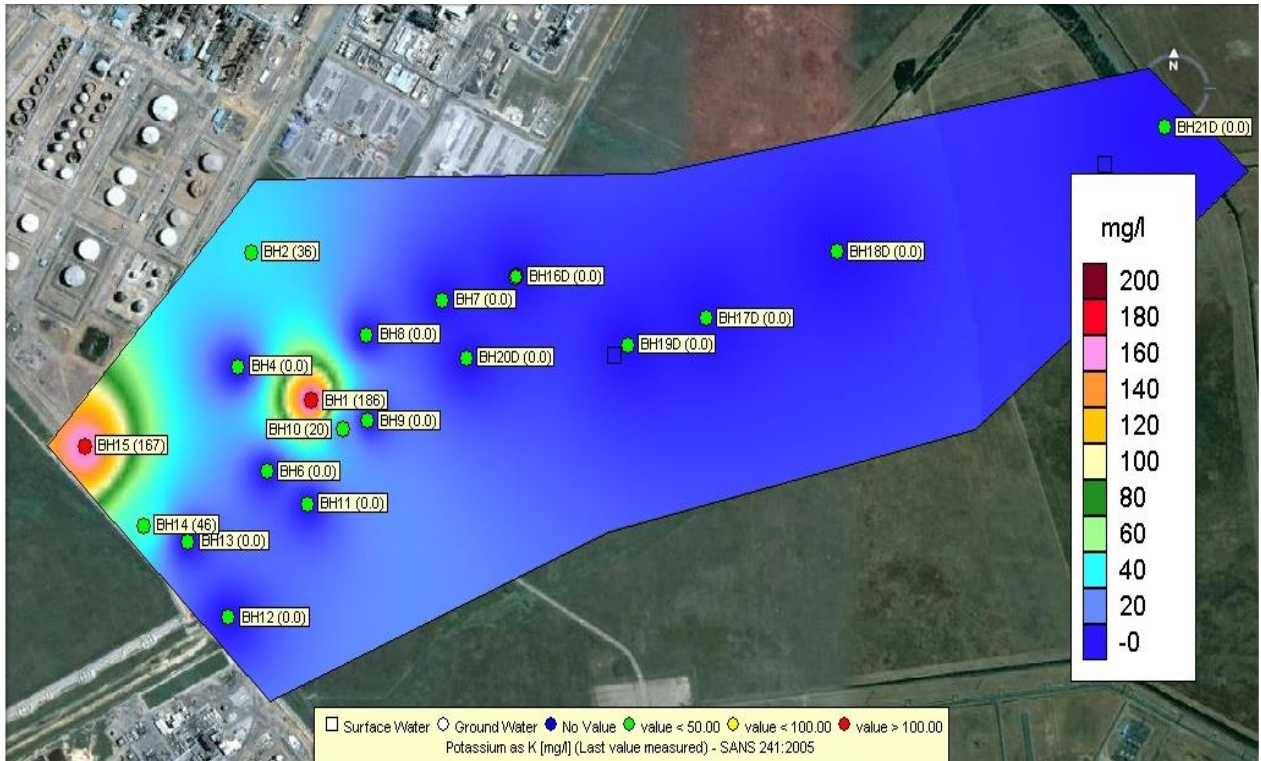


Figure 101: Potassium last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 102: Potassium last measured value shallow boreholes minus background water quality SANS 241:2006.

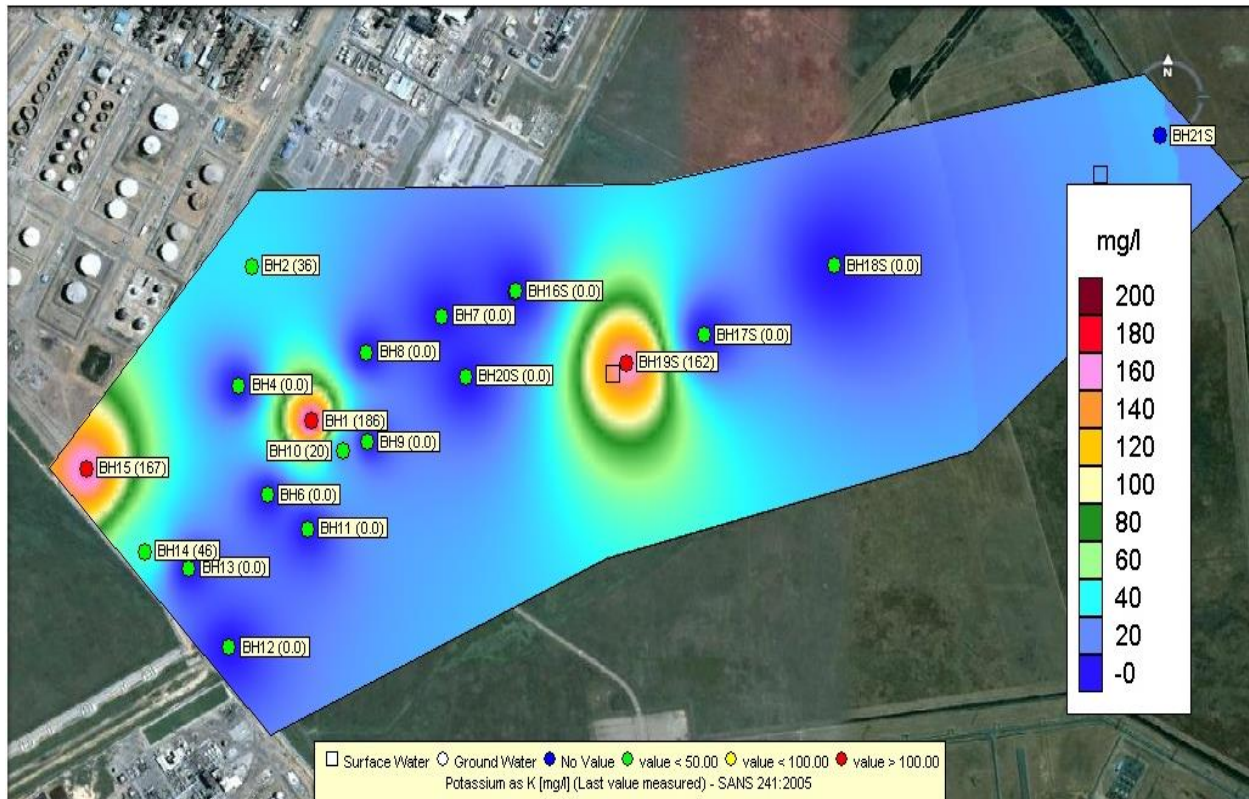


Figure 103: Potassium last measured value shallow boreholes minus background water quality contour map SANS 241:2006.

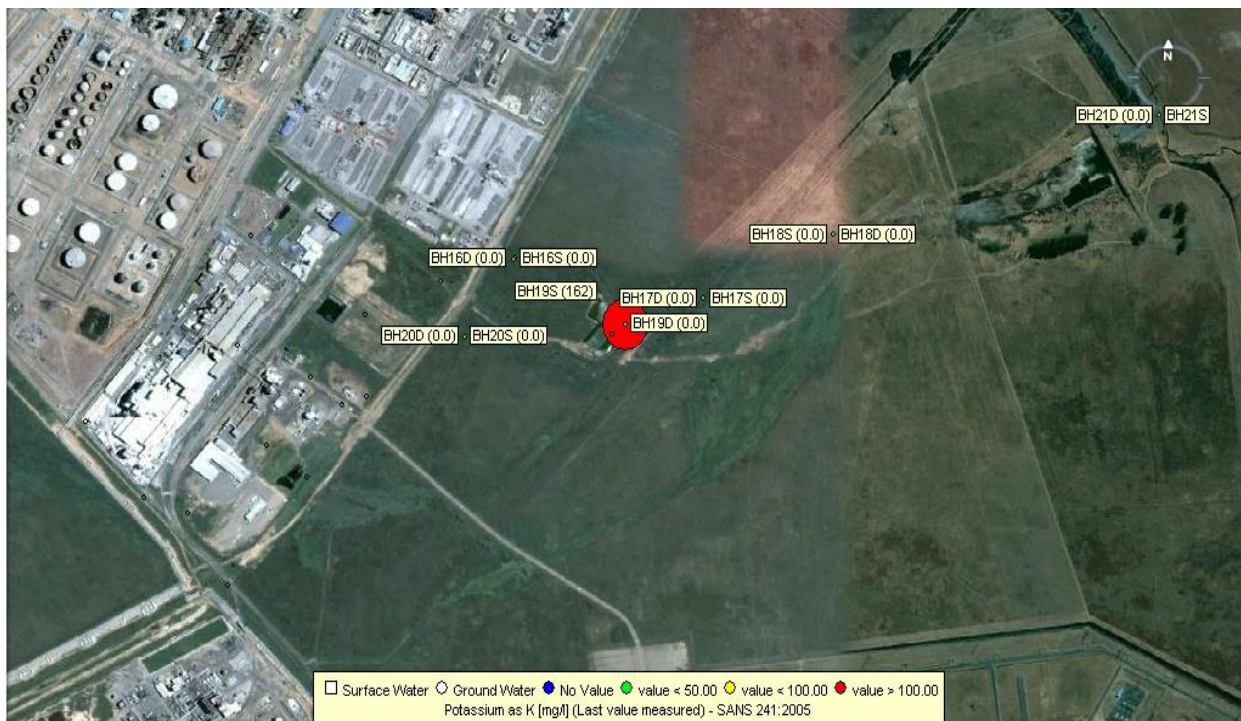


Figure 104: Potassium last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.6 Magnesium (Mg)

Magnesium exceeds the Class 1 drinking water standard for BH1, BH4, BH7, BH9, BH10, BH11, BH12, BH13, BH14, BH15, BH16D, BH16S, BH17S, BH18S and BH19S. The respective concentrations are reflected in **Figure 105** and **Figure 107**. The respective contour maps are represented in **Figures 106 and 108**. The two highest magnesium concentrations are observed at BH10 and BH9 which is closely located to each other. The area surrounding BH10 and BH9 also has high magnesium concentrations (e.g. BH1 and BH4) indicating a clear highly impacted area where a primary source of magnesium is not readily expected. Dolomitic limestone $\text{CaMg}(\text{CO}_3)_2$ from the granulators generates significant dust and the dust which accumulates in the primary factory area is transported during rainfall events to the storm water dam from which water has been released to irrigate the community vegetable garden. This could have caused artificial recharge to the aquifer system.

The area around BH9 and BH10 form a slight topographical depression against the normal topographic decline towards Henry's dam. Based on the historic design of the employees vegetable garden and the subsequent release of water from this dam for irrigation purposes, the potential presence of a dolerite dyke at BH20 (Jones and Wagener, 2004) and the fact that BH9 and BH 10 is located close to the storm water accumulation point for the South Factory makes this specific area highly vulnerable for contaminated surface water run-off. Recharge in this area from surface water will also be higher due to tendency of ponding. As indicated previously in this document there is a 98% relationship between topography and static water levels which might also that ground water might flow towards this slight depression.

Magnesium has virtually the exact same footprint impact as calcium indicating that the point pollution source might be the same and it is most likely to be Dolomitic limestone ($\text{CaMg}(\text{CO}_3)_2$) dust originating from dust caused by the granulators and transported to the Surface water dam.

Point pollution sources for calcium are solid calcium nitrate, product store, raw product store, granulation plants, speciality blending plant, loading bays, stores in the south factory, effluent dam, storm water dam, Henry's dam and Driefontein dam.

Disperse pollution sources can be regarded as dust from the granulators which is windblown off-site and storm water channels. Other sources of magnesium are Epsom salt (Magnesium sulphate). **Figure 109** indicate the comparison between the magnesium concentrations in deep fractured Karoo aquifer and the shallow Karoo aquifer. From this it is evident that the shallow Karoo aquifer is more impacted than the deep fractured Karoo aquifer. There is however a close resemblance between the magnesium concentrations of BH16D and BH16S.

The concentration of magnesium in BH2 which is used as the background water quality borehole is higher for some of the boreholes in the deep fractured Karoo aquifer. **Figures 110, 111, 112, 113 and 114** indicate the results if the magnesium quality of BH2 is subtracted from the water quality of the other boreholes.



Figure 105: Magnesium last measured value deep boreholes.

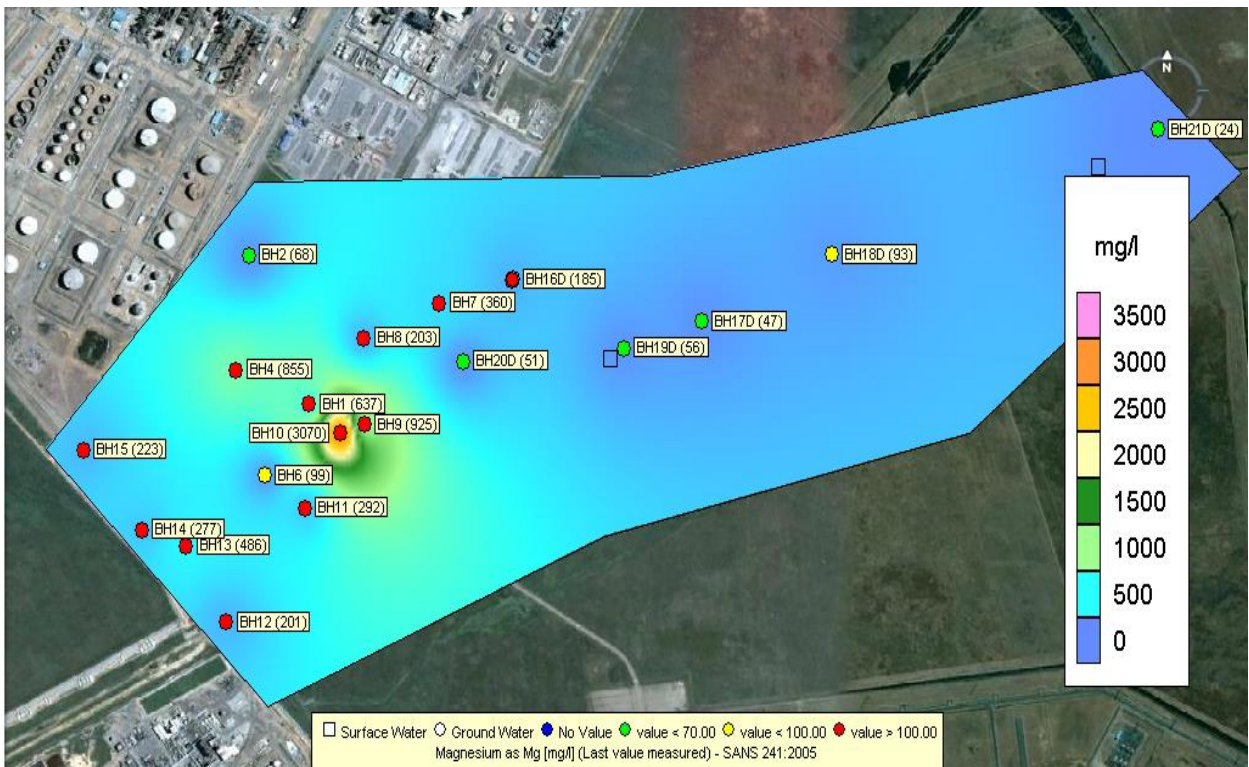


Figure 106: Magnesium last measured value deep boreholes contour map.



Figure 107: Magnesium last measured value shallow boreholes.

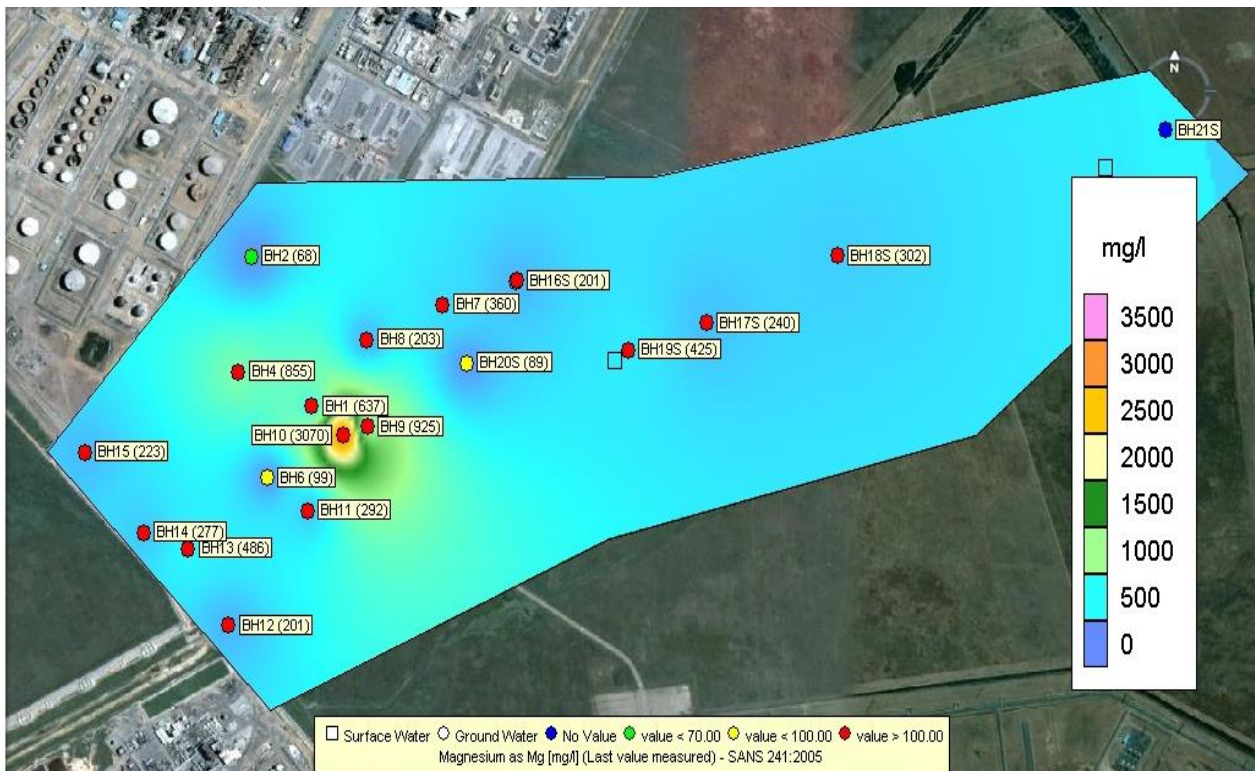


Figure 108: Magnesium last measured value shallow boreholes contour map.



Figure 109: Magnesium last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 110: Magnesium last measured value deep boreholes minus background water quality SANS 241:2006.

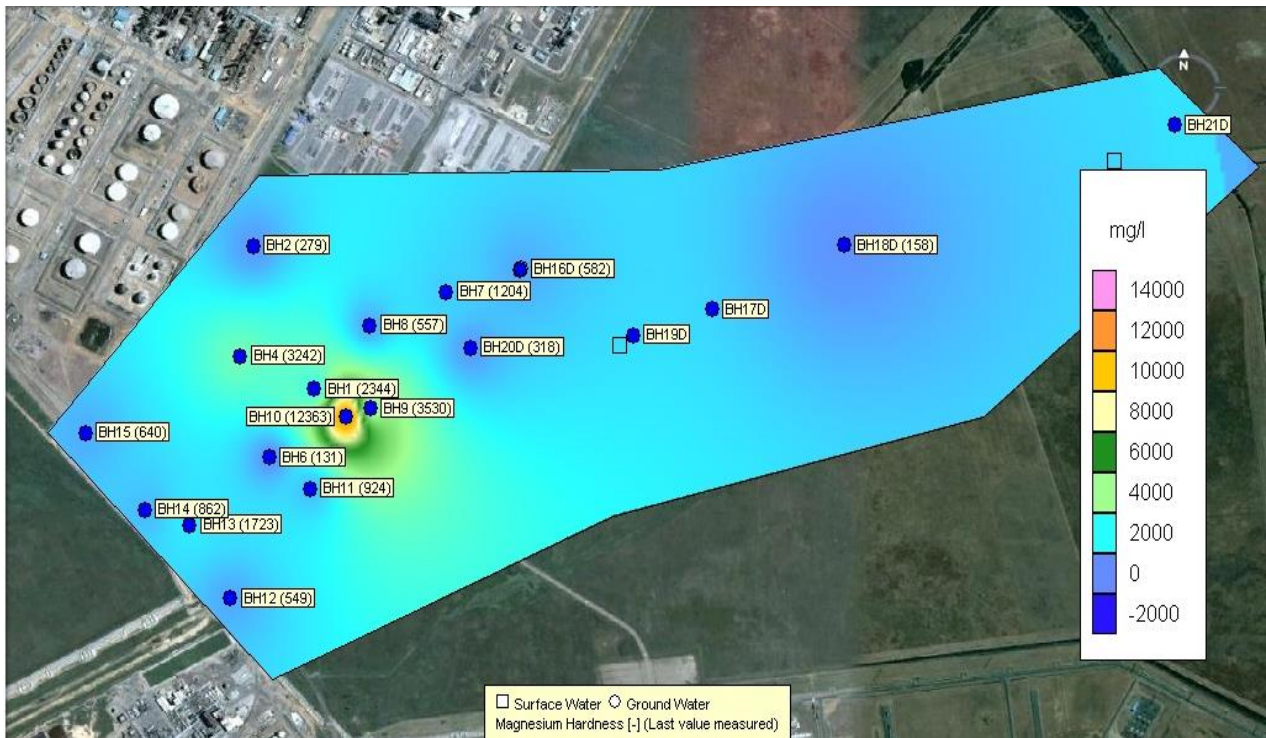


Figure 111: Magnesium last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 112: Magnesium last measured value shallow boreholes minus background water quality SANS 241:2006.

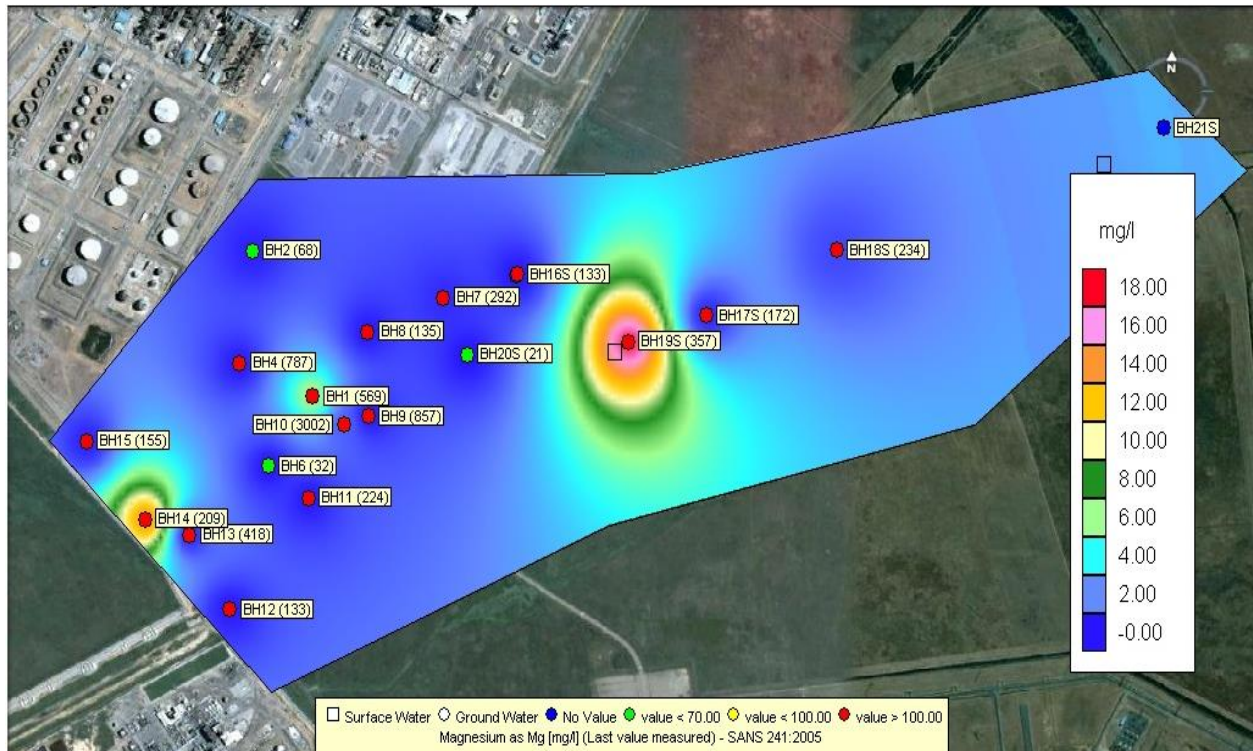


Figure 113: Magnesium last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 114: Magnesium last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.7 Manganese (Mn)

Manganese exceeds the Class 1 drinking water standard for BH1, BH10 and BH14. The respective concentrations are reflected in **Figure 115** and **Figure 117**. The respective contour maps are represented in **Figures 116 and 118**. The two highest manganese concentrations are observed at BH14 and BH1. BH14 is potentially located close to the point pollution source while the elevated concentrations observed at BH1, BH4, BH10 and BH9 are again present the lower lying topographical area. There is a high probability that the manganese point pollution source located close to BH14 contaminates the surface water run-off from the North Factory and is transported during rainfall events to the storm water dam from which water has been released to irrigate the employee vegetable garden. This could have caused artificial recharge to the aquifer system. Storm water drainage from the North Factory prior to the existence of the Storm water dam could have caused the accumulation of manganese in this area (historical impact).

Figure 119 indicate that more boreholes of the shallow Karoo aquifer is impacted than the deep fractured Karoo aquifer. BH16D is again an exception to this.

Figures 120, 121, 122, 123 and 124 indicate the manganese concentrations after the manganese concentration of the background quality borehole (BH2) has been subtracted.



Figure 115: Manganese last measured value deep boreholes.

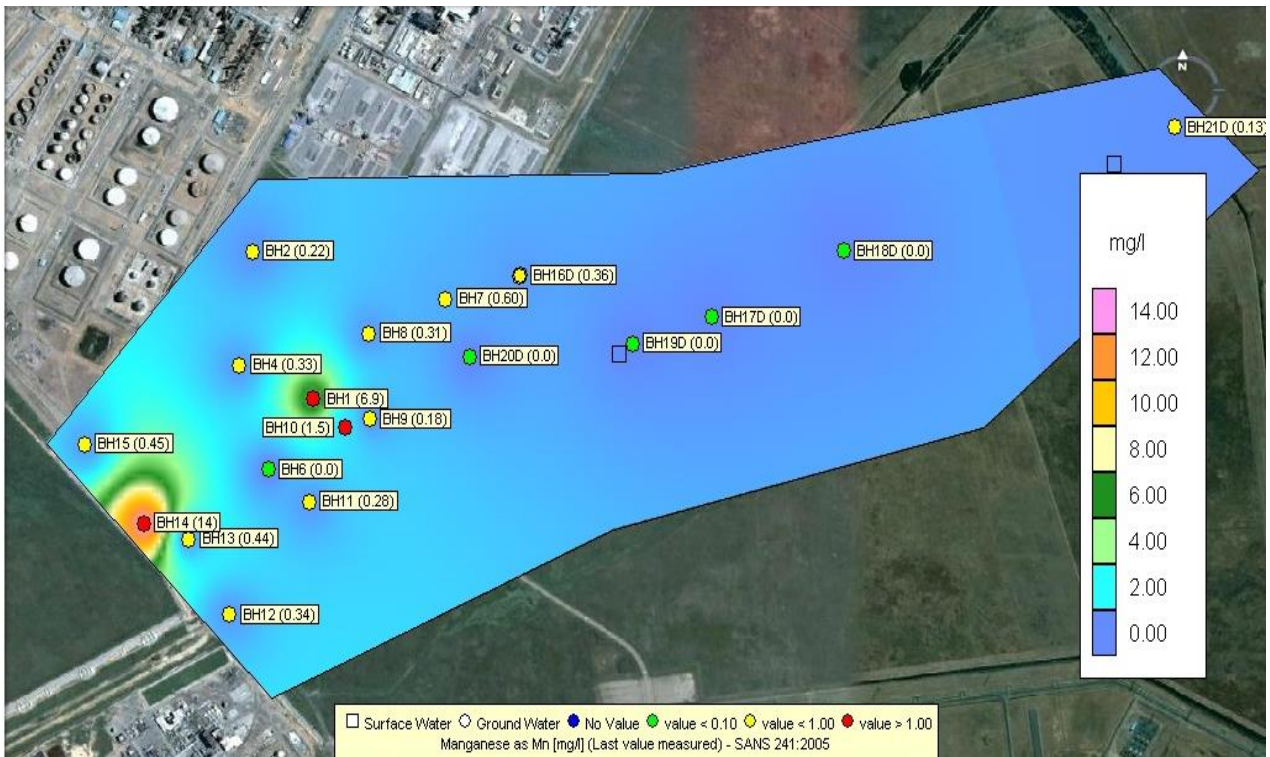


Figure 116: Manganese last measured value deep boreholes contour map



Figure 117: Manganese last measured value shallow boreholes.

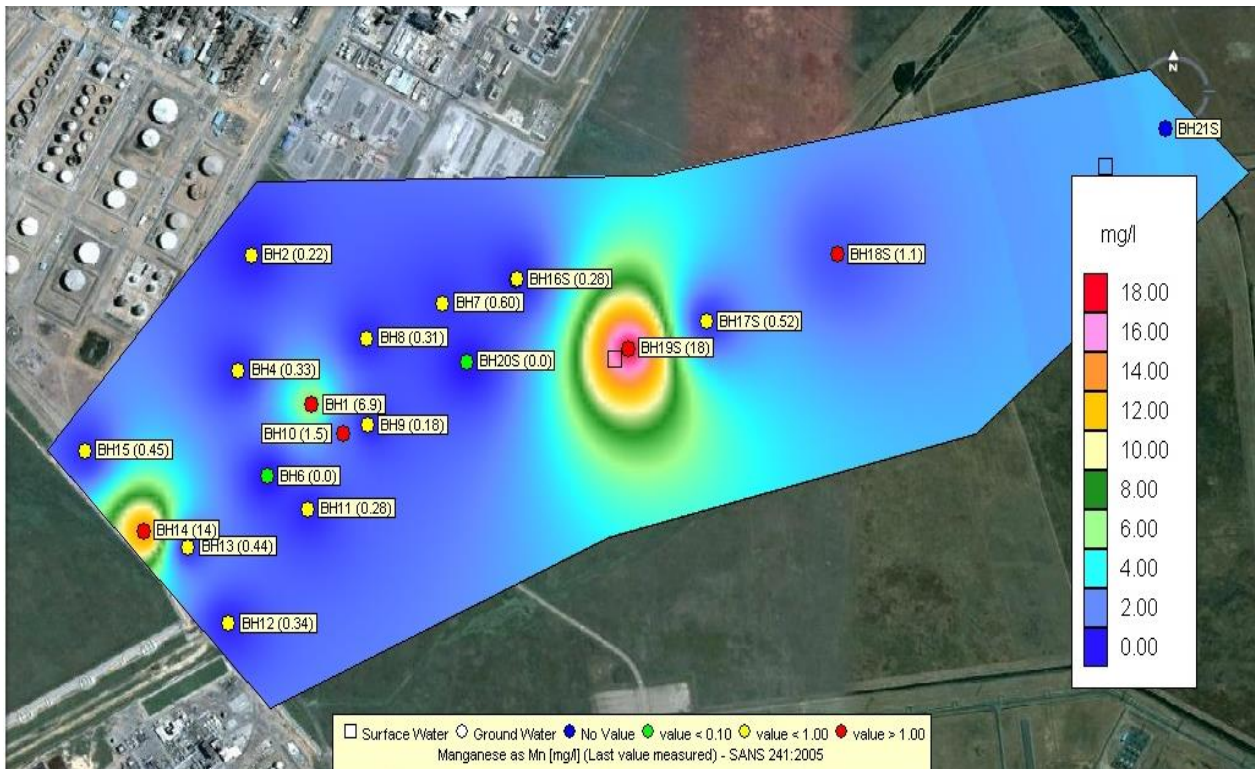


Figure 118: Manganese last measured value shallow boreholes contour map.



Figure 119: Manganese last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 120: Manganese last measured value deep boreholes minus background water quality SANS 241:2006.

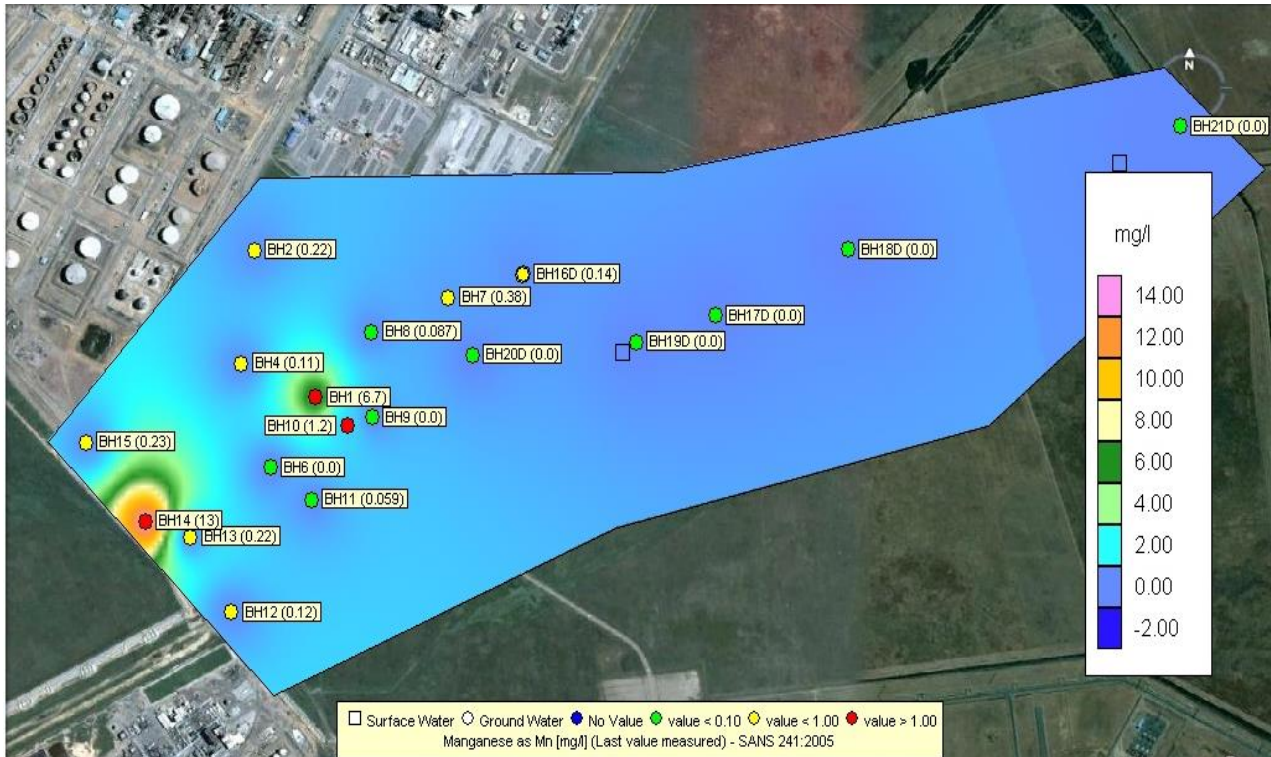


Figure 121: Manganese last measured value deep boreholes minus background water quality contour map SANS 241:2006.

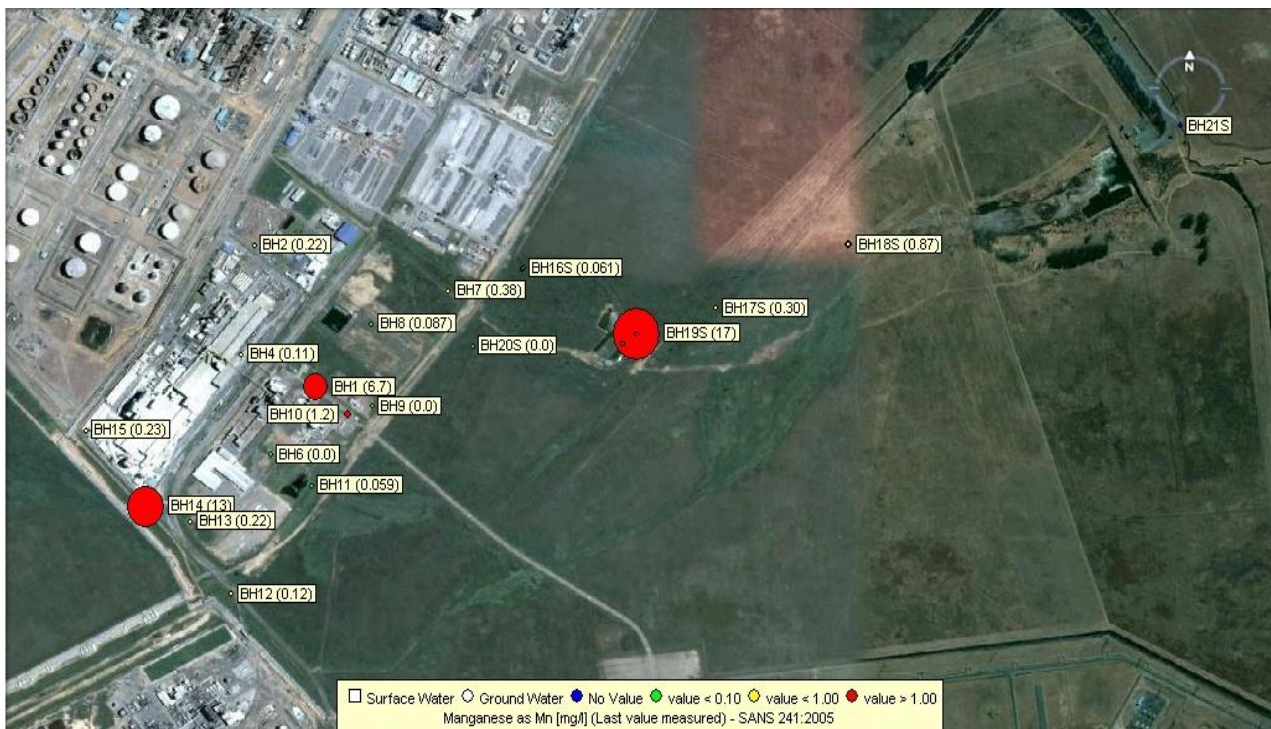


Figure 122: Manganese last measured value shallow boreholes minus background water quality SANS 241:2006.

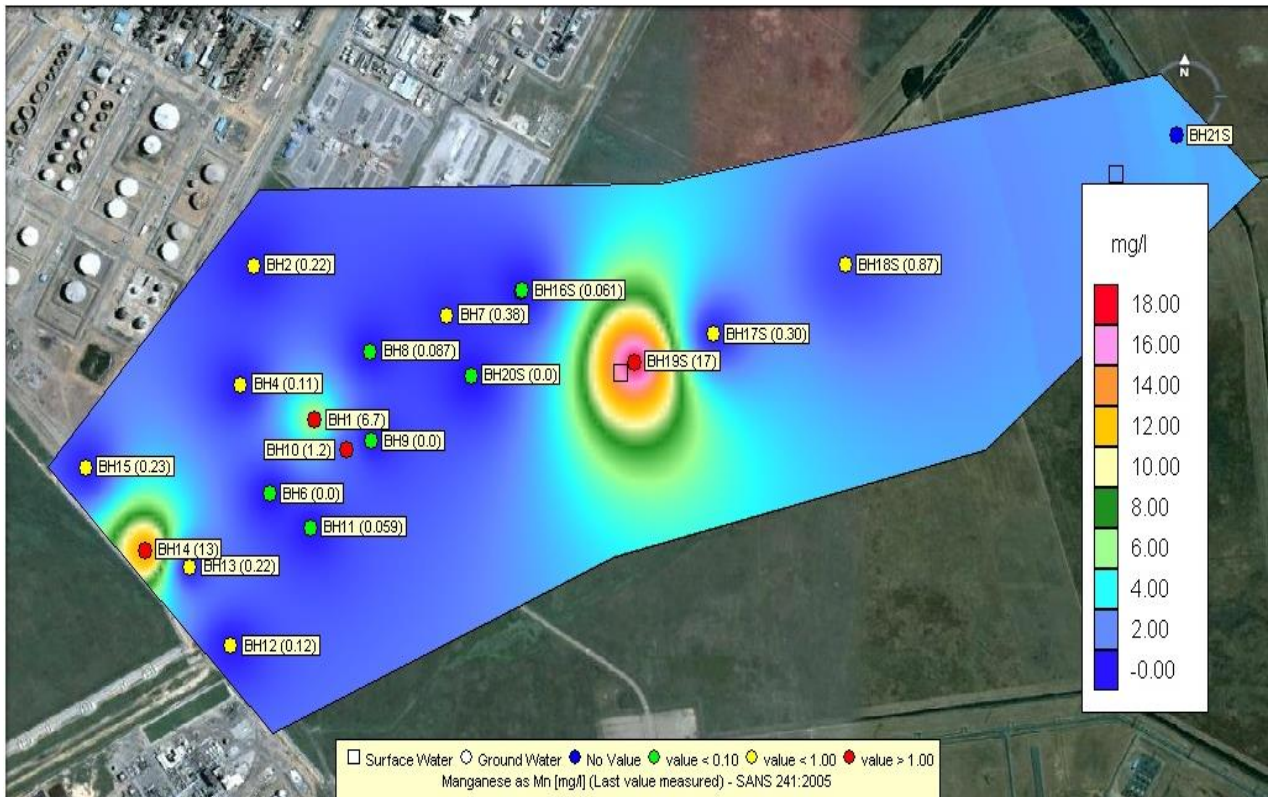


Figure 123: Manganese last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 124: Manganese last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.8 Sodium (Na)

Only BH18S exceeds the Standard Specification for Drinking Water: SANS 241:2006 Class 1. Other boreholes with elevated sodium concentrations are BH10, BH14, BH6 and BH21D. The respective concentrations are reflected in **Figure 125** and **Figure 127**. The respective contour maps are represented in **Figures 126 and 128**. The highest sodium concentrations are observed at BH18S, BH21D, BH 17S and BH10. It is surprising that the concentration of Sodium in BH18S and BH21D is so high if compared with general sodium concentrations measurements on the Omnia Fertiliser Sasolburg site boreholes. It must however be noted that the natural sodium concentration in the shale is high **Table 28**. Furthermore the contaminants associated with INCA bricks and Süd-Chemie Catalysts include sodium and could readily contribute to the elevated concentrations downstream of Henry's dam, refer to **Table 3**. The elevated concentration of sodium is the result of cumulative contamination. The shallow Karoo aquifer is more contaminated than the deep fractured Karoo aquifer as indicated in **Figure 129**.

BH19S indicate that Henry's dam has an impact on the ground water.

Figures 130, 131, 132, 133 and 134 indicate the sodium concentrations after the sodium concentration of the background quality borehole (BH2) has been subtracted.

Point pollution sources for sodium are the product store, raw product store, granulation plants, speciality blending plant, loading bays, stores in the south factory, effluent dam, storm water dam, Henry's dam and Driefontein dam.

Disperse pollution sources can be regarded as dust from the granulators which is windblown off-site and storm water channels.



Figure 125: Sodium last measured value deep boreholes.

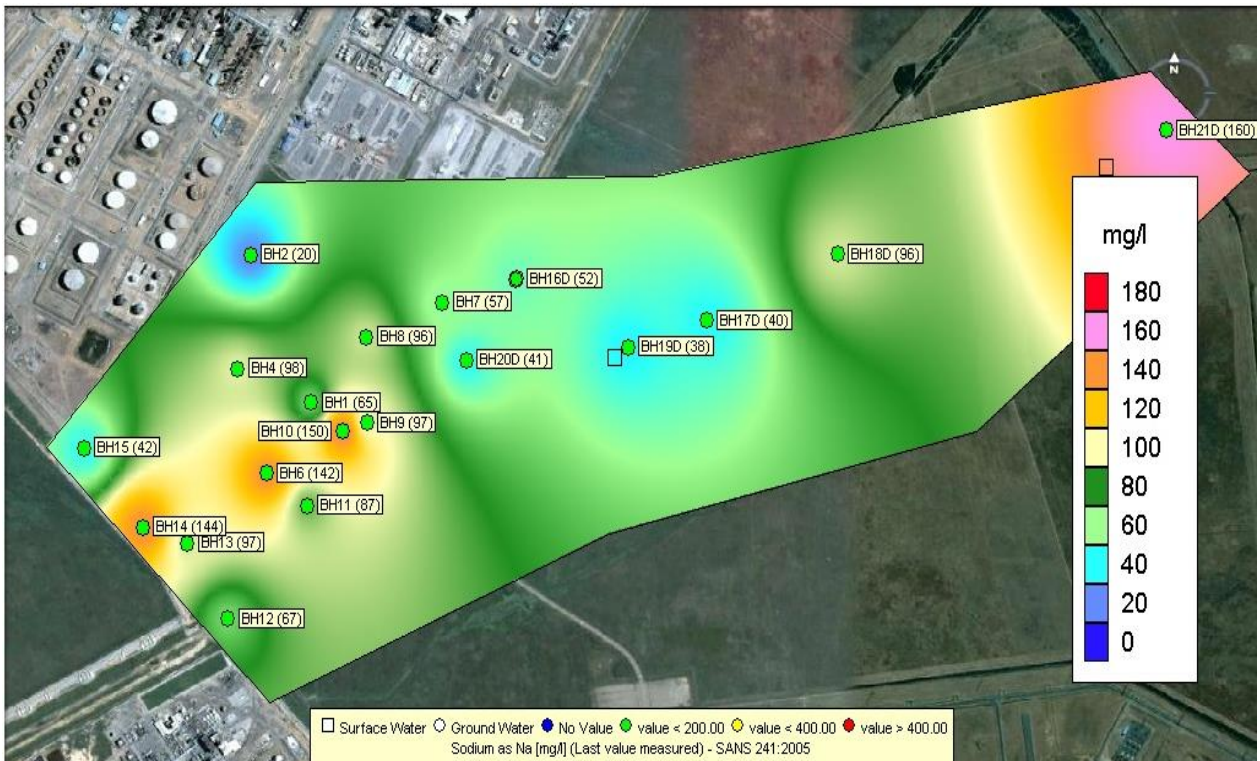


Figure 126: Sodium last measured value deep boreholes contour map.

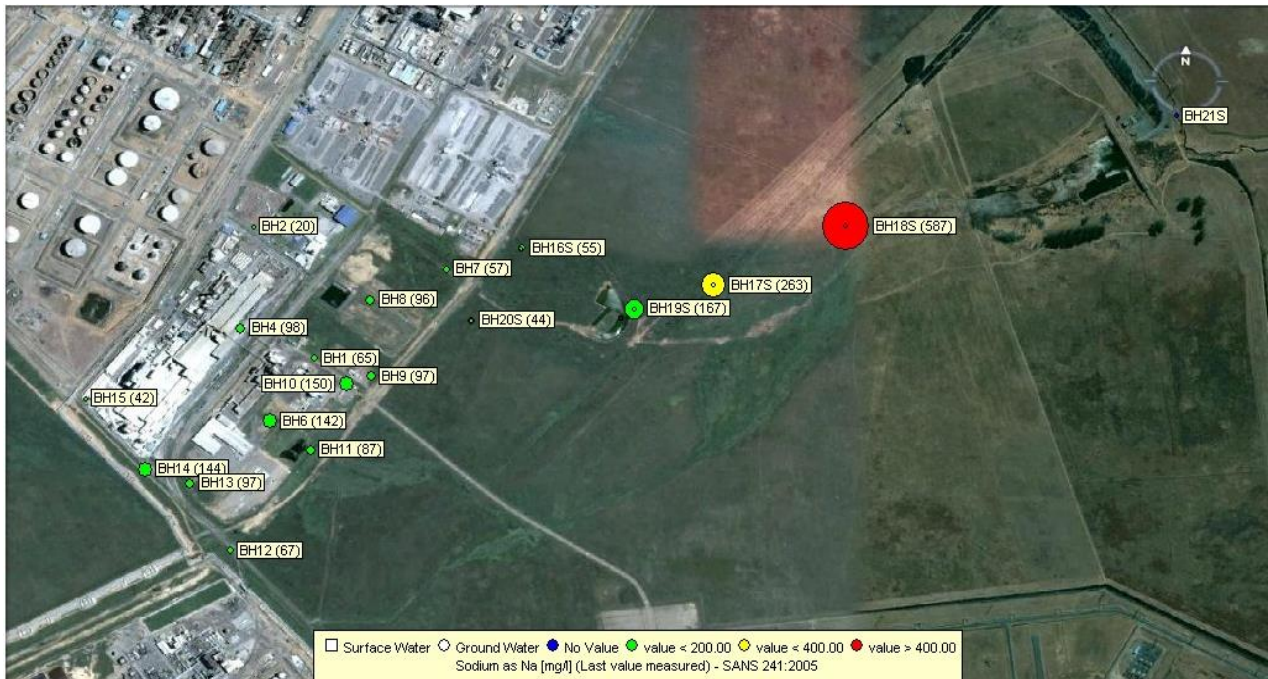


Figure 127: Sodium last measured value shallow boreholes.

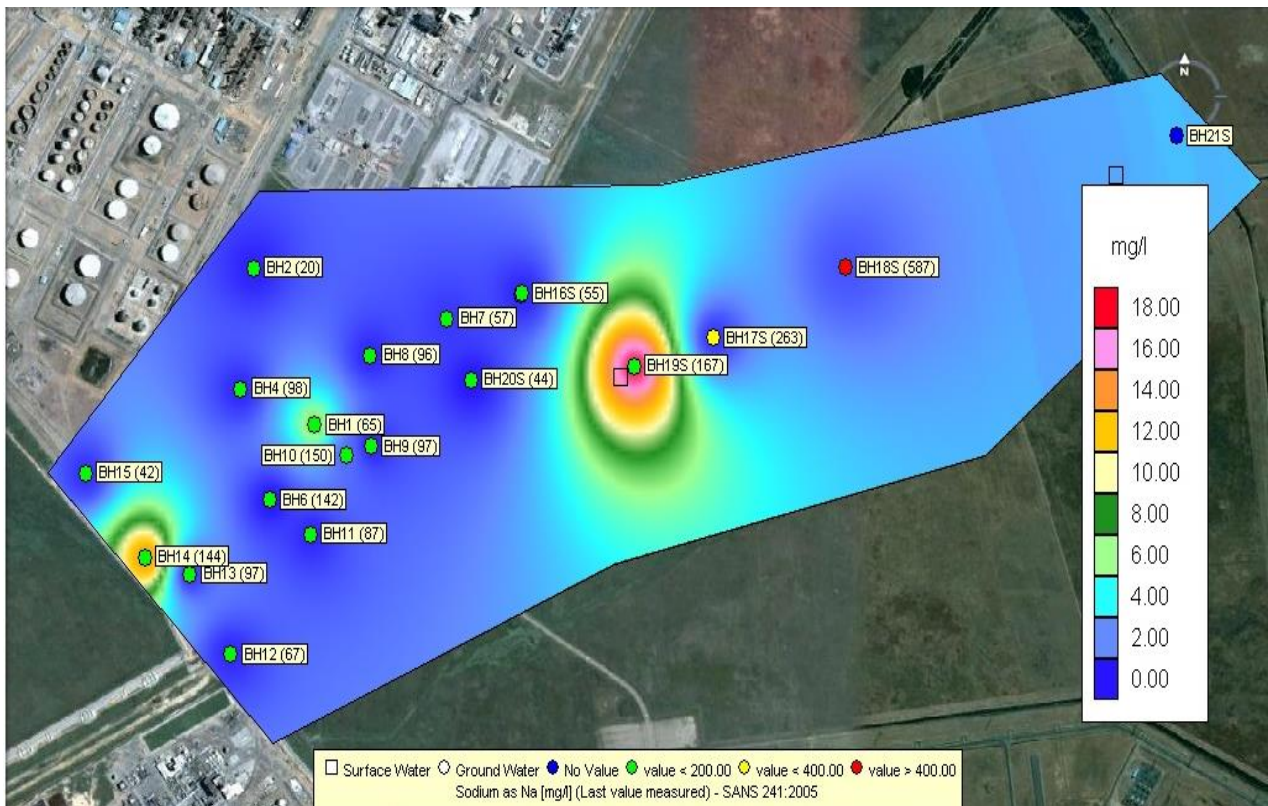


Figure 128: Sodium last measured value shallow boreholes contour map.



Figure 129: Sodium last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 130: Sodium last measured value deep boreholes minus background water quality SANS 241:2006.

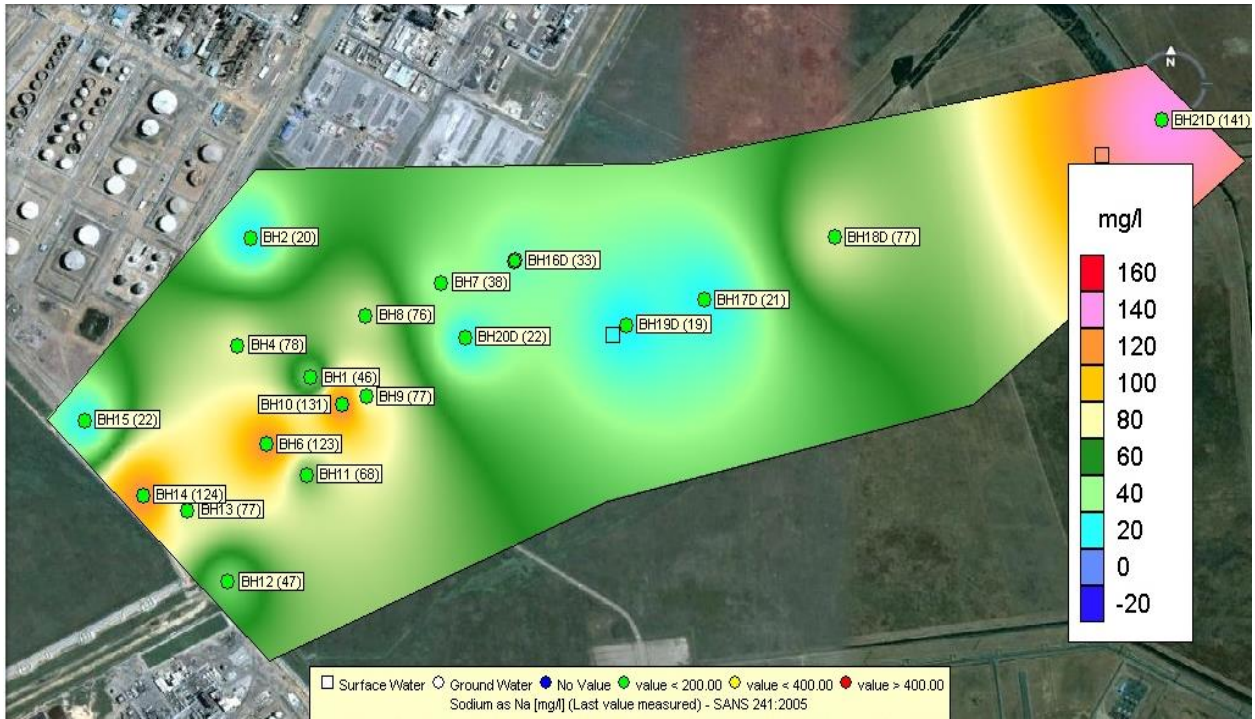


Figure 131: Sodium last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 132: Sodium last measured value shallow boreholes minus background water quality SANS 241:2006.

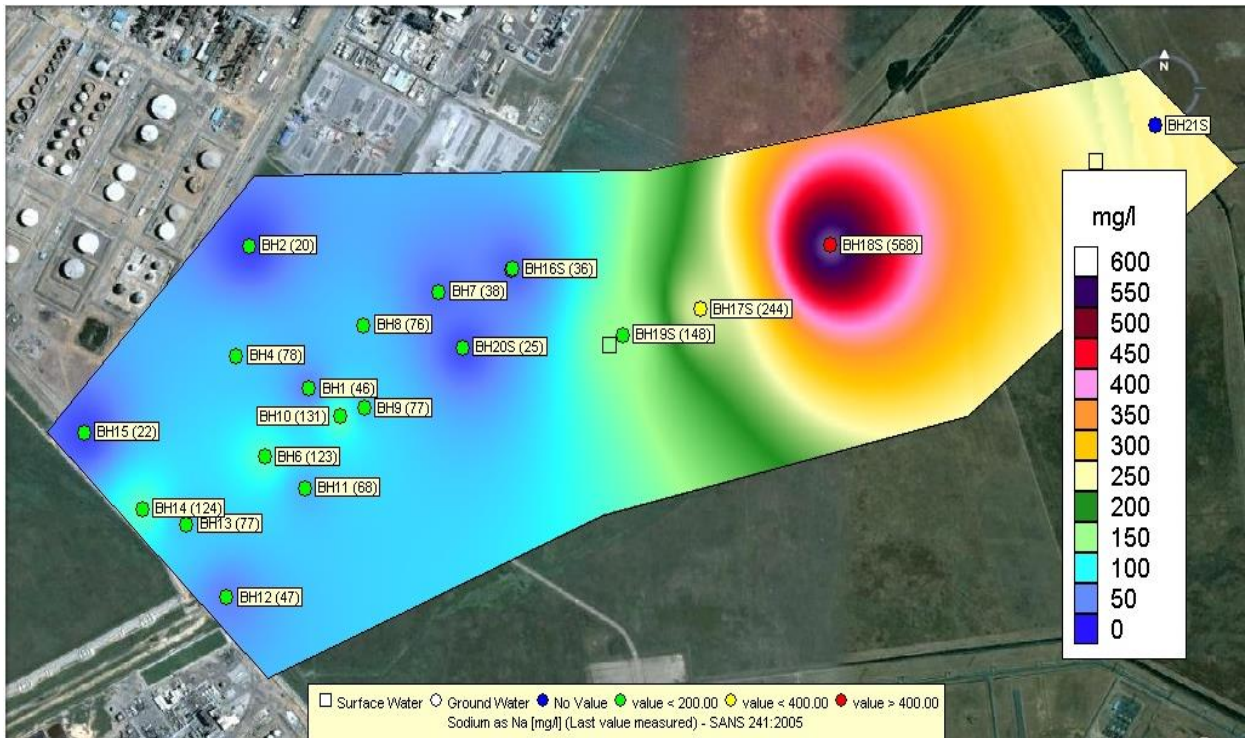


Figure 133: Sodium last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 134: Sodium last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.9 Ammonia (NH₃)

Organic Nitrogen occurs as amines where a NH functional group is attached to an organic molecule.

Inorganic forms can be reduced to ammonia which can occur as NH₄⁺ or NH₃ and oxidised forms Nitrite (NO₂⁻) and Nitrate (NO₃⁻). Nitrate is the more stable form in oxidising environments and is therefore fairly mobile.

Ammonia (NH₃) is more widely toxic, particularly to aquatic organisms, while the ionic form (NH₄⁺) is less toxic.

The Standard Specification for Drinking Water: SANS 241:2006 does not specify standards for ammonia concentration in water. Ammonia is toxic to human and ecological health at very low concentrations. Boreholes with elevated ammonia concentrations are BH14, BH15, BH1, BH19S and BH8. The respective concentrations are reflected in **Figure 135** and **Figure 137**. The respective contour maps are represented in **Figures 136 and 138**. The highest ammonia concentrations are observed at BH14, BH1 and BH19S. BH14 is located close to a point pollution source which is the effluent dam which collects mostly run-off from the granulators (LAN). The high concentration at BH1 is probably due to irrigation water being released from the storm water dam which tends to flow to the slight topographic depression on site. The liquid fertiliser plant might also contribute as point pollution source to the elevated ammonia concentration.

The source of elevated ammonia concentration level at BH2 might be from the cooling towers, which is known to spill and release effluent from the nitric acid plant.

The elevated ammonia concentration at BH19S is due to seepage and overflow from Henry's dam which is a point pollution source.

Figure 139 indicates that only two shallow boreholes are contaminated with ammonia (BH19S and BH18S).

BH2 is in this instance again impacted by ammonia due to its location to the nitric acid cooling towers and as such cannot be considered as true background water quality. **Figures 140, 141, 142, 143 and 144** indicate the ammonia concentrations after the ammonia concentration of the background quality borehole (BH2) has been subtracted.

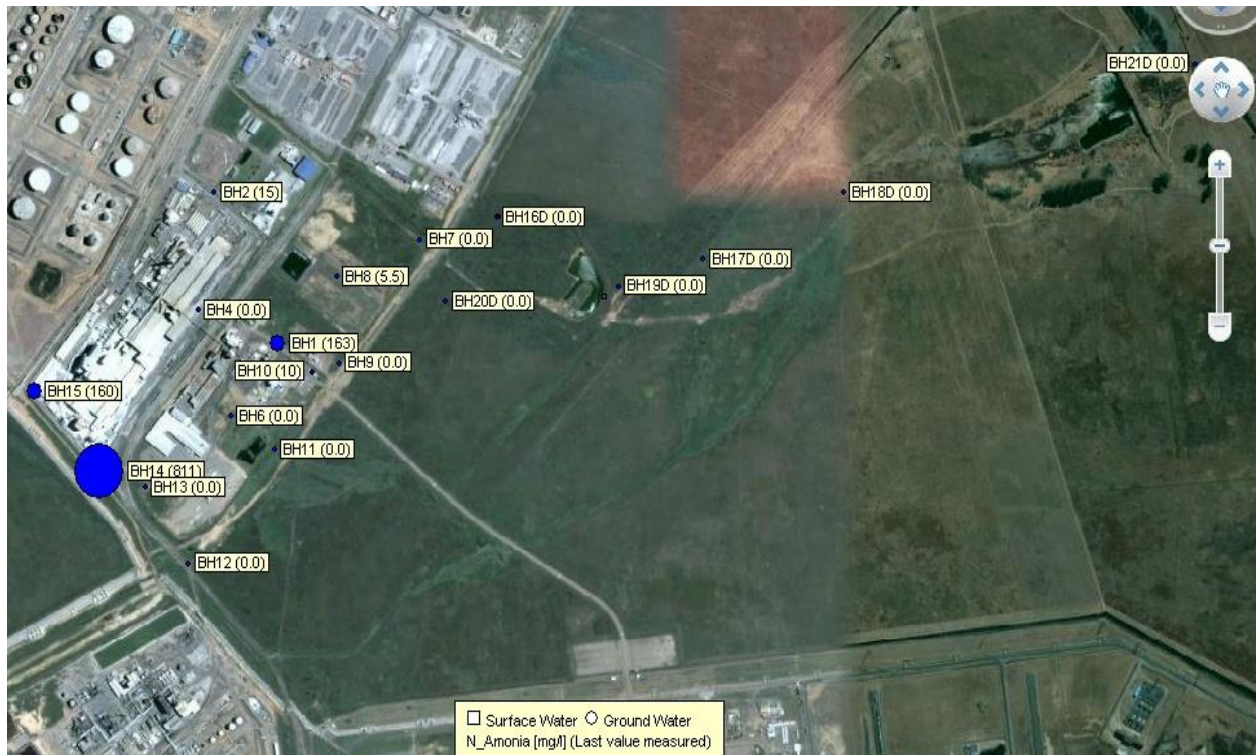


Figure 135: Ammonia last measured value deep boreholes.

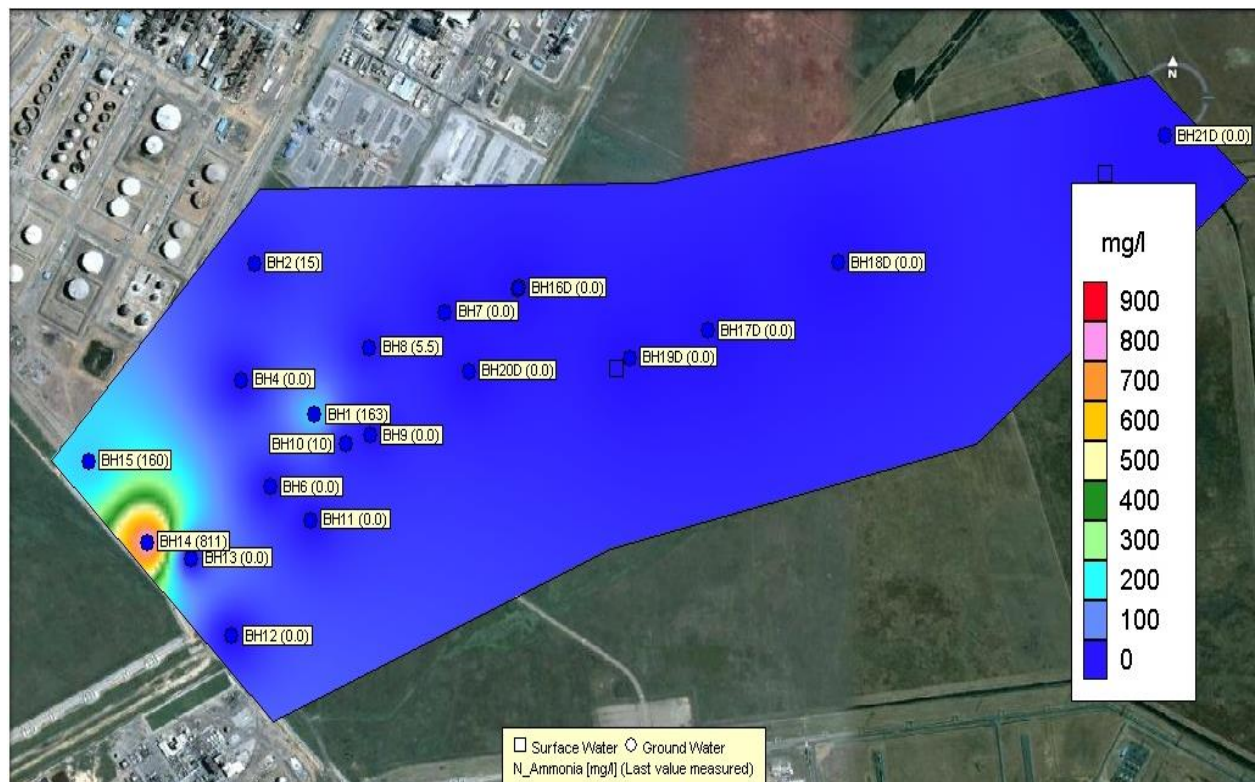


Figure 136: Ammonia last measured value deep boreholes contour map.



Figure 137: Ammonia last measured shallow boreholes.

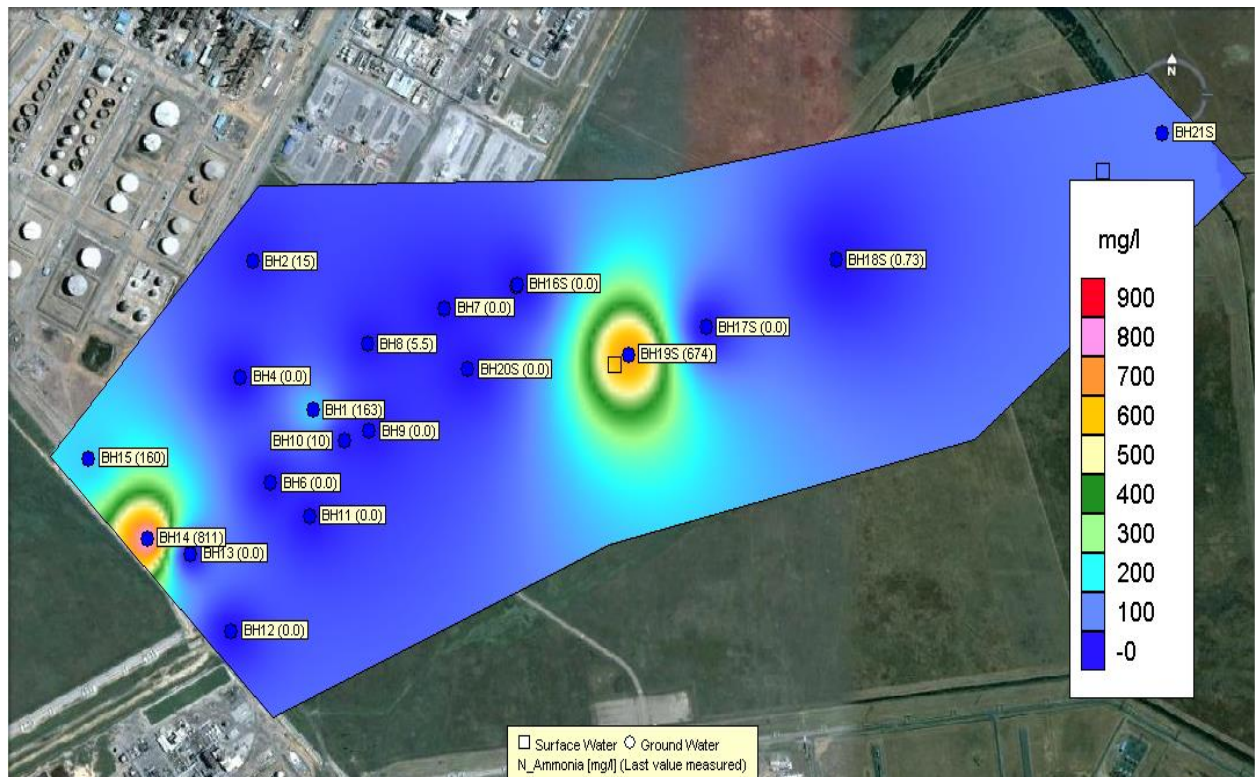


Figure 138: Ammonia last measured values shallow boreholes contour map.



Figure 139: Ammonia last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 140: Ammonia last measured value deep boreholes minus background water quality SANS 241:2006.

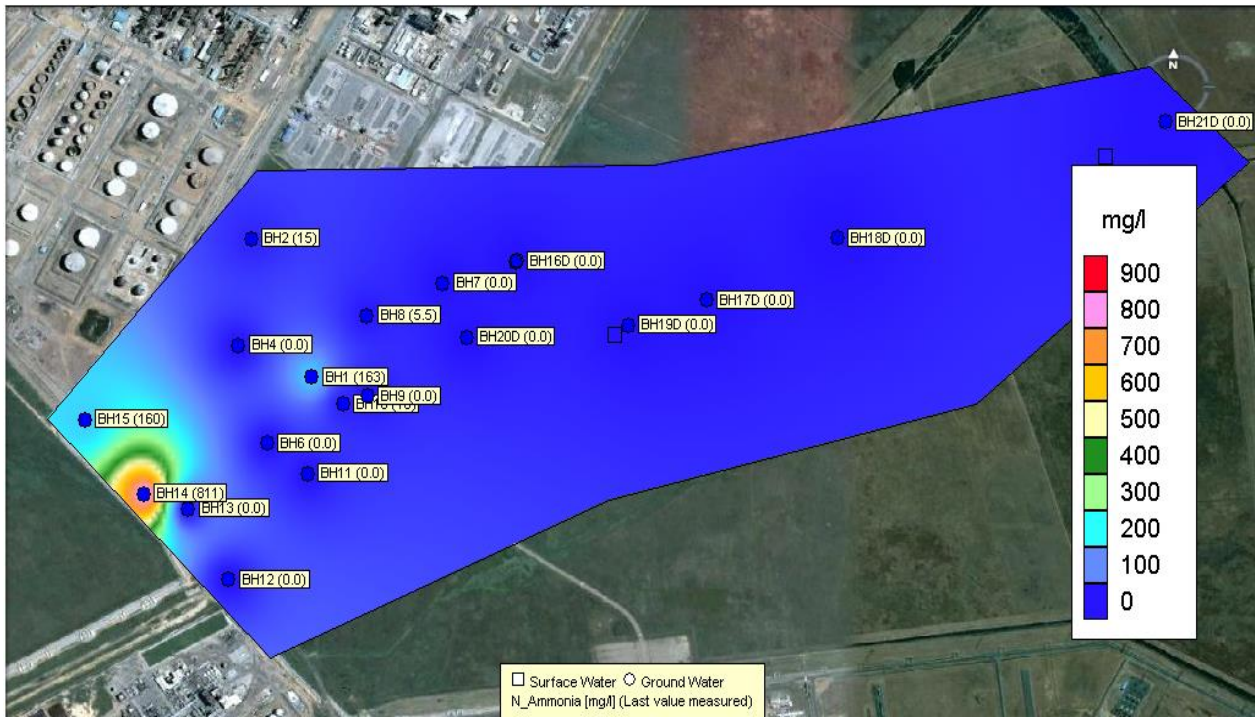


Figure 141: Ammonia last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 142: Ammonia last measured value shallow boreholes minus background water quality SANS 241:2006.

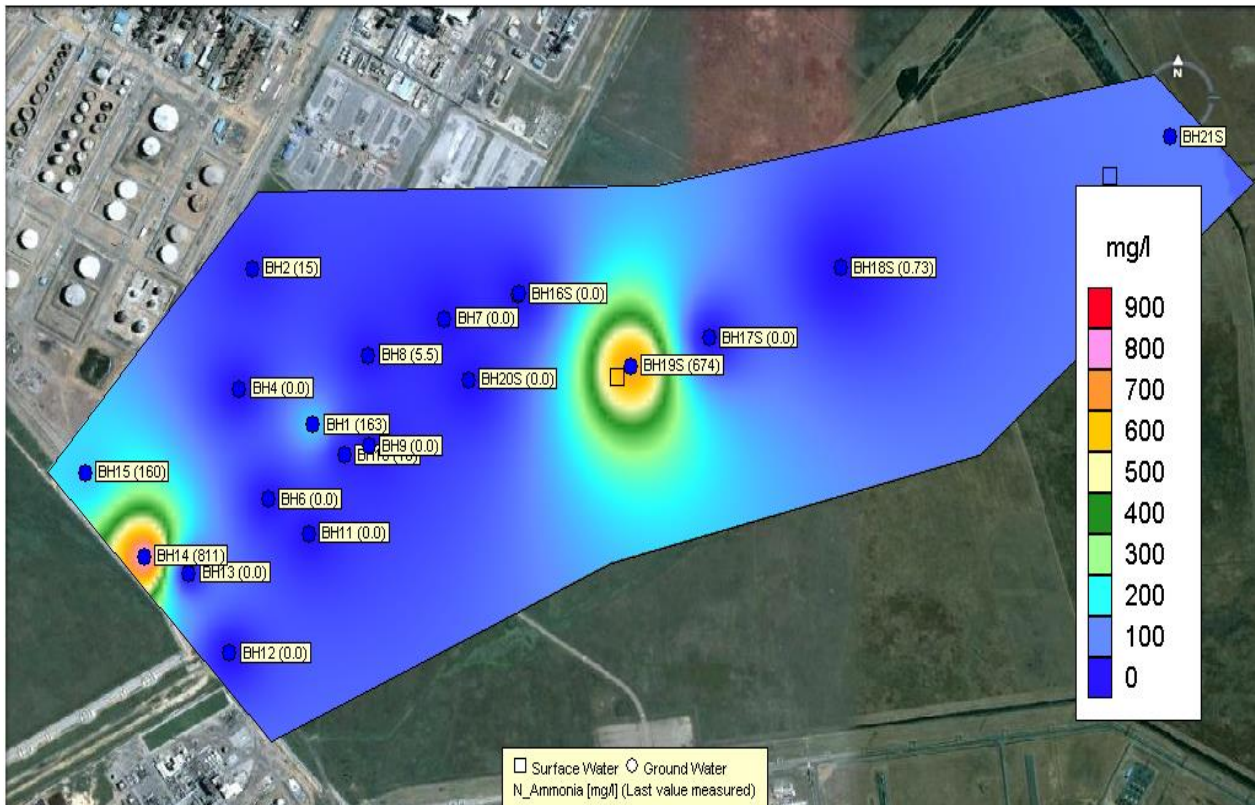


Figure 143: Ammonia last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 144: Ammonia last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.10 Nitrite (NO₂)

Ammonia (NH₃) is oxidised to Nitrite (NO₂). Nitrite is usually short lived as it oxidises to nitrate (NO₃).

The only borehole with elevated levels of nitrite is BH15. It is indicative that there might have been a recent ammonia related spillage in the area. The concentrations of ammonia and sulphate correlates well for BH15. This might be indicative that the spillage (impact source) is ammonium sulphate (NH₄)₂SO₄.

The respective concentrations are reflected in **Figure 145** and **Figure 147**. The respective contour maps are represented in **Figures 146 and 148**.

Figure 149 indicate that only the shallow Karoo aquifer is affected by nitrites.

Figures 150, 151, 152, 153 and 154 indicate the nitrite concentrations after the nitrite concentration of the background quality borehole (BH2) has been subtracted.



Figure 147: Nitrite last measured value shallow boreholes.

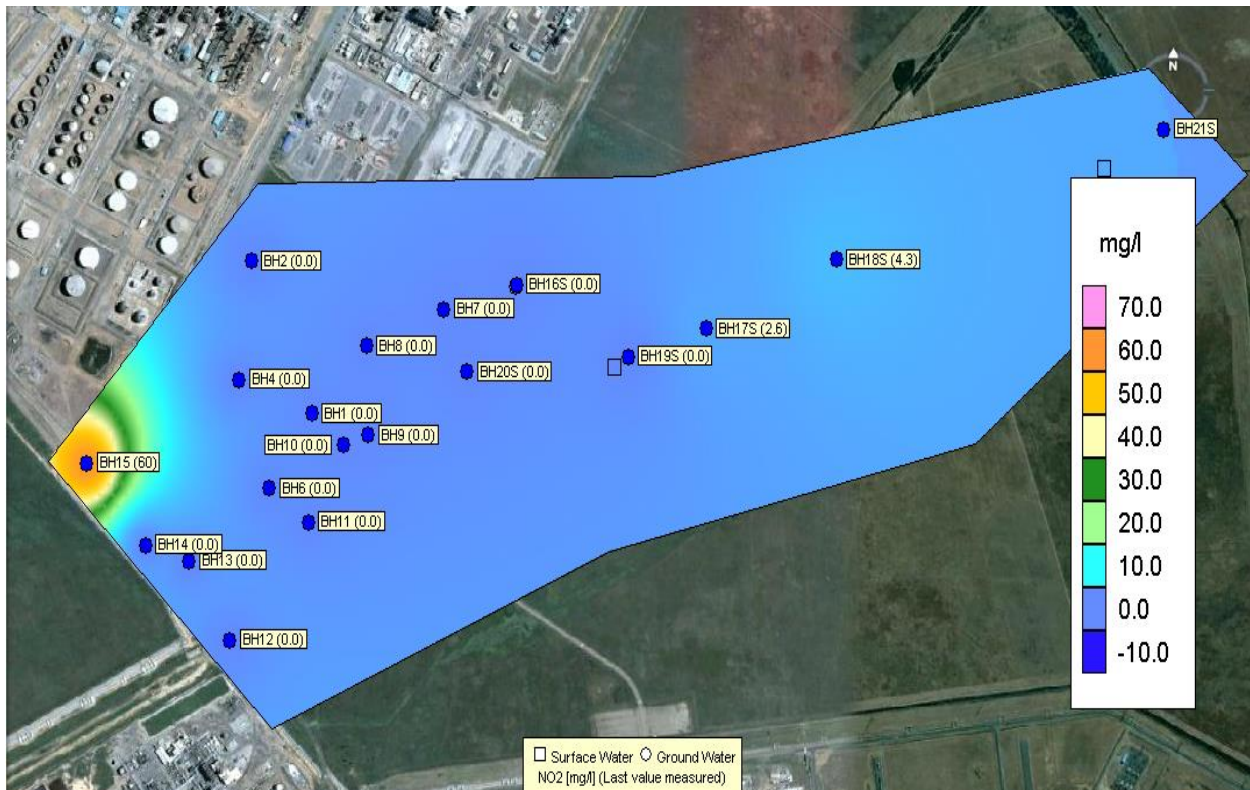


Figure 148: Nitrite last measured value shallow boreholes contour map.



Figure 149: Nitrite last measured value shallow and deep boreholes comparison SANS 241:2006.

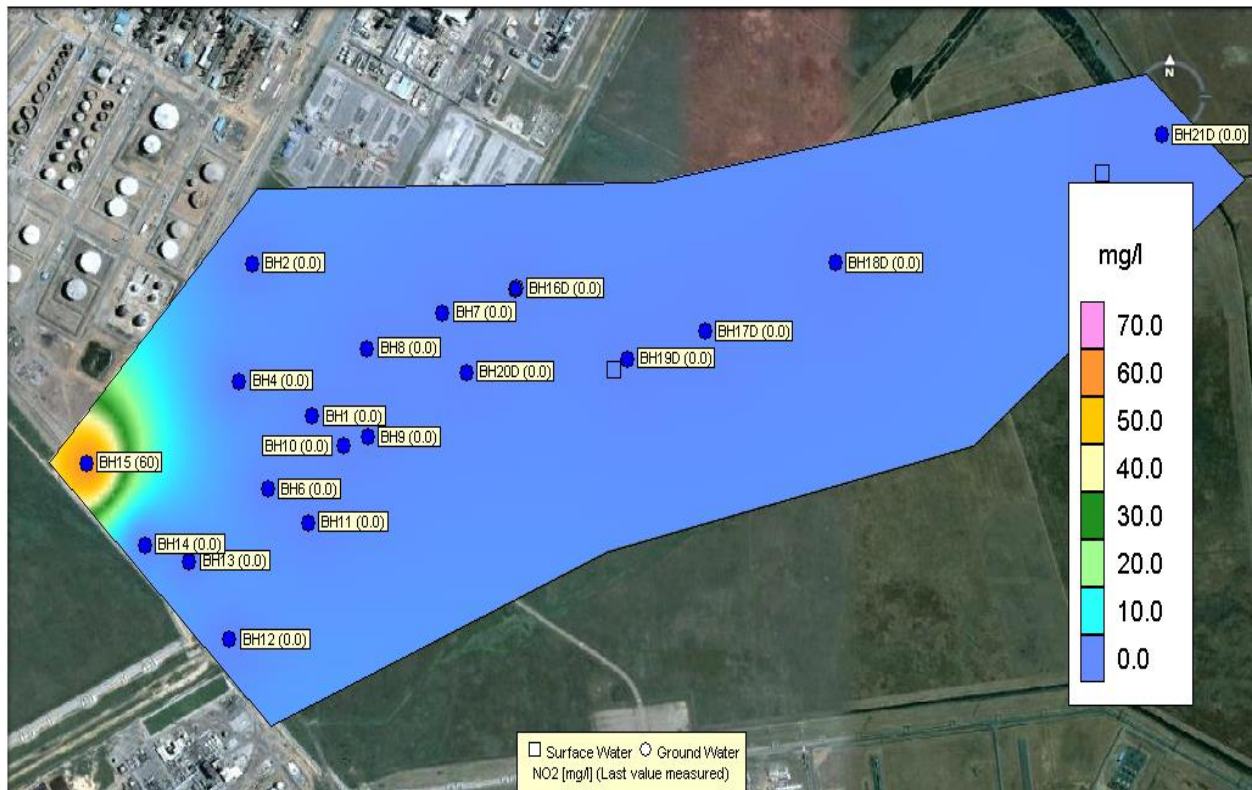


Figure 150: Nitrite last measured value deep boreholes minus background water quality SANS 241:2006.



Figure 151: Nitrite last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 152: Nitrite last measured value shallow boreholes minus background water quality contour map SANS 241:2006.

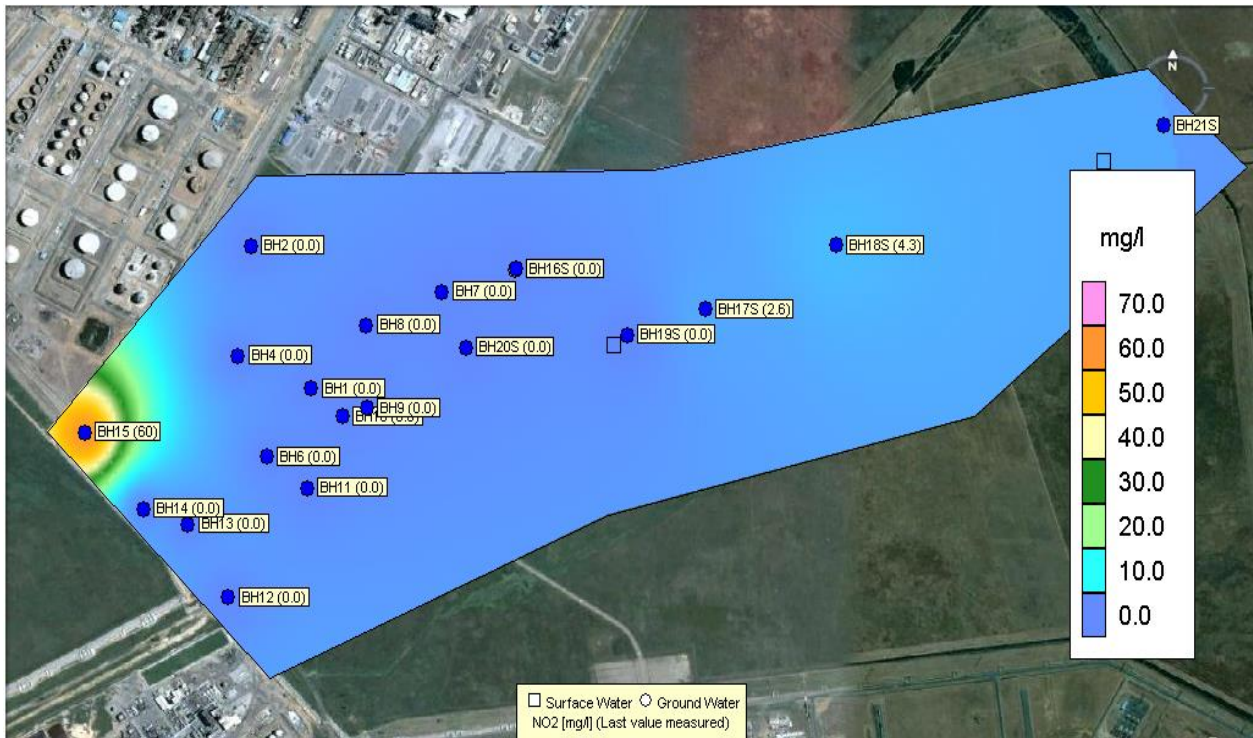


Figure 153: Nitrite last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 154: Nitrite last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.11 Nitrate (NO₃)

All boreholes have elevated levels of nitrate and all exceed the maximum standards for drinking water. The concentration of nitrate is exceptionally high all around site and is indicative of historic and current operational practises on site which revolves around nitrates.

BH10 has the highest nitrate concentration and is severely contaminated with a nitrate concentration exceeding 25,000mg/l.

The area surrounding BH10 also has high calcium concentrations (e.g. BH1 and BH9) indicating a highly impacted area where a primary source of nitrate is not readily expected. Dust from the granulators and other nitrate spillages on the Northern Factory is transported during rainfall events to the storm water dam from which water has been released to irrigate the employee vegetable garden. This could have caused artificial recharge to the aquifer system.

The area around BH9 and BH10 form a slight topographical depression against the normal topographic decline towards Henry's dam. Based on the historic design of the employee vegetable garden and the subsequent release of water from the Storm water dam for irrigation purposes, the potential presence of a dolerite dyke at BH 20 (Jones and Wagener, 2002) and the fact that BH9 and BH 10 is located close to the storm water accumulation point for the South Factory makes this specific area highly vulnerable for contaminated surface water run-off. Recharge in this area from surface water will also be higher due to tendency of ponding. As indicated previously in this document there is a 98% relationship between topography and static water levels which might also that ground water might flow towards this slight depression.

The liquid fertiliser plant, granulation complex, effluent dam, raw material store, product store, nitric acid complex, cooling towers, bagging and final product store, railway line area, stores and loading bays, speciality blending plant, ammonia storage, Storm water dam, Henry's dam and Driefontein dam can all be identified as point pollution sources contributing to the high nitrate concentrations.

Nitrate concentrations downstream of Henry's dam in the shallow and deep aquifer are also exceeding maximum levels. It is clear in this instance the shallow Karoo aquifer is impacted heavier by the nitrate pollution than the deep fractured Karoo aquifer. Henry's dam in this instance serves as the point pollution source.

Nitrate is the contaminant with the largest footprint of the Omnia Fertiliser factory and has migrated off-site.

The respective concentrations are reflected in **Figure 155** and **Figure 157**. The respective contour maps are represented in **Figures 156 and 158**.

Figure 159 indicate that both the shallow Karoo and the deep fractured Karoo aquifer has been impacted by nitrates. The shallow Karoo aquifer has been severely impacted by nitrates.

BH2 has been impacted by nitrates although in a lesser extent than any of the other boreholes. **Figures 160, 161, 162, 163 and 164** indicate the nitrate concentrations after the nitrate concentration of the background quality borehole (BH2) has been subtracted.



Figure 155: Nitrate last measured value deep boreholes.

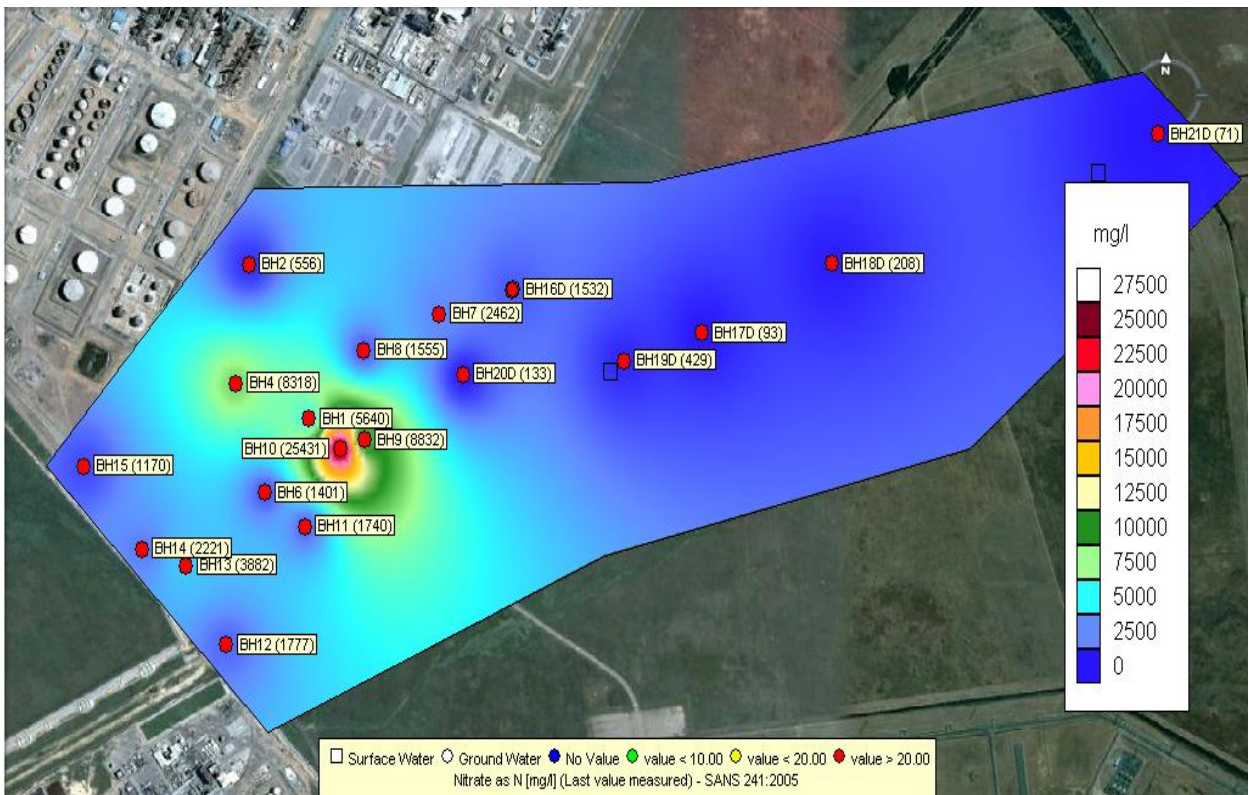


Figure 156: Nitrate last measured value deep boreholes contour map.



Figure 157: Nitrate last measured value shallow boreholes.

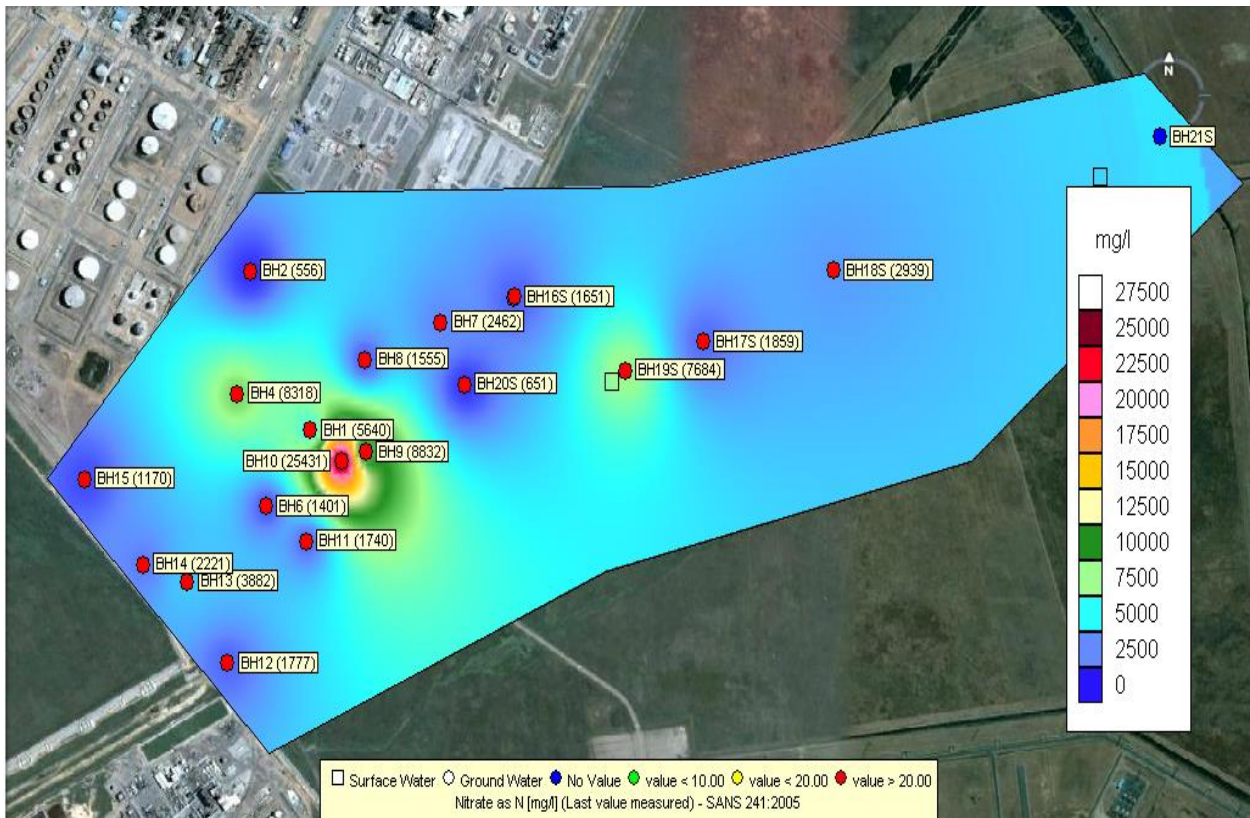


Figure 158: Nitrate last measured values shallow boreholes contour map.



Figure 159: Nitrate last measured value shallow and deep boreholes comparison SANS 241:2006.

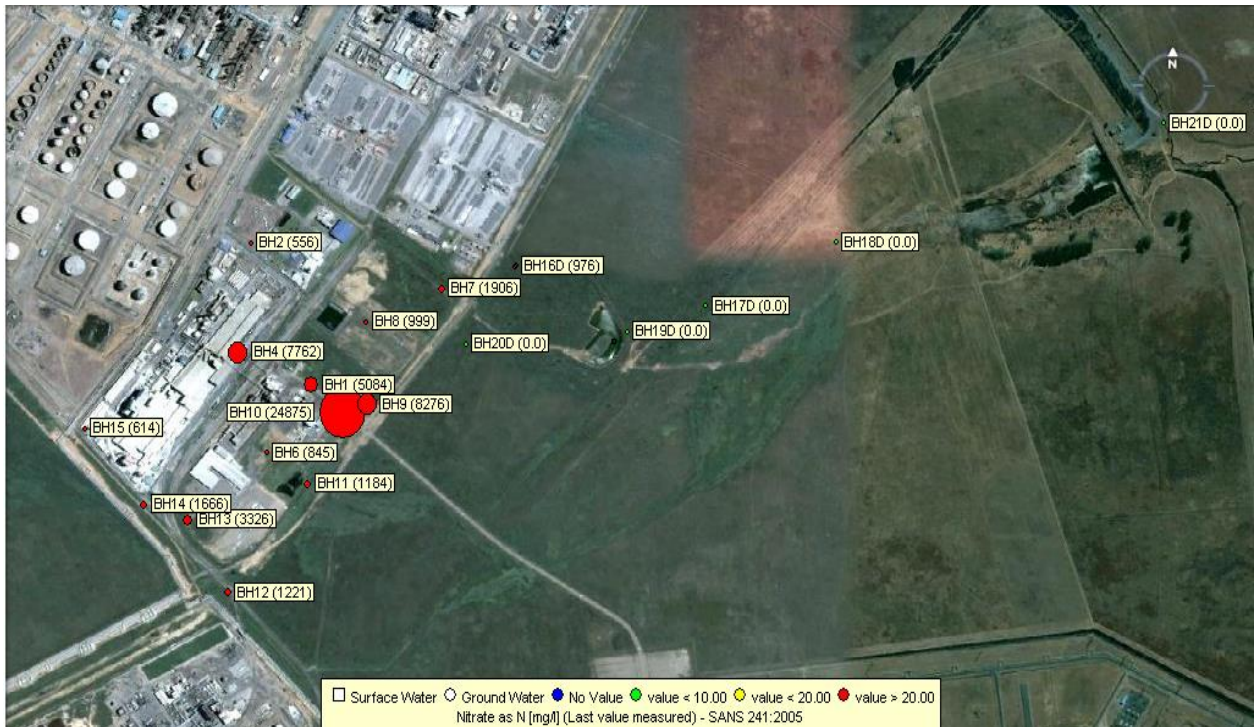


Figure 160: Nitrate last measured value deep boreholes minus background water quality SANS 241:2006.

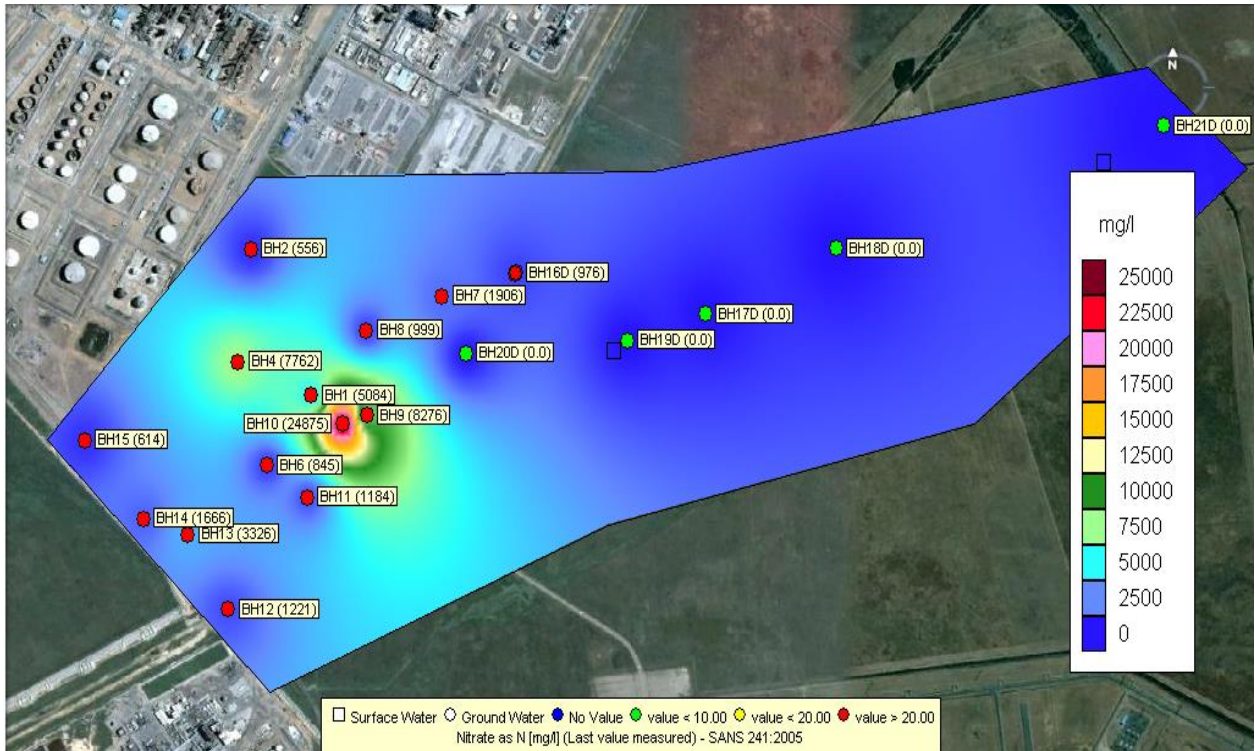


Figure 161: Nitrate last measured value deep boreholes minus background water quality contour map SANS 241:2006.

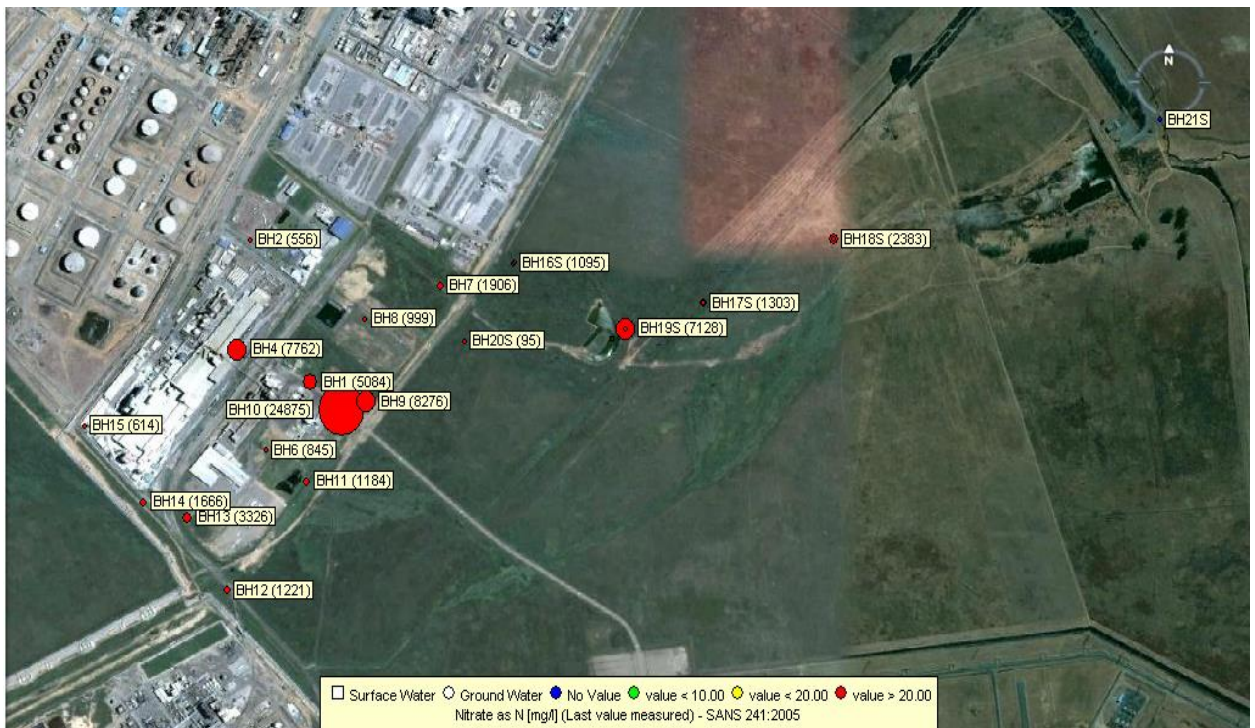


Figure 162: Nitrate last measured value shallow boreholes minus background water quality SANS 241:2006.

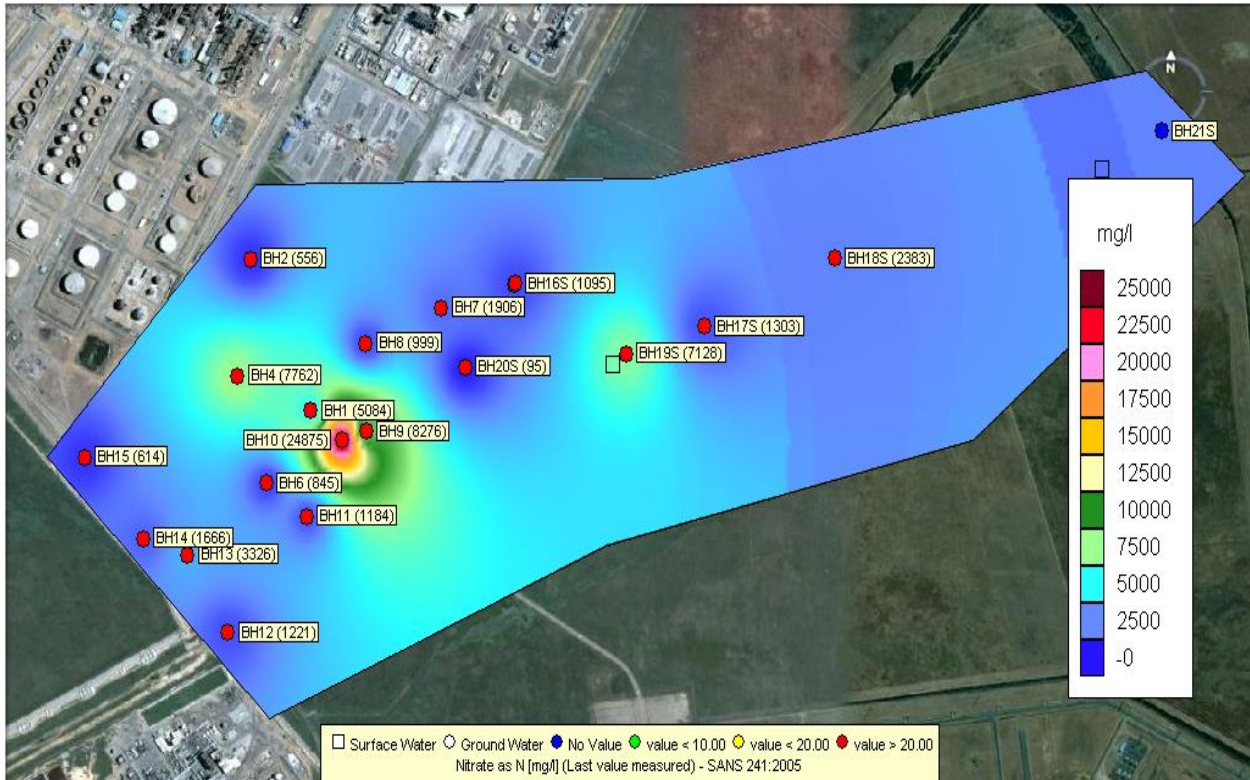


Figure 163: Nitrate last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 164: Nitrate last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.12 Phosphate (PO₄)

Phosphate levels are elevated mainly in BH16S. The contamination observed here might be from INCA Bricks as it is located close to a storm water outlet of INCA Bricks (See **Table 3**).

Phosphates have the tendency to adsorb to soil particles and hence are not readily found in ground water.

The respective concentrations are reflected in **Figure 165** and **Figure 167**. The respective contour maps are represented in **Figures 166 and 168**.

Figure 169 indicate the comparison between the phosphate values for the shallow Karoo aquifer and the deep fractured Karoo aquifer.

BH2 has not been impacted by phosphates. **Figures 170, 171, 172, 173 and 174** indicate the phosphate concentrations after the phosphate concentration of the background quality borehole (BH2) has been subtracted. Because the phosphate concentration in BH2 was not detected the figures are duplicates.



Figure 165: Phosphate last measured deep boreholes.

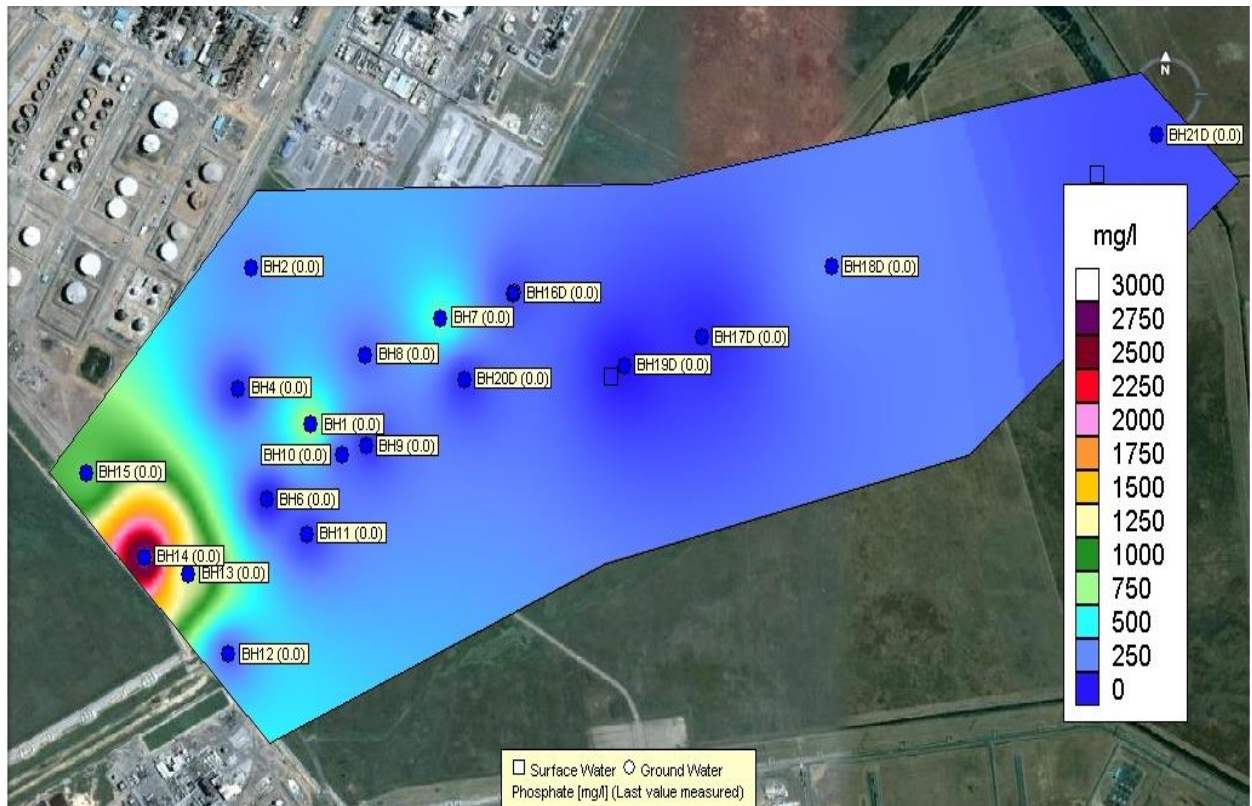


Figure 166: Phosphate last measured value deep boreholes contour map.



Figure 167: Phosphate last measured value shallow boreholes.

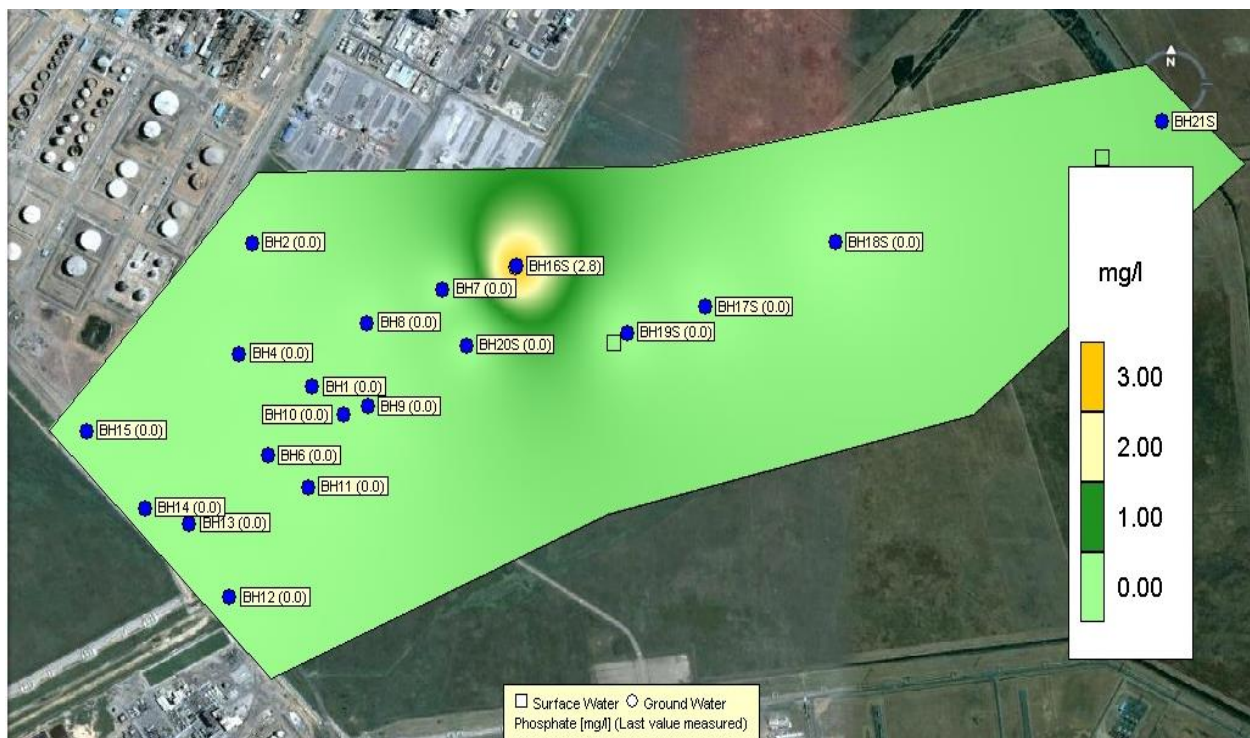


Figure 168: Phosphate last measured value shallow boreholes contour map.



Figure 169: Phosphate last measured value shallow and deep boreholes comparison SANS 241:2006.

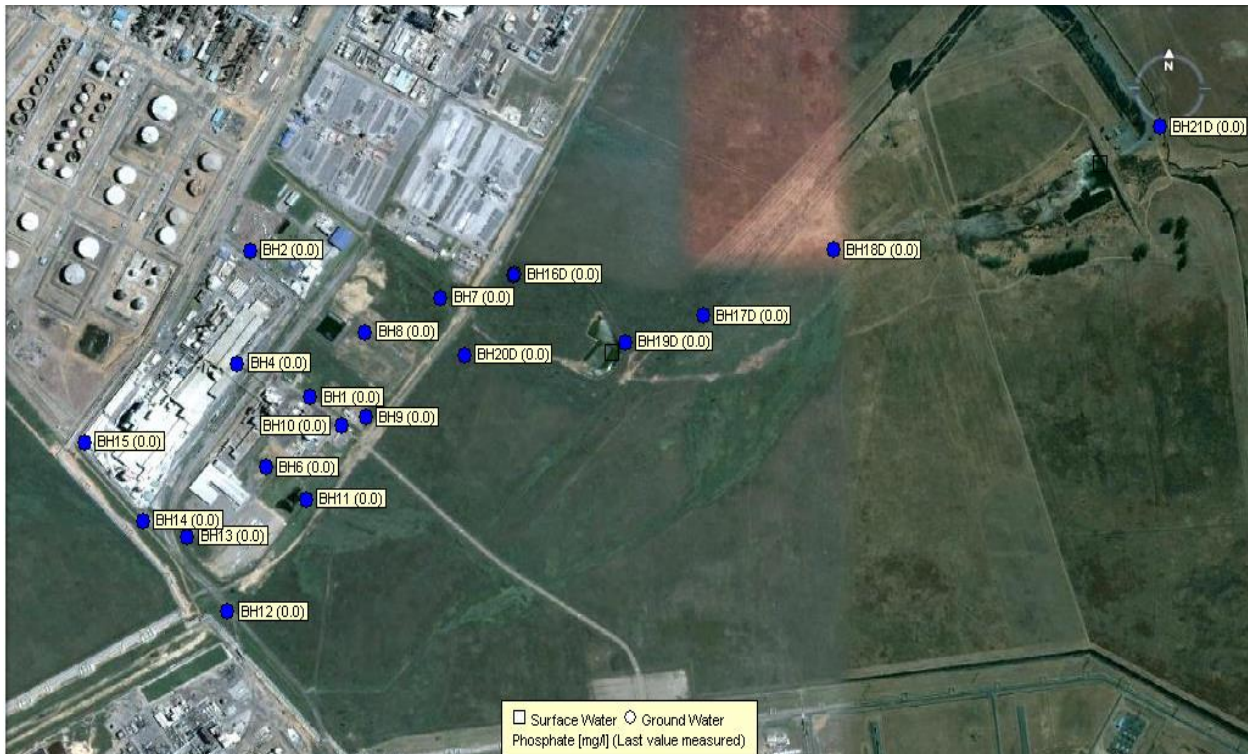


Figure 170: Phosphate last measured value deep boreholes minus background water quality SANS 241:2006.

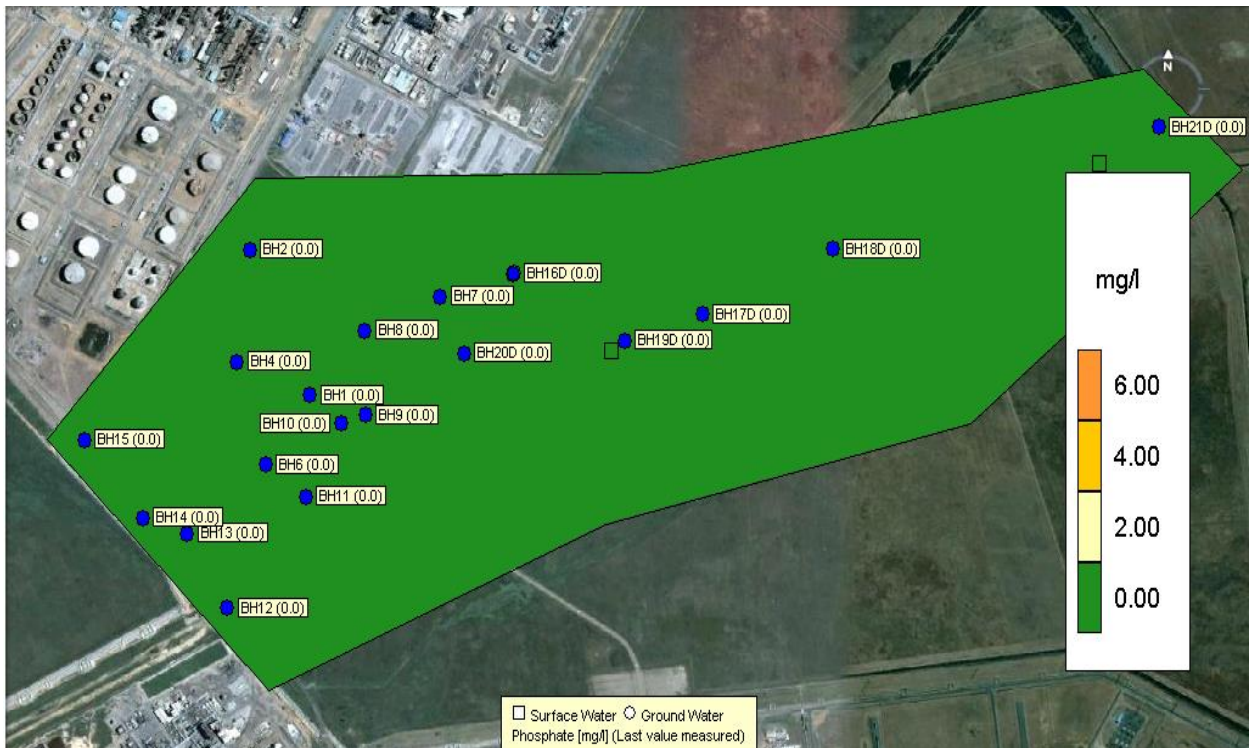


Figure 171: Phosphate last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 172: Phosphate last measured value shallow boreholes minus background water quality SANS 241:2006.

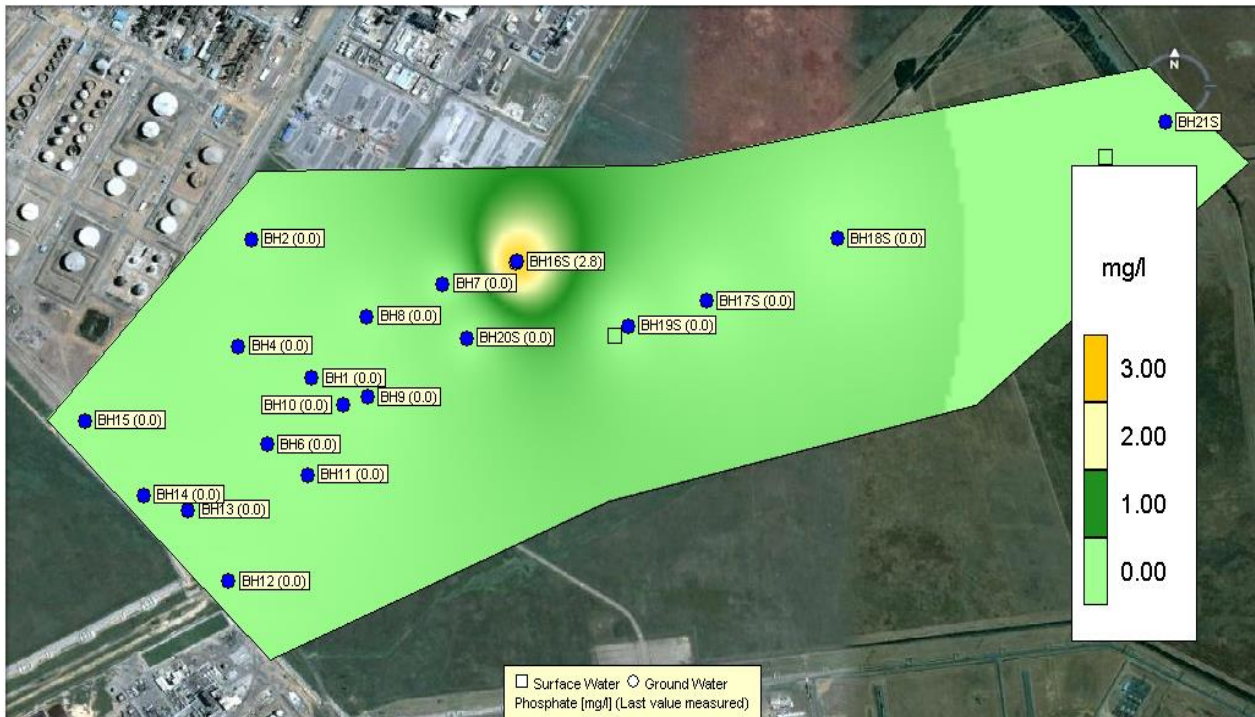


Figure 173: Phosphate last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 174: Phosphate last measured value shallow and deep boreholes minus background water quality SANS 241:2006.

6.3.13 Sulphates (SO₄)

Sulphate levels are elevated in BH14, BH13, BH15, BH1, BH7, BH19S and BH18S.

The highest sulphate concentrations are observed in BH 14 and BH13. The point pollution source is the effluent dam located in the South Eastern corner of the North Factory.

There is a good correlation between ammonium and sulphate concentration in the monitoring network which indicate that the source might be ammonium sulphate (NH₄)₂SO₄.

It should be noted that naturally occurring high sulphate levels are found in shale, which has been readily intersected particularly in the deep fractured Karoo aquifer.

The high concentration of Sulphates found in BH19S is from Henry's dam.

The respective concentrations are reflected in **Figure 175** and **Figure 177**. The respective contour maps are represented in **Figures 176 and 178**.

Figure 179 indicate the comparative sulphate concentrations between the shallow Karoo and the deep fractured Karoo aquifer. In general the shallow Karoo aquifer is more impacted than the deep fractured Karoo aquifer except again for BH16D (but this might be natural occurring sulphate levels as previously indicated).

It is not certain whether BH2 has been impacted by sulphates or whether the sulphate levels are naturally occurring. **Figures 180, 181, 182, 183 and 184** indicate the sulphate concentrations after the sulphate concentration of the background quality borehole (BH2) has been subtracted.



Figure 175: Sulphate last measured value deep boreholes.

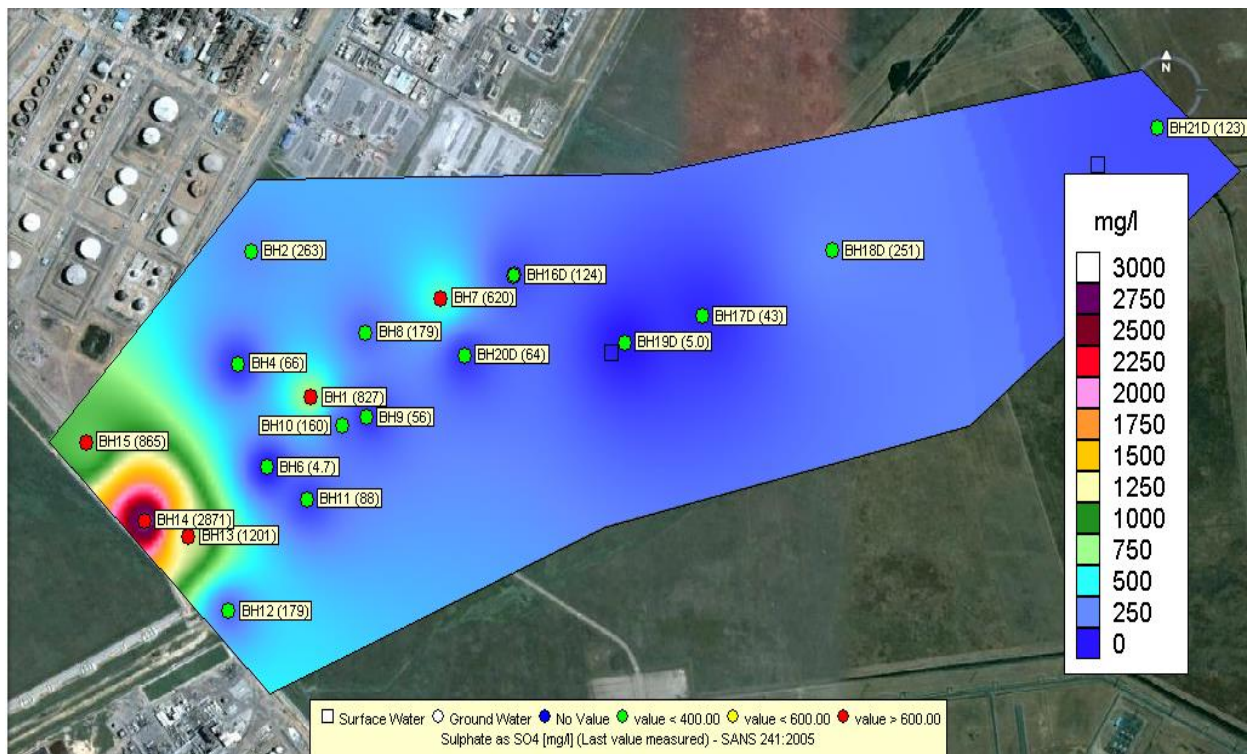


Figure 176: Sulphate last measured value deep boreholes contour map.



Figure 177: Sulphate last measured value shallow boreholes.

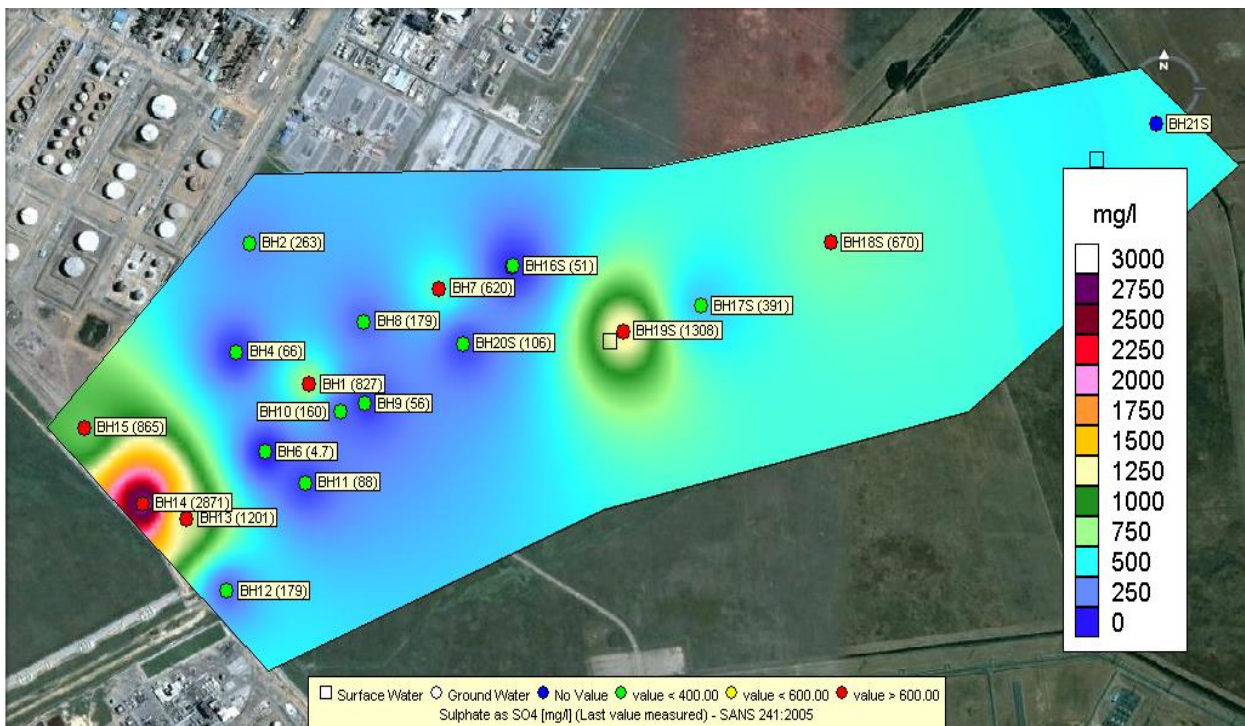


Figure 178: Sulphate last measured value shallow boreholes contour map.



Figure 179: Sulphate last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 180: Sulphate last measured value deep boreholes minus background water quality SANS 241:2006.

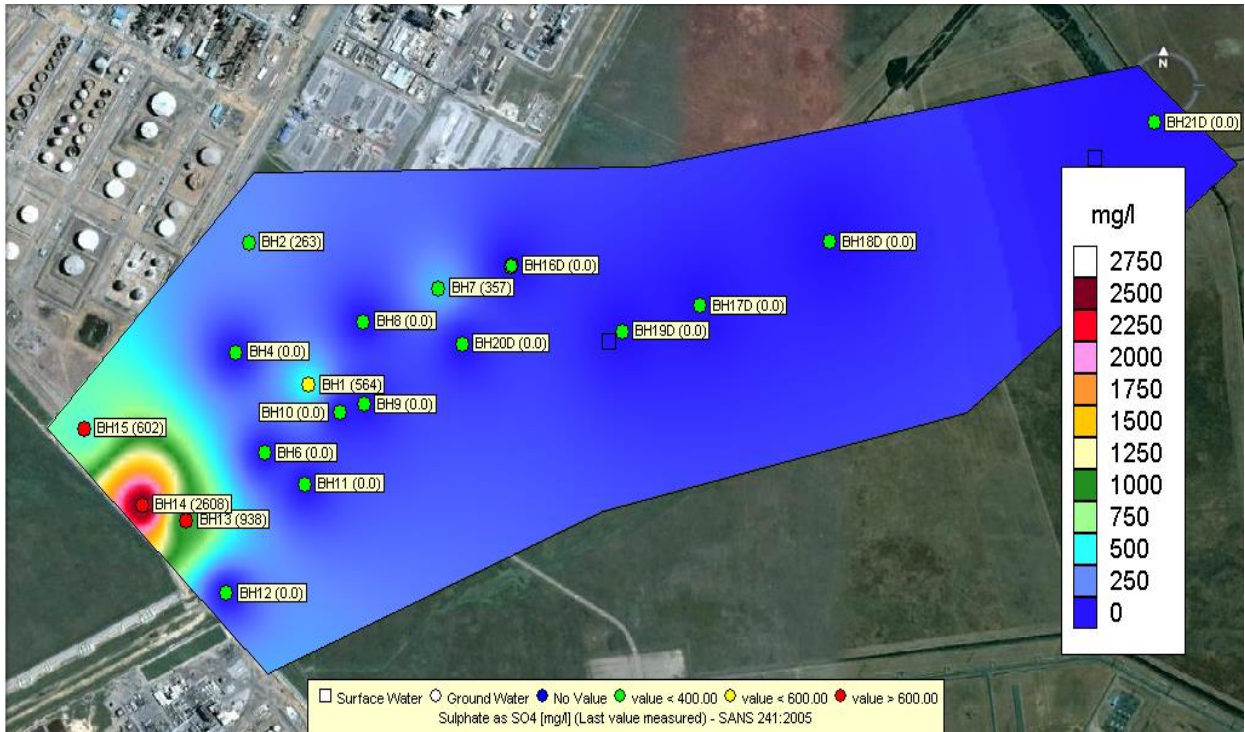


Figure 181: Sulphate last measured value deep boreholes minus background water quality contour map SANS 241:2006.

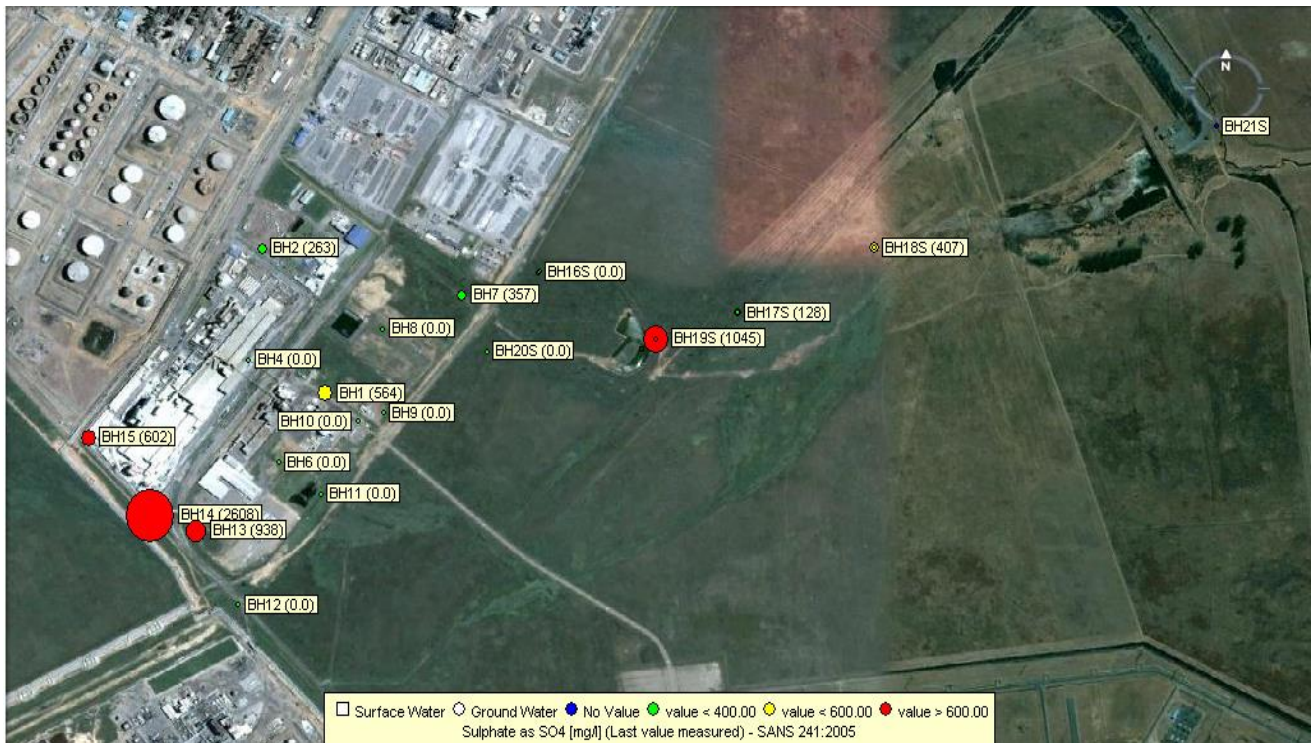


Figure 182: Sulphate last measured value shallow boreholes minus background water quality SANS 241:2006.

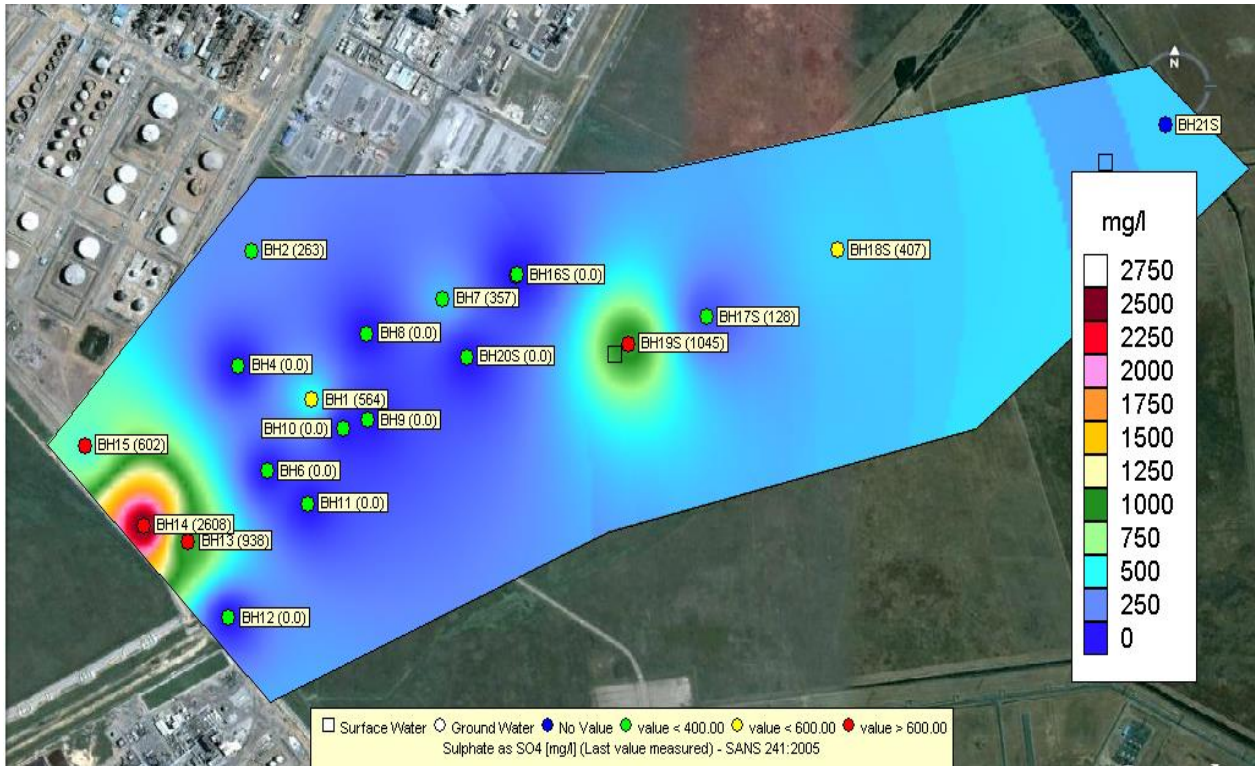


Figure 183: Sulphate last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 184: Sulphates last measured value shallow and deep boreholes minus background water quality contour map SANS 241:2006.

6.3.14 Total Dissolved Solids (TDS)

TDS is elevated and exceeds the maximum drinking water standard in all boreholes except BH2 and BH6.

The highest TDS concentrations are observed BH10, BH1, BH9, BH13 and BH4.

Most of these boreholes are located in the slight topographical depression which forms a preferred flow path for storm water from the North and South Factory.

The respective concentrations are reflected in **Figure 186** and **Figure 188**. The respective contour maps are represented in **Figures 187 and 189**.

Figure 190 indicate the comparative TDS concentrations between the shallow Karoo and the deep fractured Karoo aquifer. In general the shallow Karoo aquifer is more impacted than the deep fractured Karoo aquifer except again for BH16D.

Based on the TDS concentration in BH2, it can be deemed to have been impacted by operational site activities. Figures 191, 192, 193, 194 and 194 indicate the TDS concentrations after the TDS concentration of the background quality borehole (BH2) has been subtracted.



Figure 185: TDS last measured value deep boreholes.

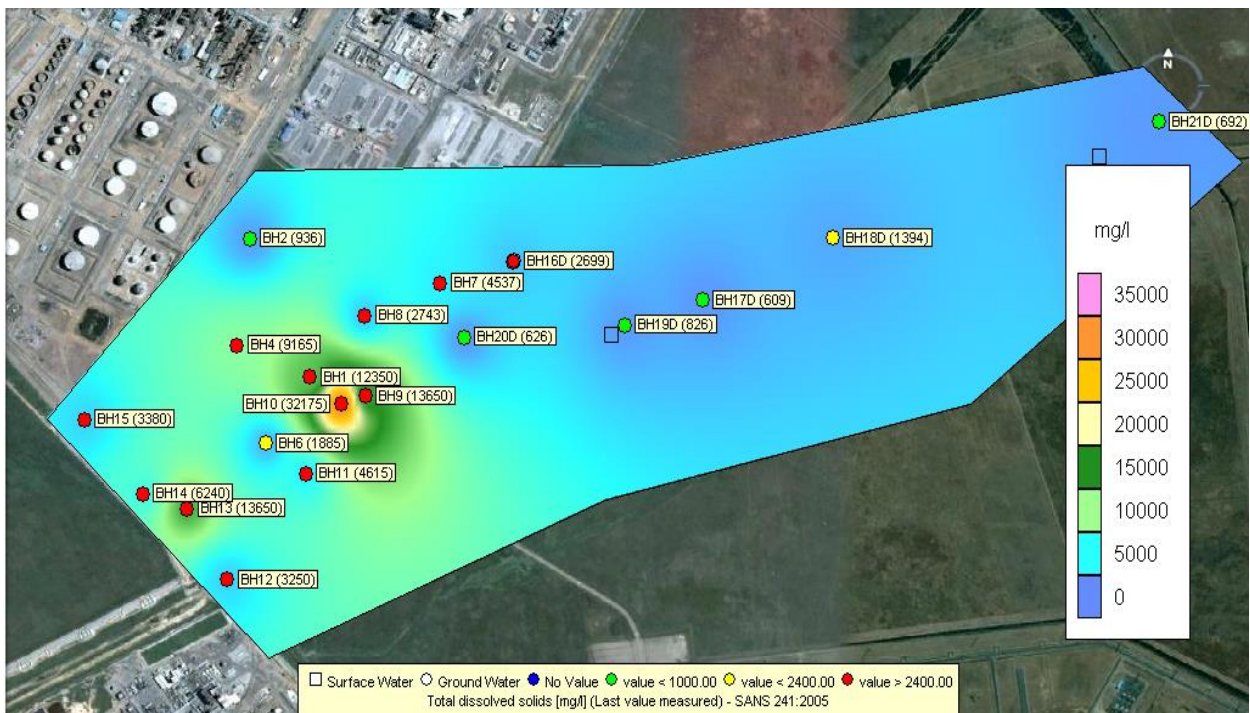


Figure 186: TDS last measured value deep boreholes contour map.



Figure 187: TDS last measured shallow boreholes.

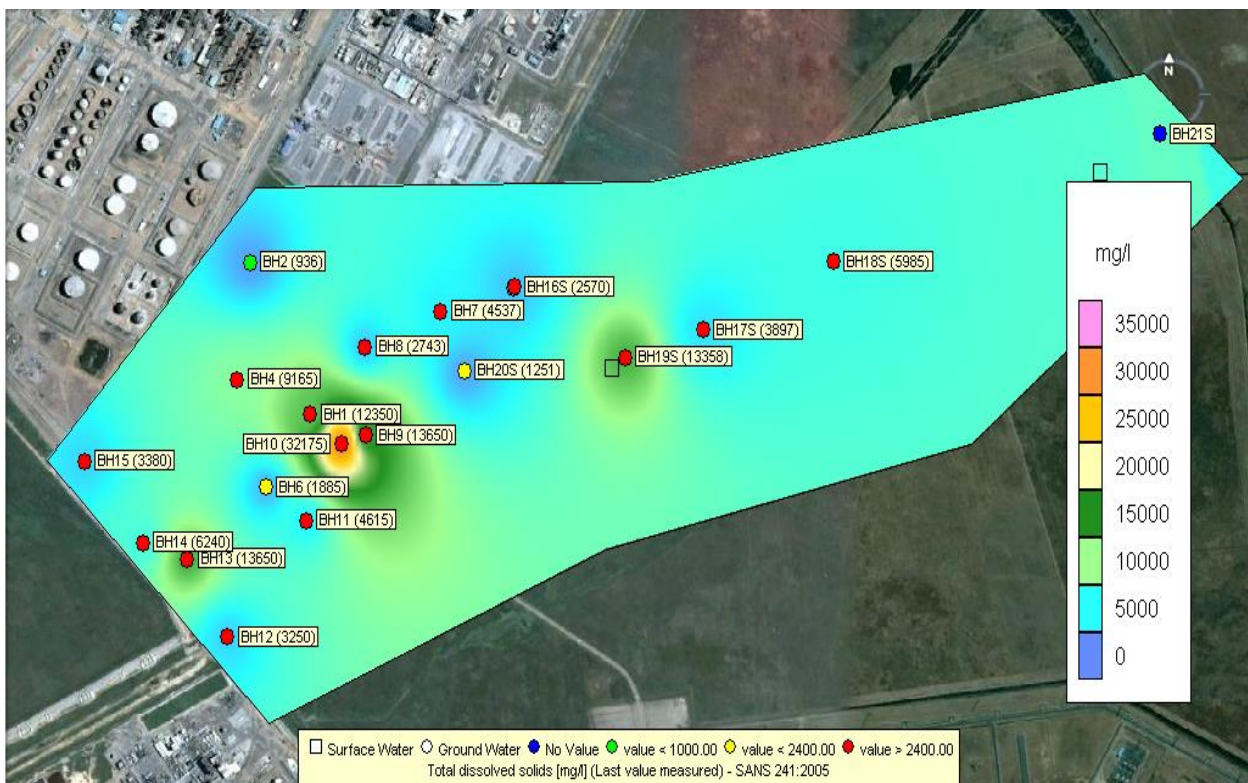


Figure 188: TDS last measured values shallow boreholes contour map.



Figure 189: TDS last measured value shallow and deep boreholes comparison SANS 241:2006.



Figure 190: TDS last measured value deep boreholes minus background water quality SANS 241:2006.

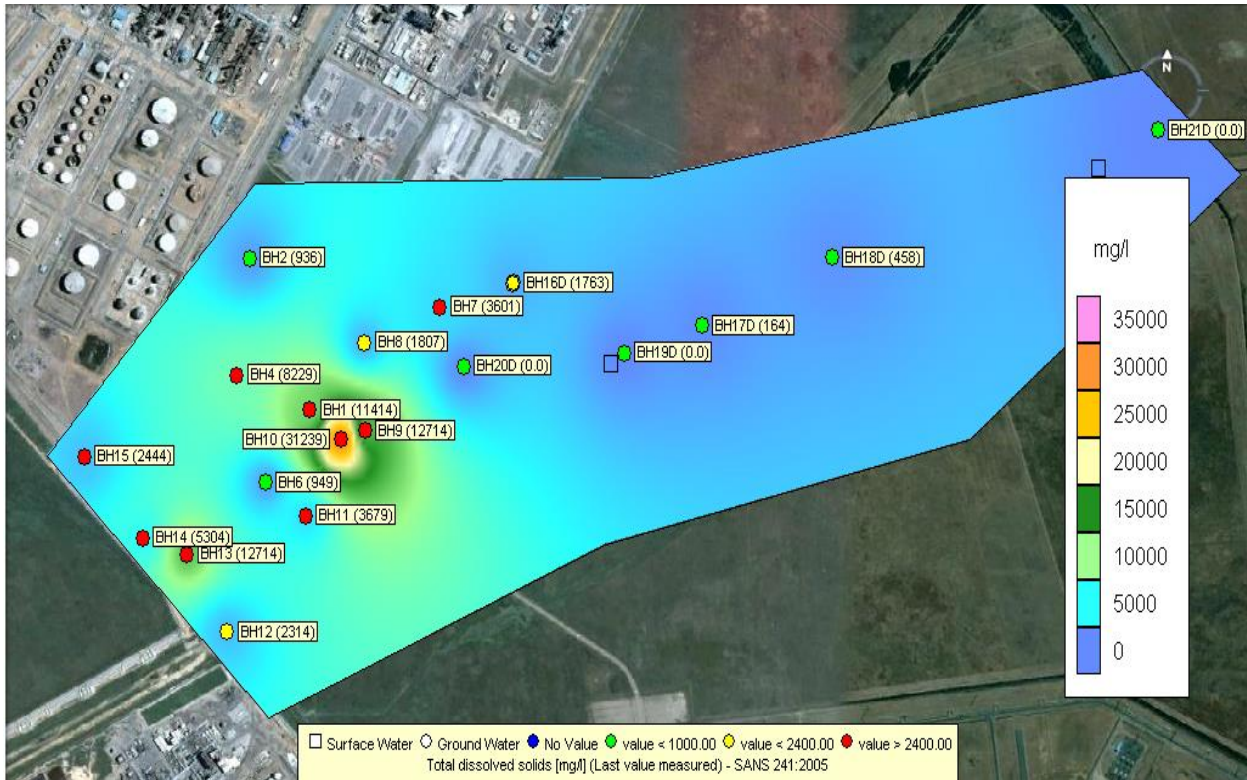


Figure 191: TDS last measured value deep boreholes minus background water quality contour map SANS 241:2006.



Figure 192: TDS last measured value shallow boreholes minus background water quality SANS 241:2006.

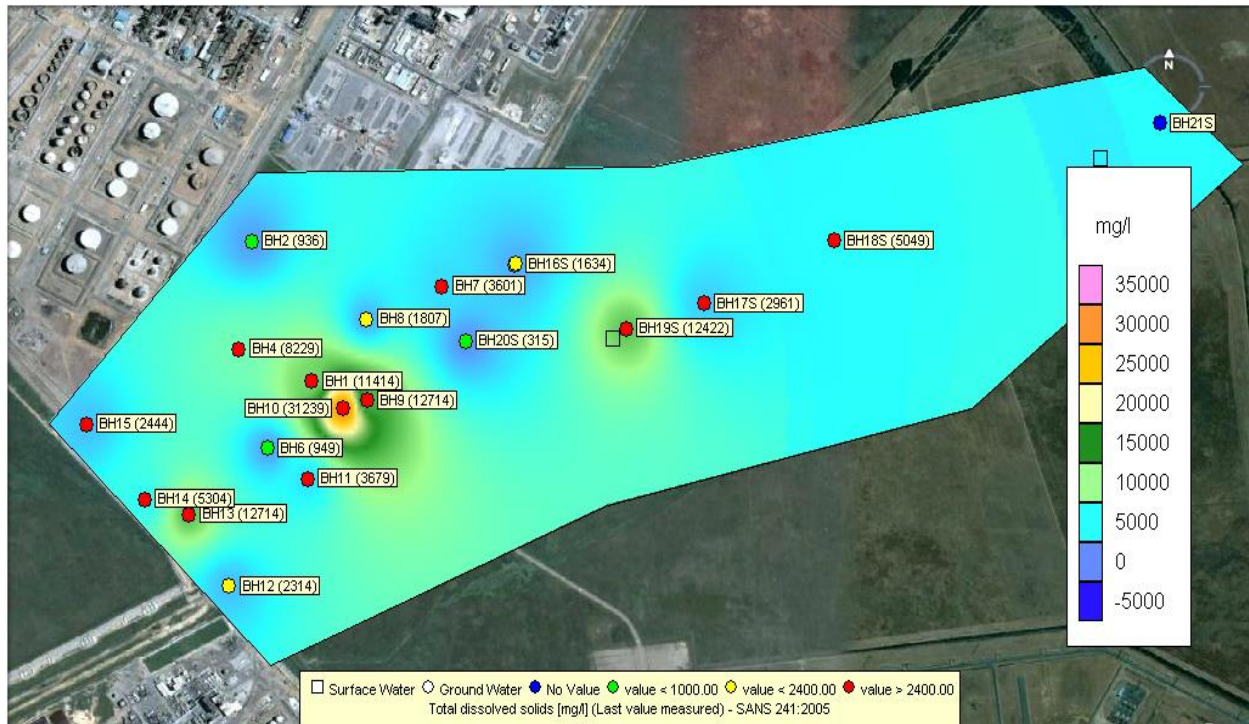


Figure 193: TDS last measured value shallow boreholes minus background water quality contour map SANS 241:2006.



Figure 194: TDS last measured value shallow and deep boreholes minus background water quality contour map SANS 241:2006.

6.3.15 Stiff Diagrams

The Stiff diagrams **Figures 195 and 196** serve as an indicator of the level of mineralisation as well as an indication of the type of mineralisation for each sampling point. The size of the graph relates to the concentration of the cations and anions.

Figures 197 and 198 provide an indication of the level of mineralisation where the background water quality (BH2) has been deducted from the actual chemical results.

Different sources of contamination can sometime be distinguished based on the shape. From the stiff diagrams it is evident that BH10, BH4, BH1, BH13, BH9, BH16S, BH17S, BH18S and BH19S have exceptionally high anion levels (chloride and nitrate).

BH19S has virtually exactly the same chemical “fingerprint” as the surface water in Henry’s dam reflecting ground water surface water interaction and the fact that Henry’s dam is a point pollution source.

STIFF Diagrams

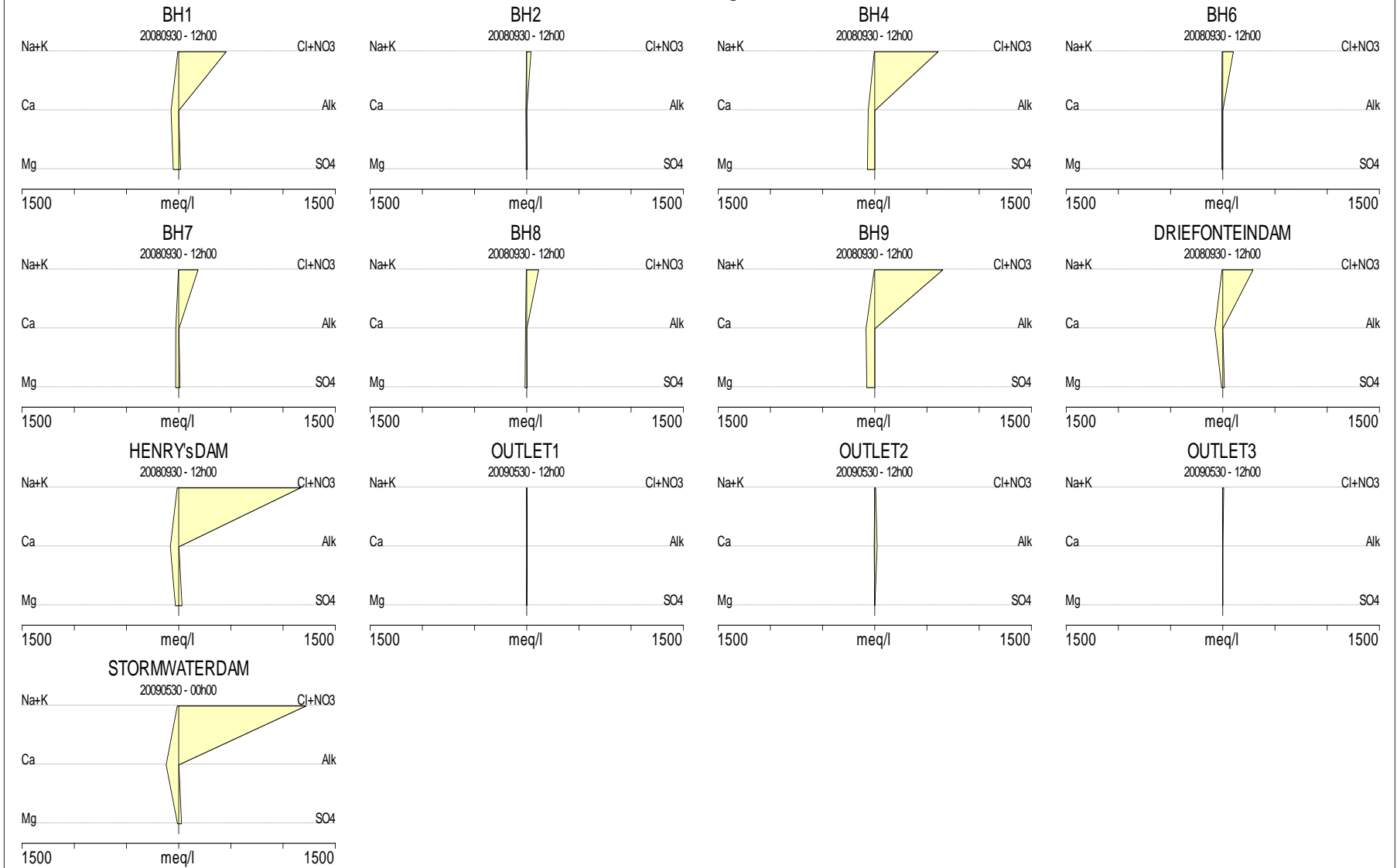


Figure 195: Stiff Diagram (1).

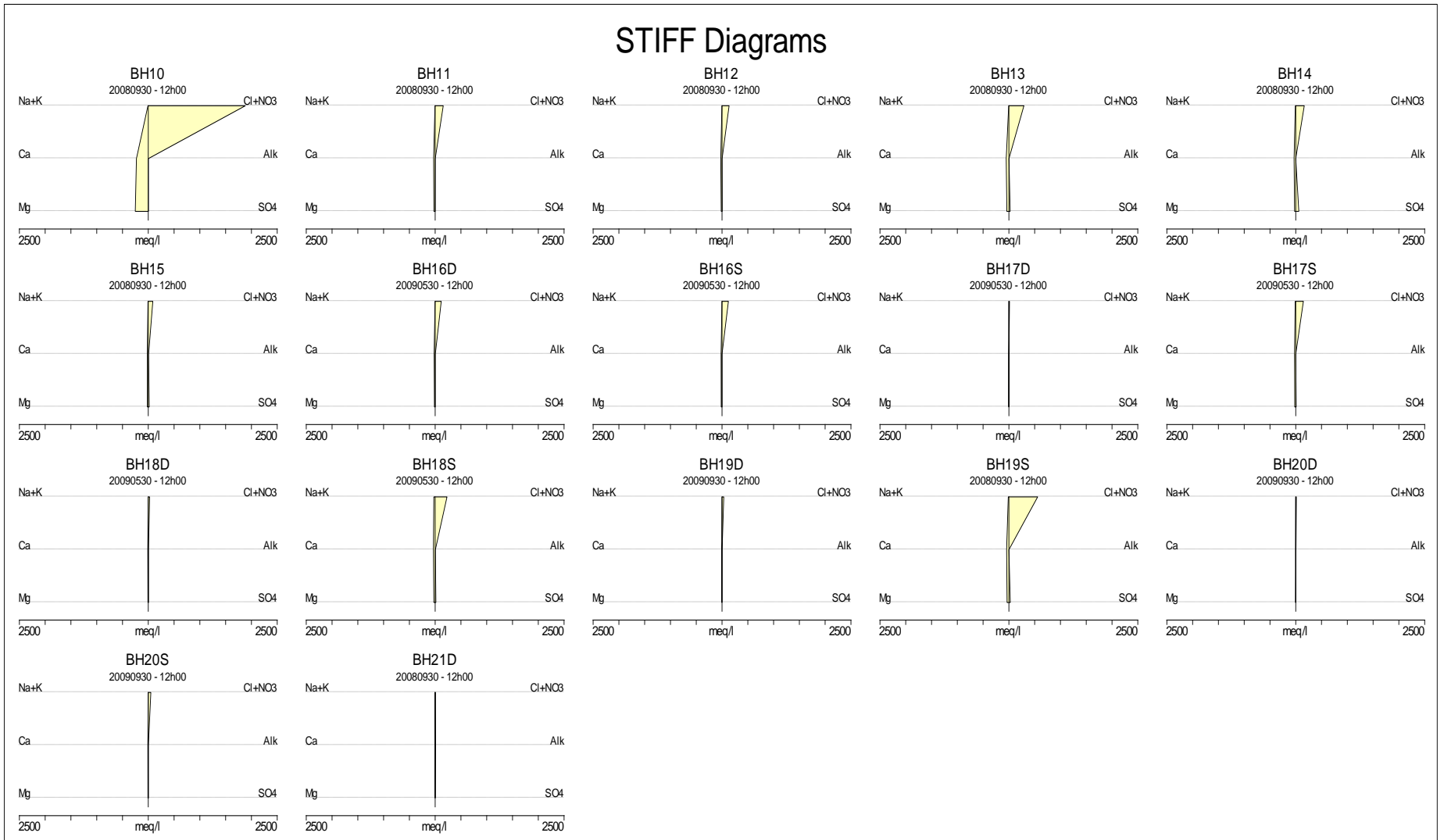


Figure 196: Stiff Diagram (2).

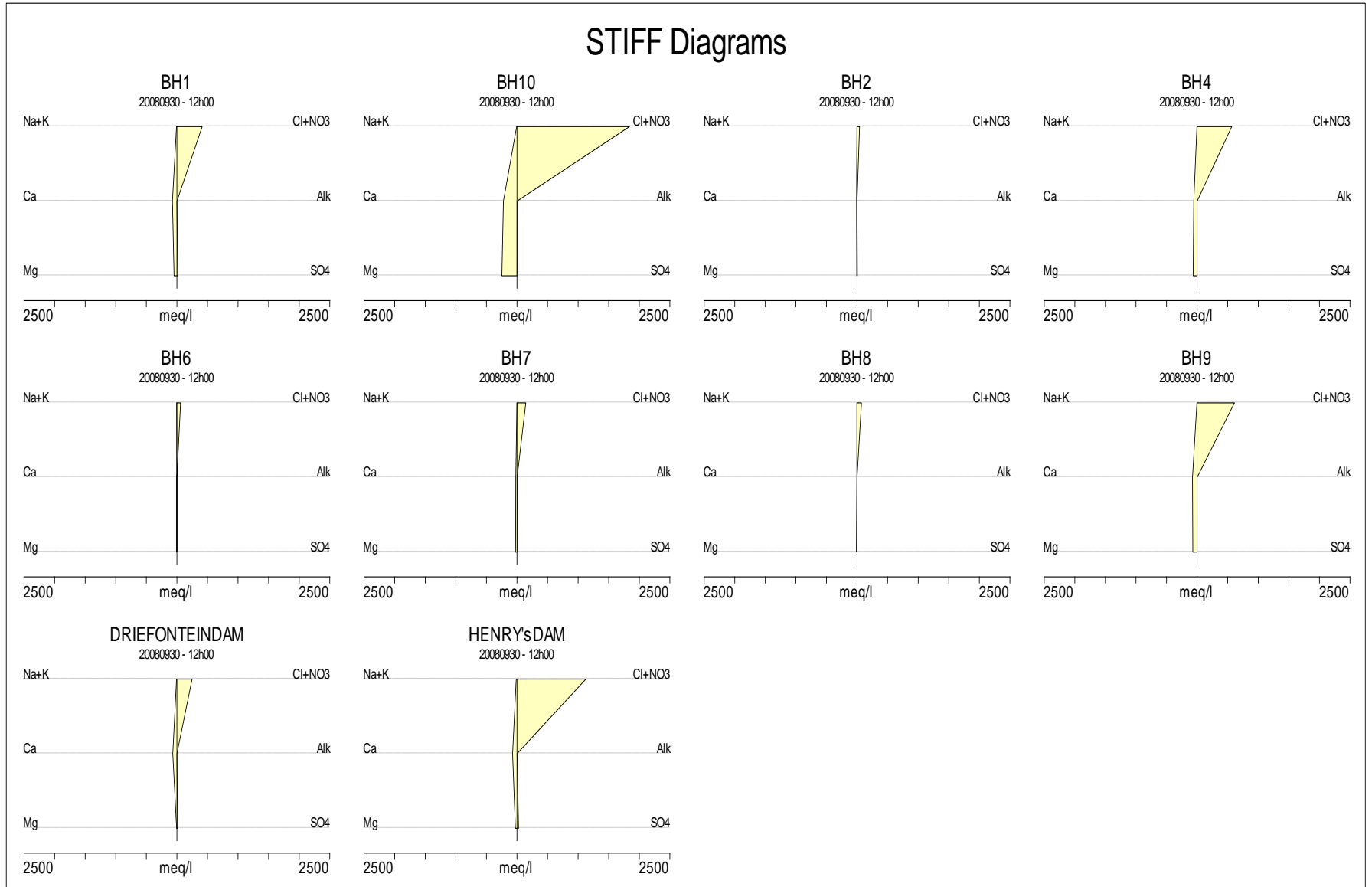


Figure 197: Stiff Diagram (1) (Ground water quality minus background water quality).

STIFF Diagrams

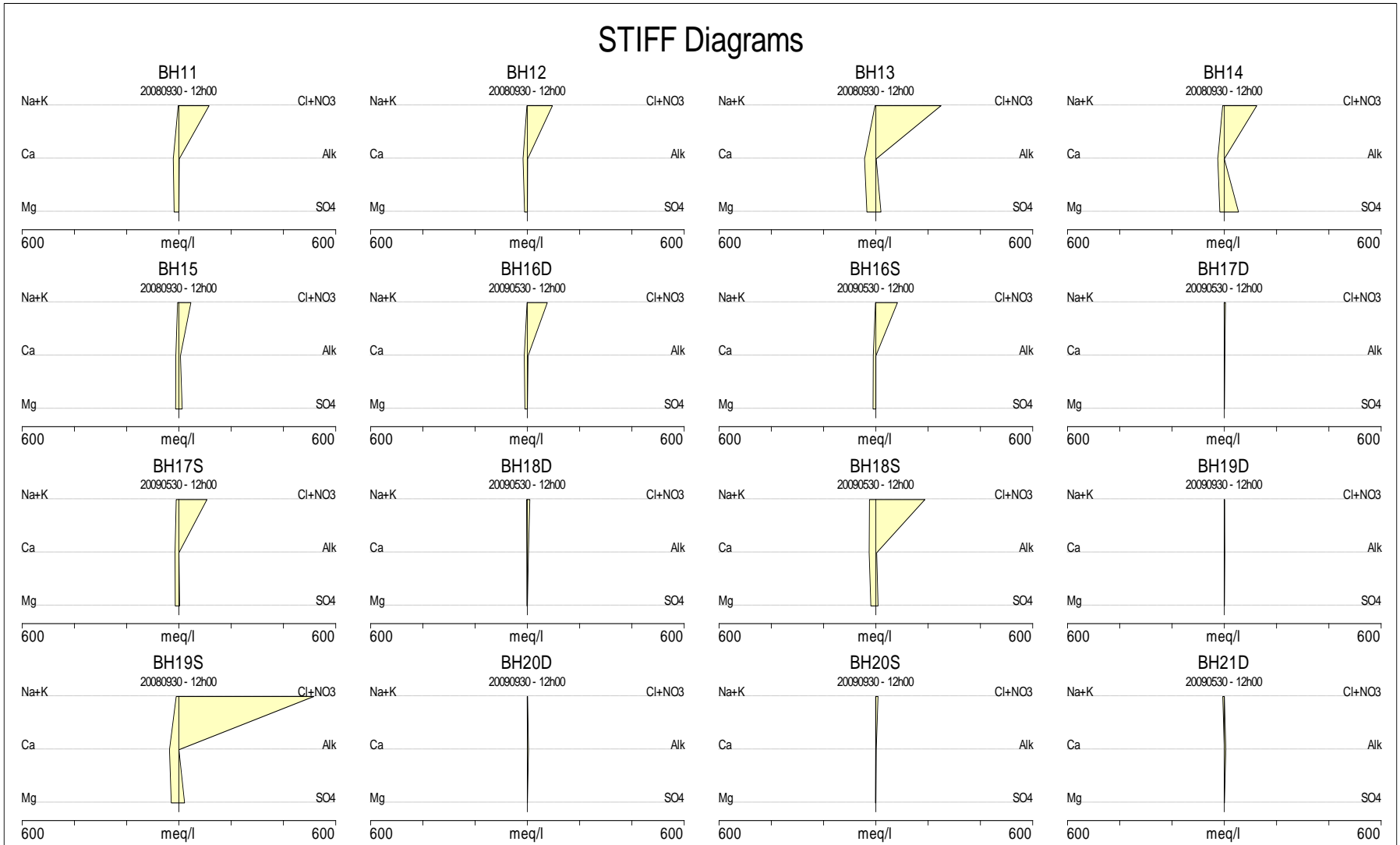


Figure 198: Stiff Diagram (2) (Ground water quality minus background water quality).

6.3.16 Expanded Durov Diagram

The expanded Durov diagram uses ratio techniques to plot the concentrations of the major ions. Six triangular diagrams are used (three for the anions and three for the cations). On each triangle the sum of the ions adds up to 50% and the ions are plotted in different combinations. The result is a plot with nine fields for classification. **Figure 199** provides an overview of the nine classes.

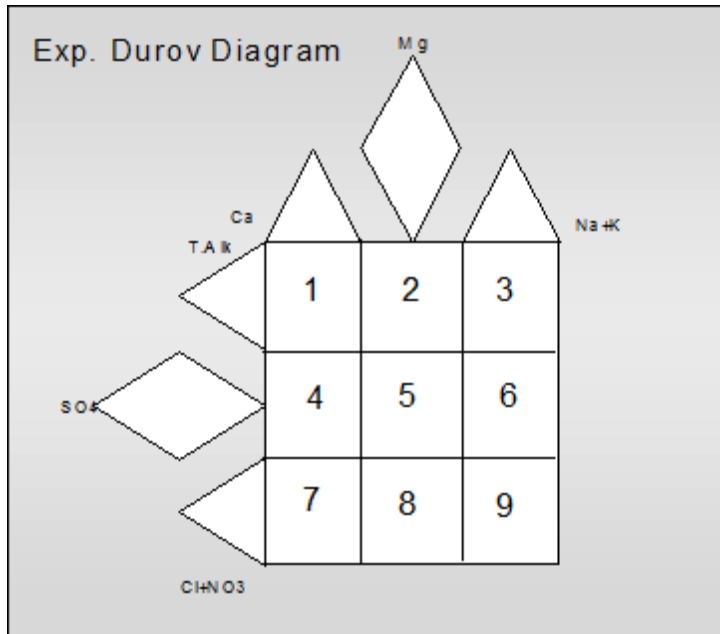


Figure 199: Expanded Durov Diagram Indicating Plotting Fields.

Water quality plotted in each of the nine classes has the following characteristics:

- Field 1:** Fresh, very clean recently recharged ground water with HCO_3 and CO_3 dominated ions;
- Field 2:** Field 2 represents fresh, clean, relatively young ground water that has started to undergo Mg ion exchange, often found in dolomitic terrain;
- Field 3:** This field indicates fresh, clean, relatively young ground water that has undergone Na ion exchange (sometimes in Na rich granites or other felsic rocks), or because of contamination effects from a source rich in Na;

Field 4: Fresh, recently recharged ground water with HCO_3 and CO_3 dominated ions that has been in contact with a source of SO_4 contamination, or that has move through SO_4 enriched bedrock;

Field 5: Ground water that is usually a mix of different types – either clean water from Fields 1 and 2 that has undergone SO_4 and NaCl mixing / contamination, or old stagnant NaCl dominated water that has mixed with clean water;

Field 6: Ground water from Field 5 that has been in contact with a source rich in Na , or old stagnant NaCl dominated water that resides in Na rich host rock / material;

Field 7: Water rarely plots in this field that indicates NO_3 or Cl enrichment, or dissolution;

Field 8: Ground water that is usually a mix of different types either clean water from Fields 1 and 2 that has undergone SO_4 , but especially Cl mixing / contamination, or old stagnant NaCl dominated water that has mixed with water richer in Mg ;
and

Field 9: Very old, stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans, etc.) or water that has moved a long time and / or distance through the aquifer and has undergone significant ion exchange.

Figure 200 indicates that except for BH21D, all samples indicate that chloride and nitrate is highly dominant. The results in block 7 indicate that chloride and nitrate is dominant. This is not a common water type and indicative that reverse ion exchange is taking place. The results in block 8 indicate significant contamination of ground water that is usually a mix of different types either clean water from Fields 1 and 2 that has undergone SO_4 , but especially Cl mixing / contamination, or old stagnant NaCl dominated water that has mixed with water richer in Mg . **Figure 201** indicates the result when the background water quality (BH2) is deducted from the actual water quality.

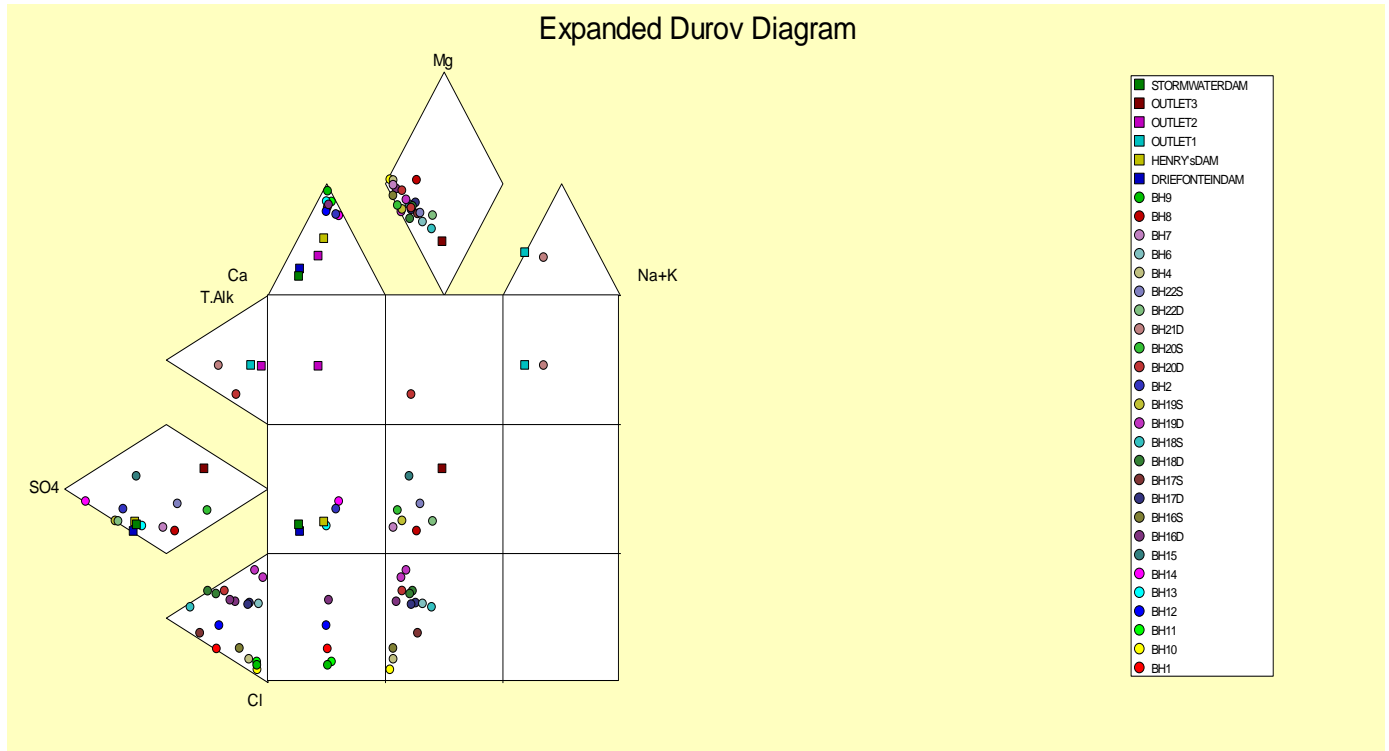


Figure 200: Expanded Durov Diagram.

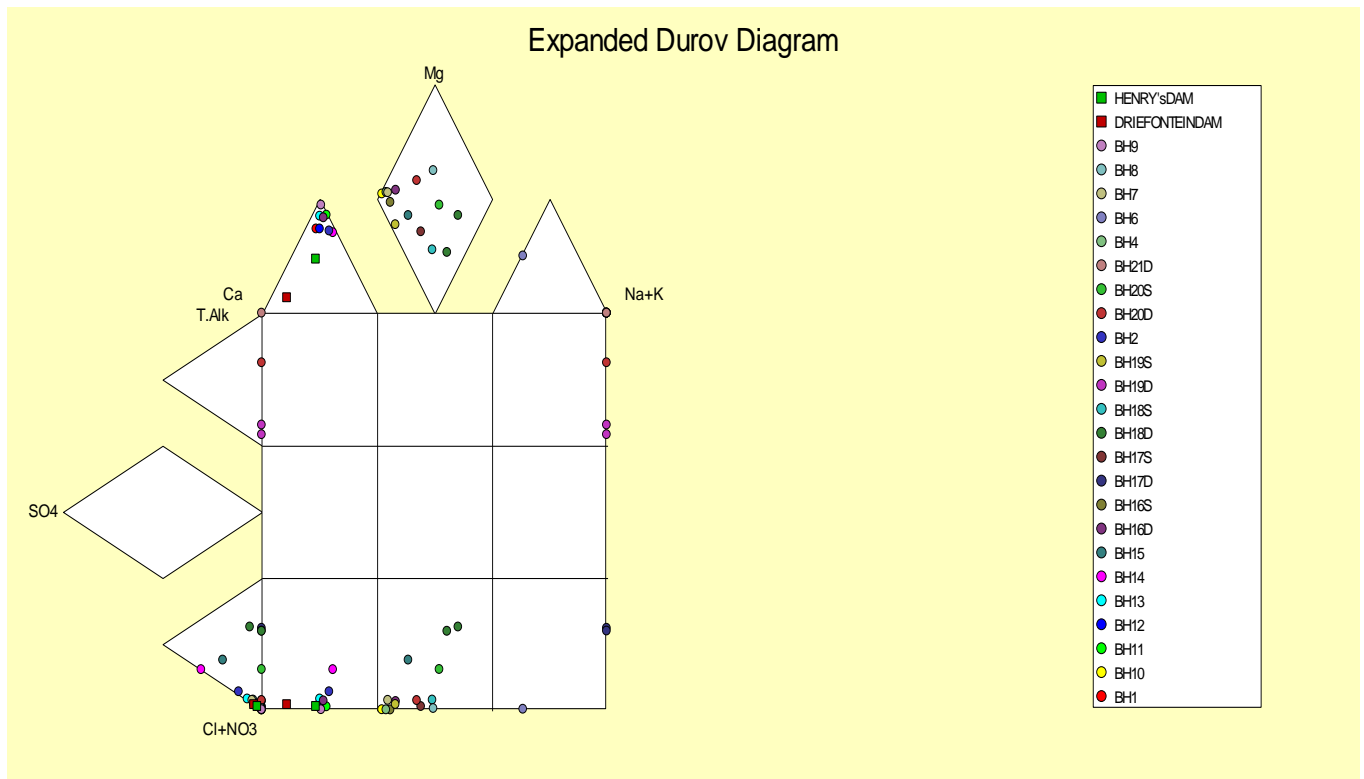


Figure 201: Expanded Durov Diagram (Ground water quality minus background water quality).

6.3.17 Durov Diagram

The Durov diagram (**Figure 202**) reflects the concentrations of contaminants in the boreholes as well as their respective pH values. The ground water is otherwise significantly chloride and nitrate dominant.

The highest pH value is recorded at BH15 (9,2) and the lowest at BH16S (3,8) and can be seen in **Figure 202**.

Figure 203 indicates the result when the background water quality (BH2) is deducted from the actual water quality.

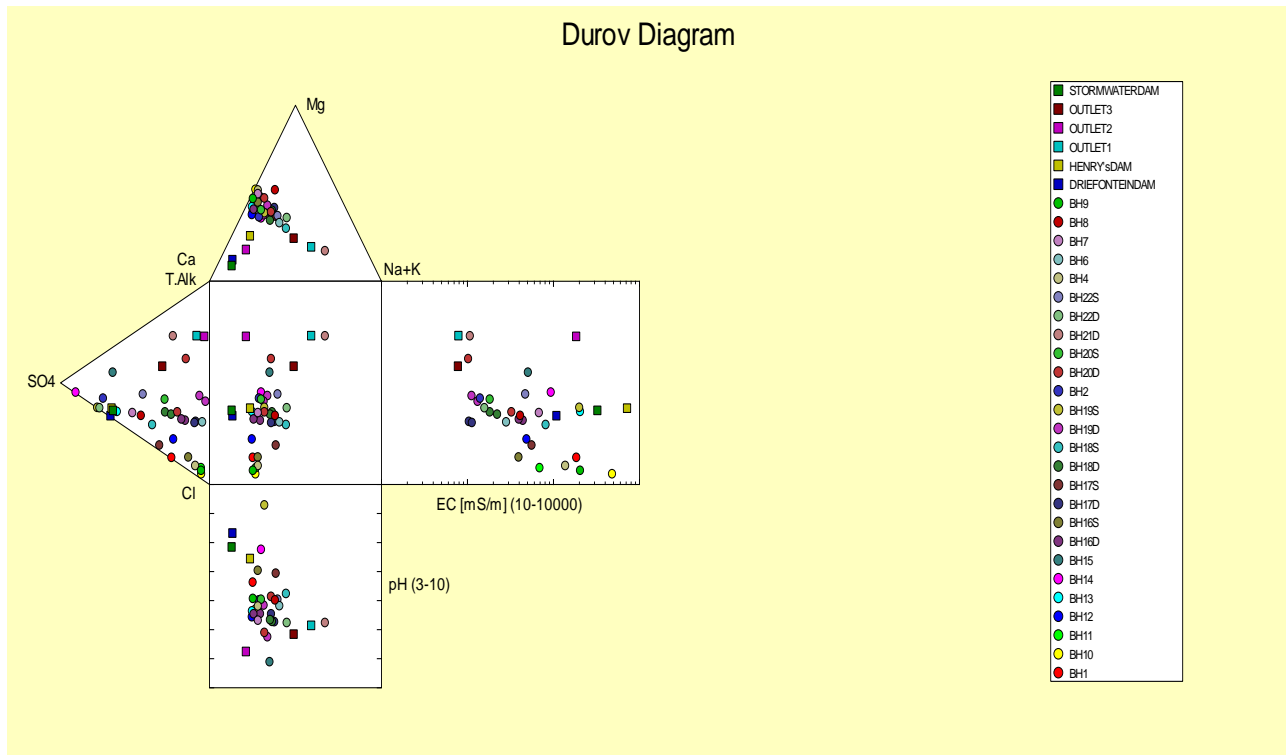


Figure 202: Durov Diagram

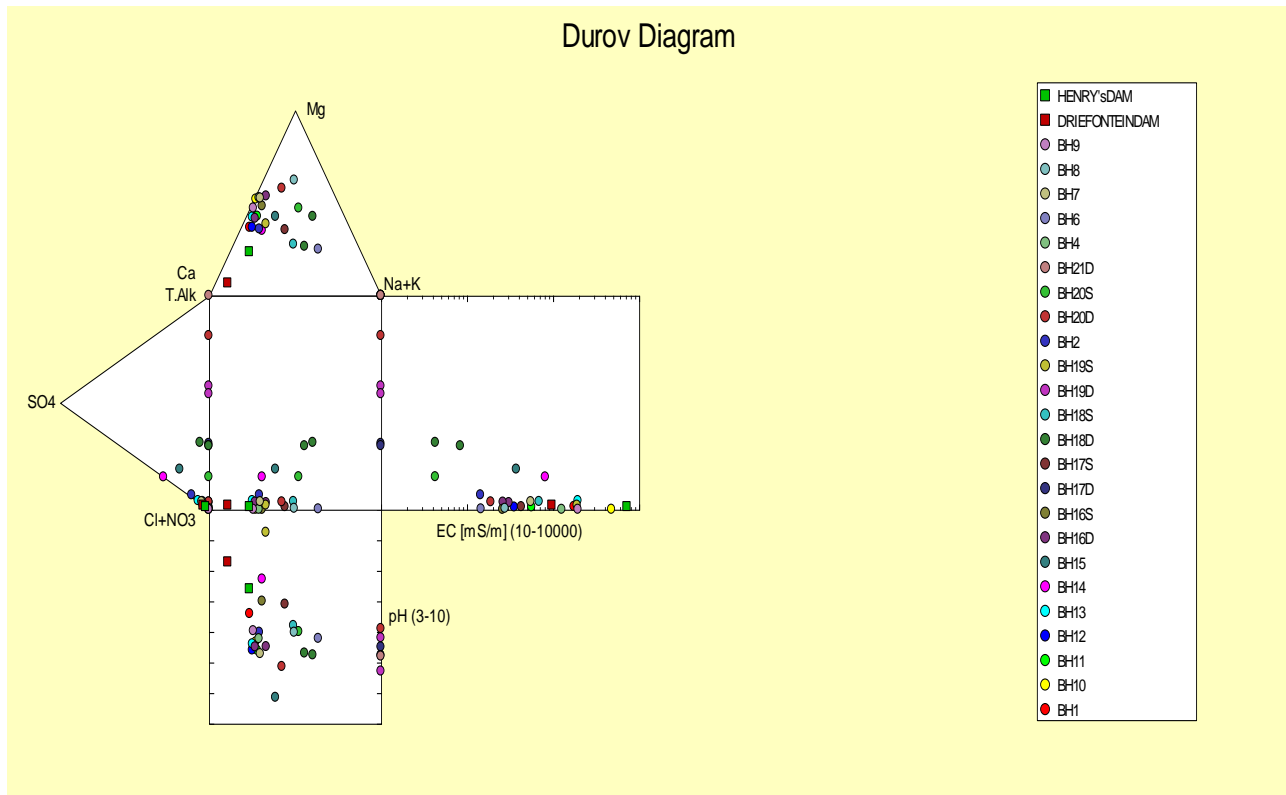


Figure 203: Durov Diagram (Ground water quality minus background water quality).

6.3.18 Piper Diagram

The major cations (Ca, Mg, Na and K) are plotted in one trilinear diagram. This is achieved by working the percentage that each represents of the major cations. For example the calcium percentage of the major cations in an analysis would be determined by (meq/l):

$$\text{Ca}/\text{Ca} + \text{Mg} + (\text{Na} + \text{K}) \text{ in } \%$$

Using the same technique the percentage contribution of each of the other species is calculated and the results are plotted as one point in the cation trilinear field. The same is done for the major anions (Cl, SO₄, HCO₃ and CO₃) and the results are plotted as one point in the anion trilinear field.

These two points are then extended into the main diamond shaped field of the Piper diagram to plot as one point. The water is classified depending on the position of this point.

Figure 204 indicates that the ground water in the study area is significantly artificially enriched with calcium, magnesium, chloride and nitrates, except for BH21D.

Figure 205 provides an overview of the result when the background water quality (BH2) is deducted from the actual water quality.

Water quality plots mostly in the Ca, Mg, Cl and SO₄ dominant category with only BH21D plotting in the Cl, SO₄, HCO₃ and CO₃ classification.

It can be seen from **Figure 205** that the pollution contribution of Omnia Fertiliser Sasolburg to the natural background water quality is significant and representative of the chemicals used in the manufacturing process.

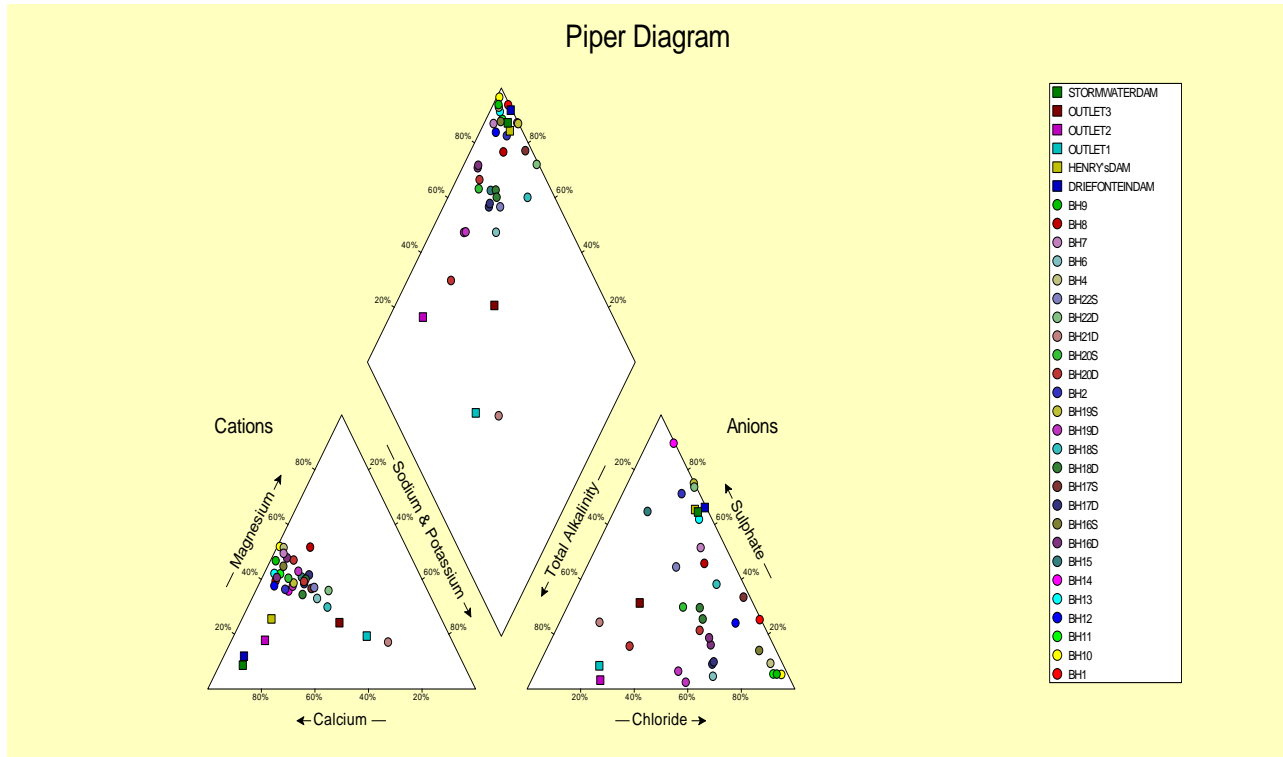


Figure 204: Piper Diagram.

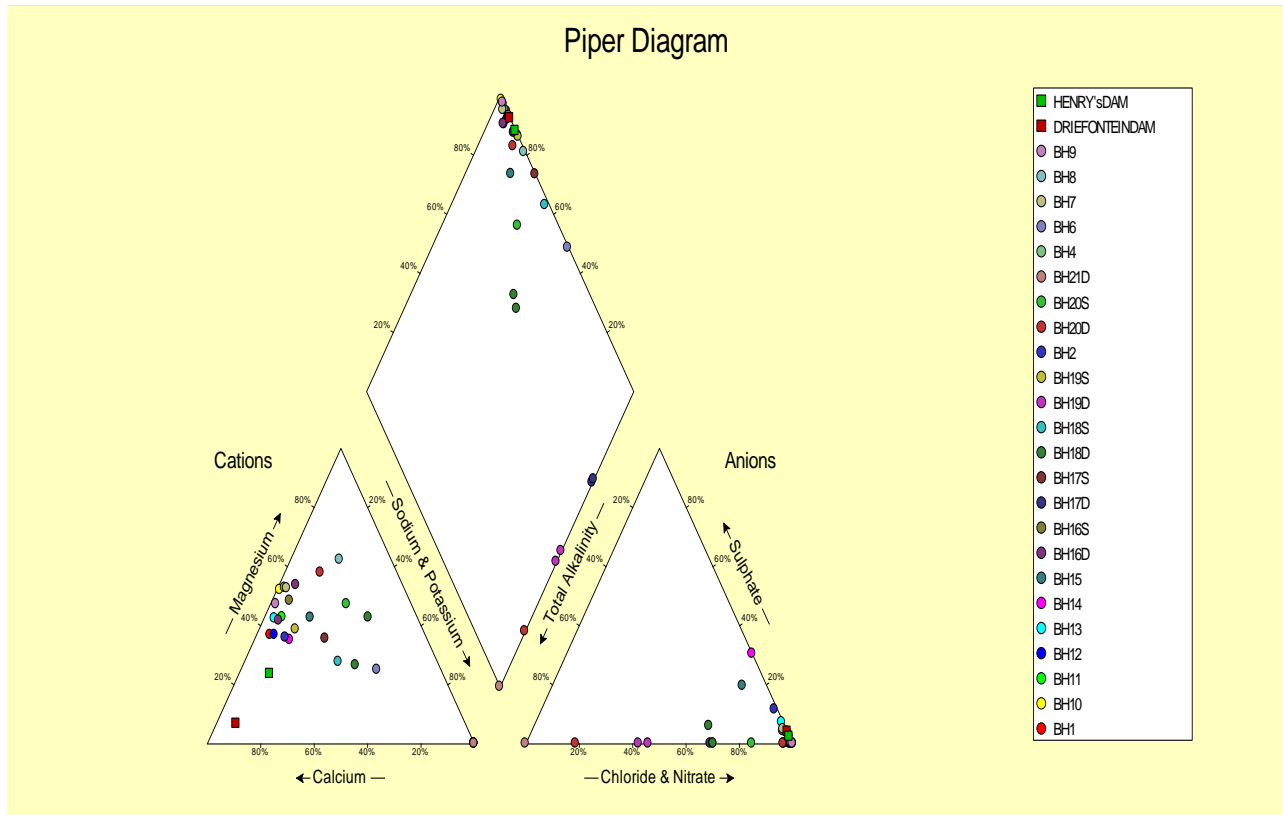


Figure 205: Piper Diagram (Ground water quality minus background water quality).

CHAPTER 7: WATER CHEMISTRY - HYDROLOGY

The surface water monitoring network is depicted in **Figure 31**. The storm water channel which exits at Outlet 2 to the Storm water dam, is the main storm water channel for the North Factory. The storm water system at the South Factory is less developed if compared to the North Factory. It is expected that infiltration will be higher at the South Factory, as there is less solid (impermeable surface areas). The North Factory has a higher potential to impact on storm water quality due to dust being generated and a higher level of general operational activity such as the handling and transport of chemicals. It can be seen from the storm water quality analysis that the quality of storm water flowing through Outlet 2, to the Storm water dam is significantly more impacted than the storm water quality at Outlet 1. The storm water quality at Outlet 3 is the least impacted. This is because Outlet 3 is located at higher topographical point (mamsl) than Outlets 2 and 3 and thus does not fall in the main storm water flow direction (**Table 31a and 31b**).

The water quality in the Storm water dam, Henry's dam and Driefontein, therefore mainly have the fingerprint of the contaminants (chemicals) used at the North Factory.

It is evident from the storm water monitoring results that storm water run-off, is a major transporter of contaminants from the Omnia Fertiliser Sasolburg site, and as such has created significant point pollution sources off-site. The main point pollution sources are the Storm water dam, Henry's dam, Driefontein dam and the water channels leading to these dams.

Table 31a: Surface water chemical analysis results evaluated against SANS 241:2006 (GPT, 2008).

Site Name	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	HCO3 mg/l	Cl mg/l
DRIEFONTEINDAM	4.7	1116.00	7254.00	1521.00	132.00	72.80	181.00	4.16	5.08	288.66
HENRY'sDAM	5.6	7400.00	48100.00	1610.00	387.00	77.90	449.00	108.08	131.81	533.81
STORMWATERDAM	5.2	3347.00	27226.00	2410.00	145.00	35.00	479.00	80.00	97.60	486.00
OUTLET1	7.9	81.00	457.00	27.00	10.00	39.00	19.90	260.00	314.80	63.00
OUTLET2	8.8	1896.00	12632.00	113.00	17.00	20.00	7.80	1168.00	1093.67	309.00
OUTLET3	8.2	79.90	562.00	59.00	22.00	61.00	9.00	68.00	81.65	31.00
Drinking water classes										
Class 1		150.00	1000.00	150.00	70.00	200.00	50.00			200.00
Class 2		370.00	2400.00	300.00	100.00	400.00	100.00			600.00
Exceeds maximum										

Table 31b: Surface water chemical analysis results evaluated against SANS 241:2006 continued (GPT, 2008).

Site Name	SO4 mg/l	Balance	N_Ammonia mg/l	NO2 mg/l	NO3-N mg/l	F mg/l	PO4 mg/l	Fe mg/l	Mn mg/l	Si
DRIEFONTEINDAM	756.66	1.87	340.14	0.00	3948.88	15.18	605.14	0.00	6.40	NS
HENRY'sDAM	1533.33	-5.45	3550.30	0.00	16137.70	0.00	1532.76	0.00	12.10	NS
STORMWATERDAM	1312.00	3.50	3892.00	2.63	16909.76	14.00	383.27	0.00	6.13	NS
OUTLET1	29.00	1.20	68.09	0.00	14.17	0.40	15.02	0.15	0.09	NS
OUTLET2	43.00	0.10	2757.59	13.47	8450.46	2.40	7.05	0.22	0.55	NS
OUTLET3	48.00	4.90	2.43	6.57	115.09	0.70	2.15	0.14	0.00	NS
Drinking water classes										
Class 1	400.00		1.22	44.00	1.00		0.20	0.10		
Class 2	600.00		2.43	88.00	1.50		2.00	1.00		
Exceeds maximum										

7.1 CALCIUM (Ca)

The most elevated calcium concentrations were measured at the Storm water dam, Henry's dam and Driefontein dam. The main point pollution source for the calcium concentration is the Granulation complex where dolomitic and calcitic limestone is utilised to cover the ammonium nitrate drops to form Limestone Ammonium Nitrate (LAN). A second point pollution source is agricultural lime which is present at the raw material store and stores at the South Factory. Lime has been used in the past to cover the railway tracks for easier conveyance of material over it. It is evident that dust generated by the Granulation complex is transported via the storm water drainage network to the storm water collection point and from there-on to the lower receiving dams (Henry's dam and Driefontein dam). A third point pollution source is Gypsum which is also present at the raw materials store and stores at the South Factory. Concentrations of calcium decreases downstream from the Storm water dam to Driefontein dam. The North and South Factory, Storm water dam, Henry's dam, Driefontein dam and storm water channels are point pollution sources to ground water. Analysis results are indicated in **Figure 206**.



Figure 206: Calcium surface water monitoring results.

7.2 CHLORIDE (Cl)

The most elevated chloride concentrations were measured at Henry’s dam, Storm water dam and Driefontein dam. Outlet 3 also had relatively high concentrations of chloride. Potassium chloride is the main source and is associated with the raw material store, product store, final product bagging area and the speciality blending plant at the South Factory.

It is evident that contaminant movement is taking place through the storm water management network. An accumulation of chloride has taken place in Henry’s dam. The chloride concentration decreases downstream to Driefontein dam.

The North and South Factory, Storm water dam, Henry’s dam, Driefontein dam and storm water channels are point pollution sources to ground water. Analysis results are indicated in **Figure 207**.



Figure 207: Chloride surface water monitoring results.

7.3 FLUORIDE (F)

The highest fluoride concentrations were measured at the Storm water dam and Driefontein dam. There is evidence of fluoride concentrations exceeding the drinking water standard at outlet number 2. It is interesting to note that fluoride was not detected in Henry's dam. Fluoride is mainly associated with phosphate fertiliser where it is being captured in the scrubbers at its main production site. The fluoride acid (hydrofluorosilicic acid), a classified hazardous waste, is collected and sold.

Main point pollution sources of fluoride might be at the granulation complex, super phosphate plant, raw material, product, bagging and final product store, liquids plant and speciality blending plant. High concentrations of fluoride were detected in the ground water around the granulation complex.

Storm water channels from the North Factory form an important contaminant transport mechanism. The concentrations between the Storm water dam and Driefontein dam does not differ significantly. There might also be other sources of fluorides in the study area such as from Natref.

The North and South Factory, Storm water dam, Henry's dam, Driefontein dam and storm water channels are point pollution sources to ground water. Analysis results are indicated in **Figure 208**.

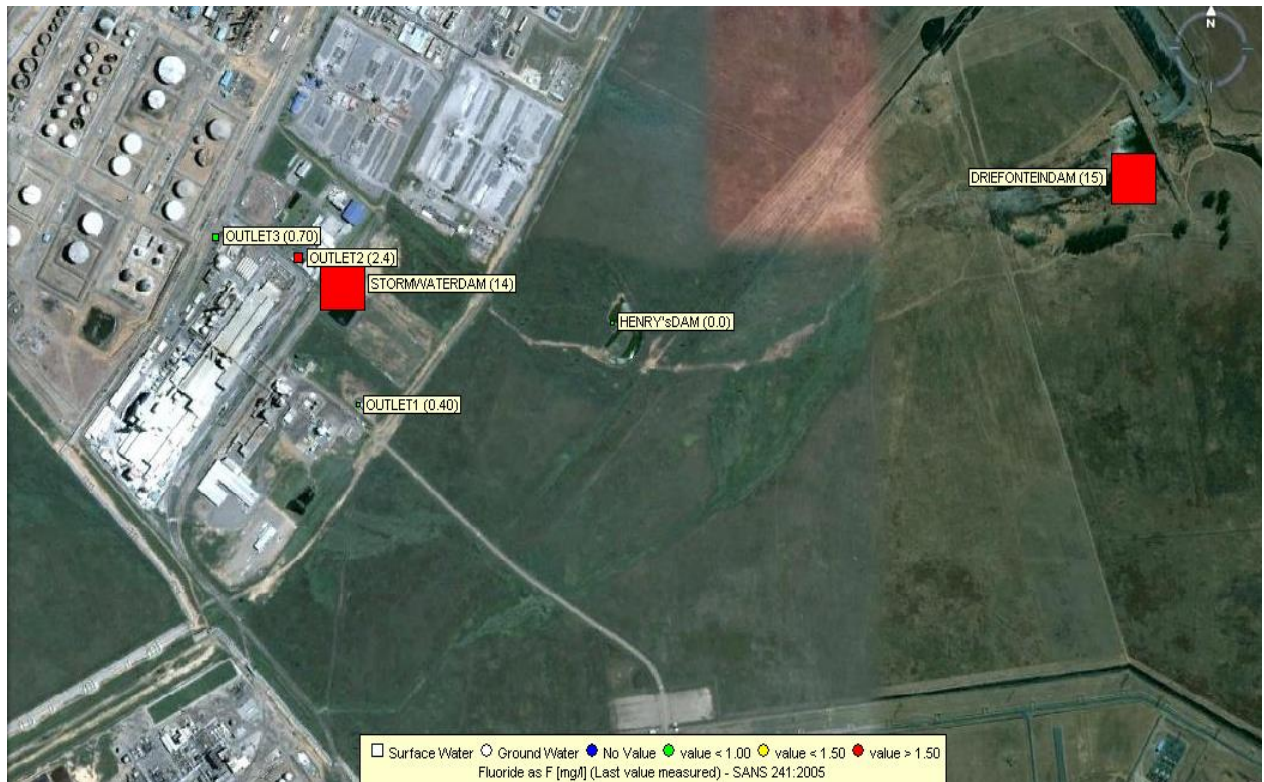


Figure 208: Fluoride surface water monitoring results.

7.4 IRON (Fe)

Chemical analysis for iron indicates that some iron was detected at outlet number 2. No iron was detected in the Storm water dam, Henry's dam or Driefontein dam.

The low iron concentrations are probably because Omnia Fertiliser Sasolburg does not produce iron sulphate compounds. The iron concentrations detected at outlet number 2 might originate from the neighbouring Süd Chemie Catalysts site.

The North and South Factory, Storm water dam, Henry's dam, Driefontein dam and storm water channels are point pollution sources to ground water. Analysis results are indicated in **Figure 209**.



Figure 209: Iron surface water monitoring results.

7.5 POTASSIUM (K)

The most elevated potassium concentrations were measured at the Storm water dam, Henry's dam and Driefontein dam. The concentrations decrease downstream. The main point pollution source for potassium as source is potassium chloride. It is interesting to note that the concentrations of chloride and potassium are almost the same in the different sampling areas.

Potassium chloride as the main source are associated with the raw material store, product store, final product bagging area and the speciality blending plant at the South Factory.

It is evident that contaminant movement is taking place through the storm water management network. An accumulation of potassium has taken place in the Storm water dam, Henry's dam and Driefontein dam.

The North and South Factory, Storm water dam, Henry’s dam, Driefontein dam and storm water channels are point pollution sources to ground water. Analysis results are indicated in **Figure 210**.



Figure 210: Potassium surface water monitoring results.

7.6 MAGNESIUM (Mg)

The most elevated magnesium concentrations were measured at, Henry’s dam, Storm water dam and Driefontein dam. The main point pollution source for the magnesium concentrations are the Granulation complex where dolomitic and calcitic limestone is utilised to cover the ammonium nitrate drops to form LAN.

The second point pollution source is Agricultural lime which is present at the raw material store and stores at the South Factory. It is evident that dust generated by the Granulation complex is transported via the storm water drainage network to the storm water collection point and from there-on to the lower receiving dams (Henry’s dam and Driefontein dam).

The third point pollution source is magnesium sulphate which is also present at the raw materials store and stores at the South Factory.

The North and South Factory, Storm water dam, Henry's dam, Driefontein dam and storm water channels are point pollution sources to ground water. Concentrations of magnesium decreases downstream from Henry's dam to Driefontein dam. Analysis results are indicated in **Figure 211**.



Figure 211: Magnesium surface water monitoring results.

7.7 MANGANESE (Mn)

The most elevated manganese concentrations were measured at, Henry's dam, Driefontein dam and the Storm water dam. All the concentrations measured exceeds the drinking water standard. The main point pollution source for the manganese concentrations are the bagging and final

product store, product store, raw material store, granulation complex, liquids plants and speciality plant. Manganese is a micronutrient and is classified as naturally occurring agricultural minerals.

The North and South Factory, Storm water dam, Henry's dam, Driefontein dam and storm water channels are point pollution sources to ground water.

Concentrations of manganese decreases downstream from Henry's dam to Driefontein dam. It appears as if Henry's dam might have historically accumulated the current manganese concentrations which are present. Analysis results are indicated in **Figure 212**.



Figure 212: Manganese surface water monitoring results.

7.8 SODIUM (Na)

The most elevated sodium concentrations were measured at, Henry's dam, Driefontein dam and the Storm water dam. None of the concentrations are exceeding the drinking water standard.

There is a close correlation between concentrations in Henry's dam and Driefontein dam. Analysis results are indicated in **Figure 213**.

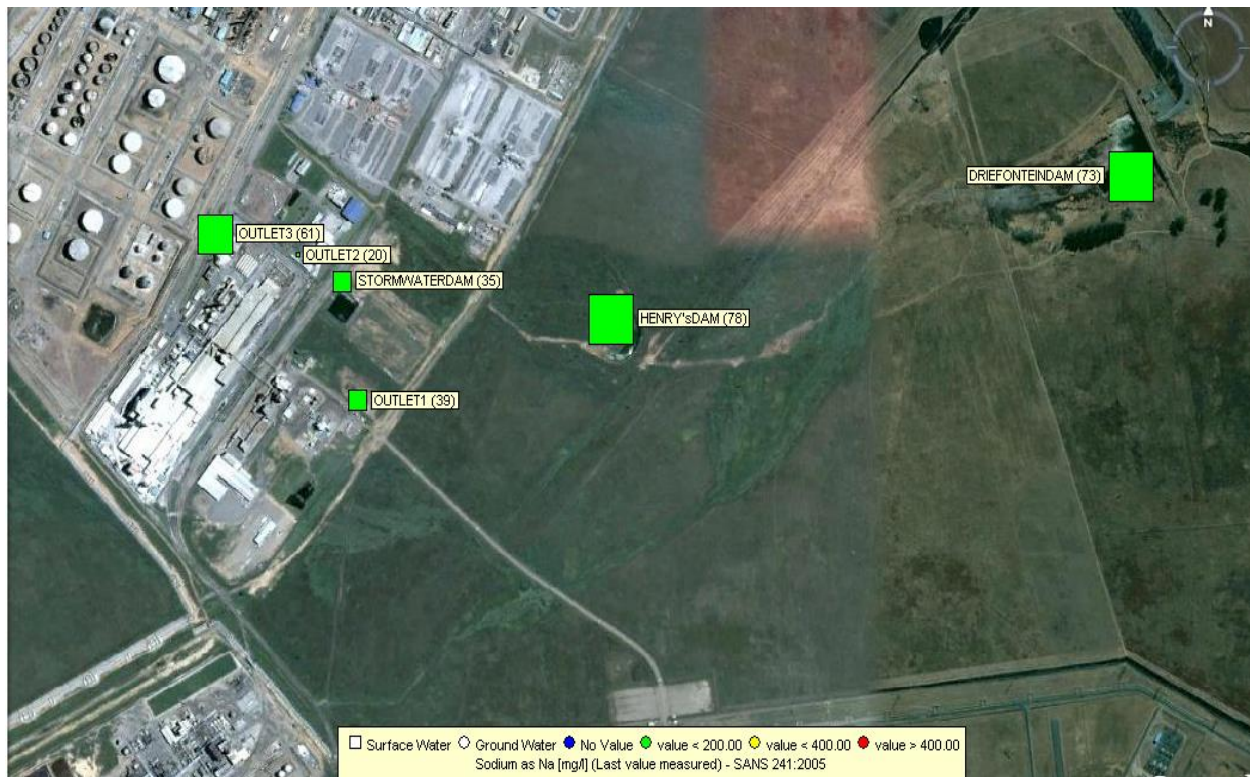


Figure 213: Sodium surface water monitoring results.

7.9 AMMONIA (NH₄)

The highest ammonia concentrations were measured at the Storm water dam, Henry's dam and outlet number 3. The main potential point pollution source for the ammonia concentrations is the nitric acid complex and the cooling towers. Ammonia is oxidised to nitrite. Nitrite is oxidised to nitrate. This activity can be seen in the changes in ammonia, nitrite and nitrate concentrations between Outlet number 3, Storm water dam, Henry's dam, and Driefontein dam (**Figures 214, 215 and 216**).

Ammonia in any concentration is toxic to human and aquatic life. Analysis results are indicated in **Figure 214**.



Figure 214: Ammonia surface water monitoring results.

7.10 NITRITE (NO₂)

The most elevated nitrite concentrations were measured at Outlet number 2, Outlet number 3 and the Storm water dam. No nitrites were detected at Outlet number 1, Henry's dam and Driefontein dam. The main potential point pollution source for the nitrites is the same as ammonia, as ammonia is oxidised to nitrite. Those are the nitric acid complex and the cooling towers.

Nitrites are toxic to humans and aquatic life. Analysis results are indicated in **Figure 215**.



Figure 215: Nitrite surface water monitoring results.

7.11 NITRATE (NO₃)

Exceptionally high nitrate concentrations were measured at the Storm water dam, Henry's dam and Driefontein dam. All measurements significantly exceeding the drinking water standard. The nitrate concentrations measured is cumulative from a number of point pollution sources on site.

The main potential point pollution source for the nitrate concentrations are the nitric acid complex and the cooling towers. Ammonia is oxidised to nitrite. Nitrite is oxidised to nitrate. Nitrate is the final product from ammonia (urea). Urea contains 46% nitrogen and ammonium nitrate 35% nitrogen. Ammonium sulphate contains 21% nitrogen, LAN 28% nitrogen and ammonium sulphate 27% nitrogen. There is thus numerous point pollution sources of nitrates and from the concentrations observed, nitrates makes up the largest pollution footprint of Omnia Fertiliser Sasolburg.

Nitrate point pollution sources are:

- Nitric acid complex;
- Cooling towers;
- Granulation plant;
- Raw material store;
- Product store;
- Liquids plant;
- Speciality blending plant;
- Stores and loading bays;
- Ammonia storage area;
- Effluent dam;
- Storm water channels;
- Henry's dam;
- Storm water dam; and
- Driefontein dam.

Analysis results are indicated in **Figure 216**.

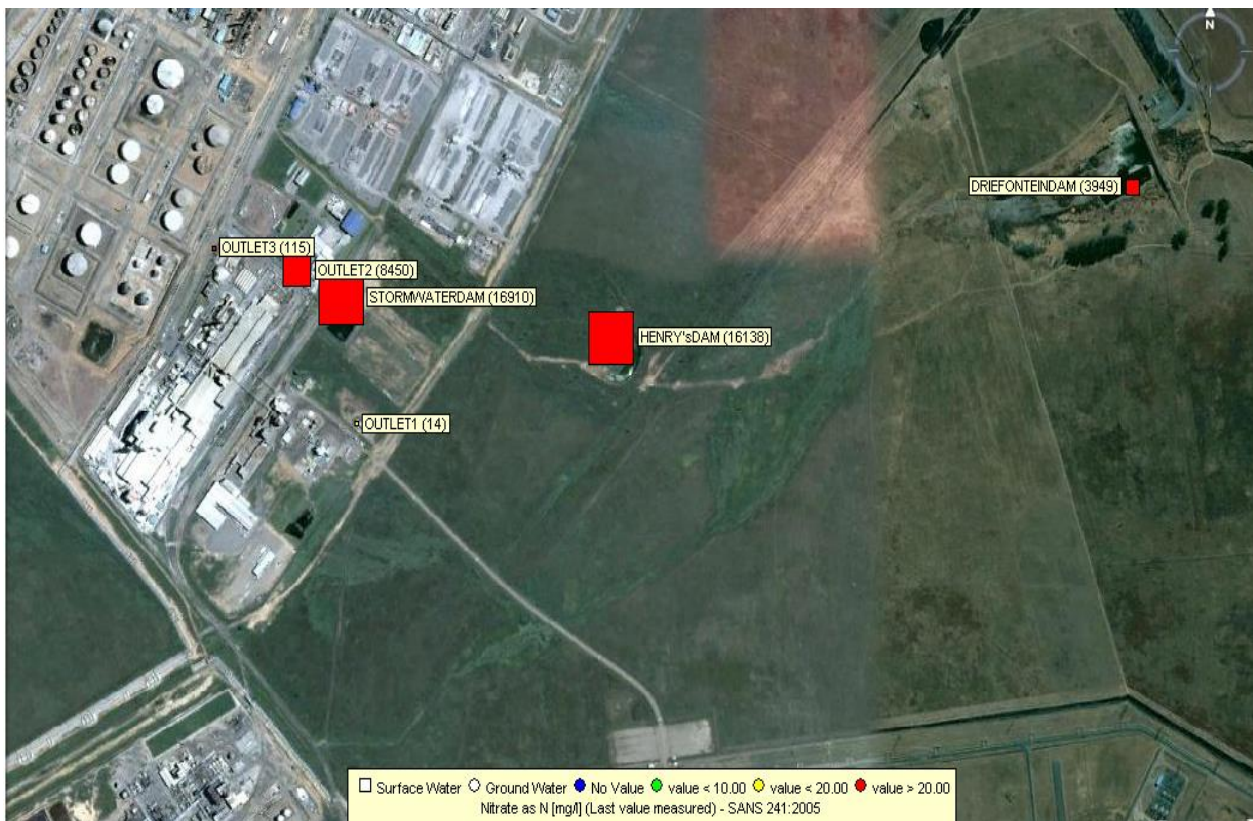


Figure 216: Nitrate surface water monitoring results.

7.12 SULPHATE (SO₄)

Sulphate concentrations exceed the drinking water standards at Henry's dam, the Storm water dam and Driefontein dam. Although sulphates have been detected at the 3 Outlets, the concentrations are low. Sulphur is known as the fourth major plant nutrient.

Major chemical sources of sulphates are ammonium sulphate and ASN. Sulphur is generated as a nutrient by the use of sulphuric acid for producing phosphate fertilisers.

The main potential pollution sources of sulphates on site are the:

- Granulation plant;
- Raw material store;
- Product store;
- Liquids plant;
- Speciality blending plant;
- Effluent dam; and
- Stores and loading bays.

The sulphur contaminants are transported off- site through storm water to the following areas

- Henry's dam;
- Storm water dam; and
- Driefontein dam.

Analysis results are indicated in **Figure 217**.

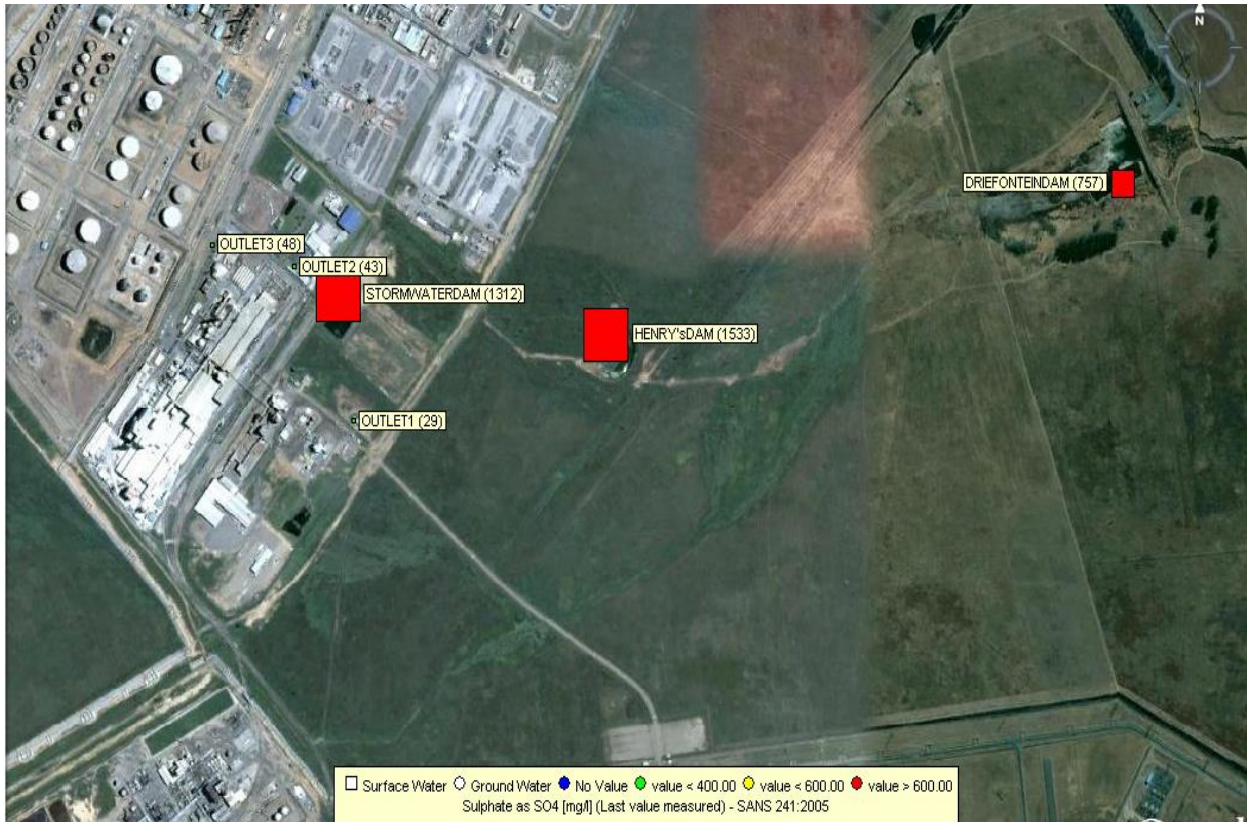


Figure 217: Sulphate surface water monitoring results.

7.13 TOTAL DISSOLVED SOLIDS (TDS)

TDS concentrations significantly exceed the drinking water standards at Outlet 2, Henry’s dam, the Storm water dam and Driefontein dam.

Henry’s dam has almost double the TDS concentration if compared with the storm water dam. This might be indicative of historical accumulation of salts due to the storm water dam only being constructed in 2006.

Henry’s dam, the Storm water dam and Driefontein dam are major point pollution sources for ground water. Analysis results are indicated in **Figure 218**.

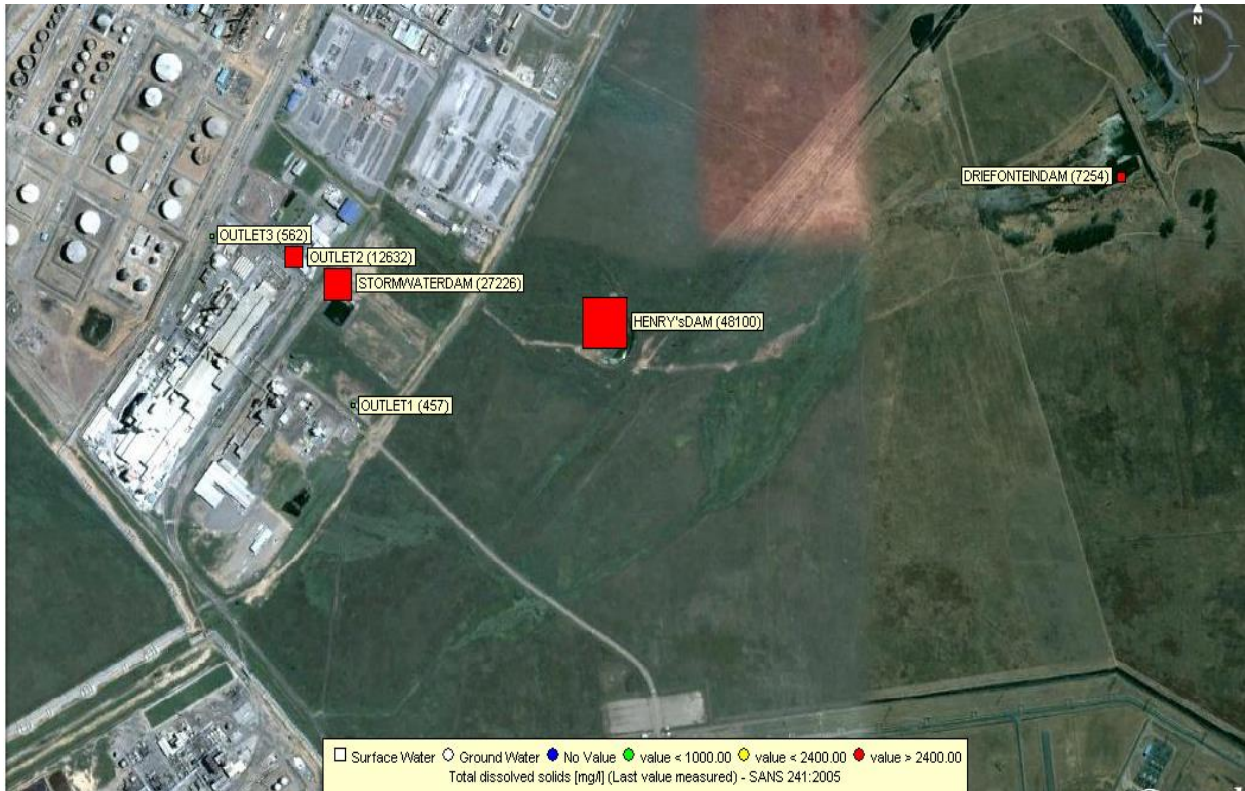


Figure 218: Total Dissolved Solids (TDS) surface water monitoring results.

7.14 pH

The pH drops steadily from Outlet 2 to Driefontein dam. This might be due to sulphate concentrations and oxidation taking place.

Analysis results are indicated in **Figure 219**.



Figure 219: pH surface water monitoring result.

7.15 Piper diagram

Figure 220 indicate that water from Outlet 2, Storm water dam, Henry's dam and Driefontein dam plot in the Ca, Mg, Cl and SO₄ dominant area. This correlates almost exactly with the Piper diagram of the ground water quality as compared to **Figure 204**. There is significant evidence that storm water run-off and temporary storage in unlined dams is a major contributor to ground water pollution in the Driefontein farm study area.

Storm water from Outlet 1 is the least impacted from operational activities and plots in the Na, Ca, HCO₃, Cl and SO₄ dominant area.

Storm water from Outlet 3 is also impacted but less than storm water from Outlet 2. Storm water quality from Outlet 3 plots in the Cl, SO₄, HCO₃, Ca, Na dominant area.

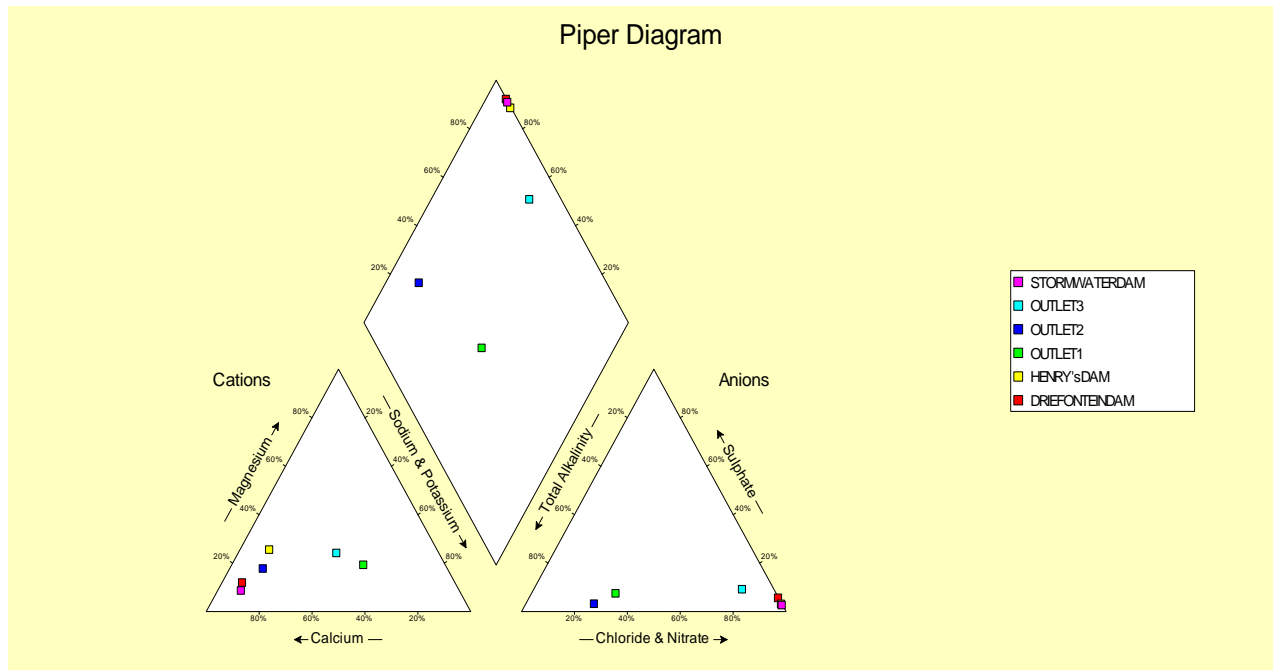


Figure 220: Piper diagram surface water.

CHAPTER 8: QUANTITATIVE RISK ASSESSMENT

8.1 HUMAN HEALTH RISK ASSESSMENT

The original paradigm for regulatory human health risk assessment has been developed by the USA National Research Council in 1983. This model has been adopted and refined by the United States Environmental Protection Agency (USEPA) and other agencies around the world and is widely used for quantitative health risk assessments (National Research Council, 1983).

The paradigm essentially entails four main steps:

- **Hazard assessment:** This relates to the identification of chemical and biological contaminants suspected to pose hazards and a description of the types of toxicity that it could cause. In contaminated land investigations it is important to obtain information on relevant agricultural and industrial activities and sources of pollution;
- **Dose response assessment (toxicological assessment):** It addresses the relationship between levels of biological exposure and the manifestation of adverse health effects in humans and how humans can be expected to respond to different doses or concentrations of contaminants. In most cases these are extrapolated from animal studies with well controlled exposures;
- **Exposure assessment:** It includes a description of the environmental pathways and distribution of hazardous substances, identification of potentially exposed individuals or communities, the potential routes of direct and indirect exposure, and an estimate of concentrations and duration of the exposure. These are often modelled values and may rely on a number of health protective assumptions; and
- **Risk characterisation:** Involves the integration of each component described above, with the purpose of determining whether specific exposures to an individual or a community might lead to adverse health effects.

8.1.1. Hazard assessment:

Area between Henry's dam and Driefontein dam: Hydrogeology

There is currently no ground water abstraction taking place between Henry's dam and Driefontein dam for domestic or agricultural purposes. There is limited risk that ground water resource development for domestic and agricultural use will take place as Driefontein Farm is zoned as an industrial area. Municipal water supply is and would be readily available in this area should Driefontein dam be developed for industrial purposes (**Figure 221**). Omnia Fertiliser Sasolburg operates a practise where farmers can collect water from the storm water dam (which contains traces of fertiliser elements). This water is then used as liquid fertiliser by the farmers on their farms. There is evidence that the farmer who rents the land from Sasol for the production of maize (Driefontein farm) has readily collected some of this water for irrigation and fertiliser practises. This practise further complicates the assessment of pollution liability as this practise also contributed to ground water pollution on Driefontein farm.

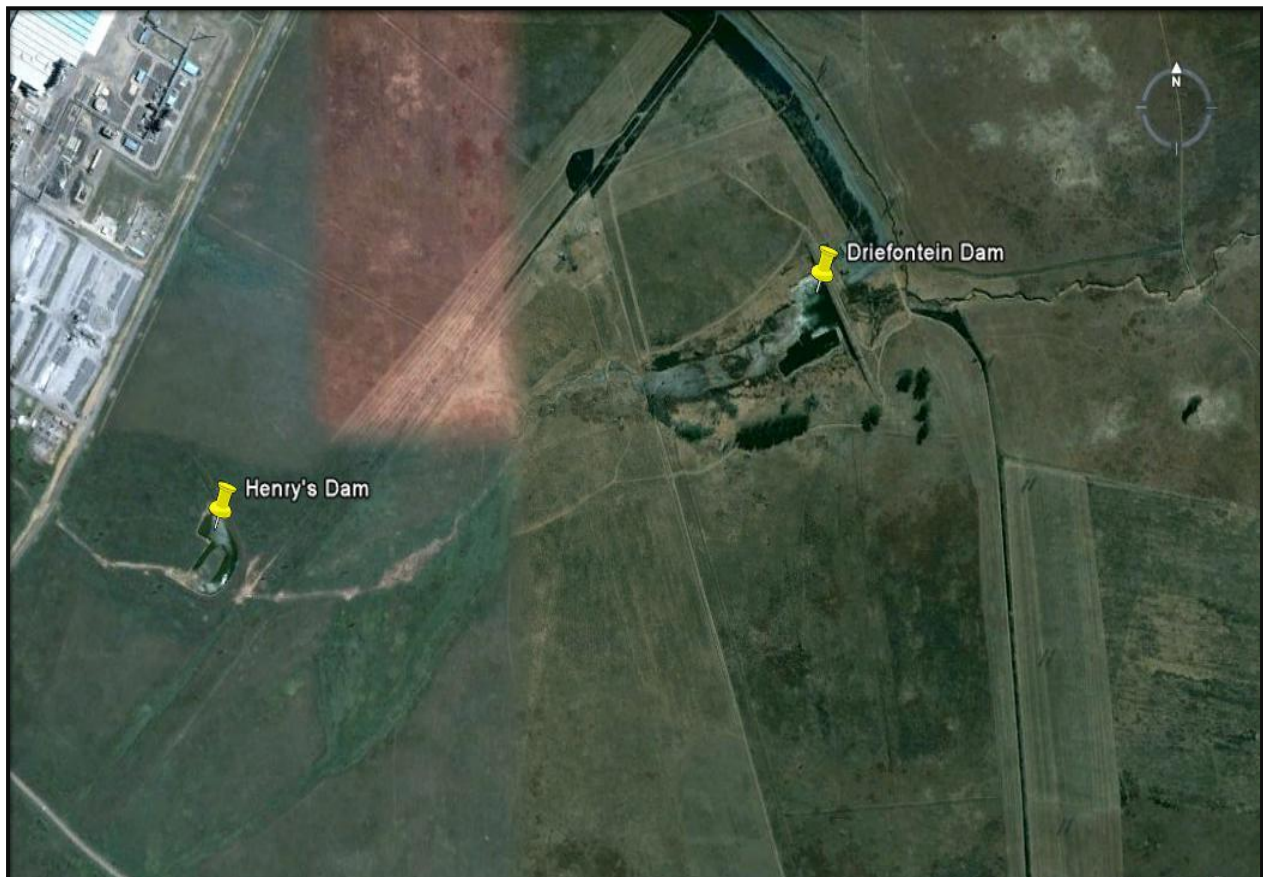


Figure 221: Area between Henry's dam and Driefontein dam (Google Earth, 2010).

Area between Henry's dam and Driefontein dam: Hydrology

Although Driefontein Farm is zoned as an industrial area, no industrial development has been conducted as can be seen in **Figure 221**.

Driefontein Farm is currently partially used for the production of maize (dry land) by a farmer who rents the property from Sasol. Henry's dam mainly obtains its water from the Omnia Fertiliser Sasolburg plant, Schumann Catalysts and storm water from Henry's street and the higher lying (South West) area of Driefontein Farm. Driefontein dam mainly obtain its water from the sites of Inca Bricks, overflow from Henry's dam, Karbochem, the lower lying and higher lying (south east) area of Driefontein Farm. This is illustrated in **Figure 222**.

The water contained in Driefontein dam has mainly the fingerprint of the water in Henry's dam. The main source of contamination in Driefontein dam is the overflow of water from Henry's dam during the rainy season. This can be seen in the water quality analysis presented in **Table 31a and 31b**.

The only element in Driefontein dam which has a higher concentration than in Henry's dam is fluoride (**Table 31b**). No fluoride was found during the sampling and analysis in Henry's dam. The fluoride concentration in Driefontein dam might be attributed from another industry such as Natref.



Figure 222: Storm water drainage from Inca Bricks and Karbochem towards Driefontein dam (Google Earth, 2010).

Area between Driefontein dam and Taaibosspruit: Hydrogeology

There is no ground water abstraction taking place between Driefontein dam and the Taaibosspruit. There is also no information on ground water quality in this area. Water used for agricultural centre pivots are contained in two dams located in a natural low lying area as indicated in **Figure 223**. There is currently limited risk that ground water as a resource will be developed in the area between the area of Driefontein dam and the Taaibosspruit for domestic or agricultural purposes. It is reasonable to assume that the groundwater yields in this area would be the same (less than 1l/s) as in the study area as the geology is mainly the same. There is thus almost no use for groundwater in this area. Depending on the quality of surface water closer to the Taaibosspruit, the surface water might have impacts as disperse pollution source on ground water quality in this area. The use of the land for agricultural purposes (centre pivot) and associated use of fertilisers might also pose a risk of pollution to ground and surface water in this area, of which nitrates would be the most prominent contaminant from farming activities.



Figure 223: Land use between Driefontein dam and the Taaibosspruit (Google Earth, 2010).

Area between Driefontein dam and Taaibosspruit: Hydrology

Table 32 represents the water quality sampled during May 2009 of Driefontein dam and it is compared to the Water Quality Guidelines for the Taaibosspruit Catchment Area (DWAF, 2009). Magnesium, manganese, fluoride, nitrate, ammonia, aluminium, phosphate, chloride, pH, electrical conductivity and chemical oxygen demand all exceed the “unacceptable” water quality guidelines while sulphates meet the “tolerable” interim water quality target. Only sodium and iron meet the “ideal” catchment water quality targets.

Driefontein dam is located approximately 3.3km from the Taaibosspruit. Land use from Driefontein dam to the Taaibosspruit is mainly agriculture. There are no communities located between Driefontein dam and the Taaibosspruit. The risk of the surface water being used for domestic purposes is thus limited. The use of surface water in this area is mainly to feed the two spill point dams as indicated in **Figure 223** for irrigation purposes. There is limited evidence that cattle farming are taking place in this area.

Table 32: May 2009 Driefontein dam water quality measured against the In Stream Water Quality Guidelines for the Taaibosspuit Catchment Area (GPT, 2009).

Element	Driefontein Dam	Ideal Catchment Background	Acceptable Management Target	Tolerable Interim Target	Unacceptable
Mg	74.00	< 8	8 - 30	30 - 70	> 70
Na	52.00	< 70	70 - 100	100 - 150	> 150
Mn	4.18	< 0.2	0.2 - 0.5	0.5 - 1.0	> 1.0
Fe	0.00	< 0.4	0.4 - 0.5	0.5 - 0.8	> 0.8
F	12.00	< 0.4	0.4 - 0.7	0.7 - 1.0	> 1.0
NO ₃	1894.60	< 0.5	0.5 - 3.0	3.0 - 6.0	> 6.0
NH ₄	448.16	< 0.25	0.25 - 0.5	0.5 - 1.00	> 1.0
Al	1.11	< 0.15	0.15 - 0.5	0.5 - 1.00	> 1.0
PO ₄	217.70	< 0.2	0.2 - 0.4	0.4 - 0.6	> 0.6
Cl	432.00	< 50	50 - 60	60 - 75	> 75
SO ₄	469.00	< 150	150 - 300	300 - 500	> 500
pH	5.50	-	7.0 - 8.5	7.0 - 9.0	< 7.0; >9.0
EC	570.00	< 42	42 - 60	60 - 70	> 70
COD	48.00	< 10	10 - 15	15 - 20	>20
SS	103.00	< 27	27 - 50	50 - 90	> 90

8.1.2. Dose response assessment:

From the hazard assessment section it can be seen that there is limited risk of ground and surface water usage for domestic purposes. Surface water in the area between Driefontein dam and the Taaibosspuit is used as a supplementary water resource for two spill point dams which is used for irrigation. The water quality of the two irrigation dams is currently unknown.

The worst case scenario (using surface water for domestic purposes at its initial element concentration as measured in Driefontein dam) is used for the human health risk assessment. The domestic use risk description is indicated in **Table 33** for the elements with their individual concentrations analysed for.

Table 33: Human health risk description for some of the elements as contained in the South African Water Quality Guidelines, Volume 1, Domestic Use (GPT, 2009).

Element	Driefontein Dam	Domestic Use Risk Description
Mg	74.00	Slight bitter taste. The taste threshold for magnesium is 70 mg/l. Scaling problems. Diarrhoea in sensitive users.

Element	Driefontein Dam	Domestic Use Risk Description
Na	52.00	No aesthetic or health effects.
Mn	4.18	Unacceptable levels of aesthetic effects. Health effects rare.
Fe	0.00	No taste, other aesthetic or health effects associated with Target Range consumption and use.
F	12.00	Severe tooth damage as above. Crippling skeletal fluorosis is likely to appear on long-term exposure.
NO ₃	1894.60	Exceptionally dangerous. Methemoglobinemia occurs in infants. Occurrence of mucous membrane irritation in adults.
NH ₄	448.16	Exceptionally dangerous. Unacceptable in domestic water. Formation of nitrite happens. Likelihood of fish deaths in aquaria. Chlorination is severely compromised in water preparation for domestic use.
Al	1.11	Intake from water exceeds 5 % of the total daily intake, but no acute health effects are expected except at very high concentrations. There may be long-term neurotoxic effects. Severe aesthetic effects (discolouration) occur in the presence of iron or manganese.
Cl	432.00	Water has a distinctly salty taste, but no health effects. Likelihood of noticeable increase in corrosion rates in domestic appliances.
SO ₄	469.00	Diarrhoea in most non-adapted individuals. Definite salty taste.
pH	5.50	Toxic effects associated with dissolved metals, including lead, are likely to occur at a pH of less than 6. Water tastes slightly sour.
EC	570.00	Water tastes extremely salty. Effects such as disturbance of the body's salt corrosion and/or scaling balance. At high concentrations, increase noticeable short-term health effects can be expected.

Ingestion has been selected as the route of exposure for drinking of surface water from Henry's dam at the analysed concentration for nitrate. The total dose can be defined as:

$$\text{Dose} = C \times \text{IR} \times \text{ED}$$

Where:

Dose = Total dose

C = Maximum concentration

IR = Average intake rate

ED = Exposure duration

The total dose for nitrate can thus be calculated as follows:

$$Dose = 1894.60mg / l \times 2l / day \times 365days$$

$$Dose = 1,383,058mg$$

Where the average intake rate has been selected as 2l/day and the exposure duration 365days.

The average daily dose is determined by dividing an estimate of the total dose accrued during the exposure duration from a pathway by an averaging time or an expected lifetime:

$$ADD = \frac{Dose}{BW \times ED}$$

8.1.3. Exposure assessment:

There is no evidence that any ground or surface water is currently utilised from Driefontein dam or from the stream leading to the Taaibosspruit for domestic purposes. There are also no boreholes in this area utilised for domestic water supply. The stream leading from Driefontein dam to the Taaibosspruit is seasonal. There is thus limited opportunity for fishing and other recreational activities. Access to this stream is mainly through private farmland. Limited risk currently exists for ground water ingestion, inhalation (water vapour) or dermal sorption, while a limited risk of surface water ingestion, inhalation (water vapour) and dermal sorption currently exist. A summary of exposure routes are included in **Table 34**:

Table 34: Exposure Routes.

Routes of exposure	Ground water exposure pathway	Surface water exposure pathway
Ingestion	Drinking ground water.	Drinking surface water.
Inhalation	Inhalation of contaminant transferred from water to vapour in air.	Inhalation of contaminant transferred from water vapour in air.
Dermal sorption	Sorption through skin in baths and showers.	Sorption through skin in baths and showers.

8.1.4. Risk characterisation:

The results from the hazard assessment, dose response assessment and exposure assessment indicate that there is currently no use of ground and surface water for domestic purposes in the area leading from Henry's dam to the Taaibosspruit. As such there is limited risk for human exposure to the quality of water resources in this area. A land use change from agricultural to residential will increase the risk.

8.2 ECOLOGICAL RISK ASSESSMENT

Fourie (2007) states that ecological risk assessment utilises Minimum Requirements (MR) available and applicable Lethal Concentration (LC50) values published in the open literature. This includes a safety factor to provide a large margin of safety so as to make provision for inter species variation and sensitivity, as well as for the fact that potential risk to the environment is based on mortality and not chronic effects. Ecological risk assessments are conducted using a phased approach. This phased approach is summarised in **Figure 224**.

No specialist studies has been performed on Driefontein farm and the area below Driefontein dam to identify the different animal species (including birds) which forms part of the ecology in this area. **Table 35** provides a simplified overview of the expected receptor groups in this area.

Table 35: Land use and ecological receptor groups.

Land use	Receptor group	Critical receptor	Exposure pathway
Agricultural: (Henry's dam to Taaibosspruit).	Water fowl.	All species present in the ecological area.	Ingestion, inhalation (water vapour), dermal sorption of surface water.
Agricultural: (Henry's dam to Taaibosspruit).	Small animals such as mice etc.	All species present in the ecological area.	Ingestion, inhalation (water vapour), dermal sorption of surface water.
Agricultural: (Henry's dam to Taaibosspruit).	Birds.	All species present in the ecological area.	Ingestion of surface water.

No fatalities of any animals have been observed at Henry’s dam, Driefontein dam or the stream below Driefontein dam leading towards the Taaibosspuit in the past three years. No specialised study has been conducted on this as Sasolburg is mainly deemed an industrial area in which a number of pollution sources are located. **Table 36** provides an overview of the acceptance level of mortality rates against risk criteria.

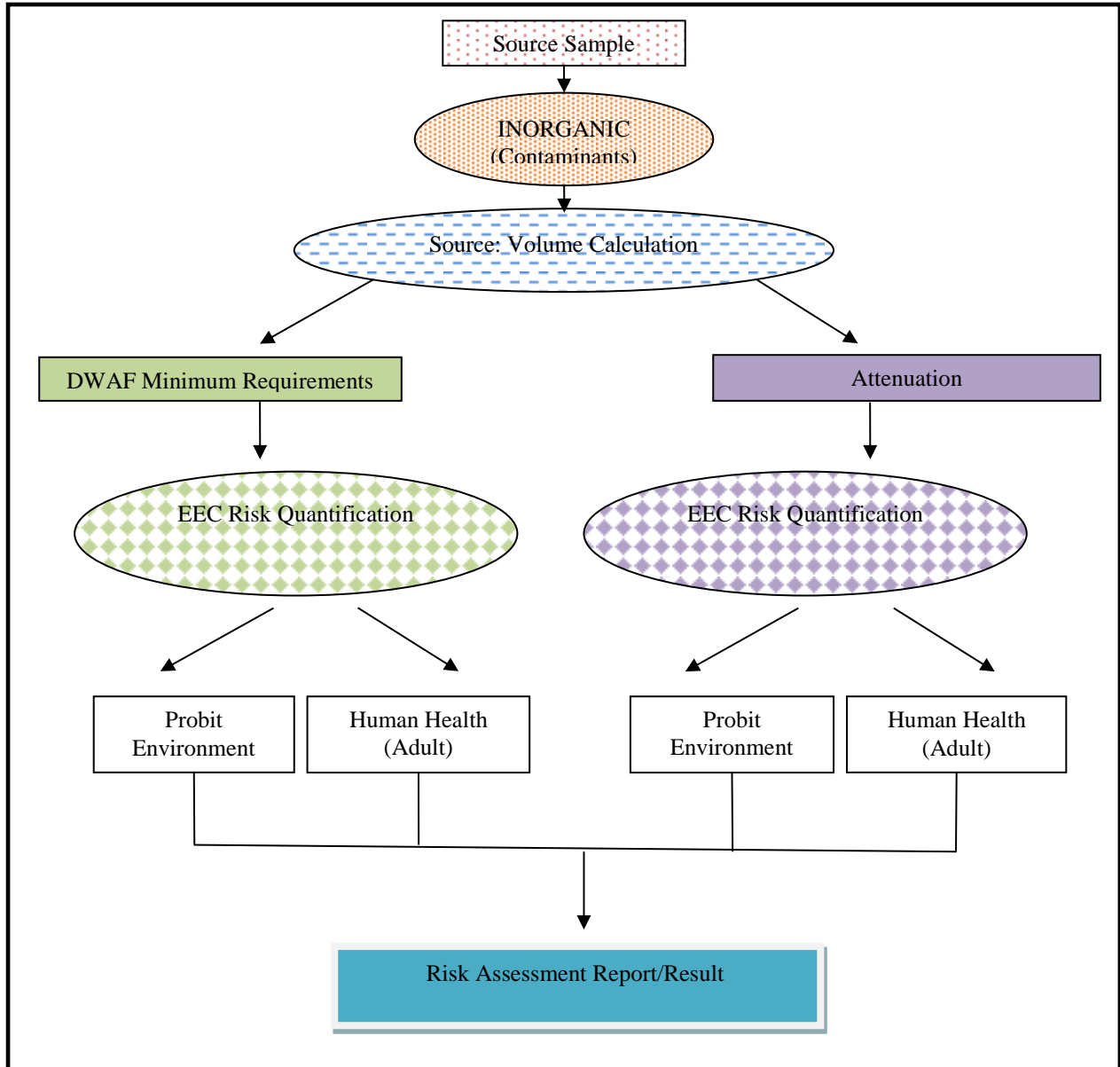


Figure 224: Ecological Risk Assessment Process (Fourie, 2007).

Table 36: Mortality Rates (Fourie, 2007)

Risk Classification	Mortality Rate	Population Size
High Risk	One mortality in a population of	100

Risk Classification	Mortality Rate	Population Size
Medium Risk	One mortality in a population of	101-10,000
Low Risk	One mortality in a population of	10,001-300,000
Acceptable Risk	One mortality in a population of	>300,000

The results of the surface water analysis done at Driefontein dam during May 2009 indicates that manganese, fluoride, ammonia, inorganic nitrogen, aluminium, zinc and phosphate as potassium exceed the DWAF aquatic ecosystem standard and interim targets. Ammonia, inorganic nitrogen, nitrates and phosphate as potassium significantly exceed the standard (**Table 37**).

The levels of nitrates and phosphates observed in Driefontein dam leads to hyper-eutrophic conditions which usually cause excessive algal blooms. This significantly reduces oxygen level creating “dead zones” beneath the surface. The relationship between measurable nutrient enrichment and measurable toxicity is indicated in **Figure 225**. **Figure 226** provides a close-up view of Driefontein dam where excessive algal blooms is evident.

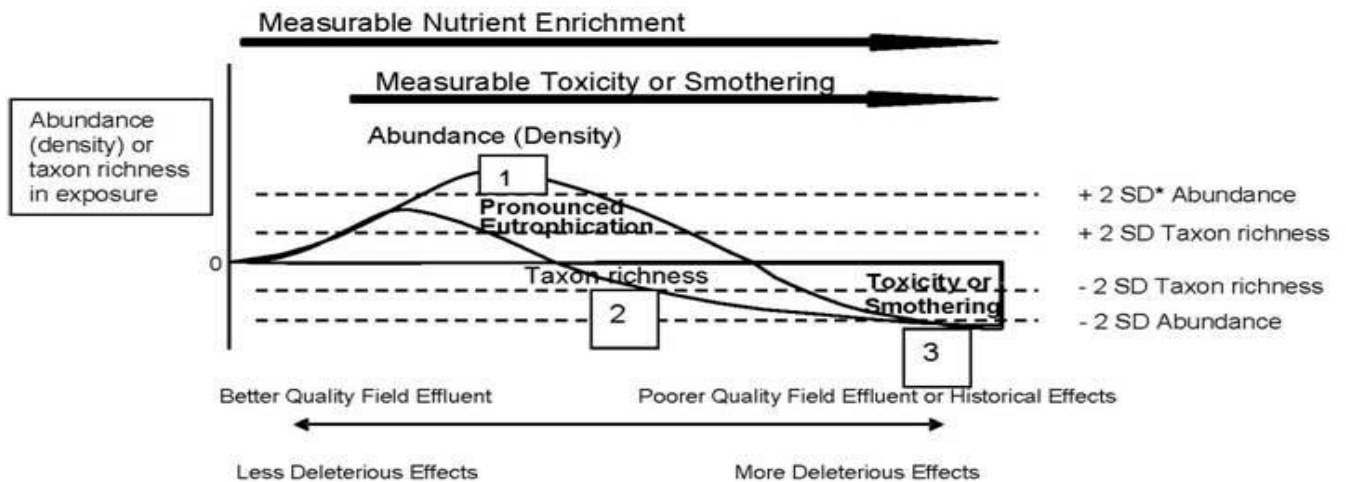


Figure 225: Relationship between measurable nutrient enrichment and measurable toxicity (Environment Canada, 2010).



Figure 226: Excessive algal blooms in Driefontein dam (Google Earth, 2010).

Table 37: Results of the surface water cation and anion analysis (DWA Aquatic ecosystem standard and interim targets, May 2009, measured against DWA 1996, South African water Quality Guidelines, volume 7, Aquatic Ecosystem second edition (GPT, 2009).

Element	Driefontein dam	Chronic	Acute	Chronic	Acute
		pH<6.5		pH>6.5	
Ca	342.00	-	-	-	-
Mg	74.00	-	-	-	-
Na	52.00	-	-	-	-
K	128.00	-	-	-	-
Mn	4.18	0.037	1.3	0.037	1.3
Fe	0.00	-	-	-	-
F	12.00	1.5	2.54	1.5	2.54
NO ₂	0.00	-	-	-	-
NO ₃	1894.60	-	-	-	-
NH ₃	423.12	0.015	0.1	0.015	0.1
Inorganic N	776.00	0.5	2.5	0.5	2.5
Si	14.00	-	-	-	-
Al	1.11	0.010	0.100	0.020	0.15
Zn	0.89	0.0036	0.036	0.0036	0.036
B	0.47	-	-	-	-
PO ₄	217.70	-	-	-	-

PO₄ as P	71.00	0.005	0.025	0.005	0.025
HCO₃	34.16	-	-	-	-
Cl	432.00	-	-	-	-
SO₄	469.00	-	-	-	-
TDS by sum	4077.00	-	-	-	-
M-Alk (CaCO₃)	28.00	-	-	-	-
pH	5.50	-	-	-	-
EC	570.00	-	-	-	-
COD	48.00	-	-	-	-
SS	103.00	100	110	100	110

8.3 DWAF In Stream Water Quality requirements for the Taaibosspruit Catchment Area

DWAF surface water sampling points for the Taaibosspruit catchment area are indicated in

Figure 228. There are 5 sampling points:

- Leeuspruit in Sasolburg;
- Taaibosspruit weir;
- Tributary downstream of Driefontein dam outlet;
- Taaibosspruit tributary; and
- Stream from Webb's farm.

The results from 01 July 2009 to 30 June 2010 indicate the following water quality concerns:

8.3.1 Leeuspruit in Sasolburg:

Dissolved oxygen and faecal coliforms are problematic and regularly exceed the catchment water quality targets. The high levels of faecal coliforms might be due to municipal sewage systems overflowing into the Leeuspruit.

8.3.2 Taaibosspruit weir:

Dissolved oxygen and faecal coliforms are problematic and regularly exceed the catchment water quality targets. The high levels of faecal coliforms might be due to sewage systems overflowing of upstream farms and communities into the Taaibosspruit.

8.3.3 Tributary downstream of Driefontein dam outlet:

Chemical oxygen demand, nitrates and conductivity are almost always exceeds the catchment water quality targets, while chloride, fluoride and phosphate also on instances exceeded the catchment water quality targets.

The sampling point is below Driefontein dam which water quality mainly constitutes fertiliser associated chemicals from Omnia Fertiliser Sasolburg and the historical Natref effluent outlet to the Taaibosspruit.

8.3.4 Taaibosspruit tributary:

Chemical oxygen demand, dissolved oxygen and faecal coliforms exceed the catchment water quality targets. The high levels of faecal coliforms might be due to sewage systems overflowing of upstream farms and communities into the Taaibosspruit.

8.3.5 Stream from Webb's farm:

Ammonia, chloride, electrical conductivity and phosphates significantly exceed the catchment water quality targets. Sasol Midland (Polypropylene) uses the stream through Webb's farm for effluent release to the Taaibosspruit. The average electrical conductivity was 654 for the period 2009/2010 (Sasol, 2006). **Figure 228** indicate the main release points of effluent and its flow paths towards the Taaibosspruit.

Table 38: Quarterly water quality status of the Leeu and Taaibospruit catchment 01 July 2009 to 30 June 2010 (Rand Water, 2009).

Sample Points	Sample Point Description	Sample Date	Al	NH4	COD	Cl	EC	Daphnia Toxicity	DO	Faecal Coliforms	F	Fe	Mg	Mn	NO3	pH	PO4	Na	SO4	SS
LS1	Leeuspruit @ Sasolburg S26.802 E27.799	01/07/09-30/09/09	<0.01	0.61	21	105	99	-	6.3	275	0.82	0.02	16	0.29	0.49	8.2	<0.05	83	185	13
		01/10/09-31/12/09	0.03	0.86	30	44	58	-	2.1	16,900	0.62	0.05	11	0.36	0.27	8.0	0.28	41	77	21
		01/01/10-31/03/10	0.06	0.12	27	78	84	-	5.1	3,080	0.75	0.09	18	0.33	0.67	8.0	0.45	66	135	16
		01/04/10-30/06/10	0.04	1.04	18	92	106	-	3.8	-	0.65	0.03	15	0.53	1.12	7.8	0.14	85	225	12
T1	Taaibospruit Weir S26.823 E27.933	01/07/09-30/09/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		01/10/09-31/12/09	0.04	0.12	19	22	46	100	5.8	5,040	0.34	0.04	18	0.02	<0.10	8.3	<0.05	24	54	78
		01/01/10-31/03/10	0.38	0.12	37	<10	25	100	6.7	3,120	0.22	0.40	9	0.03	<0.10	7.8	0.05	11	17	54
		01/04/10-30/06/10	0.47	0.12	27	16	30	100	6.6	-	0.17	0.38	13	0.03	0.13	7.9	0.07	21	26	106
T3	Tributary downstream of Driefontein Dam outlet S26.809 E27.879	01/07/09-30/09/09	0.02	0.12	30	29	78	-	6.1	-	0.57	0.02	26	0.01	29.0	8.3	0.34	45	75	<10
		01/10/09-31/12/09	0.02	0.12	29	32	70	-	8.7	-	0.60	0.03	20	0.04	14.0	8.2	0.62	30	77	<10
		01/01/10-31/03/10	0.03	0.12	24	23	84	-	5.1	-	0.74	0.02	29	0.10	23.0	8.5	0.32	26	160	<10
		01/04/10-30/06/10	0.43	0.12	42	81	184	-	7.0	-	4.78	0.03	42	0.89	18.0	7.5	0.36	55	195	17
TT1	Taaibospruit Tributary S26.884 E27.923	01/07/09-30/09/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		01/10/09-31/12/09	0.07	0.12	25	29	43	-	3.5	320	0.33	0.05	13	<0.01	<0.10	8.0	<0.05	30	54	-
		01/01/10-31/03/10	0.42	0.12	42	14	25	-	5.1	1,270	0.33	0.37	8	0.02	<0.10	7.6	<0.05	13	14	-
		01/04/10-30/06/10	0.19	0.12	39	55	33	-	5.9	-	0.22	0.17	26	0.08	0.14	7.3	<0.05	42	20	-
TW2	Stream from Webb's Farm S26.804 E27.910	01/07/09-30/09/09	<0.01	0.21	-	120	82	-	8.6	165	0.68	0.02	20	0.11	0.79	8.2	1.50	66	88	-
		01/10/09-31/12/09	<0.01	0.12	-	145	85	-	6.8	960	0.74	0.03	17	0.18	0.45	7.9	1.90	72	75	-
		01/01/10-31/03/10	0.01	1.40	-	195	115	-	5.6	870	0.94	0.04	26	0.13	1.80	7.9	1.90	72	145	-
		01/04/10-30/06/10	0.01	0.29	-	185	104	-	7.1	-	0.61	0.04	28	0.10	3.49	8.1	1.14	90	109	-

Key: Water Quality Guidelines

Ideal	Acceptable	Tolerable	Unacceptable
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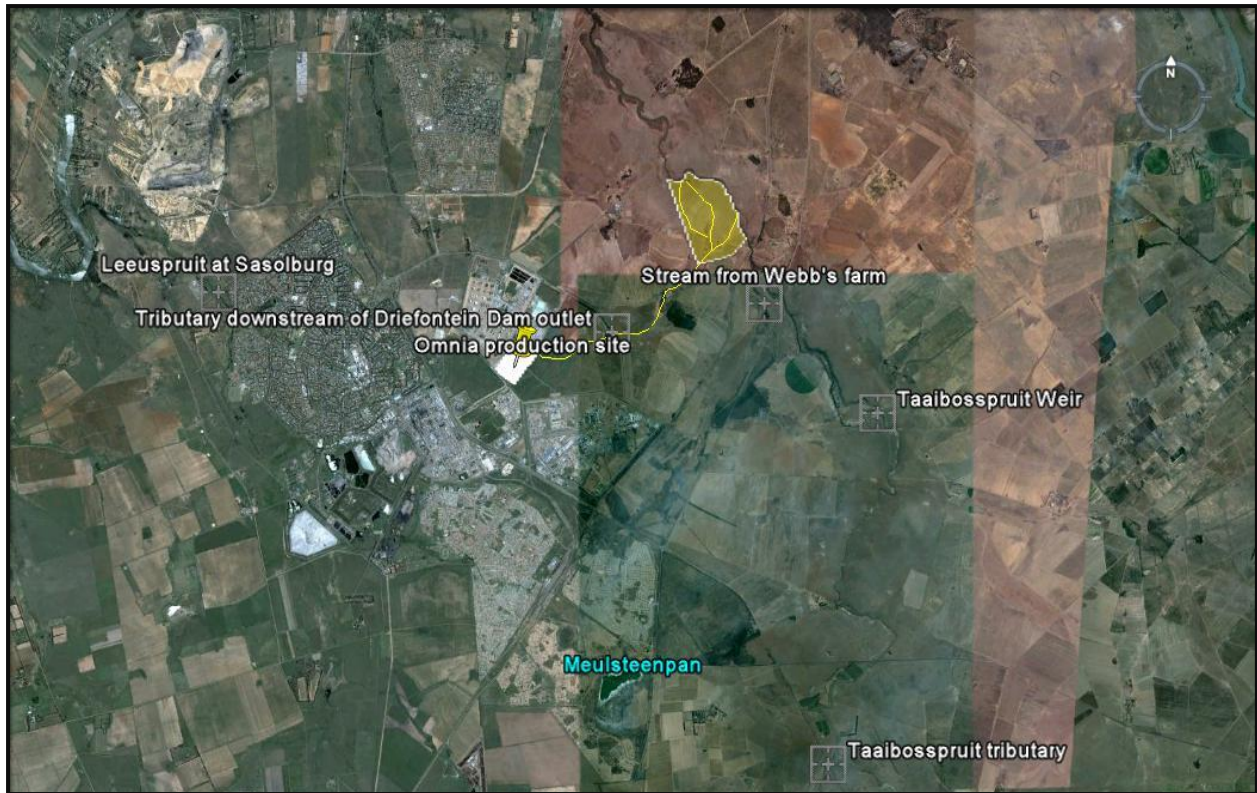


Figure 227: DWAFF Taaibosspruit catchment area sampling points (Google Earth, 2010).

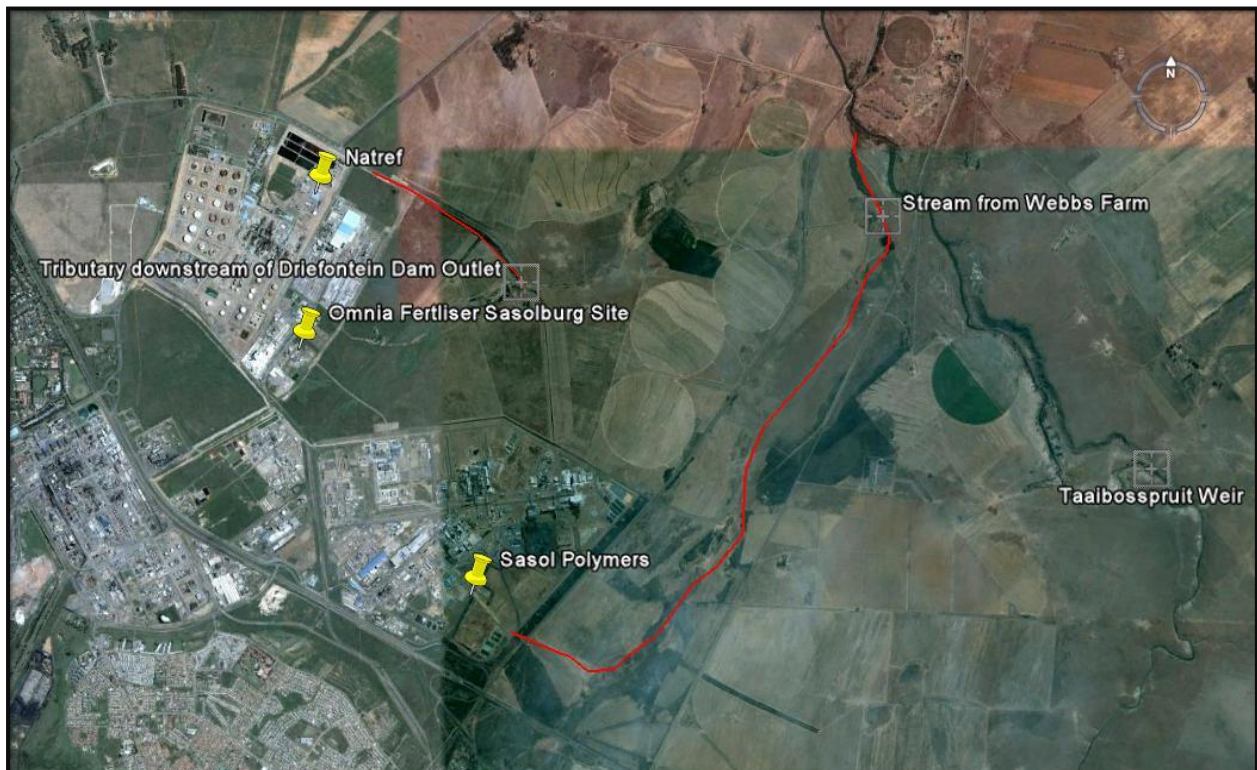


Figure 228: DWAFF Natref and Sasol Polymers effluent release streams in relation to the Taaibosspruit catchment monitoring points (Google Earth, 2010).

CHAPTER 9: ENVIRONMENTAL LEGISLATIVE FRAMEWORK IN SOUTH AFRICA AND ITS APPLICABILITY TO THE OMNIA FERTILISER SASOLBURG SITE

Numerous changes have occurred over the past two decades in the constitutional, legislative, political, socio-economic and international arena within South Africa. Environmental protection was historically seen as equal to the conservation of bio-diversity in parks, reserves and limited development areas. It was however soon discovered that the utilisation of environmental resources in South Africa and in the rest of the world, must be aimed at achieving an equitable balance between environmental protection, social upliftment and economic growth through the use and implementation of reasonable legislative and fiscal instruments (1998/36). The government's pursuit of achieving this balance is evident in the dynamic legislative processes that have taken place in South Africa since the early 1990's. These legal processes culminated in the promulgation of the National Environmental Management Act, (NEMA), and hence the dawning of a new era for matters incidental to the environment. This new era moved away from "environmental conservation" towards "environmental management", as can be seen in the titles of the two acts, namely the Environment Conservation Act (ECA) of 1989 and the NEMA of 1998.

The South African constitution (Act 108 of 1996) must be seen as a main driving force in this process. It ensures every citizen's right to a clean and sustainable environment through reasonable legislative and other measures that: prevent pollution and ecological degradation, promotes conservation, and secures ecological sustainable development and the use of natural resources while at the same time promoting justifiable economic and social development.

9.1 CONSTITUTION OF SOUTH AFRICA

The Constitution of the Republic of South Africa (1996) as adopted by the Constitutional Assembly on 8 May 1996 and as amended on 11 October provide in Section 24, that everyone has the right to an environment that is not harmful to their health or well-being and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:

- Prevent pollution and ecological degradation;
- Promote conservation; and
- Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Section 38 of the Constitution (1996) provides for certain persons listed in that section to approach a competent court if the right in terms of Section 24 of the Constitution has been infringed or threatened.

9.2 NATIONAL WATER ACT (Act 36 of 1998)

The National Water Act, No. 36 of 1998 (NWA) recognises that water is a natural resource that belongs to all people. The NWA regulates the manner in which persons obtain the right to use water and provides for just and equitable utilisation of water resources.

Sustainability and equity are identified as central guiding principles in the protection, use and management of water resources. These guiding principles recognise:

- The basic human needs of present and future generations;
- The need to protect water resources;
- The need to share some water resources with other countries; and
- The need to promote social and economic development through the use of water.

National government, acting through the Minister of Water Affairs, is responsible for the achievement of these fundamental principles. Being empowered to act on behalf of the nation, the Minister has the ultimate responsibility to fulfil certain obligations relating to the use, allocation and protection of water resources.

After providing for the basic needs of humans, the only other water that is provided as a right, is the Environmental Reserve - to protect the ecosystems that underpin our water resources, now and into the future. It is the duty of Government, as part of its public trust function, to assess the needs of the environmental reserve and to make sure that this amount of water, of an appropriate quality, is set aside.

A system is needed to work out the environmental reserve. There are a range of methods, some developed specifically in and for South African conditions that can be used to determine the quantity and quality of water needed, and the level of habitat protection that is needed. While the aim of protecting water resources is clear, the definition and selection of an acceptable level of protection may change over time.

Mechanisms and powers needed to ensure water for these purposes must be identified and provided. In many catchments all available water has already been allocated without taking these requirements fully into account. No claim for existing water-use rights that limits the water required for basic needs will be recognised. Where the needs of the Environmental Reserve cannot be met because of existing developments, provision must be made for active intervention to protect the water resources.

The NWA (36/1998) is the most important law regulating water management in South Africa. The main issues regulated by the act are:

- Pollution prevention (Section 19);
- Emergency incidents (Section 20);
- Water use licensing (Section 21);
- Water wastage; and
- Dam safety.

9.2.1 Water pollution prevention (Section 19)

Section 19 of the NWA (36/1998) requires landowners and persons in control of land to take reasonable measures to prevent the contamination of water resources. Where the extent that potential sources of water pollution cannot be eliminated altogether, containment measures must be provided to prevent the movement of pollutants.

9.2.2 Control of emergency incidents (Section 20)

In this section of the NWA (36/1998) "incident" includes any incident or accident in which a substance:

- Pollutes or has the potential to pollute a water resource; or
- Has, or is likely to have, a detrimental effect on a water resource.

In this section, "responsible person" includes any person who:

- Is responsible for the incident;
- Owns the substance involved in the incident; or
- Was in control of the substance involved in the incident at the time of the incident.

The responsible person, any other person involved in the incident or any other person with knowledge of the incident must, as soon as reasonably practicable after obtaining knowledge of the incident, report to:

- The Department;
- The South African Police Service or the relevant fire department; or
- The relevant catchment management agency.

A responsible person must:

- Take all reasonable measures to contain and minimise the effects of the incident;
- Undertake clean-up procedures;
- Remedy the effects of the incident; and
- Take such measures as the catchment management agency may either verbally or in writing direct within the time specified by such institution.

A verbal directive must be confirmed in writing within 14 days, failing which it will be deemed to have been withdrawn.

Should:

- The responsible person fail to comply, or inadequately comply with a directive; or
- It not be possible to give the directive to the responsible person timeously, the catchment management agency may take the measures it considers necessary to:

- i) Contain and minimise the effects of the incident;
- ii) Undertake clean-up procedures; and
- iii) Remedy the effects of the incident.

The catchment management agency may recover all reasonable costs incurred by it from every responsible person jointly and severally. The costs claimed under may include, without being limited to, labour, and administration and overhead costs.

If more than one person is liable, the catchment management agency must, at the request of any of those persons, and after giving the others an opportunity to be heard, apportion the liability, but such apportionment does not relieve any of them of their joint and several liabilities for the full amount of the costs.

9.2.3 Water use licensing (Section 21)

Section 21 of the NWA (36/1998) lists eleven water uses that may not be carried out without a water use license issued in terms of the Act, unless the use in question:

- Is an “existing lawful water use” (e.g. the use was authorised under the 1956 Water Act);
- Is listed in the First Schedule to the Act;
- Is authorised by a General Authorization published by the Department to Water Affairs and Forestry in the Government Gazette; or
- The relevant authority has waived the licensing requirement.

For the purpose of the Act water use includes:

- (a) Taking water from a water resource, more than 10 cubic meters per day per property from a borehole;
- (b) Storing more than 10 000 cubic meters on any property;
- (c) Impeding or diverting the flow of water in a watercourse;
- (d) Engaging in a stream flow reduction activity contemplated in section 36;

- (e) Engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
- (f) Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- (g) Disposing of waste in a manner which may detrimentally impact on a water resource;
- (h) Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
- (i) Altering the bed, banks, course or characteristics of a watercourse;
- (j) Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
- (k) Using water for recreational purposes.

This wide-ranging definition includes activities impacting on the physical system which contains water, even though the water may not be found there at a particular point in time. It should be noted that the term "water use" also includes polluting activities. This wide definition of "water use" reflects a holistic approach, which implicitly recognises the unity of the hydrological cycle.

Chapter 4 of the NWA (36/1998) then goes on to provide for permissible water use. It provides that a person may only use water if:

- Authorised by a licence (or if the responsible authority has dispensed with the licence requirement); or
- If the water use is permissible as continuation of an existing lawful water use; or
- If the water use is permissible in terms of a general authorisation issued under section 39.

9.2.4 Water Wastage (Section 22)

Section 22(2) of the NWA (36/1998) prohibits the wastage of water. This means that Omnia Fertiliser Sasolburg must be able to demonstrate optimal water use, and that they must be able to detect water losses.

Summary: Omnia Fertiliser Sasolburg has applied for a water use license in order to obtain authorisation for its water uses. Water quality requirements for groundwater as required by the Department of Water Affairs are not risk based and cannot be substantiated by the reserve determination in the catchment. Omnia Fertiliser Sasolburg had a significant impact on water resources in the catchment area where it is located together with surrounding industries. Most of this impact occurred prior to the new Constitution and its related Acts.

Omnia has invested a significant amount of money and improvement in documented operational controls in recent years to better manage water resource impacts as required by new regime legislation.

9.3 NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA, ACT 108 of 1998)

NEMA (108/1998) provides direction for the enactment of the constitution. NEMA came into operation in January 1999. It is the flagship environmental statute of South Africa. NEMA's primary purpose is to provide for co-operative environmental governance by establishing principles for decision-making on all matters affecting the environment. NEMA also establishes procedures and institutions that will promote public participation in environmental management.

Section 2 of NEMA (108/1998) sets out the environmental management principles that apply throughout South Africa to the actions of all organs of state (including local and municipal government) that may significantly affect the environment. These principles serve inter alia as guidelines as reference to which any organ of state must exercise any function when taking any decision in terms of NEMA. One of these principles requires that development must be socially, environmentally and economically sustainable (section 2(3)). In terms of section 2(4)(a)(ii), sustainable development requires that “pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied.”

In terms of section 28(1) of NEMA every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring.

9.3.1 Polluter Pays (NEMA Section 2)

The 'polluter pays' principle provides that 'the costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment' (108/1998). NEMA imposes a duty of care on every person who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent the pollution or degradation of the environment from occurring, continuing or reoccurring. Insofar as such harm to the environment is authorised by law or cannot reasonably be avoided, NEMA requires that the pollution or degradation must be minimised and rectified.

Government may direct any person who fails to take these reasonable measures, to commence, continue and complete the reasonable measures. Should a person fail to comply with a directive, Government may take reasonable measures to remedy the situation and recover all the costs of remediation from specified persons which will include the person who failed to take the reasonable measures. Liability may be apportioned according to the degree to which each person was responsible for the harm to the environment.

NEMA makes provision for damages to be awarded by the courts where loss or damage has occurred as a result of a contravention of certain environmental statutes. In addition, some offences under certain environmental statutes (for example, the National Water Act, No. 36 of 1998 and the Environment Conservation Act No. 73 of 1989) may result in penalties being imposed in terms of NEMA.

Importantly, NEMA provides for the liability on conviction of employees, managers, agents and directors for any offences resulting from the failure to take all the reasonable steps that were necessary under the circumstances to prevent the commission of an offence.

The costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment.

The principles, as simplified above, set the stage for the legislator to develop a cohesive body of generally acceptable environmental management practices.

9.3.2 Duty of Care and Remediation of Environmental Pollution (NEMA Section 28)

In terms of the precautionary approach or “Duty of Care”, it is required that all operations must be able to demonstrate that all reasonable measures have been taken to prevent clean water from becoming polluted. The fundamental principle is to prevent, inhibit, retard or stop the hydrological, chemical, microbiological, radioactive or thermodynamic processes, which result in the contamination of the water environment, at the point where the deterioration in water quality originates, or to implement physical measures to prevent or retard the transport of the generated contaminants to the water resource. This principle can be applied in many different ways, with the following examples illustrating but a few:

- Apply effective storm water management to ensure that clean runoff is maximised and diverted to the receiving streams, while contaminated runoff is minimised and contained for reuse within the operations;
- Locate waste residue deposits in areas where there is a minimum potential for contamination of the surface and ground water resource and construct water management facilities to intercept and contain any contaminated runoff and/or seepage;
- Apply appropriate geochemical assessment techniques to the evaluation of design, on-going operation and rehabilitation measures for waste residue deposits in order to identify those options that will minimise the long-term pollution risks of such facilities;
- Apply appropriate geochemical assessment techniques to the design of site closure strategies for impacted operational areas in order to identify those options that will minimise the long-term pollution risks of such facilities;
- Ensure that all dirty water dams and infrastructure does not pose a risk of ground water and surface water contamination; and

- Apply the most appropriate and long-term sustainable mining method for the specific situation, both in terms of socio-economic issues and environmental protection (108/1998).

“Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment” (108/1998).

Subsection (1) also applies to a significant pollution or degradation that:

- Occurred before the commencement of this Act;
- Arises or is likely to arise at a different time from the actual activity that caused the contamination; or
- Arises through an act or activity of a person that results in a change to pre-existing contamination.

The significance of Section 28 is that it gives effect to retrospective measures that are required to minimise and rectify significant pollution that “has (been) caused”. The “significance” of the pollution needs to be considered in the light of the constitutional right to an environment conducive to health and well-being, as well as the relevant principles in NEMA and in particular the precautionary principle of risk aversion. However, NEMA also lists the ‘conflicting’ polluter pays principle that suggests that the threshold level of significance is not particularly high Glazewski (2000). In retrospect, one should appreciate the pragmatic approach that NEMA has taken in view of a developing economy that has historically been based on the exploitation of the country’s mineral wealth.

9.3.3 Control of emergency incidents (Section 30)

Section 30 of NEMA (108/1998) gives a clear layout of the definition of an “incident”. An incident is defined as an unexpected sudden occurrence, including major emission, fire or

explosion leading to serious danger to the public or potentially serious pollution of or detriment to the environment, whether immediate or delayed.

The relevant parties involved in the control of an emergency incident are identified as:

- The responsible person (owner, person in control of the substance at the time of the incident), and
- The relevant authority

There are a number of broad steps to be taken after an incident has occurred:

- i) The relevant authority may take certain steps if it is necessary to do so;
- ii) The responsible person must assess the nature of the risk to public health and safety in order to report the outcome thereof to certain parties as identified in the act;
- iii) The responsible person or his / her employer must undertake clean-up procedures as required by the nature of the incident as well as the guidance given to him / her in this section of the act; and
- iv) The responsible person must subsequently forward a report to the relevant authority within 14 days of the accident. The structure of the report is stipulated in this section of the act.

Summary: Omnia Fertiliser Sasolburg has had a significant impact on water resources in the catchment area where it is located together with surrounding industries. Most of this impact occurred prior to the new Constitution and its related Acts such as NEMA. Omnia has recently taken reasonable measures such the construction of additional pollution control dams to contain site run-off at significant cost. Additional projects to prevent the infiltration of water on the productions site has also been undertaken e.g. paving of transport areas to decrease the permeability of these areas.

9.4 NATIONAL ENVIRONMENTAL MANAGEMENT: WASTE ACT (ACT 56 of 2009)

Tucker (2007) indicated in 2007 that the proposed section in the National Environmental Management: Waste Act, (NEM:WA) dealing with contaminated land will be the most significant aspect of the newly proposed act.

During September 2010, the Department of Water and Environmental Affairs (DWEA) Minister, Buyelwa Sonjica has placed emphasis on the contaminated land section (Section 8) of the NEM:WA during the first annual waste management officers conference held in Johannesburg. The minister confirmed that the NEM:WA which came into force in July 2009, will place focus on contaminated land. As part of this focus the DWEA has concluded the framework for remediation of contaminated land. “I will soon be able to identify contaminated land and order investigations to determine the extent of contamination as well as the form of remediation required” (Sonjica, 2010). A database of contaminated land is said to be drawn up and linked to the deeds register. The minister further committed that government will strictly apply the “polluters pay principle”. She has left no uncertainty that it would be expected from owners of contaminated land to develop remediation plans and to disclose the contamination to the deeds office.

It is the opinion of this author that the NEM:WA (56/2009) has placed a concept (foundation) principle in Section 8 (Contaminated land) which is likely to develop over time (through the promulgation of Regulations) to a comprehensive contaminated site liability legal framework such as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) promulgated in the USA in 1980 (EPA, 2011). The basic legal principles which support a contaminated site liability legal framework have already been documented in South Africa law:

- Right of all persons to a clean and safe environment;
- Duty of care and remediation of environmental pollution;
- Polluter pay principle;
- Control over emergency incidents;

- Reporting of incidents; and
- Identification, investigation, registration and remediation of contaminated land and water resources.

9.4.1 Contaminated land (Section 8)

This part of the Act applies to the contamination of land even if the contamination:

- Occurred before the commencement of this Act;
- Originated on land other than the land that is identified in terms of section 42;
- Arises, or may arise, at a different time from the actual activity that caused the contamination; or
- Arises through an act or activity of a person that results in a change to pre-existing contamination (56/2009).

Identification and notification of investigation areas (Section 42)

(1) The Minister or MEC may, by notice in the Gazette, identify as investigation areas:

- Land on which specified high-risk activities take place, or have taken place, and that may result in land contamination; and
- Specified land that the Minister or MEC suspects to be contaminated.

For the purposes of subsection (1), contamination refers to the presence of a significant risk of harm, whether or not that risk eventuated prior to the commencement of this Act.

A notice published by the Minister applies nationally and a notice published by the MEC applies to the relevant province only.

Before publishing a notice in terms of subsection (1), or any amendment to the notice, the Minister or MEC must follow a consultative process in accordance with sections 77 and 78.

Subsection (4) need not be complied with if the notice is amended in a non-substantive way.

Notwithstanding the provisions of subsection (1), the Minister or MEC may issue a notice to a person in respect of specific land indicating that the Minister or MEC suspects the land to be contaminated and requiring the land to be managed as an investigation area.

Consequences of identification and notification of investigation areas (Section 43)

An owner of an investigation area contemplated in section 42, or person who undertook or undertakes the high risk activity or activity which caused, or may have caused, the contamination contemplated in section 42, must cause a site assessment to be conducted within a period specified by the Minister or MEC to determine whether:

- The land has actually been contaminated; and
- If the land has been contaminated, whether that contamination presents a significant risk of harm.

A site assessment report must be submitted to the Minister or MEC within 30 days of the site assessment being conducted.

The site assessment report must comply with any standards or guidelines published by the Minister or MEC and must at least include information regarding:

- Whether the investigation area is contaminated;
- If the investigation area has been contaminated, an assessment of whether that contamination presents a significant risk of harm; and
- If the investigation area presents a significant risk of harm, how the area should be remediated.

An assessment made in terms of subsection (2)(b) must be supported by information on whether:

- The contamination has already caused harm;
- The substances present in or on the land are toxic, persistent or bio-accumulative or are present in large quantities or high concentrations or occur in combinations;
- There are exposure pathways available to the substances;
- The uses of the land and land adjoining increases the risk of harm;

- The substances have migrated or are likely to migrate from the land;
- The acceptable exposure for human and environmental receptors has been exceeded; and
- Any standards set by the Minister have been exceeded.

For the purposes of determining whether there is a significant risk of harm, the land may be regarded as being contaminated at any particular time if the harm could come into existence only in certain circumstances and those circumstances do not exist at that time, where those circumstances are reasonably foreseeable and consistent with the approved use of land at that time.

Consideration of site assessment reports (Section 44)

On receipt of a site assessment report, the Minister or MEC may decide that:

- The investigation area presents a significant risk of harm and declare the investigation area to be a remediation site;
- The investigation area does not present a significant risk of harm and does not require any remediation action; or
- The investigation area does not present a significant risk of harm, but that limited measures are required to address such risks as are present.

If the Minister or MEC declares an investigation area to be a remediation site in terms of subsection (1)(a), the Minister or MEC must make such remediation order as is necessary to neutralise that harm.

If the Minister or MEC decides that the investigation area does not present a significant risk of harm, the Minister or MEC may make an order regarding the measures that must be taken

Orders to remediate contaminated land (Section 45)

A remediation order issued in terms of section 44(2) must describe:

- The person who is responsible for undertaking the remediation;
- The land to which the order applies;
- The nature of the contamination;
- The measures that must be taken to remediate the land;
- The period within which the order must be complied with; and
- Any other matter prescribed by regulation.

Transfer of remediation sites (Section 46)

No person may transfer a remediation site without the permission of the Minister or MEC, as the case may be.

The Minister may not authorise the transfer of a remediation site unless he or she is satisfied that the person to whom the land will be transferred is willing and able to undertake any remediation that is required within an acceptable period.

Contaminated land registers (Section 47)

The waste management officer must keep a register of remediation sites which includes information on:

- The owner and any users of the land;
- The location of the land;
- The origin of the contamination; and
- The status of any remediation activities on the land.

The waste management officer may remove a remediation site from the register if a remediation order has been complied with (56/2009).

Summary: Omnia Fertiliser Sasolburg has had a noticeable impact on water resources in the catchment area where it is located together with surrounding industries. Most of this impact occurred prior to the new Constitution and its related Acts. There is however a material chance that the Driefontein farm area might be declared an “investigation area” in future, once Section 8 of the NEM:WA is promulgated.

This study might be deemed an initial “site assessment” report for the Driefontein farm “investigation area”. The criteria which will be applied to determine whether the Driefontein farm area needs to be remediated still have to be developed by the relevant authorities. Omnia Fertiliser Sasolburg must take cognisance in the development of these new legal requirements and must ensure that proactive information is gathered on the lateral extent of the pollution migration and engage with authorities on corrective action required and develop a comprehensive site remediation strategy and start to implement it. It is strongly recommended that a risk based corrective action approach be followed by DWA as the aquifer impacted has limited sustainable water supply value and limited risk currently exists to humans as receptors.

CHAPTER 10: LIABILITY RISK ANALYSIS

10.1 Environmental liabilities reportable under IFRS and US GAAP

Environmental legislation has an increasing influence on companies whose activities, products and services have significant environmental impacts. Their business performance and financial profitability can be influenced by non-compliance to legal and other requirements. Environmental liabilities are seen as financial obligations that companies have to provide for, incur, and disclose, to address environmental concerns such as the rehabilitation of contaminated land and ground water. Accounting standards treat environmental issues in several ways, including through valuation, provisions, and transparent presentation. The oversight body is the International Accounting Standards Board (IASB) whose mandate is to establish and review accounting standards on provisions (IASB, 2012). The IASB has covered environmental and social accounting financial reporting issues in its mainstream standards. IAS 36 (Impairment of assets) and IAS 37 (Provisions and contingent liabilities).

According to Lawrence and Cerve, as summarised by Miele (2002) there is a definitive indication of increased awareness on the potential financial liabilities of contaminated sites resulting from industrial and commercial ignorance, misuse and abuse. In certain countries sites have been identified where companies have an obligation to clean up contamination and therefore a financial liability would exist.

It is generally agreed in literature that it is currently problematic for accountants to determine the amount of liability and properly disclosing the financial liabilities. The ultimate aim for accountants is to provide shareholders with a complete and accurate environmental liability disclosure. The complexity of assessing environmental financial liabilities is attributed to:

- The identification of all potential clean-up sites;
- Monitoring them on an on-going basis for proper disclosure; and
- Recognition of liabilities on a timely basis.

It is furthermore difficult for accountants to make informed decisions on the financial liabilities of a company due to the technical aspects of environmental matters involving multiple disciplines such as health, environment, engineering, legal and government regulation.

Globally there are two mainly recognised accountancy standards:

- International Financial Reporting Standards (IFRS); and
- General Accepted Accounting Principles (US GAAP).

The IFRS are principles-based standards, interpretations and the accountancy framework adopted by the IASB.

Many of the standards forming part of IFRS are known by the older name of International Accounting Standards (IAS). IAS was issued between 1973 and 2001 by the Board of the International Accounting Standards Committee (IASC). Countries which have adopted IFRS are:

- Australia;
- Canada;
- European Union;
- Hong Kong;
- India;
- Taiwan;
- Japan;
- Pakistan;
- Russia;
- Singapore;
- South Africa; and
- Turkey (PwC, 2012).

The US GAAP are accounting rules used to prepare, present, and report financial statements for a wide variety of entities, including publicly traded and privately held companies, non-profit organisations and governments. Generally GAAP includes local applicable accounting frameworks, related accounting law, rules and accounting standards. The US GAAP is not

written in law, although the U.S. Securities and Exchange Commission (SEC) require that it be followed in financial reporting by publicly-traded companies (SEC, 2011).

10.1.1 IFAC requirements for disclosing environmental liabilities:

The following provide an overview of the IFAC standards most relevant to environmental liabilities (IFAC, 2009):

- **IAS 37 on Provisions, Contingent Liabilities and Contingent Assets:** This standard is the most relevant to environmental matters, covering contingent liabilities as possible obligations that arise from past events, or present obligations that arise from past events, but were not previously recognised. This standard defines provisions as liabilities of uncertain timing or amount, and gives guidance on when to raise a provision. It is the standard most widely used to address environmental liabilities;
- **IAS 2 on Inventories:** Industries such as mining and heavy metal manufacturing may regard their infrastructure and waste materials as assets with a residual value. However, IAS 2 does not allow this. A typical example of this would be a waste site, which should not be accounted for as an asset unless additional costs were incurred to convert the waste into a commercial item.
- **IAS 16 on Property, Plant and Equipment:** This standard addresses rehabilitation by stating that the cost of an item of property, plant or equipment. Rehabilitation costs include the cost of rehabilitating damage that incurred on initial acquisition and set-up of an asset, as well as damage incurred over the life of the asset. A provision for environmental rehabilitation costs resulting from damage caused during operation of the asset should be raised as the damage is incurred. For tangible fixed assets such as land, plant, and machinery, impairment may arise from an incident of contamination, physical damage, or non-compliance with environmental regulation. In such circumstances, IAS 16 allows reduction of the carrying amounts to the value in use or realisable value;
- **IAS 10 on Events after the Balance Sheet Date:** Subsequent events may also be relevant to environmental concerns. IAS 10 states that subsequent events cover both favourable and unfavourable events;

- **IAS 36 on Impairment of Assets:** In instances where initial set-up and dismantling costs are included as part of the cost of an asset and there is an indication that the asset may be impaired, the recoverable amount of the asset should be calculated under IAS 36.
- **IAS 38 on Intangible Assets:** Included in this standard are for example greenhouse gas emission allowances, which are subject to a test that measures impairment of their carrying value if they exceed the amount recoverable from use or realisation.
- **Accounting Policies:** It is expected that an entity should disclose the accounting policy and procedures adopted in respect of provisions for site restoration and environmental rehabilitation.
- **IFRS 3 on Business Combinations:** It covers fair values in acquisition accounting which require identifiable assets or liabilities acquired in a business combination which can be measured at their fair value at the date of acquisition, which may need to reflect environmental impacts.

10.1.2 US GAAP and requirements for disclosing environmental liabilities:

In the USA, many jurisdictions have specific requirements for disclosing environmental information for example the SEC regulations require registered companies to disclose:

- The material costs of complying with environmental regulations in future years;
- The costs of remediating contaminated sites if a liability is likely to have been incurred, and its magnitude can be approximately estimated;
- Other contingent liabilities arising from environmental exposures;
- Involvement as a party to a legal proceeding about an environmental issue, especially with an agency of government; and
- Any known trend or uncertainty involving environmental issues, including pending regulation that would materially affect the company's business.

US GAAP offers an accounting framework for dealing with contingent liabilities arising from environmental contamination. The Financial Accounting Standard Board (FASB) has developed standards which are applied in determining environmental liabilities:

- **Financial Accounting Standard No.5, Accounting for Contingencies**, stipulates the criteria for determining whether to accrue a contingent liability; and
- **Financial Interpretation No.14, Reasonable Estimation of the Amount of a Loss**, which states that if a probable range of loss can be determined, the accrual should be for the most likely amount within the range (Deloitte, 2009).

10.1.3 Accounting for Current Liabilities and Contingencies comparison between IFRS and US GAAP

A study by Epstein and Jermakowicz (2010) differentiates in reporting requirements between IFRS and the US GAAP for accounting current liabilities and contingencies. These are summarised in **Table 39**. **Table 40** differentiates between IFRS and US GAAP in the recording of environmental liabilities.

Table 39: Comparison between IFRS and US GAAP for accounting current liabilities and contingencies (Epstein and Jermakowicz, 2010).

U.S. GAAP: Current Liabilities & Contingencies	IFRS: Current Liabilities & Contingencies
Different recognition threshold for timing of recognition of liabilities associated with a restructuring than under IFRS. Recognise under U.S. GAAP only if event occurs making this a present obligation.	A variety of recognition criteria for different items that may enter into the measurement of a provision are identified, missing under U.S. GAAP. Recognise when formal plan is announced.
Short-term debt refinanced before statement issuance date can often be shown as noncurrent.	Short-term debt refinanced before statement of financial position date can be shown as noncurrent. If later (but still before issuance of financials) disclosure only.
Provisions (estimated liabilities) measured by reference to low end of range of amounts needed to settle, sometimes but not always discounted to present value.	Provisions measured by reference to best estimate to settle, discounted to present value.
Specific rules for certain provisions (e.g., for	Only general guidance provided under IFRS

U.S. GAAP: Current Liabilities & Contingencies	IFRS: Current Liabilities & Contingencies
environmental liabilities).	
Contingent gains not recognised.	IFRS provides for some recognition of contingent gains.

Table 40: Comparison between IFRS and US GAAP in consideration on recording of environmental liabilities.

Consideration	IFRS	US GAAP
Recognition criteria for recording:		
<ul style="list-style-type: none"> • Probable and reasonably estimable. 	Yes	Yes
<ul style="list-style-type: none"> • “Probable” means the event is more likely to occur than not to occur. 	Yes	No
<ul style="list-style-type: none"> • ‘Probable’ means the event is likely to occur. 	No	Yes
Estimation:		
<ul style="list-style-type: none"> • Record best estimate if known. 	Yes	Yes
<ul style="list-style-type: none"> • If no best estimate, record the mid-point of range. 	Yes	No
<ul style="list-style-type: none"> • If no best estimate, record lowest end of the range. 	No	Yes
Discounting of liability is appropriate when:		
<ul style="list-style-type: none"> • The effect of time value of money is material. 	Yes	No
<ul style="list-style-type: none"> • The amount and timing of cash payments are fixed and reliably determinable. 	No	Yes
Treatment of expected future events:		
<ul style="list-style-type: none"> • Changes recognised where there is sufficient objective evidence that they will occur. 	Yes	No
<ul style="list-style-type: none"> • Changes recognised when laws, regulations, or policies are enacted and adopted. 	No	Yes
Recoveries from other parties:		
<ul style="list-style-type: none"> • Determined and evaluated separately from liability, recorded as separate asset unless right of offset exists. 	Yes	Yes

10.1.4 Methodology for assessing environmental liability under IFAC and US GAAP.

PwC (2009) demonstrates that the financial reporting process can be simplified to five basic steps. The steps and their applicability to environmental pollution is summarised in **Figure 229**.

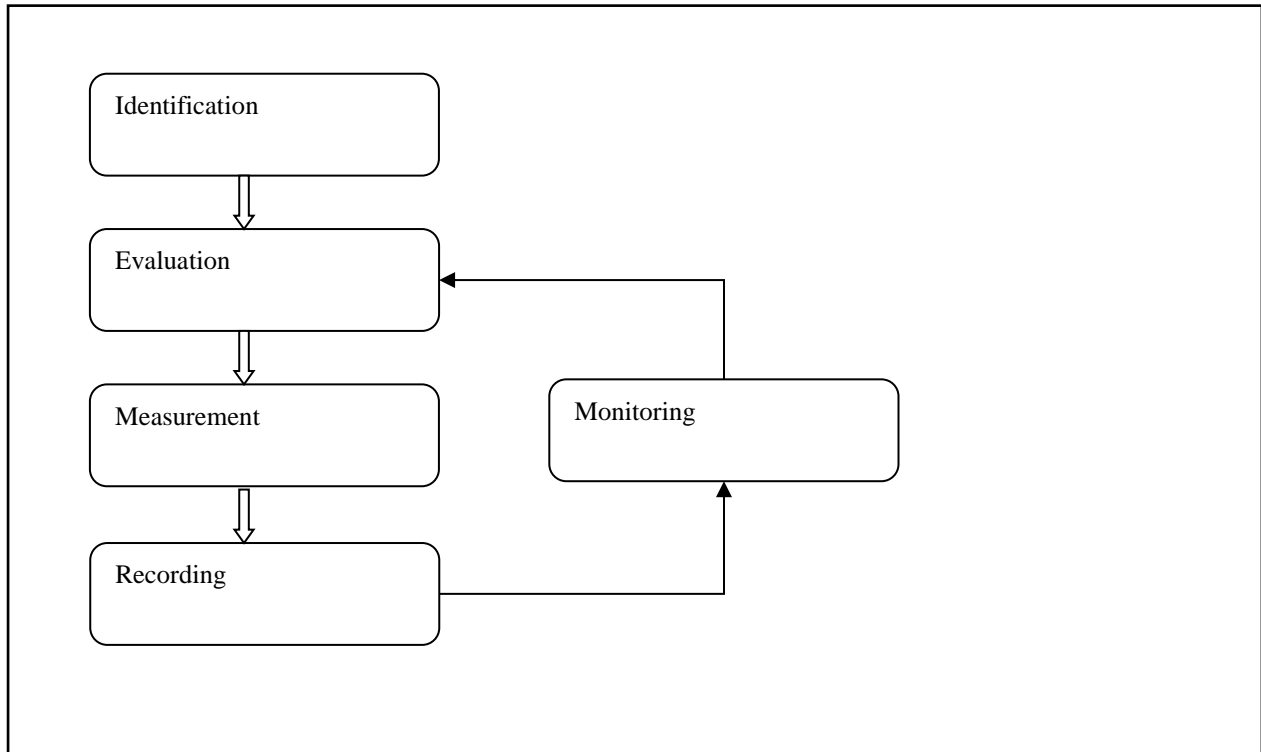


Figure 229: Simplified five step financial reporting process (PwC, 2009).

9.1.4.1 Identification: The identification of potential environmental related financial exposures, thus anything that give rise to remediation liability.

The identification step is deemed crucial because environmental liabilities generally do not occur as any intentional act of management. A critical review of the entity's processes and controls is therefore required (usually by the financial auditor) to identify potential environmental impacts which might translate in a remediation liability. For the Omnia Fertiliser Sasolburg site the following exposures assist with the completeness of identifying potential environmental related financial risks:

- Sources (point and non-point) of potential environmental pollution e.g. leaks and spillages from chemical storage facilities, underground storage tanks (UST's), channels that collect waste water, process and surface water control dams etc. Identification on whether the pollution is on and/or off-site and the risk of the pollution migrating off-site; and
- Company documentation review such as board minutes of meeting, management system (e.g. ISO 14001 management system review minutes), environmental communication and interaction with authorities, register of external environmental complaints, permit conditions and authorisations, public participation minutes (usually from EIA) and other community forum/meetings, and the results of environmental legal compliance audits.

9.1.4.2 Evaluation: The evaluation on whether remediation exposures meet “probable and estimable” criteria for recognising liabilities, both for newly identified exposures and for new developments on existing projects. When a potential remediation liability is identified, it does not always mean that the liability should be recognised in the financial statements. Under both IFRS and US GAAP the liability should be recognised when it is both probable and estimable. **Figure 230** provides a simple a simple overview of the “probable and estimable” concepts (PwC, 2009).

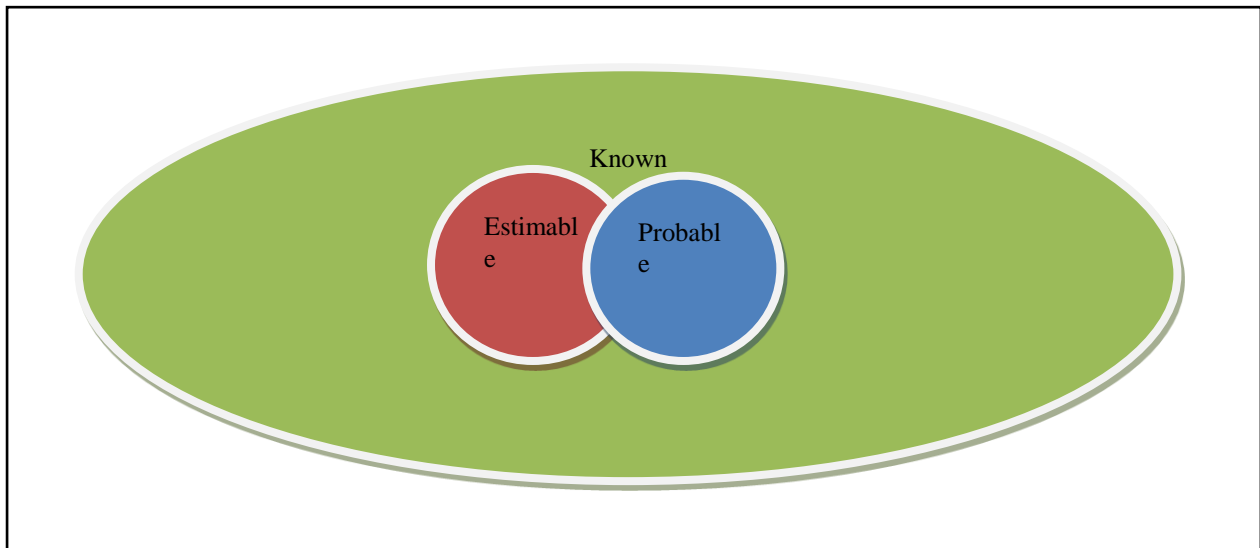


Figure 230: Relation between estimable and probable (PwC, 2009).

Probability is described as the likelihood of a future event. PwC (2009) indicates that: “A potential environmental liability meets the probable test if at least one of the following trigger events is probable (or has already occurred)”. The trigger elements are identified as:

- The introduction of new laws or regulations that require clean-up of an existing situation;
- The start of litigation;
- The assertion of a claim by another party; and
- The obligation to conduct an environmental damage assessment (PwC, 2009).

Probability is generally accepted as the actual commencement of litigation. A company should obtain legal advice and an opinion to determine what constitutes probable commencement of litigation, probable assertion of a claim or the probable obligation to conduct a contaminated land assessment. The different levels of risk are indicated in **Figure 231**.

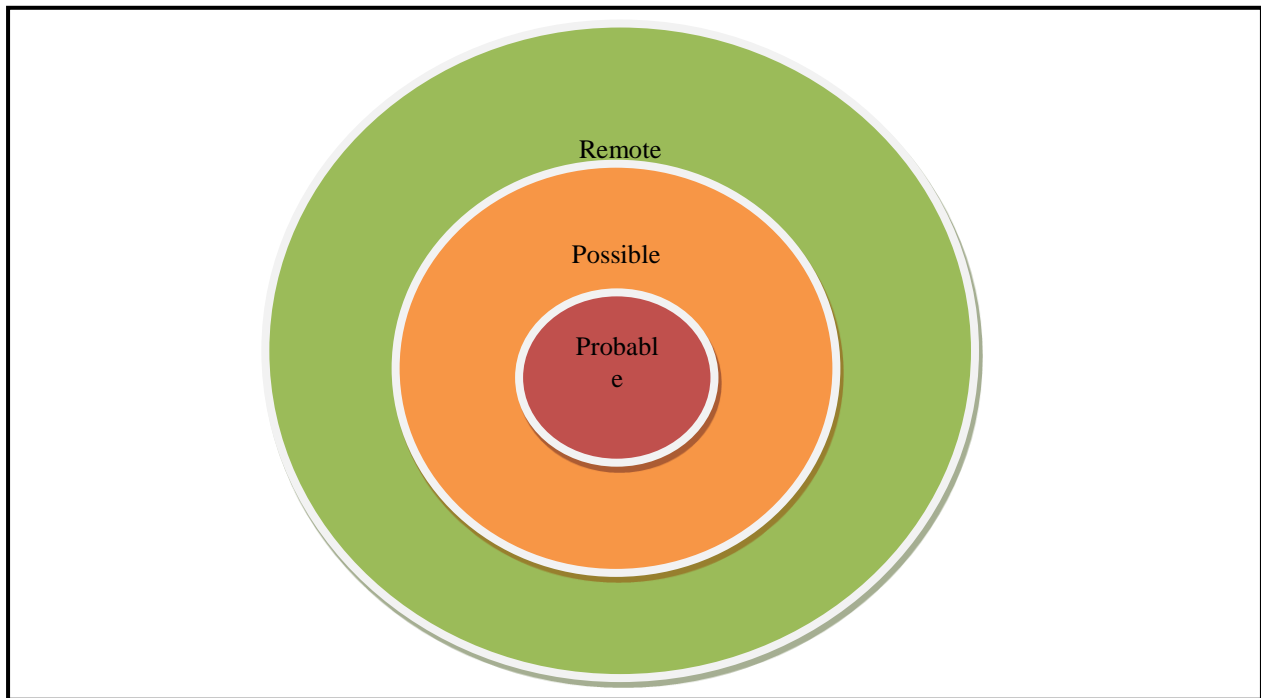


Figure 231: Risk levels (PwC, 2009).

Probability is defined in the IFRS as the “probability that (the event) will occur is greater than the probability that it will not occur, in other words when the likelihood is 51% or greater. Under US GAAP the definition is “the future event or events are likely to occur” as described in IAFS 5

(Epstein and Jermakowicz, 2010). This is generally accepted that the likelihood is greater than 75%.

There is thus a difference in approach between the US GAAP and IFRS (which is used in South Africa) relating to the evaluation of potential environmental liabilities. A future event can be considered probable under IFRS but not under US GAAP.

“Possible” is simply defined as the chance of the event occurring is more than remote but less than probable. “Remote” is interpreted as a potential of less than 10% that an event will be occurring.

An environmental liability is deemed estimable when remediation costs can be reasonably and reliably estimated. Often a range of costs is calculated by combining estimated costs over the components of liability assessment which may constitute:

- Preliminary assessment;
- Detailed investigation; and
- Remediation planning.

Each component might include:

- A range;
- A single most likely cost; and
- Different possible costs, none of which is more likely than the others.

The estimated cost is built up from the lowest and highest likely cost of each component. The components that are probable and can be reliably estimated should be recorded.

The accounting treatment of each known potential environmental liability depends on its probable and estimable status as contained in **Table 41**.

Table 41: Probable and estimable status of each accounting standard (PwC, 2009).

Scenario:	Accounting Action Required:
Probable and Estimable.	Record the environmental liability and disclose the other information specific in the relevant accounting standard.
Probable but not Estimable.	Disclose the nature of the contingency together with other details specified in the relevant accounting standard. IAS 37 states that probable but not estimable “is an extremely rare case”.
Not Probable (whether or not estimable).	<p>Possible: Disclose the nature of contingency and estimate of possible loss or range of loss, or state that such an estimate cannot be made.</p> <p>Remote:</p> <p>Under IFRS – do nothing.</p> <p>Under US GAAP – in general do nothing, but disclosure might be required under some circumstances involving certain litigation and/or environmental regulations.</p>

The status of financial reporting of the Omnia Fertiliser Sasolburg site would be not probable but possible. This is based on the fact that no litigation or site clean-up order has been issued to Omnia Fertiliser Sasolburg. As such an estimate of liability is not considered. There is however the responsibility to report (disclose) the nature of contingency and estimate of possible loss or range of loss. If not possible to estimate the range of loss it should be indicated. It is essential that shareholders and other stakeholders are informed on the possibility of environmental liability.

Factors which could influence probability are:

- Third party litigation;
- Issuance of a remediation order;
- Changes in environmental laws and accounting standards;

- Changes in land use in the contaminated land areas (e.g. from agriculture and industrial to community housing or provincial/national parks); and
- Other requirements such as the King 3 report on corporate governance (PwC, 2009).

10.1.4.3 Measurement: The valuation of environmental liabilities by developing cost estimates. This might be for new matters or for existing matters for which the facts and circumstances have changed. Given the inherent difficulties and uncertainties associated with remediation cost estimation the controls in place to assess remediation cost need to be well developed and effective. Suitable controls might include:

- Policies and procedures for estimating costs in accordance with relevant accounting procedures;
- Frequent reviews of cost estimates by management at multiple levels;
- Protocols on information sharing between the relevant functional groups such as the environmental department, finance and legal;
- Monitoring of periodical adjustments to liabilities arising from passage of time, new scientific information and new legal requirements. Where no adjustments are required positive confirmations of the reasons;
- Monitoring estimates against actual results of similar projects completed;
- Training and competency of relevant personnel; and
- Account adjustment processes for adjusting accrued amounts for costs incurred during the remediation phase of the project (PwC, 2009).

10.1.4.4 Recording: Carrying out procedures for establishing and adjusting account balances and ensuring that recognition within the financial statements is accurate and within the right period.

Essential controls relating to the recording of environmental liabilities are:

- Communication: An effective communication mechanism must exist between the environmental, legal and financial department of the company;
- Account adjustments: Responsibilities for account entries must be documented and competencies stipulated;

- Reconciliations: Responsibilities for account reconciliation and frequency of reconciliation must be documented; and
- Evaluation of consistency: Consistency evaluations across different locations, sites and business units;
- Management review: Level of management, responsibility and frequency of management reviews must be formalised (PwC, 2009).

10.1.4.5 Monitoring: Assessment in a timely manner is required to continuously assess the impact of changes in facts and circumstances until the project is complete and the liability is extinguished in full.

Important aspects to consider during continuous monitoring are:

- Time: In extreme cases, the remediation lifecycle can last for longer than 30 years;
- People: Remediation projects involve many parties, each with their own specialism and needs;
- Complexity: Remediation can involve a number of contaminants, conditions and sites;
- Choice: There may be many different and valid approaches to remediation; and
- Uncertainty: Identifying contamination and predicting outcomes of remediation are difficult especially in the early stages of a project (PwC, 2009).

The following summary from the ICAEW, 2009 provides an overview of the responsibility and role of the financial auditor in assessing the potential for environmental liabilities on the financial statements:

- **Determining if there are potential environmental impacts which are significant to the financial statements:** The auditor's procedures typically include obtaining an understanding of the entity by applying analytical procedures in assessing risk (ISA 315) obtaining a general understanding of the legal and regulatory framework applicable to the entity and how the entity is complying with that framework (ISA 250) and performing other risk assessment procedures. Analytical procedures can assist in assessing the risk of material misstatement and use both financial and non-financial information. In obtaining an understanding of the entity the auditor should be able to identify the current

environmental aspects and impact, as well as the risk of historical pollution from point and disperse pollution sources such as tailings facilities, ash dumps, wash bays, chemical storage areas, fuel (diesel) storage areas etc. In planning the audit, the auditor should obtain sufficient knowledge of the business to understand the events, transactions and practices that could have a significant effect on the financial statements, including those arising from environmental issues. While obtaining an understanding of the entity is an essential part of performing an audit, the auditor uses professional judgement to determine the extent of understanding required to assess the risk of material misstatement. The depth of understanding required by the auditor is generally less than that of management and, almost certainly, less than that possessed by those responsible for environmental issues.

- **Potential significant environmental impacts on soil and groundwater, and how the auditor should assess the risk of a consequent material omission or misstatement in the financial statements:** Some environmental impacts have definite outcomes, for example groundwater pollution caused by poor chemical storage practices, chemical spill incidents, seepage of contaminated water from tailings, ash dumps and underground diesel storage tanks and waste disposal sites. However, some other environmental issues involve the exercise of judgement by the directors about the financial outcome which depends in turn on a judgement as to the most likely environmental response, its timing and financial impact. The audit approach with regard to environmental issues is determined by the strength of the entity's controls around those impacts, their significance and the auditor's assessment of the risk of material misstatement. ISA 315, Appendix 3 sets out examples of situations where conditions or events may indicate the existence of such: e.g., pending litigation and contingent liabilities related to an expected obligation for environmental remediation.
- **Additional steps which should be considered to respond to the identified risks:** The additional steps that are necessary where environmental matters are potentially significant will depend on the auditor's assessment of the resulting risk to the reliability of the financial statements, based on professional judgement. For example, when considering estimates relating to the environment, the auditor reviews the process used by the entity to develop estimates, taking account of the completeness of available information, the use of

competent advice, the degree of prudence exercised and the approach adopted for dealing with inherent uncertainty (ISA 540). The auditor's review can also include a comparison of past estimates with subsequent events (ISA 560). The auditor reviews the basis of provisions for liabilities in the light of costs of decommissioning or remediation costs arising previously in similar circumstances and the requirements of IAS 37/FRS 12 Provisions, contingent liabilities and contingent assets. Examples 2A, 28 and 6 in the appendix to FRS 12 relate to environmental matters. The auditor's consideration of materiality and its relationship with audit risk determines the nature, timing and extent of audit procedures and the evaluation of the effect of misstatements (ISA 320). The auditor identifies and assesses the risks of material misstatement at the financial statement level and at the assertion level for classes of transactions, account balances and disclosures (ISA 315, paragraph 100). Identified risks are therefore related to what can go wrong at the assertion level (e.g., completeness) and the magnitude and likelihood of misstatement are considered. Where the assessed risks include environmental issues that are potentially material to the financial statements, the auditor considers the adoption of procedures to address the risks, such as those set out in ISA 330. Further guidance on possible tests of control and substantive procedures relating to environmental issues is set out in Appendix 2: 'Accounting and auditing standards relevant to environmental issues'. The auditor may need to seek technical advice from specialists, such as environmental advisers, engineers or lawyers. This can be derived from work carried out by a specialist engaged by management or by the auditor.

- **Responsibility in reviewing compliance with environmental laws and regulations:** Recent years have witnessed the proliferation of new environmental laws, regulations and directives, both in South Africa and internationally, particular in Europe. In understanding the external factors affecting an entity, the auditor should consider regulations applicable to the industry (ISA 315, Appendix 1). Among other procedures, audit planning may involve obtaining a general understanding of the legal and regulatory framework applicable to the entity and how the entity is complying with that framework (ISA 250, Section A, paragraph 15 and ISA 300, paragraph 5). Management is responsible for ensuring that the entity's operations are conducted in accordance with laws and regulations. Where management has failed to comply with environmental laws and

regulations, this can result in fines or penalties and, in extreme situations, may result in withdrawal of any license or permit necessary to operate, raising doubt over the entity's ability to continue as a going concern. Furthermore, where a severe violation is identified, the relevant authority has the authority to prosecute directors for a criminal offence which may result in a jail sentence. After obtaining a general understanding of the framework, the auditor performs further audit procedures to help identify possible or actual instances of non-compliance with those laws and regulations within which the entity conducts its business and which are central to the entity's operations and hence to its financial statements (ISA 250, Section A, paragraph 18-1). The auditor's understanding of any environmental compliance issues will be enhanced by discussion with management, including environmental managers. The extent and focus of such procedures would be dependent on the auditor's risk assessment:

- For some businesses, non-compliance with environmental laws or regulations would be central to the core operation and therefore to the financial statements. As well as possible fines, this would include the rare circumstances where irregularities could result in closure of the business, either because of withdrawal of an operating license or because a fine is so substantial as to be 'life threatening'; and
- For other businesses, non-compliance with environmental laws or regulations would not necessarily fall into this category despite the potential or actual financial consequences such as fines or penalties. Litigation and claims for environmental damage or pollution could possibly have a material effect on the financial statements. The auditor therefore carries out procedures in order to become aware of any litigation and claims involving the entity that may result in a material misstatement of the financial statements. When the auditor assesses a risk of material misstatement regarding litigation or claims that have been identified, or when the auditor believes that they exist, the auditor may need to seek direct communication with the entity's legal counsel. For this purpose, a letter prepared by management is sent by the auditor, requesting the entity's legal counsel to communicate directly with the auditor. If management refuses to give the auditor permission to communicate with the entity's legal counsel, this would be a scope

limitation that would ordinarily lead to a qualified opinion or a disclaimer of opinion (ISA 501, paragraphs 32-37).

- **Difficulties to consider in evaluating environmental liabilities:** There are a number of difficulties in recognising and measuring the financial effects of environmental matters in financial statements, all of which have implications for the auditor. For example:
 - There is often a considerable delay between the activity that causes an environmental issue such as the contamination of a site due to industrial activity and its identification by the entity or the regulators;
 - Accounting estimates do not necessarily have an established historical pattern and can exhibit wide ranges of reasonableness because of the number and nature of assumptions underlying the determination of these estimates;
 - Environmental laws and regulations are evolving and interpretation can be difficult or ambiguous. Consultation with an adviser may be necessary to assess their impact on the measurement of assets and liabilities; and
 - Liabilities can arise other than as a result of legal or contractual obligations, for example, a voluntary commitment.

10.2 Third party asset impact

There is a general lack of geophysical information on Driefontein farm which affects the accuracy of the prediction of third party impact. However, ground water monitoring results (of particularly the shallow aquifer) indicate that the groundwater on Driefontein farm has been impacted by the Omnia Fertiliser Sasolburg operation. Based on ground and surface monitoring results, it indicates that the groundwater beneath the Süd Chemie and Inca Bricks sites will probably also be impacted in future. The same is however also true for the Omnia site in that Karbochem and Natref have probably already impacted on the groundwater beneath the Omnia Fertiliser Sasolburg site. The Süd Chemie site is probably already being impacted as it is right next to the Omnia Fertiliser Sasolburg site (no monitoring borehole on site to confirm).

There is however limited risk that the groundwater pollution might negatively impact on the future potential land uses of Driefontein farm and subsequently impacting on property values due to the groundwater pollution as the aquifer has almost no commercial water use ability

(sustainable yield). However, the reputational risk associated with this could lead to depreciation in actual asset value and might negatively affect the marketability of the Driefontein farm to potential interested buyers. The soil profile of the Omnia Fertiliser Sasolburg site is contaminated and this will serve as a point pollution source to ground water for numerous years as it will continue to leach into the saturated zone (**Figures 232 and 233**). It should also be noted, that there is a good probability that the ground water beneath the Omnia Fertiliser Sasolburg site has been contaminated by Natref and probably Karbochem, with specific reference to fluorides. The consideration of groundwater impacts in the NEM:WA Section 8 is poor and mainly deal with soil pollution.

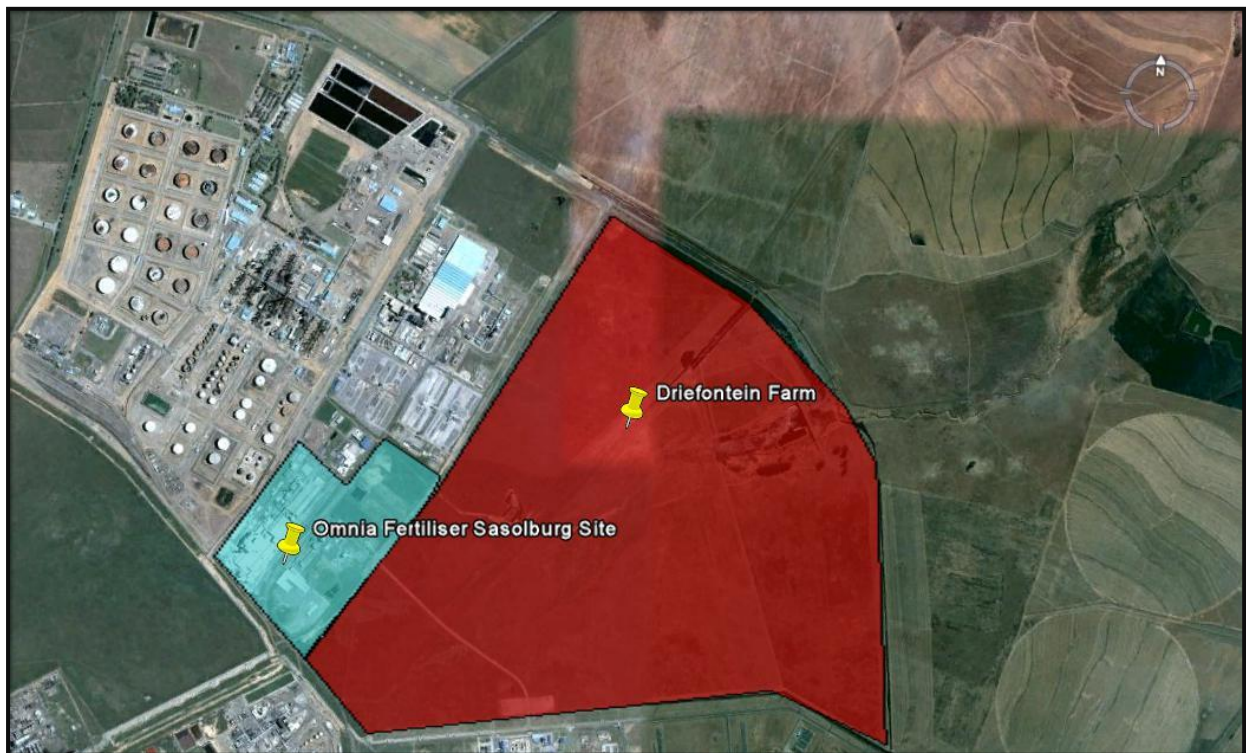


Figure 232: Omnia Fertiliser Sasolburg and Driefontein farm (Google Earth, 2010).

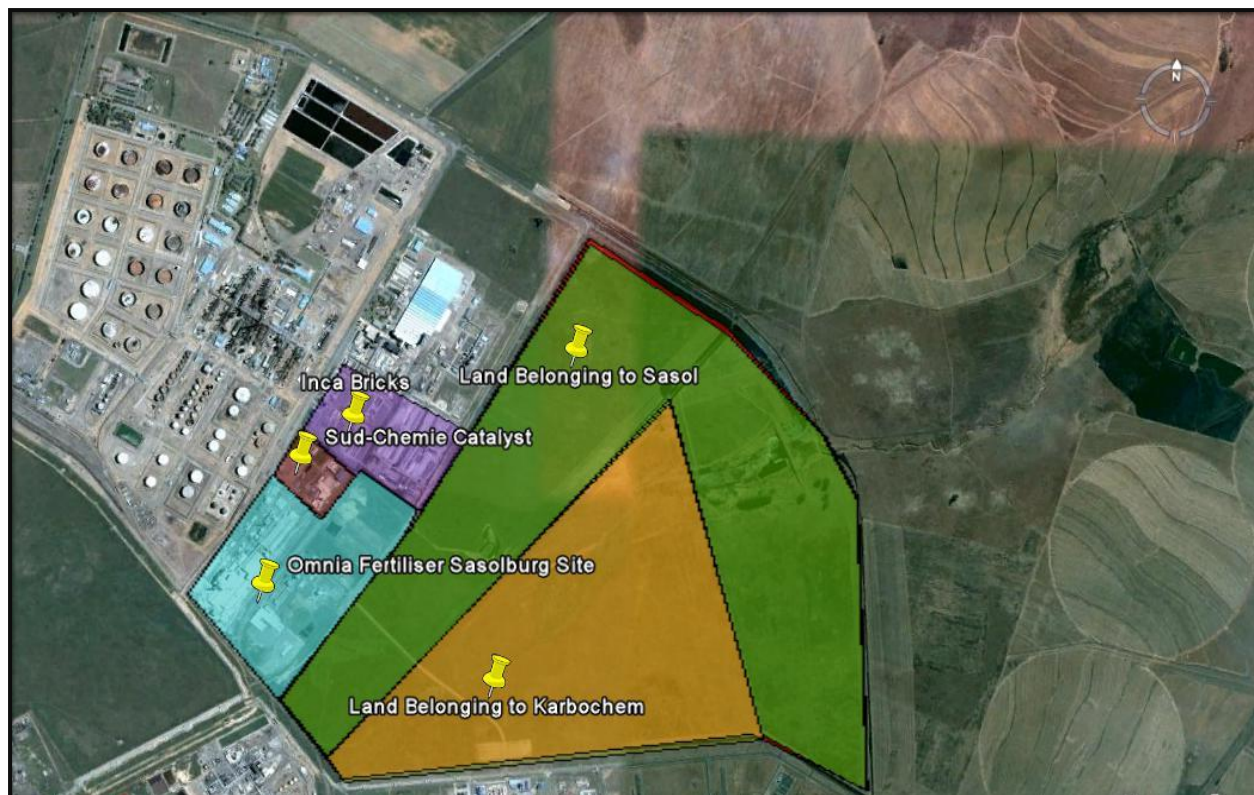


Figure 233: Land owned by Süid Chemie, Sasol and Karbochem (Google Earth, 2010).

Omnia Fertiliser has an internal risk assessment matrix which is used to identify probability and frequency of a specific risk and the potential effects in financial impact, operations, health and safety, environment, community, business and reputation (corporate image). This is reflected in **Table 42 and 43**. From a review of the probability and frequency (best and worst case scenario **Table 42 and 43**, it is evident that the associated financial impact would be between R500 million and R4 billion based on the Omnia risk table and methodology. The promulgation of Section 8 of the NEM:WA will increase the probability level to “can happen”. Furthermore, as the implementation of Section 8 of the NEM:WA is enforced by the relevant authority it might also increase “frequency” rating.

The risk of asset depreciation due to the groundwater impact on the Driefontein farm area is limited. The area has been cumulatively impacted by a number of industries. There is thus limited probability that the land value will depreciate as its intent is industrial use and there is limited ability and potential for sustainable groundwater use.

Factors which could influence the probability of land value depreciation might be influenced in future by:

- Third party litigation;
- Issuance of a remediation order;
- Changes in environmental laws and accounting standards;
- Changes in land use in the contaminated land areas (e.g. from agriculture and industrial to community housing or provincial/national parks); and
- Other requirements such as the King 3 report on corporate governance (PwC, 2009).

Table 42: Omnia Risk Matrix Assessment – Worst Case Scenario (Omnia Risk Table, 2008).

Effect Category	Category	Estimated Impact in SA Rand. (Both + and -)	Effect on Operations	Effect on Health and Safety	Effect on Environment	Effect on Community	Effect on Business	Corporate Image
6	Catastrophic	Above 4 billion	Catastrophic Damage	Effect on employees as such that an Omnia Centre is forced to close down	Effect on environment as such that an Omnia Centre is forced to close down	Effect on community as such that an Omnia Centre is legally forced to close down.	Total Loss/delisting with JSE	Prolonged international condemnation
5	Very Critical	500 million to 4 billion	Critical Damage	Several Fatalities	Irreversible damage to receiving environment / may take several years to rehabilitate	One or more fatalities	Serious impact on assets and profits/ Serious impact on share prices	Adverse international and national media coverage
4	Critical	100 to 500 million	Severe Damage/ serious down time	One Fatality or hospitalisation of employees	Environmental Damage can be reversed in less than a year	Hospitalisation of residents / One in ten chance of a fatality	Critical impact on assets and profits	Adverse national attention / prosecution , fines etc
3	Medium	20 to 100 million	Significant Damage	One or more lost time injuries or a 1:10 chance of a fatality	Rehabilitation of the environment requires the intervention of external specialists and can be done in less than a month	Adverse health symptoms such as sinusitis, respiratory illness etc	Significant impact on assets and profits	National media coverage
2	Minimal	10 to 20 million	Minor Damage	Minor injury requiring first aid - visit to medical station or doctor.	Environmental Damage can be rehabilitated internally with or without the help of external consultants	Complaints.	Minor Impact on assets and profits	Local media coverage
1	Very Low Risk	Less than 10 million	Tolerable	Near misses or minor injuries, which do not require first aid	Minor damage to the receiving environment within the plant areas	None	Tolerable impact on assets and profits	Local public complaints

Probability Category	1	2	3	4	5	6
Probability	Highly Unlikely	Rare	Low Likelihood (Possible)	Probable	Can Happen	Regular
Frequency	Could happen once in 100 years	Could happen once in 50 years	Could happen once in 10 years	Could happen once in 5 years	Could happen once a year	Could happen more than once a month

Table 43: Omnia Risk Matrix Assessment – Best Case Scenario (Omnia Risk Table, 2008).

Effect Category	Category	Estimated Impact in SA Rand. (Both + and -)	Effect on Operations	Effect on Health and Safety	Effect on Environment	Effect on Community	Effect on Business	Corporate Image
6	Catastrophic	Above 4 billion	Catastrophic Damage	Effect on employees as such that an Omnia Centre is forced to close down	Effect on environment as such that an Omnia Centre is forced to close down	Effect on community as such that an Omnia Centre is legally forced to close down.	Total Loss/delisting with JSE	Prolonged international condemnation
5	Very Critical	500 million to 4 billion	Critical Damage	Several Fatalities	Irreversible damage to receiving environment / may take several years to rehabilitate	One or more fatalities	Serious impact on assets and profits/ Serious impact on share prices	Adverse international and national media coverage
4	Critical	100 to 500 million	Severe Damage/ serious down time	One Fatality or hospitalisation of employees	Environmental Damage can be reversed in less than a year	Hospitalisation of residents / One in ten chance of a fatality	Critical impact on assets and profits	Adverse national attention / prosecution , fines etc
3	Medium	20 to 100 million	Significant Damage	One or more lost time injuries or a 1:10 chance of a fatality	Rehabilitation of the environment requires the intervention of external specialists and can be done in less than a month	Adverse health symptoms such as sinusitis, respiratory illness etc	Significant impact on assets and profits	National media coverage
2	Minimal	10 to 20 million	Minor Damage	Minor injury requiring first aid - visit to medical station or doctor.	Environmental Damage can be rehabilitated internally with or without the help of external consultants	Complaints.	Minor Impact on assets and profits	Local media coverage
1	Very Low Risk	Less than 10 million	Tolerable	Near misses or minor injuries, which do not require first aid	Minor damage to the receiving environment within the plant areas	None	Tolerable impact on assets and profits	Local public complaints

Probability Category	1	2	3	4	5	6
Probability	Highly Unlikely	Rare	Low Likelihood (Possible)	Probable	Can Happen	Regular
Frequency	Could happen once in 100 years	Could happen once in 50 years	Could happen once in 10 years	Could happen once in 5 years	Could happen once a year	Could happen more than once a month

CHAPTER 11: CONCLUSION

The following steps were undertaken as part of the approach to develop the hydrogeological environmental risk assessment methodology:

- Obtained and reviewed previous ground water investigation and environmental management related reports for the study area;
- Performed an environmental site assessment of Omnia Fertiliser Sasolburg through a site visit and site and information “walk-through” based in the clauses and principles of ISO 14001:2004, and EMS audits;
- Numerous interviews with site operational managers were held in obtaining and understanding of the site operational and production processes including the identification and description of the main chemicals used on site;
- Identified the type of activities taking place on the Omnia Fertiliser Sasolburg production site;
- Identified information contained as part of the formal ISO 14001:2004 certified EMS which might assist with ground water impact quantification;
- Identified and evaluated the environmental aspects and impacts under normal, abnormal and emergency conditions which might cause ground water and surface water impacts;
- Identified the potential historical environmental aspects which could have caused ground water and surface water impacts;
- An evaluation of historical environmental incidents which could have caused ground water and surface water impacts was conducted;
- Interacted with site employees who has invaluable knowledge on historical and current activities and processes which could/can have an impact on ground water and surface water;
- Identified the industries located close to Omnia Fertiliser Sasolburg which could have an impact on the study area and contribute as such to a cumulative impact on the ground water and surface water quality in the study area;
- Based on the above mentioned information identified and provided an overview of the point and non-point (disperse) pollution sources found on site;

- Provided an overview of the physical characteristics of the study area;
- Developed a conceptual ground water model of the study area;
- Evaluated the adequacy of the existing ground water monitoring network;
- Evaluated the ground water and surface water chemistry against the point and non-point pollution sources;
- Identified the relevant legal requirements and its implication on the ground water impact at the Omnia Fertiliser Sasolburg site;
- Identified and evaluated the ground water impact against existing financial accounting standard requirements with regard to recordability and reportability; and
- Evaluated the actual impact of Omnia Fertiliser Sasolburg on ground water and surface water quality and its subsequent potential financial consequences based on the Omnia risk assessment matrix.

Subject to the Omnia Fertiliser Sasolburg site information available for this study, as discussed in the preceding chapters in addressing the objectives envisaged in Chapter 1.3 for this study, the following conclusions can be made:

There has been a definitive increase in environmental legislation over the past decade. These new environmental laws established principles such as duty of care and the polluter pay principle. Numerous companies in South Africa have historical impacts, particularly ground water impacts deriving from the period where no or less comprehensive environmental legislation was promulgated. Furthermore, the recent, sudden evolution of environmental legislation has placed significant strain on companies to comply with environmental legal requirements. The quantification of ground water impact through a methodological approach which can provide adequate information for a decision on the need to disclose the liability as part of the financial audit process is absent in South Africa. This study focussed on deriving a methodology which can be applied in the South African Fertiliser Industry, in assisting with the investigation and quantification of ground water impacts in order to assist with the decision on the need to disclose the liability as part of the financial statements and declaration of these ground water related environmental liabilities in an integrated report.

The Omnia Fertiliser Sasolburg operation was established on a “greenfields” site in a major developing industrial area in the 1960’s. The previous land use of the Omnia Fertiliser Sasolburg site was low intensity agriculture.

Environmental impact assessment requirements was not formalised at the time of the Omnia Fertiliser Sasolburg operation establishment. The first, true environmental legal obligations were introduced in 1987 as the Environment Conservation Act (ECA, 1987). The Omnia Fertiliser Sasolburg operation was designed to comply with industrial and construction standards relevant at the time of construction (1960’s) and subsequently did not consider environmental obligations and requirements we know it today.

The manufacture of fertilisers involves the storage of large volumes of raw materials, its conveyance on site, production of chemicals etc. The environmental aspects and impacts of fertiliser production can, generally, be deemed to be significant, particular on soil, surface and ground water.

Omnia Fertiliser Sasolburg, similar to other fertiliser manufacturers has historical impacts on the environment. The responsibility and liability associated with these historical impacts, has only been introduced with the promulgation of “new” environmental legislation, mainly introduced since 1998.

This introduction of “new” environmental legislation, places a responsibility on the fertiliser industries to quantify their historical environmental impacts, prevent any continuous impacts by preventing pollution at source and to implement formal environmental management systems.

The quantification of historical impacts, particularly on ground water is challenging, particularly to the general lack of information such as the adequacy of the monitoring network, history of a production site, inadequate and incomplete monitoring information. It is further complicated by the fact that most of the fertiliser production facilities in South Africa are located in complex industrial areas where cumulative environmental impacts on soil, air, surface and ground water took, and is still taking place.

Recent environmental legislation mainly stipulates two principles:

- Duty of care; and
- Polluter pays principle.

The quantification of environmental liabilities, particular ground water impact in reporting and financial terms, remains highly controversial, particular in instances where the impacts took place prior to the commencement of “new” environmental legislation. The complexity of cumulative impacts is also a factor that increases uncertainty and scepticism.

The “Duty of care” principle is mainly applied in the fertiliser industry through the implementation of formal EMS’s, usually based on ISO 14001:2004. ISO 14001:2004 is currently a conformity based standard and thus, does not necessarily mitigate or improve environmental impact, and subsequently environmental performance. The implementation of a formal EMS therefore does not necessarily mitigate the risk of reporting financial liabilities with regard impact remediation and site closure and/or rehabilitation. The formal EMS, however, does generate valuable information to understand the potential and actual impacts caused by the fertiliser operation, in order to assist with the reporting risk of environmental financial liabilities.

The IFRS, mainly through IAS 37 try and encapsulate the “Polluter pays principle” by considering potential environmental financial liabilities and the need to disclose it to stakeholders, particularly in instances where it might impact an operation or company as a going concern. The decision on how, and if to report potential environmental liabilities under IAS 37 is highly dependent on the adequacy and quality of ground water impact information available. In most instances, where uncertainty exists to potential and extent of ground water pollution, the outcome of such a review requires additional, highly specialised scientific studies and opinions from ground water specialists, including, in most instances, environmental legal specialists.

There are numerous point and disperse pollution sources that were identified, both historically and present on the Omnia Fertiliser Sasolburg site. Some of these point and disperse pollution sources are located off-site, due to emissions that have moved off site, such as dust and storm

water. An evaluation of historical site information has identified some activities that could have impact directly and indirectly on ground water quality.

An identification of the environmental aspects and impacts of Omnia Fertiliser Sasolburg has indicated numerous potential ground water impact risks under normal, abnormal and emergency operational conditions.

As Omnia Fertiliser Sasolburg is located in a complex industrial area, where heavy industries, known for significant environmental impact are and have been operational since the early 1960's, are located. The main storm water drainage basin for some of these industries is the Driefontein farm in the direction of the Vaal River. Through an evaluation of the industries located in vicinity of Omnia Fertiliser Sasolburg, it is highly probable that the Driefontein farm area, and the aquifer systems located on these have been cumulatively impacted. The potential elements that might have been cumulatively deposited over a period of time include nitrate, phosphate, calcium, sodium, fluoride, sulphate, chloride and vanadium. Henry's dam and Driefontein dam are the main surface water (artificial) storage facilities located in the drainage path to the Vaal River. Both these dams can be regarded as ground water point pollution sources due to the high concentrations of contaminants present.

The contaminants present in the surface water features and ground water of the Driefontein farm study area indicates a significant impact from the fertiliser production activities of Omnia. All major chemical elements associated with fertiliser production in present in the study area, some of them significantly elevated such as nitrate, magnesium, chlorides, and sulphate.

It is evident from the ground water monitoring network and results that the pollution plume has migrated off-site, on Driefontein farm. The main carrier of the pollution is the shallow unconfined Karoo aquifer. The deeper semi-confined Karoo aquifer has however also been impacted in some instances. It should be noted that surface water point pollution sources exist on Driefontein farm, where historically, contaminated surface water from the Omnia Fertiliser Sasolburg site and other industries in the vicinity would accumulate (Henry's dam and Driefontein dam).

Uncertainty with regard to geophysical structures such as the location of dykes on the study area increases uncertainty with regard the pollution plume(s) flow direction and rates.

The importance of an adequately designed surface and groundwater monitoring network is exceptionally important in the reliance that can be placed on groundwater and surface water monitoring results.

An assessment of ground water use in the study area and other areas that might be impacted indicate that there is a limited risk of ground water use in the study area. Although the ground water has been significantly contaminated with especially nitrates, the limited risk of ground water use in this area subsequently, can be deemed insignificant. It should also be noted that the study area is located in a major industrial area and that municipal water services is readily available.

Ecological exposure risk however does exist with regard to contaminated storm water in Henry's dam and Driefontein dam.

The ground water pollution caused may negatively impact on property values which are impacted.

The result of the financial reporting risk evaluation performed, conform to the "not probable but possible" criteria. This is based on the fact that no litigation or site-cleanup order has been issued to Omnia Fertiliser Sasolburg. As such an estimate of liability is not considered. There is however the responsibility to report (disclose) the nature of contingency (environmental liability) and estimate of possible loss or range of loss.

The range of potential loss has been estimated as a worst case scenario, using the Omnia Fertiliser risk matrix indicated in **Table 42 and 43**. The effect category has been identified as "Irreversible damage to the receiving environment/may takes several years to rehabilitate". The probability has been identified as "can happen" and the frequency as "could happen once in ten

years”. Based on the Omnia Risk Matrix, the associated environmental liability for this risk level is R500 million to R4 billion.

Table 44 provides a simplified overview of the environmental hydrogeological site risk assessment methodology for the fertiliser industry in South Africa, which has been derived from this study.

Table 44: Environmental hydrogeological site risk assessment methodology for the fertiliser industry in South Africa.

Step Description	Objective	Detailed Activities	Considerations
1) Evaluation of historical land owners and uses applicable to the study area.	Identify historical activities that might have impacted on soil and ground water.	<ul style="list-style-type: none"> Identify historical land uses as far back as possible; Identify the typical pollutants associated with each of previous land user’s activities; and If possible, identify the location where pollutants were stored on site for each land owner. 	If the level of uncertainty on historical land owners and/or the pollutants is uncertain, record a decision with company management that the background ground water quality of the site might have been impacted and record the problematic chemical elements and its location. Document any “abnormal” ground water qualities and monitor for natural attenuation.
2) Evaluation of the current company’s history on the site (study area).	Understand historical activities, changes in process and chemicals used on site.	<ul style="list-style-type: none"> Identify the types of chemicals used in past and how it differs from the current chemicals used; Identify the volumes of chemicals stored and used; Changes to process infrastructure, particularly those related to pollution prevention; and Gather information on environmental malpractices such as spillage incidents and releases of pollutants to surface water features such as dams and streams. 	It is valuable in this instance that informal discussions are held with operational staff on site that has been in employment for a long period. Valuable information is gathered in such a way on historical operational practises incidents etc. Try and obtain historical photos of the site.
3) Evaluation of the current	Understand the type and	<ul style="list-style-type: none"> Evaluate the products, services and activities of the 	Obtain a production process flow diagram of the site and

Step Description	Objective	Detailed Activities	Considerations
product production process.	volumes of potential pollutants that are present on site and the location of storage and usage.	<p>production facility;</p> <ul style="list-style-type: none"> • Identify the associated environmental aspects of each of the products, services and activities under normal, abnormal and emergency conditions. Particular emphasis should be placed on impacts associated with surface water, ground water and soil impacts; • Summarise the historical aspects and impacts (Steps 1 and 2) and compare it with the results of Step 3); • From this information delineate on a site map the most prominent point and non-point (disperse) pollutions sources; and • Delineate on a site map the processes which related to products, services and activities which might have high risk to surface water, soil, and ground water pollution. 	<p>understand the process. Visually inspect the production process to form a proper understanding of the inputs, outputs and emissions. Observe operational challenges and abnormal practises such as planned maintenance activities.</p>
4) Gather and evaluate information generated by the formal Environmental Management System (EMS).	Review EMS information and records to understand environmental impacts and how it can relate to ground water impact.	<ul style="list-style-type: none"> • Aspects and impacts associated with the site (Clause 4.3.1); • Legal and other requirements pertaining to the site and its activities (Clause 4.3.2); • Operational control procedures, standards and work instructions (Clause 4.4.6); • Existing monitoring information (Clause 4.5.1); • Evaluation of compliance (Clause 4.5.2); • Incident reporting, 	<p>By scrutinising information and records generated by a formal EMS can provide a valuable overview of the standard of environmental management and the areas where the company experiences challenges with regard to effective implementation of the EMS. Information that is of particular relevance are:</p> <ul style="list-style-type: none"> • Aspect and impact register; • Results of environmental legal

Step Description	Objective	Detailed Activities	Considerations
		<p>corrective and preventive action) (Clause 4.5.3);</p> <ul style="list-style-type: none"> • Internal Audit (Clause 4.5.4); and • Management review (Clause 4.6) (ISO 14001:2004). 	<p>compliance audits, certification and internal audit reports;</p> <ul style="list-style-type: none"> • Management review minutes of meeting; • Environmental management plans; • Environmental incidents and incident investigations; • Operational control procedures and work instructions; and • Monitoring results.
<p>5) Identify other industries and activities in location of the study area/site.</p>	<p>Understand the potential impact of third parties on the study area and the potential for cumulative surface, soil and ground water pollution.</p>	<ul style="list-style-type: none"> • Identify third party activities such as industries in proximity of the study area/site; • Identify historical third party activities in vicinity of the study area/land which might have caused environmental impacts worthwhile considering; • Identify the typical chemicals associated with each of the third party's production processes; and • Visually inspect the sites (if possible) for onsite waste disposal facilities, storm and process water storage facilities and adequacy of clean and dirty water separation. 	<p>When identifying third party activities take into consideration:</p> <ul style="list-style-type: none"> • Geographical location; • Catchment; • Potential to impact the study area/site; and • Ground water flow direction.
<p>6) Assess the study area or potential impact area for sensitive environmental and cultural/heritage areas. Also</p>	<p>Understand the increase in risk and exposure should sensitive environmental and cultural/heritage areas be</p>	<ul style="list-style-type: none"> • Identify sensitive environmental areas such as wetlands, red species fauna and flora, national parks etc; • Identify cultural and/ or heritage areas; • Identify any abnormal impacts that might occur in the study area/site. 	<p>Abnormal impacts to a study area for example may include air pollution that settles in specific catchment with an identifiable contaminant that will accumulate in soil, surface and ground water. The presence of invader and alien plants (particularly</p>

Step Description	Objective	Detailed Activities	Considerations
scrutinise the study area/site for any other abnormal impacts.	present in the study/impacted area.		trees) should also be considered).
7) Define the physical characteristics of the study area/site.	Understand the physical characteristics of the study area/site.	Obtain information on the: <ul style="list-style-type: none"> • Geological setting; • Soil types present; • Climate (rainfall, temperatures, wind direction, evaporation); • Topography; • Hydrography (surface water flow directions, volumes and run-off intensities); and • Integrated site water balance. 	Document any interesting characteristics such as a sudden change in plant growth or soil type.
8) Develop a conceptual ground water model.	Understand the hydrogeology of the study area/site.	Obtain information on the: <ul style="list-style-type: none"> • Geophysical characteristics; • Detailed site geology; • Aquifer classification; • Ground water flow gradients; • Obtain aquifer parameters (pumping tests); • Estimate recharge; • Assess the possibility of ground water surface water interactions; • Assess ground water vulnerability; and • Assess the potential for natural attenuation. 	Continually amend and update the conceptual ground water model as new and additional information becomes available of the study area.
9) Assess the adequacy of the existing ground water monitoring network.	Establish whether the existing ground water monitoring network is appropriate to monitor the impact of the historical and	<ul style="list-style-type: none"> • Evaluate the adequacy of the monitoring network design with regard to the information gathered in Steps 1, 2, 3, 4, 5, 6, 7, and 8; • Assess the adequacy of the monitoring borehole design for the specific pollutant targeted; and 	In instances where the ground water monitoring network is inadequate document the reasons why and request extension and improvement of the monitoring network. This can be done risk based over a period of time.

Step Description	Objective	Detailed Activities	Considerations
	current pollution sources.	<ul style="list-style-type: none"> Assess conformance of the monitoring network to the basic principles of source, pathway, receptor, background (ambient) and third party impact monitoring locations of point and disperse pollution sources. 	
10) Assess the ground water quality monitoring quality results.	Evaluate the ground water quality monitoring results.	<ul style="list-style-type: none"> Identify all the chemical elements present (historically) and currently in the processes present on site. Ensure that these elements are all sampled and analysed for at least twice a year for a period of five years to obtain adequate baseline information; Ensure that sampling and analysis is done to minimum international standards; Assess chemical analysis integrity by performing cation and anion balances; Identify those elements that might be considered “tracer” elements for the specific facility (e.g. Boron). Also take into consideration the potential contribution of third party sites to ground water pollution in the study area/site; Evaluate the sampling results as a minimum to reliable natural background (ambient) ground water quality and then to other appropriate standards such as drinking water quality; 	Establish time series data management practises for seasonal comparisons. It is important to note that fertiliser production in some operations might have a seasonal trend and as such, interpretation of the monitoring data should consider this. Furthermore, it is important that environmental incidents such as chemical spillages be identified from the incidents register and considered when interpreting monitoring results.

Step Description	Objective	Detailed Activities	Considerations
		<ul style="list-style-type: none"> • Determine the contribution of pollution of the site/facility to the natural background water quality; • Determine the source(s) of the specific pollution and evaluate operational control means e.g. operational control procedure design and implementation adequacy; • Evaluate the sampling results against the chemicals used by third parties in their processes to determine if potential third party impact occurred; and • Determine if there can be differentiated between historical and current pollution in the sample analysis. 	
11) Assess the adequacy of the existing surface water monitoring network.	Establish whether the existing surface water monitoring network is appropriate to monitor the impact of the historical and current pollution sources.	<ul style="list-style-type: none"> • Identify all the chemical elements present (historically) and currently in the processes present on site. Ensure that these elements are all sampled and analysed for at least twice a year for a period of five years to obtain adequate baseline information; • Ensure that sampling and analysis is done to minimum international standards; • Assess chemical analysis integrity by performing cation and anion balances; • Identify those elements that might be considered “tracer” elements for the specific facility (e.g. 	In instances where the surface water monitoring network is inadequate, document the reasons why and request extension and improvement of the monitoring network. This can be done risk based over a period of time.

Step Description	Objective	Detailed Activities	Considerations
		<p>Boron). Also take into consideration the potential contribution of third party sites to ground water pollution in the study area/site; and</p> <ul style="list-style-type: none"> • Evaluate the sampling results against the chemicals used by third parties in their processes to determine if potential third party impact occurred. 	
12) Compare surface and ground water monitoring results.	Understand if there is any direct relationship between surface and ground water monitoring results.	<ul style="list-style-type: none"> • Critically compare surface and ground water quality results with each other to determine if there are any similarities in chemical composition and concentrations; and • Critically compare surface and ground water quality results with each other to establish if there is any evidence of ground water surface water interaction; • Review the surface water quality results and re-assess the adequacy of the ground water monitoring network as surface water run-off might impact ground water resources in a much wider area. 	In instances where there is reasonable evidence that surface and ground water interaction might be occurring it is particularly important to assess the adequacy of the ground water monitoring network. It should be noted that surface water is a main carrier of contaminants off site from fertiliser production facilities due to the nature of the operation. It is not unfamiliar to find off-site surface water pockets to be point pollution sources of fertiliser production activities.
13) Compare study area surface water quality results with surface water quality results in the catchment (particular sensitive receptors such	Understand the catchment surface water quality in comparison with those where the facility/study area/site has impacted.	<ul style="list-style-type: none"> • Compare study area surface water quality results with surface water quality results available in the catchment area in order to understand the holistic water quality regime in the catchment and what chemical constituents and concentrations are added to the salt balance of the catchment by the study 	A review of surface water quality in the catchment will in most instances provide additional information on polluters in the catchment as some chemicals can be fingerprinted to specific industries and activities.

Step Description	Objective	Detailed Activities	Considerations
as streams, rivers, dams and wetlands).		<p>area facility; and</p> <ul style="list-style-type: none"> • In particular compare the surface water quality of the study area to the catchment water quality targets and assess contribution to in the specific catchment water quality. 	
14) Quantitative Risk Assessment.	Assess the toxicity risk(s) in the water resources that are being impacted.	<ul style="list-style-type: none"> • Perform a human health risk per problematic contaminant; • Perform a dose response assessment per problematic contaminant; • Perform an exposure risk assessment per problematic contaminant; • Perform a risk characterisation per problematic contaminant; • Perform an ecological risk assessment; and • Compare the above results with that of the in-stream water quality for the catchment. 	Hydrocensus information might be valuable to determine the actual exposure risk, particularly from a ground water consumption risk. A hydrocensus should not be deemed a once-off process but the hydrocensus information should be updated based on the initial exposure risk.
15) Identification of and evaluation of compliance against environmental legal requirements applicable to the study area/site.	Determine legal compliance status against relevant environmental legal requirements.	<ul style="list-style-type: none"> • Identify the national environmental legal requirements applicable to the study area/site; • Determine the “other requirements” such as treaties etc., that might be applicable to the site and study area; and • Determine the compliance status of the site/study area to the relevant legal and other requirements. 	The interpretation of legal compliance status could in some instances become legal-technical. It is recommended that an environmental legal specialist is consulted to professionally determine compliance status should there be any uncertainty.
16) Third party impact through asset depreciation because of	Determine if third party land has been impacted by the pollution	<ul style="list-style-type: none"> • Determine the lateral extent of the pollution plume and determine if it has impacted on the ground water or soil of third party land; 	The extent and depreciation value of an asset should ideally be confirmed by performing an Environmental Due Diligence (EDD) when

Step Description	Objective	Detailed Activities	Considerations
contaminant plume movement.	plume.	<ul style="list-style-type: none"> • If third party land has been impacted, determine the significance of the impact and lateral extent if at all possible; and • Determine the potential of litigation from third parties and interpret the result with the detail stipulated in point 18. 	the liability might materialise such as the intended sale of the property.
17) Assess potential for foreseeable land use changes on impacted and future impacted groundwater area.	Determine if there is any significant risk of foreseeable land use changes that can affect the risk status.	<ul style="list-style-type: none"> • Assess the zoning status of land impacted by groundwater pollution; and • Determine the materiality of the envisaged future land uses in terms of the need for active remediation and risk based corrective action. 	Risk of groundwater use for agricultural and human consumption in future.
18) Requirement for statutory financial reporting.	Assess the statutory need to disclose the ground water impact as financial liability.	Critically review all information gathered through steps 1-15 and determine if there is any potential for legal action against the company/entity to rehabilitate/remediate the contaminated ground water. Furthermore determine, through a review of completeness of steps 1-15 whether the ground water impact is readily quantifiable (estimable).	The following criteria need to be considered when a decision on the disclosure of a liability needs to be made: <ul style="list-style-type: none"> • Probable and estimable; • Probable but not estimable; and • Not probable (whether or not estimable).
19) Integrated reporting or sustainability reporting consideration.	Determine the materiality of the ground water pollution to the legal entity and make a decision on the need to disclose the impact and risk to the	The Global Reporting Initiative (GRI) provides a voluntary framework for the reporting of sustainability information. Determine appropriate Key Performance Indicators (KPI's) to report the ground water impact against.	Materiality determination should include a proper stakeholder involvement process.

Step Description	Objective	Detailed Activities	Considerations
	organisation.		

CHAPTER 12: ABSTRACT/UITTREKSEL

There has been a definitive increase in environmental legislation over the past decade. These new environmental laws established principles such as duty of care and the polluter pay principle. Numerous companies in South Africa have historical impacts, particularly ground water impacts deriving from the period where no or less comprehensive environmental legislation was promulgated. Furthermore, the sudden evolution of environmental legislation has put significant strain on companies to comply with environmental law. The quantification of ground water impact through a methodological approach which can provide adequate information for a decision on the need to disclose the liability as part of the financial audit process is absent in South Africa. This study focussed on deriving a methodology which can be applied in the South African Fertiliser Industry, in assisting with the investigation and quantification of ground water impacts in order to assist with the decision on the need to disclose the liability as part of the financial statements and the newly derived reporting practice of integrated reporting.

Daar was 'n doelgerigte toename in die promulgering van omgewings wetgewing die afgelope dekade in Suid Afrika. Hierdie toename in omgewings wetgewing het beginsels soos die verpligting om versigtig te wees en die besoedelaar betaal gevestig. 'n Aantal maatskappye in Suid Afrika het historiese omgewings impakte, veral grondwater impakte wat hoofsaaklik toegeskryf kan word aan die tydperk voor die promulgering van nuwe omgewings wetgewing. Die toename in omgewings wetgewing die afgelope dekade het druk op maatskappye geplaas om aan die nuwe vereistes te voldoen. Daar is huidiglik geen metodologie in Suid Afrika wat die kwantifisering van grondwater impak as deel van die rapportering van finansiële state volbring nie. Hierdie studie fokus op die daarstel van 'n metodologie wat toegepas kan word in die Suid Afrikaanse Kunsmis Industrie, om te assisteer met die ondersoek en kwantisering van grondwater impak, ten doel, om besluitneming te assisteer in die rapportering van inligting omtrent die omgewingsimpak se geassosieerde finansiële verantwoordelikheid en die nuut gevonde beginsel van geïntegreerde rapportering.

CHAPTER 13: INTERNATIONAL LITERATURE STUDY

An international literature study was conducted using the resources made available by the University of the Free State Library. The literature study involved searching for electronic documents and hard copy documents.

The following electronic search resources were utilised:

- Web of Science;
- Science Citation Index;
- Sabinet; and
- Science Direct.

Limited information on similar studies could be obtained during the international literature study. Information pertaining to fertiliser associated chemicals and its impact on ground water is dominated by disperse pollution through the application of nitrate based fertilisers in the agricultural scene. Only one dissertation could be obtained directly relating to a fertiliser production site that has been recently submitted in South Africa:

Reactive transport modelling of fertiliser waste in a dual porosity aquifer:

B. Bredenkamp

November 2009

M.Sc. Institute for Ground water Studies University of the Free State.

A sample of other academic works related to the study topic is:

Nitrate contamination of ground water: A conceptual management framework:

Environmental Impact Assessment Review, Volume 27, Issue 3, April 2007, Pages 220-242

Mohammad N. Almasri.

Ground water contamination potential from storm water infiltration practices:

Urban Water, Volume 1, Issue 3, September 1999, Pages 217-236

Robert Pitt, Shirley Clark, Richard Field.

The effect of emissions of fertilizer production on the environment contamination by cadmium and arsenic in southern Brazil:

Environmental Pollution, Volume 143, Issue 2, September 2006, Pages 335-340

Nicolai Mirlean, Ari Roisenberg.

Ground water risk assessment at a heavily industrialised catchment and the associated impacts on a peri-urban wetland:

Journal of Environmental Management, Volume 88, Issue 3, August 2008, Pages 526-538

Elias Dimitriou, Ioannis Karaouzas, Konstantinos Sarantakos, Ierotheos Zacharias, Konstantinos Bogdanos, Aristidis Diapo.

Fertilizer standards for controlling ground water nitrate pollution from agriculture: El Salobral-Los Llanos case study, Spain:

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Water Science and Technology 1995;

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CHAPTER 14: REFERENCES

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APPENDIX A:

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
Granulation (plant 1 and 2).	Granulation dust (Dolomitic lime).	Soil, air, surface and ground water pollution.	Normal.
	Solid Calcium Nitrate storage.	Potential soil, surface and ground water pollution.	Abnormal.
	Cleaning of the granulation complex.	Soil, air, surface and ground water pollution.	Normal.
SSP plant.	Off-loading of dolomitic lime.	Soil, air, surface and ground water pollution.	Normal.
	Blocking of chutes causing spills.	Soil, surface and ground water pollution.	Abnormal.
	Leaks on transfer lines causing spillages and particular matter releases.	Soil, surface and ground water pollution.	Abnormal.
	Cleaning of slurry tank.	Soil, surface and ground water pollution.	Normal.
Bagging plant.	Inadequate sewage facilities (staff urinate on site).	Soil, surface and ground water pollution.	Abnormal.
	Fertiliser spillages.	Potential soil, surface and ground water pollution.	Abnormal.
	Inadequate storage facilities under roof for final product during rainy season.	Potential soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Dust generation during bagging.	Potential soil, surface and ground water pollution.	Normal.
Nitrogen complex (ammonia bulk storage tanks, ammonium nitrate and nitric acid plant).	Rupture of ammonia tank (loss of 300t).	Air, soil, surface and ground water pollution.	Emergency.
	Explosion/rupture of tank (run-off of spray water with dissolved ammonia).	Air, soil, surface and ground water pollution.	Emergency.
	Spills and consumption of water (water bath and testing water) - analysed and used in fertiliser process in contained area draining to sump).	Soil, surface and ground water pollution.	Abnormal.
Nitrates complex (ammonium nitrate, calcium nitrate, liquid calcium nitrate).	Spill, Leaks, pipe burst.	Soil, surface and ground water pollution.	Abnormal.
	Chemical splashes from nitric acid in liquid form.	Soil, surface and ground water pollution.	Abnormal.
	Sampling at absorption tower and final product line. Nitrate spillage.	Soil, surface and ground water pollution.	Normal.
	Production of	Soil, surface and ground	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	demineralised water.	water pollution.	
	Cooling tower operation – release of water.	Soil, surface and ground water pollution.	Normal.
	Ammonium nitrate pipe blockages.	Soil, surface and ground water pollution.	Abnormal.
	Off-loading of ammonia by rail – pipe ruptures.	Air, soil, surface and ground water pollution.	Abnormal.
	Loading and off-loading by road – pipe ruptures.	Air, soil, surface and ground water pollution.	Abnormal.
	Filling of ammonia nurse tanks & applicators for field services – pipe ruptures.	Air, soil, surface and ground water pollution.	Abnormal.
	Unblocking blocked lines and ducts.	Soil, surface and ground water pollution.	Normal.
	Housekeeping (effluent discharge and dust management).	Air, soil, surface and ground water pollution.	Normal.
	Dust generation through mobile equipment and product handling.	Air, soil, surface and ground water pollution.	Normal.
	Cleaning of plant	Soil, surface and ground	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	with wash water.	water pollution.	
	Management of waste water and effluent	Soil, surface and ground water pollution	Normal
	Dolomitic lime storage and feeding to reactor (dust).	Air, soil, surface and ground water pollution.	Normal.
	Operation of lime hoist & emptying of lime bags (dust).	Air, soil, surface and ground water pollution.	Normal.
	Operation of screw conveyor, screen, lime conveyor, bucket elevator and hopper (dust).	Air, soil, surface and ground water pollution.	Normal.
	Operation of reactors (overflow of the reactors).	Soil, surface and ground water pollution.	Normal.
	Operation of filter pumps, transfer lines and valves (leaks).	Soil, surface and ground water pollution.	Abnormal.
	Operation and cleaning of filters (product spillage).	Soil, surface and ground water pollution.	Abnormal.
	Feed from intermediate tank to calcium nitrate storage – spillage.	Soil, surface and ground water pollution.	Abnormal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Cleaning of calcium nitrate storage tank.	Soil, surface and ground water pollution.	Normal.
	Liquid magnesium nitrate feeding into hopper (spillages).	Soil, surface and ground water pollution.	Normal.
	Cleaning of bucket elevator and hopper.	Soil, surface and ground water pollution.	Normal.
	Operation of reactors (overflow of reactors).	Soil, surface and ground water pollution.	Abnormal.
	Cleaning of reactors.	Soil, surface and ground water pollution.	Normal.
	Operation of filter pumps, transfer lines and valves (product spillages).	Soil, surface and ground water pollution.	Abnormal.
	Operation and cleaning of filters.	Soil, surface and ground water pollution.	Normal.
	Operation of intermediate pump intermediate tank and transfer line to storage tank (spillages).	Soil, surface and ground water pollution.	Normal.
	LCN plant: Liquid Calcium Nitrate feed to mix tanks (spillages).	Soil, surface and ground water pollution.	Normal.
	Operation of pipe	Soil, surface and ground	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	lines, pumps, valves when transferring product (spillages).	water pollution.	
	Off loading of calcium nitrate.	Soil, surface and ground water pollution.	Normal.
	Calcium nitrate: operation of pipe lines, pumps, valves when transferring product (spillages).	Soil, surface and ground water pollution.	Normal.
	Operation of mix tanks (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Feed to storage or special mix dispatch: operation of pipe lines, pumps, valves when transferring product (spillages).	Soil, surface and ground water pollution	Normal.
	Out loading and dispatch (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Evaporators: Operation of pipe lines, pumps, valves when transferring product (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Operation of Granulator (dust).	Air, soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Cleaning of granulator with wash water.	Soil, surface and ground water pollution.	Normal.
	Transfer of product to primary screen (dust).	Soil, surface and ground water pollution.	Normal.
	Cleaning of transfer equipment between granulator and screen.	Soil, surface and ground water pollution.	Normal.
	Transfer of product from primary screen to secondary screen (dust).	Soil, surface and ground water pollution.	Normal.
	Cleaning of secondary screen.	Soil, surface and ground water pollution.	Normal.
	Transfer of product from secondary screen to secondary cooler (dust).	Soil, surface and ground water pollution.	Normal.
	Transfer of product from secondary cooler to store (dust).	Soil, surface and ground water pollution.	Normal.
	Cleaning of scrubber system (effluent generation).	Soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Transfer of product from adjustment tank to evaporator.	Soil, surface and ground water pollution.	Normal.
	Operation of Granulator (product leak).	Soil, surface and ground water pollution.	Normal.
	Cleaning of granulator.	Soil, surface and ground water pollution.	Normal.
	Transport of bulk bags and tearing.	Potential soil, surface and ground water pollution.	Normal.
SSP plant.	Off-loading of raw materials (spillages).	Soil, surface and ground water pollution.	Normal.
	Loading of final product – bag breakage (spillages).	Soil, surface and ground water pollution.	Normal.
	Storage of final product (solids).	Potential, soil, surface and ground water pollution.	Normal.
	Pipe breakage.	Soil, surface and ground water pollution.	Emergency.
Speciality liquids blending plant.	Off-loading of raw materials (spillages).	Soil, surface and ground water pollution.	Normal.
	Loading of final product – bag breakage (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Storage of final	Potential soil, surface and	Abnormal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	product (liquid spillages).	ground water pollution.	
	Cleaning.	Soil, surface and ground water pollution.	Normal.
	Inadequate ablution facilities employees urinate on site.	Soil, surface and ground water pollution.	Abnormal.
	Loading and off - loading of trucks – raw material bag breakage (spillages).	Soil, surface and ground water pollution.	Normal.
Liquid fertiliser plant.	Off-loading of raw materials via road trucks (liquid/dry materials).	Air, soil, surface and ground water pollution.	Normal.
	Accidental spillage: Pipe rupture, seal breaks on pumps. Valve rupture.	Soil, surface and ground water pollution.	Abnormal.
	Pipe blockages (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Transfer of solid raw material to feed hopper – bag breakage (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Transfer of liquid	Soil, surface and ground	Abnormal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	products via pipeline into road trucks (spillages).	water pollution.	
	Emptying and cleaning of vessels (spillages).	Soil, surface and ground water pollution.	Abnormal.
	Plant maintenance, spillages (oil, grease, other reagents) and waste oil.	Soil, surface and ground water pollution.	Normal.
	Loading of trucks - rupture of tanker - loss of liquid fertiliser.	Soil, surface and ground water pollution.	Emergency.
Storm water system management (including storm water dam).	Storm water flow during rainy season/events. Mud and fertiliser product spills accumulate in the trenches.	Soil, surface and ground water pollution.	Normal.
	Removal of mud/sludge and product spillage from the storm water system – disposal.	Secondary impact – soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Cracks and corrosion of storm water channels and dams from acidic storm water – seepage of contaminated storm water.	Soil, surface and ground water pollution.	Normal.
	Pond forming of storm water due to no sloping towards storm water drains and channels e.g. oil amine tank.	Soil, surface and ground water pollution.	Normal.
	Pumping of storm water from dams to superphosphate plant, or from dam to dam, or from weir to dams – pipeline leakages.	Soil, surface and ground water pollution.	Abnormal.
	Overflow of above ground and underground storm water catchment dams.	Soil, surface and ground water pollution.	Normal.
	Leakage of storm water catchment dam due to lining.	Soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	Overflow of storm water channels.	Soil, surface and ground water pollution.	Normal.
Utilities (steam, water and gas).	Supply of water to plant – broken pipes above and underground (increase in water generation).	Soil, surface and ground water pollution.	Abnormal.
	Blocked sewer system – sewage overflows.	Soil, surface and ground water pollution.	Abnormal.
Goods receiving, dispatch, stores and warehousing.	Cleaning out railway carriages to collect Omnia Product – waste temporary stored next to railway line.	Potential soil, surface and ground water pollution.	Normal.
	Storage of product. Spillage of product on floors, equipment, machinery, roads etc. - requires reprocessing of product.	Potential soil, surface and ground water pollution.	Normal.
	Product storage (dust).	Air, soil, surface and ground water pollution.	Normal.
	Acid Loading and	Soil, surface and ground	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	off-loading by road (spillages).	water pollution.	
Railway delivery.	Rail delivery – shunting. Risk of acid leaks.	Soil, surface and ground water pollution.	Emergency.
	Tippler operation – dust generation.	Air, soil surface and ground water pollution.	Normal.
Workshops and offices.	Maintenance of machines, equipment inside workshops. Oil, diesel and grease spillages.	Soil, surface and ground water pollution.	Normal.
	Maintenance of vehicles outside on ground. Spillages of oil, diesel and “anti-freeze”.	Soil, surface and ground water pollution.	Normal.
	Working with flammable substances (paraffin, diesel, oil and paint). Storage and spillages.	Soil, surface and ground water pollution.	Normal.
	Sand and shot blasting – dust generation.	Soil, surface and ground water pollution.	Normal.
	Storage of unsealed waste oil drums in	Soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
	unprotected area.		
	Storage of waste batteries – acid leaks.	Soil, surface and ground water pollution.	Normal.
	Diesel tank use (spillages).	Soil, surface and ground water pollution.	Normal.
	Wash bay generation of wash water.	Soil, surface and ground water pollution.	Normal.
	Change house usage – leaking sewage system.	Soil, surface and ground water pollution.	Abnormal.
Compressed air system.	Use of temporary compressor outside compressor room (some on hard surfaces and others not).	Soil, surface and ground water pollution.	Normal.
	Compressor operation – blow down water.	Soil, surface and ground water pollution.	Normal.
	Compressor operation – use of oil and coolants.	Soil, surface and ground water pollution.	Normal.
	Operation of Cooling system for air compressors – waste water generation.	Soil, surface and ground water pollution.	Normal.

Area	Aspect	Impact	Normal/Abnormal/ Emergency Conditions
Ammonia gas facility	Spray booth – residual paints and other chemicals.	Air, soil, surface and ground water pollution.	Normal.
	Pressure testing of vessels – residual chemicals and water.	Air, soil, surface and ground water pollution.	Normal.
	Chemical storage.	Potential soil, surface and ground water pollution.	Normal.
Material control	The high traffic area at the entrance to raw material bins, all takes place across rail lines. Agricultural lime and other materials are used to level the area between the railway lines for easy crossing.	Soil, surface and ground water pollution.	Abnormal.

APPENDIX B: OTHER REQUIREMENTS APPLICABLE TO OMNIA FERTILISER SASOLBURG

B.1 OTHER REQUIREMENTS

“Other requirements” are usually related to non-explicit legal obligations. However, some existing acts, national environmental policies etc. might already acknowledge the principles of other requirements in its application. “Other requirements” are usually deemed international obligations on burning matters which requires global action and attention.

Table B1: Other Requirements to which might be applicable to Omnia Fertiliser Sasolburg (Wickens, 2009).

Initiative	Objective	More Information	EMS Implication
United Nations Global Compact	<p>Through the power of collective action, the Global Compact seeks to promote responsible corporate citizenship so that business can be part of the solution to the challenges of globalisation. In this way, the private sector – in partnership with other social actors – can help realize the UN Secretary-General’s vision for a more sustainable and inclusive global economy.</p> <p>The Global Compact comprises of ten principles covering the areas of human rights, labour, the environment and anti-corruption. As a signatory a company is expected to:</p> <ul style="list-style-type: none"> • Set in motion changes to business operations so that 	www.unglobalcompact.org	<p>Required to demonstrate progress with implementing the 3 environmental principles, namely:</p> <ul style="list-style-type: none"> • Principle 7: Business should support a precautionary approach to environmental challenges; • Principle 8: undertake initiatives to promote greater environmental responsibility; and • Principle 9: encourage the development and diffusion of environmentally friendly technologies.

Initiative	Objective	More Information	EMS Implication
	<p>the Global Compact and its principles become part of management, strategy, culture and day-to-day operations; and</p> <ul style="list-style-type: none"> • Publish in its annual report or similar public corporate report a description of the ways in which it is supporting the Global Compact and its principles, and Publicly advocate the Global Compact and its principles via communications vehicle such as press releases, speeches etc. 		
Responsible Care	Responsible Care helps the industry to operate safely, profitably and with care for future generations. Through the sharing	http://www.responsiblecare.org	Other requirements relating to environmental performance management.

Initiative	Objective	More Information	EMS Implication
	<p>of information and a rigorous system of checklists, performance indicators and verification procedures, Responsible Care enables the industry to demonstrate how its health, safety and environmental performance has improved over the years, and to develop policies for further improvement.</p> <p>Responsible Care requires companies to be open and transparent with their stakeholders – from local communities to environmental lobby groups, from local authorities and government to the media, and of course the general public. It has driven a transformation in the way that companies operate: from being secretive and defensive about their</p>		

Initiative	Objective	More Information	EMS Implication
	activities, to being more open, honest, and actively seeking dialogue and partnerships with stakeholders.		

B.2 GOOD PRACTISE REQUIREMENTS

There are a number of industry and/or environmental standards and commitments that are considered good practice. In most instances the Board of Directors of companies are expected under good governance principles to seek good practise guidelines applicable to their industry and to implement these guidance documents in order to continually approve its activities. Good practise guidelines are usually guided “by global trends and international standards” and are usually early thinking on new principles before the concepts get international formalisation such as ISO standards etc. It provides particular guidance in countries where there is a lack of environmental law.

The purpose of good practise guidelines is to provide information to operations on what guidelines exist. These should be considered when managing environmental impacts, undertaking projects and/or implementing environmental management systems.

Table B2: Good practice requirements (Wickens, 2009).

Initiative	Objective	More Information
Chemical Industry, Codes and Declarations		
<p>ICMM Principles</p>	<p>In addition to the Principles there are a number of policy and position statements that may have relevance, also see the ICMM Toronto Declaration.</p> <p>The ICMM Principles state the following: As members of the International Council on Mining & Metals (ICMM) or as companies that have otherwise agreed to take on the same performance obligations as ICMM members, we seek continual improvement in our performance and contribution to sustainable development so as to enhance shareholder value. In striving to achieve this, we will:</p> <ul style="list-style-type: none"> • Implement and maintain ethical business practices and sound systems of corporate governance; 	<p>http://www.icmm.com/icmm_principles.php and http://www.icmm.com/policy_statements.php</p>

Initiative	Objective	More Information
	<ul style="list-style-type: none"> • Integrate sustainable development considerations within the corporate decision-making process; • Uphold fundamental human rights and respect cultures, customs and values in dealings with employees and others who are affected by our activities; • Implement risk management strategies based on valid data and sound science; • Seek continual improvement of our health and safety performance; • Seek continual improvement of our environmental performance; • Contribute to conservation of biodiversity and integrated approaches to land use planning; • Facilitate and encourage 	

Initiative	Objective	More Information
	<p>responsible product design, use, re-use, recycling and disposal of our products;</p> <ul style="list-style-type: none"> • Contribute to the social, economic and institutional development of the communities in which we operate; and • Implement effective and transparent engagement, communication and independently verified reporting arrangements with our stakeholders. 	
Organisational Management Principles and Codes		
OECD Guidelines for Multinational Enterprises	The Guidelines are recommendations addressed by governments to multinational enterprises operating in or from adhering countries. They provide voluntary principles and standards for responsible business conduct in a variety of areas including employment	www.oecd.org/departement/0,2688,en_2649_34889_1_1_1_1_1,00.html

Initiative	Objective	More Information
	and industrial relations, human rights, environment, information disclosure, combating bribery, consumer interests, science and technology, competition, and taxation.	
Equator Principles	The Equator Principles are a financial industry benchmark for determining, assessing and managing social and environmental risk in project financing. Equator Principles Financial Institutions (EPFIs) have adopted a set of Principles in order to ensure that the projects they finance are developed in a manner that is socially responsible and reflect sound environmental management practices.	http://www.equator-principles.com/
International Finance Corporation (IFC) Performance Standards	The IFC has a set of Environmental and Social Standards which it applies to all the projects it finances in order to minimize their impact on the environment and on affected communities.	http://www.ifc.org/ifcext/enviro.nsf/Content/EnvSocStandards

Initiative	Objective	More Information
King Report on Corporate Governance (King III)	<p>Although specific to South Africa, it is seen as a good international standard for Corporate Governance</p> <p>The aim of recent changes in corporate governance worldwide is to promote greater corporate accountability, transparency and stakeholder confidence. A direct result of these changes is increased accountability of company directors regarding risk control within their organisations. In South Africa, the release of the third King Committee Report (King III) in August 2009 has led to renewed interest in good corporate governance practices. With the King III Report the importance of risk management receives official consideration for the first time in South Africa. King III now requires that companies audit risk exposure annually and disclose it to their shareholders. It</p>	

Initiative	Objective	More Information
	<p>has therefore become of paramount importance that organisations that seek to conform to international best business practices implement sound corporate governance structures. It furthermore requires that sustainability information be assured by a third party and escalates the ultimate responsibility for sustainable development to the direct oversight of the audit committee.</p>	
Business Sustainability Indices		
<p>Dow Jones Sustainability Index (Strategic Asset Management (SAM) assessments)</p>	<p>Launched in 1999, the Dow Jones Sustainability Indexes are the first global indexes tracking the financial performance of the leading sustainability-driven companies worldwide. Based on the cooperation of Dow Jones Indexes, STOXX Limited and SAM they provide asset managers with reliable and objective benchmarks to manage sustainability portfolios.</p>	

Initiative	Objective	More Information
	<p>The identification of sustainability leaders for the Dow Jones Sustainability Indexes is based on the Corporate Sustainability Assessment of SAM research. A defined set of criteria and weightings is used to assess the opportunities and risks deriving from economic, environmental and social development for the eligible companies.</p>	
Management System Standards		
ISO14000 series	<p>The ISO 14000 family is primarily concerned with "environmental management". This means what the organization does to minimise harmful effects on the environment caused by its activities, and to achieve continual improvement of its environmental performance.</p>	<p>http://www.iso.org/iso/en/prods-services/otherpubs/iso14000/index.html</p>
Reporting Standards		
Global Reporting Initiative	<p>The Global Reporting Initiative's (GRI) vision is that reporting on economic,</p>	<p>www.globalreporting.org</p>

Initiative	Objective	More Information
	<p>environmental, and social performance by all organizations becomes as routine and comparable as financial reporting. GRI accomplishes this vision by developing, continually improving, and building capacity around the use of its Sustainability Reporting Framework. GRI Reporting Guidelines and Sector Supplements should be used as the basis for reporting. There is a Mining and Metals Sector Supplement that would be applicable to Letseng Diamond Mine.</p>	
Global Goals		
Millennium Development Goals	<p>The eight Millennium Development Goals (MDGs) – which range from halving extreme poverty to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 – form a blueprint agreed to by all the world’s countries</p>	<p>http://www.un.org/millenniumgoals/</p>

Initiative	Objective	More Information
	<p>and the entire world's leading development institutions. They have galvanized unprecedented efforts to meet the needs of the world's poorest.</p> <p>Goal 1: Eradicate extreme poverty and hunger;</p> <p>Goal 2: Achieve universal primary education;</p> <p>Goal 3: Promote gender equality and empower women;</p> <p>Goal 4: Reduce Child mortality;</p> <p>Goal 5: Improve maternal health;</p> <p>Goal 6: Combat HIV/AIDS, malaria and other diseases;</p> <p>Goal 7: Ensure environmental sustainability; and</p> <p>Goal 8: Develop a global partnership for development.</p>	
New Partnership for Africa's Development	The New Partnership for Africa's Development (NEPAD) is a vision and strategic framework for Africa's	http://www.nepad.org

Initiative	Objective	More Information
(NEPAD)	renewal with the following objectives a) To eradicate poverty; b) To place African countries, both individually and collectively, on a path of sustainable growth and development; c) To halt the marginalisation of Africa in the globalisation process and enhance its full and beneficial integration into the global economy; and d) To accelerate the empowerment of women.	

B.3 INTERNATIONAL CONVENTIONS

Conventions are signed and agreed upon by the highest level of authority within a country e.g. parliament. The commitments of the conventions are translated into the legislation of the country concerned, it is however important to have an understanding of these conventions, particularly prior to their inclusion into national legislation. The following are examples of some of the International Conventions.

Table B3: International conventions (Wickens, 2009)

Convention	Description	More Information
Agenda 21	Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment.	http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=52&ArticleID=
Ramsar Convention	Convention on Wetlands of International Importance especially as Waterfowl Habitat. The broad aims are to stem the loss and to promote wise use of all wetlands.	www.ramsar.org
Convention on Biological Diversity	The principal objectives are the conservation and sustainable use of biological diversity, and the fair and equitable sharing of benefits arising from its utilization.	www.biodiv.org
Convention to combat desertification.	This Convention aims to promote effective action through innovative local programmes and supportive international partnerships. The treaty acknowledges that the struggle to protect drylands will be a long one - there will be no quick fix. This is because the causes of desertification are many and complex, ranging from international trade patterns to unsustainable land management practices.	www.unccd.int
World Heritage Convention	The Rotterdam Convention is a multilateral environmental agreement designed to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals, in order to protect human health	www.pic.int

Convention	Description	More Information
	<p>and the environment from potential harm and to contribute to their environmentally sound use by facilitating information exchange about their characteristics, providing for a national decision-making process on their import and export and disseminating these decisions to Parties. In other words, the Convention enables the world to monitor and control the trade in certain hazardous chemicals.</p>	
<p>Stockholm convention on persistent organic compounds</p>	<p>The Stockholm Convention is a global treaty to protect human health and the environment from persistent organic pollutants (POPs). POPs are chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of living organisms and are toxic to humans and wildlife. POPs circulate globally and can cause damage wherever they travel. In implementing the Convention, Governments will take measures to eliminate or reduce the release of POPs into the environment.</p>	<p>www.pops.int</p>
<p>Kyoto Protocol</p>	<p>Over a decade ago, most countries joined an international treaty -- the <u>United Nations Framework Convention on Climate Change</u> (UNFCCC) - to begin to consider what can be done to reduce global warming and to cope with whatever</p>	<p>http://unfccc.int/essential_background/kyoto_protocol/items/2830.php</p>

Convention	Description	More Information
	<p>temperature increases are inevitable. Recently, a number of nations have approved an addition to the treaty: the <u>Kyoto Protocol</u>, which has more powerful (and legally binding) measures.</p>	
<p>Montreal Protocol on substances that deplete the ozone layer</p>	<p>The Protocol was designed so that the phase out schedules could be revised on the basis of periodic scientific and technological assessments. Following such assessments, the Protocol was adjusted to accelerate the phase out schedules. It has also been amended to introduce other kinds of control measures and to add new controlled substances to the list.</p>	<p>http://www.unep.ch/ozone/Treaties%5Fand%5FRatification/index.shtml</p>
<p>Vienna Convention</p>	<p>In 1985, nations agreed in Vienna to take "appropriate measures to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the Ozone Layer", thus the Convention for the Protection of the Ozone Layer was born. Several amended to the convention have been signed these include the London Amendment, the Copenhagen Amendment, the Montreal Amendment and the Beijing Amendment.</p>	<p>http://www.unep.ch/ozone/Treaties%5Fand%5FRatification/index.shtml</p>
<p>Convention on the International Trade in</p>	<p>Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten their survival.</p>	<p>www.cites.org</p>

Convention	Description	<u>More Information</u>
Endangered Species of Wild Fauna and Flora (CITES)		