HYDROGEOLOGICAL REPORT

FOR

Samancor Chrome's 30CDR Slimes dam on the property Portion 280 of Portion 155 Middelburg town and Townlands no. 287 JS, Mpumalanga Province

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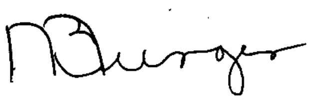

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EXECUTIVE SUMMARY

Geo Pollution Technologies is an ISO 9001 certified groundwater specialist company that has been tasked by ENVASS to do a baseline groundwater study on the 30CDR Slimes dams (also known as the old slimes and unused slimes dam) at Samancor Middelburg Ferrochrome, Mpumalanga.

This report was guided by the Department of Environmental Affairs, National Environmental Management: Waste Act, 2008 (Act No.59 of 2008), Regulations for Site Assessments and Reports (Notice 234 of 2012, March 2012) and (Act No.59 of 2008) Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (Notice 233 of 2012, March 2012).

Results of Investigation

Observations from the site visit as well as work done during previous studies suggest that seepage and migration of groundwater and potential pollution plumes occur predominantly within the weathered lithologies. This shallow groundwater discharges into the Vaalbank spruit to the east of the 30CDR Slimes dam. The shale/rhyolite or diabase underlying the weathered sediments or unconsolidated material tends to be relatively impermeable. However, there may be site specific areas where hydraulic continuity (vertical fractures) exists between the weathered zone and the underlying fractured aquifers. Pollution may migrate along these fractures or the contacts of igneous intrusions (dolerite dykes) to deeper levels within the fractured aquifer.

A total of 5 boreholes were sampled. Water levels were measured in all the boreholes. The measured water levels ranged from 0.9 (minimum) to 4.7 m (maximum) below surface. The relative shallow water table measured in the boreholes increases the aquifers susceptibility to contamination from surface structures such as the 30CDR Slimes dam.

A total of 10 auger holes were drilled in to the slimes dam and soil samples were taken at different depths. From these 10 holes which could be considered to be representative of the general 30CDR Slimes dam, 10 samples were sent in for geochemical assessment by TCLP/Acid Rain analyses[1].

The samples were analysed to determine the water soluble leachates that may arise from the slimes dam and move into the groundwater and impact onto the Vaalbank spruit.

Based on the selected samples and limited analyses the following can be concluded regarding the hydro chemical/geochemical results.

[1] *TCLP/Acid Rain analysis extracts solids. Total metals in solids are determined after extractions by either ICP-OES*

- The major percentage cation/anion constituents (70%) of the samples analysed for are Sodium (22%) Calcium (21%) Potasium (16%) and Magnesium (12%).
- According to the soil screening values for the parameters analysed f indicate that the soil is not contaminated above acceptable limits.
- The parameters analysed indicate that the groundwater underlying the site has been affected through pollution especially if Fe and Al is considered. WD-08 shows water quality that is directly impact by pollution source(s) such as the 30CDR Slimes as it is elevated for most of the parameters analysed (see Table 8).
- The chemicals of concern for the 30CDR Slimes dam as listed by Golder, 2011 are Chromium, Fluoride, Aluminium, Arsenic and Magnesium. Based on these named parameters the 30CDR Slimes is contributing to the pollution load onto the groundwater underlying the 30CDR Slimes dam especially if Aluminium is considered.

Mitigation Measures

A shallow interception trench constructed downstream of the 30CDR Slimes dam. Such a design should only be considered following a thorough geotechnical study. Alternatively, the Samancor could decide to mitigate at the downstream reaches of the local streams

Monitoring Network

Boreholes WD01, WD02, WD08, WD10 and N3880 are available for plume/source monitoring. The construction of the boreholes should be made available or be determined for future studies.

The following parameters should be analysed for on a quarterly basis.

Inorganic chemicals including:

- Heavy metals, particularly Iron, Aluminium and Chromium
- Sulphate
- Arsenic
- Magnesium
- Fluoride
- Ammonia
- Magnesium
- Calcium and Potassium
- Bicarbonate

Other parameters:

- pH
- Electrical Conductivity
- Total Dissolved Solids

LIST OF ABBREVIATIONS

HCO3	=	Bicarbonate
NO3	=	Nitrate
Cl	=	Chloride
SO4	=	Sulphate
NH3	=	Ammonia
F	=	Fluoride
Na	=	Sodium
K	=	Potassium
Ca	=	Calcium
Mg	=	Magnesium
Fe	=	Iron
Mn	=	Manganese
Al	=	Aluminium
Zn	=	Zinc
B	=	Boron
Ni	=	Nickel
Co	=	Cobalt
Cd	=	Cadmium
Si	=	Silica
Se	=	Selenium
Cu	=	Copper
Pb	=	Lead
Ag	=	Silver
TDS	=	Total Dissolved Solids
EC	=	Electrical Conductivity
Cat/an bal%	=	Cation/anion balancing error
SSL	=	Soil screening level
SWL	=	Static Water Level
BDL	=	Below detection limit
AH	=	Auger hole
BH	=	Borehole
DRO	=	Diesel Range Organics
GRO	=	Gasoline Range Organics
ICP-OES	=	Inductively Coupled Plasma Optical Emission Spectroscopy
GC-MS	=	Gas Chromatography Mass Spectrometer
GPT	=	Geo Pollution Technologies
GW	=	Groundwater
ℓ	=	litre
m	=	metres
mamsl	=	metres above mean sea level
mbgl	=	metres below ground level
mg/l	=	milligram per litre
PAH	=	Poly Aromatic Hydrocarbons
n.a.	=	not analysed
ppm	=	parts per million
RBCA	=	Risk based corrective actions
RBSL	=	Risk Based Screening Levels

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1 INTRODUCTION

This document was compiled by Geo Pollution Technologies (Pty) Ltd (GPT) for Environmental Assurance (Pty) Ltd, further referred to in this document as ENVASS. Geo Pollution Technologies is an ISO 9001 certified groundwater specialist company that has been tasked by ENVASS to do a baseline groundwater study on the 30CDR Slimes dams (also known as the old slimes and unused slimes dam) at Samancor Middelburg Ferrochrome, Mpumalanga (Figure 1).

This report was guided by the Department of Environmental Affairs, National Environmental Management: Waste Act, 2008 (Act No.59 of 2008), Regulations for Site Assessments and Reports (Notice 234 of 2012, March 2012) and (Act No.59 of 2008) Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (Notice 233 of 2012, March 2012).

The objective of this study is to report on the findings of the baseline groundwater /geochemical study conducted by Geo Pollution Technologies on and around the 30CDR Slimes dam during February 2012. The Slimes dam is approximately 3.7 km southeast of the center of the town Middelburg, Mpumalanga.

During the execution of the groundwater study, it was necessary to conduct a basic borehole (groundwater) census directly around the slimes dam. This entailed, visiting the borehole, taking of a photo, recording their locations, measuring the depth to the groundwater level and groundwater sampling/soil sampling. A water sample was taken for the analysis of the major groundwater anions and cations as well as certain suspected constituents such as chromium from strategically selected boreholes. The data will serve as a reference for future comparisons, if needed.

Soil samples of the 30CDR Slimes dam were also taken. The samples were geochemically analyzed to determine the constituents of the potential pollution source. Soil sampling was thus required to characterize the pollution potential of the 30CDR Slimes dam.

1.1 TERMS OF REFERENCE

The aim of the investigation is to assess and characterise the potential impact that the 30CDR Slimes dam at Samancor Middelburg has on potential ground/surface water receptors and groundwater/surface water pathways around the Slimes dam. To adhere to the preceeding, the following should be done:

- Chemically characterised the product within the slimes dam;
- Evaluate the pollution potential of the product;

- Chemical analysis of the groundwater as sampled from the surrounding boreholes for the characterisation of the groundwater quality.

Furthermore the vulnerability of the subsurface to contamination emanating from the 30CDR Slimes dam will be assessed. An impact assessment was done to comply with the requirements as outlined in the Environmental Impact Regulations R543 of 18 June 2010 of NEMA required by ENVASS for an Environmental Impact Assessment (EIA).

Please note that this report did not include a comprehensive geohydrological investigation, rather the analysis and interpretation of soil and groundwater samples in terms of a site conceptual model.

The environmental process followed in this groundwater contamination assesment is guided by the National Environmental Management Act, 1998 (Act 107 of 1998, NEMA), its Amendment Acts, the EIA Regulations of July 2010 and the EIA Regulations of June 2010.

2 SCOPE OF THE STUDY

The aim of the investigation is to obtain a baseline Hydrogeological/Geochemical status report of the area surrounding the 30CDR Slimes dam. The following was done as part of the limited investigation:

- Site inspection, mapping of relevant geohydrological features and gathering of existing information from topographical maps, ortho-photos, geological maps, hydrological information, meteorological information, etc.

- Desktop study of previous relevant hydrogeological studies done at the site.

- Execution of a borehole / spring water census in the area to assess groundwater utilisation by neighbours in a 1km radius. Spot checks were done in a 1-2km radius. Analysis of boreholes surrounding the 30CDR Slimes dam. The following data will be collected:

    - ♦ Site information (Farm name, owner and contact details)

    - ♦ Borehole information (coordinates, depth of casing, casing type, borehole depth, date drilled, yield, pump type, reservoir, open/closed, in-use and water level)

    - ♦ Spring information (coordinates, estimated yield (volume), frequency of flow, storage and pipelines)

- Water samples were collected from selected hydrocensus boreholes for laboratory analysis to establish the background water quality of the area. The results of analysis will be compared to DWA standards.

- Soil samples were collected around and from the 30CDR Slimes dam to establish the contaminant as well as the leaching potential of the contaminant.

- The groundwater recharge of the property was estimated using appropriate techniques.

- The vulnerability of the aquifer to potential pollution was assessed. The aquifer was also classified according to the Parsons aquifer classification methodology.

- A groundwater monitoring network was recommended and standard operational procedures for groundwater monitoring and management was discussed.

3 METHODOLOGY

3.1 DESK STUDY

A desk study was conducted, entailing the gathering of information from the relevant topographical maps (1:50 000 2529CD and 2529DC Topographic Sheet) and geological map (1:250 000 sheet 2528). The following literature was reviewed:

- Golder Associates, Delineation of Groundwater Pollution Plumes and Predictions of Plume Migration-Rev1, June 2011. Middelburg Ferrochrome, a division of Samancor Chrome Ltd. Report nr: 12622-9952-2.
- Golder Associates, Samancor Chrome: Middelburg Ferrochrome, 2010. Interim Intergrated Water and Waste Management Plan. Report nr. 12065-9021-1.
- Environmental Science Associates, Middelburg Chrome Chemicals Plant, Groundwater Report, March 2008. Prepared for Samancor Chrome (Pty) Ltd.
- Environmental Science Associates, Proposed Chrome Chemicals Plant Middelburg, Scoping Report, June 2007. Samancor Chrome (Pty) Ltd.

3.2 HYDROCENSUS

A limited hydrocensus/field work was conducted during February 2012 around the 30CDR Slimes dam to obtain a representative population of boreholes surrounding the 30CDR Slimes dam. During the hydrocensus, all available details of boreholes and borehole-owners were collected and populated onto hydrocensus field forms. Water samples were collected from boreholes and surface water as described in the relevant paragraph below. Information was collected on the use of the boreholes in the area, the water levels and yields of boreholes, etc. This information can be used to assess the risk which potential groundwater pollution poses to groundwater users. The following parameters were captured during the hydrocensus:

- GPS position
- Owner details
- Existing equipment
- Current use
- Reported yield
- Reported or measured depth
- Static water level
- Photograph

3.3 30CDR SLIMES DAM GEOCHEMICAL SAMPLING

Soil samples of the Slimes dam were taken by drilling auger[2] holes until refusal into the Slimes dam. The soil sampling was guided by the South African Engineering and Environmental Geologists Soil Profiling and Chip Logging Course, 2010[3]. All relevant information regarding soil sampling was recorded.

[2] *Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the hole by the blade of the screw*

[3] *Available on request from morne@gptglobal.com*

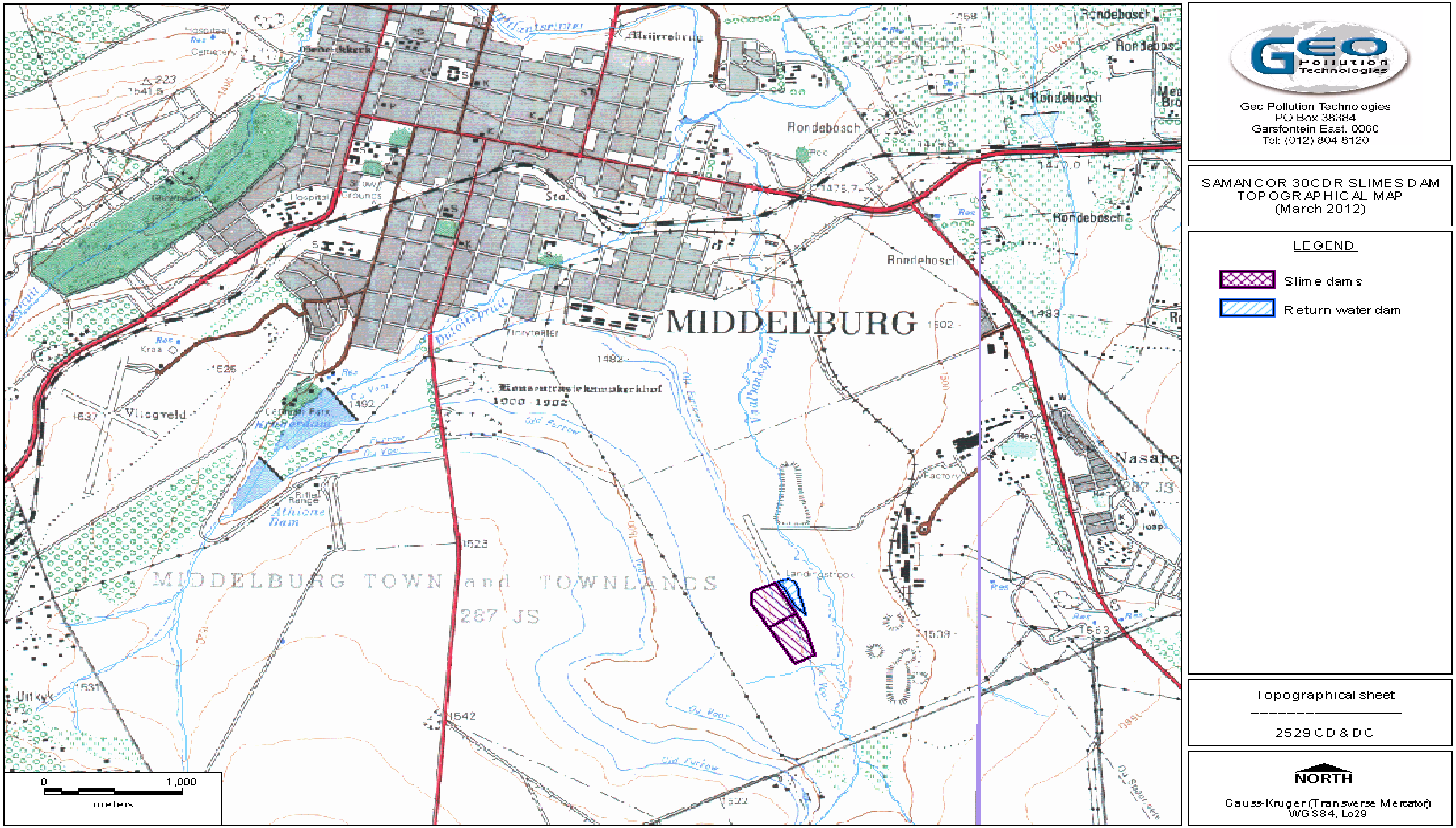

Figure 1: Location of the 30CDR Slimes dam in relation to Middelburg

3.4 WATER SAMPLING AND QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

Groundwater was sampled during February 2012 according to the GPT Standard Operating Procedure (SOP's) for groundwater sampling by bailing[4]. The groundwater level was measured before introducing any equipment in the borehole. Geo Pollution Technologies (Pty) Ltd, incorporating our subsidiaries and regional offices, commits to comply with the Quality Management System and the requirements of ISO 9001:2008.

The methodology followed by GPT for groundwater and surface water monitoring are in accordance with the American Environmental Protection Agency (EPA). On request of the Client, GPT can supply Chain of Custody forms, field notes as well as standard operating procedures outlining the methodology followed for groundwater and surface water monitoring.. One-litre plastic bottles were used for the cation/anion analyses. All the collected groundwater samples were kept cool prior to their dispatch to the laboratories for analysis. The water samples were submitted to Clean Stream laboratories in Pretoria.

All monitoring data related to groundwater and surface water were interpreted by GPT using EnviroInsite version 7.0.0.20 and WISH. The chemical data were compared to the SABS Drinking Water Standards document[5] (SANS 241:2006, Ed. 6.1) for domestic use.

In interpreting the data and deciding on appropriate action, a Risk Based Approach was used which requires an understanding of the groundwater in terms of the primary and secondary sources of contamination, the pathways thereof and the receptor on which the contamination can impact.

3.5 GROUNDWATER RECHARGE ESTIMATION

The groundwater recharge was estimated using the RECHARGE program[6], which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge:

- Soil information
- Geology
- Groundwater Recharge Map (Vegter)
- Acru Recharge Map (Schulze)
- Harvest Potential Map
- Chloride (Cl) method

[4] *Available on request from morne@gptglobal.com*

[5] *South African Bureau of Standards document "Specification: Drinking Water" SANS 241 Ed. 6.1 2006*

[6] *Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.*

The above-mentioned programme incorporates all the different methods to calculate recharge. The following assumptions are necessary for successful application of the Cl Method:

- There is no source of chloride in the soil moisture or groundwater other than that from precipitation
- Chloride is conservative in the system
- Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone
- A piston flow regime, which is defined as downward vertical diffuse flow of soil moisture, is assumed.

4 DESCRIPTION OF THE ENVIRONMENT

4.1 LOCALITY

Middelburg Ferrochrome (MFC) on which the 30CDR Slimes dam is located is approximately 4.5 km southeast of the center of the town Middelburg. MFC covers an area of approximately 360 ha and falls within the Steve Tshwete Municipality (IWMMP, 2010).

4.2 TOPOGRAPHY, CLIMATE AND DRAINAGE

The 30CDR Slimes dam is adjacent to the Vaalbank spruit directly to the east. The spruit flows from south to north and eventually joins the Klein Olifantsriver north of the site (Figure 3). The Vaalbank spruit is a perennial stream but in some areas may be seasonal. The surface elevation on which the 30CDR Slimes dam is located ranges from a minimum elevation of 1476 mamsl[7] (east near the spruit) to a maximum of 1495 mamsl (west) see Figure 3. It is expected that surface water drainage from the 30CDR Slimes dam will be in a predominately west to east direction towards the Vaalbank spruit (Figure 3).

[7] *Mamsl- meters above mean sea level*

4.3 GROUNDWATER RESOURCE DIRECTED MEASURES DATA

Based on the data sourced from DWAF's GRDM[8] the 30CDR Slimes dam falls within the B12D Quaternary Catchment which falls within the Olifants Water Management Area. The B12D catchments eco status category can be classified as E or F which is considered poor. This poor condition can be attributed to the influence of the town Middelburg and the effects humans have on eco systems through industrialisation. A summary of the relevant GRDM data is shown in Table 1.

Table 1: GRDM Data

GRDM Data (2003)	
Quaternary Catchment Name	B12D
Area	362.3 km^2
Mean Annual Precipitation	703 mm/a
Mean Annual Run-off	38 mm/a
Base flow	10 mm/a
Population	110000 count
General Authorization	75 m^3/ha/a
Present Eco Status Category	Category E or F
Recharge	53 mm/a (7.5 %)
Use	1.53 mm^3/a
Exploration Potential	5mm^3/a

4.4 SITE GEOLOGY

According to the 1:250 000 Geological Sheet 2528 (Figure 4) the surface geology underlying the 30CDR Slimes dam consists predominately out of rhyolite (Vs) of the Selons River Formation, shales and quartzite (Vls) of the Loskop formation, tillite and shale of the Dwyka Formation and dolerite intrusions.

The majority of the northern area underlying the Slimes dam consists out of shales and quartzites while the southern part is underlain by rhyolites (Figure 4). In general rhyolites are resistant to erosion with little residual cover.

4.5 REGIONAL HYDROGEOLOGY

Two distinct superimposed groundwater systems are present within the MFC plant. They can be classified as the upper weathered shale, rhyolite and diabase aquifer and the fractured aquifers within the unweathered shale, rhyolite and diabase deeper below. (Report no.12622-9952-2, Golder Associates).

[8] *DWAF's Groundwater Resource Directed Measures. (2006)*

4.5.1 The upper weathered aquifer

The shale, rhyolite and diabase are weathered to depths of 15 metres below surface throughout the site (Report no.12622-9952-2, Golder Associates). The upper aquifer, typically perched, is associated with this weathered zone and water is often found within a few metres below surface. This aquifer is recharged by rainfall. The percentage recharge to this aquifer is estimated to be in the order of 1 - 3% of the annual rainfall, based on work by Kirchner *et al.* (1991)[9] and Bredenkamp (1978)[10] in other parts of the country.

Rainfall that infiltrates into the weathered rock reaches an impermeable layer of shale/rhyolite or diabase underneath the weathered zone. The movement of groundwater on top of these layers is lateral and in the direction of the surface slope. This water reappears on surface at fountains where the flow paths are obstructed by a barrier, such as a dolerite dyke, paleo-topographic highs in the bedrock, or where the surface topography cuts into the groundwater level at streams such as the Vaalbank spruit.

4.5.2 The fractured deeper aquifer

The pores within the unweathered shales/rhyolites or diabase are too well cementated to allow any significant permeation of water. Bulk groundwater movement is therefore along secondary structures, such as fractures, cracks and joints in the sediments. These structures are better developed in competent rocks such as sandstone, hence the better water-yielding properties of the latter rock type.

It should, however, be emphasised that not all secondary structures are water-bearing. Many of these structures are constricted because of compressional forces that act within the earth's crust. The chances of intersecting a water-bearing fracture by drilling decrease rapidly with depth. Scientific siting of water-supply boreholes is necessary to intersect these fractures.

4.6 SITE HYDROGEOLOGY

Observations from the site visit as well as work done during previous studies suggest that seepage and migration of groundwater and potential pollution plumes occur predominantly within the weathered lithologies. This shallow groundwater discharges into the Vaalbank spruit to the east of the 30CDR Slimes dam (Figure 2). The shale/rhyolite or diabase underlying the weathered sediments or unconsolidated material tends to be relatively impermeable. However, there may be site specific areas where hydraulic continuity (vertical fractures) exists between the weathered zone and the underlying fractured

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[9] *Kirchner, J., Van Tonder, G.J. and Lukas, E. (1991). Exploitation Potential of Karoo Aquifers. Report to the WRC, Report 170/1/91, Water Research Commission, Pretoria, 283p.*

[10] *Bredenkamp, D.B. (1978). Quantitative Estimation of Groundwater Recharge with Special Reference to the use of Natural Radio-active Isotopes and Hydrological Simulation. Unpubl. Ph.D. thesis, UOFS, Bloemfontein, 367p.*

aquifers. Pollution may migrate along these fractures or the contacts of igneous intrusions (dolerite dykes) to deeper levels within the fractured aquifer.

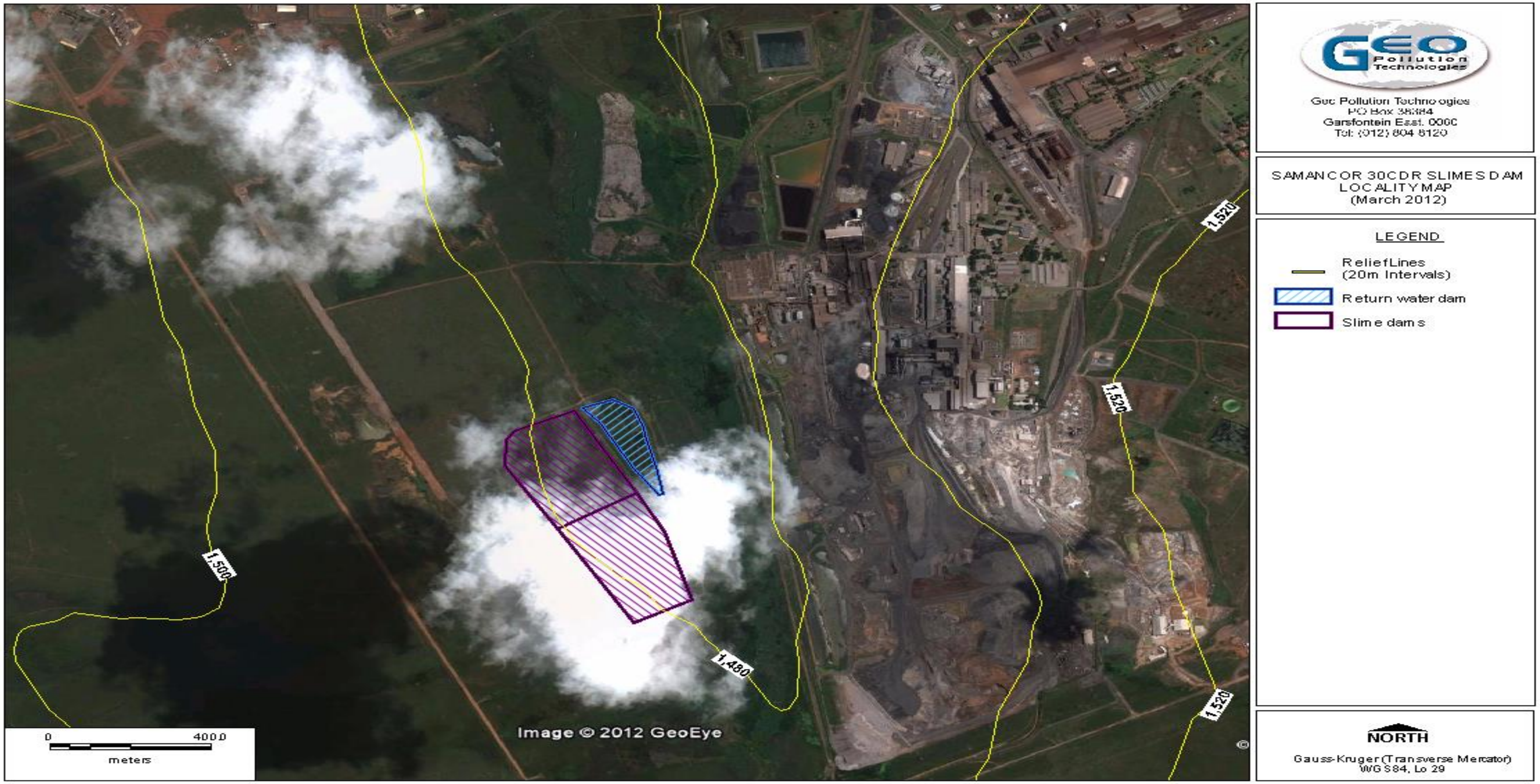

Figure 2: Vaalbank spruit adjacent to the 30CDR Slimes dam

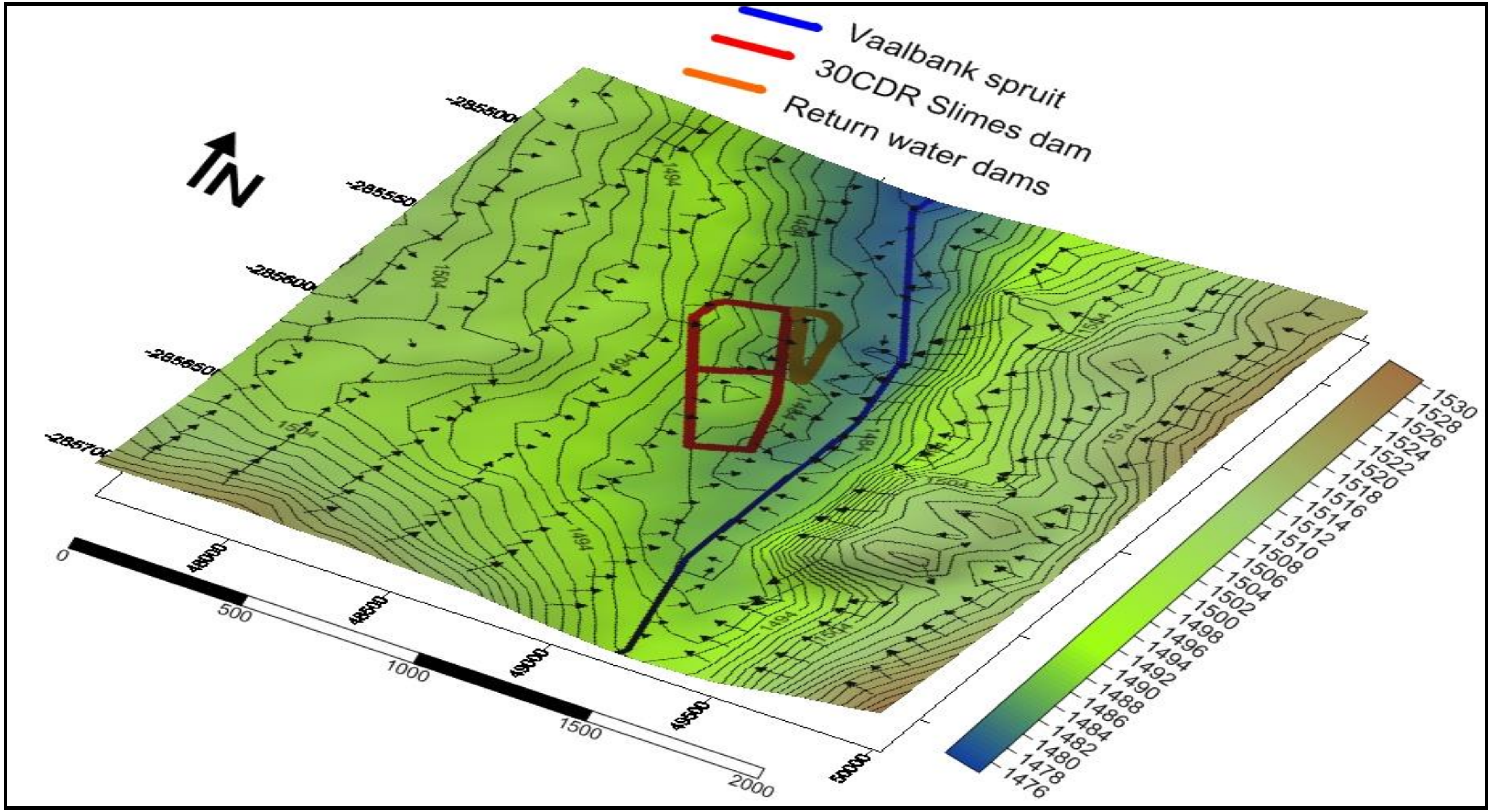

Figure 3: Topographical map with surface flow vectors

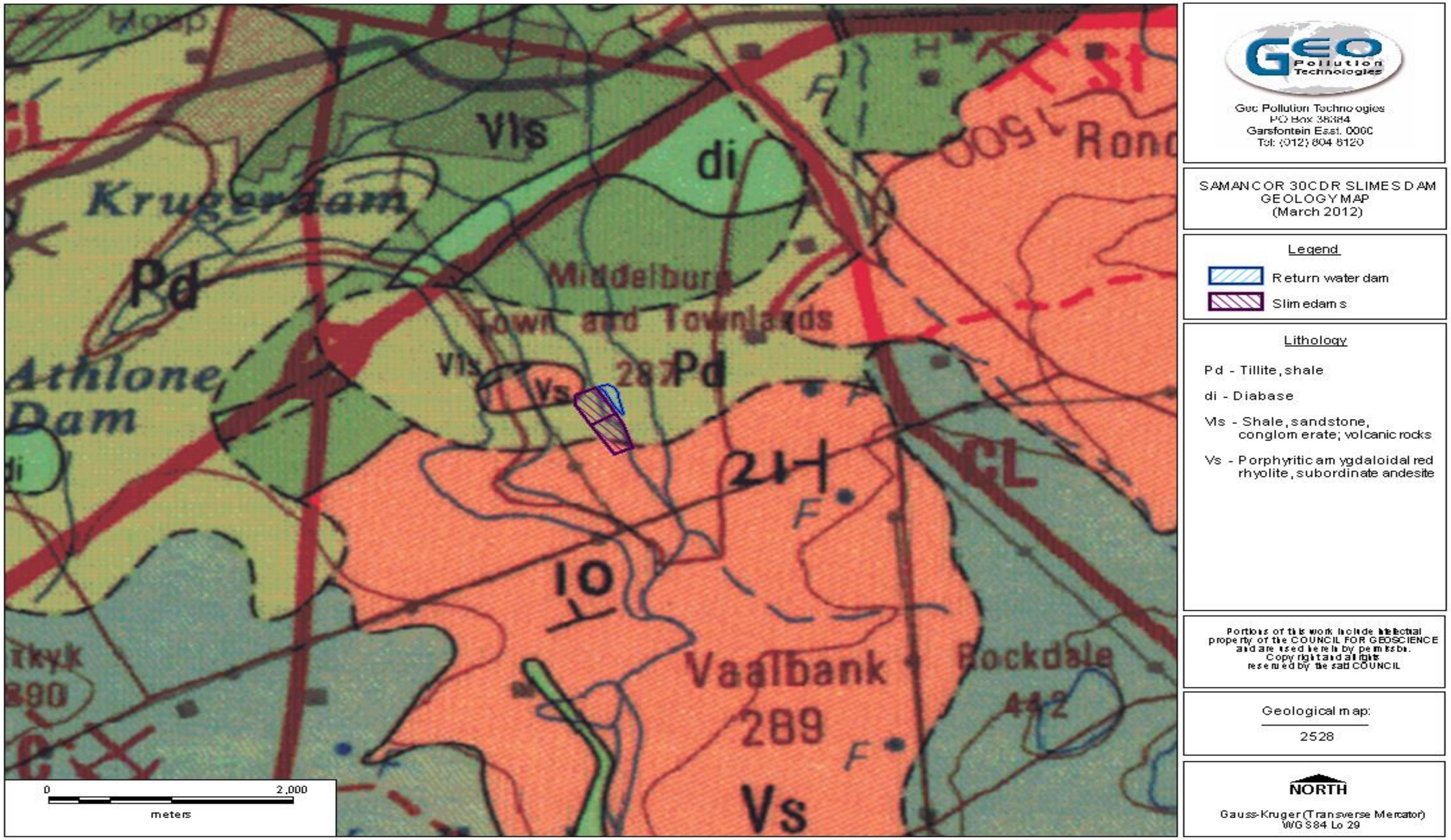

Figure 4: Geological Map

5 RESULTS OF INVESTIGATION

5.1 HYDROCENSUS

5.1.1 Water sampling and water levels

A total of 5 boreholes were sampled and measured for water levels (Figure 5). The results of the hydrocensus are summarised in Table 3. The borehole positions and surface sampling positions are depicted in Figure 5.

Water levels were measured in all the boreholes. The water levels ranged from 0.9 (minimum) to 4.7 m (maximum) below surface. The relative shallow water table increases the aquifers susceptibility to contamination from surface structures such as the 30CDR Slimes dam.

5.1.2 30CDR Slimes dam Soil Sampling

A total of 10 auger holes were drilled into the Slimes dam and soil samples were taken at different depths. From these 10 holes which could be considered to be representative of the general 30CDR Slimes dam, 10 samples were sent for geochemical assessment by TCLP/Acid Rain analyses[11]. The auger positions can be seen in Figure 6 and a summary of the samples is shown in Table 4.

[11] *TCLP/Acid Rain analysis extracts solids. Total metals in solids are determined after extractions by either ICP-OES*

5.1.3 Groundwater Recharge Estimation

The groundwater recharge was estimated using the RECHARGE program[12] (van Tonder, et al., 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge:

- Soil information
- Geology
- Groundwater Recharge Map (Vegter)
- Acru Recharge Map (Schulze)
- Harvest Potential Map
- Chloride (Cl) method

According to the rainfall data, the average rainfall of the area is 660mm/year. A Cl concentration of 29 mg/ℓ was used in the Cl method estimation. The concentration was calculated as the mean of the Cl concentrations in the sampled boreholes unlikely to be affected by any contaminants. The other methods used to estimate the recharge are qualified guesses derived from certain thematic maps and equations.

The result of the estimations including the Cl method can be seen in Table 2. The groundwater recharge is averaged at 3.5% percent of the rainfall.

It is evident that a recharge estimated through the Cl method is in the same order of the qualified guesses. The geological map estimates a realistic recharge of 4.3%, similar to that found by Cl-method. Therefore a recharge of 3.5% to 4% was deemed to be a realistic value for this area.

Table 2: Recharge Estimation

Recharge Estimation			
Method	**mm/a**	**% of rainfall**	**Certainty (Very High=5 ; Low=1)**
Chloride	29	4.3	4
Qualified guesses			
Soil	19.8	3.0	3
Geology	28.4	4.3	3
Vegter	20.0	3.0	3
Acru	15	2.3	3
Harvest Potential	25	3.8	3
Annual Rainfall= approx 660 mm per annum			

[12] *Van Tonder, G.; Xu, Y. 2000. RECHARGE program to Estimate Groundwater Recharge. Bloemfontein: Institute for Groundwater Studies, 2000.*

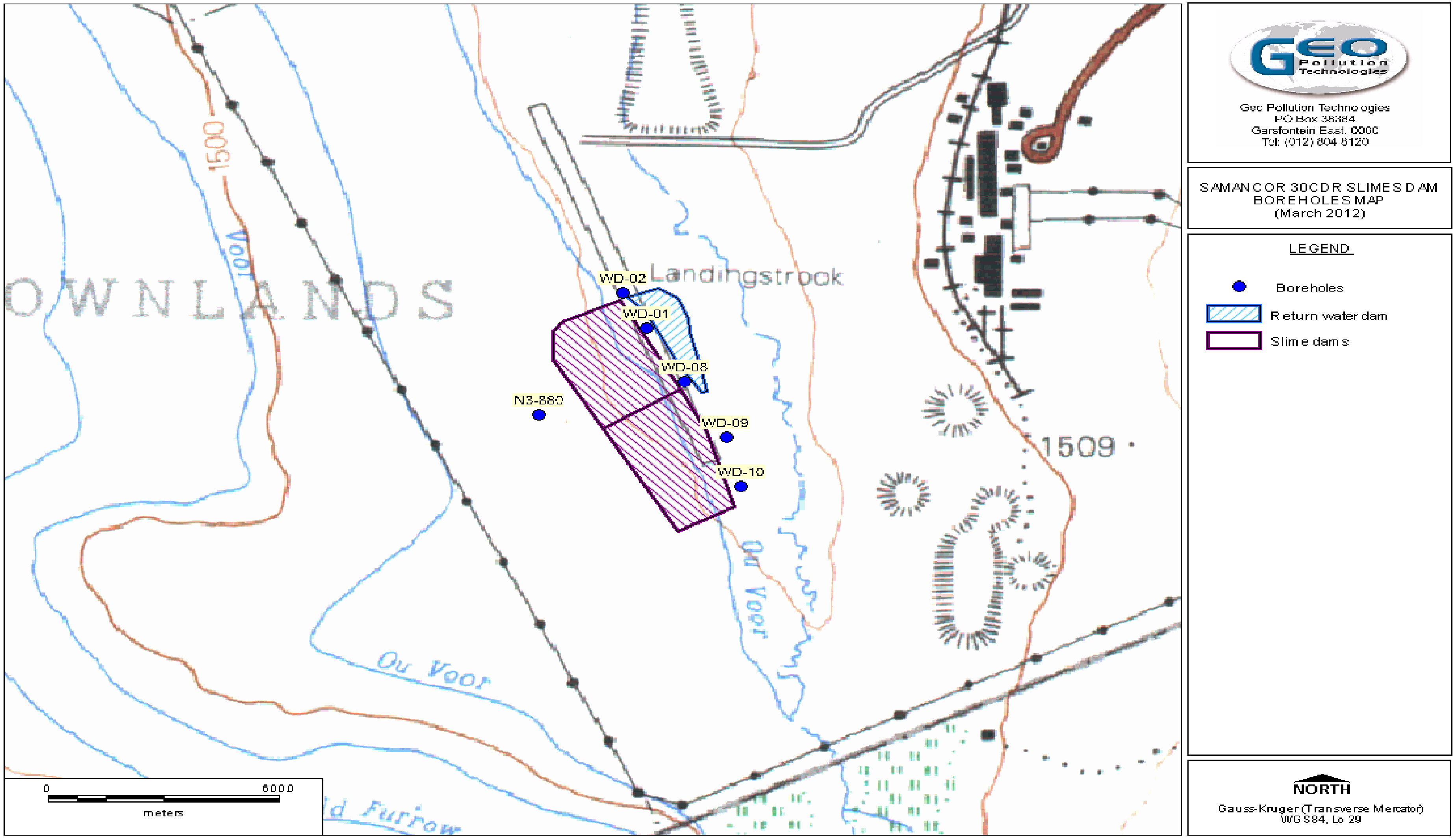

Figure 5: Hydrocensus positions

Table 3: Hydrocensus information

Site Name	X coordinate	Y coordinate	Water level in m below surface	Use	Sampled	Lab analyzed	Owner	Contact nr
N3-880	48439.97503	-2855813.102	4.75	Monitoring	Yes	Yes	Samancor	0132494477
WD-01	48716.74953	-2855542.688	0.93	Monitoring	Yes	Yes	Samancor	0132494478
WD-02	48656.98817	-2855431.678	2.3	Monitoring	Yes	Yes	Samancor	0132494479
WD-08	48814	-2855712	1.142	Monitoring	Yes	Yes	Samancor	0132494480
WD-10	48959	-2856040	1.17	Monitoring	Yes	Yes	Samancor	0132494481

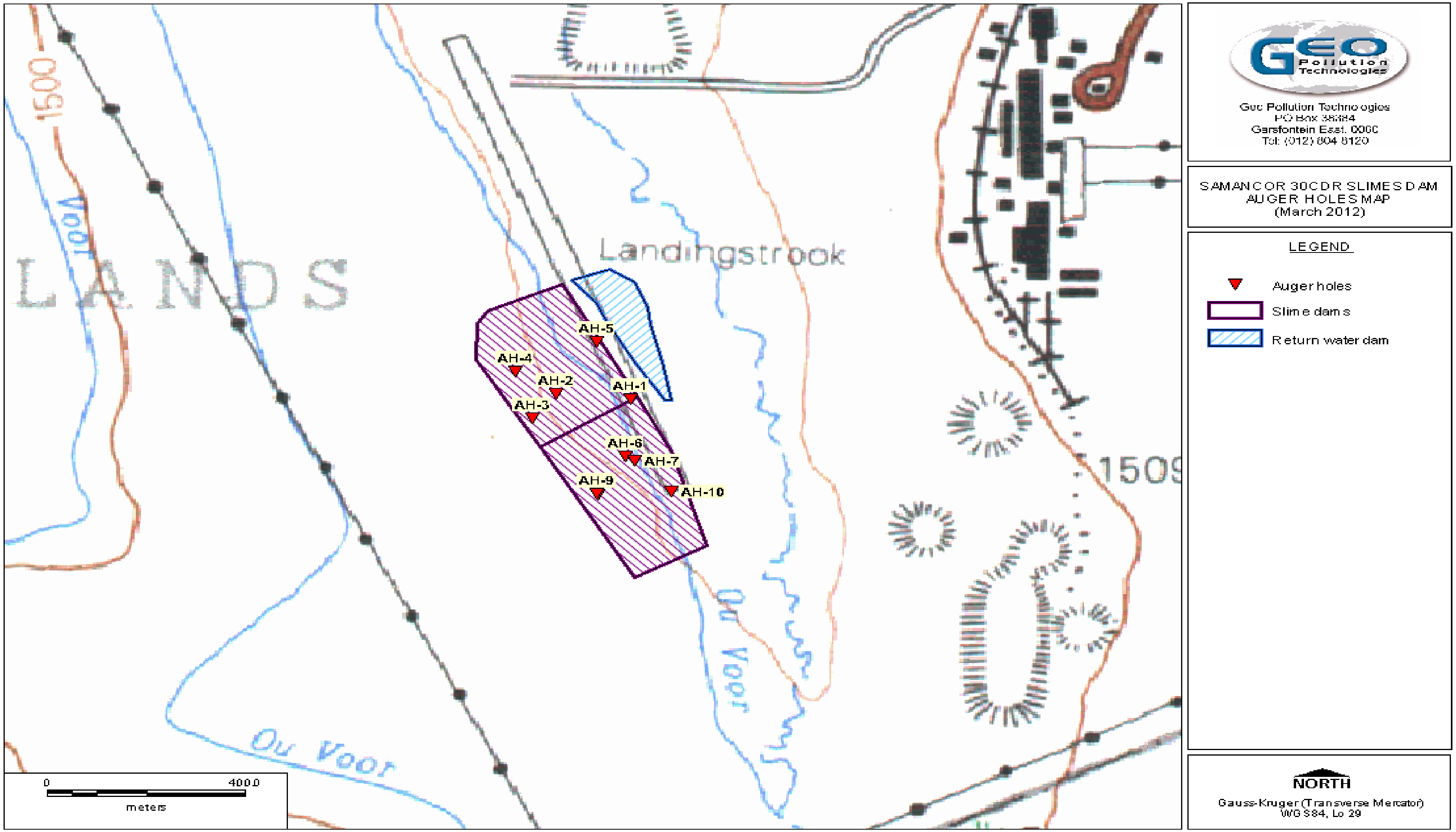

Figure 6: 30CDR Soil Samples

Table 4: 30CDR Slimes dams Soil Sampling

Name	X-coordinate	Y-coordinate	Depth of sample in m below surface	Visual permeability	Samples description
AH-1	48788.22836	-2855739.048	1	Low	Orange/Grey fine clayey sand
AH-2	48636.84411	-2855727.411	1	Low	Orange/Grey fine clayey sand
AH-3	48591.49712	-2855787.07	1	Low	Orange/Grey fine clayey sand
AH-4	48555.82392	-2855670.61	1	Low	Orange/Grey fine clayey sand
AH-5	48720.55636	-2855598.096	1	Low	Orange/Grey fine clayey sand
AH-6	48777.67195	-2855881.927	1	Low	Grayish black silty clay
AH-7	48796.68836	-2855891.969	1	Low	Black fine silty clay
AH-8	48721.16722	-2855975.889	0.65	Low	Greyish fine sand with ferricrete
AH-9	48719.16981	-2855973.666	0.5	Low	Browniish fine, silty sand with gravel
AH-10	48870.60861	-2855969.795	1	Low	Greenish black fine-silty clay

5.2 POTENTIAL CONTAMINANTS

5.2.1 30CDR Slimes dams

The Slimes dam has been identified as a potential source of groundwater pollution. The chemicals of concern as listed by Golder, 2011[13] are Chromium, Fluoride, Aluminium, Arsenic and Magnesium. There exists the potential for heavy metals to be progressively released through the weathering of the disposed materials. These elements may be subsequently transported into the groundwater systems by acidic leachates.

5.2.2 Surface run-off

This potentially polluted water flows into groundwater systems via surface structures such as the 30CDR Slimes dam.

5.2.3 Toxicity of Chemical Contaminants

The contamination associated with the metal processing industry may be subdivided into two categories:

- ***Inorganic pollutants***. These chemicals modify the pH and toxicity of the water. Inert soluble inorganics may also result in the formation of sludge deposits. Inorganic pollutants such as heavy metals like Cr (VI) may have a major impact on the environment.
- ***Organic contaminants***. These compounds have a potential to deplete the surrounding aquatic resources of dissolved oxygen. The bacteria oxidise the organic matter to produce carbon dioxide and water while consuming the necessary quantity of oxygen and nutrients. Certain organic substances are also toxic.

However, there are also inorganic substances that deplete the dissolved oxygen in the receiving environment. Caution should be exercised when labelling a chemical as toxic, since small quantities may be essential for human bodily functions. Elements only assume toxic characteristics if the quantity needed for optimum biological growth are exceeded. This concept is illustrated in Figure 7. However, one cannot allow effluent to be discharged if the constituents subsequently form toxic compounds through the processes of oxidation or reduction.

- [13] *Golder Associates, Delineation of Groundwater Pollution Plumes and Predictions of Plume Migration-Rev1, June 2011. Middelburg Ferrochrome, a division of Samancor Chrome Ltd. Report nr: 12622-9952-2.*

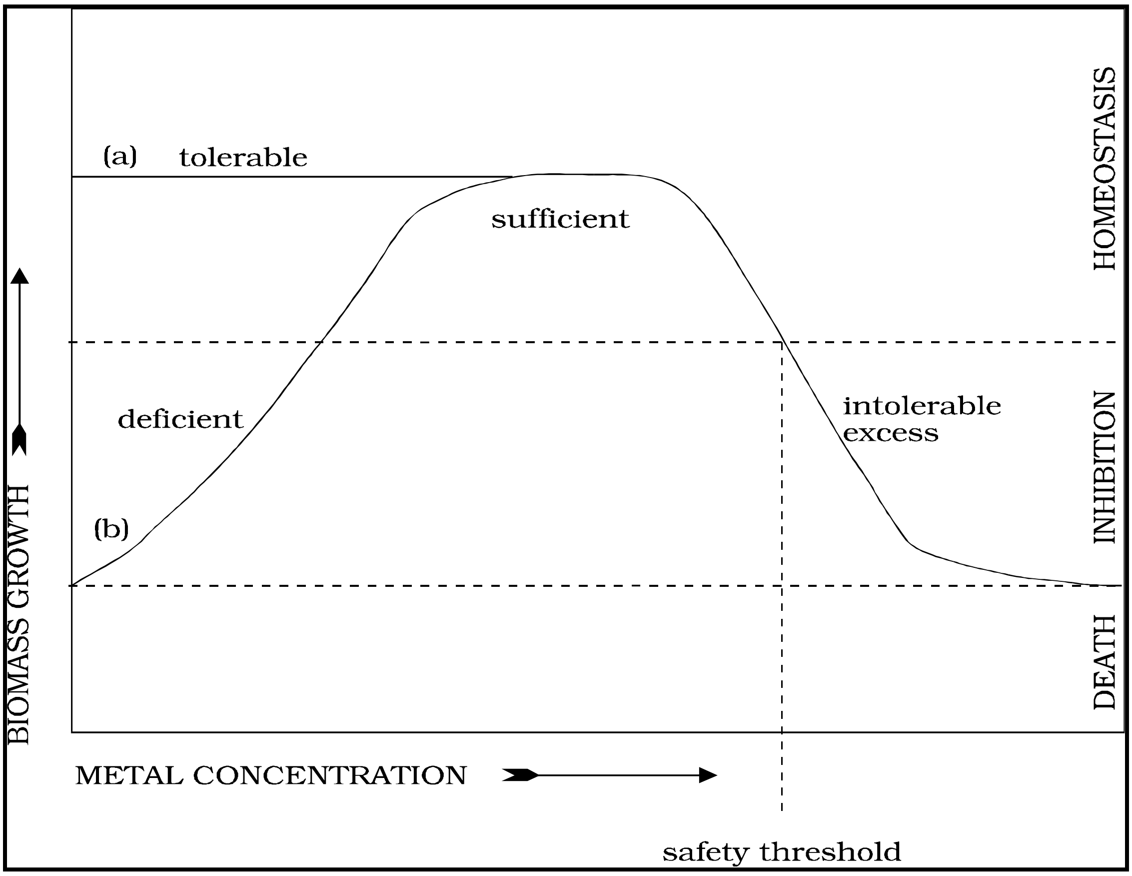

Figure 7: Effects of increasing metal concentration on biomass for (a) a non-essential element and (b) for an essential element (after Rudd, 1987)[14].

There is a tendency for metal industry leachates to exceed the recommended drinking standards as outlined by the South African Water Quality Guidelines Volume 1: Domestic Water Uses Second Edition, 1996.2006 with regard to the following constituents:

Inorganic chemicals including:

- Heavy metals, particularly hexavalent chromium
- Chromium
- Fluoride
- Aluminium
- Arsenic
- Magnesium
- Fluoride
- Ammonia

[14] *Rudd, T. (1987). Scope of the Problem. In: Lester, J.N. (ed.). Heavy Metals in Wastewater and Sludge Treatment Processes, 1, pp 1-30.*

- Sulphate
- Sodium

Organic chemicals including:

- Phenolic compounds

The above components increase the toxicity and/or salinity of the water. These parameters will be discussed in terms of their impact on groundwater quality.

It is evident from the above information that contaminants associated with the metal industry may be toxic in nature and could be detrimental to the environment. Species that are relatively non-toxic degenerate the water quality, by contributing to the total salt load. The non-biodegradability of inorganic compounds results in a progressive accumulation of these elements within water systems. Although certain levels of concentrations may still be within the legal limit, the water quality will deteriorate where water is recycled through the manufacturing process.

Table 5: Potential contaminants and sources

Source	Potential contaminant	Potential Pathway	Process
30CDR Slimes dam	Chromium, Fluoride, Aluminium, Arsenic and Magnesium	Seeping from the tailings facility	Sulphates and heavy metals are progressively released through the weathering of the tailings material in the tailings facility
30CDR Slimes dam	Chromium, Fluoride, Aluminium, Arsenic and Magnesium	Surface runoff from the tailings facility	Avenues of contaminant transport include the infiltration of run-off from the tailings facility

Most of the potential contaminants are mainly confined to surface but due to shallow water table there exists a potential risk to the groundwater environment through surface to groundwater interaction.

5.3 30CDR SLIMES DAM GEOCHEMICAL CHARACHTERISATION AND WATER QUALITY

5.3.1 30CDR Slimes dam Geochemical Characterisation

The Slimes dam was geochemically characterised by taking soil samples from the site as mentioned in section 5.1.2. Soil samples screening values where compared to the Department of Environmental Affairs, Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (Notice 233 of 2012, March 2012).

The working methodology followed during this study also aligns with the Duty of Care principle as outlined in Section 28 of NEMA and the Framework for Management of Contaminated Land of the Department of Environmental Affairs. Recent changes in legislation and the structure of government departments have seen Environmental Affairs and Water Affairs merged into one national department. Part 8 of the Waste Act (Act 59 of 2008) deals with issues regarding contaminated land. Although this portion of the act still needs to come into effect, all the documentation that has been released indicates that a risk based approach is likely to be followed

5.3.1.1 Sample discussion

The samples received from Geo Pollution Technologies – Gauteng (Pty) Ltd were analysed to determine the water soluble leachates that may arise from the slimes dam. The full analyses can be seen in Appendix A. The major percentage cation/anion constituents (70%) of the samples analysed for are Sodium (22%) Calcium (21%) Potassium (16%) and Magnesium (12%) shown in Figure 8. As seen from Table 6 and Table 7 below there are no samples exceeding the soil screening values.

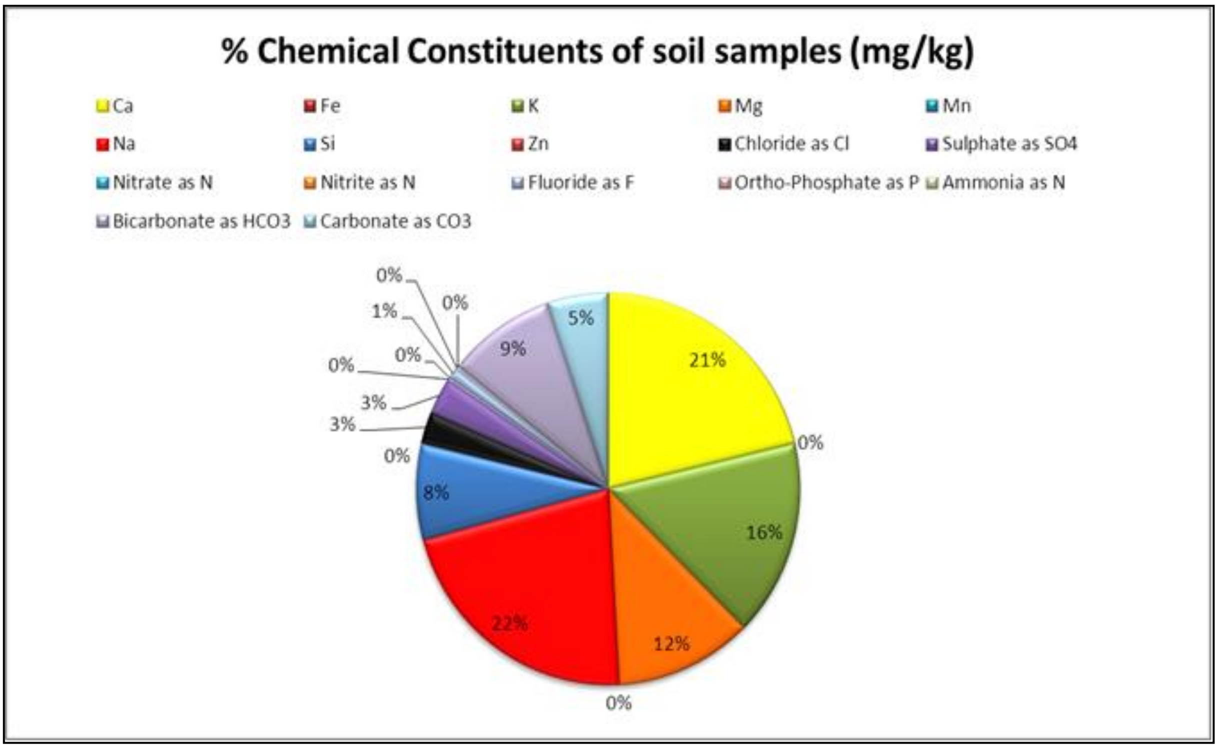

Figure 8: Chemical Composition of soil samples

Table 6: Soil screening levels compared to SSV1 (Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (March, 2012. Notice 233 of 2012).

Sample nr	AH1	AH2	AH3	AH4	AH5	AH6	AH7	AH8	AH9	AH10	SSV1
Soil Screening Values for Metals mg/kg											mg/kg
Arsenic	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	5.8
Chromium	1.22	2.84	1.86	2	2.62	<0.500	<0.500	<0.500	<0.500	<0.500	46000.0
Lead	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	20.0
Manganese	2.8	<0.500	<0.500	<0.500	<0.500	0.8	0.6	3.7	12.8	1.0	740.0
Nickel	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	91.0
Vanadium	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	150.0
Zinc	<0.500	1.8	1.1	1.3	2.0	1.5	1.4	2.4	1.6	1.4	240.0
Soil Screening Value (SSV) 1 represents the lowest value calculated for each parameter from both the Human Health and Water Resource Protection pathways. SSV1 values are not land-use specific.											
Within limits											
Exceeding limits											

Table 7: Soil screening levels compared to SSV2 (Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (March, 2012. Notice 233 of 2012).

Sample nr	AH1	AH2	AH3	AH4	AH5	AH6	AH7	AH8	AH9	AH10	SSV2
Soil Screening Values for Metals mg/kg											mg/kg
Arsenic	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	48.0
Chromium	1.22	2.84	1.86	2	2.62	<0.500	<0.500	<0.500	<0.500	<0.500	96000.0
Lead	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	230.0
Manganese	2.8	<0.500	<0.500	<0.500	<0.500	0.8	0.6	3.7	12.8	1.0	1500.0
Nickel	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	1200.0
Vanadium	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	320.0
Zinc	<0.500	1.8	1.1	1.3	2.0	1.5	1.4	2.4	1.6	1.4	19000.0
SSV2 represents Commercial/Industrial Screening values											
Within limits											
Exceeding limits											

5.3.2 Water Quality

All of the 5 hydrocensus positions visited were hydro-chemically analysed (Table 8). The water sampling results can be seen in Table 8 and compared with the maximum recommended concentrations for the water classes for domestic use as defined by the South African Water Quality

Guidelines Volume 1: Domestic Water Uses Second Edition, 1996.This guideline classifies domestic water in four classes, namely:

- Class I, Target quality
- Class II, Moderate effects
- Exceeding allowable limits Severe effects

Groundwater and quality is described by means of the conventional Piper diagram. Groundwater may be classified into four major hydro chemical types, and this is graphically illustrated using the Piper diagram. These quadri- and trilinear diagram show the relative concentrations of the major cations and anions on four and three axes respectively. The number on the side of the diagram indicates the percentage of specific ion(s) in the sample

Piper diagrams are normally subdivided in four quadrants, corresponding to the four major hydro chemical types. Fresh recently recharged groundwater, containing only small amounts of soluble minerals and bi-carbonate, plots in the left quadrant. In contrast, groundwater that has accumulated higher amounts of solutes, either through percolation through the aquifer or pollution, plots in the rightmost quadrant. The top and bottom quadrants are representative of intermediate states.

5.3.3 Hydro chemical characterisation

The water samples collected during the hydrocensus were used to hydro-chemically characterise the groundwater at Samancor Middelburg through the use of piper, pie (Figure 10) and stiff diagrams (Figure 11).

5.3.3.1 Groundwater

The on-site groundwater composition based on the available data, are illustrated in diagrams below shown in Figure 9 to Figure 11. The following can be deduced from the diagrams. There is little trend between the samples indicating mixing of clean groundwater with contaminated water.

By comparing the results to the South African Water Quality Guidelines the following could be concluded (Table 8). The major anion is bicarbonate and to lesser extent sulphates while the pH of the groundwater remains relatively neutral. This indicates that the underlying geology (carbonate rocks) has sufficient buffering capacity to prevent the sulphates in lowering the pH.

It can be seen from Table 8 that the only elevated constituents exceeding the standards for all the samples is Iron (Fe) and Aluminium (Al) while Fluoride (F) exceeds the standards in samples WD-08 and WD-10. What is evident from the table is that WD-08 exceeds the standards for most parameters analysed (Ca, Mg, Na, Fe, Al, F, $S0_4$, TDS and EC). This is a clear indication that WD-08 has been affected by a pollution source and to a lesser extent the other samples if iron and aluminium is considered.

5.3.3.2 Geochemical and Water quality conclusions

Based on the selected samples and limited analyses the following can be concluded regarding the hydro chemical results.

- The major percentage cation/anion constituents (70%) of the samples analysed for are Sodium (22%) Calcium (21%) Potasium (16%) and Magnesium (12%).
- According to the soil screening values for the parameters analysed f indicate that the soil is not contaminated above acceptable limits.
- The parameters analysed indicate that the groundwater underlying the site has been affected through pollution especially if Fe and Al is considered. WD-08 shows water quality that is directly impact by pollution source(s) such as the 30CDR Slimes as it is elevated for most of the parameters analysed (see Table 8).

The chemicals of concern for the 30CDR Slimes dam as listed by Golder, 2011 are Chromium, Fluoride, Aluminium, Arsenic and Magnesium. Based on these parameters the 30CDR Slimes is contributing to the pollution load in the groundwater underlying the 30CDR Slimes dam especially if Aluminium is considered.

Table 8: Results of the chemical analysis compared with the regional groundwater quality and the Domestic Water Standards.

Sample Nr.	WD01	WD02	WD08	WD10	N3 880	Class I (acceptable)	Class II (maximum)
Ca	81.00	36.00	353.00	9.00	2.00	80 - 150	150 - 300
Mg	46.00	23.00	280.00	7.00	3.00	30 - 70	70 - 100
Na	65.00	49.00	687.00	74.00	7.00	100 - 200	200 - 400
K	2.10	1.00	36.00	2.40	1.00	25 - 50	50 - 100
Mn	0.77	0.70	0.20	0.22	0.09	0.1 - 1.0	1.0 - 2.0
Fe	4.67	44.00	63.00	4.78	139.00	0.1 - 0.2	0.2 - 2
F	1.20	0.30	2.50	2.90	0.40	1.0 - 1.5	1.5 - 3.5
NO_3	0.40	0.40	0.50	0.50	0.70	25 - 44	44 - 88
Al	2.43	1.09	2.11	3.73	0.58	0.15 - 0.5	-
Cr	0.03	0.04	2.00	0.03	0.03	-	-
Zn	0.07	0.03	0.45	0.07	0.06	3.0 - 5.0	5.0 - 10.0
HCO_3	210.00	268.00	405.00	219.00	24.00	-	-
Cl	43.00	17.00	469.00	10.00	6.00	100 - 200	200 - 600
SO_4	234.00	79.00	2 604	34.00	10.00	200 - 400	400 - 600
TDS by sum	577.00	338.00	4 631	247.00	45.00	450 - 1000	1000 - 2400
M-Alk($CaCO_3$)	172.00	220.00	332.00	180.00	20.00	-	-
pH	7.00	7.00	7.40	7.70	6.50	5.0 - 9.5	4.0 - 10.0
EC	84.90	57.40	580.00	41.30	7.70	70 - 150	150 - 370
Cat/An Bal. %	94.20	94.00	98.10	94.80	95.30	-	-

Notes:
Ideal quality
Class I: Target quality
Class II: Moderate effects
Exceeding maximum allowable concentration - adverse effects
All concentrations are presented in mg/l, EC is presented in mS/m
0 = below detection limit of analytical technique

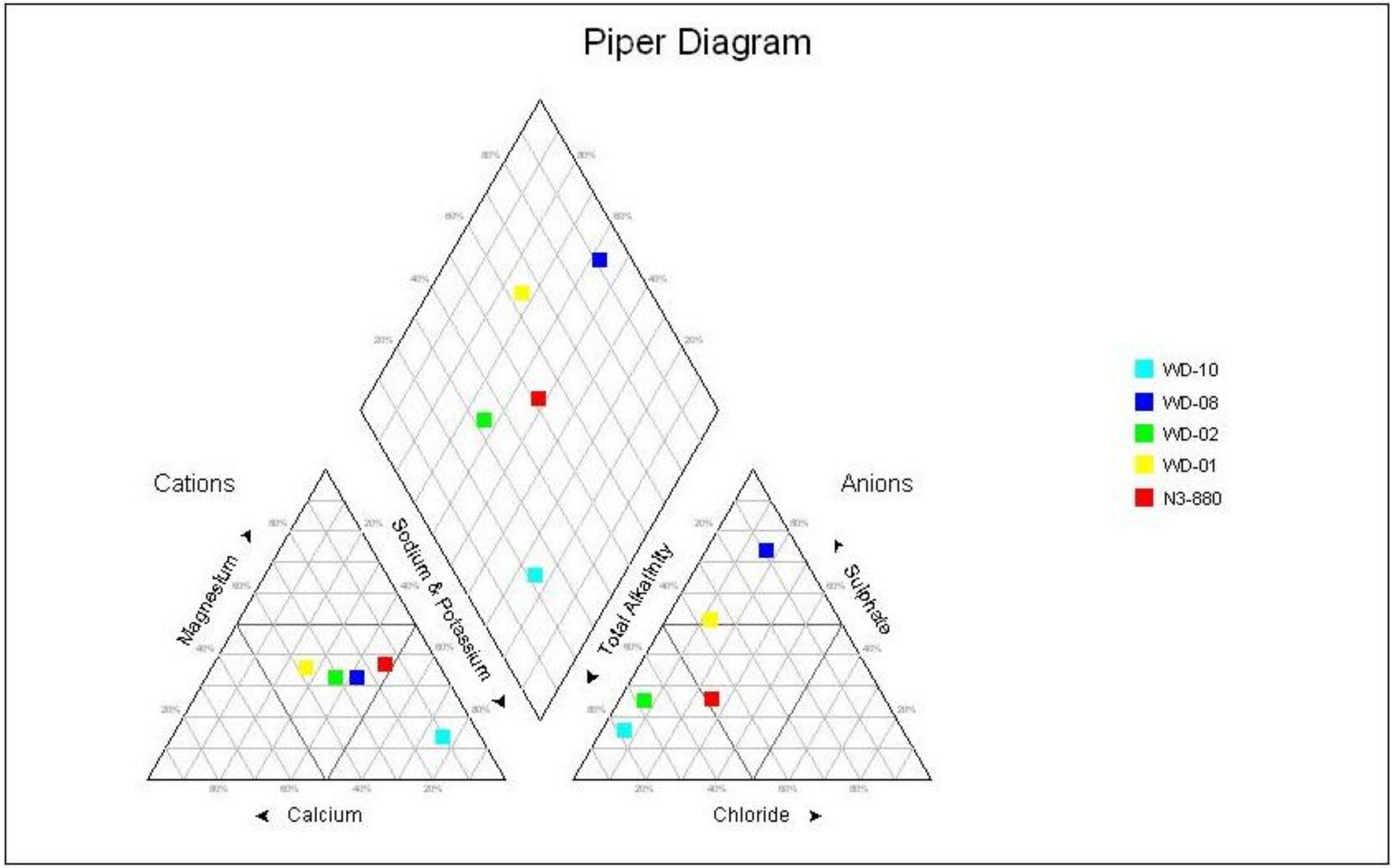

Figure 9: Piper diagram

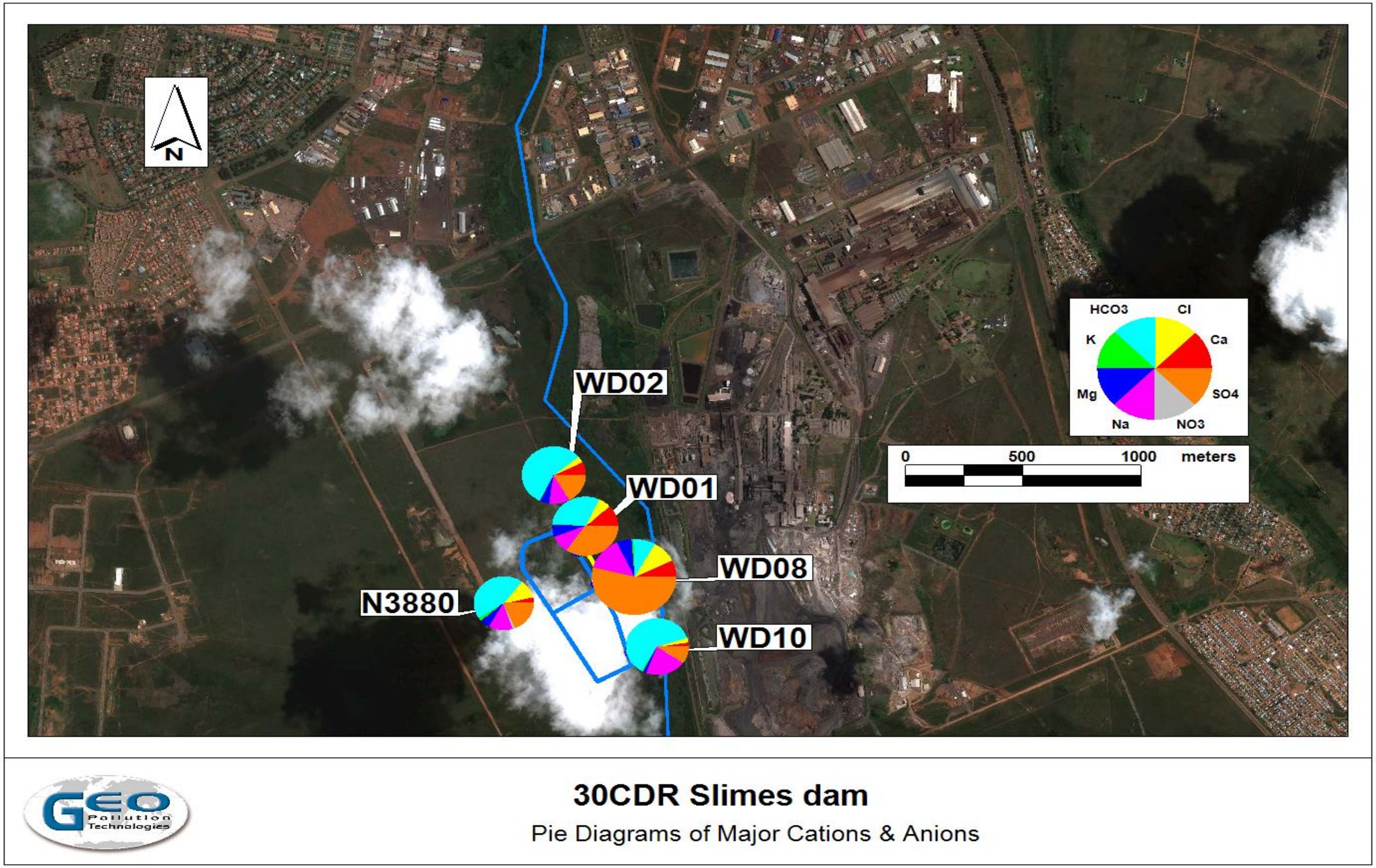

Figure 10: Spatial Distribution of Major Cations and Anions using a Pie diagram

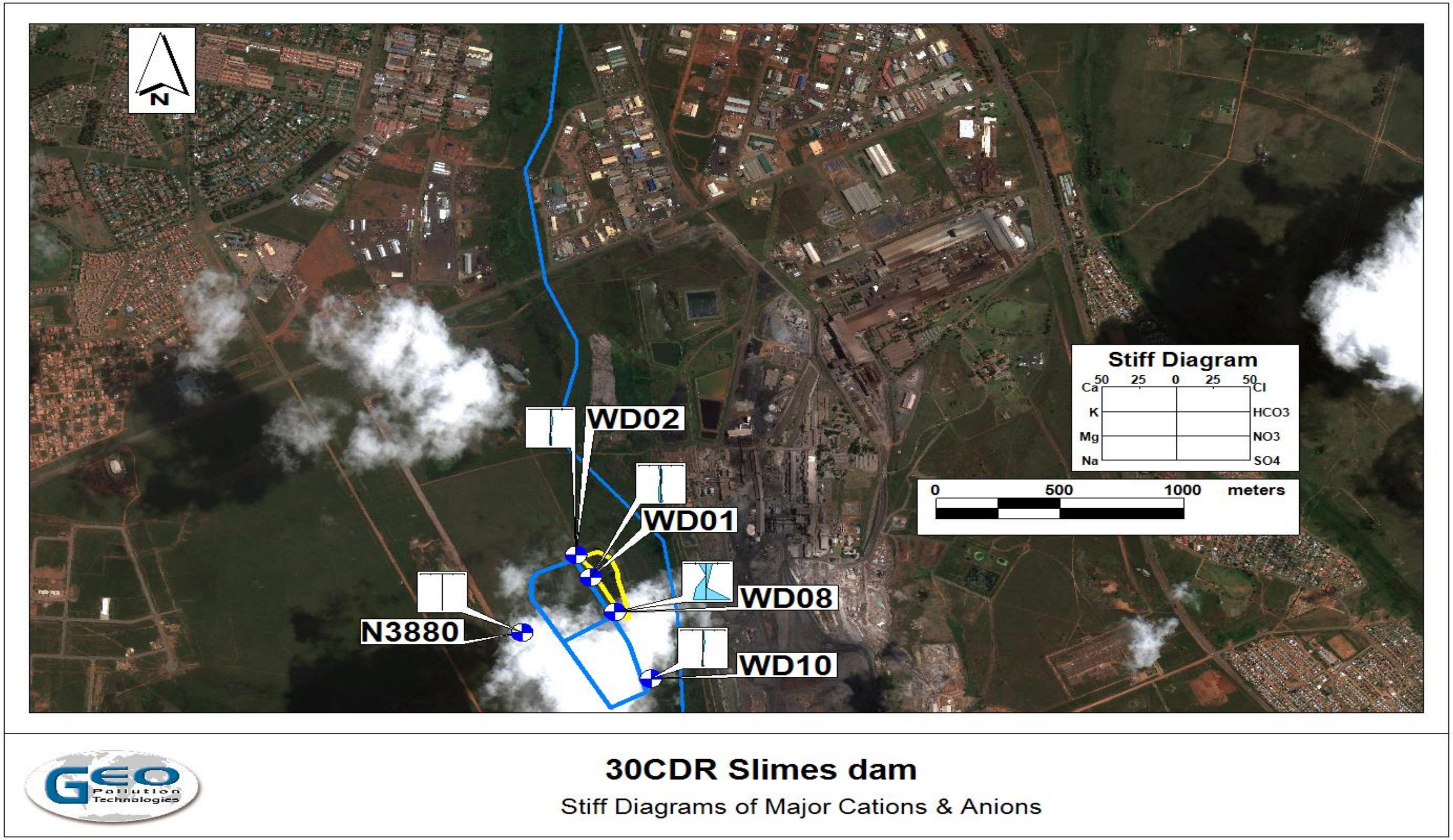

Figure 11: Stiff diagrams of Major Cations and Anions

6 AQUIFER CLASSIFICATION

An aquifer classification system provides a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection. Other uses could include:

- Defining levels of investigation required for decision making.
- Setting of monitoring requirements.
- Allocation of manpower resources for contamination control functions.

The aquifer classification system used to classify the aquifers is the proposed National Aquifer Classification System of Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification. Parsons suggests that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues. He also suggests that some level of flexibility should be incorporated when using such a classification system.

The South African Aquifer System Management Classification is presented by five major classes:

- Sole Source Aquifer System.
- Major Aquifer System.
- Minor Aquifer System.
- Non- Aquifer System.
- Special Aquifer System.

The following definitions are taken from Parsons (1995) [15] and applied as an aquifer classification system:

Sole source aquifer system:
"An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there are no reasonable alternative sources should the aquifer become depleted or impacted upon. Aquifer yields and natural water quality are immaterial".

Major aquifer system:
"Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good".

---

[15] *Parsons, R.P., (1995), A South African aquifer system management classification. WRC Report No. 77/95, Water Research Commission, Pretoria*.

Minor aquifer system:

"These can be fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are both important for local supplies and in supplying base flow for rivers".

Non-aquifer system:

"These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks does occur, although imperceptible, and needs to be considered when assessing risk associated with persistent pollutants".

Special aquifer system:

"An aquifer designated as such by the Minister of Water Affairs, after due process".

6.1 AQUIFER CLASSIFICATION AT SAMANCOR MIDDELBURG

Considering the geology and hydrogeology characteristics as well as the information collected during the hydrocensus, the shallow weathered aquifer directly underlying the 30CDR Slimes damis the most vulnerable to the Slimes dam. However as mentioned in the hydrogeological discussion there might be a connection between the shallow weathered and deeper fractured aquifers as they might be interconnected. Therefore both the aquifers underlying the 30CDR Slimes damcould be classified as a Minor Aquifer System based on the following:

- The aquifer has a limited extent
- The groundwater quality is variable
- A portion base flow of the Vaalbank spruit is dependent on the aquifer
- Shallow water table

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 9 and Table 10 was used.

Table 9: Ratings - Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	**2**
Non-Aquifer System:	0	
Special Aquifer System:	0 – 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	
Medium:	2	**2**
Low:	1	

Table 10: Ratings - Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	**2**
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	
Medium:	2	**2**
Low:	1	

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 11.

The vulnerability, tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above mentioned, is classified as **medium.**

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = **Aquifer System Management x Aquifer Vulnerability**

= 2 x 3 = 6

Table 11: GQM index for the study area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	**Medium Level**	**6**
6 - 10	High Level	
>10	Strictly Non-Degradation	

6.2 AQUIFER PROTECTION CLASSIFICATION

A Groundwater Quality Management Index of 6 was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate a **medium level groundwater protection** is required for the aquifers underlying the 30CDR Slimes dam.

DWA's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is:

- The protection of the underlying aquifer (weathered & fractured)
- The Vaalbank spruit

7 SITE CONCEPTUAL MODEL

The site conceptual model was developed using a risk based approach, whereby contaminant source areas are identified, pathways are characterised and potential receptors identified.

It is expected that the groundwater movement will follow the topography from west to east across the 30CDR Slimes dam towards the Vaalbank spruit. It is expected that the bulk groundwater movement is along the upper weathered aquifer.

7.1 POTENTIAL CONTAMINANT SOURCES

The relevant potential contaminant source and contaminants were identified as the following (Table 12):

Table 12: Potential contaminant sources

Source	Potential contaminant	Potential Pathway	Process
30CDR Slimes dam	Chromium, Iron, Fluoride, Aluminium, Arsenic and Magnesium	Seeping from the tailings facility	Sulphates and heavy metals are progressively released through the weathering of the tailings material in the tailings facility
30CDR Slimes dam	Chromium, Iron, Fluoride, Aluminium, Arsenic and Magnesium	Surface runoff from the tailings facility	Avenues of contaminant transport include the infiltration of run-off from the tailings facility

The hydraulic characteristics of the source and the geochemical properties of the sub-surface will determine the behaviour of the contaminants emanating from the source. In addition, the location and extent of the pollution source will have an effect on the extent of the contaminant plume.

7.2 PATHWAYS

Pathways along which contaminants may be mobilized and migrate toward groundwater receptors include:

- The vadose zone (unsaturated zone)
- Groundwater (weathered/fractured aquifers)
- Surface runoff in storm water or water courses (Vaalbank spruit)

For accurate prediction of the behaviour of contaminants along pathways it is critical that the monitoring and field measurements are representative of the physical environment. It is also important to keep seasonal and annual trends in mind as it affects on the water quality at the receptor. Pathways of concern are the groundwater underlying the 30CDR Slimes dam. Contamination of the groundwater was found in all the boreholes for parameters Al and Fe.

7.3 RECEPTORS

Any user of a groundwater or surface water resource that is affected by pollution from any of the above mentioned sources is defined as a receptor. Furthermore, a borehole or river/stream/wetland may also be a receptor of deterioration in groundwater quality. The following potential receptors where found:

- Although not in use the following monitoring holes were found to be affected by pollution from the 30CDR Slimes dam. Boreholes WD01, WD02, WD08, WD10 and N3 880

- The main receptor is the Vaalbank spruit flowing across the site from south to north. However no evidence of pollution in the Vaalbank spruit was found due to the contribution of the 30CDR Slimes dam. See Geo Pollution Technologies (2012) Samancor Chrome's Historical Kloof Slag Disposal Site on the property Portion 280 of Portion 155 Middelburg town and Townlands no. 287 JS, Mpumalanga Province. Reference Nr. ENV-12-229

7.4 GROUNDWATER MITIGATION MEASURES

Based on the, hydro-chemical and soil sampling results of the 30CDR Slimes The following mitigation measures are recommended and was guided by DWAF's best practice guidelines of July, 2008[16]

Surface water

Each site requires a slightly different network of surface water controls because of differences in topography, climate, hydrology, geohydrology, etc. Most controls are a combination of storm event, flood event, seepage control, recycling, and dewatering processes.

- ***Diversion of external surface water***: A system of storm water drains may be designed and constructed to ensure that all water that falls outside the area of the tailings facility is diverted clear of the deposit. Provision must be made for the maximum precipitation to be expected over a period of 24 hours with a probability of once in one hundred years. A freeboard of at least 0.5 m must be provided throughout the system above the predicted maximum water level.

- ***Decant systems*** are generally used in conjunction with other forms of surface water control. Major costs associated with the decant systems are pumping, maintenance, and treatment costs. It may be difficult, in areas with large surface water run-off volumes, to provide enough wells for removal of the run-off in a

[16] *Department of water affairs and forestry (July, 2008). Water Management for Mine Residue Deposits. Best Practice Guideline for Water Resource Protection in the South African Mining Industry. Series A: Activity Guidelines.*

timely manner.

- ***Spillways*** generally are designed as temporary structures because they will change (i.e., be moved or increase in length) as raised embankments increase in height. They are constructed of an impervious material able to withstand rapid flow velocities. The spillway also is designed to contain and control hydraulic jumps that occur at the bottom of the spillway. In addition, a spillway design has to consider and plan for water treatment if the surface water runoff passes through the tailings dam.

- ***Water removal***: Water can be removed by various means, including a barge, penstock or siphon. The design of a penstock system is set out in the Chamber of Mines (1996) guidelines. Penstocks should be designed to remove process water and to clear the design storm off the surface of the tailings within a suggested period of 48 to 72 hours. Other discharge periods should be adequately motivated.

- ***Containment of Storm Water***: All water that falls within the catchment area of the tailings must be retained within the area. For most tailings the catchment can be divided into component catchments, as follows:

    1. The top area of the tailings together with any return water storage dams which have been connected to the top area of the tailings by means of an outfall penstock, and

    2. The faces of the tailings together with the catchment paddocks provided to receive run-off from the faces and any additional catchment dams associated with the faces and catchment paddocks.

Water that has been in contact with residue, and must therefore be considered polluted, must be kept within the confines of the tailings until evaporated, treated to rendered acceptable for release, or re-used in some other way. The storage capacities for each component catchment must be sufficient to ensure a freeboard of at least 0.8m above the maximum predicted water level. It should be based on the average monthly rainfall for the area concerned less the gross mean evaporation in the area plus the maximum precipitation to be expected over a 24 hour period with a frequency of once in 50 years. The storage capacity of the top surface of a MRD should be calculated from accurately surveyed contours where possible.

In view of the above, the following mitigation measure options are recommended:

A shallow interception trench constructed downstream of the 30CDR Slimes dam. Such a design should only be considered following a thorough geotechnical study. Alternatively, the Samancor could decide to mitigate at the downstream reaches of the local streams.

8 GROUNDWATER MONITORING SYSTEM

An effective groundwater management plan should include a sound groundwater monitoring network. The reason for a groundwater monitoring network is to manage any impact that might arise from the source (30CDR Slimes dam).

A monitoring system is crucial to identify possible sources, pathways and likely receptors. The operations manual should include the groundwater monitoring plan. This plan should include the following:

- A plan showing the location and co-ordinates of the monitoring boreholes
- The expected groundwater levels in the monitoring boreholes
- The monitoring frequency (quarterly) and the monitoring procedure
- The groundwater sampling procedure
- The list of tests to be undertaken on the groundwater samples to monitor the groundwater quality

8.1 GROUNDWATER MONITORING NETWORK

Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas, viz:

• **Source monitoring:** Monitoring boreholes are located close to or at the source of contamination to evaluate the impact thereof on the groundwater chemistry.

• **Plume monitoring:** Monitoring boreholes are placed in migration path of the primary groundwater plume to evaluate the migration rates and chemical changes along the pathway.

• **Impact monitoring**: Monitoring of possible impacts of contaminated groundwater on sensi¬tive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination breakthrough at areas of concern.

• **Background monitoring**: Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

Boreholes WD01, WD02, WD08, WD10 and N3880 are available for plume/source monitoring. The construction of the boreholes should be made available or be determined for future studies.

If data for the upper weathered aquifers is unavailable it is recommended that shallow piezometer boreholes be installed in the existing boreholes to monitor the weathered zone. DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first is suitably penetrated, to ensure the most realistic monitoring result.[17]

A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

The parameters analysed should include the following and should be sampled on a quarterly basis.

Inorganic chemicals including:

- Heavy metals, particularly Iron, Aluminium and Chromium
- Sulphate
- Arsenic
- Magnesium
- Fluoride
- Ammonia
- Magnesium
- Calcium and Potasium
- Bicarbonate

Other parameters:

- pH
- Electrical Conductivity
- Total Dissolved Solids

[17] *Department of Water Affairs and Forestry (DWAF). (1998). Minimum Requirments for the Water Monitoring at Waste Managmenet Facilities. CTP Book Printers. Capetown.*

9 CONCLUSIONS

Based on the results of this investigation the following conclusions can be made:

The 30CDR Slimes dam is adjacent to the Vaalbank spruit directly to the east. The spruit flows from south to north and eventually joins the Klein Olifantsriver north of the site. The Vaalbank spruit is a perennial stream but in some areas may be seasonal. The surface elevation on which the 30CDR Slimes dam is located ranges from a minimum elevation of 1476 mamsl[18] (east near the spruit) to a maximum of 1495 mamsl (west). It is expected that surface water drainage from the 30CDR Slimes dam will be in a predominately west to east direction towards the Vaalbank spruit

Observations from the site visit as well as work done during previous studies suggest that seepage and migration of groundwater and potential pollution plumes occur predominantly within the weathered lithologies. This shallow groundwater discharges into the Vaalbank spruit to the east of the 30CDR Slimes dam. The shale/rhyolite or diabase underlying the weathered sediments or unconsolidated material tends to be relatively impermeable. However, there may be site specific areas where hydraulic continuity (vertical fractures) exists between the weathered zone and the underlying fractured aquifers. Pollution may migrate along these fractures or the contacts of igneous intrusions (dolerite dykes) to deeper levels within the fractured aquifer.

A total of 5 boreholes were sampled. Water levels were measured in all the boreholes. The measured water levels ranged from 0.9 (minimum) to 4.7 m (maximum) below surface. The relative shallow water table increases the aquifers susceptibility to contamination from surface structures such as the 30CDR Slimes dam.

A total of 10 auger holes were drilled in to the slimes dam and soil samples were taken at different depths. From these 10 holes which could be considered to be representative of the general 30CDR Slimes dam, 10 samples were sent in for geochemical assessment by TCLP/Acid Rain analyses[19].

The samples were analysed to determine the water soluble leachates that may arise from the slimes dam and impact onto the groundwater.

Based on the selected samples and limited analyses the following can be concluded regarding the hydro chemical/geochemical results.

- The major percentage cation/anion constituents (70%) of the samples analysed for are Sodium (22%) Calcium (21%) Potasium (16%) and Magnesium (12%).

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[18] *Mamsl- meters above mean sea level*

[19] *TCLP/Acid Rain analysis extracts solids. Total metals in solids are determined after extractions by either ICP-OES*

- According to the soil screening values for the parameters analysed f indicate that the soil is not contaminated above acceptable limits.
- The parameters analysed indicate that the groundwater underlying the site has been affected through pollution especially if Fe and Al is considered. WD-08 shows water quality that is directly impact by pollution source(s) such as the 30CDR Slimes as it is elevated for most of the parameters analysed (see Table 8).
- The chemicals of concern for the 30CDR Slimes dam as listed by Golder, 2011 are Chromium, Fluoride, Aluminium, Arsenic and Magnesium. Based on these parameters the 30CDR Slimes is contributing to the pollution load in the groundwater underlying the 30CDR Slimes dam especially if Aluminium is considered.

10 • RECOMMENDATIONS

10.1 Mitigation Measures

A shallow interception trench constructed downstream of the 30CDR Slimes dam. Such a design should only be considered following a thorough geotechnical study. Alternatively, the Samancor could decide to mitigate at the downstream reaches of the local streams

10.2 Monitoring Network

A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

If data for the upper weathered aquifers is unavailable it is recommended that shallow piezometer boreholes be installed in the existing boreholes to monitor the weathered zone. DWAF (1998) states that “A monitoring hole must be such that the section of the groundwater most likely to be polluted first is suitably penetrated, to ensure the most realistic monitoring result.

Boreholes WD01, WD02, WD08, WD10 and N3880 are available for plume/source monitoring. The construction of the boreholes should be made available or be determined for future studies.

The parameters analysed should include the following and should be sampled on a quarterly basis.

Inorganic chemicals including:

- Heavy metals, particularly Iron, Aluminium and Chromium

- Sulphate
- Arsenic
- Magnesium
- Fluoride
- Ammonia
- Magnesium
- Calcium and Potasium
- Bicarbonate

Other parameters:

- pH
- Electrical Conductivity
- Total Dissolved Solids