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**A GEOHYDROLOGICAL SITUATION ANALYSIS FOR THE  
CONSTRUCTION OF A GROUNDWATER MANAGEMENT PLAN FOR  
THE SASOLBURG INDUSTRIAL AND MINING AREA**

**BY**

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# 1 Background

## 1.1 Introduction

The Department of Water Affairs and Forestry in collaboration with the Institute of Groundwater Studies, UOVS, conducted a situation analysis of the current groundwater status in the Taaibos and Leeu Spruit Catchments. The Groundwater Situation Analysis together with the Surface Water Situation Analysis completes the first phase of the eventual Catchment Management Plan (CMP) for these catchments.

The main aims of this study were:

- To determine the status quo of the study area with regard to all groundwater quality and quantity issues
- To identify all land and water users and establish an amiable working relationship with and between them
- To identify emerging water quality and quantity issues and fill any information gaps needed to design the CMP
- To make recommendations towards future management of the groundwater in the study area, identifying the aspects that need to be dealt with for the eventual implementation of a CMP

## 1.2 Approach to Catchment Management

The Department of Water Affairs and Forestry, as custodian of South Africa's water resources, is responsible for managing the quantity and quality of water. Recent changes by the Department included the National Water Act of 1998, Integrated Water Resource Management (IWRM) and particularly Integrated Water Management (IWM).

Integrated Catchment Management (ICM) is a process and an implementation strategy to achieve a sustainable balance between utilisation and protection of all environmental resources in a catchment, to sustain a sustainable society (Görgens et al. 1998)). This involves establishing receiving water quality objectives for rivers in the catchment based on requirements of stakeholders and interested and affected parties, and developing catchment management strategies to ensure that these water quality objectives are met.

There has also been a shift towards a people orientated approach to water management, where users actively participate in the decision making process. This is achieved by forming a Steering Committee representing all stakeholders, communities, local authorities and other interested and affected parties (IAP's). This steering committee then evolves through the management process to become an Advisory Catchment Co-ordinate Committee (CCC)<sup>1</sup>. Together with the Catchment Management Agency (CMA) the CCC are responsible for managing the catchment so that no degradation of natural resources occurs, and the quality of all water bodies is suitable for all users in the catchment.

## 1.3 Water Management at the Catchment and River Basin Scale

The water resource at a particular location is the product of runoff or groundwater recharge that originates in, and reflects conditions and events throughout, a physiographically defined drainage area, known as a catchment ("local" scale) or basin (large scale, multiple catchments) (Görgens et

---

<sup>1</sup> The name of this committee may vary between management regions

al. 1998). The Taaibos and Leeu Spruit catchments are considered to be sub-catchments of the "larger" catchment or river basin of the Upper Vaal River. By dividing the management process into smaller scales of sub-catchments, it becomes a more people-friendly and manageable process. Residents of a particular area, such as the Sasolburg area, often have a valuable understanding of the local area's problems and solutions.

The way that humans utilise land inside a catchment has a significant impact on the quality and quantity of the water resource and the aquatic ecosystem reliant on that resource. In this way the hydrological cycle, land use and the ecosystem are bounded together in a catchment or river basin. This fact calls for the recognition that naturally occurring water can only be managed effectively and efficiently within catchment or river basin boundaries, because of the need to technically account for all aspects of the hydrological cycle as well as for human interference.

There are certain factors that could detract from the notion that a catchment or river basin is an ideal management unit. These include factors such as administrative regions within society that do not always coincide with water management areas. This is the rationale behind the Department of Water Affairs' decision to divide the country into Water Management areas, rather than use the provincial boundaries for water management.

Inter-basin transfers and ecological systems that traverse across catchment boundaries also complicate the situation. Fortunately none of these factors need to be accounted for in the study area.

#### **1.4 Management process**

The management process through which a Catchment Management Plan is developed and maintained, includes at least five stages (Ninham Shand, 1999):

- *Initiation:* the management process has been triggered by the water demand and water quality problems in the area. The management process will be driven by the Steering Committee, which is representative of all IAP's in the area.
- *Assessment:* where studies are undertaken to understand the physical environment in the catchment and to determine the causes of the water related problems experienced.
- *Planning:* where a vision for the catchment is formed by all IAP's and consensus is sought about institutional needs, water and land management strategies, social and ecological concerns, funding and stakeholder responsibilities. A Catchment Management Strategy is drafted and then refined as a Catchment Management Plan (CMP) during the public participation process.
- *Implementation:* where responsible parties implement the CMP to address issues of concern. During this stage an Advisory Catchment Co-ordinate Committee should be established.
- *Administration:* The Advisory Catchment Co-ordinate Committee (together with the CMA) will be responsible for the administrative functions such as monitoring, application, and adjustments of management strategies, licensing issues and screening of new licences for development. The committee will also have to maintain community support and funding for the process.
- *Review:* the process should be reviewed periodically to reassess its success, re-plan and revise responsibilities, objectives and strategies.

Chronology is implied in the five stages of the management process; however considerable overlap and iteration between stages is expected in the implementation, administration and review stages.

### 1.5 The assessment stage of the management process

This report, together with the surface water situation analysis report, will form the major part of the assessment stage of the management process for the Taaibos and Leeu Spruit catchments. As mentioned before, the aim of this stage is to provide a comprehensive and accurate information base on which the CMP may be developed.

Mining and industrial activity and urban development (Greater Sasolburg including Zamdela) dominate the land use in the catchment area and impact heavily on the quantity and especially the quality of the water resources in the area. This report will concentrate on providing answers regarding the interaction between these factors and their influence on groundwater.

This study therefore focused more on the water quality assessment and less so on the water quantity assessment.

To ensure water quality assessment is cost-effective and appropriate to the issues and problems at hand, the features of the selected assessment techniques must suit the level of detail required for management decision-making (Pegram et al. 1997). The appropriate level of assessment to support any phase of the management process depends upon the information needs to be addressed, the nature of the problem and the characteristics of the catchment.

Table 1 indicates the type of assessment and management decisions required at each stage of the assessment process, which is associated with the three phases of the catchment management process.

**Table 1: Assessment and management decisions required for the assessment process.**

Management Phase	Level of Assessment	Assessment action ⇒ management decision
	Screening/ scoping	Preliminary overview of the existence and extent of a problem ⇒ the water quality issues to manage
Situation analysis	Evaluation	Detailed investigation of the cause-and effect relationships ⇒ key areas and constituents of concern
	Prioritisation	Rank the problems and causes in terms of severity and manageability ⇒ priority sources and/or water bodies and management strategies
Planning	Selection	Design and estimate the cost effectiveness of possible actions ⇒ appropriate actions to achieve the specified strategies
	Operation	Estimate the impacts of 'real-time' actions ⇒ ongoing operational decisions
Implementation	Auditing	Monitor the degree to which conditions are meeting objectives ⇒ reassessment, replanning or further implementation.

The following is an indication of the types of information needs that a water quality assessment must provide to assist decision making during the situation analysis phase of the management process.

What are the likely water quality problems (**constituents**)?

How bad are they (**fitness-for-use**)?

Where do they occur (**impacts**)?

When do they occur (**periods and cyclicity**)?

What is causing them (**processes**)?

Where do they stem from (**sources**)?

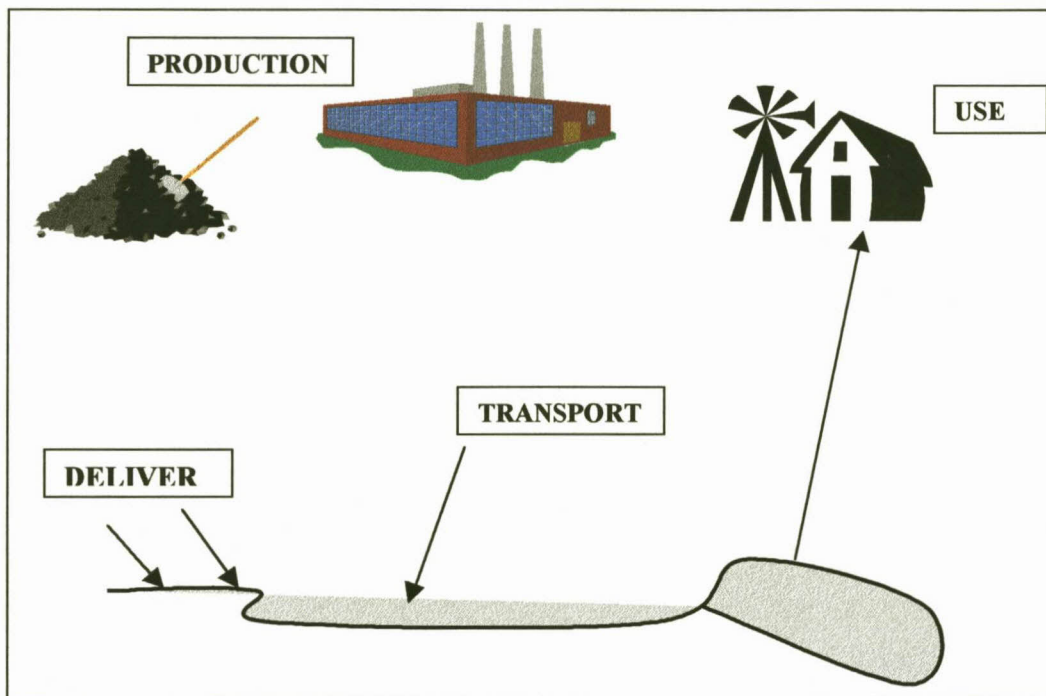
What should be managed to reduce the water quality problems (**key issues**)?

What should be managed first (**priorities**)?

The framework in Table 1 compares well with the work completed on the project for the Taaibos and Leeu Spruit catchments. At the assessment level of screening and scoping a preliminary overview of the problem was achieved by reviewing all historical data of the study area. A literature review that included groundwater reports of various sites, relevant scientific articles and government guidelines was performed to decide on the water quality issues that need to be managed.

The investigation of the cause-and-effect relationships was done through several investigative procedures during the evaluation level of assessment. The four conceptual physical elements of water quality management, production, delivery, transport and use were quantified. This included the work done during the field investigations.

**Figure 1. Conceptual elements of water quality management**



Production processes and possible pollution sources were investigated through site visits and sampling. Analysing of the data collected in the database have highlighted key areas of concern. The numerical modelling together with use of aquifer parameters and the geophysical investigation provides valuable information on the transport and delivery processes. General catchment characteristics, used with land use practices quantified the use of water and the fitness-for-use was established by using appropriate quality guidelines.

During the last level of assessment "prioritisation" of the situation analysis a certain amount of overlapping took place with the planning phase. Problems are ranked according to severity and manageability. This was done by performing a risk analysis with the modelling data and by making use of the program TAG that was developed specifically for the purpose of highlighting problem areas. Appropriate management strategies are suggested. For the Taaibos and Leeu Spruit catchments a groundwater-monitoring plan is suggested along with preliminary groundwater quality guidelines.

All of the information gathered during this phase will be incorporated into the eventual Catchment Management Strategy/ Plan for the Taaibos and Leeu Spruit catchments. This Strategy/ Plan will be the guideline for the appointed Catchment Co-ordinate Committee to manage the water resources in the catchment area.

### 1.6 *Aquifer Classification*

As stated in terms of the Groundwater Quality Management Strategy an aquifer classification system would provide a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection. This would facilitate the adoption of a policy of differentiated groundwater protection.

Other uses could include:

- defining levels of investigation required for decision making;
- setting of monitoring requirements; and
- allocation of manpower resources for pollution control functions.

The aquifer classification system used to classify the aquifers in the Taaibos and Leeu Spruit catchments are the proposed National Aquifer Classification System by R. Parsons (WRC Report No. KV 77/95). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification.

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*

In the Taaibos and Leeu Spruit catchments there are four aquifer systems that need to be classified:

The first aquifer comprises of all the sediments above and including the dolerite sill and is referred to as the *shallow aquifer*. This aquifer overlays the major part of the study area. This is a low yielding aquifer with low permeabilities and moderate quality. The classification of a **Minor Aquifer System** can be used for the shallow aquifer. The definition of this system is as follows:

*"These can be fractured or potentially fractured rocks which 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 important both for local supplies and in supplying base flow to rivers."*

A second variable classification is needed for sound decision making, as the ability of an aquifer to yield water to a particular user is not adequate. In this case it was decided to use the vulnerability of the aquifer to contamination as a second parameter. A weighting and rating approach is then used to decide on the appropriate level of groundwater protection (See table 2).

AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		AQUIFER VULNERABILITY CLASSIFICATION	
Class	Points	Class	Points
Sole Source Aquifer system	6	High	3
Major Aquifer system	4	Medium	2
Minor Aquifer System	2	Low	1
Non-aquifer System	0		
Special Aquifer System	0-6		

**Table 2. Ratings for the aquifer Quality management classification system.**

GQM INDEX	LEVEL OF PROTECTION
<1	Limited protection
1-3	Low Level protection
3-6	Medium level protection
6-10	High level protection
>10	Strictly non-degradation

**Table 3. Appropriate level of groundwater protection required.**

After rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a GQM (Groundwater Quality Management) index. The GQM index for the shallow aquifer is calculated at 6. (Minor aquifer as by definition 2 x High aquifer vulnerability, due approximation of pollution sources and rivers and the high level of contamination that already exist 3 = 6). The appropriate level of protection for the aquifer is thus **medium level** (Table 3.).

The second aquifer to be classified is the *sandy alluvial aquifer* in the vicinity of Wonderwater Open Cast Mine. This aquifer can be classified as a **Major Aquifer System**, as it is a good yielding aquifer with excellent water quality (EC < 40 mS/m). This aquifer supplies a number of small holdings of drinking water. The definition of a Major Aquifer System is as follows:

*“Highly permeable formations, usually with a known or probable presence of significant fracturing (or high porosity). They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good.”*

The GQM index for the sandy alluvial aquifer is calculated at 12. (Major aquifer 4 x high aquifer vulnerability 3 = 12). This aquifer requires a **strictly non- degradation level** of protection. This level of protection is taken into account with the setting up of preliminary water quality standards.

The third aquifer is the one described as the *sandstone aquifer*. This aquifer is higher yielding than the shallow aquifer and also of a better water quality. This aquifer is also classified as a **Major Aquifer System** (4) but due to the distance from any pollution sources (industries and mines) is assigned a low aquifer vulnerability (1). The GQM index for this aquifer is calculated at 4, which amounts to **medium level** protection.

The fourth aquifer, the *dolomitic aquifer*, which is found in certain areas of the study area, can also be classified in the same way as the sandstone aquifer. The great depth at which this aquifer is found results in the low aquifer vulnerability and thus the GQM will also be 4.

This classification can now be used during the setting up of the Groundwater Management Plan. The classification supports a differentiated groundwater protection policy and embraces the concepts of a precautionary principle, fitness-for-use and sustainable development.

## 2 Catchment Description

### 2.1 Location and Catchment Boundaries

The study area ( $\pm 1070 \text{ km}^2$ ) is located south of the Vaal River in the Free State Province, and includes the municipal area of Sasolburg. The catchment boundaries, as defined by Walmsley Environmental Consultants (1998), include the northerly draining tributaries of the Vaal River, the Leeu and the Taaibos Spruit. The Leeu Spruit is situated on the western side of Sasolburg and is approximately 15 km in length. The Taaibos Spruit and its tributaries are located east of Sasolburg and is approximately 55 km in length. The Vaal River forms the northern boundary and the major surface drainage feature of the study area.

### 2.2 Climate

The climate of the area can be described as typical Highveld type climate characterised by warm summers and cold, frosty winters.

The summer rainfall occurs principally in the form of thunderstorms. The rainfall is variable with a MAP of around 643.5 mm/a based on the long-term record (1953–1998) of gauging at station no. 0438588 (Sasolburg). The owner of the farm Mooidraai, Mr De Kock, also collected rainfall data for the time period 1954 to 1997. This farm is located in the Middel Taaibos catchment. The data compares favourably with that measured at the rainfall station (table 4.).

Month	Average Rainfall: Station No. 0438588 (mm)	Average Rainfall: Mooidraai (mm)
January	108.8	110
February	81.6	79
March	75	74
April	50	45
May	15.9	17
June	6.4	6
July	3.5	3
August	11.2	12
September	25.4	24
October	74.1	76
November	84.8	93
December	106.5	108
<b>Total for year</b>	<b>643.5</b>	<b>647</b>

Table 4: Rainfall measured in the Taaibos and Leeu Spruit Catchments

The seasonal temperature in the study area is characterised by moderate fluctuations. The mean temperatures range between 19°C and 22°C in the summer months (October to March), and 10°C to 17°C in the winter months (April to September) (Walmsley, 1998).

The prevailing wind direction is north-westerly although south-westerly winds are common during the months of May to July.

### 2.3 Topography

The topography in the study area is very gentle with the elevation varying in the south from 1600 mamsl to 1420 mamsl in the north. The average gradient in the area is 33%.

### 2.4 Land Use

The natural landscape is dominated by farming activities in the form of dryland agriculture and cattle farming. Maize, sunflowers and sorghum are the main products produced. At the Wolwehoek settlement towards the south of the Leeu Spruit catchment a large abattoir, with the associated feedlots and a tannery, are located.

Mining activity to the West of Sasolburg comprises of the Sigma Colliery that supports Sasol Chemical Industries. Mining operations are both underground and on surface. At Sigma Underground seams are mined by the bord- and-pillar technique as well as total extraction mining. Closure of the underground mining operation will take place some time during the year 2000. Surface mining operations comprise of the Wonderwater Open Cast Mine. To the east of the study area land was identified for the proposed North West Strip Mine. To the South of the catchment, Coalbrook Colliery, now closed, used to supply the Kragbron power stations with coal.

The industries in Sasolburg are mainly of a chemical nature. The industrial area is located to the East of Sasolburg. A large variety of chemical products for the South African and overseas market are produced by these industries. A few transport companies and brickworks are also based here.

Sasol Chemical Industries has its own waste disposal site to the South West of the Sasol factory area, and all the industrial effluent, sewerage waste and municipal waste are collected and treated on this site.

### 2.5 Geology

The study area is underlain primarily by sedimentary lithologies of the Karoo Supergroup, in particular those associated with the Vryheid Formation. This is reflected on the published geological map 2626 West Rand (1976) at scale 1:250 000.

The composition of the Karoo sediments includes shale (often carbonaceous), mudstones, siltstones, sandstone and the economical important coal seams that are mined. The sedimentary rocks are invaded by post-Karoo dolerite intrusions in the form of dolerite sills (sheets) and - dykes. The Karoo sediments thins out towards the north of the catchments and inliers of the Hekpoort basalts, of the Transvaal sequence, feature with Quaternary alluvial sediments to form the topmost unit in certain places north of the Sasolburg industrial area.

The Karoo sediments are underlain by Dwyka Group tillite that represents the basal unit of the Karoo Supergroup. To the south of the catchments the tillite overlies the "floor" rocks represented by dolomite of the Malmani Subgroup of the Chuniespoort Group or lava of the Ventersdorp Supergroup.

The two structural elements that occur are faults and dolerite intrusions that take the form of dripping sheets and non-vertical dykes. Faults and subvertical dykes in the area are known from

the intersection in underground mine workings. The sheet intrusions are known primarily from exploratory drilling conducted from the surface (VSA GeoConsultants, 1996).

In a regional context the Karoo sediments dip undulatingly to the South. As a result the present-day depth of burial of coal seams increases from 25 m below surface (mbs) in the north, to greater than 180 mbs in the south. The deepest portion of mining activity in the area is thus located in the south, down to a depth of 190 mbs.

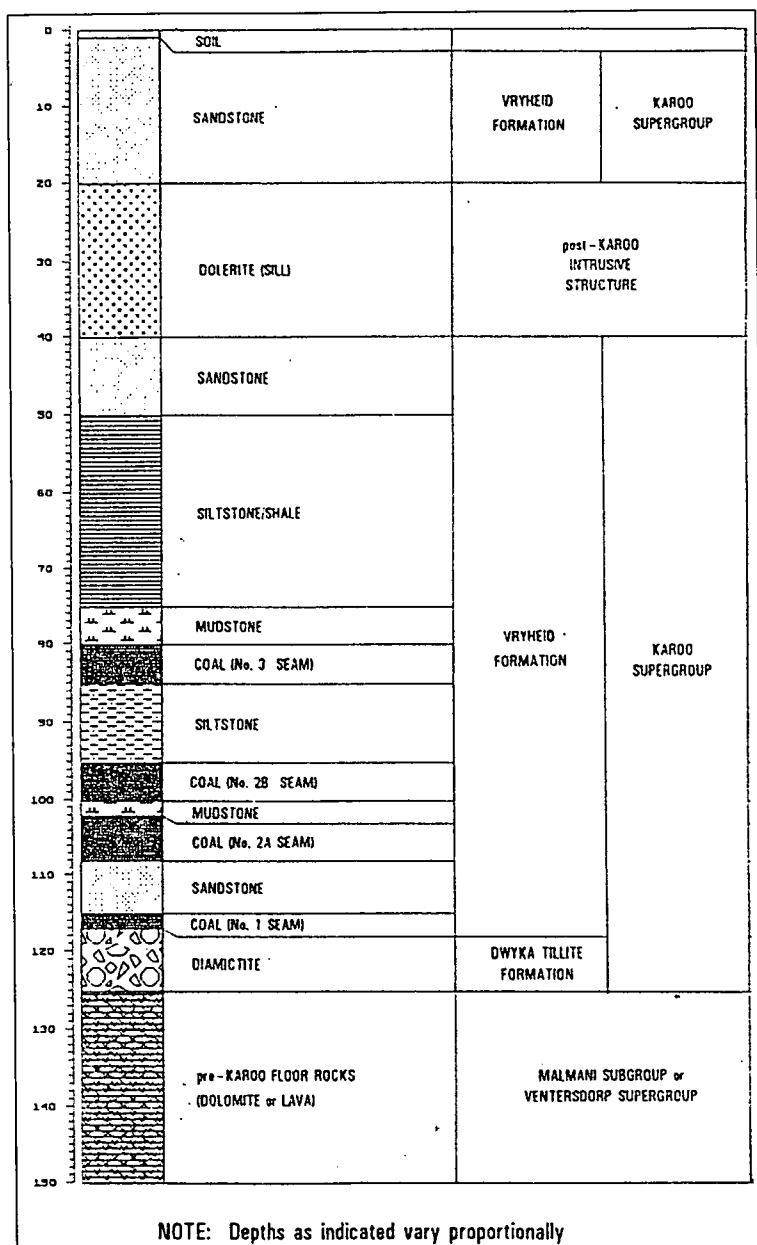


Figure 2: Generalised lithostratigraphic profile, (VSA Geoconsultants, 1996)

## 2.6 GEOHYDROLOGY

The hydrogeological regime within the study area is a complex system and groundwater experts that have done work in the area have identified several different aquifer systems. Since this is a regional study, a generalised system consisting of four major aquifer systems are proposed for the area:

- A *shallow aquifer* that is located within and above shallow dolerite sheet intrusions. This aquifer includes the dolerite sills down to the contact zone with the Karoo sediments as well as all the weathered sediments above the sill.

- An *alluvial aquifer* comprising of alluvial sands that are found along the rivers, especially in the vicinity of Wonderwater Open Cast mine and in the area of the proposed North West Strip mine.
- A *sandstone aquifer* represented by a clean, white, arenaceous sandstone horizon, located some distance above the coal seams and below the dolerite sheet intrusions.
- A *karst aquifer* represented by the dolomitic formations that partly underlie the Karoo sediments.

A fifth component of the hydrogeological regime is the underground mine workings, both at Sigma Colliery and Coalbrook Colliery. This represents the voids left by the bord- and - pillar mining and the disturbed geological environment where subsidence and collapse have resulted from total extraction mining. These components have variable impacts on the natural hydrogeological regime.

Each of these hydrogeological components is characterised by different hydraulic parameters (eg. transmissivities, storativities and yield potential) as well as distinct hydrogeochemical "signatures".

A generalised description of each aquifer system is given below.

### 2.6.1 Shallow Aquifer

The *shallow aquifer* is a low yielding ( $\pm 1$  l/s) aquifer and the water table is fairly shallow (water level  $\pm 1-5$  mbs). This implies that the unsaturated zone is fairly thin. This has several implications regarding groundwater pollution, and this aquifer is the main concern for pollution risk in the industrialised area. The groundwater has a marginally sodium-bicarbonate character, and the water quality is moderate with EC values of approximately 70 mSm.

Usage of the groundwater in this aquifer is mainly for domestic and stockwatering purposes on farms and smallholdings in the study area. Most of the monitoring boreholes in the industrial area are drilled into this aquifer.

### 2.6.2 Alluvial Aquifer

The *alluvial aquifer* is a low to moderate yielding (2-5 l/s) and of excellent quality (EC = 20 mSm). The water quality and character suggest a high rate of recharge from rainfall. Water levels vary between 3 to 10 mbs.

The aquifer is mainly used for domestic purposes on the smallholdings near the rivers.

### 2.6.3 Sandstone aquifer

The sandstone aquifer comprises of clean, white, arenaceous sandstone. The waterbearing capability of these sediments can be attributed to secondary porosity (or fracturing). The aquifer is heterogenous with considerable variability in terms of extent, depth and exploitability. (VSA GeoConsultants, 1996). The yield ( $\pm 10$  l/s) is substantially higher than that of the shallow aquifer. The groundwater exhibits a definite sodium-bicarbonate character but contains less nitrate and sulphates than the shallow aquifer and has a lower total hardness.

The groundwater of this aquifer is utilised for irrigation purposes to the south of Sigma Colliery mining activity.

### 2.6.4 Karst Aquifer

The dolomite formations that underlie the Karoo sediments represent the karst aquifer. The waterbearing capabilities are due to dissolution of dolomite by groundwater. The yield (3 - 4 l/s) of this type of aquifer is highly variable due to the heterogeneity of these solution cavities. The groundwater has a strong sodium-bicarbonate character in contrast to the normal

calcium/magnesium-bicarbonate type found in dolomitic aquifers. One can conclude from this and the high chloride levels that the groundwater is stagnant and does not receive recharge.

The use of this aquifer is limited because of the great depth (> 200 mbs) at which it occurs. High fluoride levels also limit the potability of the water.

### 3 Literature review

During the literature review phase of the project all relevant information about the study area was collected. This information was used to determine the status quo of the groundwater situation and to highlight information gaps. This collection of information was an ongoing process throughout the project.

The information that was collected included the following:

- *Reports*: reports of previous surface and groundwater investigations, Environmental Impact Study reports of industries and mines, Water Research Commission reports, monthly water status reports to DWAF, and internal monitoring and pollution incident reports from industries
- *Electronic info*: borehole and surface water analyses and site layouts
- *Maps*: site layouts, topographical, geophysical, geological and municipal planning maps
- *Other*: published scientific articles, chemical inventories of factory sites, production processes on sites, effluent treatment cycles, sampling protocols, and weather data.

#### 3.1 Status Quo of Groundwater Quality and Quantity

The following is a summary of information that was gathered during the literature review. Each water user unit is described separately with an overview of the current groundwater status quo at each site. (Site maps are included in Appendix F.)

##### 3.1.1 Chemical industries

###### 3.1.1.1 African Catalysts (Pty) Ltd

African Catalysts is a company that has produced solid phosphoric acid catalyst (SPA) since 1981. In 1986 the company diversified into mining chemicals (styrene phosphoric acid, sodium di-thiophosphate, and later potassium xanthate) (Cooper, 1998).

At the end of 1994 the mining chemical's division was closed down. When the company started it had a permit that allowed them to spray irrigate the effluent on site that was produced in the process. After the mining chemical division was opened, effluent treatment had to become more intensive. New equipment was installed to remove impurities. The pH of the effluent was adjusted with sulphuric acid; lime and a coagulant were added before filtering.

Regeneration of spent hydrotreating catalysts, which began in 1990, made pH adjustments unnecessary due to the sulphuric acid scrubbed out of the stack gasses acidifying the effluent. Lime was added to neutralise the pH. In 1992 a further effort was made to limit the volume of effluent by recycling wash water where possible and replacing the once through cooling process with three cooling towers.

After the mining chemical's division was closed down, it became possible to recycle sufficient effluent through the catalyst off-gas scrubbers to evaporate more water than the plant required. Thus zero effluent was achieved in 1996. The water is still treated to precipitate the phosphates that are filtered out before being transferred by Envirotech to a hazardous waste site.



Sources of pollution were identified as the following:

#### Manufacturing plants

- Effluent dams (Leakage from dams 3 & 17 were evident, dam 13 was emptied and liner removed)
- Loading bays next to dams 19 & 13 (frequent chemical spills on no concrete floor)
- Informal waste disposal from 10 - 15 years ago (Rubber, orchemtar drums, and other chemicals in series of 2m deep trenches)
- Spills (14 recorded incidents since October 1994, consisting mostly of sulphates and some organic substances)

At the time of investigation there were 21 existing boreholes (BH1 - BH19, BHA & BHB) on the property. They ranged in depth from 2.15 m - 4.13 m. Water levels were measured between 0.37 - 2.4 m. From the boreholes' positioning, it was evident that their purpose was to monitor the movement of leachate from various dams that are located on site. Chemical analyses indicated that there was very little organic contamination and that some of the effluent dams were leaking. Slug tests were performed on four of these boreholes to provide an initial estimate of the aquifer permeability ( $\pm 0.001$  m/d).

A geophysical investigation with EM 34 equipment suggested fracture zones and a possible pollution plume on the property. The magnetic survey showed no anomalies. The results of this survey were used to site new monitoring boreholes (GCS1A & B, GCS 2A & B, GCS 3 - GCS 7). The A and B represent deep and shallow boreholes. Depth of the new boreholes range between 10 and 42 m below surface. During the drilling, dolerite was intersected between 0 - 18 m and 3 - 30 m. The thickness and weathering of the dolerite sill seem to vary across the site, but generally it pinches out towards the eastern boundary. Other geological formations included silty sandy clays, clayey sands, and fractured to weathered shale.

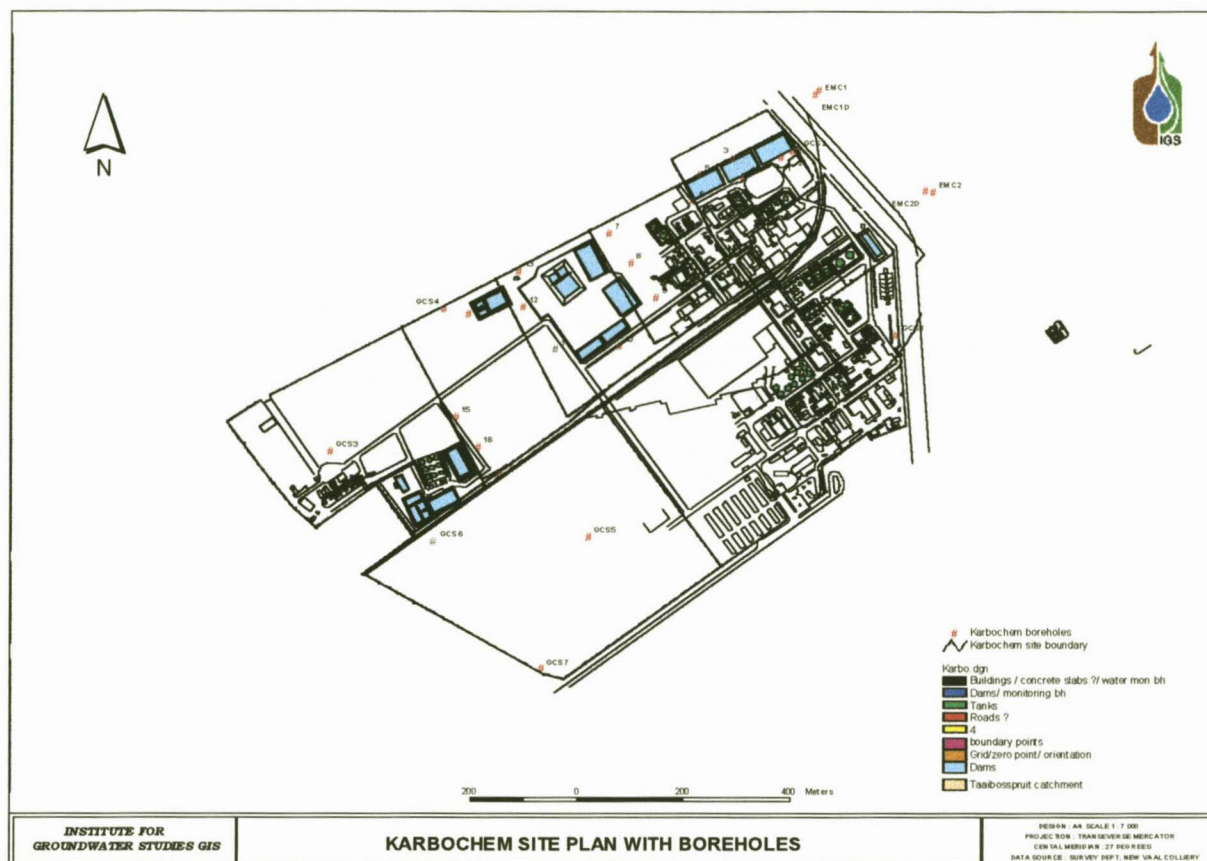
A series of shallow well points (P1 - P10) was hand augered to a maximum depth of 4 m in the area surrounding the informal waste site to address this concern. P4 and P10 showed signs of contamination or intersected fill material.

Pump tests were performed on four new boreholes to determine the aquifer parameters. Transmissivity was calculated to be between 0.13 - 2.32 m<sup>2</sup>/day. The highest yield, 0.71 l/s, was in GCS 7, where a fracture was intersected.

Conclusions drawn by this first phase investigation were the following;

- Aquifer potential has limited applications in terms of groundwater supply.
- The samples from upstream boreholes show that upstream users have affected the ambient groundwater quality.
- Vertical migration of contaminants will be slow under natural conditions, due to low permeabilities. However, shallow groundwater level and depth of the trench and effluent dam excavations will reduce the retardation effect of this barrier.
- Vertical migration may also take place via fractures in the dolerite, as was indicated by the EC log of GCS1A where contaminants associated with the fracture at 39 m were found.
- Potential lateral migration of contaminants may take place along the contact between the silty sandy clays and the sill.
- Impact with reference to groundwater: Evidently groundwater is polluted on site, especially in the vicinity of the informal waste site and towards the eastern boundary.

- Impact with reference to surface water: Monitoring of the Driefontein dam is conducted on a regular basis and no ill effects are apparent at this stage.



**Figure 4: Site layout of Karbochem site**

During the second half of phase I (IGS, 1995), the following were determined with the help of groundwater modelling:

- Geology, groundwater gradients, and hydrogeological parameters;
- Delineation of the nature and extent of the pollution plumes;
- Evaluation of potential for off-site migration;
- Prioritisation of risk.

From this investigation no new observations were made, but it increased the understanding of groundwater conditions on site. Groundwater movement is generally towards the south on the western portion of the site, and towards the eastern boundary in the East. From the risk assessment it was clear that the greatest potential for off-site migration of contaminants is towards the northeast (GCS2). Risk of pollution migration towards the south (GCS7) will increase if this borehole is pumped.

Phase II (EMC, 1997) of the investigation started in April 1997 and was confined to the northeastern boundary of the site. Field work included geophysics (EM34) and drilling of two additional monitoring boreholes off-site. Sampling of these boreholes was also included.

From the geophysics two prominent NE -SW trending fracture zones were delineated as well as an inferred pollution plume. These fracture zones were used to site the boreholes. As the integrity of bentonite seals in multiple piezometers were questionable, four boreholes were drilled: two shallow ( $\pm 10$  m) and two deep ( $\pm 30$  m) boreholes.

During drilling two distinct aquifers were intersected. A shallow perched aquifer is situated within the highly weathered horizon above the dolerite and yielded  $\pm 0.1$  l/s. A deeper semi-confined aquifer consists of the dolerite sill and the moderately weathered and fractured underlying shales. The semi-confined aquifer yielded  $\pm 0.25$  l/s.

Pump tests yielded the following results: calculated transmissivities are between  $0.48 - 0.95$  m<sup>2</sup>/day. This indicates a slower migration of groundwater in the shallow perched aquifer than in the semi-confined aquifer. In the latter, migration takes place within the preferential pathways.

Groundwater samples were analysed for major cations and anions, COD, EC, and alkalinity. Piper and Durov diagrams were used to interpret the results. These showed that the groundwater consists mainly of saline and sulphate-rich water. Results of these samples were compared with Phase I's findings. It was found that the groundwater chemistry remained constant over the two years.

Conclusions of phase II were the following:

- Most of the monitoring wells exceed the crisis limit (drinking standards) for EC, Na, Mg, Mn, Cl, and SO<sub>4</sub>;
- A potential source of contamination is identified within the Alkylate plant;
- The increase of EC in the vicinity of the Informal waste dump suggests deterioration of the condition of the deposited containers;
- Increase in EC at GCS7 suggests that contamination is migrated off-site towards the south-west;
- The removal of the No. 13 dam has led to a decrease in EC in the surrounding boreholes;
- Rehabilitation of the dam complex (No. 18) has also led to a decrease in EC in surrounding boreholes;
- Geophysics confirmed the migration of the contamination plume off-site towards the northeastern boundary.

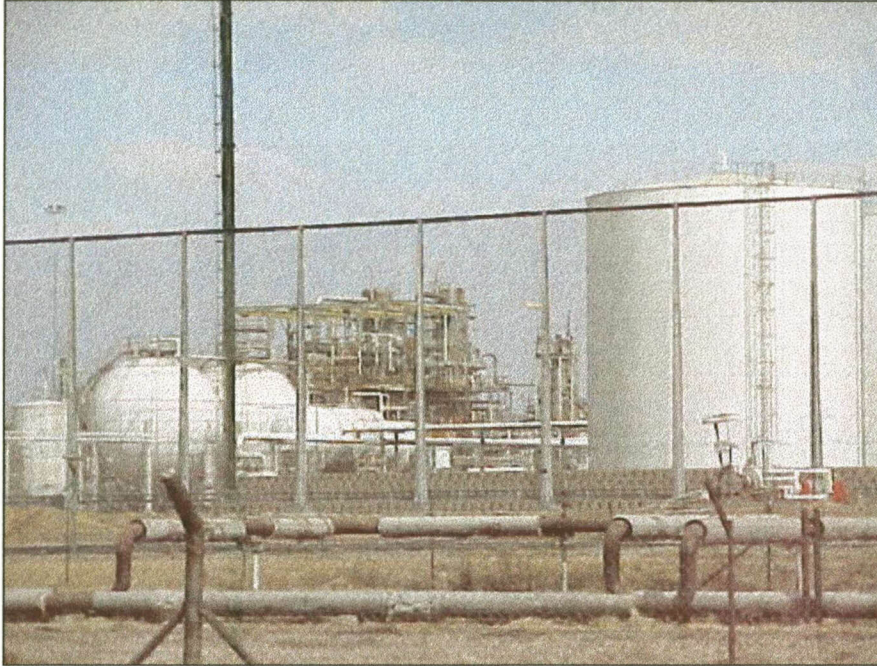
Karbochem is performing ongoing monitoring of groundwater and surface water. Phase III, which includes numerical flow and transport modelling to assess the regional impact on the groundwater regime, is planned for the future.

### 3.1.1.3 Natref (Pty)Ltd

Natref is a petroleum refinery that produces a variety of fuels (Jet fuel, diesel, petrol, etc.) Hydrocarbon contamination of the groundwater in the vicinity of the refinery is a threat due to spills and accidents during the processes.

A study (GHT, 1994) to evaluate the "Ecoprobe" gas analysis technique as a method to determine the location and surface extent of a hydrocarbon contamination plume was done in 1994. From previous borehole analyses it was clear that most of the boreholes were polluted as indicated by high Na, EC and COD values. Results from the soil vapour survey indicated that both the

landfarming area and the evaporation dams could be regarded as a source of pollution.



**Figure 5: The Natref Refinery site**

After this initial study, an assessment (Jones & Wagener, 1996) of possible contamination from the evaporation ponds on the northern side of Natref was done. The investigation included an assessment of historical chemical data of the perched watertable samples in the thirty monitoring boreholes situated along Natref's northern boundary prior to relining the dams. It appears that seepage from the dams has been continuous and is not related to a single isolated spill event. If the source of the contamination was removed by relining the dams, it was expected that qualities would improve after a rainy season or two.

Four auger holes were excavated down to soft rock and profiled, and where possible groundwater samples were taken. The positions of the auger holes were based on areas of elevated electromagnetic readings in order to pick up any contamination downstream of the monitoring boreholes. The site is underlain by transported sediments, overlying weathered Karoo shales, and intruded by Karoo dolerites. Seepage inflows into the holes were generally slow and associated with either the weathered shales or the dolerite. Groundwater samples were taken from two of the holes.

Analysis of the groundwater samples indicated that the contamination encountered in the monitoring boreholes is not detectable in the auger holes. Because these points represent the more conductive areas, the likelihood of contamination existing in adjacent areas is low. Thus, it appears that the contamination has remained fairly close to the source, probably due to the presence of the impermeable sandy clay layer and adsorption by the soil. It is unlikely that the deeper watertable within the Karoo rocks will have been impacted on. However, for this to be verified a percussion borehole would need to be drilled into the Karoo down to the dolerite aquifer.

Graphs of monitoring data, supplied by Natref, have indeed shown an improvement of water quality after the relining of the dams. Ongoing monitoring of the groundwater quality is conducted on site

#### *3.1.1.4 Omnia Fertiliser*

Omnia produces a variety of fertilisers, and also explosives, on a large scale and as a result a great variety of chemicals are stored, processed and produced on site. It is therefore natural that the risk of contamination to the surrounding surface and groundwater exists.



**Figure 6: Omnia Fertiliser factory (Photo: Omnia, 1999)**

The potential sources of pollution at Omnia Fertilisers are numerous and include the following:

- The manufacturing plants
- The raw material storage areas and storage tanks
- The loading and stockpiling areas
- The effluent dams
- Uncontrolled spillages and flows

A preliminary groundwater study (Usher and Grobbelaar, 1998) was initiated at the beginning of 1998. The purpose of this study was to identify the potential risks and shortcomings as well as to recommend the correct actions that need to be taken.

After the preliminary study (phase I) several conclusions were drawn:

- The water management system in place at Omnia is currently not up to an adequate standard. At the time of the investigation after fairly persistent rain the shortcomings were highlighted.
- The current monitoring system at this site was not up to standard.
- The surface waters flowing on and from the site are of poor quality, exceeding the drinking water standards and the catchment targets as set by the DWA&F.
- The sole borehole on site is not sufficient to accurately represent the nature of the aquifer hydrochemistry, despite the fact that it appears to be of relatively good quality.
- The risks associated with the poor quality waters on site are fairly high where these waters can interact with the natural environment.

Further work was needed to quantify the risks associated with the site. The levels of parameters found in the auger holes show that groundwater contamination has already occurred on site.

Based on the findings of this preliminary investigation, various recommendations were made:

- The storm water/ drainage system on site needs to be upgraded. Indications are that Omnia has set aside funds to implement the upgrading over various phases.
- A complete monitoring system needs to be put into place at Omnia. A more regular sampling schedule is suggested until a clear picture of the hydrogeochemistry surrounding the site is obtained.
- As part of the upgrading of the monitoring system additional monitoring boreholes will have to be drilled.
- It is recommended that a computer model of the area around the site be done. Such a model will delineate likely pollution plume extent and give indications of future movement of contamination, should there be any.

During the site investigation (phase II) conducted at the end of August 1998, six new boreholes were drilled. Generally sandstone, siltstone, mudstone and dolerite were encountered. It was found that the upper layers are very unconsolidated in regions and that significant interconnectivity is apparent between the ground surfaces and the canals surrounding the site. This suggests that the contamination that could/has occurred can easily be transported to the groundwater table and further downgradient. Slug tests performed on the boreholes show that the site is underlain by low permeability formations and that any pollution movement would occur at a slow rate of spreading.

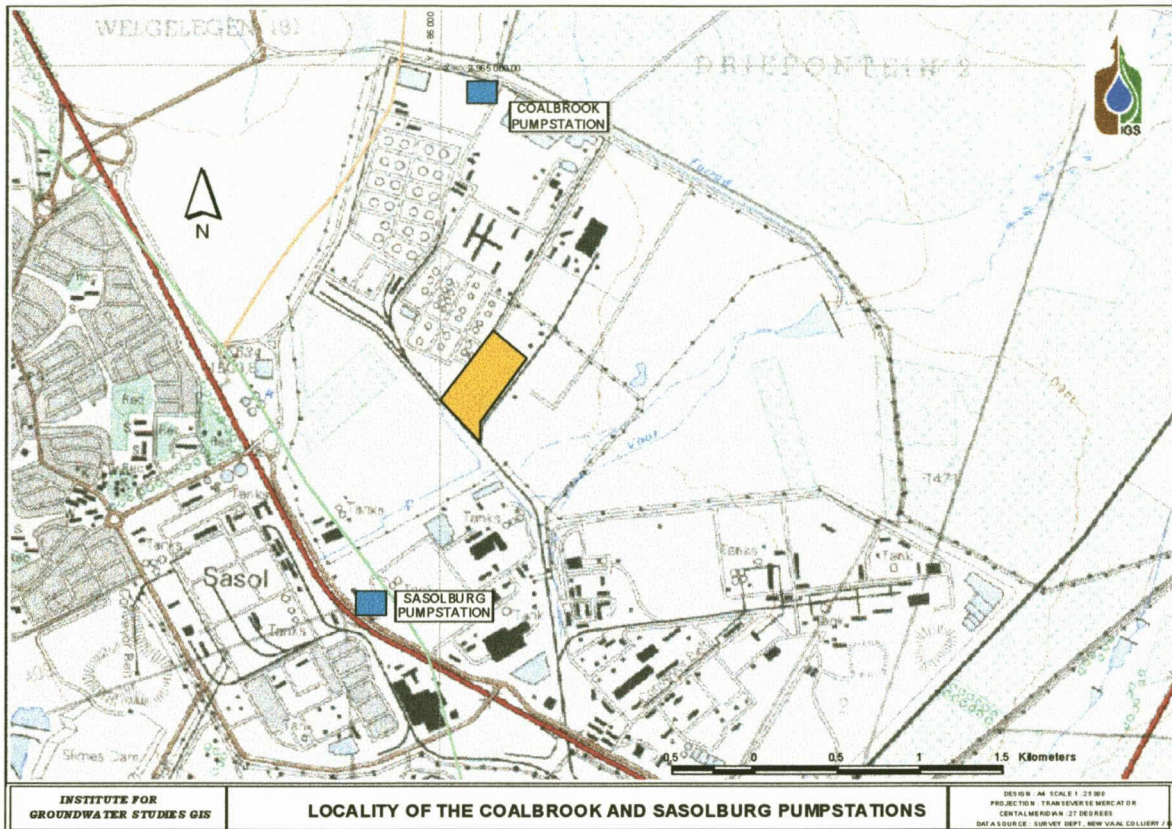
Preliminary chemical results of the water samples taken suggested that groundwater contamination has already occurred. Omnia has committed itself to doing regular monitoring and was also in the process of upgrading the surface water drainage system on site.

#### 3.1.1.5 *Petronet- Sasolburg and Coalbrook Pumpstations*

A full soil and groundwater investigation (GHT, 1997) was done during 1997, at the Coalbrook and Sasolburg pump stations of Petronet in the Sasolburg area. There was concern that pollution has occurred on the site due to past spillages and leakages. The pump stations mainly provide Natref with crude oil via the pipeline from Durban. Various other refined products are also transported along the pipelines to other pump stations across the country.

The site assessment has indicated that hydrocarbon pollution is present in the vapour phase, free phase, adsorbed onto the soil, and in solution with the groundwater. The assessment further found that:

- Soil samples have confirmed low levels of hydrocarbon pollution in the soil at the Coalbrook pump station and high levels in the soil at the Sasolburg pump station.
- At Sasolburg pump station it was evident that the groundwater is polluted with high levels of petrol, diesel and most probably paraffin.
- At Coalbrook pump station high levels of toluene and the absence of benzene, ethylbenzene and xylene were found. This is an indication of "old" hydrocarbon pollution and the source is most probably upstream of the pump station.
- The unsaturated zone can be described as having low to medium transport characteristics.
- The impact that the polluted soil and groundwater might have on the surrounding environment, will probably be masked by other role-players in the vicinity of the pump stations.



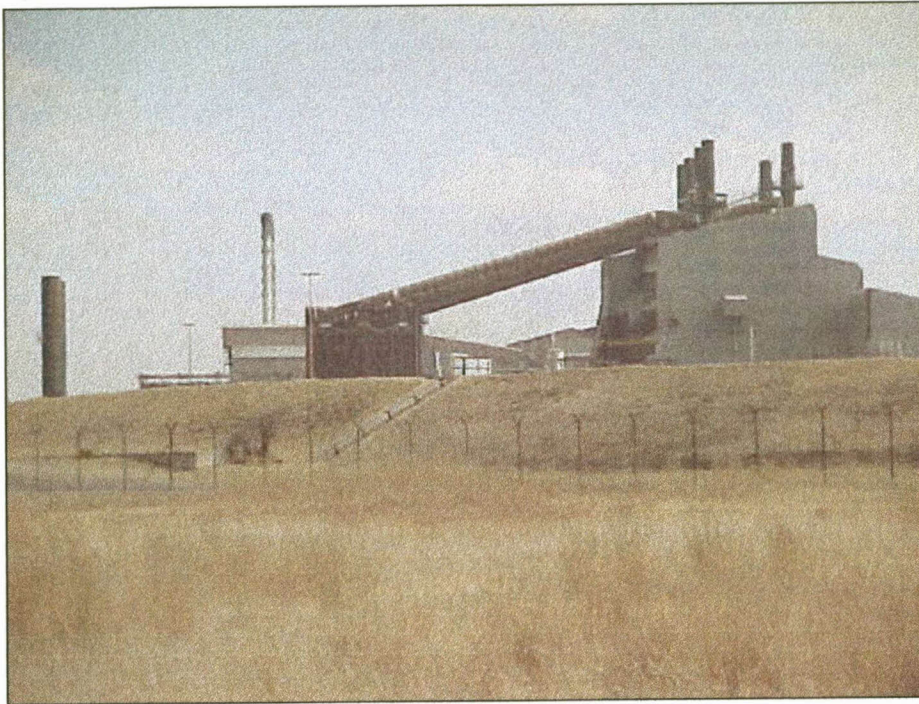
**Figure 7: Locality of the Petronet Pumpstations**

At the Coalbrook pumpstation no remediation was proposed but regular monitoring of the groundwater was advised. At the Sasolburg pump station Pump-and-Treat remediation was proposed as well as regular monitoring. Petronet has an ongoing monitoring program at both these pumpstations.

#### 3.1.1.6 Polifin

The Polifin Midlands Factory produces a variety of bulk chemicals such as Polyvinyl Chloride, Polyethylene, Sodium and Calcium Cyanides, Organic Peroxides, Arctons/Frezones, Carbon Tetrachloride (CTC), Perchloroethylene (PCE), and calendered PVC. During the manufacturing process spillages have occurred which may have resulted in contamination of the soil and groundwater on site.

In March 1994 a study (SRK, 1994) was carried out to assess the likely costs of remediation of soils and groundwater at several of the plants likely to become redundant as a result of the proposed merger between SASOL and AECI. Findings of that study were based entirely on available information. Costs of remediation were very high and therefore it was proposed that the study should be carried out in eight stages to provide Polifin with an optimal business solution to the problem. Up to date four of the stages are completed.



**Figure 8: A view of the Polifin factory site from the Taaibos tributary in the southeast.**

The following is a summary of the work completed by SRK at Polifin :

Stage 1 of the investigation indicated that, in terms of selected criteria, various plants could be prioritised in terms of the need for remediation. The primary objectives of Stages 2 and 3 were to ascertain the extent of groundwater contamination beneath and immediately surrounding the plant area, and to determine the rate of migration of various contaminant plumes.

Background information for the investigation was found in in-house reports done before 1995. These included:

- McNulty Report – a record of the history of spillages on site
- Mercury Plant Contamination Report
- Cyanide Contamination Investigation Report
- Investigation at the Existing Waste Disposal Site

Fieldwork included the drilling of 189 auger holes at various locations on site. Thirty-one percussion boreholes were also drilled. Some of these boreholes were located downstream of potential pollution sources and some outside the site. A number of groundwater sampling runs have been carried out on site since 1994. Sampling on site is undertaken according to the methods of a protocol that was set up by Polifin and their consultants.

During stage 1 of the investigation certain fate and mobility ratings were ascribed to contaminants of concern. The findings were further studied during stage 2, to validate the ratings. A conceptual hydrogeological model of the site has been developed from the geological and hydrogeological data collected. The AQUA software package was used to develop groundwater flow, and contaminant transport models of the site.

Based on the findings of the investigation, the following conclusions have been reached:

- Groundwater occurs within five aquifer systems, of which the upper two are shallow, and the remaining three are deep.

- The shallow aquifers comprise a perched aquifer and a semi-confined to confined weathered and fractured dolerite aquifer.
- The deeper aquifers comprise fracture zones within the dolerite and sedimentary bedrock formations.
- Inorganic groundwater contamination, with the exception of nitrates, is largely confined to the perched aquifer and occurs mainly in localised areas.
- Inorganic contamination outside the boundary has been identified in both the shallow and deep aquifers in one borehole only.
- Nitrate contamination is evident across the western and central parts of the site. Highest concentrations are related to a source west of Polifin.
- Mercury contamination occurs within localised areas in the perched aquifer only. The levels of mercury in the groundwater are less than 10µg/l. In a previous investigation localised high concentrations were identified within the soils and perched aquifer at the Chlorine CAP area.
- No cyanide has been detected in any of the monitoring piezometers during the investigation. This is consistent with information from previous work.
- Volatile and semi-volatile organic contamination levels within and outside the site boundaries are high in both the weathered and fractured aquifers, and in the deeper fractured aquifers.
- The concentrations of volatile organics are generally in excess of international standards for groundwater cleanup.
- Volatile and semi-volatile organics are considered to be the highest priority in terms of contamination both within and beyond the site boundaries.
- The groundwater flow model indicates that groundwater flows mainly towards the east and southeast, towards the local streams.
- The results of the sulphate transport model indicate that sulphate concentrations are low.
- The sodium transport model indicated that contamination levels are high at the source areas, but low in the shallow monitoring piezometers.
- The EDC (Ethylenedichloride) transport model indicates that contamination levels are high, and that plumes have crossed the site boundary in four areas. The sources of these contamination plumes are the VC-CAP area, CAP Dams, South Dams, and Chemical Waste dump.
- Indications are that contamination plumes from the South Dams and the Chemical Solids Dump are likely to cross the southeast site boundary in the near future. The possibility of off site migration due to lateral spreading from the VC-CAP area and Peroxide Plant also exists.
- The results of the EDC model indicate that the contamination plumes from both the South Dams and the Chemical Solids dump have migrated for a distance of up to 250 m across the site boundary.
- Notwithstanding the apparent off site migration of EDC in the groundwater, there are no users in the vicinity and therefore no immediate risk of adverse impact.

Stage 4 of the investigation comprised of a risk assessment (SRK, 1999). Although it was found that there is no immediate risk to human health, it was set to be the basis from where to formulate an overall management strategy for the site.

During the risk analysis priority levels were set for four parameters: *toxicity of chemicals, fate of chemicals, mobility in the groundwater and the historical load*. Priority ratings were then calculated

for each area of concern. Additional data was collected to fill any information gaps that still existed. Data was strictly collected according to international standards to ensure the integrity of the data. Use was also made of groundwater modelling to simulate groundwater flow and contaminant transport. A CHC (Chlorinated Hydrocarbon) and sulphate transport model was used.

The procedure that was followed for the risk assessment was based on the US EPA document EPA 540.1.89.002 of December 1989, titled Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A).

The following conclusions were drawn from this investigation:

- The groundwater modelling confirmed the off-site migration of contaminants at certain locations at the site.
- Some of the concentration levels of contaminants selected for inclusion in the risk assessment are higher than the acceptable risk based concentrations quoted by the US EPA.
- The groundwater does pose a potential risk to human health if it was to be ingested.
- Of the chemicals assessed several of the CHC compounds, nitrate and fluoride are of concern.

Polifin will now set up a formalised site management strategy to deal with the water contamination on their site.

#### 3.1.1.7 *Safripol*

Safripol produces granules of High Density Polyethylene (PE-HD) and polypropylene (PP) on large scale and as a result a great variety of chemicals are stored, processed and produced on site. It is thus natural that a risk of contamination to groundwater exists. A preliminary groundwater study (Usher & Grobelaar, 1998) was initiated during the beginning of 1998. The purpose of this study was to identify the potential risks and shortcomings as well as to recommend the correct actions that need to be taken.

After the preliminary study (phase I) several conclusions were drawn:

The water management system at Safripol is up to an adequate standard. The current monitoring system is not up to standard. One borehole that could be sampled is not sufficient to represent the aquifer hydrochemistry, despite the fact that it appears to be of good quality. It was therefore suggested to put a monitoring system in place on site, as the risk associated with the poor quality waters on site are fairly high where these waters interact with the natural environment.

During the site investigation (phase II) conducted at the end of August, six new boreholes were drilled. Generally sandstone, siltstone, mudstone and dolerite were encountered, but the shallow dolerite sill reported in previous investigations was never thicker than 8m and always weathered. At borehole number SB1 massive (fresh) dolerite was found at a depth of  $\pm 50$ m. This could be the result of faulting or the sill is rather more heterogeneous than had been assumed and could be very undulating.

The boreholes SB4 and SB5's borehole log's were basically the same, with sand on top followed by weathered dolerite to a depth of 8-10m. The dolerite is followed by sedimentary rocks (clay, sandstone and siltstone) to a depth of 12-13m, then there is weathered shale (often carbonaceous) to a depth of 21m(SB4) and 26m(SB5).

The other 4 boreholes also correlate with each other. They also have loose sand on top to a depth of 4-5m followed by weathered shale to a depth that vary from 8 to 18m. Sedimentary rocks (sandstone and siltstone) follow the shale to the bottom of all boreholes, except SB1 where the sedimentary rocks are followed by weathered dolerite to the bottom of SB1.

Magnetic geophysics was done to find out if there was any evidence of a dolerite sill or a dolerite dyke at the site. None of the geophysics could be done on the site, because there was too much interference on the magnetometer due to buildings and other magnetic materials such as power lines. The magnetic survey was done in open fields to the North of the site.

No concluding evidence that showed a definite shallow dolerite sill or dyke was found. That could be due to the fact that there was no dolerite at all, or due to the fact that it was too deep for any influence on the magnetometer to indicate any anomalies to prove the fact. After drilling the first borehole on 24 August 1998 we found out that the dolerite was indeed too deep for any influence on the magnetometer readings. This is in contradiction to what was found during the desk study done in phase 1 and the first part of phase 2.

The findings on site, regarding the dolerite sill have several implications for the local geohydrology. Previous reports assumed that there are two distinct aquifers, a shallow weathered aquifer consisting of the sands, etc. (encountered at shallow depths at Safripol), and a deeper sandstone aquifer separated by an impermeable barrier (the fresh dolerite sill). There is no such impermeable layer acting as an aquiclude at this site. The most likely path for groundwater, and pollution, to migrate is therefore not at shallow depths along the top of the fresh sill.

At this stage the groundwater gradient could not be determined unequivocally, due to the fact that the water levels in the boreholes are still recovering after the initial drilling took place. The static water levels were measured 24 hours after drilling, except in SB1, which was measured two days after drilling. The water levels in the boreholes were fairly shallow, ranging approximately from 3.9m to 7.2m, except once again in SB1 where the static water level was 19.67m.

Boreholes SB2 – SB6 were slug tested to obtain their respective K values. The mean of the hydraulic conductivity gives  $K_{area}=0.0311$  m/d, which is a fairly low value.

From the results of the slug tests and the observed blow yield during drilling SB2 was selected to be pump tested. The very short pump test yielded the following:  $T(SB2)=0.299m^2/d$ .

Shale and clays typically absorb and adsorb all kinds of foreign particles that might be in the system. The geology underlying Safripol consists mostly of shale and clays. With the low T and K values of the aquifer the water in the aquifer can also not move very fast. This implies that any pollution has more time to absorb onto the shale and clays. Groundwater and any groundwater-borne contamination will also migrate very slowly and pollution plume propagation will be slow.

These factors indicate a very low potential of groundwater pollution, but monitoring should still take place to ensure no pollution enters the system. This will ensure that should any pollution occur, it will be detected fairly soon and appropriate measures implemented to limit the impact.

As far as inorganic pollution is concerned, it appears as if there is nothing of significance at Safripol. Two boreholes have high COD values that could be indicative of "hydrocarbon" pollution, with one of these also having slightly elevated nitrate values (above 10mg/l as N).



**Figure 9: Poly 4 plant at the Safripol factory site.**

The groundwater has, as yet, not been sampled or analysed for non-aqueous pollution. In the newly drilled holes, the water was blown out by the drilling. As the short summary has shown, the formations underlying the site are of such a nature that the water, and any associated pollution, moves very slowly. Samples were taken once the water levels had (apparently) recovered, but due to the different interactions between hydrocarbons (as a broad term) and the surrounding material influences such as absorption and adsorption, etc. start playing an important role. Sampling and subsequent analyses would more than likely not have given a realistic reflection of (possible) contamination. Future sampling of the boreholes should be analysed only for the organic constituents.

#### *3.1.1.8 Sasol Chemical Industries*

Sasol Chemical Industries produces a variety of chemical and wax products from coal. This is done via the indirect coal liquefaction process where coal is gasified in the presence of steam and oxygen, under high pressure and high temperature, to be converted to crude gas. After cooling the gasification condensates yield co-products such as tars, oils and pitches. Other co-products such as nitrogenous compounds, sulphur and phenolics are recovered as ammonia, sulphur, cresols and phenol respectively. The purified synthesis feed gas is then available for conversion by means of the slurry phases distillate technology to produce linear chained hydrocarbon waxes. Some of the tail gas from the wax plants is fed to the ammonia production plant. The tail gasses from the ammonia plant and wax plant are blended into a fuel gas that is suitable for pipeline gas.

SCI has its own waste disposal site where the waste that is produced during the processes is dumped in designated areas. At the waste site there is a sewage works, coarse ash dumps, fine ash dams, evaporation dams, tar pits and a domestic waste dump. All domestic sewage along with any effluent produced at SCI and the other industries are treated at the sewage works and effluent dam system.

Jones and Wagener conducted a hydrogeological investigation for SCI (1996). During phase I the study was aimed at defining the geohydrological regime at the colliery. Phase II addressed the factory and waste disposal site of Sasol Chemical Industries.



**Figure 10: View from the earthdams at the waste disposal site, towards the SCI factory and coarse ash dumps.**

The aquifers on these sites were primarily classified the same as those found at Sigma Colliery. Most of the study was confined to the shallow watertable. Other aquifers were also assessed as far as possible.

It was found the general movement of the groundwater followed the topography. Main drainage is thus towards the Leeu Spruit situated southwest from the disposal site. A water divide runs approximately along the middle of the factory (North to South).

Field and lab work during the study comprised of the following:

- Electro magnetic survey
- Drilling and sampling of 20 auger holes ( $\pm 10$  m in depth)
- Sampling of existing percussion drilled boreholes

From the data collected various conclusions were drawn on the status of the groundwater contamination. Results of each area, which may impact on the groundwater, were discussed separately. These results are assimilated from various previous reports and the contaminants of concern are indicated below. Highlighted parameters exceed water quality standards in certain cases and are still within prescribed limits for others. These parameters are mentioned to indicate the type of contaminants emanating from each source.

- **SCHUMANN-SASOL (Catalyst Plant)** - The results indicated conclusively that there is contamination of the soil and perched groundwater table. Contaminants of concern were nitrate, calcium, magnesium,  $\text{HCO}_3$ , and to a lesser extent, sodium.
- **ASH DISPOSAL AREA** - Contaminants of concern in this area were sulphates and fluoride.
- **OLD TAR PITS** - Seepage from these pits add to the contamination of the area. Contaminants that showed elevated concentrations, were sodium, sulphate, fluoride, boron and COD.
- **NEW TAR PITS** - Most of the samples were very dilute. High levels of sodium, bicarbonate and nitrate were found.

- **OMNIA DUMP** - Groundwater was contaminated in terms of Ca, Mg, Na, Cl and Nitrates. The contamination suggests a fertiliser type source.
- **SEWAGE WORKS** - At the sewage works domestic sewage from the whole of Sasolburg municipal area is treated, as well as industrial effluent from SCI and the other industries. The results of the analyses in this area were highly variable. High levels of E-coli, Cl, COD and sulphates were found.
- **MUNICIPAL DUMP** - Although SCI is not responsible for the dump, it is located on the waste disposal site. Elevated levels of Ca, Cl and COD were found.
- **DAM SYSTEM** - Seepage from the earth dam is suspected due to the comparison of the groundwater and the final effluent. Elevated levels of nitrate and conductivity.



**Figure 11: Municipal waste dump.**

It was clear from this study that there is a variety of point pollution sources on site. After the completion of the study, SCI started with a groundwater monitoring program. Borehole sampling is undertaken every six months and trends of water quality and water levels are being identified.

A desalination strategy was proposed for the SCI facilities to reduce the salt loading to the Vaal River by 25 % as an initial target. The closed ash loop at the No. 5 ash dam represents one of the potential mechanisms whereby this may be achieved. A groundwater modelling exercise was completed on the No. 5 ash dam to determine the current and future impacts on the Leeu Spruit (EMC, 1997). The results showed a potential of 12% reduction in salt load to the Vaal River. It was also found that additional measures should be taken to reduce water seepage from the dam to reduce direct impact on the Leeu Spruit.

During 1999 an Environmental Impact Assessment of the Venco Park, SMX and Powerstation 1 areas was undertaken. As part of this study an investigation of the surface and groundwater situation at these three sites was done. The results of this study will only be available in October 1999, and could not be discussed in this report.

#### *3.1.1.9 SMX - Sasolburg*

SMX Sasolburg manufactures fertiliser and explosives. During 1994 an investigation was undertaken (Jones and Wagener, 1995) to assess the then present and future impacts of the SMX

plant on ground and surface water. Of particular concern were the high levels of nitrates occurring in the Stormwater Canal adjacent to the plant.

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 detailed and costed. The impact on surface water was significant due to decant from the dam reaching the stormwater canal at the Heilbron Vereeniging road, from where it eventually reaches the Taaibos Spruit.

The study showed that, if the effluent dam was to be emptied and the area remediated, the resulting impact on surface and groundwater would be minimal. Modifications to the plant resulted in no storage of effluent being required and release of water in terms of a Section 21 Permit. As a remediation measure, the size of the dam was considerably reduced by selling off the effluent water as a liquid fertiliser, thereby reducing the source of contamination.

As part of an ongoing ground and surface water investigation, a further study addressing the shallow- and deeper groundwater aspects around the effluent dam area (after the size of the dam was considerably reduced) was undertaken.

A comparison of the quality of the dam water, after the remediation measures, showed a marked improvement. However the results from the shallow groundwater still showed extremely high levels of contamination with nitrates. Sampling at Polifin (downstream from SMX) showed high nitrate contamination of both the shallow and deep aquifers. The migrating nitrate pollution plume will directly affect the Polifin property. Another risk that was identified was concrete corrosion of any buildings on site due to the high sulphate levels in both surface and shallow groundwater.

Recommendations were made to install several more boreholes on the site to be incorporated in the SCI regional groundwater monitoring network. This was done during the site assessment in 1999 and results will be available in October 1999.

### **3.1.2 Transport Companies**

#### *3.1.2.1 Bothma Transport*

Bothma's is a transport company that is situated in the vicinity of Wonderwater Opencast mine, on the western side of Sasolburg. The company transports a variety of products (solvents, oils, liquid fertiliser, etc.) and has a sandworks on site.

At the sandworks the sand is washed with mine water from Wonderwater Mine before it is transported in trucks to other sites. This water is stored in dams alongside the sandworks. There is no known contamination of this water.

There is a formal washbay on site. All effluent generated from the washing process is kept in holding dams and tanks. Recyclable liquids such as oils are re-sold to the manufacturing companies.

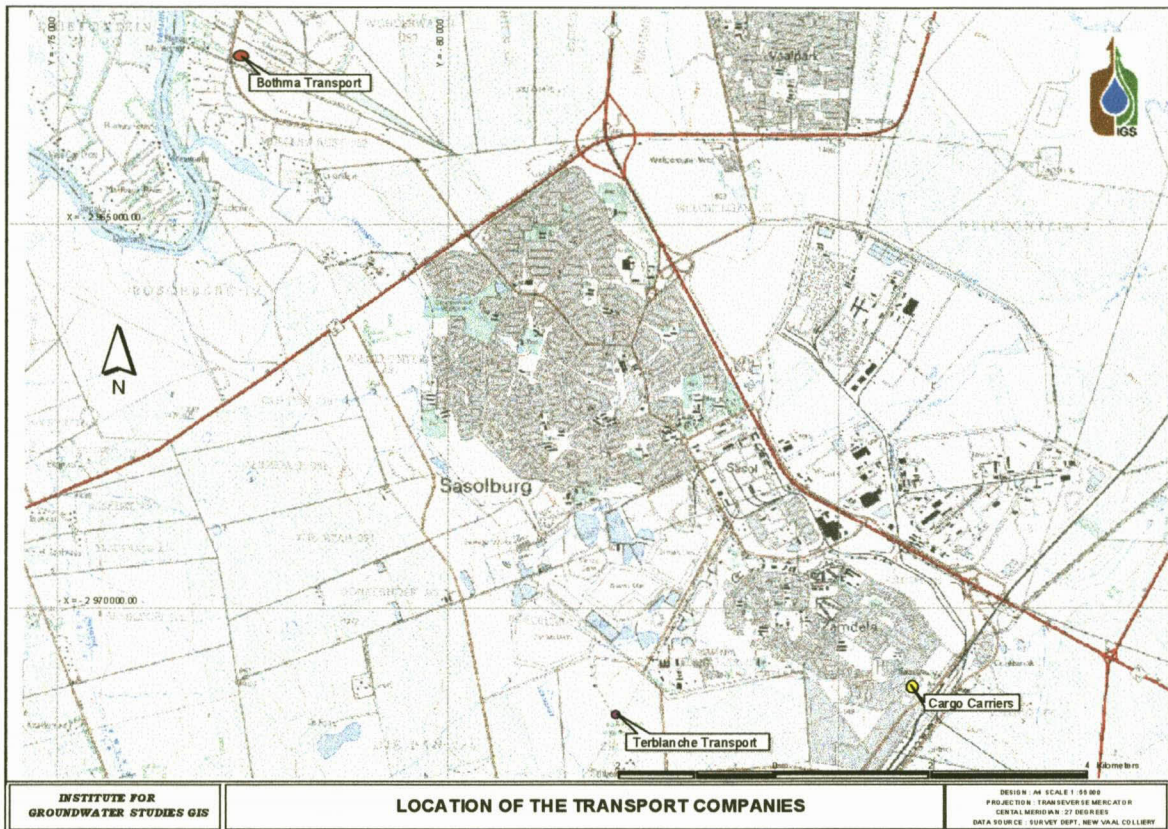
There is one borehole on the site and four boreholes on adjacent private properties that have been sampled and analysed for conductivity, pH, hardness, alkalinity and nitrates. These boreholes are used for domestic supply. Average conductivity is 316  $\mu\text{S}/\text{cm}$  and the highest is 460  $\mu\text{S}/\text{cm}$  at the depot. No obvious contamination is apparent but before any conclusions are drawn there should be a more detailed analysis of the groundwater.

#### *3.1.2.2 Cargo Carriers*

Cargo Carriers are a transportation company situated south of Zamdela. Main products that are transported in the tankers are cattle fat, hydrocarbons,  $\text{NH}_3\text{NO}_3$  and detergents. Most of the tankers are dedicated to one product, thus minimising flushing of the tanks. At the wash bay effluent is kept in holding ponds and transported to SCI's treatment works every two days.

There is one unused borehole on site. No information is available about the borehole or the quality of the groundwater. Contamination from the site as well as from the informal settlement upstream is suspected.

Upgrading of the site itself and the storm water management system is in progress and was completed during 1999. This will deal with the possibility of contaminants entering the river and groundwater system, and solve the historical flooding problem.



**Figure 12: Locality of the transport companies**

### 3.1.2.3 Terblanche Transport

Terblanche Transport is a company that mainly transports sand, gravel, and coal. The depot is situated west of SCI's waste site and west of the Leeu Spruit. A trucking parking is situated on to the North west on AFCAT's property. According to the management no tankers are in use on either of these sites.

Wash water from the washbay is collected in a pond that overflows in the Leeu Spruit. No contamination of river or groundwater from this source is suspected at this stage. There are no known boreholes on the properties.

## 3.1.3 Mining Activities

### 3.1.3.1 Coalbrook Colliery

The Coalbrook Colliery is located 13 km south-east of Sasolburg and was in operation since 1904. The colliery is an underground mine that used to supply coal to the adjacent Kragbron power stations. The closure of these power stations by ESKOM has resulted in the decision to close Coalbrook colliery, in spite of the fact that the mine still has 400 million tons of coal in reserve.

On closure of the mine, groundwater inflow will result in the flooding of the mine. An investigation was undertaken in 1990 on the implications of the subsequent flooding (SRK, 1991). The following were the results of that study:

- Major water inflows are reported to have been associated with structural features (dykes, fracture zones and faults) and not so much the coal seams as suspected at first.
- From the available geological information it seems that groundwater in the flooded workings will be contained, except to the south.
- The degree of effectiveness of the horizontal dolerite sill (107 - 148 m below surface) to act as a hydrogeological barrier to vertical flow will depend upon its structural competence.
- The effects of the flooding should have a minimal influence on the surrounding aquifer systems.
- In areas where the dolerite sill is not fractured, a shallow aquifer is likely to occur in the rocks above the sill from which shallow boreholes will obtain their water.
- In terms of General Effluent Standards and Drinking Water Specifications, the underground water is unsuitable for discharge and domestic usage. It would also be unsuitable for irrigation although it may be suitable for stock watering.
- High sodium, chloride and fluoride levels in the groundwater are derived from leaching of the Karoo sediments.



**Figure 13: Ruins at the Coalbrook Colliery site.**

- Flooding of the workings may result in a stratified water body. The quality of the water in the shallower parts of the aquifer is more likely to be less polluted as a result of exclusion of oxygen and a retardation in the rate of pyrite oxidation.
- Insufficient data is available on the flow conditions. While workings are flooding flow will be towards the workings. The risk of pollution migration away from the workings is likely to increase after flooding is complete. Chemical composition of the contaminant front is likely to change with time as it undergoes various dissolution and buffering reactions.
- Available information suggests that anticipated inflows will be in the order of 200 m<sup>3</sup>/hr into the old workings. The flooding period of 32 years is thus calculated.
- Insufficient number of boreholes are available to monitor water levels and water quality.

No further information available on any of the aspects mentioned above could be found and to the author's knowledge there is no monitoring of the current situation at Coalbrook.

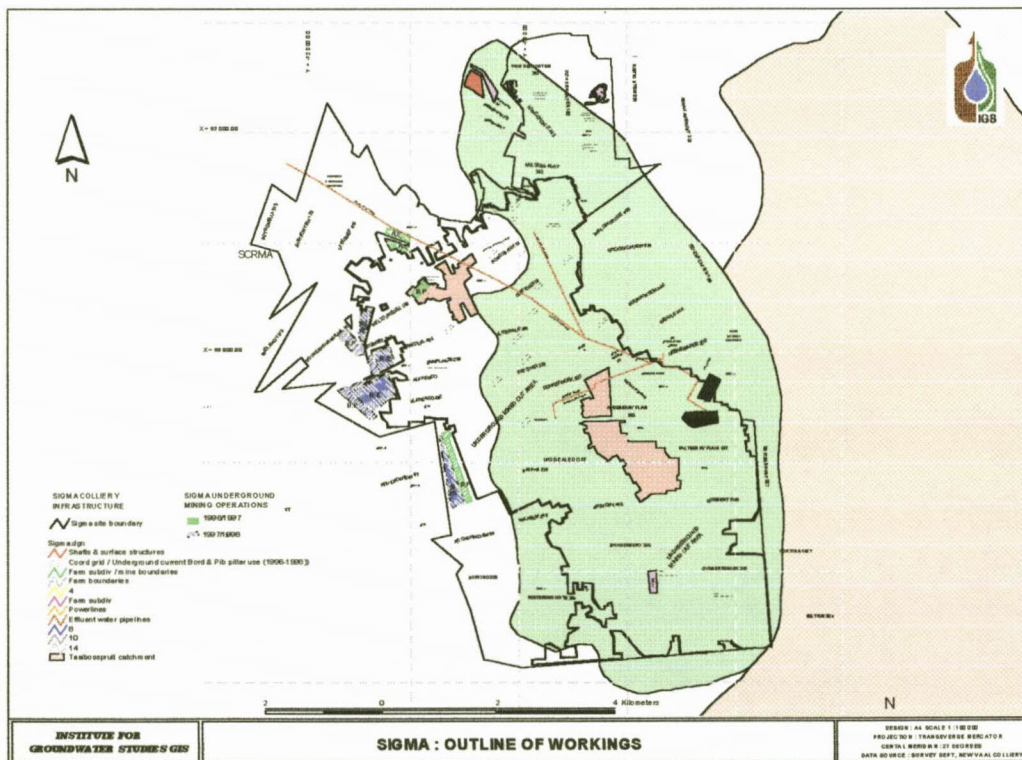
### 3.1.3.2 *Sigma Colliery*

Sigma colliery supplies Sasol Chemical Industries with the coal that is used in their process. In areal magnitude, Sigma is the single biggest potential impactor on the groundwater resources in the area under investigation.

Most of the following discussion is based on previous reports by VSA GeoConsultants (1997, 1998 & 1999).

The Colliery at this stage seems to have a limited impact on the surrounding groundwater regime. Investigators have characterised the area affected by mining into three main aquifers:

- 1- an upper shallow aquifer consisting of alluvium /colluvial material, with typical Karoo lithology and dolerite intrusions
- 2- an intermediate white sandstone aquifer and
- 3- a deeper lying aquifer consisting of dolomites, which are often karstic.



**Figure 14:Sigma Colliery-Extent of workings within the catchment boundaries**

From these previous reports it appears that the sandstone aquifer has a vast potential to yield water and that where the upper aquifer consists of alluvium the potential for storage and utilisation is also good. The other aquifers seem to have, from the records available, a fairly limited potential for usage.

As far as impacts are concerned, these can be classified into impacts on water quantities and then water quality. It appears that, up to now, the influence on water quality from mining has been limited. As with the rest of the country, the mined materials have, the potential to cause a large degree of water degradation. The main processes responsible are typically acid rock drainage and other oxidation processes that can lead to the acidification of the water and associated rise in salinity and sulphates in particular. Mobilisation of heavy metals can also occur under these conditions. From the data available, it appears that these processes are occurring at a scale that is too small to be noticeable on the surrounding groundwater regime or that the surrounding material is of such a nature that the effects of these processes are not observed. There are, however, a few boreholes where low pH values have been recorded. To our knowledge no acid-base accounting in the area or hydrogeochemical modelling has been done to suggest the reasons for these observations.

VSA GeoConsultants have also identified the different aquifers as having typical hydrochemical signatures. The shallow Karoo aquifer is typically sodium-bicarbonate in nature, with neutral pH values and moderate salinity (expressed as EC). Locally there are variations where site specific activities cause contamination. The sandstone aquifer has a similar characteristic composition but chloride values are elevated compared to the upper aquifer. Elevated nitrate values are often indicative of these aquifers. In the deep aquifer chlorides become more pronounced, with higher fluoride values often used as characteristic finger print.

As far as reduction in water resources is concerned, it was calculated that the mine's Wonderwater section should dewater the area by about 6890m<sup>3</sup>/day that could increase to above 9000m<sup>3</sup>/day. This will naturally have an impact on the surrounding aquifer, but at the time of the report, it was suggested that there would be no groundwater users in the immediate proximity impacted upon. This report also calculated a recharge of 7% for the mining area. The industrial area's recharge can therefore be assumed to be less than 5%. The report also tentatively suggests that water levels will recover to the original levels within less than 30 years.

As far as the monitoring is concerned, Sigma seems to have an excellent monitoring network in place. From the data available it seems that monitoring of both water levels and water quality is done on a regular basis to ensure that any problems that may arise can be identified and the influence thereof limited.

During the extent of this project more studies have been completed at Sigma Colliery due to the planned closure of Sigma Underground. Studies included an assessment of the decant situation at Sigma Underground and the ash-filling project of subsidence zones. The results of these investigations will be discussed in the relevant sections of this report.

### **3.1.4 Brickworks**

#### *3.1.4.1 Inca Brickworks*

Inca Brickworks is situated in the industrial area between the factory sites of Afcatt and Omnia, and produces cement bricks from power station fly ash. There is no effluent produced during the process as all incoming water is used in the end product. There seems to be no threat of contamination to either surface or groundwater sources.



**Figure 15: Inca Brickworks factory site**

There is one borehole on site that is pumped at 20 000 l/h and used for dust suppression on site. No conclusions can be drawn on the chemistry of the water before it's been sampled.

### **3.1.5 Power Stations**

#### *3.1.5.1 Kragbron Power Station*

After closure of Kragbron (Taaibos and Highveld power stations) an environmental impact assessment was conducted (Speirs, 1990). The following was regarded as factors that could have an impact on the surface- and groundwater on the site and surrounding area:



**Figure 16: Kragbron Powerstation**

- Raw water supply - Impacts will be low due to good quality of water received.

- Water treatment plant - Impacts will be low due low salt load of water entering and leaving the potable water production plant.
- Combined clean and dirty drains and associated effluent dams - Low to high impact depending on amount of oil and grease contained.
- Sewage treatment plant - Low impact, effluent will be discharged into the ash water return dam.
- Ash dams and associated ash water dams - Low impact due to low volume of effluents being generated.
- Mollensteen ash dam and pan - Low impact due to low volume of effluents being generated.
- Solid waste disposal site - Low impact, site was decommissioned in eighties/ early nineties.
- Coal stockpile - Impact will be medium to low, pollution was detected in monitoring borehole.
- Eskom village - Low impact, only small amount of residents.
- Asbestos removal and disposal - Low impact, not applicable on ground or surface water.

There is no further information available on the closure of the power stations and their consequent impacts. Eskom is currently monitoring boreholes on the site and rehabilitation of the ash dams is planned for 1999.

### 3.1.6 Farming Activities

Generally the farming activities in the area consist of stock farming and dry land cultivation with small-scale irrigation along the rivers and streams. The surface water report (Walmsley, 1998) gives figures, based on the hydrocensus, for the proportion of use of water on farms in the catchments. It can be seen that groundwater is an important resource especially for domestic use. Groundwater is also widely used for stock watering and to a lesser degree for irrigation purposes. These farmers are very important in terms of end use of water and in terms of the amounts of water they use, and the implications of contamination to their survival.

As far as the impact of the farmers on the water quality is concerned, certain previous reports have alluded to local deterioration in groundwater quality as a result of agricultural activities. The pollutants are usually fertilisers, herbicides/pesticides, increased nitrates due to animal/human excrement and then a multitude of site specific contributions. On a regional scale the impact of agriculture is, with the data reviewed thus far, not regarded as significant. Farming represents a diffuse source of pollution from the activities mentioned. Once the sampling has been done a clearer picture of the influence of agriculture on the overall catchment will be possible.

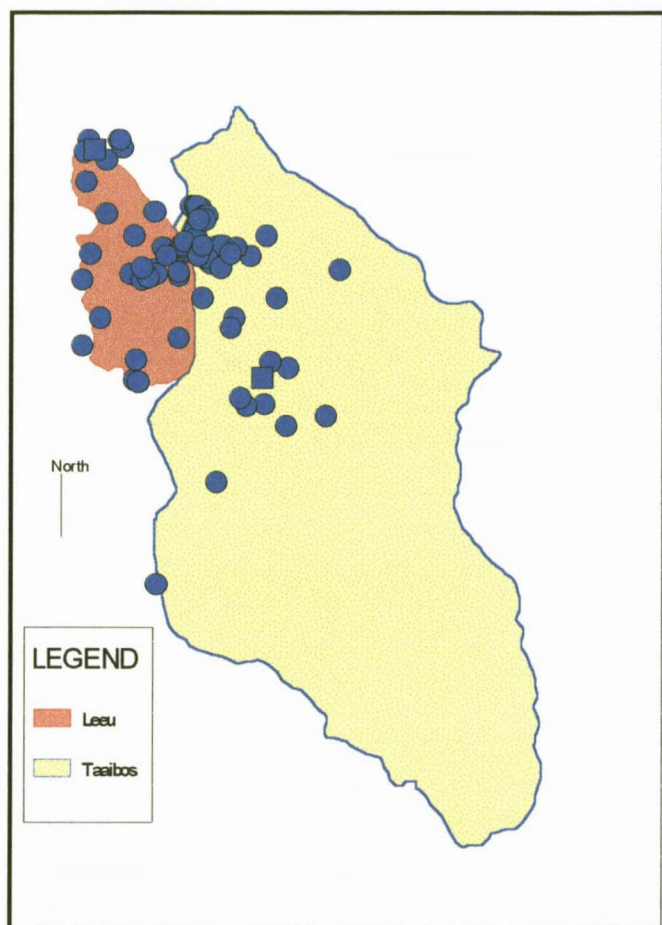
## 4 Groundwater Sampling

During the fieldwork phase of the project one hundred groundwater samples were taken throughout the two catchments, both at potential impactors and in areas where the groundwater should be unaffected by the industrial and mining activities in the area.

The sites sampled are described in detail in this section and the methodology used for sampling is also discussed. The samples obtained were analysed for inorganic parameters and chemical oxygen demand as a screen for organic pollution. The results of the analyses were incorporated into the existing databases that have been created for the different sites so that a comparison can be drawn and a continuous evaluation of the groundwater regime can be made.

In many cases apparent anomalies are evident. A once off sampling run is inadequate to resolve all the issues but for the purposes of a situation analysis it provides sufficient information to highlight the most important aspects. As part of the recommendations for the next phase of the Groundwater Management Plan, these issues will have to be investigated to provide further clarity.

Ten sites were also selected to be tested for toxicity. This is a relatively new technique that has not yet been widely used for groundwater investigations. The results of these tests yielded interesting results, indicating that these tests have the potential of becoming important tools in groundwater quality assessments.



**Figure 17: Positions of Sampled Sites Relative to the Catchment Boundaries (Catchment area =  $\pm$  54 km x 34 km)**

The results are all in a format to be used with WISH and integration of the results, as stated previously, has been completed. All contributing companies received a copy of this software, together with the data that has been made available, for the specific sites. All the data from the different industries will be given to the Department of Water Affairs and Forestry, so that updating of data from the individual companies can be done easily.

The results of all these analyses, together with all the information gathered before, will be used in conjunction with the results of the geophysical investigation currently underway to set up a conceptual model of the aquifers underlying the area. This will form the basis from which the area will be modelled using computer-driven numerical models to give groundwater flow directions and plume movement.

#### **4.1 Sites sampled**

It was attempted to sample representative sites in the catchments in terms of position relative to likely pollution sources and relative to the catchment as a whole.

The tables in Appendix A show a summary of the sites that have been sampled and Appendix F shows site specific maps for several industries. On these tables the site name, owner, water use, water level and other information gathered during sampling are shown.

The following figure shows the distribution of positions of the sites in the catchment.

#### **4.2 Inorganic Sampling Methodology**

Briefly, the following methodology was followed during the sampling, in order to obtain a good overall picture of the groundwater quality in the two catchments:

Firstly a profile of the water quality with depth by using a down-the-hole Electrical Conductivity and Temperature probe was run. Any peaks in Electrical Conductivity and/or Temperature were recorded. The logging provided an indication of stratification in the boreholes and also information regarding possible fractures and/or preferred pathways. By using this it was possible to identify optimal and appropriate sampling depths so that any pollution plumes could be accurately delineated. This approach provides a more realistic picture of the pollution plume extent than could be obtained by purging the boreholes, which will give a composite sample of the water in the boreholes. In most cases the correlation between the borehole logs (showing changes in lithology or water strikes or borehole construction) and the depth where samples were taken was very good.

Once the sampling depth was determined the samples were taken by using a depth specific stainless steel bailer. This bailer allowed sample collection at the desired depths.

To avoid cross contamination between boreholes a three-step decontamination method was used. After every sample taken the bailer was washed with Sunlight Liquid detergent and tap water. The bailer was then rinsed with de-ionised water and acetone, which were allowed to evaporate.

The samples were stored in cool boxes to ensure that no chemical degradation could occur.

The samples were analysed at the laboratory at the Institute for Groundwater Studies. These samples were analysed for all major cations and anions, trace metals and minor ions identified by the literature review. Chemical Oxygen Demand was also measured to serve as a rough indication of organic contamination.

Boreholes where significantly high COD values are obtained have been identified and it will be recommended that the responsible parties have these boreholes analysed for the constituents on site. In this way cross-subsidisation will be prevented for expensive organic analyses between industries. In cases where these values seem anomalous further investigation will be needed.

In cases where access could not be gained to the boreholes, such as where boreholes were equipped with pumps, the sample was taken as close as possible to the borehole at taps or pipelines.

The method used as described above was chosen after considering all other possible sampling methods. This depth specific bailing method has been proven (LV Parker, 1994) to be best at recovery of sensitive constituents (eg. VOC's) and also has the least possibility of cross-contamination. The results of this sample run was compared to samples taken at the same time by SCI and Sigma using a submersible pump. The inorganic results compared favourable with the results from this sample run. This proved that either of the two methods could be used for future monitoring.

It should however be kept in mind that when the boreholes are sampled for organic constituents the method used should minimise degassing and loss of oxidizable and volatile inorganics and VOC's as this can affect the results (Varljen, 1997). A depth specific bailer would then prove to be better than a submersible pump.

#### **4.3 Interpretation of Chemical Analyses**

Since this was a once off sampling exercise and for several sites no previous data exists, this set of samples was evaluated in comparison to set standards. The SA drinking water standard (Kempster

and Smith, 1985) was used to identify parameters in each sample, which exceed the standard and could be regarded as problematic.

Determinand	Unit (mg/l unless stated)	Recommended Limit	Maximum permissible Limit	Crisis Limit
EC	mS/m	70	300	400
pH	pH units	6-9	5.5-9.5	<4 or>11
Cl		250	600	1200
SO <sub>4</sub>		200	600	1200
Cu		0.5	1	2
Fe		0.1	1	2
Mn		0.05	1	2
Zn		1	5	10
NH <sub>4</sub>		1	2	4
Ca		150	200	400
F		1	1.5	3
Li		2.5	5	10
Mg		70	100	200
NO <sub>3</sub> as N		6	10	20
K		200	400	800
Na		100	400	800
Al		0.15	0.5	1
As		0.1	0.3	0.6
Ba		0.5	1	2
B		0.5	2	4
Br		1	3	6
Cd		0.01	0.02	0.04
Ce		1	2	4
Cr		0.1	0.2	0.4
Co		0.25	0.5	1
Pb		0.05	0.1	0.2
Hg		0.005	0.01	0.02
Mo		0.05	0.1	0.2
Ni		0.25	0.5	1
Se		0.02	0.05	0.1
Sn		0.1	0.2	0.4

**Table 5: SA Drinking Water Standards (Kempster and Smith, 1985)**

Although this standard is in many cases too severe to apply to industrially influenced water that is currently not used for domestic use, it does provide a screening value with which problem areas can be highlighted.

Interim objectives for the Vaal Barrage have also been setup from previous workshops. These objectives are as follows:

VARIABLE	VAAL DAM STATUS	BARRAGE STATUS	IDEAL OBJECTIVE	INTERIM OBJECTIVE
EC (mS/m)	20	61	30	61
Sodium (mg/l)	9	40	40	70
Sulphate (mg/l)	12	20-265	80	150
Chloride (mg/l)	12	20-80	50	80
Nitrate(as N03) (mg/l)	0.50	0.5-3.5	6	6
Phosphate (as P04 in mg/l)	0.08	0.31	0.26	0.26
Boron (mg/l)	0.05	0.12	0.20	0.20
Fluoride (mg/l)	0.18	0.26	1	1
Manganese (mg/l)	0.30	0.30	0.10	0.15
Phenol (mg/l)	-	0.004	0.01	0.01
PH	7.80	8.30	6.5-8.4	6.5-8.4
Ammonia (mg/l)	0.10	0.13	0.015	0.10

**Table 6: Interim Objectives for the Vaal Barrage**

As can be seen the interim objectives for water flowing into the Barrage are also fairly stringent. These interim objectives will be used in conjunction with the results from the numerical modelling to determine realistic objectives for groundwater quality in the area.

In an attempt to classify the samples from the different sites, use was made of a diagram called the Expanded Durov diagram. In this diagram the major cations and anions are expressed as percentages of the total sum of these major ions. They are consequently split into nine different fields according to the dominant cations and anions in the water. It must be noted that these diagrams can only be used as a classification and quick typing of waters, and the overall concentrations do not play a role. It is thus possible for a dilute sample to plot alongside a polluted one in the same field. As will be shown further on in the report the unpolluted samples all tend to plot in the uppermost rows of fields representing Ca/Mg or Na-HCO<sub>3</sub> waters. This is the general character of the ambient waters in the study area.

The figure below shows the Expanded Durov diagram of all the samples. It is evident from this diagram that the samples vary tremendously in terms of hydrochemical character. The Expanded Durov diagrams for different areas are shown in Appendix C.

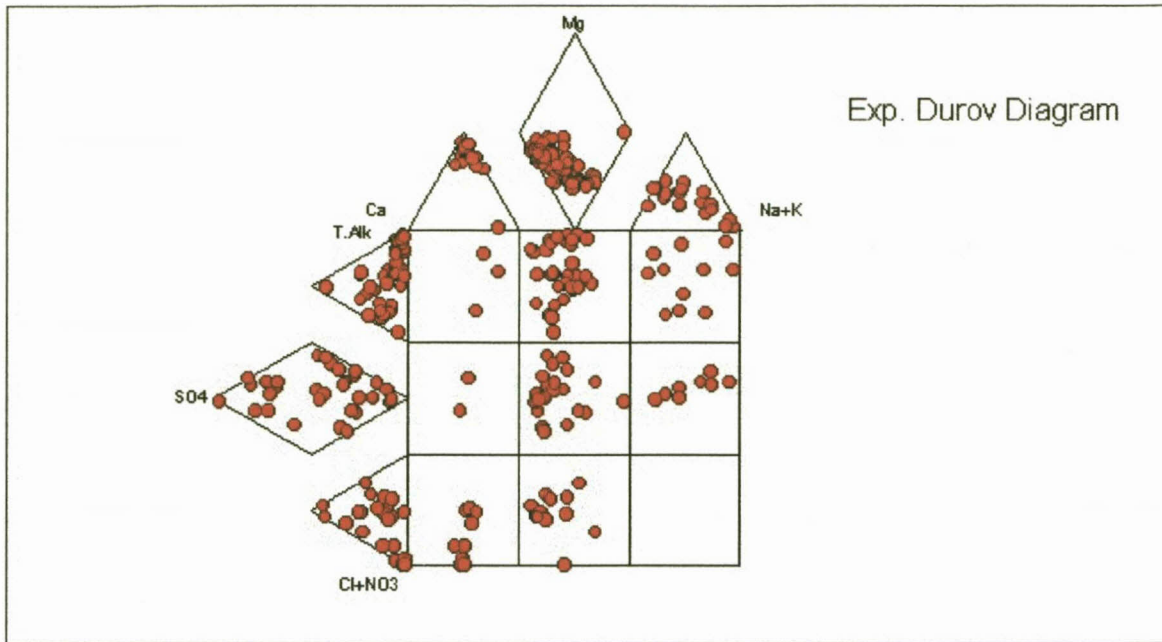


Figure 18: Expanded Durov Diagram of all the sampled sites

#### 4.4 Discussion of Inorganic Results

The areas sampled have been divided into different sections for discussion. The results of the analyses for each area are given in Appendix B while Appendix C gives the Expanded Durov diagram for the different areas.

During the sampling water levels and electrical conductivities were measured in all boreholes. In cases where the borehole was constructed with piezometers, to give access to the so-called “deep” and “shallow” aquifer<sup>1</sup>, the EC was measured in both piezometers, and the piezometer with the highest reading was sampled. In several of these double piezometer boreholes there was no difference in EC readings or water levels measured. These similarities in the adjacent deep and shallow boreholes indicate either confined hydrostatic pressures or problems in the borehole construction. Evidence of both these cases exists and again indicates the complexity of the hydrogeology in the study area.

Further observations in the field showed evidence that a perched aquifer exists in certain places. These perched aquifers are localised and not pervasive throughout the area.

An interesting observation that was made at several of the sites was an apparent correlation between high ammonia values and COD (Chemical Oxygen Demand) values. The following table and graph show a few of these values:

<sup>1</sup> These terms of “shallow and “deep” aquifers refer to terminology that was used by consultants who worked at the various industrial sites and not to the description of different aquifers in this report. “Shallow” normally refers to weathered unconsolidated material above the “deeper” aquifer consisting of more consolidated unweathered sediments including in some instances the dolerite sill.

BOREHOLE	NH3 (mg/l)	COD (mg/l)
SRK20D	24.202	1054
INCA	169.98	5469
NW047	58.64	100
SRK25D	16.985	2767
SA4	24.94	777
SM2	25.4	745
V2S	185	442.9

Table 7: Measured values of ammonia and COD in some of the boreholes sampled.

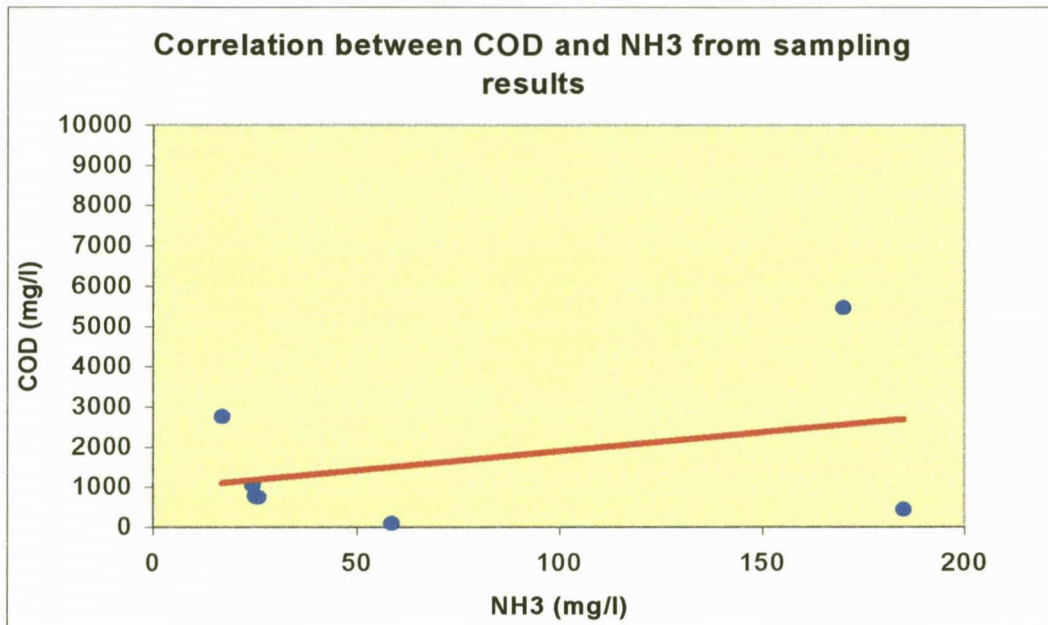


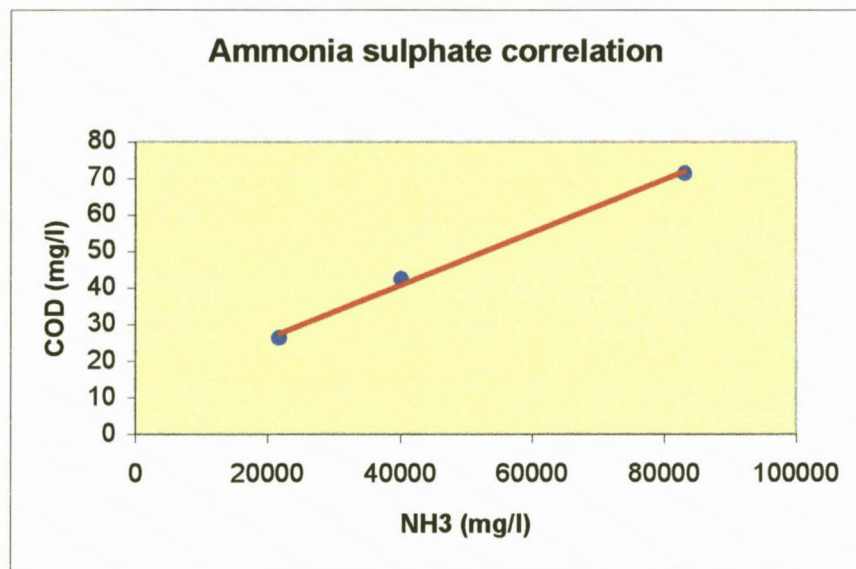
Figure 19: Correlation between COD and NH3 from sampling results.

The Chemical Oxygen Demand measures the oxygen needed to complete reduction-oxidation reactions in a solution. Typically the test will involve the total organic carbon to oxidise to carbon dioxide with chromic acid. This is why COD is often used as an indicator of organic contamination. Ammonia ( $\text{NH}_3\text{-N}$ ) is the reduced aqueous nitrogen species with nitrate ( $\text{NO}_3^-$ ) the oxidised equivalent and thus high ammonia levels could produce an elevated level of COD through this oxidation reaction to  $\text{NO}_3^-$ .

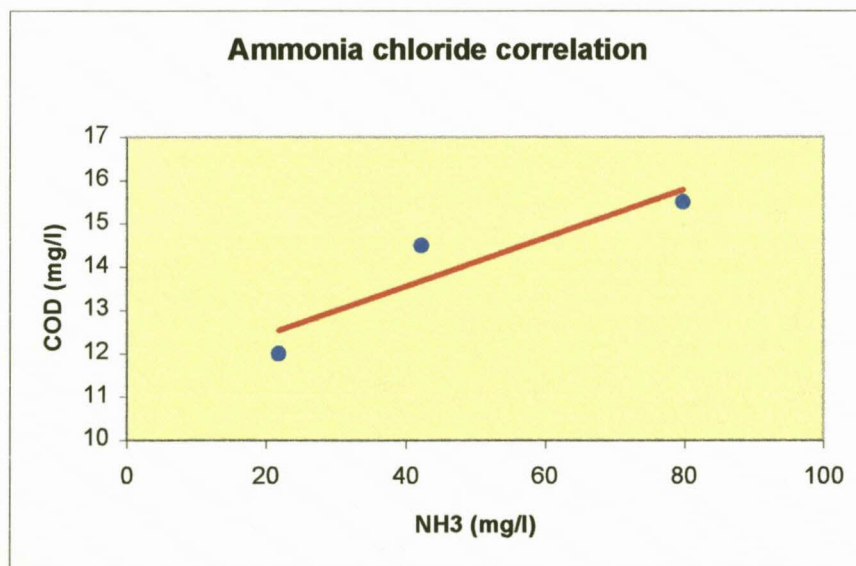
A laboratory experiment involving the testing of standardised ammonia sulphate and ammonia chloride solutions, was performed in order to prove that the correlation exists. Three solutions of varying concentrations were made up and then analysed with the Spectrophotometer for ammonia concentration and COD. The following were the results:

	COD (mg/l)	NH <sub>3</sub> (mg/l)
Ammonium sulphate	21637.6	26.5
	40040.7	42.5
	83073.4	71.5
Ammonium chloride	21.7	12
	42.16	14.5
	79.75	15.5

**Table 8: Laboratory results for COD and NH<sub>3</sub> concentrations.**



**Figure 20: Results from Ammonia Sulphate**



**Figure 21: Results for Ammonia Chloride**

These results give a definite linear correlation between COD and NH<sub>3</sub> measurements. Although the graph in figure 19 do not give the same linear correlation as the laboratory experiments, one can conclude that the high values of COD measured in some instances can be attributed to the high ammonia levels in some of the samples and not necessarily organic contamination. Outliers that are

found in the field samples can be caused by other reduced species in the sample that can be oxidised during the reaction that takes place during the measurement of COD and this will need further investigation.

#### 4.4.1 Municipality

Two boreholes were sampled in the municipal area of Sasolburg. These boreholes are owned by the municipality and were used for garden irrigation during times of drought. The samples were taken from a tap next to the boreholes. Results are listed in Appendix B.

**SM1** is located at the public swimming pool in the town centre. The water is of moderate quality (EC = 71 mS/m) and of a Mg-HCO<sub>3</sub> type signature. The extremely high COD concentration (1898 mg/l) is cause for concern and should be investigated further to see if it is an anomaly or to determine the cause.

**SM2** is located next to the fire station. The water is of a very good quality and also of a Mg-HCO<sub>3</sub> type signature. The high ammonia (25.405 mg/l) concentration is a possible indication of reducing conditions in the groundwater.

The Expanded Durov Diagram of these two samples is shown in the figure in Appendix C and confirms the classification of the samples as mentioned above.

#### 4.4.2 Farmers

17 boreholes were sampled on farms surrounding the industrial and mining areas. The selection of the boreholes was determined by various factors. Some boreholes were selected as close as possible to mining activities (WW2, WWF1, HC1, FB8 & FB14) to see if there is any threat of contamination from these sources. Others were chosen for the possibility of obtaining an ambient water quality (FB11, FB12 & FB13) of the catchment. Samples were also taken to observe other possible influences from the industrial area (FB2, FB3 & FB4), the informal settlement (ZA1), Mollensteen Pan (FB5 & FB10) and other farming activities (W3, FB6 & FB7). Results are listed in Appendix B.

Most of the boreholes were not sampled with the method described, due to the obstruction of borehole equipment. The samples were taken from a tap or tank near the boreholes.

Borehole **FB1** is located on the farm Vaalbank, east of the industries towards the Taaibos Spruit. The borehole is used for domestic and stockwatering purposes. The water is of good quality except for a high nitrate value (33.2 mg/l) that is well in excess of the proposed crisis limit (20 mg/l) for drinking water. This nitrate contamination is probably caused by agricultural activities on the farm.

Borehole **FB2** is located on the neighbouring farm Verdun and used for domestic purposes. The owner, Mr Nienaber, complained about dewatering caused by the mine workings of the Cornelia Colliery. No water levels could be measured to confirm this statement. The sample was taken from a tap near the house. The water quality is excellent (EC = 35 mS/m) except for an elevated nitrate level (14.3 mg/l) that is also probably caused by agricultural activities.

Borehole **FB3** is situated east of the industries next to the Koppies - Vereeniging road on the farm Delville. The water is used for domestic purposes. This sample was also taken from a tap at the house. The water quality (EC = 100 mS/m) is moderate with high total alkalinity (405 mg/l) and sodium level (126 mg/l).

Borehole **FB4** was sampled using the same methodology as outlined previously. The borehole is located on the farm Amelia, southeast of Sasolburg, next to the Heilbron road. The borehole depth is 26 mbgl and the water level was measured at 13.5 mbgl. No geological information was available. The water quality is good (EC = 58 mS/m) and there are no parameters that exceed the limits for drinking standards.

Boreholes **FB5** and **FB10** were both sampled on the farm Moidraai. The boreholes are located to the east of the Mollensteen Pan. The sample from borehole FB5 was taken from the tap at the house and the one from FB10 was bailed. A toxicity test sample was also taken at FB5. The results of borehole FB5 showed that it is good quality but the minimum limit for drinking water standards is exceeded for conductivity (75 mS/m) and nitrate (12.3 mg/l). Once again the source of the nitrate is probably agricultural activities.



**Figure 22: Mollensteen Pan**

Borehole FB10 was drilled by Eskom to serve as a monitoring borehole to monitor the influence of the Mollensteen Pan and associated ash water dam. Eskom has not sampled the borehole for a number of years. The borehole is 20 m deep and the water level is at 0.08 mbgl. The quality is about the same as FB5 but there are elevated levels of sodium (204 mg/l), fluoride (1.4 mg/l) and COD (53 mg/l).

The hydrochemical compositions of the two boreholes differ since FB5 is mainly of CaMg-  $\text{HCO}_3$  type water and FB10 is of a Na- $\text{HCO}_3$  type water. From the results it seems that the old ash dam and the Mollensteen Pan has an adverse influence on the quality of the groundwater.

Boreholes **FB6** and **FB7** are both located in the Wolwehoek village south of Sasolburg. FB6 is at the EAC abattoir and FB7 is in the centre of the town. The water is used to supplement the municipal water supply in town and is also used as wash water in the abattoir. Both these boreholes are reportedly drilled deeper than 200 m and are high yielding (>5 l/s). This and the difference in chemistry of especially borehole FB7 suggests that these boreholes have been drilled into the sandstone aquifer and not the shallower aquifer that is associated with the dolerite contact with the other Karoo sediments.

Both these boreholes were sampled at a tap adjacent to the boreholes. Borehole FB7 is of excellent quality (EC = 22 mS/m). Borehole FB6 also has a low conductivity (68 mS/m) but has more of a NaCl type signature than FB7. The higher sodium and chloride levels can probably not be attributed to pollution but rather as a natural occurrence of these elements in the sediments forming the aquifer.

Borehole **W3** is located on the farm Gysbertshoek south of Sasolburg. The farming activities on this property consist of a cattle feedlot of about 12 000 livestock. The borehole is drilled down gradient from the feedlot and equipped with a handpump. The water is used by workers for drinking and washing as well as sometimes for stockwatering. The water is of moderate quality (EC = 83 mS/m) and of CaNaMg- $\text{HCO}_3$  type. The feedlot does not seem to have a negative impact

the water quality in this borehole. Until the flow directions from the feedlot have been ascertained this can not be regarded as proof that the feedlot does not influence the water quality underlying the site.



**Figure 23: Wolwehoek abattoir**

Borehole **ZA1** is located on a farm east of the informal settlement of Zamdela. The borehole is not in use and is open to a depth of 17 m. The water level was measured at 7.15 mbgl. The sample was taken at a depth of 14 mbgl. The water quality (EC = 50 mS/m) of the borehole is good with only a slightly high nitrate value of 7 mg/l. From this it can be seen that the informal settlement appears to have a negligible effect on the surrounding groundwater quality. However, this area falls almost on the catchment divide, and further work will be required to quantify the effects of these settlements on the groundwater quality.



**Figure 24: Borehole ZA1**

Borehole **FB14** is located southwest of Sasolburg, in the lower Leeu Spruit catchment. The borehole is equipped with a windmill and the water is used for stockwatering. The groundwater is

of moderate quality ( $EC = 79 \text{ mS/m}$ ) and can be typed as  $\text{Na-HCO}_3$ . The borehole shows no contamination from any particular source.

Boreholes **BT1** and **WWF2** were sampled to quantify the impact of the Wonderwater opencast mine on groundwater users in the surrounding area. A spring near the mine (named **WWF1**) was also sampled. The chemistries of these three samples are very much alike and they represent the water chemistry of the sandy alluvial aquifer that is found in this area.

The spring **WWF1** that was sampled is located next to the road between Bothma Transport and Sigma Wonderwater. There are no known users of this spring. The water quality ( $EC = 33 \text{ mS/m}$ ) is very good and is of a  $\text{CaNa-HCO}_3$  type.

Borehole **BT2** is located on a plot northwest of Bothma Transport. The water is used for domestic purposes and the sample was taken from a tap in the kitchen. The water is of very good quality ( $EC = 18 \text{ mS/m}$ ) but has a slightly elevated level of nitrate ( $6.2 \text{ mg/l}$ ). The water chemistry is of type  $\text{NaCa-HCO}_3$ .

Borehole **WWF2** is located on the farm Wonderfontein next to the Vaal River. The water is of very good quality ( $EC = 33 \text{ mS/m}$ ) and none of the parameters exceed the drinking water standards.

Borehole **HC1** is located adjacent to the golf course of the Holly Country Estate. The borehole was drilled for the purpose of irrigating the golf course. The borehole is not equipped at this stage so the sample could be bailed. The borehole is drilled to a depth of  $30 \text{ mbgl}$ , the water level was measured at  $2.51 \text{ mbgl}$  and the sample bailed at  $20 \text{ mbgl}$ . This borehole is drilled into the sediments above the old mine workings of the Coalbrook Colliery.

The salinity is moderate to high ( $EC = 157 \text{ mS/m}$ ) with the mine workings apparently influencing the quality. Elevated levels of sulphate ( $284 \text{ mg/l}$ ) and sodium ( $204 \text{ mg/l}$ ) were measured.

Borehole **FB8** is located southeast of Kragbron on the farm Rietfontein. The sample was taken from a water storage tank. The borehole is used for domestic purposes. The water quality is moderate ( $EC = 87 \text{ mS/m}$ ) with high nitrate ( $13.1 \text{ mg/l}$ ) values. Once again farming activities could be the cause of this high nitrate value.

Borehole **FB11** is located east of the Coalbrook colliery and Kragbron. This borehole was chosen to serve as a good example of the ambient water quality of the catchment, since there was no possible pollution sources in the immediate vicinity of the farm. The sample was taken from a tap near the house. This water is characterised by a high chloride character, which is possibly indicative of the Ecca sediments. In previous investigations in Ecca sediments water with high sodium and chloride has been reported. (Cogho, et al. 1992). The conductivity, calcium, sodium, magnesium and chloride values all exceed the minimum requirements for drinking water standards.

Boreholes **FB12** and **FB13** were sampled to the south of the Taaibos Spruit catchment.

**FB13**'s sample was taken from a tap at the Cash Store on the farm Schaapplaas. No information was available except that it was used for domestic purposes and that it was very brackish according to the shopkeeper. The conductivity ( $EC = 246 \text{ mS/m}$ ), sodium, magnesium, calcium and chloride levels exceed the minimum requirements for drinking water standards. High levels of nitrate ( $5.5 \text{ mg/l}$ ), phosphate ( $0.93 \text{ mg/l}$ ), ammonia ( $2.25 \text{ mg/l}$ ) and COD ( $53 \text{ mg/l}$ ) indicate possible pollution from a septic tank.

**FB12** seem to be the best example of an ambient water quality for the middle and lower catchment but appears to be derived from a different aquifer to **FB11** and **FB13**. The sample was taken at a farmhouse near a rather large earth dam. The water is of moderate quality ( $EC = 67 \text{ mS/m}$ ) and of a  $\text{Na-HCO}_3\text{Cl}$  type. There are no indicators of any type of pollution in this borehole.

From these analyses the ambient water quality was obtained for the catchment. The farmer's boreholes are generally all of good quality and can be classified as  $\text{Ca/Mg}$  – or  $\text{Na-HCO}_3$ . As will

be seen in the sections to follow, the water samples influenced by the industrial activities tend to differ from this, most notably in the anion character. These analyses also show that at several of the farmer's boreholes, the agricultural activities tend to yield elevated nitrate values- a problem throughout the catchment.

### 4.4.3 Industries

#### 4.4.3.1 *Afcat*

There is only one borehole at Afcat, which is equipped and used for make-up water in the processes and to irrigate the gardens. This borehole was sampled at a tap next to the security building. A sample for the toxicity testing was also collected. No borehole logs or information regarding the geology or construction of the borehole is available.

The water quality of this borehole is moderate to poor (EC = 214mS/m). There are several surrounding industries, which could also be influencing the quality of this borehole. The nitrate value, particularly, is very high (228mg/l). Since there are no processes on site which produce nitrates, the cause should be investigated. It is possible that contamination is moving onsite from beyond the site boundaries but this will only be possible to confirm once flow direction determination and modelling has been done. Afcat has indicated that the expected parameters to pose problems on site would be phosphates and possibly organic contamination but from this analysis the COD value is fairly low, as is the phosphate. Due to the high nitrate values the water from this sample can be classified as being Ca-NO<sub>3</sub> which is a very rare occurrence indicative of unnatural additions to the system.

#### 4.4.3.2 *INCA Brick Works*

The borehole is located in the works adjacent to an ablution block/office building. The borehole is equipped and there is no information regarding the geology or depth of the borehole. The static water level measured on site was 2,78 m below ground level. The sample was taken at a pipeline entering the storage tank. The water is used mainly for dust suppression on site. On site there are large stockpiles of fly ash and cement that is used in the brick making process.

The water quality is fairly good with an EC value of 81 mS/m. There are no real dominant ions, with elevated sulphate and calcium values, probably the result of the fly ash on site. Nitrates are again higher than expected and the NH<sub>3</sub> and COD's are very high. The reasons for these high values need investigation since they are either indicative of extremely reducing conditions or are anomalies. Unfortunately once off analyses do not provide clarity in this regard.

#### 4.4.3.3 *Natref*

At the Natref refinery six monitoring boreholes were sampled. All six boreholes were bailed. Four (B4, B14, B21 & B26) are located inside the property below the evaporation dams, and two (EX1 & EX3) are off-site. No geological logs were available for any of the boreholes sampled. Some auger holes were drilled in the same vicinity and these logs were used to gain insight into the geology.

Borehole **B4** is located east of the evaporation ponds. The borehole is 5.2 m deep; the water level was measured at 1.72 mbgl, and the sample taken at 4 mbgl. From the log of auger hole TH3 that was drilled to 12.2 mbgl, there was no dolerite intercepted at that depth.

B4 is the least contaminated of the boreholes on site. Only the conductivity (76 mS/m) and the sulphate concentration (302 mg/l) exceed the drinking water standards. The water is of a slightly CaMg- SO<sub>4</sub> type signature.

Borehole **B14** is located below the API separator. The borehole is drilled to a depth of 4.6 mbgl, the water level measured at 1.765 mbgl and the sample was taken at 4 mbgl. According to the log of TH2 there is no dolerite up to 7 mbgl in this area but only sandy silt and shale was intercepted.

The groundwater in this borehole is definitely contaminated with regard to sodium (593 mg/l) and sulphate (1341 mg/l). Both these concentrations exceed the crisis limit. The COD (40 mg/l) concentration indicates that there could be some organic contamination.

Boreholes **B21** and **B26** are located below the evaporation ponds. From the log of TH1 the dolerite sill is intercepted at between 6 to 8 mbgl in this area. Both these boreholes are very polluted (EC = 407 & 538 mS/m respectively) with regard to sodium, manganese and sulphates. Both these boreholes are drilled to a depth of ~5 mbgl, and sampled at 4 mbgl. The water levels were measured at 1.43 mbgl and 3.34 mbgl respectively.

During the sampling at B21 there was a slight smell of hydrocarbons but the COD (3 mg/l) concentration did not confirm this. The reason for this could be that the soil has been contaminated and the remnants of the contamination still adhere to the soil but not the groundwater. The sodium (662 mg/l), sulphate (1940 mg/l) and manganese (2.8 mg/l) concentrations all exceed the risk limits.

B26 has a slightly alkaline pH (8.34) and high alkalinity (790 mg/l). The sodium (1274 mg/l), sulphate (2651 mg/l) and manganese (4.096 mg/l) also exceed the risk limits. The COD (53 mg/l) concentration is also high, thus indicating possible organic pollution.

The last three boreholes discussed are all sodium-sulphate type waters. This could be a result of the evaporation dams.

Boreholes **EX1** and **EX3** are located outside the property on the opposite side of the road. The depth (9 mbgl), water level measured (2.43 mbgl) and the sampling depth (4 mbgl) were the same for both of the boreholes. No information regarding the geology is available.



**Figure 25: External borehole EX1, at Natref.**

The water quality in both these boreholes is very good (EC = 23 & 22 mS/m). Both have Na Ca – HCO<sub>3</sub> type signatures. The COD concentration (160 mg/l) in EX1 is high, and is a possible indication of organic pollution.

From the results of all the boreholes on site it can be concluded that there is inorganic pollution on site but it does not seem to have migrated outside of the property. However, from the COD concentration in EX1 it seems that some organic pollution may have been transported by the natural gradient and pathways off-site.

The comparison of these results to the previous monitoring data from the boreholes, confirms the ongoing trend of improvement in groundwater quality ever since the evaporation dams have been rehabilitated.

It must be noted that all the Natref boreholes are located north of the plant. As such these boreholes only give an indication of the activities in this area and cannot be regarded as completely representative of the entire Natref site.

#### 4.4.3.4 *Safripol*

Four monitoring boreholes (SB1, SB2, SB3 & SB5) were sampled on the Safripol site. All four were sampled with the bailer. The geological logs were available for all four boreholes. Results are listed in Appendix B.

Borehole **SB1** was drilled close to the stormwater and effluent outflow. The borehole was drilled to a depth of 61 mbgl. The water level was measured at 2.86 mbgl and the sample taken at 13.5 mbgl. The geology intercepted consists of mudstone, shale, sandstone and siltstone. The dolerite sill was intercepted at 47 -61 mbgl.

The water quality is very good (EC = 41 mS/m) from an inorganic perspective. The high COD concentration (1393 mg/l) indicates that there is some organic pollution present. Further work will be needed to confirm this aspect.

Borehole **SB2** is located in the north eastern corner of the site. The depth of the borehole is 26 mbgl, the water level measured was 4.34 mbgl and the sample was taken at 18 mbgl. The geology intercepted was the same as in SB1 except no dolerite was intercepted. The water is of very good quality (EC = 29 mS/m) and no pollution, inorganic or organic, is evident from the analysis.

Borehole **SB3** is located downstream from the new Poly4 plant. The depth of the borehole is 26 mbgl, the water level measured was 4.750 mbgl and the sample was taken at 18 mbgl. The geology was the same as in SB2 with no dolerite intercepted. The water from SB3 (EC = 17 mS/m) is also unaffected by any pollution.

Borehole **SB5** is located in the factory area. The depth of the borehole is 26 mbgl and the sample was taken at 18 mbgl. The geology differed from the other boreholes in that dolerite was intercepted at 2-8 mbgl. The quality (EC = 46 mS/m) of the water is much the same as in SB1. The COD concentration suggests that there may be some organic contamination present.

As far as classification is concerned all the samples fall into the CaMg HCO<sub>3</sub> type. This is also considered to be the ambient quality for the aquifers underlying the site

From these analyses it seems that there is very little groundwater contamination on site. The reasons for the elevated COD's need further investigation, but Safripol is in the process of sampling for organic parameters in the near future.

#### 4.4.3.5 *Omnia*

Four boreholes were sampled on Omnia's site using the methodology discussed previously.

Borehole **OB1** is located near the SOP plant adjacent to the informal canal. The borehole is 20 m deep and dolerite was intercepted from the depth of 3mbgl to 15mbgl. The dolerite is very weathered to a depth of approximately 7mbgl. The rest of the geology consists of clays, siltstones and some fine sandstone. The water level was measured at 1,86mbgl and the sample was taken at a depth of 7mbgl. A sample was also collected for toxicity testing.

The quality of the groundwater in this borehole is very poor (EC = 1794 mS/m). The pH is slightly acidic with extremely high values for calcium, magnesium, chloride and particularly nitrate (2882, 1430, 701 and 3195 mg/l respectively). These parameters all greatly exceed the maximum risk levels for drinking water. This water shows typical contamination from a fertiliser source. The

water type is strongly Ca-NO<sub>3</sub>/Cl dominant. An interesting feature was that when the down-the-hole logging was done a sharp drop in EC values was observed from 7m to about 19m. This could indicate that the dolerite does act as a fairly impermeable barrier against downward migration of pollution.

**OB3** is situated at the north eastern corner of the plant, next to the storm water /effluent canal and near the fertiliser stores. The borehole is 20m deep with dolerite intercepted from 4-11mbgl. The water level is 0.67mbgl and the sample was taken at 6.5mbgl. The water quality in this borehole is moderate (EC = 131 mS/m). Once again the nitrate value is very high, as are nitrite and phosphate values. The water contains no dominant anions and cations and plots or indicates a region of mixed water.

**OB4** is situated alongside the storm water /effluent canal. The borehole is 15 m deep with dolerite from 3-9m. The water level was measured to be 5.5m while the sample was taken just below the surface of the water. The water quality in this borehole is poor (EC = 579mS/m) with parameters of concern: Ca, Mg, and very high NO<sub>3</sub> and PO<sub>4</sub> values.

**OB6** is situated alongside the PPAN plant and storage area. The borehole is 20m deep with some dolerite intercepted from 2-8m. The rest of the geology consists of silt and mudstones. The water level was measured at 1.04m and the sample was taken at 10m. The water quality in this borehole is fairly good with high nitrate and ammonium values. This indicates that this fairly new plant has already influenced the groundwater. The high COD values need investigation - the borehole needs to be resampled to see if this anomaly is from analytical error and, if not, the reason will have to be investigated.

The Expanded Durov diagram indicates the unusual positions these samples plot in. From these results it is evident that there are several boreholes on site, which are very contaminated. This is a natural result of the type of operation and the solubility of the chemicals used on site. It is, however, recommended that these aspects receive immediate and drastic attention, so that remedial action and improvement of the water management systems can be done. Omnia has started with this process.

#### 4.4.3.6 SCI

Seventeen of SCI's monitoring boreholes were sampled. These include boreholes in the plant area, waste disposal area and the newly drilled boreholes in the area of Venco Park. The bailing method was used for sampling all of the boreholes. Results are included in Appendix B.

Boreholes A2B and A4 were sampled to represent the groundwater chemistry of the area below the Sasol Chemical Industries Factory. Borehole **A2B** is located north of the coarse ash dump to monitor the impacts from the factory. The borehole is drilled to a depth of 48 mbgl and intercepted only clay, sandstone and shale, with no dolerite. The water level was measured at 9.53 mbgl and the sample taken at a depth of 21 mbgl. (The water level in A2A, the shallow borehole was measured at 1.99 mbgl.)

The water can be classified as Ca-HCO<sub>3</sub> type. This was the only borehole sampled in the catchment that exceeded the proposed pH risk criteria with the highly alkaline value of 11.64. Although the conductivity (136 mS/m) is not excessively high it is, according to a previous monitoring report (Reyneke, 1996) from SCI, the only deep borehole in this area where the EC values are so high.



**Figure 26: Coarse Ash dump at SCI waste disposal site**

Borehole **A4** was drilled east of the coarse dam area to depth of 26 mbgl. From 4 mbgl alternating dolerite and sandstone was intercepted. The sample was taken at 19 mbgl and the water level was measured at 4.010 mbgl. The pH of the water is slightly alkaline (8.1) and the conductivity moderately high (125 mS/m). The nitrate (154 mg/l) and ammonium (24.94 mg/l) concentrations are very high.

From these two borehole analyses, as well as the borehole monitoring data from SCI, it can be seen that the area below the coarse ash dump is contaminated with nitrates. According to a previous monitoring report there are three possible sources of nitrate contamination:

- Fe catalyst dump
- Old section 4200 catalyst dumping area
- The formal factory area, particularly the S4200

At the effluent dam area, borehole **D1A** was sampled. The borehole is located below the emergency dam area and drilled through clay to a depth of 8 mbgl. The sample was taken at 4 mbgl and the water level measured at 0.46 mbgl. The conductivity (99 mS/m) was moderate and the pH almost neutral. Comparing the result of this analysis with monitoring data from other boreholes in the area, the effluent dams seem to act as a buffer against pollution migrating from the factory area.

Boreholes **P1A** and **P1B** was sampled in the SCI factory area. These two boreholes are located below the Merisol plant inside the factory area. P1A is 5 m deep and P1B is drilled to 10 mbgl. Dolerite was intercepted in both these boreholes from 1 mbgl.

P1A was sampled at a depth of 4 m and the water level measured at 1.885 mbgl. The water quality is good (EC = 43 mS/m) with a high level of nitrate (9.58 mg/l). P1B was sampled at a depth of 9.2 m and the water level was measured at 1.875 mbgl. Although the water strikes are similar in the two boreholes the water chemistry differs. P1B is more contaminated with respect to nitrate (48 mg/l) and has a higher conductivity (71 mS/m).

Even though P1A and P1B were the only boreholes sampled in the factory area, the results together with the monitoring data from SCI, show that the factory area has been impacted on during operation. Nitrate contamination seems to be the greatest problem in the factory area. Since there is a water divide running through the factory, both the Leeu Spruit and Taaibos Spruit catchments could be impacted on from this pollution source.

Borehole **O1A** and **O1B** were drilled between the Fertiliser dump and the main sewage line, which traverses the site from Zamdela, in the waste disposal area just north of the Leeu Spruit. The borehole is constructed with a double piezometer of which A (12.5 mbgl) is the shallow piezometer and B (29 mbgl) is the deeper piezometer. No dolerite was intercepted in either of the holes. The water levels differed in the two piezometers: A was 0.37 mbgl and B 5.33 mbgl.

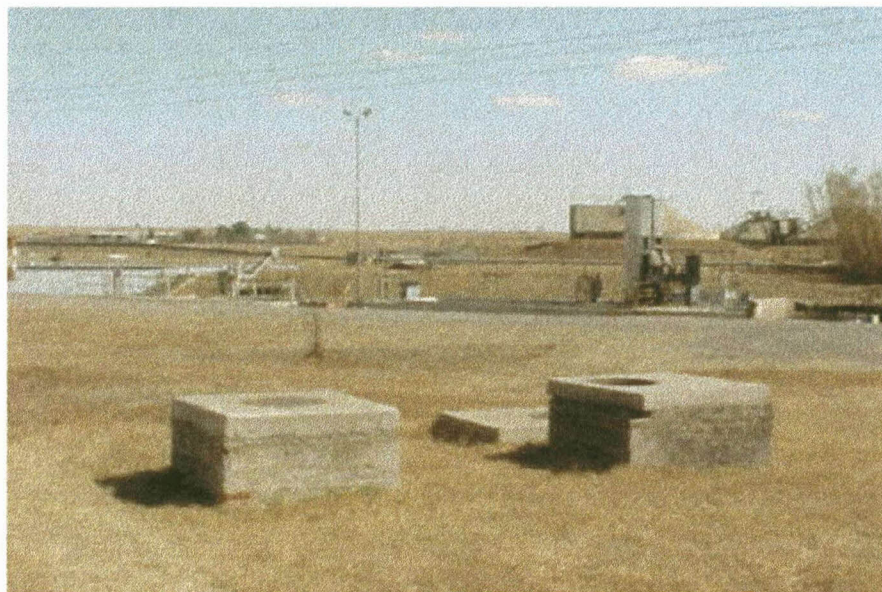
The shallow borehole O1A was sampled at 6 mbgl and is very contaminated. The pH (5.88) is acidic and the water has a very high conductivity (1 885 mS/m). The concentrations of calcium (2882 mg/l), magnesium (1430 mg/l), chloride (4486 mg/l), COD (153 mg/l), nitrate (1301 mg/l) and ammonium (7.48 mg/l) all exceed the risk limits by far.

O1B was sampled at 10 mbgl and is a lot less contaminated (EC = 59 mS/m) than O1A. The nitrate (14.2 mg/l) concentration exceeds the risk limits. The COD (391 mg/l) concentration is also a matter of concern and could be indicative of organic contamination. When one looks at the historical monitoring data it is evident that pollution is migrating from the upper weathered clays and sands down into the lower Karoo sediments. The borehole logs show that there is a carbonaceous shale layer separating the sediments of O1A and O1B

It is interesting to note that these two boreholes differ significantly as far a hydrochemical grouping is concerned. O1A exhibits a strongly Ca-NO<sub>3</sub>/Cl character whilst O1B shows similar characteristics to the ambient quality with much higher percentage of Mg-HCO<sub>3</sub>. This indicates that the shale layer is fairly impervious in this area.

This area should receive priority concerning remediation due to the proximity of the Leeu Spruit.

Three boreholes were sampled in the vicinity of the sewage works (**S2, S3 & S4**). S2 is drilled east of the sewage works sludge beds. The borehole has been drilled to a depth of 30 m and intercepted dolerite at 17 – 30 m. Six meters of ash were intercepted at a depth of 5 m. The borehole must have been back filled or collapsed as the depth was measured only to ~14 mbgl. The sample was taken at 12 mbgl and the water level measured at 1.565 mbgl.



**Figure 27: Sewage works at the SCI waste disposal site**

The borehole is polluted in terms of conductivity (224 mS/m), calcium, sodium, chloride and sulphates that all exceed the drinking water standards. The high level of COD (317 mg/l) is also a concern.

S3 was drilled to a depth of 30 m. Dolerite was intercepted at 7–30 mbgl. The water level was measured at 21.01 mbgl and the sample taken at 22 mbgl. Water could be heard cascading down

the hole as the current water level is below the water strike. This could be the result of subsidence due to mining in the area. This depressed water level suggests that this area can act as a sink for contamination.

The water is less polluted in S3 than S2 but they have similar chemical characters. Conductivity (159 mS/m), calcium, sodium and sulphate levels exceed the drinking water standards.

Borehole S4 was drilled to a depth of 30 mbgl, but the depth was measured to be only ~15.5 mbgl. Dolerite was intercepted at 22 –30 mbgl and ash at 7 –14 mbgl. The water level was measured at 1.94 mbgl and the sample taken at 5 mbgl.

S4 was, with the exception of the nitrate concentration (8.87 mg/l), the least polluted of the boreholes sampled at the sewage works. Conductivity was moderate (85 mS/m) and the water chemistry is dominantly of a Ca HCO<sub>3</sub> type. The higher nitrate (and nitrite & phosphate) concentrations can be contributed to the nearby sludge beds.

This area where these three boreholes are located should also receive priority due to the proximity of the Leeu Spruit and the amount of pollution that could migrate to the river. Any possible impact on the groundwater quality from the ash layer that was intercepted in S2 and S4 should also be quantified.

In the tar pit area of the waste disposal area two boreholes were sampled, T1 and T7. T1 is located below the new tar pit area. No logs are available for this borehole. The depth was measured at ~9 mbgl and the water level at 2.77 mbgl. The sample was taken at 5 mbgl.

The water chemistry is of a NaHCO<sub>3</sub> type and of good quality. No contaminants of concern were found. Monitoring data suggest that there is an increase in sulphate concentrations but this was not confirmed by this analysis.

T7 is located below the old tar pit area. This borehole is drilled to a depth of 6 mbgl and no dolerite was intercepted. The water level was measured at 2.37 mbgl and the sample taken at 4 mbgl.

Borehole T7 and T8 were constructed as double piezometers, with T8 drilled deeper to 40 mbgl where the dolerite was intercepted at 36 – 40 mbgl.

T7 is polluted as shown by the high conductivity (364 mS/m) and has SO<sub>4</sub> with no real dominant cation signature. Manganese (3.19 mg/l) and sulphate (1295 mg/l) concentrations are in excess of the risk limits. High COD (205 mg/l) concentrations possibly indicate organic pollution from the tar pits.

When these results are compared with the monitoring data, it is evident that the area below the new tar pits is at this point in time, less polluted than at the old tar pits.

Three boreholes were sampled below the no. 5 ash dump, EMC1S & D and EMC3D. EMC1S was drilled on the opposite side of the groundwater divide i.e. the old Leeu Spruit river course. The depth of the borehole is 10 m, the water level measured was 2.71 mbgl and the sample was taken at 5 mbgl. No dolerite was intercepted.

The water quality is of a NaCl type signature. The water has a high conductivity (313 mS/m) and is contaminated with chlorides (659 mg/l) and there is an elevated level of sulphate (362 mg/l). The COD (103 mg/l) concentration suggests slight organic pollution. The conductivity of this borehole is much higher when compared to monitoring data from the other shallow boreholes in the vicinity. It has been suggested that these elevated values are a result of the diverted river course, which is channelling the water to the borehole as a preferred pathway.

EMC1D was drilled next to EMC1S to a depth of 17 mbgl. The water level was measured at 2.85 mbgl and the sample taken at 6 mbgl. The quality (EC = 58 mS/m) is much better than in the shallow borehole. The water is of a Na Ca - HCO<sub>3</sub> type signature. The difference in EC was found between the deep and shallow boreholes and this suggests that they are recharged by different

sources. The pressure exerted on the deeper sandstone aquifer by the surrounding dam system might explain the similarity in water level.

Borehole EMC3D is drilled to a depth of 20 mbgl, below the No. 5 Ash dam. No dolerite was intercepted. The water strike was intercepted in the fractured sandstone. The water level was measured at 0.8 mbgl and the sample taken at 10 mbgl. The water quality (EC = 237 mS/m) is poor and of a NaCa - HCO<sub>3</sub>Cl type. A high sulphate concentration (374 mg/l) showed that the water is from ash origin. The COD (216 mg/l) concentration also suggests organic pollution.

According to the monitoring reports and data, these boreholes represent the cumulative effect of the pollution migration from the lower end of the waste site. The other concern is the threat of base-flow discharge of the high salt load in the groundwater to the Leeu Spruit.

The last three boreholes (V11D, V1D & V2S) sampled were the newly drilled monitoring boreholes in the Vencopark area. These were drilled as part of an impact assessment currently underway. No geological information on these boreholes was available at the time.

V11D was drilled to a depth of 30 mbgl next to entrance of the Valid Butchery in the Venco Park business area. The purpose of this borehole is to assess the impact of off-site pollution migration from the SCI factory area, towards the Taaibos Spruit. The water level was measured at 3.66 mbgl and the sample taken at 15 mbgl.

The water quality (EC = 186 mS/m) is moderate and of a Ca-Cl/NO<sub>3</sub> type signature. The water is very contaminated with regard to nitrate (138 mg/l) and exceeds the risk limit (20 mg/l) by far. From this it can be concluded that there is off-site pollution migration from the factory area or that previous activities have influenced the quality.

V1D and V1S are located below the old fertiliser disposal area. V1D is drilled to a depth of 30 mbgl, the water level was measured at 1.410 mbgl and the sample taken at 16 mbgl. The water quality (EC = 474 mS/m) is very poor and exceeds the risk limits for several constituents. These are calcium (474 mg/l), magnesium (234 mg/l), chloride (733 mg/l) and nitrate (287 mg/l).



**Figure 28: Venco Park Disposal area**

V1S was drilled to a depth of 5mbgl, the water level measured at 0.32 mbgl and the sample was taken at 4 mbgl. This borehole is extremely polluted. The water is very acidic (pH = 3.5) and the conductivity is 4486 mS/m. Most of the constituents tested, including the trace metals, exceeded the risk limits by far. To name a few: sulphate (49618 mg/l), nitrate (263 mg/l), phosphate (919

mg/l), aluminium (389 mg/l), ammonia (442.87 mg/l) and COD (573 mg/l). The high values of trace metals can be attributed to mobilisation through the low pH conditions.

From these results it is evident that the shallow aquifer is extremely polluted by the old fertiliser dump in this area and rehabilitation measures need to be taken immediately to stop this pollution migrating towards the Taaibos Spruit.

From the above chemical results on the SCI sites, there are several conclusions that can be drawn. The first is that on site at the plant nitrate appears to be the only problem. This is based on a single area that could be accessed at the time of investigations. It is suggested that more be focussed on the rest of the factory site. The old tar pits area seems to be contaminating the area below it, while at the new pits no evidence of contamination is apparent as yet. The two areas which need the most attention, are the Fertiliser dump at the waste disposal area and the Venco Park old disposal dump area. The Fertiliser dump can significantly impact on the Leeu Spruit while contamination from the old dump area at Venco Park can impact on the Taaibos Spruit. The latter area potentially holds a threat due to its proximity to Zamdela. Groundwater use from this area must be prevented. SCI is currently doing a risk assessment on the area.

#### 4.4.3.7 *SMX*

Two boreholes (**V4S** & **V3D**) were sampled in the SMX factory site. Both these boreholes are located downstream of the old effluent dam to monitor the pollution migrating from this source. The groundwater in both these boreholes is extremely polluted.

**V4S** is drilled to a depth of 4 mbgl, the water level was measured at 1.33 mbgl and the sample taken at 3 mbgl. The conductivity is very high (2313 mS/m) and the water is of a CaNO<sub>3</sub> type signature. This is typical of water polluted by fertiliser. Calcium (3531 mg/l), magnesium (1463 mg/l), sodium (847 mg/l), sulphate (1709 mg/l), nitrate (3921 mg/l), manganese (1.23 mg/l) and ammonia (28.73 mg/l) all exceed the risk limits.

**V3D** was drilled to a depth of 30mbgl, the water level was measured at 1.540 mbgl and the sample was taken at 16 mbgl. The deeper aquifer is also very polluted but less than **V4S**. The water is slightly acidic (pH = 6.11) and has a very high conductivity (1918 mS/m). The water is of the same signature as **V4S**. Calcium (1918 mg/l), magnesium (956 mg/l), sulphate (1735 mg/l), nitrate (2537 mg/l), phosphate (13.3 mg/l), manganese (14.2 mg/l) and ammonia (625.74 mg/l) all exceed the risk limits.

This should be another area of concern and it will need to be rehabilitated. Of special concern is the high level of pollution in the deeper aquifer.

#### 4.4.3.8 *POLIFIN*

Twelve boreholes were sampled on the Polifin Site. All these boreholes are constructed with piezometers to represent the different aquifers. In most cases only one of these piezometers was sampled but both the shallow and deep piezometers were logged with the down-the-hole EC probe and water levels were measured in both. All the boreholes were sampled using the methodology outlined previously.

**SRK1D** is situated east of the North Dams, adjacent to the site. The geological information indicates that this borehole is 42m deep and is drilled largely in dolerite that was intercepted from 5-35mbgl. The borehole was sampled at 8m and the water level was recorded as 0.635m. In the shallow piezometer the water level was measured at 0.17m. Inorganically the quality (EC = 41 mS/m) appears to be good with no clear elevated levels. As a result it can be characterised as a Na-HCO<sub>3</sub> type water. The COD values suggest that there may be some organic contamination occurring.

**SRK2D** is east of the solid waste dump. The borehole is 30 m deep and has been drilled in dolerite that occurs from 8-30m. The borehole was sampled at 15m with the water level at 2,80m. In the shallow borehole the water level was measured as 2.86m. The water quality in this borehole is fairly poor (EC = 1961 mS/m) with high values of calcium, magnesium and chloride being the major features. Several heavy metals were also recorded in the analyses. The COD values are also high. The sample can be classified as a Ca-Cl water. This borehole is located between the Polifin site and a tributary of the Taabos Spruit and these high concentrations are cause for concern.

Borehole **SRK29D** is situated south of the South Dams, outside the site. The borehole is 30m deep with dolerite again encountered from 7m downwards. The conductivity values measured in the shallow and deep boreholes were virtually identical and the water levels are also almost the same. The water level measured in the SRK29D was 2,32m. The quality in this borehole is moderate (EC = 254 mS/m) with higher than expected sulphate values. The nitrite values in this borehole are also very high. Once flow directions have been established, the source of these elevated parameters may become evident.



**Figure 29: Borehole SRK2**

Borehole **SRK17D** is south of the CAP dams outside the site. It is 27m deep and dolerite was encountered from 6m to the bottom. The sample was taken at 7.5m. The water levels in the shallow and deep piezometers are at 1.86 and 1.91 meters respectively. The quality is good to moderate (EC = 105 mS/m) with a high nitrate value. The water can be classified as a Na-HCO<sub>3</sub> type.

**SRK12D** is situated north of the peroxide plant. The borehole is 27m deep with dolerite again occurring from 7m. The sample was taken at 13,8m. The water levels in the shallow and deep piezometers are 1.92m and 1.99m respectively. Water quality in this borehole seems to be good to moderate (EC =130 mg/l). The dominant ion is chloride and the water can be grouped as a CaNa-Cl type water.

**SRK20D** lies between the warehouses on site. The borehole is 24m deep with dolerite encountered from 5m downwards. The water levels in the two piezometers differ significantly with levels of 1.832mbgl and 11.18mbgl measured in the shallow and deep aquifer. This is an indication of the localised perched aquifer that was mentioned before. The sample was taken at 18.4 m. Water quality is fairly good with sodium and chloride being the most dominant ions. The high NH<sub>4</sub> and COD values need further investigation, could be indicative of reducing conditions.

Borehole **SRK14 D** lies near the PVC cap area. The borehole is 24m deep and dolerite occurs from 6m. The water level was measured to be 2.94m in both the piezometers. Due to prior warning that

high concentrations of DNAPLs may be present, the probe was not used to log the borehole. The sample was taken at a depth of 20m. The water quality in this boreholes is poor (EC = 546mS/m) with very high chloride values and high calcium and manganese detected as well. As expected the COD values in this borehole are also high. A toxicity test was also done on a sample from this borehole.

**SRK25D** is situated near SRK14. The geological information for this site is the same as SRK14. The water levels in both piezometers are identical and the sample was taken at 12,5m. Field measurements indicate that the quality in the two piezometers differs with EC values in the shallow borehole of slightly better quality. The water quality in this borehole is poor (EC = 748 mS/m). Calcium values are high while nitrate values are extremely high.  $\text{NH}_4$  and COD values are again high.

**SRK8D** is situated in the area where the storage areas are located on site. The borehole is 42m deep with dolerite encountered from 2-27m. The shallow piezometer was dry while the water level in the SRK8D was at 2,39m. The sample was taken at 10m. The analysis shows that inorganically the water quality is good (EC = 39mS/m). The water is typically Ca- $\text{HCO}_3$ . Higher than expected COD values need further investigations.

Borehole **SRK18D** is situated near the chlorine complex. The borehole is 24m deep with dolerite found from 4-16m. The water levels in the two piezometers are identical, but the field measurements show that the water qualities differ. The borehole was sampled at a depth of 5mbgl. The quality is again good, apart from high COD values.

**SRK16S** is south of the old solid waste dump near several on site activities. The borehole is 22m deep with dolerite from 2-13m. Water levels in the two piezometers are virtually identical (2,05mbgl) but qualities seem to differ. The sample was taken at 11m. The water quality is very poor (EC = 5072 mS/m). There are very high values, all the major ions with chloride being dominant. Fluoride values are high with fairly high COD values also evident. There are several sources of pollution that could be influencing the quality of this borehole.

Borehole **SRK19D** is 30m deep with dolerite from 3-23m. Water levels in the two piezometers are the same at 2,83m with very similar conductivities measured during sampling. The water quality is moderate (EC = 95 mS/m). There are no dominant cations or anions evident in this sample.

From the analyses it can be seen that there are several different sources of possible contamination. There seems to be inorganic and organic pollution on site. Several sample runs that have been taken during the past few years of operation confirm these findings. In many cases the reasons for a specific pollutant are evident whilst in others the reasons for elevated values needs to be ascertained. These samples verify the presence of organic contaminants in the area of SRK14 and SRK25. The consultants working on site have done modelling of this contamination. From these analyses there appears to be some evidence of offsite migration. The proximity to the tributary of the Taaibos Spruit makes this migration a cause for concern.

#### 4.4.3.9 *Petronet*

Five boreholes were sampled on the Petronet sites. Three were sampled at the Sasolburg pumpstation and two at the Coalbrook pumpstation.

Boreholes **PSB2** and **PSB6** are situated at the Coalbrook pump station. PSB2 is situated near the fence between Natref and Petronet. It is 13m deep and the sediments consist of mostly clayey and silty sands. The sample was taken at 2.5m while the water level was measured at 1.9m. Water quality is fair (EC = 84 mS/m) with the only major anion being an elevated sulphate value. The COD level was low, thus no organic contamination is suspected.

PSB6 is situated in the southern portion of the site. The borehole is 15.5 m deep and the underlying soils are the same as PSB2. The borehole was sampled at 4.5 m and the water level was 0.93mbgl.

This borehole also has a good quality (EC= 58mS/m) with low COD. From these and previous monitoring results it would appear as if this pump station is at present largely uncontaminated as far as groundwater is concerned.

The three boreholes sampled at the Sasolburg pump station are all located alongside pumping/storage facilities on site. In all three boreholes free product was smelled and seen. The boreholes are all drilled into clayey and sandy soils.

**PAB3** is 7.8m deep with a water level of 1,99m. There was a significant amount of free product floating on the surface of this borehole. This was removed by bailing and the sample was taken below this free product. A sample was also taken for toxicity testing. The inorganic quality of the borehole is moderate (EC = 106 mS/m) with high iron and manganese levels found. The COD of the sample is obviously also very high, despite trying to sample as little of the free product as possible.

Borehole **PAB5** is 6.2m deep with a water level at 1.75mbgl at the time of sampling. The sample was taken at 2m. Inorganically the quality is good, with the exception of high iron and manganese values, but again COD values are very high.

**PAB6** is 4m deep with the measured water level at 1.9m. There was again a large amount of free product in this borehole and the sample was taken once most of the visible free product was removed. Inorganically the quality was good but high COD levels were measured.

These results and the observation of significant amounts of free product in the boreholes can be considered problematic. The reasons need to be investigated and remedial action will need to be taken.

#### 4.4.3.10 Karbochem

Ten boreholes were sampled on site and surrounding Karbochem's site. They were all sampled using the methodology outlined previously. Geological information was available for all the boreholes.

Boreholes **KEMC1S and 1D** are situated outside the site next to the outflow canal. The deep and shallow boreholes were sampled. These two holes are 10m and 32 m deep respectively. In both boreholes shale was found and in the deep borehole dolerite is intercepted at 19m. Water levels in the two boreholes were 0.88mbgl and 0.85mbgl respectively. They were sampled at 9m and 30m respectively.

From the analyses the shallow portion of the aquifer appears to be more contaminated than the deeper aquifer. The quality in the shallow borehole is very poor (EC = 489 mS/m) with high fluoride, chloride (1217mg/l) and sulphate values (1403 mg/l).

The water is of better quality in the deeper borehole (EC = 169 mS/m). The water type seems to be the same with lower concentrations occurring. The nitrate value are slightly higher than in the shallow aquifer.

Boreholes **KEMC2S and 2D** are north-east of the site. The shallow borehole was drilled to 9m while the deeper borehole was drilled to 30m. Dolerite was encountered at 9m. The shallow borehole was sampled at 7.7m (water level = 2.8m) while the deeper one was sampled at 16.5m (water level = 3.46m). The quality of the two boreholes is similar. The overall salinity is moderate (EC = 156 mS/m) with high chloride, nitrate and COD values.

In the deep borehole the quality is also moderate with lower chloride and higher nitrate values as in **KEMC1D**. It is also enriched with respect to calcium.

Boreholes **GCS1S and 1D** are located next to the fence to the south of the aerator dams. The deep borehole (**GDS1D**) is 42m deep while the shallow borehole is 10m deep. The dolerite is from 2m-

18mbgl. Water levels are 2.75m and 2.87 in the deep and shallow borehole, respectively. Samples were taken at 15.5m and 8.5m in the deep and shallow borehole.

The water quality in the two boreholes is fairly poor. In the shallow borehole (EC = 300 mS/m), sulphate and nitrate values are again very high (998 and 1539mg/l). The deep borehole has a lower sulphate value, which gives it a slightly lower salinity (EC= 228mS/m). The COD value is slightly higher.

Borehole **GCS3** is located north-east of the Petronet Sasolburg pump station. The purpose of this borehole is to serve as a background value for groundwater flowing into the site. The borehole is 30 m deep and dolerite was intercepted from 6m to 26 m. The sample was taken at 5.5 mbgl and the water level was measured at 3.64 mbgl. The water quality is very good (EC = 36 mS/m) and of CaHCO<sub>3</sub> character and can be considered as uncontaminated.

**GCS5** is located downstream from the old solids waste dump. The borehole is 30 m deep and dolerite was intercepted from 5 mbgl. The sample was taken at 15.3 mbgl and the water level measured at 2.56 mbgl. The water quality is very poor (EC = 746 mS/m) and contaminated with regard to sodium, chloride (1745 mg/l), sulphates and nitrates.

**GCS7** is located in the south-western corner of the site to monitor the pollution migration off-site. This borehole is equipped with a pump and was previously used for garden irrigation. The borehole was drilled to a depth of 31 mbgl and the dolerite was intercepted from 7mbgl. Water level was measured at 2.44 mbgl and the sample was taken at 13.3 mbgl.

The water quality is moderate (EC = 265 mS/m) with high sulphate and very high nitrate (145 mg/l) values. Based on these values and previous investigations to determine flow directions, it can be seen that off-site migration is a threat. This borehole should not be used for irrigation purposes in the future, as this would cause a greater rate of migration of pollution towards this point.

**P8** is a piezometer borehole south of the Petronet Sasolburg pump station and the benzene plant. This hole is drilled in an area where rubber waste was reportedly buried. Water quality is very poor (EC = 1132 mS/m). Sodium, sulphate, fluoride, phosphate and COD all exceed the risk limits.

From these results it seems as if the greatest problems on site are due to sulphates and nitrates. Some evidence of organic pollution is also present. Several boreholes contain water of poor quality. These results coupled with previous work on site, shows that there is migration off-site and suggests that measures should be implemented to minimise these impacts.

#### **4.4.4 Mining Activities**

##### *4.4.4.1 Sigma Collieries*

Ten boreholes were sampled in the mining area of Sigma colliery. Four were sampled in the Underground mine area, four in the Wonderwater Opencast mine area and two in the proposed North West Strip mine area. The geology in the mining areas is generally as described in this report.

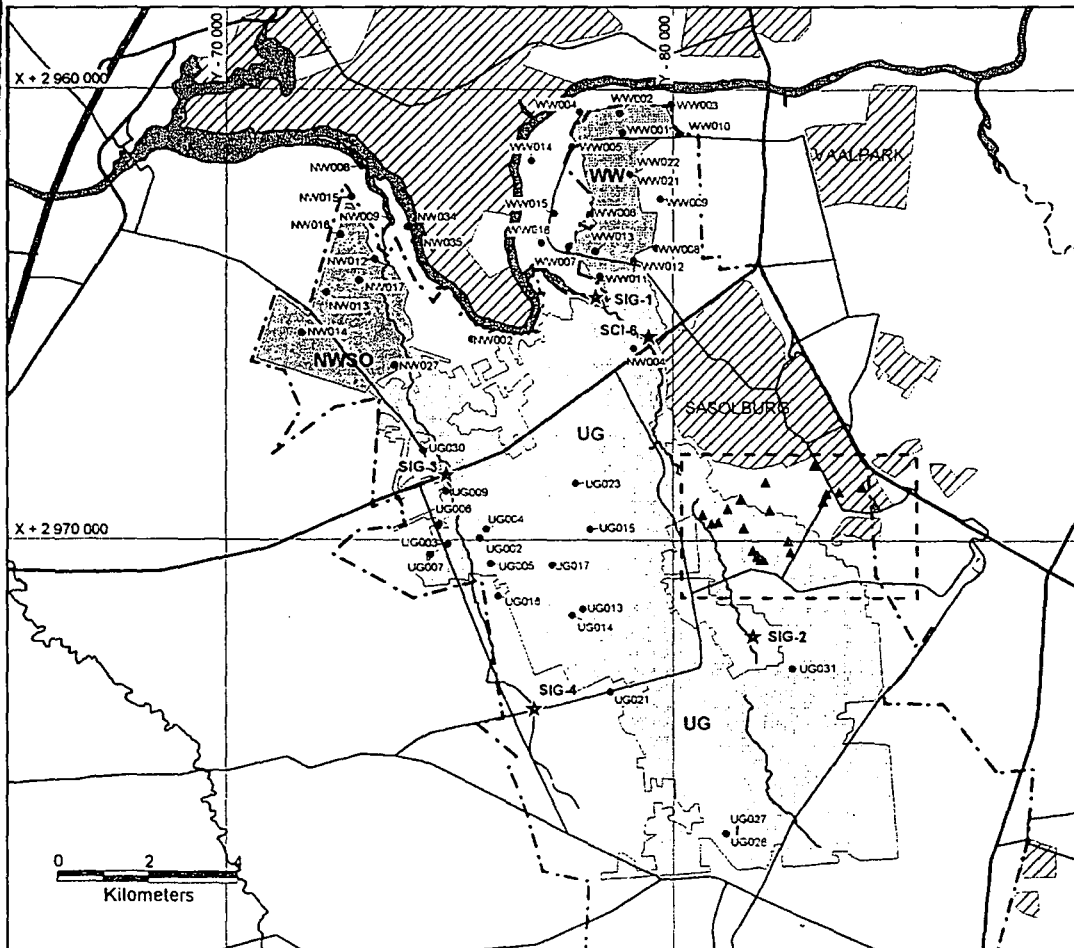
The four boreholes sampled in the Wonderwater area were **WW003, WW007, WW010 and WW021**. Although these boreholes were sampled at different depths (14.6, 30 and 5 mbgl) they are all derived from the same alluvial sand aquifer that is found in this area. The water levels of WW007 and WW010 were measured at the same depth (3.1 mbgl) and WW003 water level was measured at 9.7 mbgl.

WW003, WW007 and WW010 are of very good quality (EC <19 mS/m). The mining activities do not have any effect on the quality. It would appear from the quality and character of these samples that the recharge is from rainfall and the rate of the recharge is high.

**WW021** is located in a rehabilitated area of the opencast mine pit and drilled into backfill material. The water quality is poor and is affected by the mine workings, as can be seen from the high sulphate (1445 mg/l) and COD (369 mg/l) concentrations. The water level was measured at 42.345

m and the sample was taken at 45 m. It is clear that the dewatering of the mining area influences the water levels. This contamination should be prevented from migrating outside of the mine workings towards the alluvial aquifer that is utilised for domestic use on the surrounding plots.

Although borehole NW047 is located outside of the Leeu Spruit catchment, it yields valuable information. It was sampled to obtain a comparison with the samples within the catchment. If the Northwest Mine becomes operational in the future, the impact that these operations will have on the study area will also need to be considered as part of the final Groundwater Management Plan. At present the quality of the water is good except for high COD values and ammonium. This ammonium value could be indicative of reducing conditions but the anomaly needs further investigation to ascertain the cause.



**Figure 30: Figure showing three areas of groundwater monitoring for Sigma Mines: North West Strip Mine, Wonderwater Opencast and Sigma Underground. (From VSA GeoConsultants, 1997)**

NW004 is situated near Boschbank shaft. The water level is 11.52 mbgl and the sample was taken at 23 m. The quality of the water is good ( $EC=25$  mS/m) with none of the parameters being above the set standards. COD values are high, possibly due to carbonaceous material in the borehole.

All the UG-boreholes are drilled on farms above the underground mine workings in the Leeu Spruit catchment. All the water levels are slightly lower than encountered in the rest of the area, between 10 mbgl and 19 mbgl. Water levels at other boreholes in this region are all depressed. The mine currently supplies water to several of the farms in this area. The four sites sampled in this phase are all in what the mine refers to as the "upper" aquifer. The geology in these boreholes generally consists of a thick layer of dolerite with sandstones underlying and/ or separating the dolerite. The heterogeneity of the dolerite intrusions is again born out by these logs.

**UG17 and UG22** seem unaffected by the mining operations at this stage. Water quality is good (EC = 27 and 29 mS/m respectively). The samples were taken at depths of 26 mbgl and 20 mbgl respectively. These waters are of type CaMg-HCO<sub>3</sub> which is considered to be the ambient quality in this part of the catchment.

**UG23** was sampled at 12 m with the water level recorded as 10.81 m. The EC was constant with depth, as the borehole had been purged two days previously. The water quality in this borehole is moderate (EC = 89 mS/m). Nitrate is high in this borehole. The only problematic values are the NH<sub>4</sub> values and COD. These values need further investigation to ascertain the reason for the anomaly.

Boreholes **UG26's** water level is at 19.345 mbgl. The sample was taken at 30 m. This borehole appears to have to been influenced by the mine since sulphate and sodium values are elevated. Despite this, water quality is moderate (EC = 96 mS/m).

These results seem to reinforce the earlier impression stated in previous reports that, at this stage, the mines influence on the surrounding area's hydrochemistry is relatively small. The major impact currently seems to be the depression of water levels that has occurred as a result of the underground mining activities. This has the effect of limiting spreading of mining related contamination.

#### 4.4.4.2 Coalbrook Colliery

There is very little information regarding this colliery. One borehole was sampled on what is now called the Holly Country Estate. This borehole was dealt with in the section pertaining to the farmer's boreholes. The situation around Coalbrook will need to be monitored, since the mine has been left to flood and although previous reports suggest that the effects of the recharged water should be minimal, there is no available information to draw conclusions from.

The contribution of Coalbrook, once it has refilled and started contributing base flow or decant to the stream, must be kept in mind when the salt loads of the Taaibos Spruit is considered.

### 4.4.5 Power Stations

#### 4.4.5.1 Kragbron

Eskom's four existing monitoring boreholes (B1, B2, B3 & B4) and one surface water sample (ST) were sampled at this locality. (For the purpose of this report the boreholes were renamed to KB1 – KB4, to avoid confusion with similarly named boreholes in the catchment.) All four boreholes were without equipment so they were sampled according to the method described. The location of the four boreholes with the possible pollution sources is shown in figure 31.

Borehole **KB4** is located south of the now disused domestic waste disposal site, 20 m downstream. The purpose of this borehole was to intercept any possible pollution from this site. The borehole was drilled to depth of 50m, and the dolerite sill was intercepted at 1 – 14 m below surface. The rest of the geology is alternating layers of sandstone and shale.

The water is typical of wet ash disposal, high sulphate and low to intermediate levels of calcium, sodium and chloride levels. The close proximity of the ash dams will mask any effect that the disposal site might have had. When the results are compared to the monitoring data from the past a definite improvement of water quality has taken place.

Borehole **KB3** is located next to the ash water return dam and **KB2** is located at the point where a tributary of the Taaibos Spruit is leaving the property. The purpose of these boreholes is to monitor any groundwater pollution leaving the site. The results of these boreholes need to be compared to the surface water samples to fully understand the chemistry. One surface water sample was taken in a stream halfway between the two boreholes.

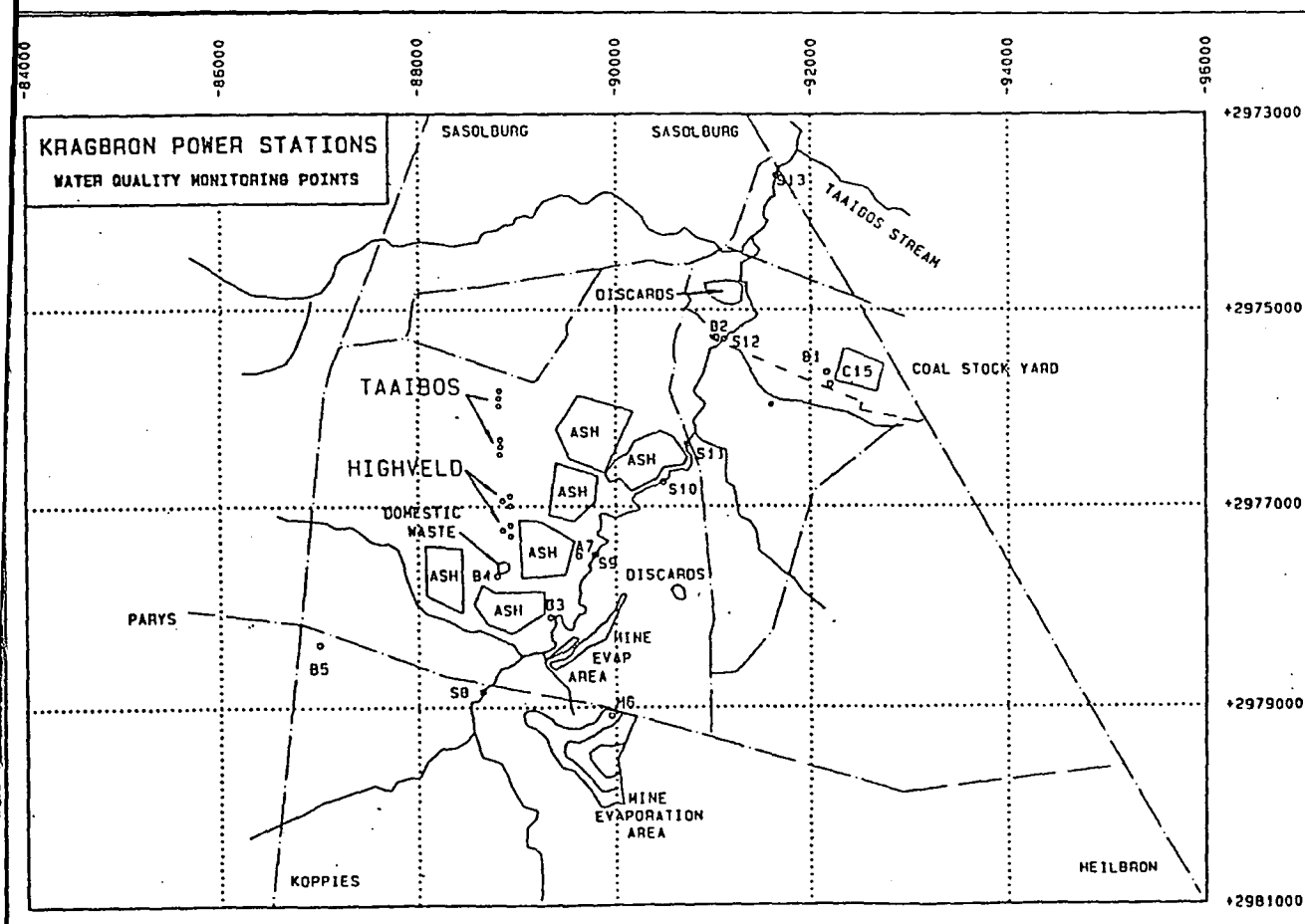


Figure 31: Locality plan (from Speirs, 1990)

KB2 was drilled to a depth of 42 m and intersected the dolerite sill at 20 – 42 m. KB3 was drilled to a depth of 50 m and intersected the sill at 9 – 11 m. The geology is the same sandstone and shale formations that were found elsewhere.

There are two principal pollution sources in the Kragbron/ Holly Country area. One is from the Coalbrook colliery and the other the ash dams. Mining activities will contribute to the sodium, chloride, alkalinity and fluoride levels in the water and the ash water will contribute to the calcium, magnesium and sulphate levels. As there is no more pumping from the mine into the river, the influence from the mine should have diminished. Water which contributed to the stream from the ash dams is derived from rainfall on top of the dams, as they are no longer in use (Speirs, 1990).

One of the major problems at old power stations is the build-up of sodium in the ash water. During the dry season large areas of white sodium sulphate precipitate can be seen in the area between the ash dams and the stream. As sodium sulphate is very soluble in water, it is washed into the stream after the first rain.



**Figure 26: Photograph showing the sodium sulphate precipitate between the ash dams and the Taaibos Spruit tributary.**

KB2 shows elevated levels of sodium, chloride and sulphate. KB3 also has elevated levels of sodium and sulphate but less than in KB2. The stream sample has high levels of sodium, sulphate and aluminium. The sodium sulphate that was precipitated and washed into the stream by the rain probably causes the higher salt load of the stream water.

When compared to historical monitoring data the quality of the boreholes and stream water is improving. This is due to no more contribution from mine water. The ash dams however are still polluting the ground and surface water to some extent.

The last monitoring borehole, **KB4**, is located west of the old coal stockyard. The borehole was drilled to a depth of 50 m and intersected the dolerite sill at 29 –50 m. The coal stockpile is underlain by about 14 m of soil and clay that form a practically impermeable layer above the shale and sandstone. The water level is at 15.76 m and the conductivity is 102 mS/m. This indicates that no significant pollution of the groundwater is taking place, apart from the elevated sulphate levels.

As the coal stockpile no longer exists, it cannot be considered as a potential pollution source anymore. Historical data shows improvement of water quality.

The rehabilitated ash dam located north of Kragbron next to the Mollensteen Pan will not be discussed under this section. Although it was historically part of the power station it will be discussed under farming activities, as the boreholes sampled in that vicinity were on the surrounding farms.

#### **4.4.6 Transport Companies**

No boreholes at Terblanche transport were sampled. The borehole on the Cargo Carriers site could not be sampled due to the obstruction of borehole equipment.

At the Bothma Transport depot the one borehole that is used for washing purposes was sampled. No geological information was available and no water level could be measured. The sample was taken at a pipe that flows into the reservoir.

The water quality (EC = 18 mS/m) is very good and of a Ca –HCO<sub>3</sub> type signature. The water chemistry is typical of the alluvial sand aquifer close to the Vaal River. None of the parameters

(except nitrate = 6.2 mg/l) analysed for exceeds the minimum requirements for drinking water. The results from a previous sample analysed by Bothma Transport, compares well with this analysis.

It is not expected that the transport companies play a significant role in the groundwater pollution in either catchment.

#### 4.5 Toxicity Testing

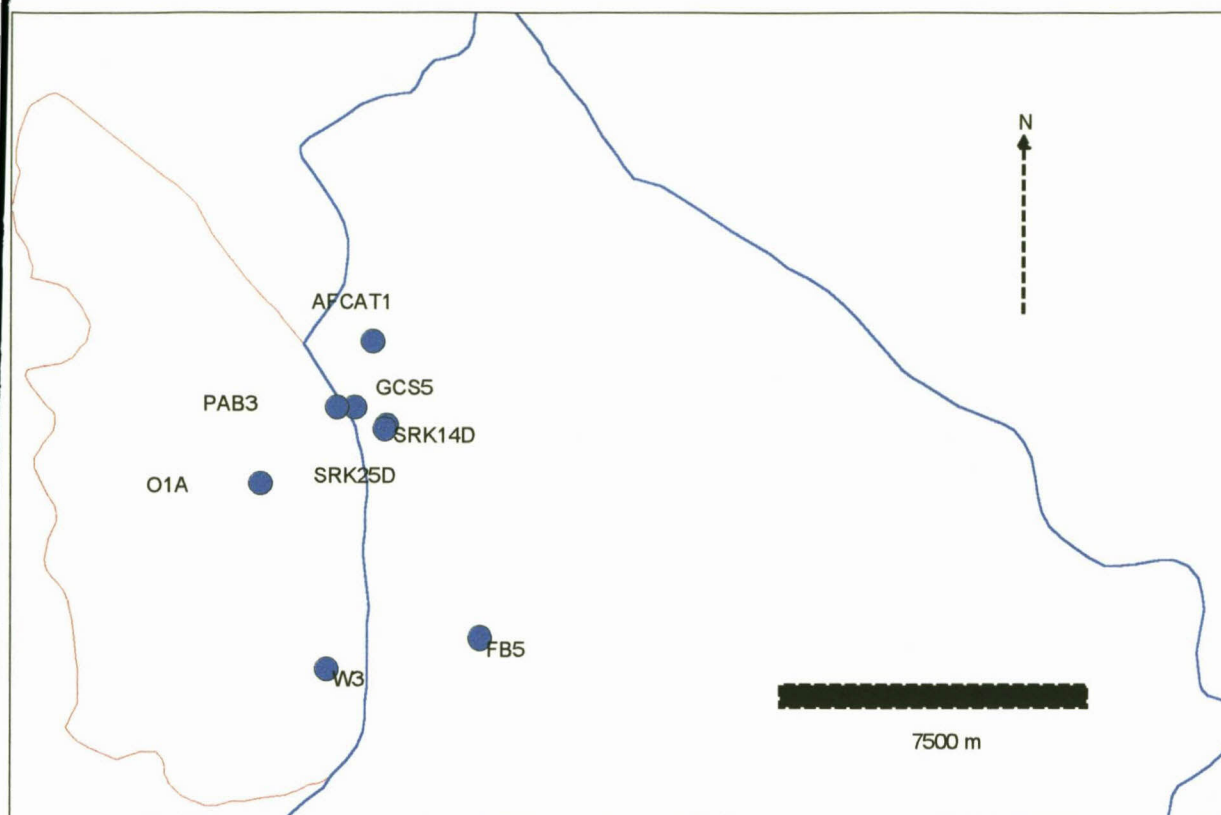
Twenty 2 l sample bottles were collected during the sample run, two samples for each borehole. These samples were submitted to the Institute of Water Quality Studies for toxicity testing. The number of samples was constrained by the time factor. The samples had to reach the laboratory within 48 hours of sampling and only five samples could be tested per week. The method of sampling was the same as used during the sampling for the inorganic chemical sampling.

The boreholes that were sampled for these tests are listed in the table below.

Site name	Borehole number	Water use
Polifin	SRK14D	Monitoring
Polifin	SRK25D	Monitoring
SCI (Waste disposal site)	O1A	Monitoring
SCI (Vencopark)	V2S	Monitoring
Petronet (Sasolburg Pumpstation)	AB3	Monitoring
Omnia	OB1	Monitoring
Karbochem	GCS5	Monitoring
De Kock (Moodraai)	FB5	Domestic
Afcac	AFCAT1	Industrial
EAC (Gysbertshoek)	W3	Stock watering

**Table 9: Boreholes sampled for toxicity testing**

During the selection of the ten sites, quality and water use was taken into consideration. Boreholes ACAT1, W3 and FB5 represented the main water uses of groundwater in the catchment. The other seven monitoring boreholes' selection was based on previous chemical analyses.



**Figure 32: Sites sampled for toxicity testing**

#### 4.5.1 Background

Traditional physical-chemical analytical procedures are used to monitor and control water pollution. Some of the chemical detection systems available are highly sophisticated, very sensitive and accurate. However these measures have certain disadvantages (Slabbert, 1998) when applied to control harmful chemicals in water, particularly in complex effluents. These can be summarised as follows:

- Water pollution involves a vast number and diversity of chemical substances and many harmful chemical pollutants are unknown,
- Chemical analysis cannot detect all possible harmful chemicals which may be present in water,
- Chemical characterisation is expensive,
- Chemical analyses cannot predict the effect of exposure to combinations of substances and cannot account for changes resulting from reactions within the matrix of constituents, and
- Chemical analysis cannot predict the long-term effects of toxicants.

Currently countries throughout the world are using biological toxicity assays for quality testing. But in South Africa a large part of this application is still aimed at research and development. For effective quality control standardised methods are required. Fish, water flea and algal tests have been standardised so far.

As with all water analyses methods, there are certain advantages and limitations of using these biotests.

Some of these advantages are:

- Provide an indicator of biological response in the environment
- Establish whether or not water/ effluent contains chemicals that are toxic

- Take account of chemical and toxicological interactions
- May provide an indication of the occurrence of contaminants (intermediates and/ or end products of degradation) that would not be detected by current laboratory analytical methods
- They are cheap compared with chemical analyses

#### Limitations:

- Results are variable and not always reproducible
- Usually reaches endpoint only after two days
- Only provides an indication of the toxicity of a solution and does not identify the specific toxic components, nor is it indicative of the complexity of the mixture
- Relationship between a laboratory result and a field effect is poorly understood (compare toxicity to single species under controlled conditions with whole ecosystem).

A toxicity test is a technique that determines the adverse affect of a chemical/ water/ effluent on a group of organisms or cellular/ sub-cellular systems, using standardised, reproducible conditions. Such a test either measures the proportions of test organisms affected (e.g. number of fish dead) or the degree of effect (e.g. percentage inhibition in oxygen uptake) after exposure to specific concentrations of a chemical/ water/ effluent. The actual factor that determines whether a chemical substance is potentially harmful or safe is the relationship between the concentration to which an organism is exposed and the duration of exposure.

Unlike chemical concentration, which can be measured with an instrument, toxicity can only be measured by use of living material. When using living organisms, toxic effects may be expressed in various quantifiable variables, for example mortality, egg hatchability, changes in size or weight, growth inhibition, changes in biochemistry, changes in physiology and changes in behaviour.

There are two types of tests, acute and chronic tests. In chronic toxicity tests, death of organisms is recorded but other effects such as on fertilisation, growth and reproduction are also monitored. These tests are used to observe the influence of a stimulus that lingers or continues for a relatively long period of time, often one-tenth or more of an organism's life span.

An acute test is used to determine the short-term effect of different concentrations of a test material on a group of test organisms. The organisms are exposed under controlled conditions. The organisms are selected to be very nearly the same age (which eliminates some variability in response) and are kept under almost ideal physical and chemical conditions. The exposure time varies according to the type of organism used for the test, but is usually no longer than 96 hours.

The most common type of acute toxicity test is the *acute lethality test*. Lack of movement of the test organism is usually considered as mortality. Experimentally, a 50% response (e.g. 50% mortality) is regarded as the most reproducible measure of toxicity of a test material. The concentration of the test material (water sample) that causes 50% mortality of the test organism is called the LC50 (median lethal concentration). The LC50 value is subject to the exposure time. If *Daphnia* (waterflea) are used in a 24-hour lethality test, then the test concentration that kills 50% of the test organisms will be referred to as the 24 h LC50 for *Daphnia*.

Bioassays are established techniques for the characterisation of wastewater. They can, however, also be used for the characterisation of surface and groundwater.

Studies on dealing with toxicity testing of groundwater are very limited. According to Dr. Anders Baun (Ph. D thesis: *Application of biotests for assessment of groundwater toxicity*, 1998), results from groundwater toxicity testing primarily should be used for hazard identification in terms of pointing out and ranking toxic samples. The present knowledge concerning aquatic toxicity tests on complex samples is insufficient for a proper risk assessment.

As part of a South African WRC project (Slabbert et al, 1998) a battery of biotests was performed on a number of water samples. These water samples included raw untreated drinking water, chlorinated drinking water, dam/lake water, river and groundwater samples. The results of the tests were compared and evaluated for applicability and effectiveness. The tests that proved to be the most effective for groundwater testing, was the water flea, algal bacterial growth inhibition and fish tests.

Detailed chemical analyses were also carried out to explain the toxic effects of the bioassays. The chemical analyses showed that, in general, potential toxic chemicals in the groundwater samples were low, and that the adverse effects were probably due to a combination of chemicals.

#### 4.5.2 Results

The results obtained for the toxicity testing are thus discussed keeping the above statements in mind. The results are in **addition** to the inorganic chemical analyses and are used only for pointing out and ranking the toxicity of the samples.

The full laboratory results are included in Appendix D and a summary of LC50 results is listed in table 10.

The standard 24-hour and 48 hour *Daphnia pulex* (waterflea) and 96 hour *Poecilia reticulata* (Guppy) acute lethality tests were used for the samples. pH and oxygen levels were adjusted to 6 – 9 pH and > 40% sat oxygen, respectively.

Sample number	Result as LC50
SRK14D	<i>Daphnia pulex</i> 48 h – LC50 = 3.8%
SRK14D	<i>Poecilia reticulata</i> 96 h – LC50 = 16%
SRK25D	<i>Daphnia pulex</i> 48 h – LC50 = 32%
O1A	<i>Daphnia pulex</i> 48 h – LC50 = 16%
V2S	<i>Daphnia pulex</i> 24 h – LC50 = 13%
V2S	<i>Poecilia reticulata</i> 96 h – LC50 = 34%
PAB3	<i>Poecilia reticulata</i> 96 h – LC50 = 14%
OB1	<i>Daphnia pulex</i> 48 h – LC50 = 13%
OB1	<i>Poecilia reticulata</i> 96 h – LC50 = 56%
GCS5	<i>Daphnia pulex</i> 48 h – LC50 = 65%
FB5	<i>Daphnia pulex</i> 48 h – LC50 = 95%
AFCAT1	<i>Daphnia pulex</i> 48 h – LC50 = NA (Mortality must be >50%)
W3	<i>Daphnia pulex</i> 48 h – LC50 = NA (Mortality must be >50%)

**Table 10: Toxicity results**

The following is a brief discussion of each sample tested:

- SRK 14D tested to be extremely toxic. This sample diluted to 3.8% of its original composition is still toxic enough to cause a 50% mortality in the *Daphnia*. The toxicity of this sample can be attributed to the organic contaminants that is present in this borehole. Although SRK 25D had no visible organic contamination, as in the case of SRK14D, it was also highly toxic.

- The high toxicity of PAB3 can be attributed to the hydrocarbon contamination at the pumpstation site.
- The very high salinity in O1A makes this water very toxic to living organisms.
- The same argument holds for V2S, which was very toxic despite the correction for acidity.
- OB1's high salinity also makes it very toxic to *Daphnia* while it is less toxic to the guppy. It must still be noted that at almost half strength it was still toxic enough to satisfy the LC50 criteria.
- The slight toxicity in GCS5 could arise from the high chloride and sulphate values.
- Interestingly, FB5 showed some degree of toxicity. It would seem that it could be that nitrate values are responsible for this slight toxicity to *Daphnia*. It is non-toxic to the guppies.
- The boreholes at Afcats and at the EAC feedlot at Gysbertshoek, both tested non-toxic to *Daphnia* or the Guppies.

Although there are certain chemical parameters in all of these samples that could contribute to the toxicity of the samples, the toxicity is most probably increased and caused by the complex combination of chemicals in these samples.

The most significant point that should be noted from these results, is that should water of very poor quality such as these found in some of the boreholes shown above, reach any water course the results would be catastrophic to the ecology of the rivers. This is a very likely scenario in the Leeu/Taaibos Spruit catchments, since shallow aquifers interact with and help maintain streams, lakes estuaries and most wetlands. These are factors that must be borne in mind when the final GMP is structured and catchment standards are drafted.

## 5 Geophysics

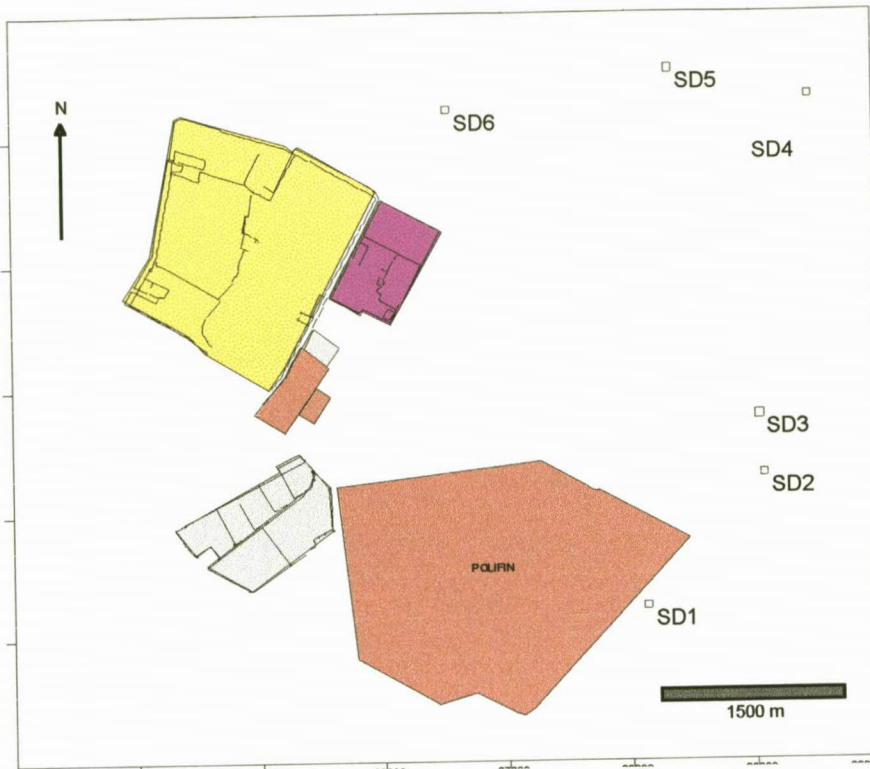
### 5.1 Resistivity soundings

A team of geophysicists from Geohydrology Head Office performed a series of six resistivity soundings in the area between the industries and the Taaibos Spruit

Due to the earth having a heterogeneous conductivity it is possible to measure the resistivity of different rock types. Usually more dense "dry" rock is more resistant than less dense moist rock. Therefore an intruding body that is more dense (e.g. dolerite sill) than the surrounding material can be delineated utilising the resistivity method.

An artificial field is created by passing an electrical current into the ground from a pair of electrodes, thus causing a potential difference between points in the vicinity of the electrodes. Essentially, the equipment consists of a direct current circuit and a voltage measuring circuit, which is able to measure the small voltages, developed.

The Schlumberger method was used during the investigation. This method involves the placing of four equi-spaced electrodes in a line on the ground. A current is passed through the outer electrodes. The potential between the inner electrodes was measured and the resistivity calculated. The resistivity is the electrical resistance per unit length. This gives the resistance down to a depth of approximately equal to the spacing of the electrodes. The electrodes are moved further away in stages to measure at greater depths. This is called a sounding and only measures a profile over depth at a single point.



**Figure 33: Positions where soundings have been done.**

Results of these soundings are in figures 31 and 32. The purpose of these soundings was to determine the different layers and approximate depth for the layers. The results were calibrated with borehole SRK2 (Outside the property of Polifin) to determine the depth to the dolerite sill. From the above soundings it can again be seen how variable the dolerite intrusion is.

The depth of the dolerite as well as the depth and level of weathering of this sill varies in a fairly small area. Borehole logs throughout the area reiterates these findings. These intrusions play an important role in the distribution and transport of the contaminants and groundwater gradients. As far as possible these variations will be considered in the numerical modelling, although on the scale of model, it will be a very simplified version, giving more generalised results.

### SASOLBURG SCHLUMBERGER SOUNDINGS

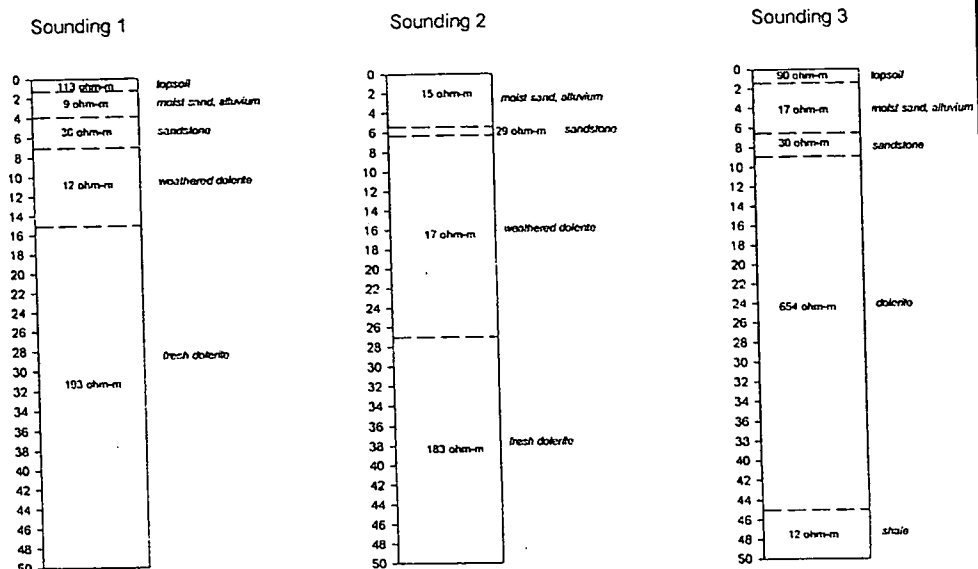
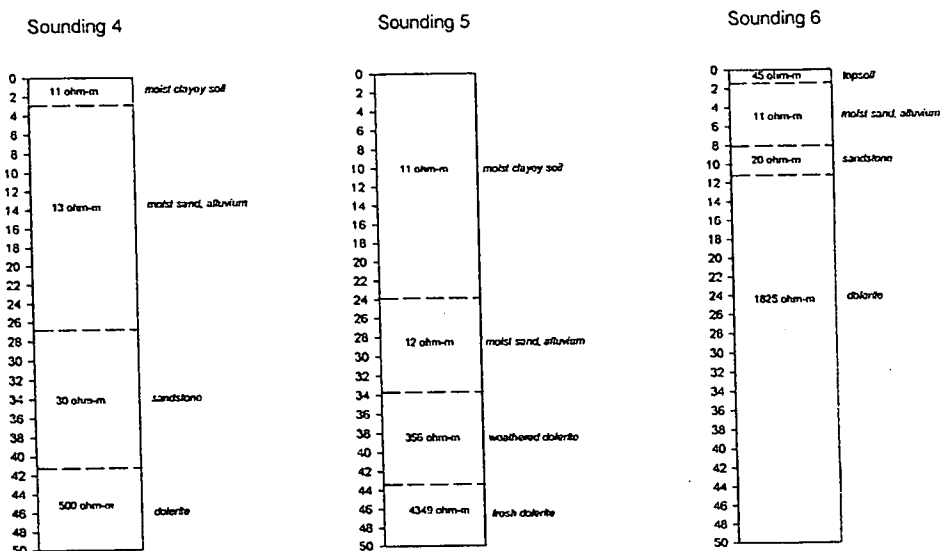


Figure 34: Interpreted results of the soundings

### SASOLBURG SCHLUMBERGER SOUNDINGS



S26.47.32,2  
E027.53.58,9

S26.47.24,7  
E027.53.18,2

S26.47.36,3  
E027.52.12,6

( coord. in deg.decimal minutes)

Figure 35: Interpretation of soundings

## 5.2 Aerial Geophysics

An airborne geophysical survey was conducted by the Council for Geoscience, on the farm Waagstuk 78 and a portion of Driefontein 2, north of the industries. The purpose of the survey was to identify subsurface geological features that might be striking in a north-south direction from below the industries towards the Taaibos Spruit. The magnetic and radiometric methods were used for the survey. A grid of 100 meter line spacing was flown over the area. Recordings were taken at intervals of 3 meters for the magnetic data and 30 meters for the radiometric data. Some of the results are shown in Appendix E.

A study of the subsurface is necessary to delineate possible geological structures, such as dykes or fault zones (Groenewald, et al, 1999). This is necessary in order to estimate if leakage of any waste material can cause pollution to the surrounding area via underground water systems and into the adjacent river system.

The magnetic method measures subtle variations of the earth's total magnetic field from point to point, due to the differing magnetic mineral content in different rock types. Readings are noted in nanoTesla.

The airborne gamma-ray spectrometer is an aircraft-mounted multi channel spectrometer, which is used to measure gamma rays in several energy windows. For normal geological mapping, and for the detection of naturally occurring radionuclides, three energy windows, centred on 1.46 MeV, 1.75 MeV and 2.61 MeV are used. These measure the activities of  $^{40}\text{K}$ ,  $^{214}\text{Bi}$  and  $^{208}\text{Tl}$  respectively, these activities then being used to calculate the concentrations of  $\text{K}_2\text{O}$ ,  $\text{U}_3\text{O}_8$  and  $\text{ThO}_2$  ( $^{214}\text{Bi}$  and  $^{208}\text{Tl}$  are gamma emitting intermediate daughters of  $^{238}\text{U}$  and  $^{232}\text{Th}$ ). In addition, one wide band or total count is measured. Note that gamma rays have extremely limited penetration in soil and rock, so the results of any gamma ray survey represent the radio-element concentration of the top few centimetres of the earth, while the count rate over water is zero after correcting for background radiation.

The investigators made the following conclusions and recommendations:

- The magnetic method worked exceptionally well for delineating the structures on site. The radiometric method shows some interesting anomalies that need to be verified by sampling and drilling. The structures correspond well with those mapped on the 1:250 000 geological map.
- The interpretation of the data needs a lot of informative backup. Existing borehole information together with coal exploration borehole data will provide a better understanding of the detail geology.
- Agricultural activities could account for the potassium anomalies.
- Present stream trends could account for possible sediment enrichment of radionuclides through natural processes.
- Drilling of exploration boreholes on the edge of the dolerite sill, together with water and soil sampling, will provide information on the possible pollutant transfer along this weathered zone to the streams and wetlands.
- In order to gain more information about the conductive zones, it is recommended that the electromagnetic method must be used for further geophysical investigations.

As there were no conclusive proof that there are any subsurface structures that could act as conduits to pollution, no such areas were taken into account with the numerical modelling.

## 6 Surface Water

Although it was beyond the scope of this report, some of the surface water aspects were dealt with. WISH was again used as database and presentation tool for the subset of surface water quality data obtained from DWA&F. If this is carried through, an interactive database of surface and groundwater quality will be established. Since all contributing members have WISH at their disposal, reporting can be done in a WISH compatible EXCEL format and the collated data can be integrated by DWA&F. This will provide all members with the capability of viewing the data relevant to the catchment and seeing the impacts of all the site activities. In this way the members of the Forum and the state regulators can manage the water issues in the catchment far more easily and efficiently than is currently the case.

The Vaal Barrage Interim Objectives were entered into WISH to use as comparison for evaluating the water quality at the different sampling points. WISH has the capability of being easily updated should these standards be altered in the future, thereby enabling all interested persons to change the standard and re-evaluate the data using the new guidelines. The system is thus dynamic for any changes in policy or approach within the eventual catchment committee.

When viewing the data a couple of points are immediately evident. The first of these is that the sampling points are situated such that a detailed record of the discharges from all key points in the catchments can be obtained.

The variability in quality over the catchment and over time is also evident. One can thus easily see the influence different activities within the catchment have on the quality. Unlike groundwater systems, surface water qualities can show a great variability over short space of time. This is particularly true in areas where "unnatural" discharges are added to system. Thus any event such as the overflow of a particular holding dam in an industrial area can immediately produce a sharp increase in concentrations at a particular sampling point. This increase can be very short lived depending on the duration and magnitude of the overflow.

From the time series graphs, an increase in EC over time, is clear at all the sites. Also important to note is that the water quality at several sites greatly exceeds the set objectives for the Vaal Barrage and is thus cause for concern. Detailed analysis of the flow paths, flow rates and qualities at different points is needed to make meaningful deductions. This must be done in the next phase when the catchment management plan is constructed.

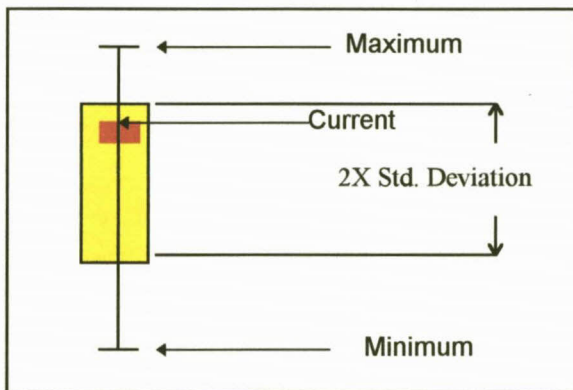
Another way of viewing the data is by employing graphs which display the minimum, maximum, current and standard deviation at each site for the selected period. This graph shows the variation in each site more clearly with the current value shown. In longer time periods, the variability and the maximum and minimum records can easily be viewed and compared.

Each of the bars for a number of sample sites can be plotted on a single chart for comparison. The sketch of such a bar, shown in figure 33, serves to explain the meaning of each element in the presentation. Instead of only an average value twice the standard deviation (one above and one below the mean) is supplied to give a better idea of the usual range of values, not just the maxima and minima which are also shown in these plots. The standard deviation is a measure of the distribution of the values, in this case, over time. It thus represents the distribution of the values about the mean or average. A small standard deviation thus indicates a stable sample while a large value represents a high variation in values.

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**Figure 36: Explanation of the Elements Plotted in a Maximum, Minimum, Average and Current Plot (Box and Whisker Plot)**

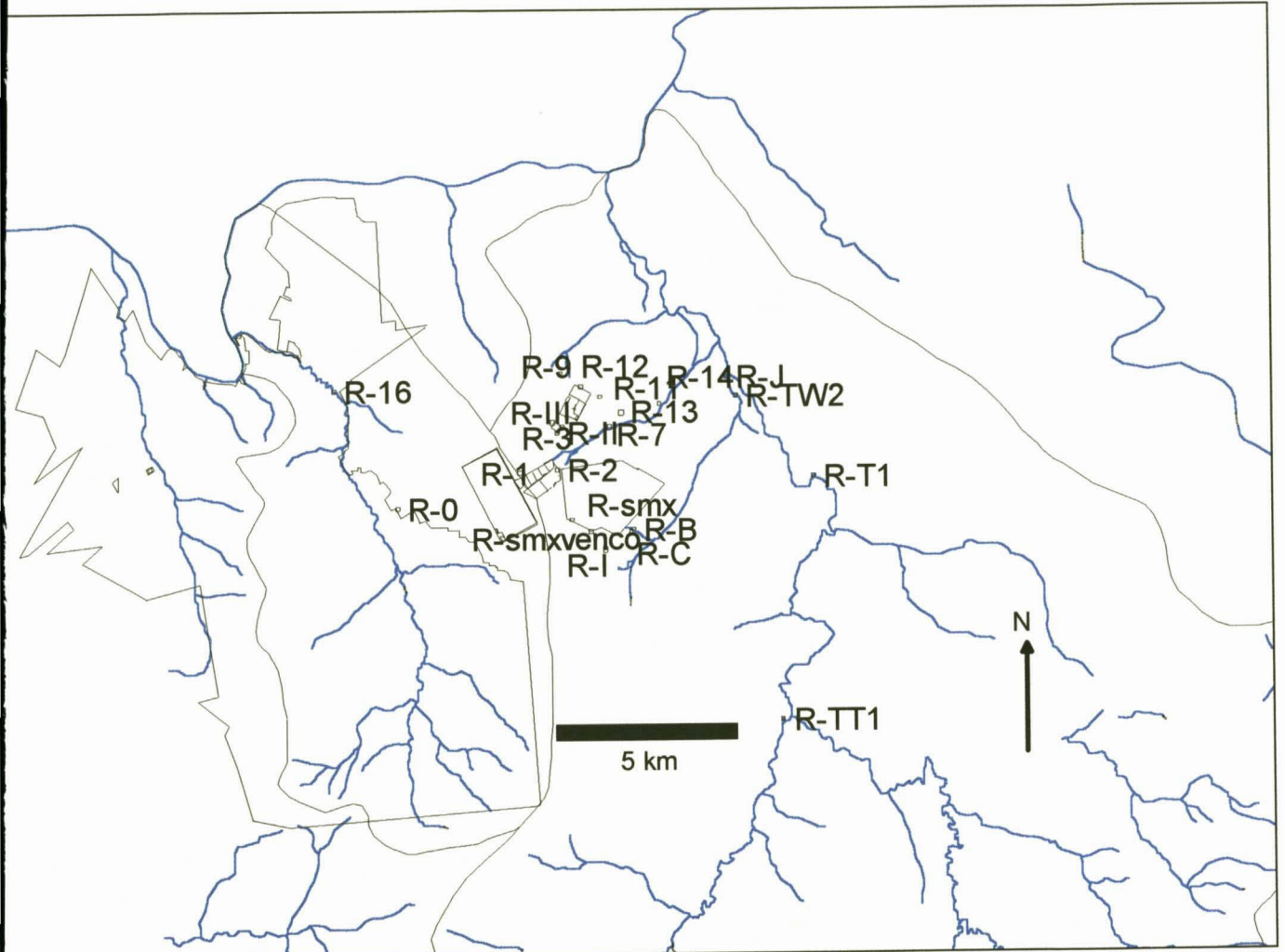
In this way a visual comparison may be made between the different sampling points for each period, at the same time, the history of each sampling point can be assessed. For example, if the bar shown in the sketch were an actual data point, it is clear that the current value is higher than the average. If this is the case for other parameters, and the condition persists through a number of monitoring events, then progressive degradation is indicated.

These graphs are also displayed below. The graph where the two sites with the highest values have been removed (figure 41) is also shown. When the masking effect that these two high values have, is removed, it can be seen that the other sites are also very variable and often greatly exceed the Interim Vaal Barrage objectives.

A graph (figure 42) showing the variation from the upstream samples to samples taken once the industrial discharges are included is also shown to give an indication of the impact of the industries on the Taaibos Spruit's quality.

It is thus clear that a lot of data interpretation can be done using the WISH system. Since the data inputs are relatively simple, over time all the industries' and DWA&F's data can be combined to give a very good representation of the water quality (both surface and groundwater) over time. As a

management tool this will be extremely powerful and user friendly for all members and interested parties in these two catchments.



**Figure 37: Positions of Surface Water Sampling Sites in the Area**

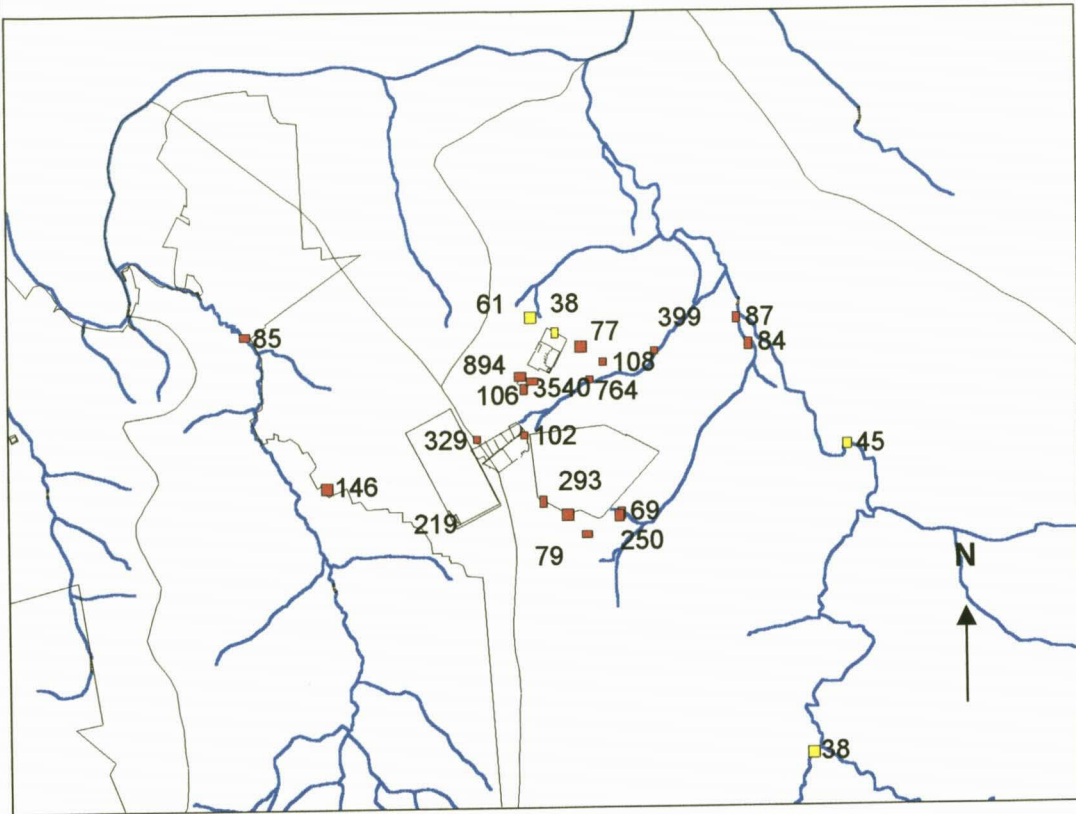


Figure 38: Last Recorded Values at these sites as displayed by WISH (Points in red exceed the Interim Vaal Barrage Objective and those in yellow are in excess of the Ideal Objective)

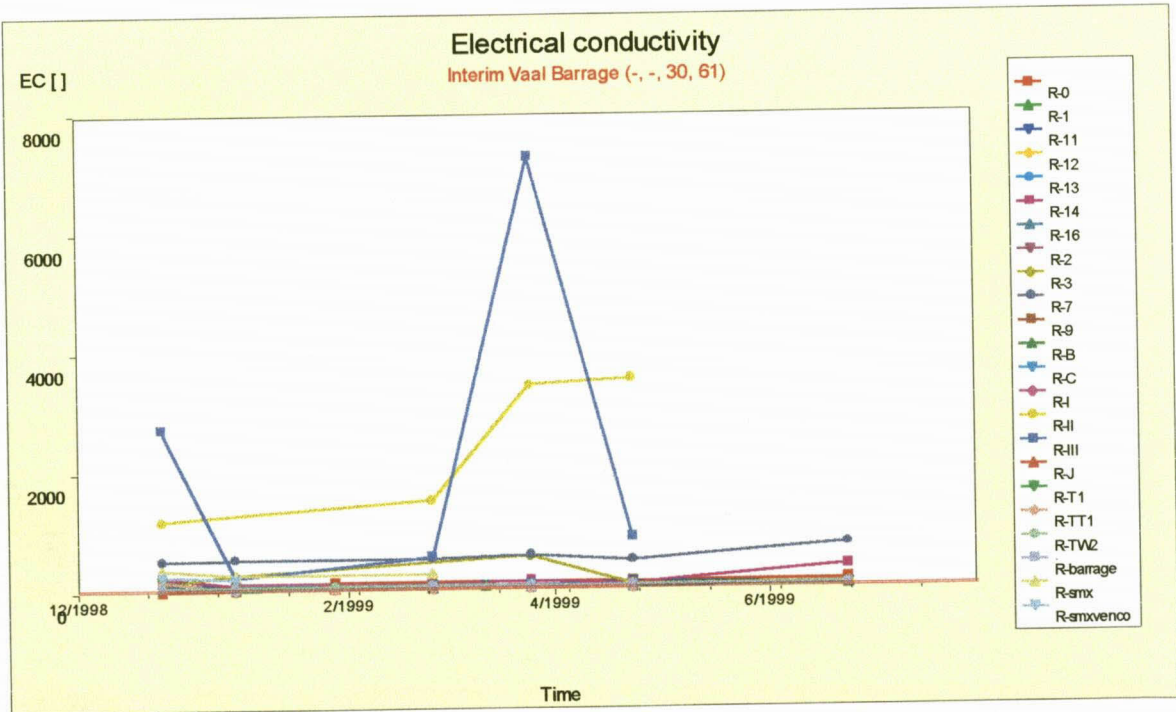


Figure 39: Time Series graph of all sites for period from December 1998 to July 1999

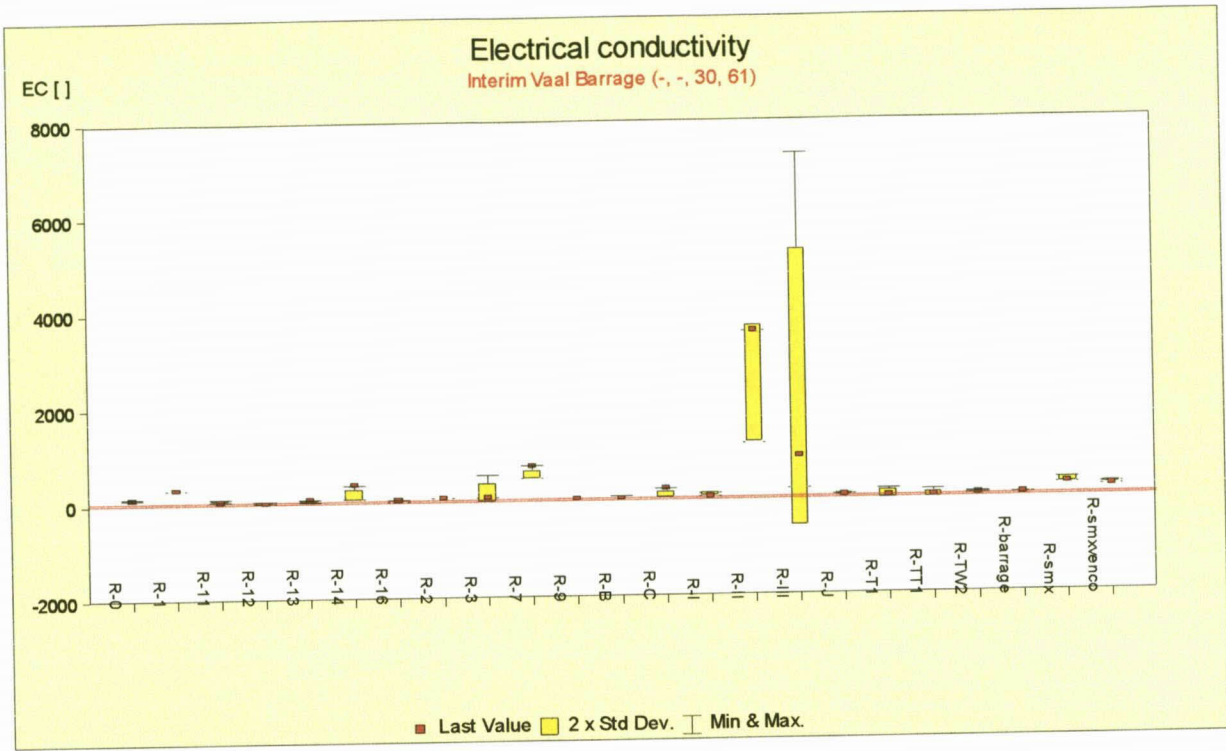


Figure 40: Electrical conductivity variability

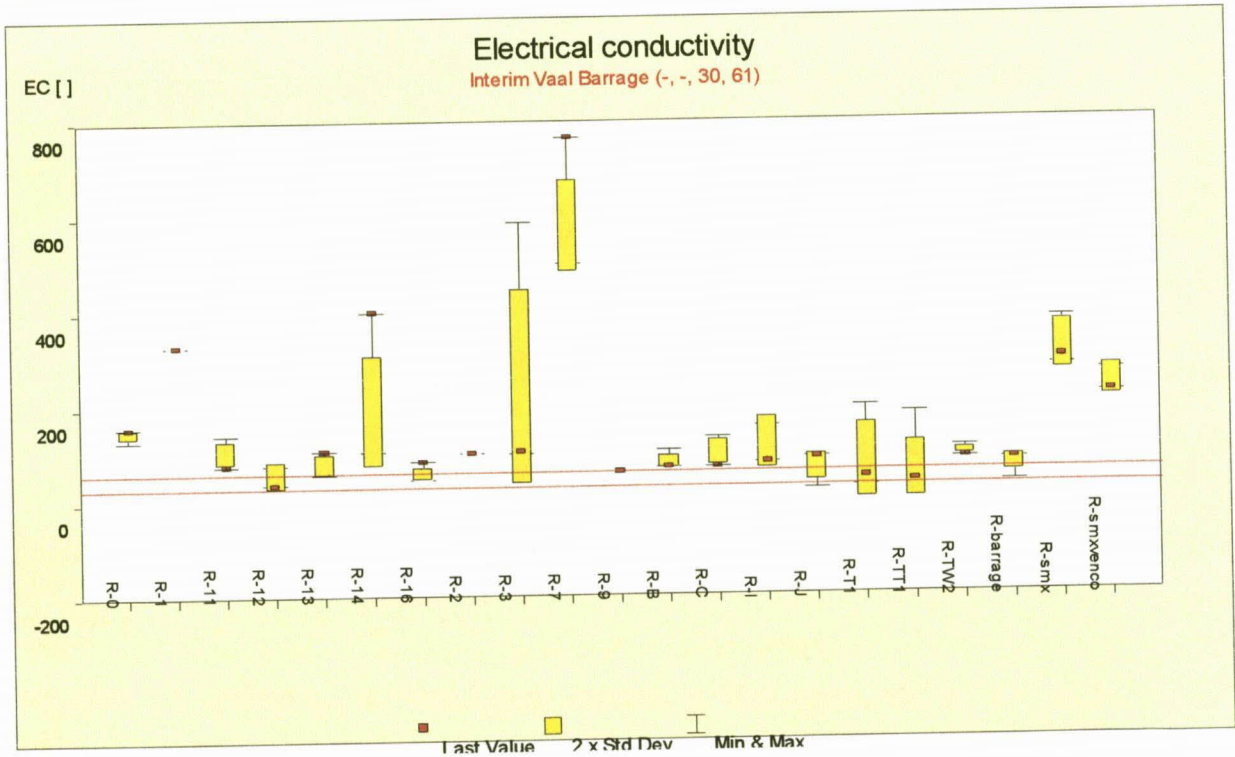
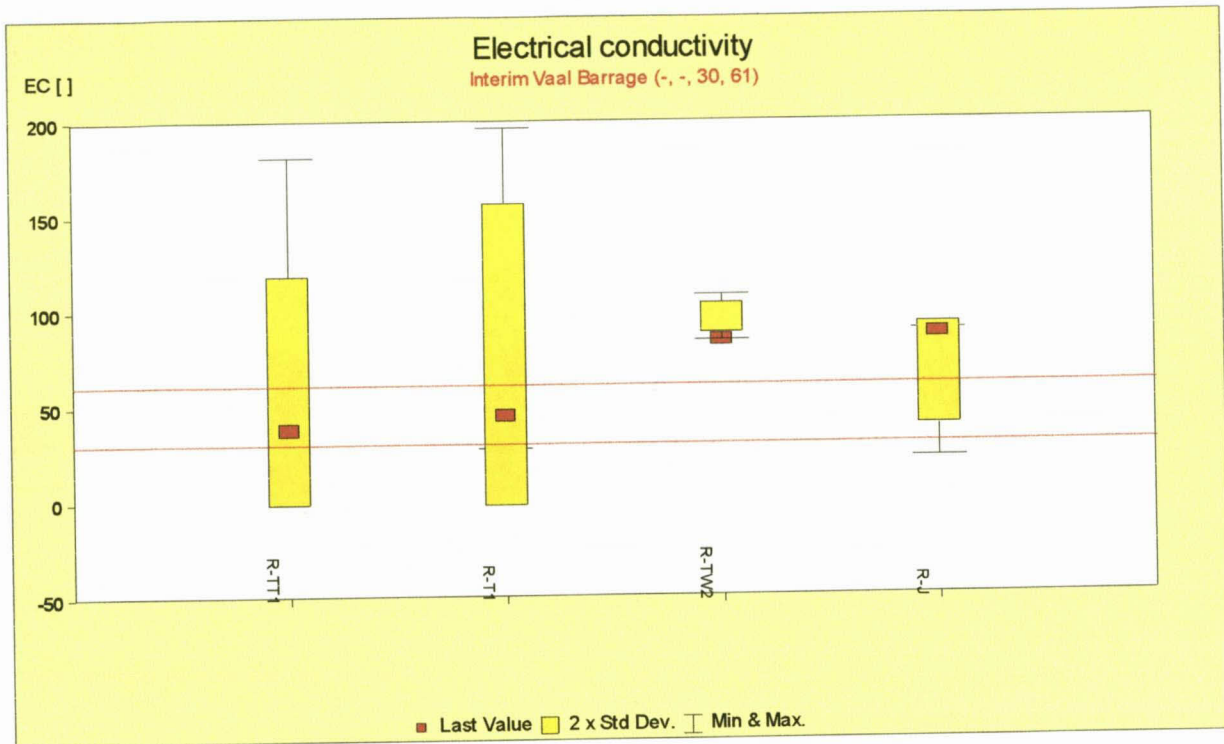


Figure 41: Electrical Conductivity variability shown with sites RII and RIII removed



**Figure 42: Figure showing progressive increase in salinity as Taabos flows past industrial area**

## 7 Numerical modelling

### 7.1 Previous Investigations

Several of the member companies in the Forum have done hydrogeological investigations on their sites. As a result there have been several previous modelling investigations in the area (VSA, 1996; ENC, 1998; IGS, 1995; SRK, 1999; and others), and additionally different researchers have also determined the aquifer parameters. All these investigations have, however, been site-specific and different results have been obtained. In an area as large as this, the variations in aquifer parameters have to be taken into account but can be averaged out unless the variation has a marked effect on groundwater movement.

The following table shows a selection of aquifer parameters as obtained by different investigators:

Site	Transmissivity (m <sup>2</sup> /day)	Hydraulic Conductivity(m/d)	S-value	Investigator
Karbochem		0.08		GCS 1991
Sigma Underground	10-13 (Sandstone)			VSA 1996
Karbochem	0.5-1( perched)			EMC 1997
	0.75-6 (semi- confined)			
Northwest Strip Mining	25-50 (alluvium)			VSA 1996
	0.5-5 (intermediate)			
Polifin		0.01-0.5 (perched) 1-10 (fractured)		SRK 1999
Coalbrook	0.7-60		0.0003- 0.00005	Hodgson 1987
Sigma Wonderwater	5-15			VSA 1996
SCI	0.58-8.8			EMC 1998

Table 11: Aquifer parameters as obtained by other investigators

### 7.2 Conceptual Model

The crux of any modelling exercises rests on the proper conceptual design of the model. This design incorporates all the information available on the system and simplifies it via several assumptions. In this way the system can be adequately summarised and different scenarios simulated.

Modelling an area of this magnitude and complexity is an iterative process, requiring incorporation of factors as the investigation progresses.

For the area under investigation the system was simplified by using the following assumptions.

- Previous modelling exercises (EMC, 1998, IGS, 1995, VSA, 1996, etc.) were taken into account and the information used and generated by these were in most cases incorporated into the model.
- The model was done over a very large area. Due to this and the uncertainties in the geological variation of the area, a two-dimensional model was used. Most previous modellers used two dimensional models on specific sites to obtain results, on a larger scale the effects of the variations should be even less noticeable. The model used in this exercise was a 2D finite element model.
- Due to lack of detailed information, no reactions such as retardation, adsorption, etc. were taken into account.
- Despite evidence of some so-called "perched" aquifers in the area, little evidence exists to suggest that they are pervasive, and therefore it was felt that on a regional scale the aquifer parameters could be averaged out.
- From previous investigations on several of the industries and mining areas, it was concluded that the dolerite sill forms a virtually impermeable layer underlying most of the area.
- The depth to this sill varies but for the purposes of this modelling exercise this variation was averaged to give a shallow aquifer depth of 20m.
- This aquifer incorporates all the material overlying the sill. This approach is used fruitfully by Sigma Collieries for their classification and monitoring. (Hobbs, Pers Comm, 1999)
- The country rocks were assigned typical Karoo rock parameters, as was confirmed by the aquifer tests performed on the boreholes in the area. From these tests an average T value of  $3\text{m}^2/\text{day}$  will be used.
- Previous investigations and evidence collected in this project have suggested that for the aquifer(s) overlying the sill a good correlation between topography and water levels exists. Consequently Bayesian interpolation techniques could be used to generate water levels throughout the area
- The dolerite intrusions are considered to be very important in terms of water and pollution movement. It is felt that it forms a virtually impermeable base along which any contamination should move.
- The deeper aquifers are of very little consequence to pollution spreading and are disregarded in this initial modelling phase.
- Several investigations have suggested that fracture zones may be present. These zones represent preferred pathways along which pollution can be transported by the groundwater. Due to manmade structures in the industrial area that cause high interference with geophysical techniques these structures could not be delineated in this area. Since the geophysical survey of the area north of the industries did not show any clear preferential pathways or structures along which pollution could be transported, such zones were not included in the model and the effects were averaged.
- The alluvial-type aquifer alongside the Vaal River needs to be assigned different values to the Karoo type rocks in the rest of the area.
- Areas of notable subsidence and the opencast mine pit have also been included in the model.

### 7.3 Methodology

It is pertinent to reiterate that the results given below are generalised results based on limited amount of information. *At this scale the models are necessarily an averaged overview giving indications rather than absolute values.* These results should therefore not be used to do site specific evaluations.

All the results must be examined with this in mind.

The software used was the *Aquamod for Windows* suite of programs.

The first step when undertaking a modelling exercise is to delineate the extent of the model. For this exercise an area was chosen to include all the likely impactors on the groundwater in the area. A finite element network was set up for this area using the program Netgen. The network was constructed in such a way as to incorporate the streams and rivers in the area and the most important features as far as impacts on groundwater are concerned. A finer network was constructed around the streams, in the industrial area and around the opencast mining, so that more accurate answers could be obtained in these areas.

Different zones were included to account for the rivers, tributaries, alluvial/colluvial sediments, the opencast pit, and zones of subsidence. The rest of the area was assigned to a single zone with average parameters.

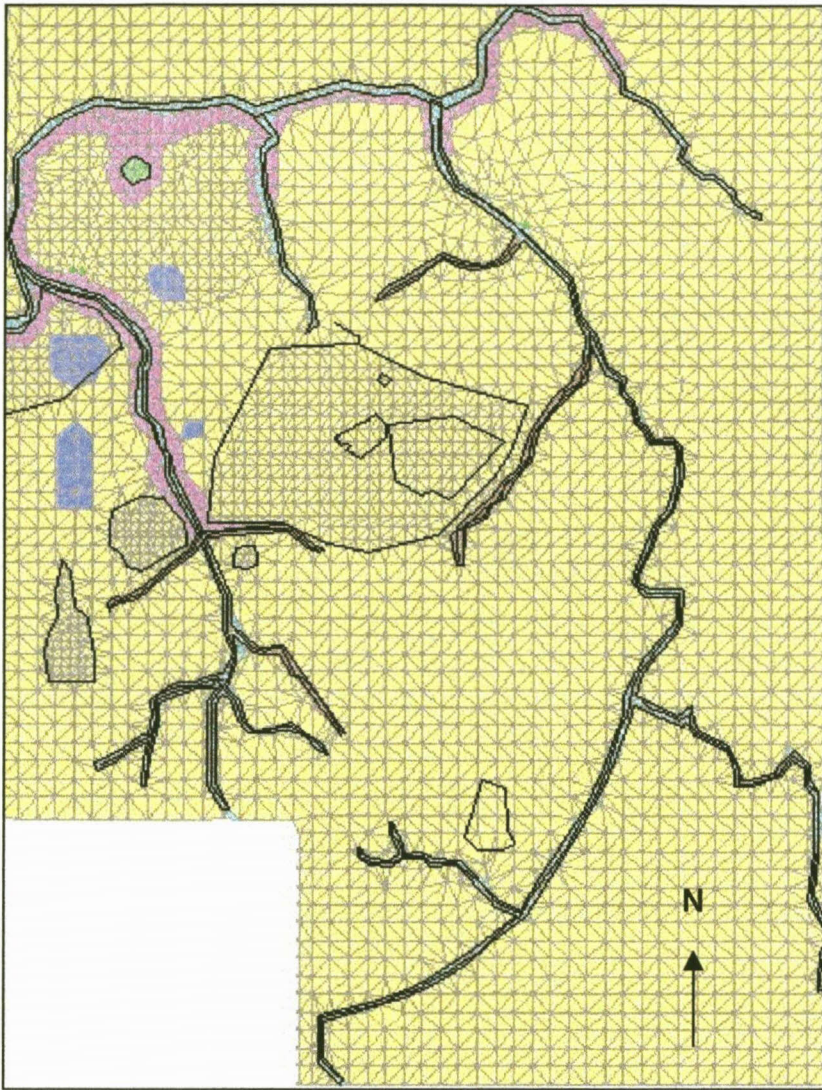
Table 12 lists the hydrogeological/ aquifer parameters assigned to each of these zones.

Zone	Colour	Transmissivity (m <sup>2</sup> /d)	Storativity
Shallow Aquifer	Yellow	3	0.001
Alluvial Aquifer	Pink	25	0.07
Rivers	Blue	50	0.001
Tributaries	Red	40	0.001
Subsidence Zone	Purple	15	0.1
Opencast Pit	Green	50	0.2

**Table 12: Aquifer Parameters used in the network**

The following figure indicates the constructed network with the catchment boundaries and streams shown for reference. Aquifer parameters used are also shown. A small transmissivity (3 m<sup>2</sup>/d) and S-value (0.001) were assigned to the shallow aquifer zone. Higher T values were assigned to the alluvium and subsidence zones, with the river zones assigned high T values and low S values (50m<sup>2</sup>/d and 0.001 respectively) to realistically simulate field conditions. The river tributaries were assigned lower T values (40 m<sup>2</sup>/d) to take into account lower flow rates than the expected flow rates in the main streams.

The boundary conditions consisted almost entirely of no-flow boundaries with the exception of constant heads where the river tributaries flow into the model. The no-flow boundary conditions were chosen because areas of interest for the transport model were beyond influence from this boundary. The constant heads were assigned to the river tributaries to ensure that the flow would follow the river flow direction and not flow into the aquifer.



**Figure 43: Network elements and zones (Area: N-S 22.1 km, W-E 19.7 km)**

The initial water levels are of great importance when undertaking any modelling exercise, since they are largely responsible for the gradients and flow directions which exist. As stated previously, use was made of the Bayesian interpolation technique to obtain water level contours throughout the area. Previous investigators in this area have also made use of this technique.

In this technique use is made of measured water levels in the area, topography throughout the area and the correlation of topography and measured water levels. Use was made of all measured water levels from boreholes considered to be part of the broadly defined shallow aquifer. In the regions where several measurements are available the interpolation leads to an accurate picture of the water level contours. Extrapolation of water levels to areas where few or no measurements are available often leads to inaccuracies and seemingly discontinuous gradients. To compensate for these inaccuracies the water levels are smoothed to give a more accurate representation.

The following graph gives a correlation between the topography and the water levels measured in the area. The linear relationship between the water levels and topography vindicates the use of the Bayesian interpolation technique.

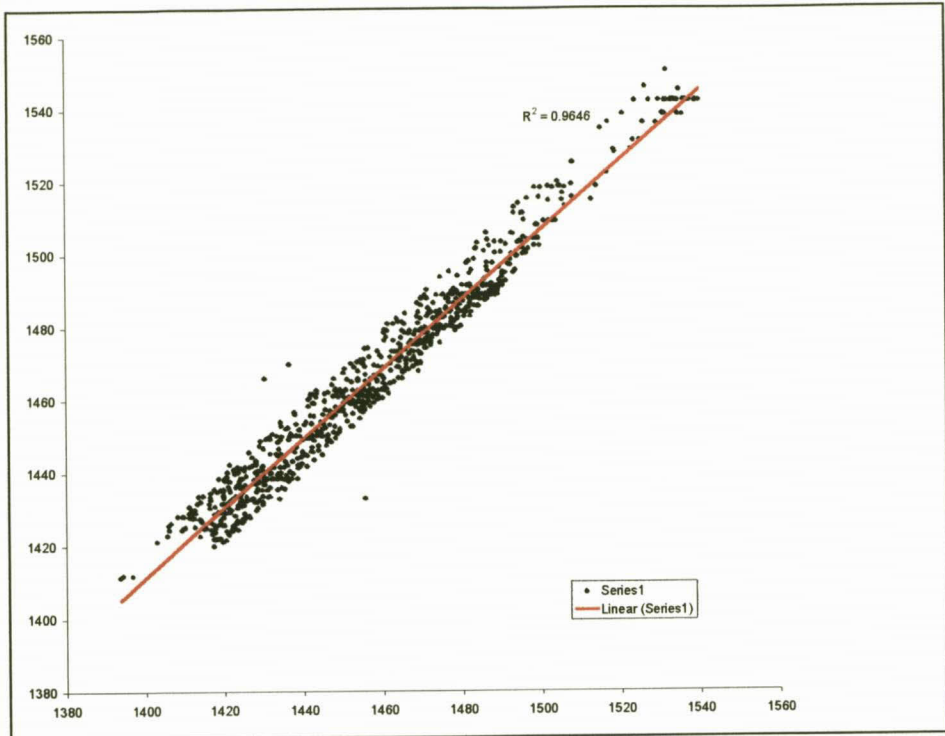


Figure 44: Correlation between topography and water levels

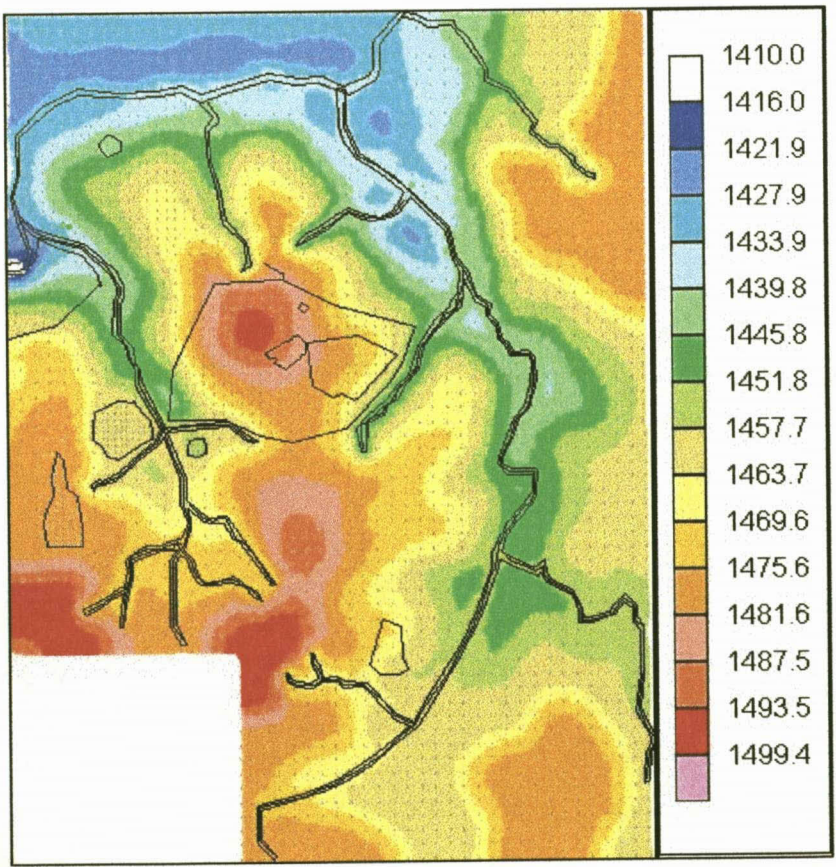
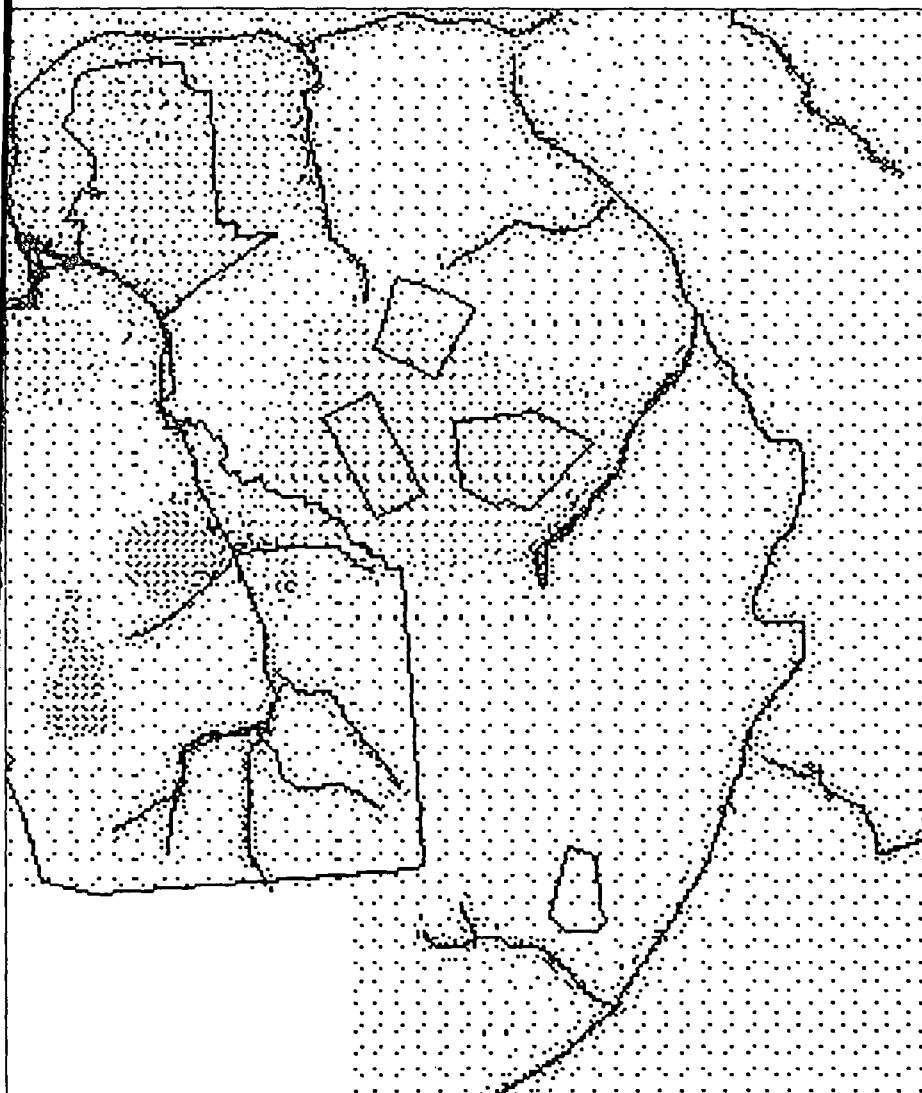


Figure 45: Smoothed Water Levels (mamsl) used as Initial Values.

Figure 45 gives the smoothed water levels that were used as initial values for the flow and transport model.

A flow simulation of the area was done to obtain the flow patterns and velocities throughout the area. The water levels and flow directions correspond well to those simulated by VSA, 1996. From these it could then be determined in which direction groundwater would move.

Figure 46 shows the simulated groundwater velocities for the area using the parameters shown previously. It must be noted that for this initial model the influence of rainfall recharge was disregarded, by running the model under pseudo-steady state conditions.



**Figure 46: Flow velocities and directions across the entire area**

The flows were used to obtain an indication of the directions and rate of propagation of any pollution plumes which may arise. These flow directions correspond well to those given by EMC, 1997, IGS, 1995 and SRK, 1999.

After the completion of the flow simulation several transport models were run to give an indication of the extent of the plumes and the magnitude in terms of concentration for EC, SO<sub>4</sub> and NO<sub>3</sub>. Areas at risk were also highlighted.

#### **7.4 Transport Modelling**

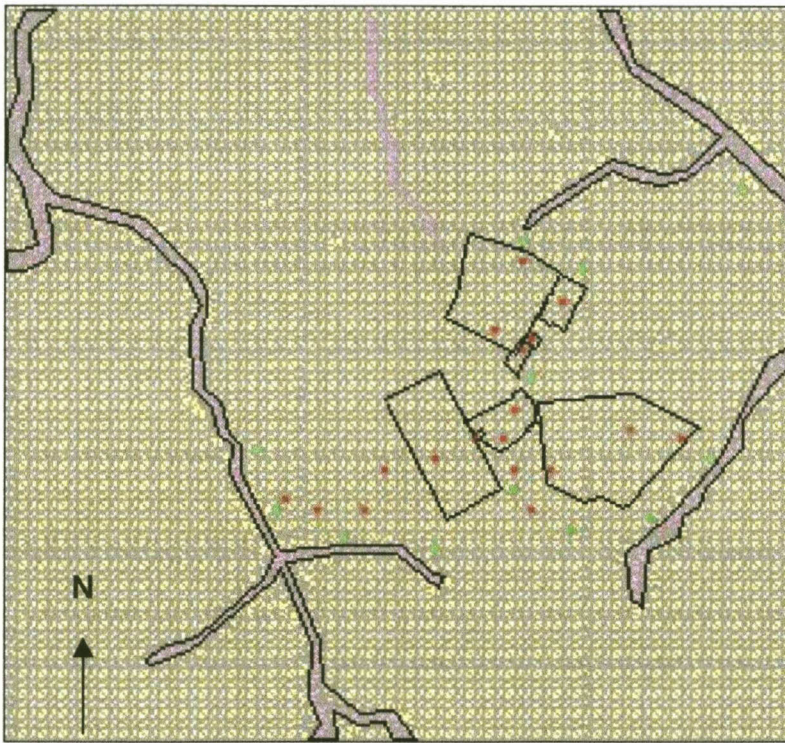
A smaller network with the same parameters used in the main network was set up for the transport models. This smaller network included the industrial areas and the rivers and tributaries most likely to be impacted on by contamination from the industries.

The aquifer parameters that were used in setting up of this network were the same as in the original. The transmissivity value assigned to the tributaries in the first network was lower than in the main streams but after several simulations the results obtained with one transmissivity value for the rivers and tributaries yielded more realistic results and correlated better with previous modelling results (EMC, 1998).

The dispersivity values used differ from those used in previous models. Values of 100 and 10 were used respectively for longitudinal and transversal dispersivity. This is due to the size of the pollution plumes. As a rule of thumb (Chaing, 1999, Pers. Comm.) the longitudinal dispersivity should be approximately 1/10 of the length of the plume :

$$\alpha L \sim \text{length of plume}$$

$$10$$

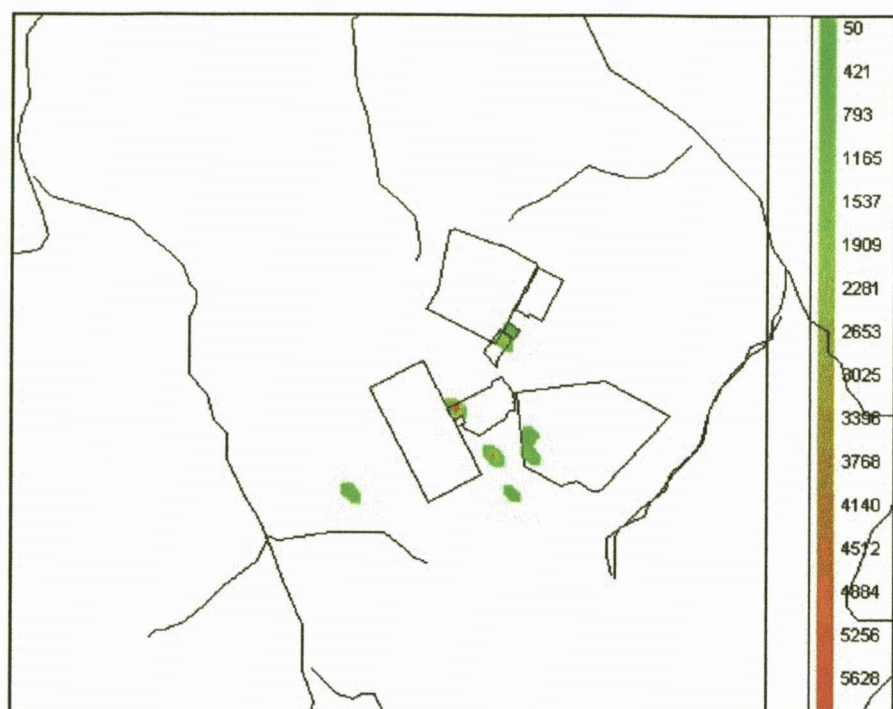


**Figure 47: Smaller network used for transport model with positions of pollution sources and observation nodes. (Pollution sources-red, observation nodes-green) Area: N-S 11.5 km W-E 10.8 km**

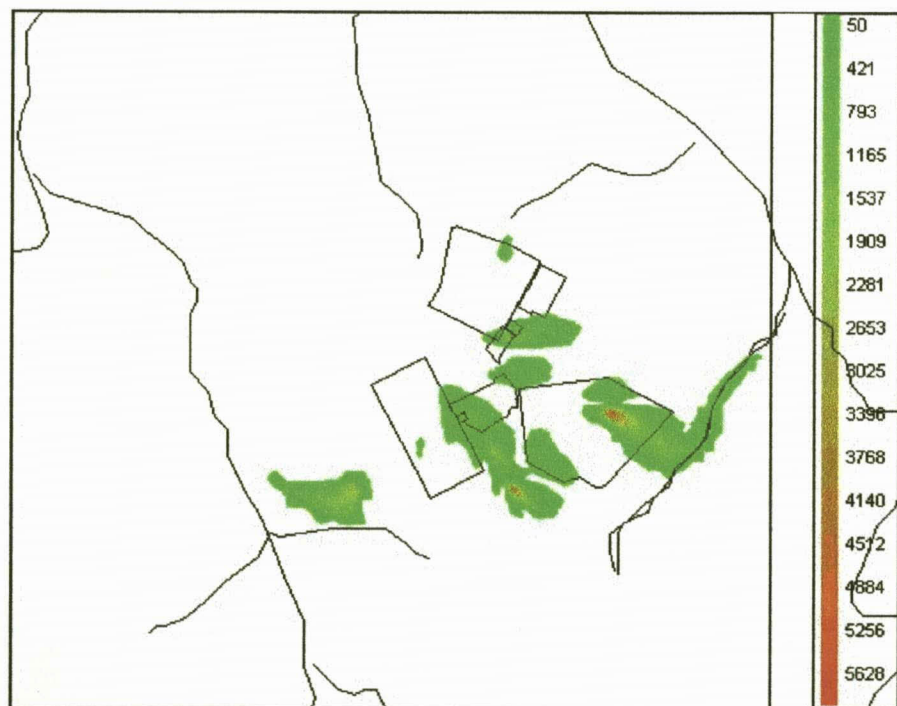
During the literature review and the sampling phase, possible pollution sources were identified. Transport models were run for three chemical parameters (Sulphate, nitrate and conductivity). The values used for these parameters were the values measured during the sampling phase of the project. This enabled us to determine the extent of the pollution plumes over a time period of 20 years.

#### 7.4.1 The results

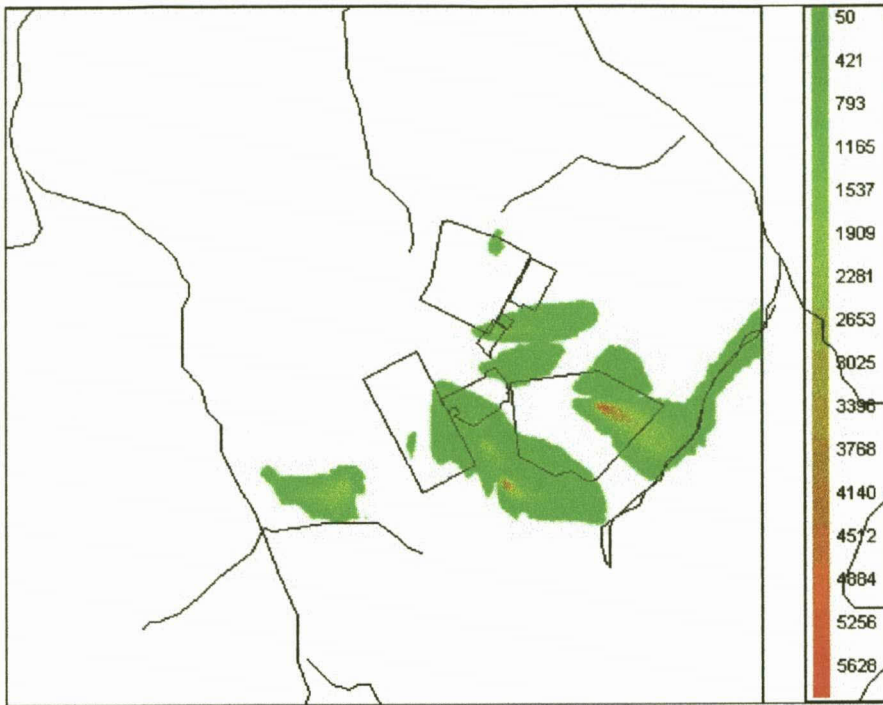
When viewing the results, it is again mentioned that several assumptions (such as no reactions between constituents, no adsorption or retardation etc.) were made to simplify the modelling. These results should be used as tools to guide the rest of the process of constructing an integrated catchment management plan.



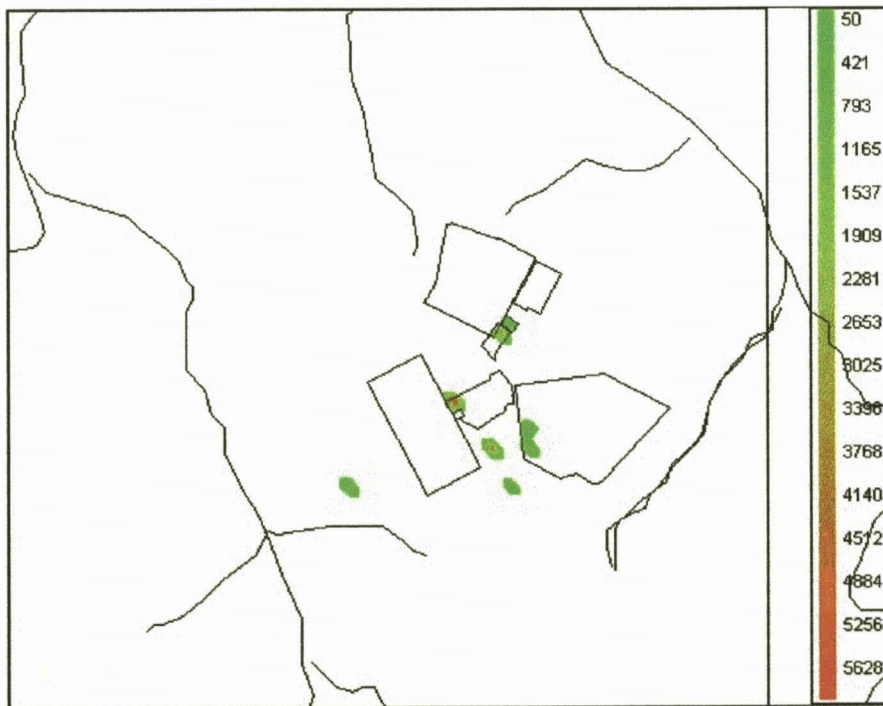
**Figure 48: Initial concentrations for EC (mSm)**



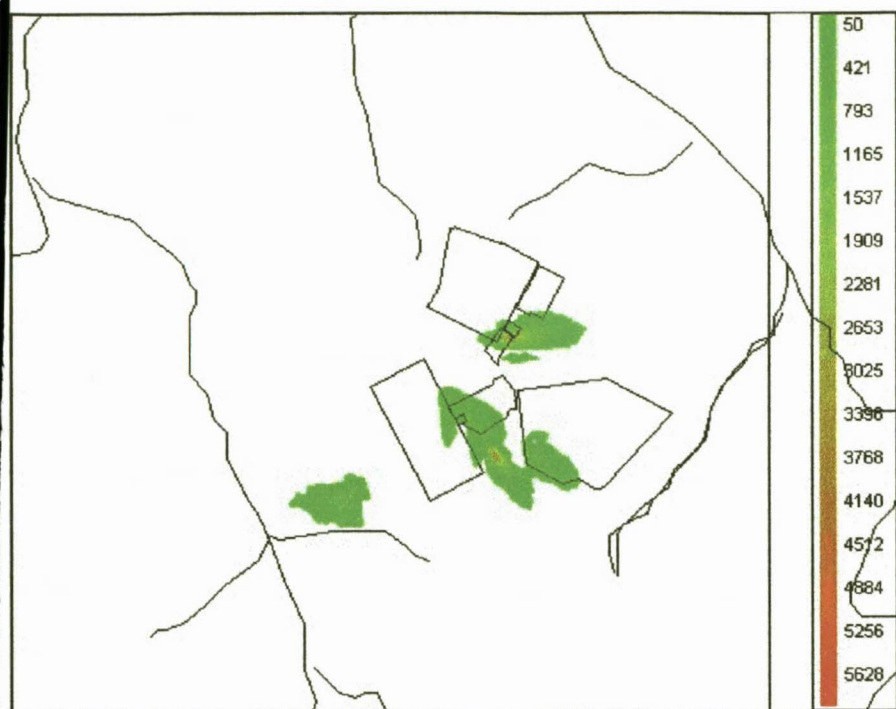
**Figure 49: Plume spread for EC after 10 years (mSm)**



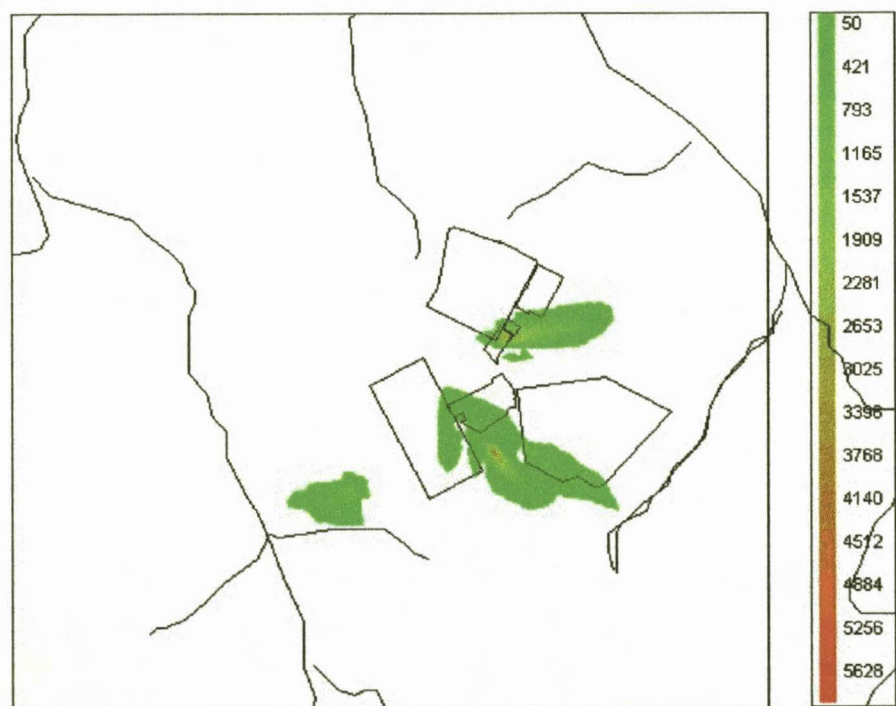
**Figure 50: Plume spread for EC after 20 years (mSm)**



**Figure 51: Initial concentrations for nitrate (mg/l)**



**Figure 52: Plume spread for nitrate after 10 years (mg/l)**



**Figure 53: Plume spread for nitrate after 20 years (mg/l)**



Figure 54: Initial concentrations for sulphate (mg/l)

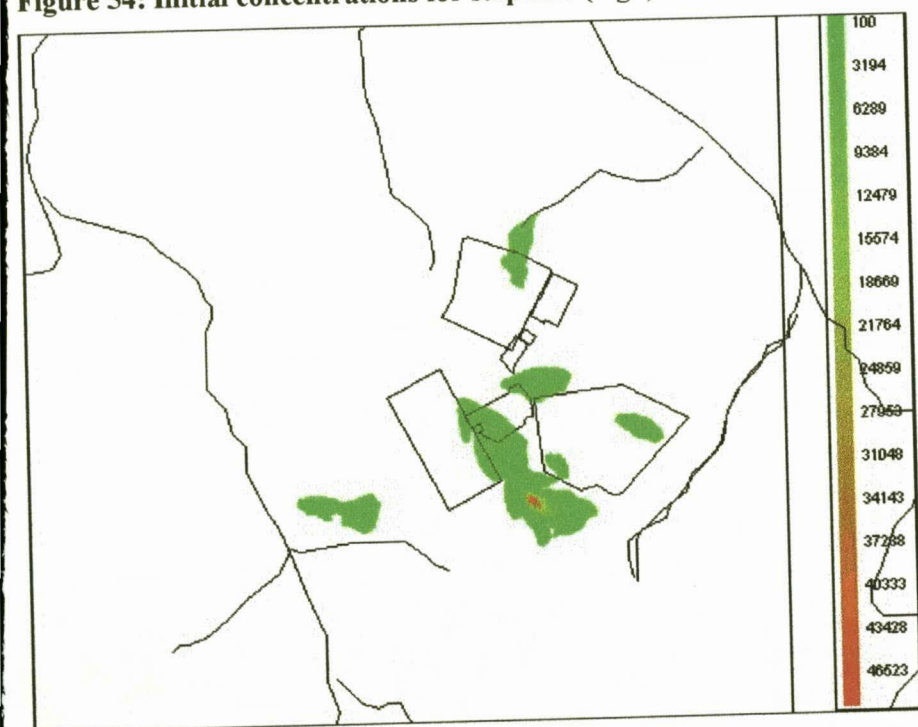
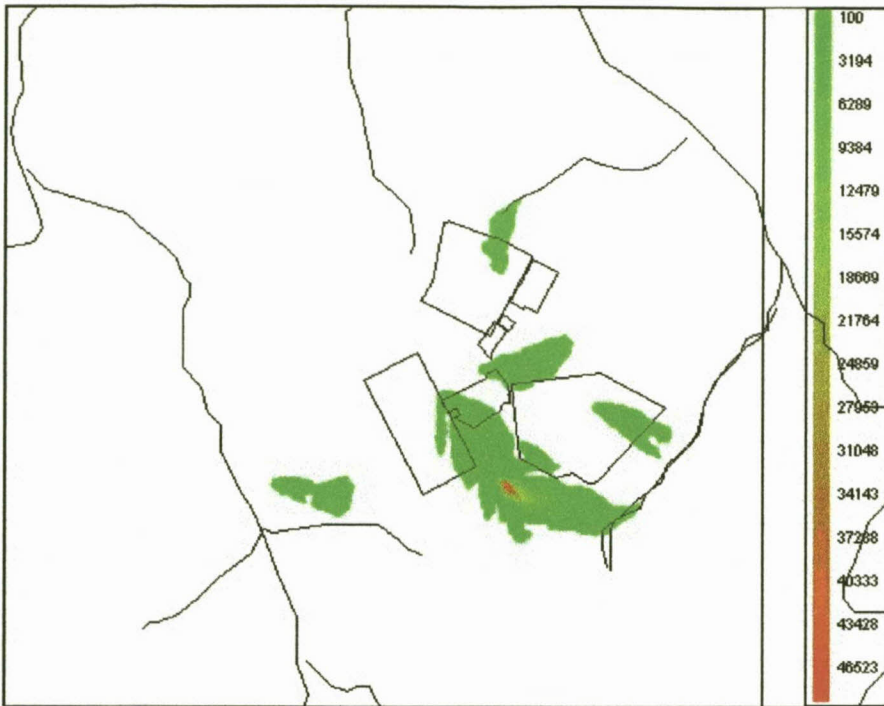


Figure 55: Plumes for sulphate after 10 years (mg/l)



**Figure 56: Plume spread for sulphate after 20 years (mg/l)**

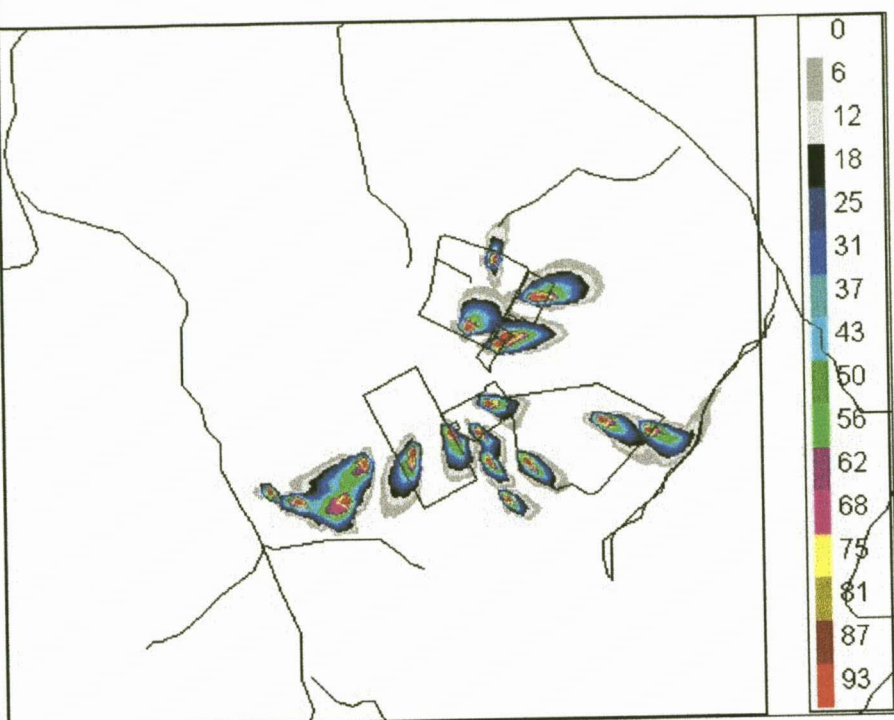
The conductivity plumes show that both the Taaibos- and Leespruit tributaries are at risk. Pollution from the SCI waste disposal site in the south and from Polifin's site to the east would be the first to reach the tributaries, the EC plumes indicate this most clearly. The accumulated plume from the centre of the industrial area will also start to reach both rivers after twenty years.

Nitrate contamination poses a larger threat to the Leeu Spruit than to the Taaibos Spruit. The nitrate plume extends to the Leeu Spruit after ten years but only reaches the Taaibos Spruit tributary after twenty years.

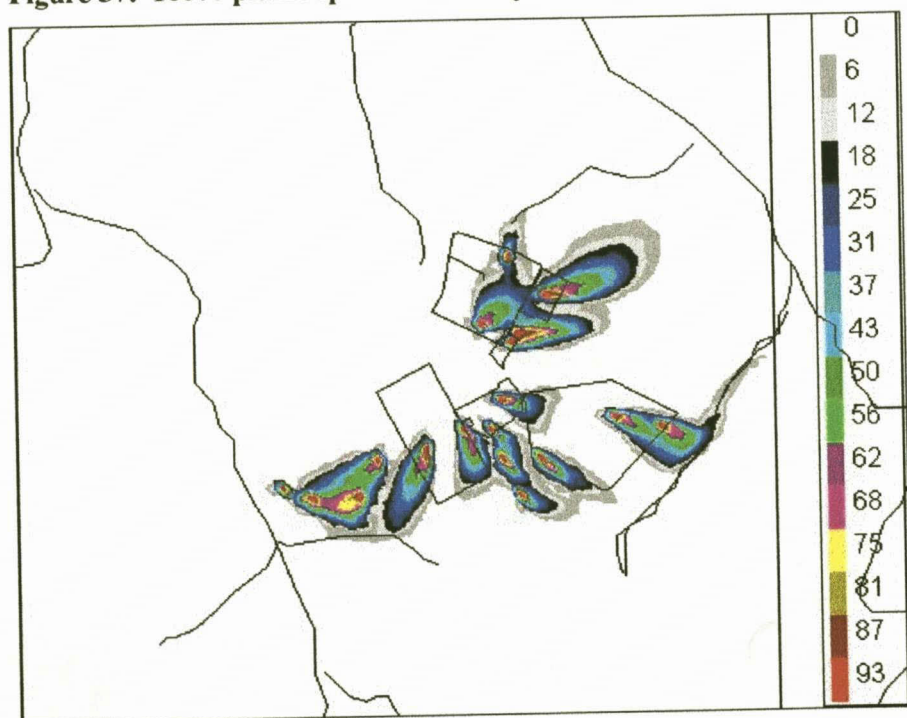
There is a threat from sulphate to Taaibos Spruit in the north where a small plume reaches one of the river's tributaries as well as in the south where a cumulative plume reaches the lower tributary of the Taaibos Spruit.

A last transport model was run where a value of 100% was assigned to the pollution sources to obtain more accurate positions for the redefining of the protection zones.

The results for 10 and 20 year simulations are shown in the following figures (57 to 58).



**Figure 57: 100% plume spread after 10 years**



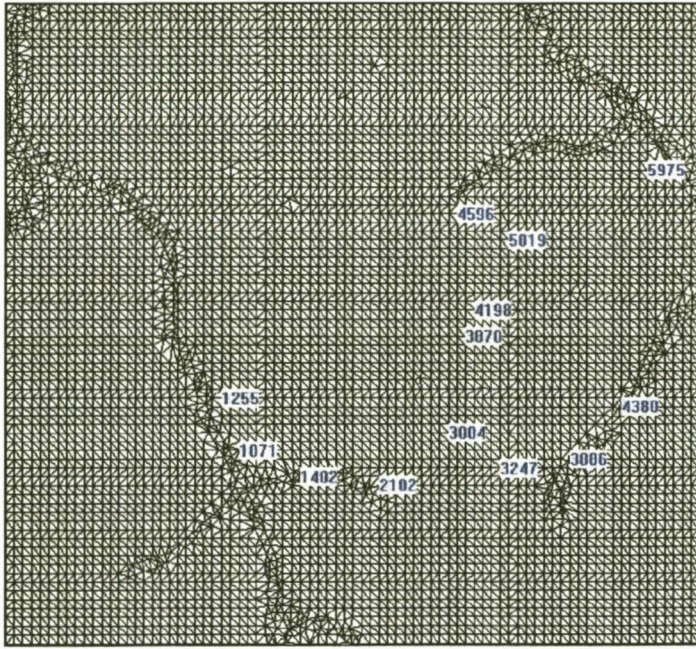
**Figure 58: 100% plume spread after 20 years.**

These transport models were now used to perform a stochastic risk analysis to compensate for variability uncertainties. The risk analysis is discussed in the following section.

### 7.5 Risk Assessment

Two approaches to risk analysis in the area were followed. Firstly a system to quantify risks associated with each pollution source was developed and then a probability approach was followed in numerical modelling.

### 7.5.1 Risk Assessment by Monte Carlo Stochastic Modelling



**Figure 59: Observation node numbers and positions**

Figures 47 and 60 show positions of the 13 selected points used for the risk analysis assessment. The green points are the observations and the red points are points where current concentration values have been assigned. Figure 59 shows these values and node positions.



**Figure 60: Positions of pollution sources (red) and observation points (green) for stochastic risk assessment**

A Monte Carlo risk analysis was performed on these points. One hundred values of transmissivity, porosity and longitudinal dispersion were stochastically generated by using the mean values described in the conceptual model and using a variance of 30%. The output is thus the equivalent of running the model 100 times with different transmissivity, porosity and dispersivity values. The eighty percent percentile at each observation point is subsequently obtained. The reported results

thus indicate the concentrations expected at these points with an 80% certainty, based on the information at our disposal.

Observation Point No	Node number	Time in days				
		360	1800	3600	5400	7200
1	1255	0.02	0.18	1.35	1.88	2.39
2	1071	3.30	2.99	2.95	2.93	2.92
3	1402	78.44	362.79	377.44	387.09	392.66
4	2102	0.06	47.95	75.42	68.44	65.06
5	3004	205.94	722.32	744.02	737.47	735.81
6	4596	32.64	33.75	34.23	34.67	34.96
7	3870	79.48	108.60	109.62	109.67	109.69
8	4198	1011.26	1219.40	1219.39	1219.39	1219.38
9	3247	128.23	1598.79	1994.17	2121.93	2155.36
10	5019	0.08	5.79	9.45	10.48	11.10
11	3886	0.64	102.47	145.54	153.73	150.36
12	4380	476.19	1721.84	1869.88	1871.16	1871.16
13	5975	0.00	0.02	0.35	0.03	8.24

**Table 13: Risk analysis results. 80% percentile EC values (mS/m) after specific times in the future. With the current available data 80 % sure that the value will be equal or less than the value quoted in the table.**

Observation Point No	Node number	Time in days				
		360	1800	3600	5400	7200
1	1255	0.02	0.19	1.33	1.92	2.23
2	1071	2.89	3.09	2.82	2.62	2.54
3	1402	10.13	65.08	125.07	168.65	187.89
4	2102	0.06	84.93	163.08	184.95	193.62
5	3004	407.04	1826.16	2113.36	2134.97	2134.88
6	4596	400.73	410.68	411.06	411.11	411.16
7	3870	228.96	311.72	313.89	314.50	314.48
8	4198	33.50	34.99	34.28	34.28	34.27
9	3247	1417.81	17194.04	20017.03	20369.98	20408.44
10	5019	0.99	2.30	2.57	2.60	2.63
11	3886	0.03	191.61	338.53	361.26	361.05
12	4380	25.06	554.26	748.88	798.06	804.72

**Table 14: Risk analysis results. 80% percentile SO<sub>4</sub> values (mg/l) after specific times in the future. With the current available data we are 80 % sure that the value will be equal or less than the value quoted in the table.**

Observation Point No	Node number	Time in days				
		360	1800	3600	5400	7200
1	1255	0.00	0.17	1.33	1.94	2.49
2	1071	0.00	0.00	0.00	0.00	0.00
3	1402	35.09	164.09	167.35	166.45	166.46
4	2102	0.04	39.99	41.00	19.73	9.70
5	3004	339.11	785.42	803.58	807.16	808.73
6	4596	0.16	1.41	2.69	3.46	4.21
7	3870	2.40	3.51	5.96	5.56	5.25
8	4198	2008.98	2360.14	2360.29	2360.28	2360.27
9	3247	7.32	285.42	648.90	716.58	738.35
10	5019	0.00	8.16	12.46	13.37	13.77
11	3886	0.74	133.24	178.84	182.80	178.24
12	4380	0.22	43.04	76.12	87.78	91.84
		0.00	0.00	0.11	0.51	2.16

**Table 15: Risk analysis results. 80% percentile NO<sub>3</sub>-N values (mg/l) after specific times in the future. With the current available data it is 80 % sure that the value will be equal or less than the value quoted in the table.**

From the above tables it is clear that the values predicted for certain nodes are of great concern. Observation point 12 shows a value of 1879 mS/m for EC after twenty years. The proximity of the stream to this node is of great concern. Points 5, 8, 9 and 12 consistently show high values for the different parameters. These are thus the areas of greatest concern and measures must be implemented to minimise the long-term impact of these plumes. These are predicted values using current values and thus the management of the area must strive to prevent the situation from reaching these very high values. The pollution sources giving rise to these plumes therefore need urgent attention.

The values above therefore give the predicted concentrations at the selected observation points. It is emphasised again that the values are based on the information currently available and the restraints regarding lack of information. More in-depth and site-specific work will be needed to more precisely quantify pollution migration from the different sources and sites.

### **7.6 The Threat Action Guide system**

For the second risk approach, the Threat Action Guide (TAG) system was developed for this project. It is hoped that this program will be a useful tool for all the role players in the catchment, from the Department of Water Affairs and to each industry. The program is Microsoft Excel based and thus should be compatible with the majority of software used by role players. Inputs are very simple and there are instructions incorporated to assist users. All the functions and the menu are driven by clickable buttons to assist users.



Figure 61: Tag title sheet

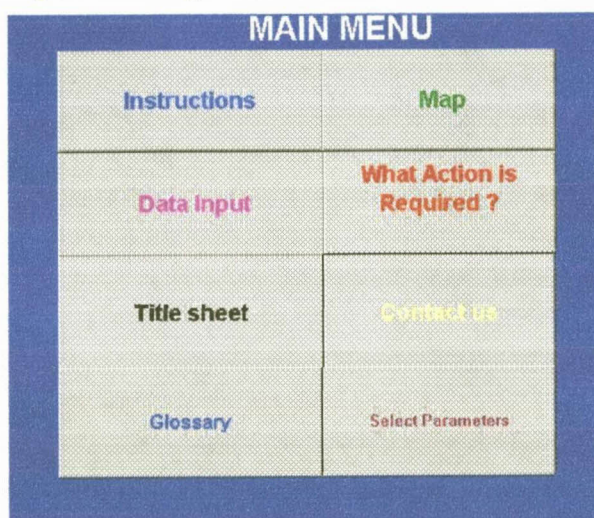


Figure 62: Main menu of TAG

The inputs needed are the following:

- The Zone within which the particular site falls
- The chemical parameters that should be considered for the evaluation. From inspection of the data available it is suggested that generally in the catchment the following parameters give a good indication of the groundwater contamination: Electrical Conductivity, Sulphate, Sodium, Nitrate and Chemical Oxygen Demand. COD is automatically selected to give a rough measure of the organic contamination. This compensates for the lack of information regarding the organic contamination in the catchments. These parameters are also selected as default values.
- The distance from the nearest critical point. A critical point is defined as the nearest stream or zone 3 area/aquifer.

Based on this information, Threat Action Guide will give the following output:

- The Aquifer Classification.
- The Water Quality Objective for each parameter. The program currently uses the Preliminary Objectives proposed in section 8 and the standards based on Kempster et al. 1985, South African Drinking Water Critical and Maximum allowable values.

- A Threat Index Value for each Parameter. This value is based on empirical equations taking into account the aquifer classification, the water quality standard, the value recorded for the parameter at that site and the distance from the nearest critical point.
- An associated action required for each parameter based on the calculated risk index.
- The number of problematic parameters.

A sheet summarising the management action required for each site, showing what the primary and secondary management action at each site is. The number of problematic parameters is also given in this summary.

The actions suggested by the Threat Action Guide are the following (from highest priority or seriousness to lowest)

*“Immediate Remedial Action”*,

*“Do Intensive Risk Assessment”* or *“Investigate Cause of High COD”* and

*“Continue Monitoring”*

These actions, in the context of this program, mean the following:

<b>Continue Monitoring</b>	Regular sampling and analysis of specific point
<b>Intensive Risk Assessment</b>	Quantifying the risk associated with a particular pollution source. Health risks and exposure, pathways and potency of pollutant etc. will need to be considered and quantified. May indicate need for remedial action
<b>Immediate Remedial Action</b>	Action that needs to be taken to improve the quality of the water. This could be by reducing the impact of a source, removing the source, improving water management on site etc. An Intensive Risk Assessment may show that remedial action is not required

**Table 16: Explanation of actions**

The system has been tested with the data from the sampling done in the field work phase of this study and also with different hypothetical situations and so far has given good results.

At this stage it is only intended as an additional tool to identify possible problem areas but with feedback some degree of verification can be obtained.

A glossary of all the terms used in the guide is given to explain all the inputs and actions more clearly.

The message below will come up when TAG is opened. Please click on “Enable Macros” for the system to work properly. TAG has been checked on several different systems and no reported problems regarding macros or macro viruses have been reported. It is therefore stated with confidence that no problems should arise.

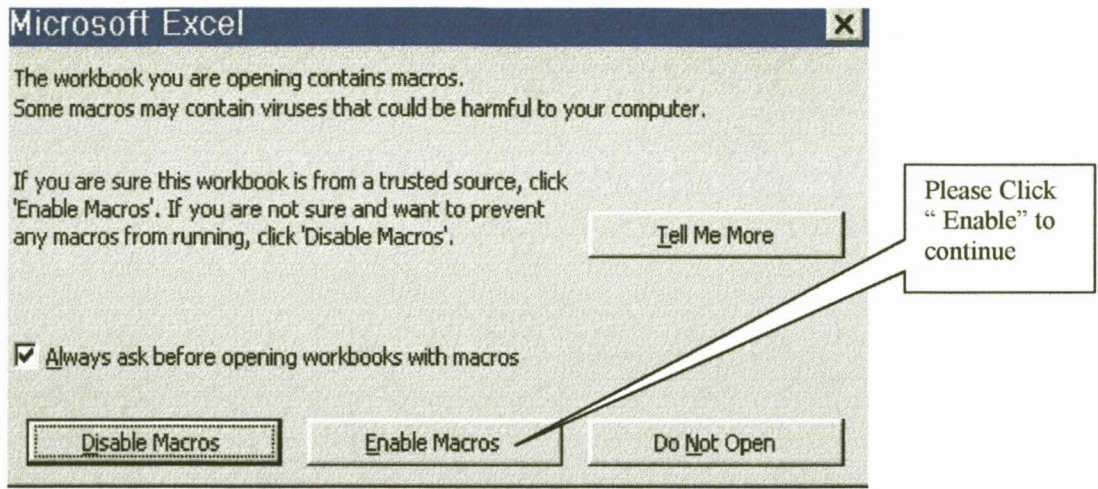


Figure 63: Screen which will display in EXCEL when TAG is opened.

Once the titel sheet is shown, click on main menu to proceed into TAG. A full step-by-step methodology is given in the “Instructions” sheet. Please refer to this for guidance through the program. The data sheet to be filled in is shown below.

Main Menu				What Action is Required ?					Select Parameters			
Parameter Number				1	2	3	4	5				
No. of Problematic Parameters	Site Name	Zone number	Aquifer Classification	EC	Na	SO4	NO3 as N	COD	Distance from Closest Critical point	Zone Standard EC	Threat Index EC	Action Required EC
0	AZB	1	6	136	70	20	0.64	62	2100	400	0	Continue Monitoring
0	PSB2	1	6	84	34	216	0.34	4	400	400	0	Continue Monitoring
0	PSB6	1	6	58	30	75	0.09	3	385	400	0	Continue Monitoring
1	AFCAT1	1	6	214	39	55	228	6	1200	400	0	Continue Monitoring
0	B14	1	6	324	593	1341	0.01	40	168	400	1	Continue Monitoring
1	B21	1	6	407	662	1940	0.02	3	180	400	2	Continue Monitoring
2	B26	1	6	538	1274	2651	0.02	53	200	400	4	Continue Monitoring
0	B4	1	6	76	33	302	0	1	180	400	0	Continue Monitoring
0	BT1	2	8	18	6	17	6.2	54	150	300	0	Continue Monitoring
0	BT2	2	8	16	24	8	0.02	2	350	300	0	Continue Monitoring
0	D1A	1	6	99	51	98	0.07	14	400	400	0	Continue Monitoring
0	EX1	1	6	23	17	6	0.02	7	150	400	0	Continue Monitoring
0	EX3	1	6	22	19	5	1.43	13	200	400	0	Continue Monitoring
1	FB1	2	8	53	95	17	33.2	5	500	300	0	Continue Monitoring
0	FB10	2	8	81	204	23	0.1	6	100	300	0	Continue Monitoring
0	FB11	2	8	264	178	130	3.8	11	100	300	2	Continue Monitoring
0	FB12	2	8	67	110	26	1.7	8	100	300	0	Continue Monitoring
0	FB13	2	8	246	148	146	5.5	9	100	300	1	Continue Monitoring
0	FB14	2	8	79	51	27	0.9	219	100	300	0	Continue Monitoring
1	FB2	2	8	35	15	9	14.3	26	100	300	0	Continue Monitoring

Figure 64: “Instructions” sheet

An example of the input sheet and the resultant actions is given below:

Site Number	Primary Action Required	Secondary Action	No. of Problematic Parameters
UG17	Continue Monitoring		0
UG22	Continue Monitoring		0
UG23	Immediate remedial action		2
UG26	Continue Monitoring		0
V11D	Immediate remedial action		1
V1D	Immediate remedial action		2
V2S	Immediate remedial action		4
V3D	Immediate remedial action		2
V4S	Immediate remedial action		2
W3	Continue Monitoring		0
WW003	Continue Monitoring		0
WW007	Continue Monitoring		0
WW010	Continue Monitoring		0
WW021	Immediate remedial action		1
WWF1	Investigate cause of high COD		1
WWF2	Investigate cause of high COD		1
ZA1	Continue Monitoring		0

Figure 65: Input sheet and resultant actions

The sites of concern are thus easily identified and target areas for action at each site can be set. This will enable the regulators and the industries to compare potential problems and thus prioritise the actions that need to be taken on a site-specific basis.

This system is, as with the numerical modelling, intended to be used as a tool to assist in the management of the groundwater in the area.

## 8 Management Options

### 8.1 Preliminary Groundwater quality guidelines

In order to manage the groundwater of these catchments, groundwater quality standards are needed. Using all the data available, discussions were held between the Department of Water Affairs and the researcher to ascertain guidelines to suggest possible standards.

Several pertinent points should be mentioned:

- The application of Drinking Water Standards to the industrial area is unrealistic since this water is unlikely to be used for drinking water.
- Despite the fact that much of the groundwater contamination has arisen from historical practices, some form of standard is required to ensure that quality does not deteriorate further.
- In cases where severe contamination is present some form of standard is required as a threshold value at which action needs to be taken.
- The ambient water quality in the catchment needs to be considered when the standards are set.
- The standards should be realistic for enforcement and compliance.
- The most important aspects that need to be protected by such standards are the streams in the catchments, the alluvial aquifer to the north of the area, and groundwater users in the catchments.

Based on these considerations it was decided to divide the catchment into three or more protection zones. Zone 1 comprises the industrial area and stretches from the outer boundaries of all the industries in all directions. In this zone, due to the industrial activities the groundwater objectives are the most lenient. Beyond this zone lies another zone where more stringent objectives will apply.

This zone is regarded as a buffer zone between the potential groundwater polluters and the areas where critical protection is required. As more information becomes available other issues can be incorporated to delineate the zones and objectives used.

Kempster and Smith, 1995, assigned different values for drinking water. It was decided to apply these **maximum** permissible limits and **crisis** limits to the buffer and industrial zones. The crisis values are those above which **immediate action is required**. In cases where this is exceeded the onus will fall on the responsible party to show that a pollution source holds no risk, to remain in compliance. The maximum value will hold in the buffer zone, while at the boundary of this buffer zone **ideal** values will be assigned. These ideal values represent the ambient quality in the different parts of the catchment, as determined from the sampling phase last year.

These standards are far less stringent in the industrial area than current drinking water standards are.

As an example for sulphate the crisis value=1200mg/l, the maximum permissible value = 600mg/l while the ideal catchment value =45 mg/l.

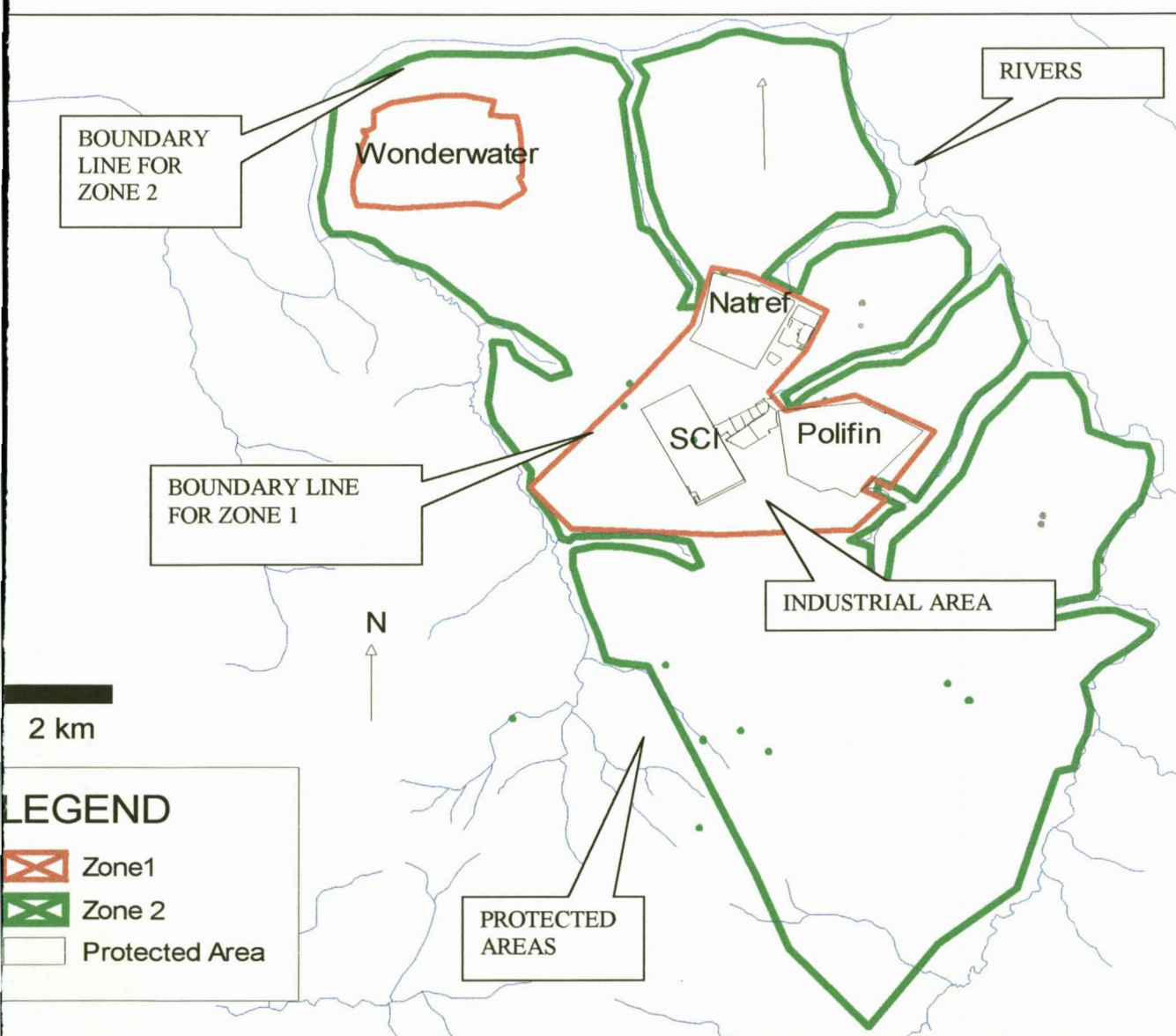


Figure 66: Delineation of the different zones

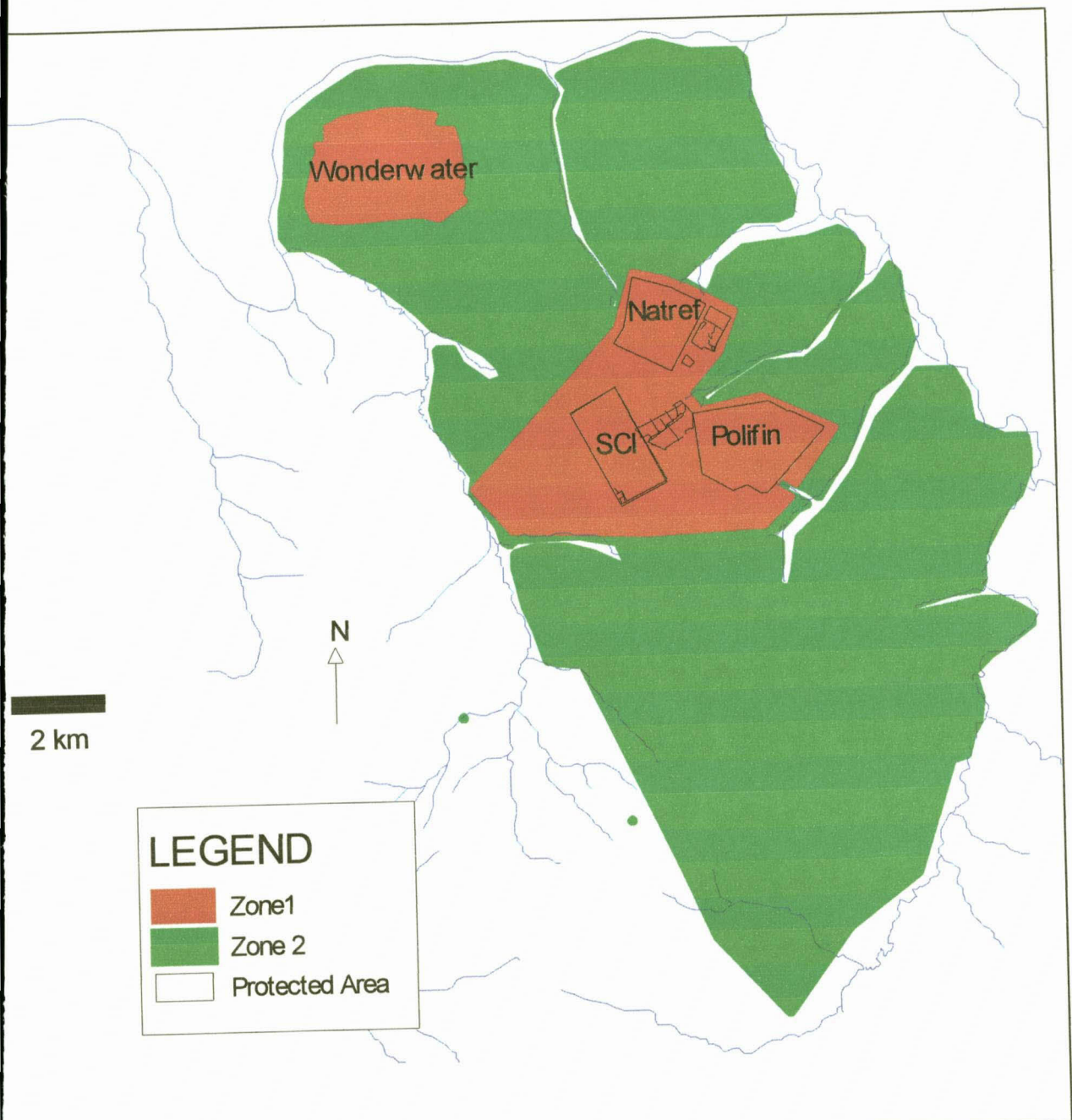
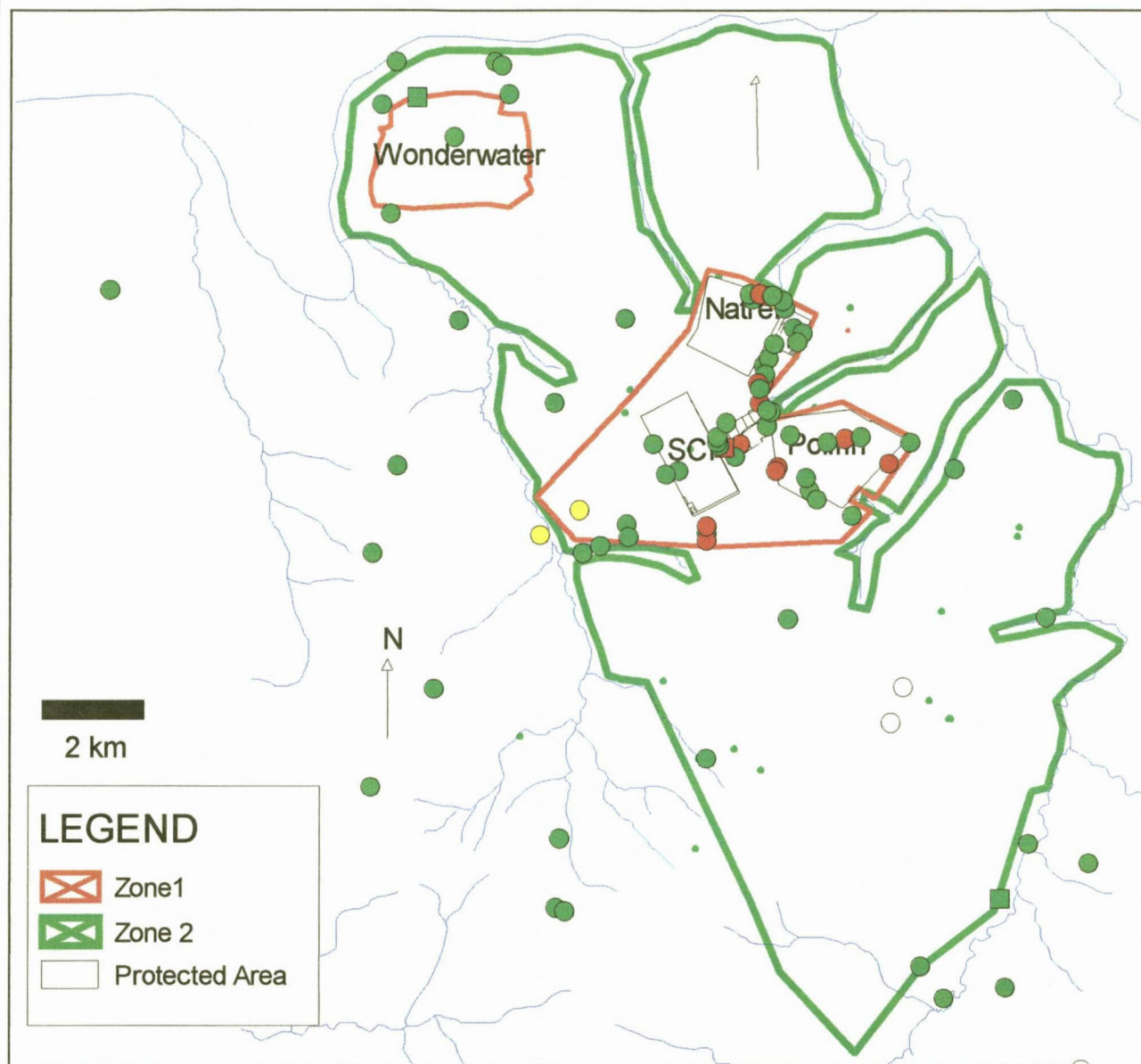


Figure 67: Zones Shown more clearly



**Figure 68: EC Values According to suggested standards.**

In the figures **red points** exceed **crisis** limits and need immediate attention, **yellow** points fall **between** the maximum and crisis levels and are acceptable in zone 1 but need attention in zone 2, while points showing **green** are between the range of **ideal** and **maximum** values. These values are acceptable up to the boundary of zone 2. Points showing white values are either below this ideal standard or the particular parameter has not been measured at this site.

These zones allow differential management objectives in different areas, according to the activity involved. Thus the Industrial and Opencast mining area have more lenient objectives, since historic practices have been such as to make groundwater contamination unavoidable. The protected areas are, however, still protected by buffer zones of more stringent objectives and very strict objectives in the protected areas. In this way the catchment can be managed in a meaningful way and the areas of concern can be protected against groundwater contamination. Using tools such as TAG, which take the distance to these critical areas into account and the standard applicable to each management zone, areas of concern can be highlighted and appropriate steps taken to improve this situation, or

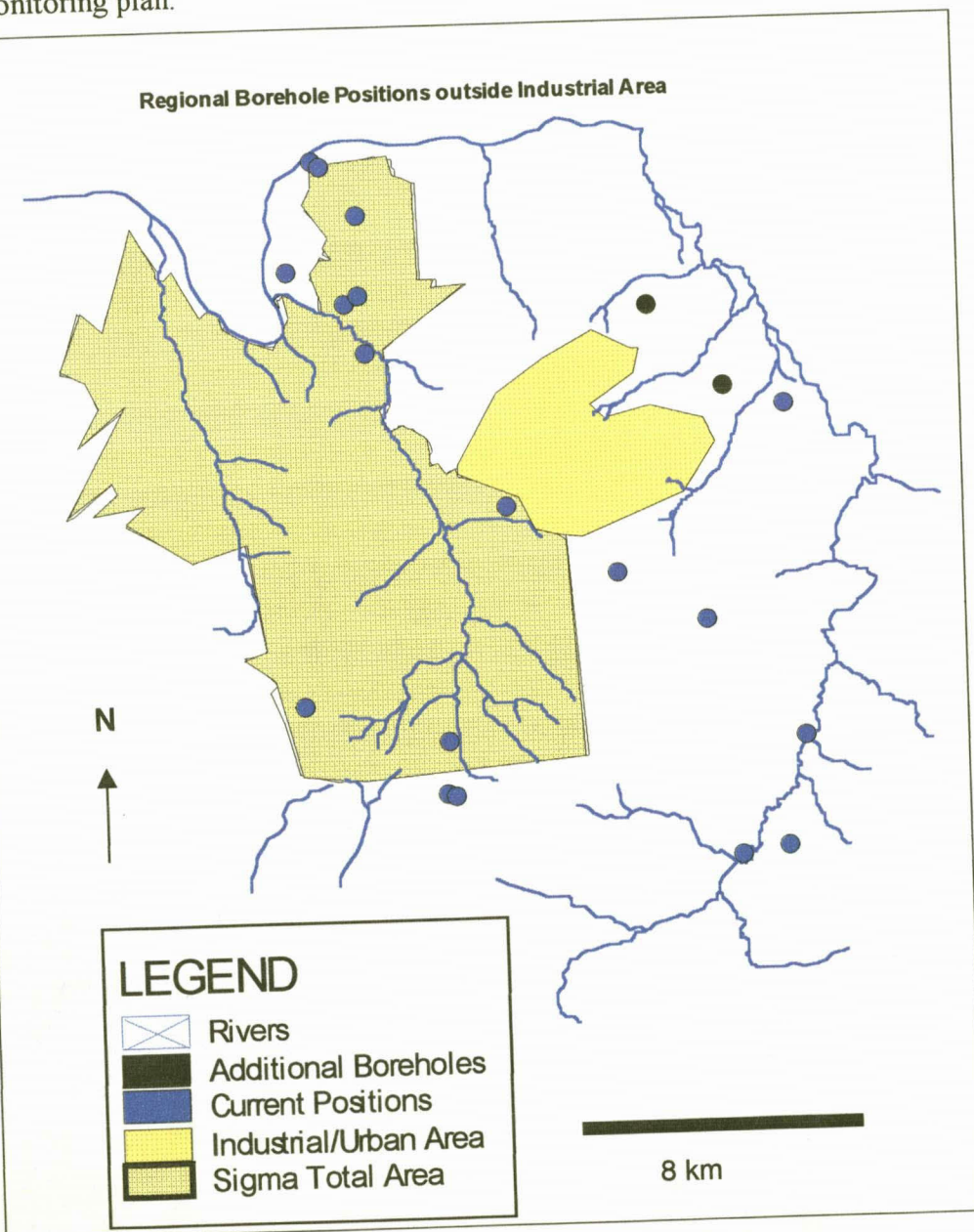
ensure that any contamination is contained for infinity. The onus of proving this will fall on the particular party identified by such standards and techniques such as TAG.

## 2 Proposed regional monitoring points

The following section contains a short summary of areas of concern within the study area and sites that should be considered in regional groundwater monitoring program. These proposed sites would then form part of a regional monitoring network for the two catchments. It is stressed that identification of these points does not indicate that monitoring done on site must be discontinued. The identified sites will need to be monitored on a very regular basis as part of the overall management strategy.

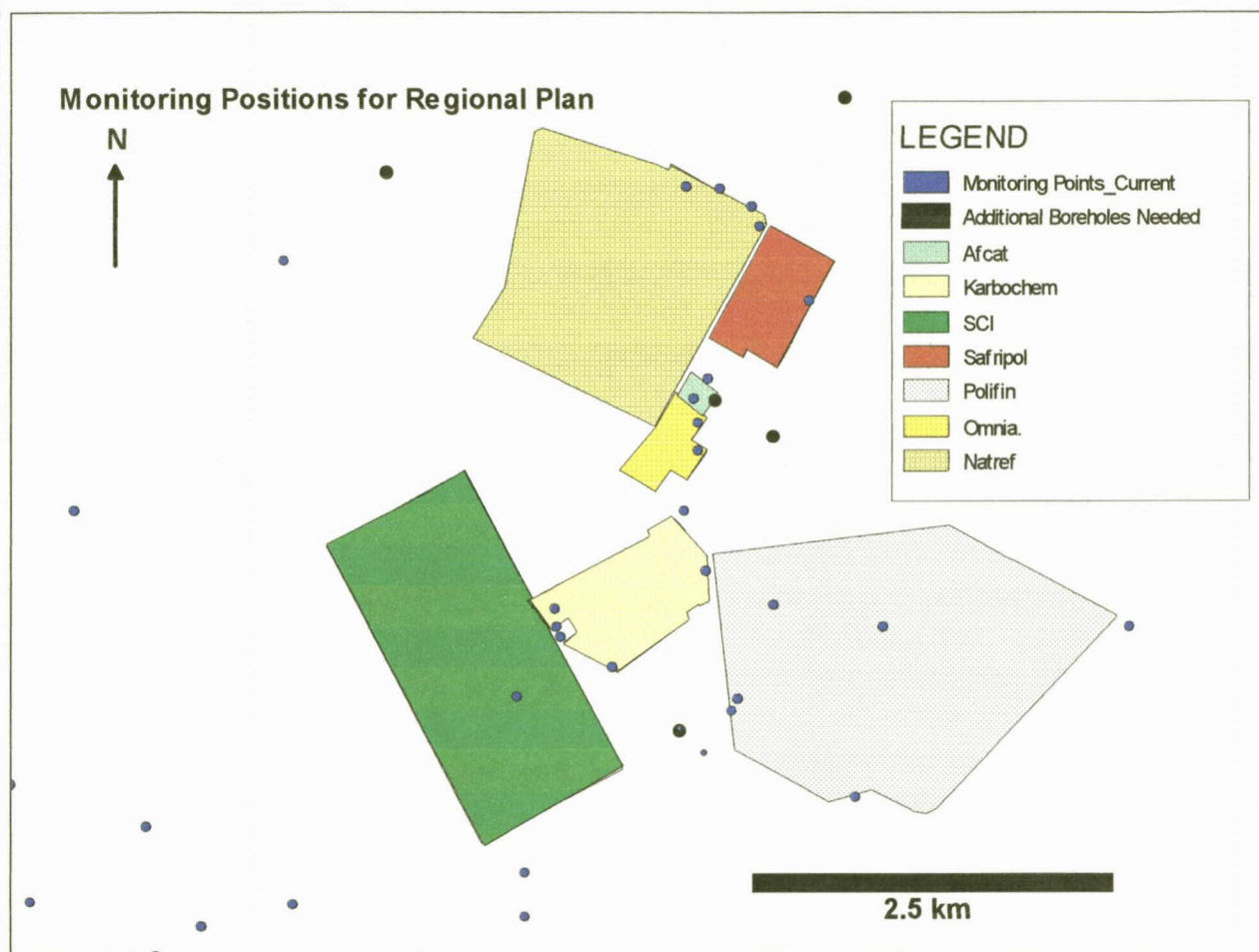
The following figure gives a layout of the monitoring points that is selected for the regional monitoring plan.

Regional Borehole Positions outside Industrial Area



**Figure 69: Suggested monitoring points**

The following figures give a more detailed layout of the boreholes suggested for the regional monitoring plan.



**Figure 70: Proposed monitoring boreholes in the industrial area**

### 8.2.1 Municipal area

During the sampling phase of the project two boreholes were sampled within the municipal area. One was located near the fire station and the other near the municipal swimming pool. From the sampling results only two problems were identified. These are the high COD near the swimming pool area and high ammonia near the fire station. The cause of these problems needs to be identified.

These two boreholes are ideally located for monitoring the groundwater in the municipal area and could be included in the regional monitoring network.

### 8.2.2 Farming area

17 boreholes were sampled on farms in the two catchments. The boreholes were sampled to determine several factors. Some were selected to obtain the ambient water quality while others were used to observe influences from possible pollution sources.

Overall the water quality of the boreholes that were sampled was satisfactory and represented the ambient water quality. High nitrate levels were detected in some boreholes but this is most likely caused by farming activities such as fertilisation, animal faeces, etc. Septic tanks and air pollution could also contribute to these elevated nitrate values.

It is suggested that the following areas should all be included in the groundwater monitoring plan. Where possible existing boreholes should be used, otherwise new boreholes must be drilled for monitoring purposes.

- The area north and north-east of the industries. This would be to detect any influence from the industries to the west and north, as well as the collieries that are situated to the east, outside of the catchment.
- The influence of the Mollensteen Pan should be monitored. The borehole that was sampled during this project (FB10) is ideally located as a monitoring point.
- Although there is no evidence at this point in time of any pollution from the Wolwehoek abattoir, it is suggested that monitoring points should be set up downstream of the abattoir and at the associated feedlots and planned tannery.
- From the information gathered up to this point there is no ongoing monitoring of groundwater in the vicinity of the Coalbrook colliery. From the sample that was taken from HC1 next to the golf course at Holly Country, it was evident that the colliery does have a negative effect on the groundwater. A monitoring point for this area is thus also necessary. This is important to ascertain both the recharging waterlevel and quality of this water.
- No additional boreholes need to be monitored in the Wonderwater area. Sigma has an extended groundwater monitoring network surrounding the open cast mine. Some of these existing boreholes could be used for the monitoring plan.
- The last of these areas that need to be monitored is the area down stream of the informal settlements at Zamdela. As proven in other parts of the country this type of settlement could have an adverse effect on groundwater quality and should therefore be monitored.

### 8.2.3 Industries

#### 8.2.3.1 *African Catalysts (Pty) Ltd.*

There are two monitoring points on this site. One is a production borehole and the other a sump downstream from the plant. Afcats monitors both regularly. The groundwater tested was of moderate to poor quality. The major concern on Afcats is the high nitrate levels in the production borehole. As no nitrates are involved in the production processes on site the reason for this should be investigated.

The monitoring of the boreholes should continue and it is suggested that another monitoring borehole must be drilled down stream of the factory site. This would be to monitor any possible off-site migration of contaminants that could enter the groundwater from production processes or spillages.

One borehole on this site should be sufficient for the regional monitoring network.

#### 8.2.3.2 *INCA Brick works*

There is one production borehole on site. The water from this borehole is used for dust suppression. Elevated levels of sulphate and calcium in the sample taken from this borehole show that the fly ash on site does have a slightly negative impact on the water quality. Further investigation should include the causes of the high COD and nitrate/ammonia levels.

It is suggested that this borehole should be regularly monitored and should also be included in the regional plan.

### 8.2.3.3 *Karbochem*

From this and previous investigation that were done on site several problem areas have been highlighted. Groundwater entering the site (GCS3) on the north-east is less contaminated than groundwater migrating off-site (GCS7 & KEMC1).

The principal sources of pollution that were identified were the production areas such as the Alkylate plant, effluent dam areas and the informal waste area.

Management of Karbochem has a monitoring program and completed two phases of a groundwater investigation on site. It is suggested that the monitoring and the groundwater investigation should continue as planned, and that approximately four of these boreholes (KEMC1, GCS3, GCS7 & GCS1) should be included in the regional monitoring plan. Further investigation of possible organic contamination should also be performed.

### 8.2.3.4 *Natref*

From this study and previous studies done on the Natref site the major sources of pollution was pointed out to be the evaporation ponds on the north side of the site. Sodium and sulphate levels were found to exceed the water quality standards. After the rehabilitation of the evaporation dams monitoring results showed an improvement of the water quality.

It is suggested that the existing groundwater monitoring program should continue on site and some organic analyses should also be performed occasionally to monitor the possibility of organic contamination. Since all the monitoring boreholes are located on the north side of the site, it is suggested that additional boreholes should be drilled to give a more representative picture of the site. (Natref has drilled several boreholes on site which have been refilled immediately. Some information regarding these boreholes is available.) Apart from this ongoing monitoring an Environmental Impact Assessment is planned for future expansion of the refinery.

For the regional monitoring plan it is suggested that approximately two boreholes on site and two of the "external" boreholes should be used.

### 8.2.3.5 *Omnia*

The groundwater investigation on the Omnia site identified several potential sources of contamination on site. These included the manufacturing plants, storage areas, effluent dams, uncontrolled spillage and flows. Due to the type of operation and the solubility of the chemicals used on site several boreholes drilled on site are polluted. Major contaminants include calcium, magnesium, chloride and nitrates. From soil samples it was clear that the soil on site is also contaminated and this could be a long-term source of groundwater contamination.

Omnia has started a groundwater investigation and is in the process of upgrading the stormwater runoff system on site. As there is already a monitoring network in place on site regular monitoring is suggested.

For the regional monitoring two of the Omnia boreholes are suggested.

### 8.2.3.6 *Petronet*

From the investigations done on the two sites it was evident that there were very little contamination found at the Coalbrook pumpstation. At the Sasolburg pumpstation the groundwater is polluted with hydrocarbons. Regular monitoring of the groundwater takes place at both pumpstations.

For the regional monitoring plan one borehole at the Sasolburg pumpstation should be included. None of the boreholes at the Coalbrook pumpstation need to be monitored since the Natref boreholes would cover that area.

#### 8.2.3.7 *Polifin*

Several potential causes of contamination were identified on this site. These included: spillages, failures at production areas, old evaporation ponds and waste dumps. Contaminants of concern range from inorganic to organic constituents. A complete groundwater investigation that included numerical modelling and a risk analysis exercise was performed on site.

As with other sites the monitoring of groundwater should continue. The following sites are suggested for the regional monitoring plan: SRK14, SRK25, SRK18, SRK17, SRK8 and SRK1.

#### 8.2.3.8 *Safripol*

From the investigations that was performed on site little or no inorganic contamination was evident on site. Monitoring of the groundwater should continue on site and an investigation concerning organic contamination should be done.

One borehole on this site should be sufficient for the regional monitoring plan.

#### 8.2.3.9 *SCI*

SCI has completed several groundwater investigations on the various sites. The latest study included the powerstation, SMX and Venco Park areas. An ongoing monitoring program is in place for all the sites.

Several sources of groundwater pollution have been identified at the SCI site.

- Schumann-SASOL (Catalyst Plant)
- Ash disposal area
- Old and new tar pits
- Fertiliser dump
- Sewage works
- Municipal dump
- Dam system
- Venco Park area

A variety of contaminants (nitrate, sulphate, sodium, fluoride, etc.) are found at these different sites. High COD levels indicates possible organic pollution in some areas and need further investigation.

For the regional monitoring plan a borehole at each of these pollution sources should be included.

#### 8.2.3.10 *SMX*

During recent groundwater investigation of the site several monitoring boreholes were drilled. The monitoring boreholes are included in the SCI monitoring program. From the analytical results of samples taken it was clear that the groundwater downstream of the old effluent dam is highly polluted with regard to calcium, sodium, magnesium and sulphate.

For the regional monitoring plan two of the boreholes at SMX should be included.

### 8.2.4 **Transport Companies**

Although no contamination was found during the investigation at the sites of the various transport companies (Bothma Transport, Cargo Carriers and Terblanche Transport), the threat of contamination exists. This is due to the fact that various chemicals are transported from and to these sites and occasional spills can occur.

It is suggested that a monitoring point should be established at each of these sites for a site specific and the regional monitoring plan.

## 8.2.5 Mining Activities

### 8.2.5.1 *Sigma*

Sigma Collieries has a very extensive monitoring network, which is regularly monitored. Areas of concern are the effects of flooding of the underground workings and possible pollution from Wonderwater Opencast to the surrounding alluvial aquifer. Several measures are in place to prevent contamination of the alluvial aquifer. These include the construction of capture trenches, recycling of incoming water etc. The boreholes in the opencast and on the outer edges of the mine as it expands must be included in the regional network.

Sigma is currently undertaking an extensive study to quantify aspects such as rates of flooding, time to decant and quality of decanting water. The results from these investigations will pinpoint suitable sites for inclusion into the monitoring network and will also provide information so that the necessary water management measures can be implemented.

Sigma has proposed the following boreholes as monitoring points to be included in the regional monitoring plan: WW024, WW010, WW017, WW018, NW004, UG026, WW019, UG033, UG043, WW021, and WW022. These boreholes cover a large area of the catchments and are suitable for monitoring the various factors pertaining to the effects of the mining activities.

## 9 Conclusions from the Study

From the aforementioned sections there are several conclusions which should be highlighted:

- The Situation Analysis is a first step in the construction of a final Integrated Catchment Management Plan for the two catchments. This report is thus provided as an overview of this area and acts as guide to the rest of the process to the eventual management of the surface and groundwater in these catchments.
- The Taaibos Spruit and Leeu Spruit catchments cover a very large area (over 1000 km<sup>2</sup>). Within this area there are a multitude of issues pertaining to groundwater, which need understanding.
- Most of the larger impactors on groundwater (industries, mines and power stations) have in the past undertaken groundwater studies and monitoring. On most of these sites this is an on-going process, and consequently new data and further understanding of the interactions in the area is being obtained.
- The independent site-specific studies have highlighted several issues of concern and problem areas on different sites. This data was used in conjunction with data collected by this investigation to understand the area.
- There are several aquifers of concern within the two catchments. The most important of these are a shallow aquifer above and including the dolerite sill which is fairly pervasive throughout the area, a deeper fractured sandstone aquifer which is especially important towards the southern reaches of the study area, a very deep dolomitic aquifer, and a high yielding alluvial aquifer associated with the major river systems in the area.
- Sampling was done at 101 sites throughout the two catchments. The results of this sampling verified that contamination of the groundwater has occurred at several points in the area. The severity of this contamination is dependent on the specific pollution source and ranges from very slight to highly problematic.
- The sampling method used yielded reliable results, which compared very well with monitoring done during the same period at SCI and Polifin with a different sampling method.
- Toxicity testing of certain boreholes yielded good results since the toxicity compared very well to the chemical analyses of the different borehole samples. These tests also indicated that

certain areas of groundwater pollution held a severe threat in terms of toxicity to organisms commonly encountered in aquatic ecosystems.

- The sampling also allowed quantification of the ambient water quality in the catchments. This provides an ideal value towards which areas currently beyond the influence of major pollution sources can be managed with.
- The results of the sampling reflected the heterogeneity of activities in the catchments. In this area no specific contaminants could be identified throughout the catchment as being problematic. Data analysis of the sampling results and historical results from the different sites showed that nitrate, sulphate and organic contamination were parameters of particular concern. High overall salinity associated with different sources were found.
- Using various techniques the most important impactors have been identified and broadly defined future management strategies have been proposed.
- Classification of the different aquifers showed that the aquifers in this area could be considered to be marginal aquifers. This is particularly true for the shallow aquifer system underlying most of the industrial area. The only two aquifers, which can be regarded as important aquifers according to this method, is the alluvial aquifer along the rivers and the deeper sandstone aquifer. These aquifers are thus the most important areas to be protected by different management strategies to be employed in the catchments.
- Two-dimensional numerical modelling with generalised parameters, gave an indication of the directions and rates of pollution transport in the aquifer. The results of this model showed good correlation with other site -specific modelling which has been done in the area.
- The models showed that pollution from several sources could impact on the groundwater quality in the area. It was also shown that it is possible for this pollution to reach streams flowing through the area and thus it holds severe implications for the overall water management of the area.
- Areas where possible mixing of plumes from different sources could occur were also identified. The reactions and interactions between pollution from different sources can give rise to several secondary problems that will require intensive research to quantify.
- The numerical modelling also indicated the areas where the risk of contamination from a particular source is the greatest. These are particularly at streams, which flow close to the industrial activities.
- Based on the results obtained in the investigation, the area could be divided into different groundwater management zones or area. These zones represent areas where groundwater contamination has occurred due to on site activities, a buffer zone around these areas, and the critical areas which form a zone that needs to be protected. The latter includes the rivers, the alluvial aquifer and the sandstone aquifer to the south of the area. The aim of any future water management plan must be to ensure that no degradation in quality occurs in these areas.
- In each of the different zones different standards have been defined which should be complied with. These interim standards are less stringent in zone 1 so that realistic target levels can be set, so that the industries and mines and the state regulators can have workable values to manage the sites with.
- The TAG system, which was specially developed for this study, gave an indication of the sites that hold the greatest threat in the catchment. This system can be used fruitfully by both interested parties within the catchment and state regulators.

- The results of all the information gained in from this study has allowed the prioritisation of areas on each site that require attention and inclusion in a management plan for each site. These are discussed in detail on a site-specific basis in the report.
- Sites which should be included as part of a regional groundwater monitoring network have also been identified. The monitoring of these sites will provide a good regional indication of water quality in the area, but do not replace site-specific monitoring programs in the short term.

## 10 Recommendations

Based on what has been learned in the course of this study the following actions are recommended:

- Site specific monitoring at each site must continue in the interim until the final monitoring positions for regional monitoring have been finalised, and results from these boreholes are shown to be indicative of the conditions in the catchment.
- A sub-committee should be formed to address the issue of organic contamination in the industrial area. This should consist of key personnel from all the industries, experts on organic contamination and representatives from the state regulators. The function of this committee would be to quantify the problem, set appropriate groundwater standards, define key parameters which should be analysed for and decide on management plans to limit the long-term impact of these chemicals.
- Before the final integrated management plan for the catchments is developed full integration of surface water and groundwater data must be done. All available surface and groundwater data must also be entered into appropriate databases so that maximum benefit can be obtained from the data. Currently a lot of the data is in hard copy form and is only used to measure compliance to permits and standards. For proper water management better use of this data will be required. It is suggested that a package such as WISH, which can easily accommodate all the types of data involved, is used.
- The results of the numerical modelling and the TAG program must be used to identify areas where priority management is needed. The appropriate level of risk assessment and remedial action required at each site must then be implemented as part of the management plan for the two catchments.
- The problem areas on each site, which have been identified in the report, must receive immediate attention.
- Areas where pollution plumes from different sources flow into one another must be investigated. The areas have been identified through the numerical flow and transport models, particularly where 100% values of initial pollution have been used. This is very important since the cumulative effect of different types of pollution can act either synergistically (where the two pollution types increase the toxicity of the mixture) or antagonistically (where the two plumes reduce the impacts of the individual plumes). The interactions are difficult to predict without detailed information and where the secondary mixtures hold severe risks to the receiving environment, measures will need to be implemented to limit the long term impact.
- It is suggested that toxicity testing as done in this project be done as part of the regional monitoring plan. The results from this study have shown that these tests give a very good indication of the true risk associated with each water sample. The frequency of this testing should be at least once a year for the short term until there is enough data to make further recommendations, when the frequency and location of the sampling can be modified according to what emerges.
- Detailed information on the flooding of Sigma underground will be needed to be included in the final management plan. Although it appears that this will not effect that shallow aquifer system,

the positions and time to decant will be very important to the water management of the catchments. The decanting quality will also be vitally important since it could be used to dilute problem areas if of good quality, and may need treatment or other management options if this quality is going to be poor.

- The interaction between the deep, flooding workings and the shallow system must also be quantified. This is particularly true in the region of the Leeu Spruit at SCI's waste site where a high level of interconnection can have several implications on decant quality, time and positions that are likely to be encountered.
- More sampling in areas unaffected by potential impactors must be done. This will allow refinement of the suggested interim standards and ensure that these areas remain beyond the influence of the pollution sources.
- New monitoring boreholes may need to be drilled north of the industries to form part of the regional monitoring plan. Information from these new boreholes could provide confirmation of the geophysical investigation. This data will also provide valuable insight into the conceptual model of the area.
- It is suggested that parties such as ESKOM (for Kragbron and Lethabo), Anglo Coal for New Vaal Colliery, Cornelia Colliery and Coalbrook Colliery, EAC ( abattoir, feedlots and leather tannery) be invited to join the Committee. Information on all these possible impactors is scarce and these parties can all contribute positively to the CMP by providing data and forming part of the eventual management strategy. While some of these fall outside the catchment boundaries they can still influence the water quality (surface water, particularly).
- All the industries and mines should in the future submit the results of the monitoring to DWA&F in an electronic format that is WISH compatible. All the contributing members have received copies of WISH, with the sites currently monitored on the site entered into the database. The Department of Water Affairs also has WISH and sets of all the data submitted to the IGS in the course of this investigation. Thus for future ease for all parties and data compatibility as agreed on by members during the course of the project, data should be submitted in this format. Any problems regarding WISH or input difficulties can be addressed to Eelco Lucas at the Institute for Groundwater Studies.
- In phase two of the CMP the interaction between surface and groundwater must be looked at in more detail. Evidence collected in this phase suggested that groundwater pollution can impact on the surface water quality in the streams and rivers in these catchments. This will need quantification.
- The interim standards suggested and the catchment management zones defined must be used to manage groundwater within these catchments. In this way realistic goals are set for the industries and mines and a good measure of protection is given to areas regarded as needing protection
- Standards should be set as soon as possible. The input from the organic pollution sub-committee will be needed to make these final catchment groundwater quality standards as inclusive as possible.
- In areas where severe contamination is in publicly accessible areas, measures must be put into place to prevent this water from being accessed or used by any persons or animals.
- In several areas there are more than one industry responsible for a specific area or pollution plume. It is proposed that there needs to be co-operation between these industries to solve the problem.

The parameters that need to be analysed for in the regional monitoring also needs to be determined. It is suggested that as an **absolute minimum** the following parameters (the minimum requirements that would be acceptable) are included: **water level, pH, Electrical Conductivity, sulphate, nitrate, sodium, and Chemical Oxygen Demand/ Total Organic Carbon**. The last parameter, namely that of organic contamination indicator is problematic. Unfortunately low values of either TOC or COD do not indicate that the organic pollution is not a problem. Several organic parameters are extremely hazardous at extremely low concentrations and thus even if the recorded TOC or COD is low the groundwater might present a significant risk. This is an issue, which might fruitfully be dealt with by the suggested organic contamination task group. This group could also indicate if TOC might be preferable to COD as an indicator parameter for organic pollution.

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**APPENDIX A**  
**DETAILS OF SAMPLED SITES**

SiteName	Owner	SiteType	Water use	DepthBot	Diam	Depth	SPCOND	Temp	Sample no.	Date	WL	Sample from	Toxicity Test	Comment
GCS1D	Karbochem	B	Monitoring	30	165	15.50	244.80	21.40	GCS1D	19/10/98	2.750	Ball	No	
P8	Karbochem	P	Monitoring	2		1.90			P8	19/10/98	1.900	Ball	No	Smell styrene. Rubber buried on site. No probe.
GCS3	Karbochem	B	Monitoring		165	5.50	348.00	17.50	GCS3	19/10/98	3.640	Ball	No	
GCS1S	Karbochem	B	Monitoring		165	8.50	317.20	21.60	GCS1S	19/10/98	2.870	Ball	No	
EMC2D	Karbochem	B	Monitoring	30	165	16.50	137.50	18.20	KEMC2D	19/10/98	3.460	Ball	No	
GCS7	Karbochem	B	Monitoring	18	165	13.30	302.80	18.00	GCS7	19/10/98	2.440	Ball	No	Previously used for irrigation of grass.
GCS5	Karbochem	B	Monitoring		165	15.30	176.00	18.30	GCS5	19/10/98	2.560	Ball	Yes	
EMC1D	Karbochem	B	Monitoring	30	165	13.00	157.00	17.70	KEMC1D	19/10/98	0.880	Ball	No	
EMC1S	Karbochem	B	Monitoring	9	165	8.30	455.00	16.00	KEMC1S	19/10/98	0.855	Ball	No	
EMC2S	Karbochem	B	Monitoring	10	165	7.50	143.50	16.80	KEMC2S	19/10/98	2.805	Ball	No	
AFCAT1	Afcat	B	Industrial						AFCAT1	20/10/98		Tap at gate	Yes	Pump was running.
OB1	Omnla	B	Monitoring		165	7.00	2583.00	19.00	OB1	20/10/98	1.860	Ball	Yes	EC reduced with depth from 7 m - 18 m.
OB8	Omnla	B	Monitoring		165	10.00	73.30	19.50	OB8	20/10/98	1.040	Ball	No	
OB3	Omnla	B	Monitoring		165	6.50	153.20	19.30	OB3	21/10/98	0.870	Ball	No	
OB4	Omnla	B	Monitoring		165	5.50	80.60	19.40	OB4	21/10/98	5.500	Ball	No	
SB5	Safripol	B	Monitoring		165	18.00	47.00	21.30	SB5	21/10/98		Ball	No	
SB1	Safripol	B	Monitoring	58	165	13.50	38.90	19.10	SB1	21/10/98	2.860	Ball	No	EC reduces with depth
SB2	Safripol	B	Monitoring		165	18.00	31.40	19.20	SB2	21/10/98	4.340	Ball	No	
SB3	Safripol	B	Monitoring		165	18.00	19.58	18.40	SB3	21/10/98	4.750	Ball	No	
SRK14D	Poilfin	B	Monitoring			20.00	269.00	19.90	SRK14D	20/10/98	2.920	Ball	Yes	
SRK14S	Poilfin	B	Monitoring							20/10/98	2.940	None	No	DNAPL's, smell and see.
SRK8S	Poilfin	B	Monitoring			10.00	35.65	17.90	SRK8S	20/10/98	2.390	Ball	No	DNAPL's, smell and see. No sample
SRK8D	Poilfin	B	Monitoring	3						20/10/98	2.065	None	No	Dry, no water.
SRK18D	Poilfin	B	Monitoring			5.00	49.70	19.40	SRK18D	20/10/98	2.556	Ball	No	EC reduces with depth
SRK18S	Poilfin	B	Monitoring	9		8.00	131.10	19.80		20/10/98	2.530	None	No	No sample
SRK19D	Poilfin	B	Monitoring			22.00	112.70	20.70	SRK19D	20/10/98	2.835	Ball	No	
SRK19S	Poilfin	B	Monitoring			10.00	95.20	19.90		20/10/98	2.830	None	No	No sample
SRK18S	Poilfin	B	Monitoring	18		11.00	58.20	19.40	SRK18S	20/10/98	2.070	Ball	No	
SRK16D	Poilfin	B	Monitoring			15.00	168.00	19.40		20/10/98	2.050	None	No	No sample
SRK25D	Poilfin	B	Monitoring			12.50	81.00	18.50	SRK25D	20/10/98	2.430	Ball	Yes	Suspect organics.
SRK25S	Poilfin	B	Monitoring	5		5.00	477.00	17.80		20/10/98	2.430	None	No	No sample
SRK12D	Poilfin	B	Monitoring	20		13.80	132.30	19.10	SRK12D	20/10/98	1.920	Ball	No	
SRK20S	Poilfin	B	Monitoring	8			34.50	18.80	SRK20S	20/10/98	1.832	None	No	No sample
SRK20D	Poilfin	B	Monitoring			18.14	70.60	18.35		20/10/98	11.180	Ball	No	
SRK17D	Poilfin	B	Monitoring			7.50	104.50	7.50	SRK17D	20/10/98	1.860	Ball	No	Seems to be the same aquifer.
SRK17S	Poilfin	B	Monitoring			7.50	89.50	18.20	SRK17S	20/10/98	1.910	Ball	No	
SRK12S	Poilfin	B	Monitoring	10		7.62	124.50	18.70	SRK12S	20/10/98	1.990	Ball	No	
SRK29D	Poilfin	B	Monitoring			18.3	330.10	18.70	SRK29D	20/10/98	2.320	Ball	No	
SRK29S	Poilfin	B	Monitoring			7.00	327.60	17.60		20/10/98	2.380	None	No	No sample
SRK2D	Poilfin	B	Monitoring			15.00	195.50	18.30	SRK2D	20/10/98	2.800	Ball	No	
SRK2S	Poilfin	B	Monitoring			7.8	115.30	17.80		20/10/98	2.860	None	No	No sample
SRK1S	Poilfin	B	Monitoring	15		1.00	38.50	16.50	SRK1S	20/10/98	0.170	Ball	No	
SRK1D	Poilfin	B	Monitoring			8.00	111.00	18.20		20/10/98	0.835	None	No	No sample
BT1	Bothma transport	B	Washing water		165				BT1	21/10/98		Pipe at reservoir	No	Pump was running.
BT2	T. Bothma	B	Domestic		165				BT2	21/10/98		Tap at house	No	Pump was running.
INCA1	Inca Brickworks	B	Industrial						INCA1	21/10/98	2.780	Pipe from tank	No	Pump was started on request.
AB2	Petronet (Coalbrook)	B	Monitoring	3	70	2.50	78.10	17.70	PN1	21/10/98	1.900	Ball	No	
AB8	Petronet (Coalbrook)	B	Monitoring	9	70	4.50	58.80	19.80	PN2	21/10/98	0.930	Ball	No	
SB8	Petronet (Sasolburg)	B	Monitoring		70				PN3	21/10/98	1.900	Ball	No	Free product/ no probe
SB5	Petronet (Sasolburg)	B	Monitoring	3	70	2.00	53.40	19.30	PN4	21/10/98	1.750	Ball	No	Cleaner than PN3 and PN5.
SB3	Petronet (Sasolburg)	B	Monitoring		70				PN5	21/10/98	1.990	Ball	Yes	Free product/ petrol no probe
B4	Natref	B	Monitoring	5.2		4.00	75.10	20.10	NB4	21/10/98	1.720	Ball	No	
B21	Natref	B	Monitoring	5		4.00	412.90	19.60	NB21	21/10/98	1.430	Ball	No	Smell Hydrocarbons
B13	Natref	B	Monitoring	3					NB13	21/10/98	2.370	None	No	No water dry.
B14	Natref	B	Monitoring	4.8		4.00	323.80	19.80	NB14	21/10/98	1.785	Ball	No	
B28	Natref	B	Monitoring	4.9		4.00	556.00	19.60	NB28	21/10/98	3.340	Ball	No	Smell Hydrocarbons
EX3	Natref	B	Monitoring	9		4.00	20.10	18.90	EX3	21/10/98	2.430	Ball	No	

SiteName	Owner	SiteType	Water use	DepthBot	Diam	Depth	SPCOND	Temp	Sample no.	Date	WL	Sample from	Toxicity Test	Comment
EX1	Natref	B	Monitoring	9		4.00	22.10	18.80	EX1	21/10/98	2.430	Ball	No	
B2	Kragbron	B	Monitoring	40	165	21.00	183.70	18.00	KB2	21/10/98	2.920	Ball	No	
B3	Kragbron	B	Monitoring		165	15.00	105.20	18.10	KB3	21/10/98	3.930	Ball	No	
B1	Kragbron	B	Monitoring		165	19.00	119.00	18.20	KB1	28/10/98	3.350	Ball	No	
B4	Kragbron	B	Monitoring		185	18.00	179.60	18.10	KB4	28/10/98	15.760	Ball	No	
SM1	Munisipaliteit	B	Irrigation						SM1	28/10/98		Tap	No	Swimmingpool
SM2	Munisipaliteit	B	Irrigation						SM2	28/10/98	15.650	Tap	No	Fire station
FB1	Nienaber (Vaalbank)	B	Domestic						FB1	23/10/98		Tap at house	No	Water in storage tank combination of 2 boreholes
FB2	Nienaber (Verdun)	B	Domestic	25					FB2	23/10/98		Tap at house	No	Complain about dewatering due to mine workings.
FB3	Scott (DeNille)	B	Domestic						FB3	23/10/98		Tap at house	No	Occupants of farm not home.
FB4	Danhauser (Amelia)	B	Domestic	28	185	13.50	58.60	18.10	FB4	23/10/98	2.680	Ball	No	
FB5	De Kock (Mooldraai)	B	Domestic	33	185				FB5	23/10/98		Tap at house	Yes	
FB10	De Kock (Mooldraai)	B	None		185	20.00	90.40	17.10	FB10	27/10/98	0.060	Ball	No	Mdiensleenpan
FB6	EAC (Abattoir)	B	Wash/ Domestic	208	185				FB6	23/10/98		Tap in kitchen	No	
FB7	EAC (Town)	B	Domestic	200	185				FB7	23/10/98		Tap in town	No	
W3	EAC (Gysbertshoek)	B	Stockwatering		185				W3	27/10/98		Handpump	Yes	Feedlot (12000 cattle)
ZA1	Unknown	B	Unknown	17	185	14.00	51.90	18.80	ZA1	27/10/98	7.150	Ball	No	On deserted farm across informal settlement
FB8	Du Plooy (Rietfontein)	B	Domestic						FB8	27/10/98		From tank	No	East of Holy Country
HC1	Holly Country	B	Irrigation	30	165	20.00	298.70	19.50	HC1	27/11/98	2.510	Ball	No	Water used on golfcourse
FB11	Herbst	B	Domestic						FB11	28/10/98		Tap at house	No	SE from Kragbron
WWF1	Sigma (Fountain)	F	None						WWF1	28/10/98		At source	No	Fountain next to road towards Bohma
WWF2	VNlekerk (Wanderfontein)	B	Domestic	50	185				NW042	28/10/98	48.120	None	No	No sample too deep.
NW042	Sigma (NW mine)	B	Monitoring		185				NW032	29/10/98	3.175	None	No	Piezometers to small for bailer.
NW032	Sigma (NW mine)	B	Monitoring		65				NW047	28/10/98	3.270	Ball	No	
NW047	Sigma (NW mine)	B	Monitoring		185	11.50	394.50	19.00	WWF2	29/10/98	13.500	Tap at borehole	No	
WW003	Sigma (Wanderwater)	B	Monitoring		165	14.60	190.40	19.50	WW003	29/10/98	9.720	Ball	No	Farmhouse on Vaal River.
WW007	Sigma (Wanderwater)	B	Monitoring		165	30.00	102.00	19.80	WW07	28/10/98	3.160	Ball	No	
WW021	Sigma (Wanderwater)	B	Monitoring			45.00			WW021	30/10/98	42.345	Ball	No	In opencast mining pit.
UG23	Sigma (Underground)	B	Monitoring			12.00	10.00	18.40	UG23	30/10/98	10.810	Ball	No	EC constant, was purged.
UG28	Sigma (Underground)	B	Monitoring			30.00	120.70	18.80	UG28	30/10/98	19.430	Ball	No	
UG22	Sigma (Underground)	B	Monitoring			20.00	312.00	18.50	UG22	30/10/98	14.080	Ball	No	
UG17	Sigma (Underground)	B	Monitoring			28.00	51.40	18.80	UG17	30/10/98	19.040	Ball	No	
NW004	Sigma (Boschbank)	B	Monitoring			23.30	42.82	19.40	NW004	30/10/98	11.520	Ball	No	
WW010	Sigma (Wanderwater)	B	Monitoring			5.00	20.63	19.10	WW010	30/10/98	3.150	Ball	No	
FB12	Du Plooy	B	Domestic		165				FB12	28/10/98		Tap in garden	No	South of Kragbron
FB13	Skaapplaas	B	Domestic	40	165				FB13	29/10/98		Tap in house	No	"Kontantwinkel"
FB14	Unknown	B	Stockwatering		165				FB14	29/10/98		Windpump	No	
ST	Taibosspuit	S							ST	21/10/98		Grab	No	Sample downstream from Kragbron ashdams
A2A	SCI	B	Monitoring	9	185	5.00	165.40	18.60	A2A	28/10/98	1.990	None	No	No sample.
A2B	SCI	B	Monitoring	29	185	21.00	248.20	18.40	A2B	28/10/98	9.530	Ball	No	
EMC1S	SCI	B	Monitoring	10	216	5.00	345.20	17.80	EMC1S	28/10/98	2.710	Ball	No	
EMC1D	SCI	B	Monitoring	22	216	8.00	64.30	18.70	EMC1D	28/10/98	2.850	Ball	No	
D1A	SCI	B	Monitoring	7	185	4.00	112.00	17.10	D1A	28/10/98	0.480	Ball	No	EC stayed constant down hole.
O1A	SCI	B	Monitoring	12.5	150	8.00	2202.00	18.20	O1A	28/10/98	0.370	Ball	Yes	Acidic/ brown
O1B	SCI	B	Monitoring	25	150	10.00	48.40	17.00	O1B	28/10/98	5.330	Ball	No	
T7	SCI	B	Monitoring	6	150	4.00	340.00	17.00	T7	28/10/98	2.370	Ball	No	EC stayed constant down hole.
EMC3D	SCI	B	Monitoring	30	216	10.00		18.70	EMC3D	28/10/98	0.800	Ball	No	EC reduces after 15 m.
T1	SCI	B	Monitoring	9	185	5.00	28.80	18.80	T1	28/10/98	2.770	Ball	No	
S3	SCI	B	Monitoring	30	185	22.00	144.40	18.40	S3	28/10/98	21.010	Ball	No	Next to Leespruit, hear water falling down hole
S2	SCI	B	Monitoring	14	185	12.00	231.3	17.40	S2	28/10/98	1.585	Ball	No	
S4	SCI	B	Monitoring	15.5	185	5.00	81.9	18.10	S4	28/10/98	1.940	Ball	No	EC stayed constant down hole.
P1B	SCI (Plant)	B	Monitoring	10	152	8.20	485.2	20.30	P1B	27/10/98	1.875	Ball	No	
P1A	SCI (Plant)	B	Monitoring	5	152	4.00	77.4	20.30	P1A	27/10/98	1.685	Ball	No	
V11D	SCI (Vencopark)	B	Monitoring	30	185	15.00	122.7	19.40	V11D	27/10/98	3.680	Ball	No	New hole, next to Valid Butchery
V1D	SCI (Vencopark)	B	Monitoring	30	185	18.00	533	18.90	V1D	27/10/98	1.410	Ball	No	New hole, EC constant down hole
V2S	SCI (Vencopark)	B	Monitoring	5	185	4.00	488.8	17.20	V2S	27/10/98	0.320	Ball	Yes	New hole, Very low pH!!!!
V4S	SMX	B	Monitoring	4	185	3.00	2401	18.50	V4S	27/10/98	1.330	Ball	No	New hole
V3D	SMX	B	Monitoring	30	185	18.00	2816	18.80	V3D	27/10/98	1.540	Ball	No	New hole
A4	SCI	B	Monitoring	28	203	19.00	224.2	20.20	A4	28/10/98	4.010	Ball	No	

**APPENDIX B**  
**TABLES OF CHEMICAL ANALYSES**  
(All units mg/l except EC=mSm and pH =pH units)

## Boreholes at AFCAT, Inca and municipality

SiteName	SM1	SM2
pH	7.750	7.170
EC	71.000	25.000
Ca	63.000	22.000
Mg	24.000	6.900
Na	68.000	23.000
K	2.000	2.700
Palk	0.000	0.000
Malk	249.000	123.000
Cl	43.000	2.000
SO4	69.000	7.000
N	2.800	0.100
F	0.100	0.140
NO2	0.000	0.000
PO4	0.000	0.000
Br	1.440	0.000
Al	0.041	0.136
Fe	0.000	0.895
Mn	0.001	0.324
NH4(N)	1.704	25.405
COD	1898.000	745.000
Ag	0.000	0.018
As	0.000	0.000
Be	0.000	0.000
Cd	0.000	0.000
Co	0.019	0.000
Cr	0.001	0.000
Cu	0.006	0.003
La	0.000	0.000
Mo	0.000	0.000
Ni	0.036	0.032
Pb	0.000	0.000
Se	0.000	0.000
Sn	0.000	0.000
V	0.000	0.000
Zn	0.041	0.041
Hg	0.000	0.000
<b>IONBAL</b>	<b>4.458</b>	<b>-3.190</b>

SiteName	AFCAT1	INCA1
pH	7.710	7.790
EC	214.000	81.000
Ca	255.000	89.000
Mg	109.000	46.000
Na	39.000	27.000
K	4.500	3.600
PAIk	0.000	0.000
MAIk	114.000	103.000
Cl	150.000	44.000
SO4	55.000	141.000
N	228.000	38.000
F	0.260	0.330
NO2	0.000	0.000
PO4	0.370	0.000
Br	0.241	0.180
Al	0.019	0.020
Fe	0.011	0.028
Mn	0.003	0.012
NH4(N)	0.080	169.980
COD	6.000	5469.000
Ag	0.000	0.000
As	0.000	0.000
Be	0.000	0.000
Cd	0.000	0.000
Co	0.000	0.080
Cr	0.000	0.000
Cu	0.008	0.074
La	0.000	0.000
Mo	0.000	0.000
Ni	0.000	0.138
Pb	0.000	0.041
Se	0.000	0.000
Sn	0.000	0.000
V	0.000	0.000
Zn	0.094	0.103
Hg	0.000	0.000
<b>IONBAL</b>	<b>4.150</b>	<b>-8.860</b>

**Farmers Boreholes**

SiteName	FB1	FB10	FB11	FB12	FB13	FB14	FB2
pH	7.190	8.140	7.720	8.050	7.760	7.680	7.660
EC	53.000	81.000	264.000	67.000	246.000	79.000	35.000
Ca	42.000	5.800	204.000	31.000	204.000	80.000	43.000
Mg	24.000	1.200	123.000	11.000	121.000	41.000	19.000
Na	35.000	204.000	178.000	110.000	148.000	51.000	15.000
K	2.100	2.000	34.300	2.900	70.000	3.200	1.600
PAIk	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAIk	85.000	360.000	300.000	206.000	245.000	346.000	128.000
Cl	32.000	49.000	530.000	79.000	689.000	53.000	12.000
SO4	17.000	23.000	130.000	26.000	146.000	27.000	9.000
N	33.200	0.100	3.800	1.700	5.500	0.900	14.300
F	0.140	1.400	0.300	1.480	0.320	0.240	0.040
NO2	0.000	0.100	0.000	0.000	0.000	0.000	0.000
PO4	0.000	0.000	0.390	0.000	0.930	0.000	0.000
Br	0.100	0.370	2.630	0.490	4.000	0.000	0.160
Al	0.021	0.077	0.065	0.069	0.051	0.097	0.020
Fe	0.007	0.125	0.046	0.033	0.025	0.091	0.016
Mn	0.002	0.008	0.002	0.002	0.004	0.002	0.002
NH4(N)	0.060	0.160	0.910	0.100	2.254	0.220	0.120
COD	6.000	53.000	14.000	1.000	54.000	2.000	14.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.004	0.005	0.007	0.003	0.004	0.014	0.004
La	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.007	0.000	0.000	0.000	0.008	0.000
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.053	0.000
Zn	0.232	0.031	0.146	0.099	0.208	0.046	0.794
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>3.148</b>	<b>0.999</b>	<b>9.740</b>	<b>1.710</b>	<b>1.490</b>	<b>3.676</b>	<b>3.820</b>

SiteName	FB3	FB4	FB5	FB6	FB7	FB8	HC1
pH	7.640	7.660	7.920	7.990	7.620	7.680	7.290
EC	100.000	58.000	75.000	68.000	22.000	87.000	157.000
Ca	70.000	64.000	79.000	19.000	18.000	76.000	110.000
Mg	43.000	32.000	30.000	7.600	8.000	30.000	55.000
Na	126.000	30.000	51.000	143.000	18.000	79.000	204.000
K	2.100	4.800	8.000	1.800	3.800	24.200	11.700
PAlk	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAlk	405.000	288.000	240.000	211.000	74.000	326.000	381.000
Cl	77.000	13.000	74.000	84.000	15.000	41.000	178.000
SO4	58.000	19.000	31.000	33.000	19.000	50.000	284.000
N	0.420	2.300	12.300	0.600	0.150	13.100	2.900
F	0.290	0.170	0.300	0.100	0.200	0.450	0.490
NO2	0.000	0.040	0.000	0.000	0.020	0.000	0.000
PO4	0.000	0.000	0.000	0.170	0.000	0.000	0.760
Br	0.440	0.100	0.520	0.560	0.000	0.370	0.990
Al	0.045	0.027	0.032	0.024	0.050	0.093	0.099
Fe	0.036	0.021	0.187	0.015	0.037	0.128	0.243
Mn	0.004	0.020	0.005	0.012	0.002	0.001	0.127
NH3	0.560	0.100	0.070	0.140	0.090	0.120	0.130
COD	7.000	13.000	5.000	6.000	11.000	8.000	47.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.008	0.007	0.013	0.005	0.011	0.006	0.004
La	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.038	0.010	0.010	0.005	0.000	0.000
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zn	0.957	0.024	1.902	0.236	0.108	0.043	0.015
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>4.690</b>	<b>4.329</b>	<b>2.636</b>	<b>3.476</b>	<b>2.879</b>	<b>3.471</b>	<b>1.231</b>

SiteName	WWF1	WWF2	ZA1	BT2
pH	6.990	7.210	7.560	7.250
EC	33.000	21.000	50.000	16.000
Ca	22.400	15.000	32.000	10.000
Mg	14.000	5.900	13.852	3.500
Na	27.000	22.000	57.000	24.000
K	3.600	1.200	12.100	0.700
PAIk	0.000	0.000	0.000	0.000
MAIk	81.000	81.000	206.000	65.000
Cl	3.000	14.000	10.000	8.000
SO4	61.000	1.000	14.000	8.000
NO3 as N	4.700	1.500	7.000	0.020
F	0.030	0.400	0.300	0.300
NO2	0.000	0.000	0.000	0.000
PO4	0.130	0.000	0.000	0.340
Br	0.000	0.000	0.000	0.060
Al	0.037	0.073	0.081	0.092
Fe	0.000	0.000	0.022	0.100
Mn	0.002	0.001	0.002	0.002
NH3	0.080	0.060	0.080	0.080
COD	8.000	5.000	9.000	6.000
Ag	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000
Cu	0.000	0.000	0.000	0.008
La	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000
Ni	0.004	0.000	0.000	0.000
Pb	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000
Zn	0.013	0.020	0.027	0.094
Hg	0.000	0.000	0.000	0.000
IONBAL	3.565	1.720	3.227	4.150

**Natref Boreholes**

SiteName	EX1	EX3	B14	B21	B26	B4
pH	7.270	7.650	7.760	7.400	8.340	7.190
EC	23.000	22.000	324.000	407.000	538.000	76.000
Ca	19.000	18.000	149.000	231.000	165.000	72.000
Mg	11.000	11.000	93.000	159.000	123.000	49.000
Na	17.000	19.000	593.000	662.000	1274.000	33.000
K	0.400	0.500	1.700	2.400	3.800	0.680
PAIk	0.000	0.000	0.000	0.000	8.000	0.000
MAIk	117.000	109.000	424.000	472.000	790.000	60.000
Cl	3.000	3.000	170.000	263.000	184.000	10.000
SO4	6.000	5.000	1341.000	1940.000	2651.000	302.000
N	0.020	1.430	0.010	0.020	0.020	0.000
F	0.290	0.280	0.270	0.290	0.630	0.270
NO2	0.000	0.000	0.000	0.000	0.000	0.050
PO4	0.000	0.550	0.000	0.000	0.000	0.000
Br	0.070	0.000	1.350	2.200	1.170	0.180
Al	0.039	0.038	0.028	0.030	0.039	0.038
Fe	0.011	0.017	0.017	0.013	0.053	0.013
Mn	0.002	0.003	0.093	2.810	4.096	0.004
NH4(N)	2.590	0.190	0.360	0.190	0.160	0.100
COD	160.000	3.000	40.000	3.000	53.000	1.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.018	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.005	0.004	0.005	0.004	0.005	0.003
La	0.000	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.027	0.000	0.007	0.000
Pb	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.000
Zn	0.030	0.024	0.042	0.024	0.031	0.099
Hg	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>4.425</b>	<b>3.289</b>	<b>2.006</b>	<b>3.289</b>	<b>0.999</b>	<b>1.710</b>

**Safripol Boreholes**

SiteName	SB1	SB2	SB3	SB5
pH	7.460	7.460	6.900	7.520
EC	41.000	29.000	17.000	46.000
Ca	34.000	29.000	14.000	47.000
Mg	21.000	17.000	8.000	30.000
Na	30.000	15.000	8.000	10.000
K	2.700	1.300	0.820	4.200
PAIk	0.000	0.000	0.000	0.000
MAIk	159.000	154.000	64.000	148.000
Cl	31.000	4.000	5.000	45.000
SO4	22.000	5.000	21.000	33.000
N	0.090	0.140	0.040	1.460
F	0.270	0.130	0.180	0.040
NO2	0.280	0.000	0.000	0.000
PO4	0.000	0.000	0.000	0.000
Br	0.080	0.000	0.000	0.410
Al	0.048	0.071	0.048	0.042
Fe	0.016	0.037	0.064	0.125
Mn	0.159	0.472	0.259	0.087
NH4(N)	8.332	0.170	0.080	0.070
COD	1393.000	11.000	1.000	216.000
Ag	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000
Cu	0.003	0.003	0.000	0.011
La	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.005	0.017
Pb	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000
Zn	0.105	0.114	0.042	0.021
Hg	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>11.373</b>	<b>3.739</b>	<b>4.233</b>	<b>-0.590</b>

**Omnia Boreholes**

SiteName	OB1	OB3	OB4	OB6
pH	6.030	8.220	7.090	7.220
EC	1794.000	130.000	579.000	75.000
Ca	2882.000	134.000	696.000	68.000
Mg	1430.000	57.000	338.000	33.000
Na	105.000	47.000	68.000	27.000
K	10.600	34.800	9.200	1.500
Palk	0.000	0.000	0.000	0.000
Malk	4.000	232.000	61.000	39.000
Cl	701.000	140.000	141.000	50.000
SO4	60.000	144.000	63.000	2.000
N	3195.000	42.700	854.000	65.900
F	3.200	1.400	1.800	0.080
NO2	0.000	20.100	0.000	0.470
PO4	0.000	6.600	6.100	0.000
Br	0.000	0.210	0.000	0.180
Al	0.022	0.068	0.051	0.027
Fe	0.640	0.031	0.026	0.062
Mn	0.994	0.401	0.111	0.177
NH4(N)	0.130	0.140	0.120	7.846
COD	4.000	14.000	21.000	2345.000
Ag	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000
Cu	0.000	0.000	0.004	0.005
La	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000
Ni	0.000	0.003	0.004	0.007
Pb	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000
V	0.000	0.000	0.010	0.000
Zn	0.024	0.031	0.047	0.037
Hg	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>2.846</b>	<b>2.130</b>	<b>-1.940</b>	<b>4.864</b>

**SCI Boreholes**

SiteName	A2B	D1A	O1A	O1B	P1A	P1B	S2	S3
pH	11.640	6.810	5.880	7.550	7.420	7.370	7.780	7.660
EC	136.000	99.000	1885.000	59.000	43.000	71.000	224.000	159.000
Ca	109.000	102.000	2905.000	66.000	31.000	61.000	164.000	159.000
Mg	1.000	48.000	1020.000	20.000	24.000	36.000	68.000	57.000
Na	70.000	51.000	443.000	45.000	21.000	26.000	245.000	155.000
K	27.900	4.500	18.400	3.500	9.000	11.100	6.400	4.800
Palk	320.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAlk	335.000	127.000	20.000	154.000	112.000	132.000	376.000	408.000
Cl	50.000	231.000	4486.000	84.000	22.000	24.000	389.000	128.000
SO4	20.000	98.000	400.000	12.000	46.000	49.000	312.000	310.000
N	0.640	0.070	1301.000	14.200	9.580	48.000	0.000	0.070
F	0.800	0.110	0.200	0.140	0.210	0.120	0.050	0.040
NO2	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PO4	1.800	0.100	0.000	0.000	0.000	0.250	0.000	0.000
Br	0.120	1.130	0.000	0.180	0.090	0.009	1.930	0.350
Al	1.229	0.054	0.046	0.065	0.083	0.106	0.184	0.051
Fe	0.022	0.055	0.063	0.021	0.016	0.044	0.079	0.015
Mn	0.000	1.951	0.463	0.002	0.002	0.003	0.051	0.196
NH4(N)	1.640	0.360	7.477	0.120	0.140	0.120	2.250	0.090
COD	62.000	40.000	155.000	391.000	14.000	21.000	317.000	17.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Cu	0.007	0.005	0.003	0.003	0.000	0.004	0.005	0.005
La	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.000
Mo	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.026	0.027	0.090	0.000	0.003	0.004	0.012	0.019
Pb	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
Zn	0.505	0.042	0.014	0.017	0.031	0.047	0.009	0.027
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>4.491</b>	<b>2.006</b>	<b>4.705</b>	<b>2.240</b>	<b>2.130</b>	<b>-1.940</b>	<b>-0.275</b>	<b>3.572</b>

SiteName	S4	SA4	SEMC1D	SEMC3D	T1	T7	V11D	V1D	V2S
pH	7.320	8.100	7.850	7.760	8.320	6.610	7.020	7.100	3.500
EC	85.000	125.000	58.000	237.000	31.000	364.000	186.000	474.000	4486.000
Ca	76.000	91.000	52.000	193.002	4.700	324.000	174.000	532.000	484.000
Mg	29.000	53.000	21.000	77.000	7.700	185.000	87.000	234.000	5544.000
Na	74.000	39.000	62.000	246.000	55.000	308.000	74.000	154.000	9955.000
K	1.800	7.900	5.200	7.500	2.300	8.200	10.900	8.200	327.000
Palk	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Malk	330.000	36.000	318.000	408.000	128.000	203.000	112.000	239.000	0.000
Cl	49.000	28.000	4.000	402.000	19.000	543.000	124.000	733.000	1010.000
SO4	26.000	20.000	6.000	374.000	3.000	1295.000	170.000	489.000	49618.000
N	8.870	154.000	0.030	0.110	0.090	6.400	138.000	287.000	263.000
F	0.210	0.050	0.160	0.040	0.300	0.430	0.150	0.100	1.970
NO2	2.560	0.310	0.000	0.000	0.050	0.000	10.300	21.200	0.000
PO4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	919.000
Br	0.400	0.000	0.000	1.550	0.140	1.760	0.000	0.910	0.000
Al	0.082	0.074	0.081	0.160	0.053	0.039	0.047	0.071	389.000
Fe	0.104	0.006	0.014	0.034	0.000	0.032	0.056	0.031	0.085
Mn	0.001	0.008	0.001	0.128	0.002	3.189	0.029	0.132	185.000
NH3	0.100	24.940	0.080	0.070	0.340	0.805	0.824	0.395	442.868
COD	19.000	777.000	1.000	216.000	24.000	205.000	22.000	90.000	573.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.050
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022
Cu	0.000	0.002	0.000	0.011	0.000	0.000	0.003	0.002	2.200
La	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.704
Mo	0.014	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Ni	0.004	0.000	0.005	0.017	0.000	0.030	0.007	0.010	7.400
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170
Zn	0.014	0.010	0.042	0.021	0.008	0.021	0.066	0.036	22.880
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IONBAL	0.765	-1.160	4.233	-0.590	2.614	-1.492	-0.917	-4.152	-5.309

**SMX Boreholes**

SiteName	V3D	V4S
pH	6.110	7.490
EC	1948.000	2313.000
Ca	1918.000	3531.000
Mg	956.000	1463.000
Na	641.000	847.000
K	82.000	26.000
Palk	0.000	0.000
Malk	40.000	197.000
Cl	255.000	353.000
SO4	1735.000	1709.000
N	2537.000	3921.000
F	0.230	0.100
NO2	1.900	2.100
PO4	13.300	0.000
Br	0.000	0.000
Al	0.220	0.167
Fe	0.000	0.000
Mn	14.200	1.230
NH4(N)	0.860	0.691
COD	14.000	17.000
Ag	0.000	0.000
As	0.000	0.000
Be	0.000	0.000
Cd	0.000	0.000
Co	0.000	0.000
Cr	0.000	0.000
Cu	0.001	0.012
La	0.000	0.000
Mo	0.000	0.000
Ni	0.000	0.025
Pb	0.000	0.000
Se	0.000	0.000
Sn	0.000	0.000
V	0.000	0.000
Zn	0.016	0.038
Hg	0.000	0.000
IONBAL	-1.001	-0.951

**Polifin Boreholes**

SiteName	SRK12D	SRK14D	SRK16S	SRK17D	SRK18D	SRK19D
pH	7.840	7.570	6.750	7.880	7.490	6.860
EC	130.000	546.000	5072.000	105.000	51.000	95.000
Ca	128.000	798.000	4873.000	53.000	49.000	80.000
Mg	51.000	360.000	2255.000	23.000	25.000	52.000
Na	78.000	82.000	4444.000	138.000	13.000	29.000
K	2.500	8.400	42.200	1.900	3.900	2.700
Palk	0.000	0.000	0.000	0.000	0.000	0.000
Malk	179.000	129.000	106.000	303.000	111.000	102.000
Cl	319.000	2290.000	23340.000	116.000	85.000	173.000
SO4	47.000	13.000	410.000	64.000	21.000	174.000
N	1.800	8.000	0.830	12.300	1.500	0.790
F	0.140	1.010	19.300	0.190	0.070	0.060
NO2	0.000	0.000	0.000	0.000	0.840	1.240
PO4	0.000	0.000	0.000	0.000	0.700	0.570
Br	0.210	0.000	0.000	0.340	0.290	0.000
Al	0.060	0.292	0.032	0.051	0.056	0.050
Fe	0.018	0.111	0.012	0.028	0.017	0.011
Mn	0.001	9.099	1.032	0.001	0.001	0.016
NH4	0.150	4.021	1.966	0.140	4.410	3.845
COD	14.000	562.000	144.000	25.000	528.000	47.000
Ag	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.004	0.000	0.000	0.002	0.000	0.000
Cu	0.006	0.005	0.007	0.003	0.004	0.004
La	0.000	0.000	0.000	0.000	0.000	0.000
Mo	0.019	0.006	0.000	0.000	0.011	0.000
Ni	0.000	0.000	0.008	0.006	0.000	0.007
Pb	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000
V	0.028	0.000	0.000	0.000	0.000	0.000
Zn	0.061	0.065	0.071	0.024	0.020	0.035
Hg	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>-4.148</b>	<b>2.257</b>	<b>-4.363</b>	<b>4.217</b>	<b>-2.487</b>	<b>-4.894</b>

SiteName	SRK1D	SRK20D	SRK25D	SRK29D	SRK2D	SRK8D
PH	8.370	7.220	7.060	7.730	6.860	7.650
EC	41.000	77.000	748.000	254.000	1961.000	39.000
Ca	5.500	32.000	1136.000	263.000	2296.000	40.000
Mg	1.100	11.600	365.000	100.000	1101.000	15.000
Na	103.000	112.000	103.000	185.000	264.000	11.000
K	0.730	2.200	10.600	3.400	9.300	3.400
Palk	4.000	0.000	0.000	0.000	0.000	0.000
Malk	205.000	169.000	53.000	730.000	83.000	109.000
Cl	5.000	120.000	314.000	374.000	8560.000	40.000
SO4	9.000	68.000	198.000	222.000	77.000	25.000
N	0.640	0.000	1228.000	0.840	0.500	0.370
F	0.080	0.490	0.680	0.090	1.040	0.080
NO2	0.000	0.000	0.000	16.400	0.000	1.580
PO4	0.950	0.300	0.000	0.000	1.800	0.000
Br	0.000	0.240	0.000	0.420	0.000	0.000
Al	0.304	0.054	0.055	0.065	0.024	0.031
Fe	0.174	0.060	0.016	0.018	0.217	0.006
Mn	0.018	0.010	0.648	0.058	0.832	0.003
NH4	1.798	24.209	16.985	0.340	0.805	0.060
COD	177.000	1054.000	2767.000	24.000	205.000	104.000
Ag	0.000	0.012	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000
Bc	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.090	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.004	0.004	0.002	0.000	0.000	0.000
La	0.000	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.005	0.000	0.000
Ni	0.007	0.012	0.000	0.000	0.030	0.000
Pb	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.000
Zn	0.021	0.023	0.018	0.008	0.021	0.007
Hg	0.000	POSITIEF	0.000	0.000	0.000	0.000
IONBAL	-2.053	-5.270	11.780	2.614	-1.492	3.061

**Petronet Boreholes**

SiteName	PSB2	PSB6	PAB3	PAB5	PAB6
pH	7.260	7.080	5.870	6.260	7.470
EC	84.000	58.000	106.000	55.000	75.000
Ca	78.000	54.000	138.000	43.000	88.000
Mg	58.000	32.000	65.000	33.000	45.000
Na	34.000	30.000	35.000	22.000	23.000
K	0.650	2.500	3.880	1.350	2.200
Palk	0.000	0.000	0.000	0.000	0.000
Malk	223.000	217.000	537.000	165.000	389.000
Cl	29.000	18.000	71.000	71.000	29.000
SO4	216.000	75.000	12.000	39.000	7.000
N	0.340	0.090	0.370	0.350	0.290
F	0.290	0.320	0.430	0.210	0.710
NO2	0.000	0.000	0.000	0.000	0.120
PO4	0.000	0.000	0.000	0.270	0.000
Br	0.360	0.190	0.220	1.330	5.790
Al	0.033	0.124	0.046	0.066	0.033
Fe	0.032	0.153	0.477	9.841	0.824
Mn	0.590	0.039	5.234	2.149	1.414
NH4	0.933	0.160	6.423	1.067	2.250
COD	4.000	3.000	>16665	3260.000	317.000
Ag	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.023	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.007	0.005	0.000
Cr	0.000	0.000	0.000	0.000	0.000
Cu	0.003	0.003	0.019	0.015	0.005
La	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.004	0.000
Ni	0.000	0.000	0.037	0.024	0.012
Pb	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000
Zn	0.059	0.079	0.037	0.042	0.009
Hg	0.000	0.000	0.000	POSITIEF	0.000
IONBAL	-0.528	3.730	4.787	5.288	-0.275

**Karbochem boreholes**

SiteName	KEMC1D	KEMC1S	KEMC2D	KEMC2S	P8
pH	7.750	7.220	7.490	7.700	8.630
EC	169.000	489.000	143.000	156.000	1132.000
Ca	183.000	601.000	165.000	157.000	77.000
Mg	85.000	319.000	69.000	85.000	80.000
Na	65.000	143.000	35.000	48.000	3080.000
K	0.910	0.920	2.500	0.780	54.300
PAIk	0.000	0.000	0.000	0.000	153.000
MAIk	110.000	179.000	113.000	147.000	2199.000
Cl	402.000	1217.000	260.000	398.000	621.000
SO4	207.000	1403.000	90.000	50.000	6000.000
N	11.150	5.240	49.500	20.100	1.000
F	0.270	3.330	0.160	0.230	32.500
NO2	0.000	0.000	0.000	0.000	0.000
PO4	0.090	0.000	0.000	0.000	16.800
Br	0.408	0.570	0.380	0.180	1.600
Al	0.016	0.041	0.015	0.178	0.208
Fe	0.016	0.010	0.008	0.086	0.216
Mn	0.151	2.095	0.001	0.006	0.532
NH4	1.140	0.140	0.070	7.477	2.440
COD	54.000	10.000	10.000	155.000	346.000
Ag	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.046
Cr	0.000	0.000	0.000	0.000	0.000
Cu	0.006	0.003	0.000	0.003	0.005
La	0.000	0.000	0.000	0.038	0.000
Mo	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.005	0.090	0.017
Pb	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.002	0.000	0.000
Zn	0.043	0.004	0.004	0.014	0.074
Hg	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>8.391</b>	<b>4.843</b>	<b>4.277</b>	<b>4.705</b>	<b>2.878</b>

SiteName	GCS1D	GCS1S	GCS3	GCS5	GCS7
pH	7.720	7.390	7.780	6.850	7.720
EC	228.000	300.000	36.000	746.000	265.000
Ca	355.000	404.000	43.000	415.000	281.000
Mg	138.000	173.000	16.000	245.000	150.000
Na	34.000	114.000	17.000	810.000	179.000
K	6.900	75.900	3.100	10.200	4.600
PAlk	0.000	0.000	0.000	0.000	0.000
MAIk	123.000	95.000	160.000	135.000	373.000
Cl	174.000	212.000	9.300	1745.000	120.000
SO4	998.000	1539.000	7.000	750.000	560.000
N	60.200	52.900	4.400	34.600	145.000
F	0.050	0.100	0.130	0.500	0.300
NO2	0.000	0.400	0.030	0.000	0.000
PO4	0.000	0.000	0.190	0.000	0.000
Br	0.250	0.000	0.100	0.000	0.290
Al	0.025	0.024	0.097	0.021	0.019
Fe	0.041	0.009	0.031	0.041	0.011
Mn	0.010	0.010	0.002	0.160	0.027
NH4	0.510	0.908	0.790	0.580	2.260
COD	75.000	32.000	7.000	8.000	14.000
Ag	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000
Cu	0.005	0.004	0.003	0.002	0.006
La	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000	0.000
Ni	0.007	0.239	0.011	0.037	0.310
Pb	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000
Zn	0.019	0.127	0.023	0.030	0.102
Hg	0.000	0.000	0.000	0.000	0.000
IONBAL	1.337	-3.510	1.310	2.029	-2.184

**Sigma Colliery Boreholes**

SiteName	NW004	NW047	UG17	UG22	UG23	UG26	WW003	WW007	WW010	WW021
PH	8.130	7.700	7.010	7.420	7.580	8.390	7.570	6.900	7.730	7.770
EC	25.000	35.000	27.000	29.000	89.000	96.000	16.000	4.000	18.000	238.000
Ca	9.900	33.000	23.000	32.000	87.000	16.000	12.000	2.500	15.000	362.000
Mg	7.400	13.000	10.700	9.700	47.000	12.000	5.000	0.500	7.327	188.001
Na	42.000	31.000	9.700	17.000	25.000	186.000	18.000	3.500	10.000	44.000
K	1.400	2.100	13.100	6.700	10.300	2.160	1.100	1.200	1.700	11.500
Palk	0.000	0.000	0.000	0.000	0.000	7.000	0.000	0.000	0.000	0.000
Malk	123.000	184.000	76.000	146.000	182.000	202.000	82.000	14.000	94.000	327.000
Cl	4.200	2.000	12.000	6.000	119.000	98.000	2.000	2.000	2.000	3.000
SO4	6.000	4.000	3.000	3.000	31.000	163.000	2.000	1.000	1.000	1445.000
N	0.050	0.020	9.900	0.160	27.900	5.910	0.030	0.340	0.080	0.160
F	0.200	0.120	0.100	0.060	0.090	0.400	0.300	0.020	0.040	0.400
NO2	0.000	0.000	0.120	0.000	0.000	0.000	0.000	0.000	0.000	0.080
PO4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.510
Br	0.070	0.000	0.000	0.000	0.410	0.520	0.000	0.020	0.000	0.000
Al	0.079	0.113	0.055	0.035	0.082	0.190	0.044	0.083	0.096	0.055
Fe	0.129	0.478	0.000	1.080	0.039	0.131	0.046	0.632	0.265	0.025
Mn	0.001	0.062	0.009	0.389	0.006	0.006	0.038	0.009	0.163	1.095
NH4	0.120	58.640	0.824	0.395	442.868	625.737	0.080	0.060	0.080	2.220
COD	391.000	100.000	22.000	90.000	573.000	67.000	8.000	5.000	9.000	369.000
Ag	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.011	0.000	0.000	2.050	0.170	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000
Cu	0.003	0.005	0.003	0.002	2.200	0.000	0.000	0.000	0.000	0.017
La	0.000	0.002	0.000	0.000	0.704	0.660	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.050	0.007	0.010	7.400	0.480	0.004	0.000	0.000	0.007
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.170	0.000	0.000	0.000	0.000	0.000
Zn	0.017	0.035	0.066	0.036	22.880	0.227	0.013	0.020	0.027	0.103
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>2.240</b>	<b>4.391</b>	<b>-0.917</b>	<b>-4.152</b>	<b>-5.309</b>	<b>5.268</b>	<b>3.565</b>	<b>1.720</b>	<b>3.227</b>	<b>-0.042</b>

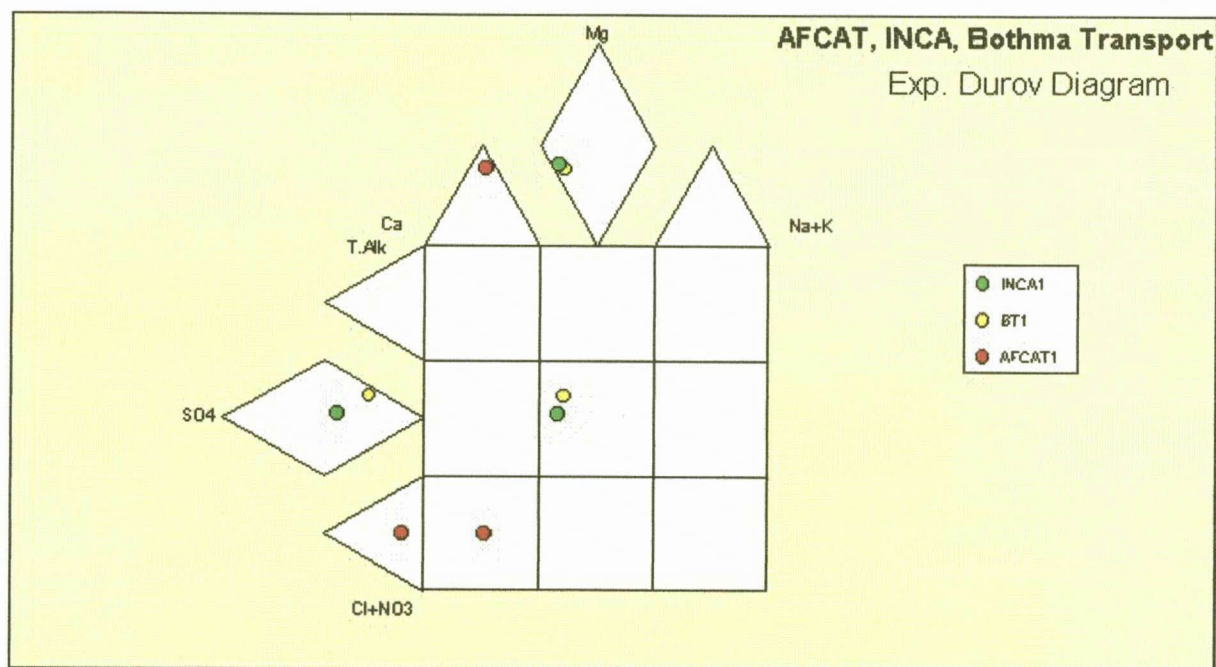
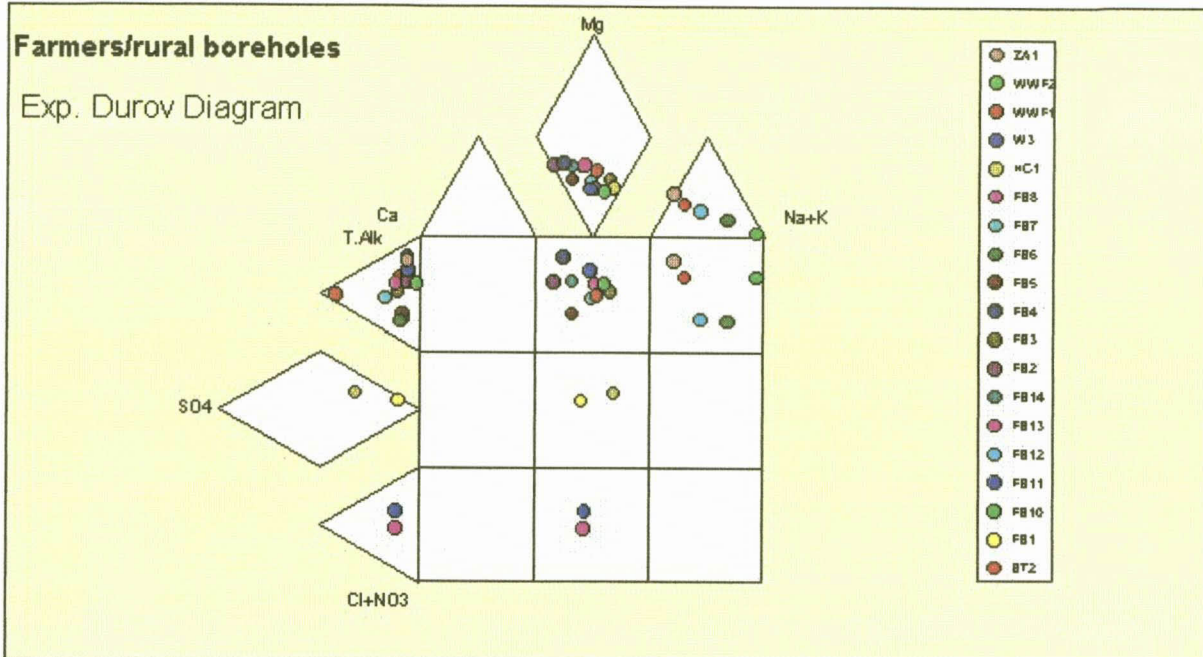
**Kragbron Sites**

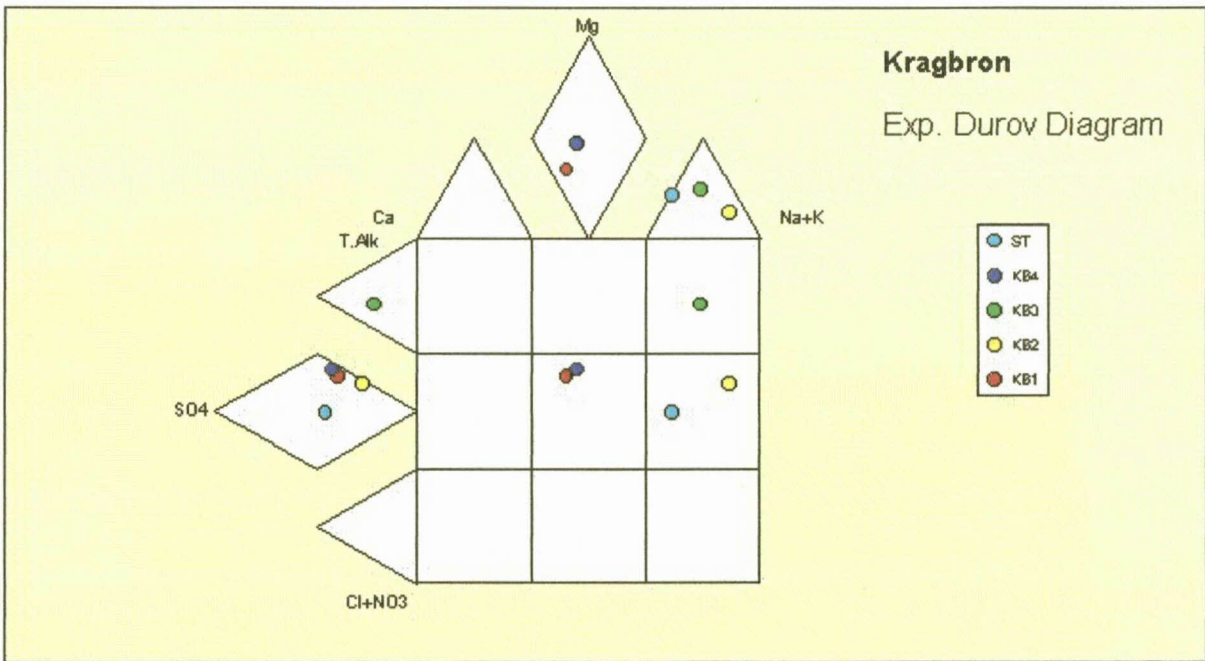
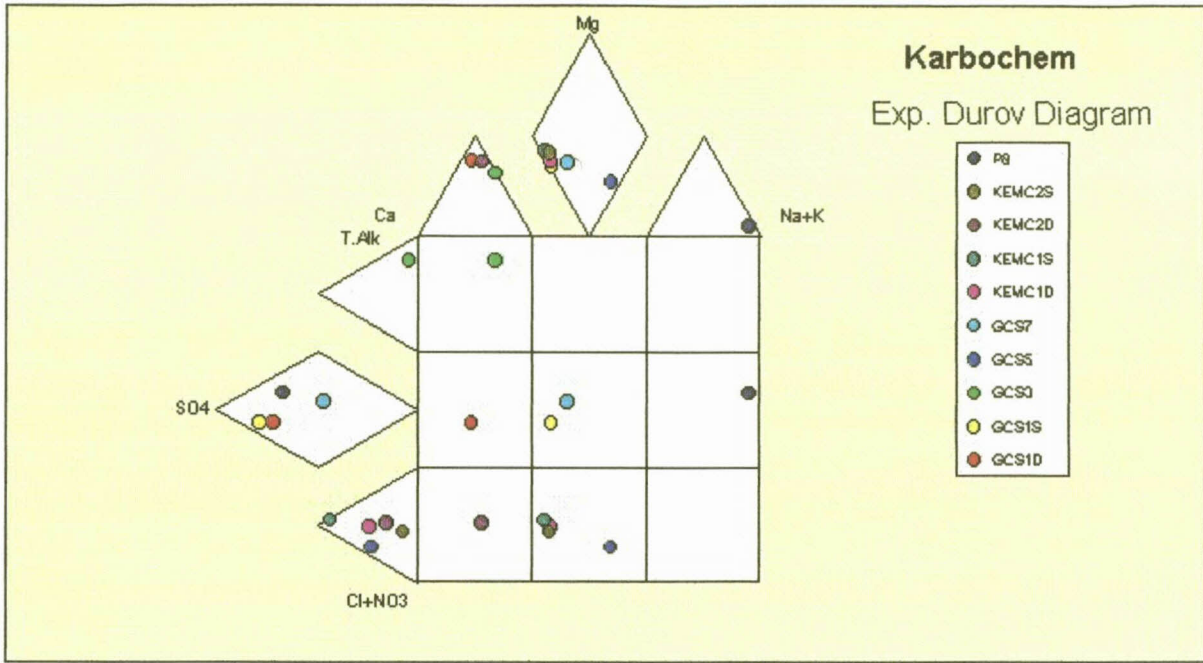
SiteName	KB1	KB2	KB3	KB4	ST
pH	7.410	8.140	7.850	7.830	8.130
EC	125.000	171.000	111.000	102.000	188.000
Ca	139.000	29.000	38.000	72.000	130.000
Mg	67.000	30.000	39.000	65.000	60.000
Na	84.000	376.000	194.000	56.000	272.000
K	7.600	0.470	0.400	2.100	9.300
Palk	0.000	0.000	0.000	0.000	0.000
Malk	341.000	484.000	382.000	295.000	301.000
Cl	82.000	180.000	82.000	50.000	229.000
SO4	280.000	254.000	126.000	252.000	497.000
N	0.030	0.600	0.030	0.870	0.270
F	0.280	0.810	0.730	0.230	0.430
NO2	0.000	0.000	0.000	0.000	0.000
PO4	0.000	0.000	0.000	0.000	0.390
Br	0.361	1.150	0.930	0.670	2.020
Al	0.068	0.036	0.049	0.016	0.155
Fe	0.103	0.097	0.055	0.000	0.083
Mn	0.002	0.005	0.537	0.000	0.022
NH4(N)	0.470	0.030	0.110	0.270	0.420
COD	25.000	21.000	34.000	15.000	233.000
Ag	0.000	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000	0.000
Be	0.000	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.004	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000
Cu	0.005	0.002	0.009	0.001	0.009
La	0.000	0.000	0.000	0.000	0.000
Mo	0.000	0.000	0.009	0.000	0.027
Ni	0.000	0.000	0.018	0.000	0.011
Pb	0.000	0.000	0.000	0.000	0.000
Se	0.000	0.000	0.000	0.000	0.000
Sn	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000
Zn	0.016	0.020	0.036	0.000	0.056
Hg	0.000	0.000	0.000	0.000	0.000
<b>IONBAL</b>	<b>4.584</b>	<b>0.454</b>	<b>3.862</b>	<b>-4.610</b>	<b>1.528</b>

**Bothma Transport**

SiteName	BT1
PH	6.770
EC	18.000
CA	16.000
Mg	8.000
Na	6.000
K	1.500
Palk	0.000
Malk	30.000
Cl	9.000
SO4	17.000
N	6.200
F	0.030
NO2	0.000
PO4	0.000
Br	0.000
Al	0.025
Fe	0.018
Mn	0.002
NH4(N)	2.254
COD	54.000
Ag	0.000
As	0.000
Be	0.000
Cd	0.000
Co	0.000
Cr	0.000
Cu	0.004
La	0.000
Mo	0.000
Ni	0.000
Pb	0.000
Se	0.000
Sn	0.000
V	0.000
Zn	0.208
Hg	0.000
IONBAL	1.490

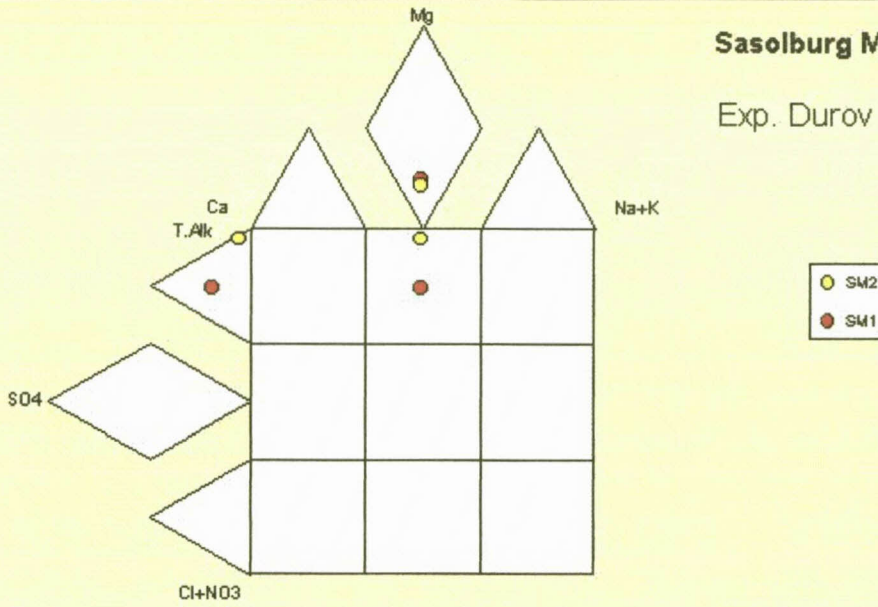
**APPENDIX C**  
**EXPANDED DUROV DIAGRAM**





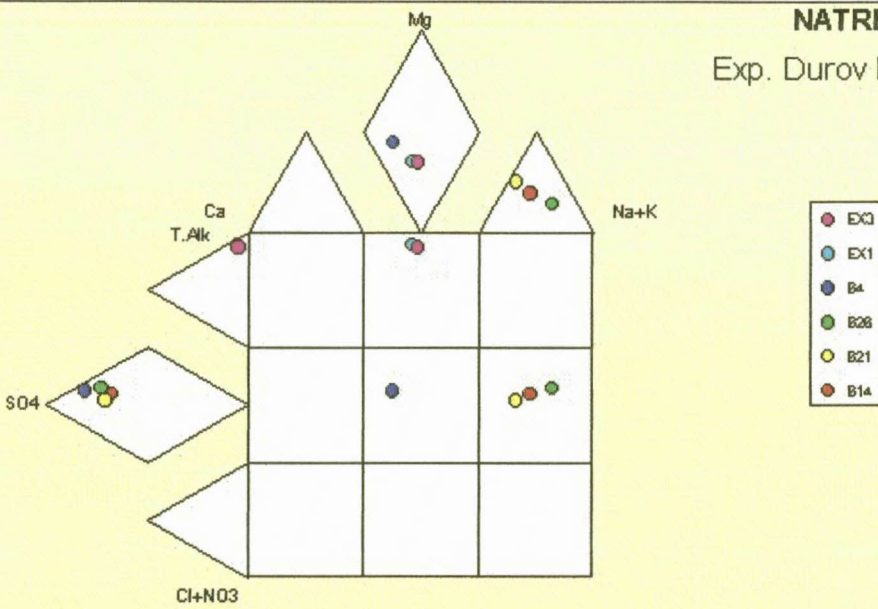
## Sasolburg Municipality

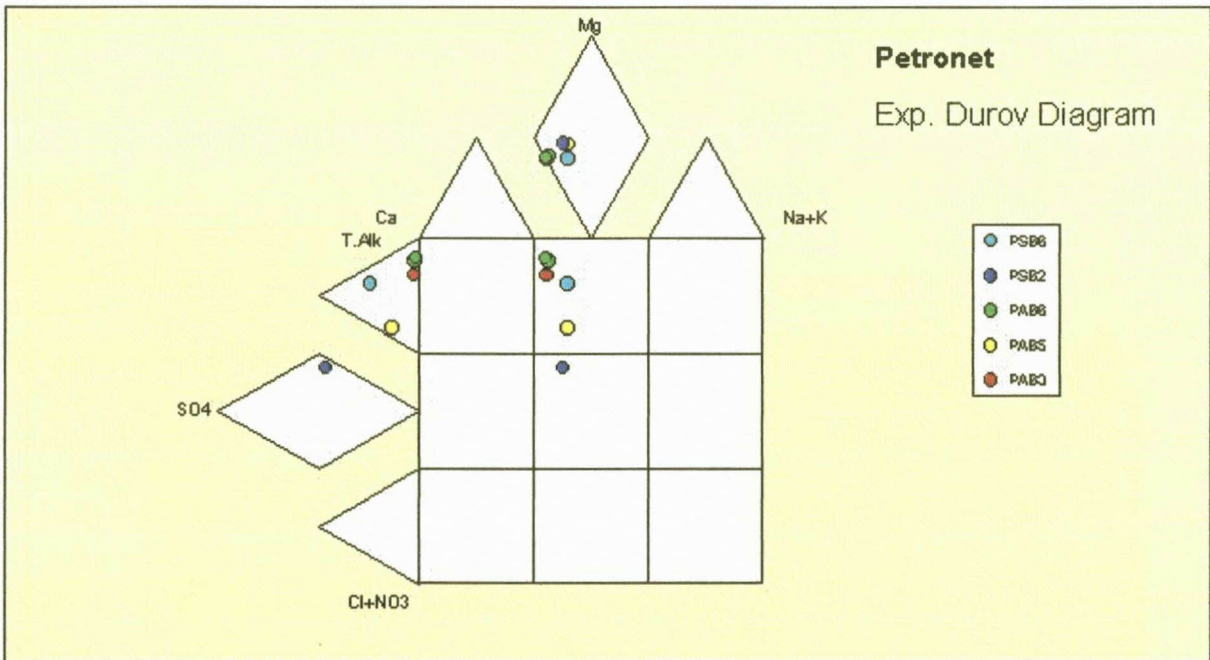
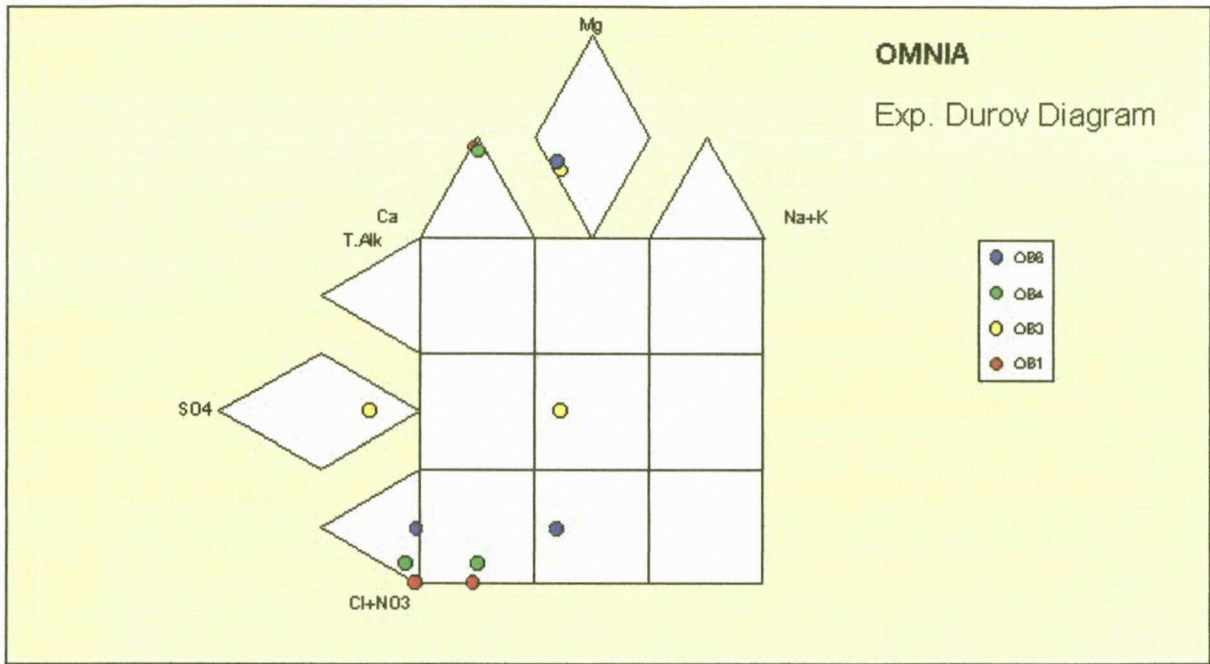
Exp. Durov Diagram

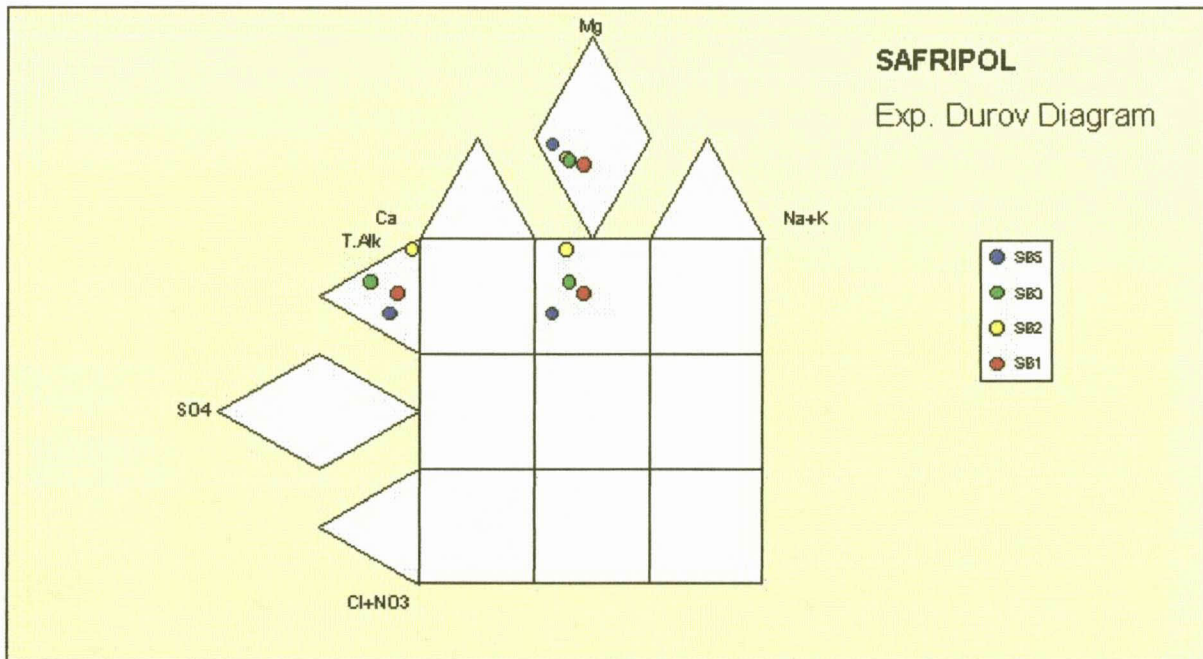
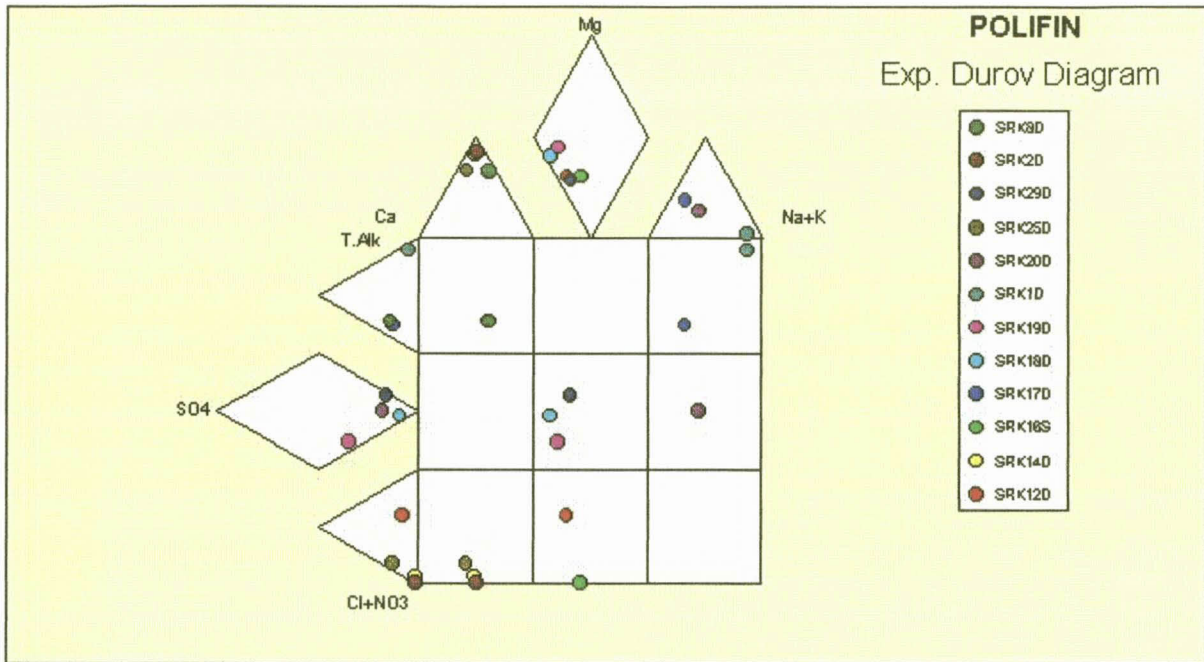


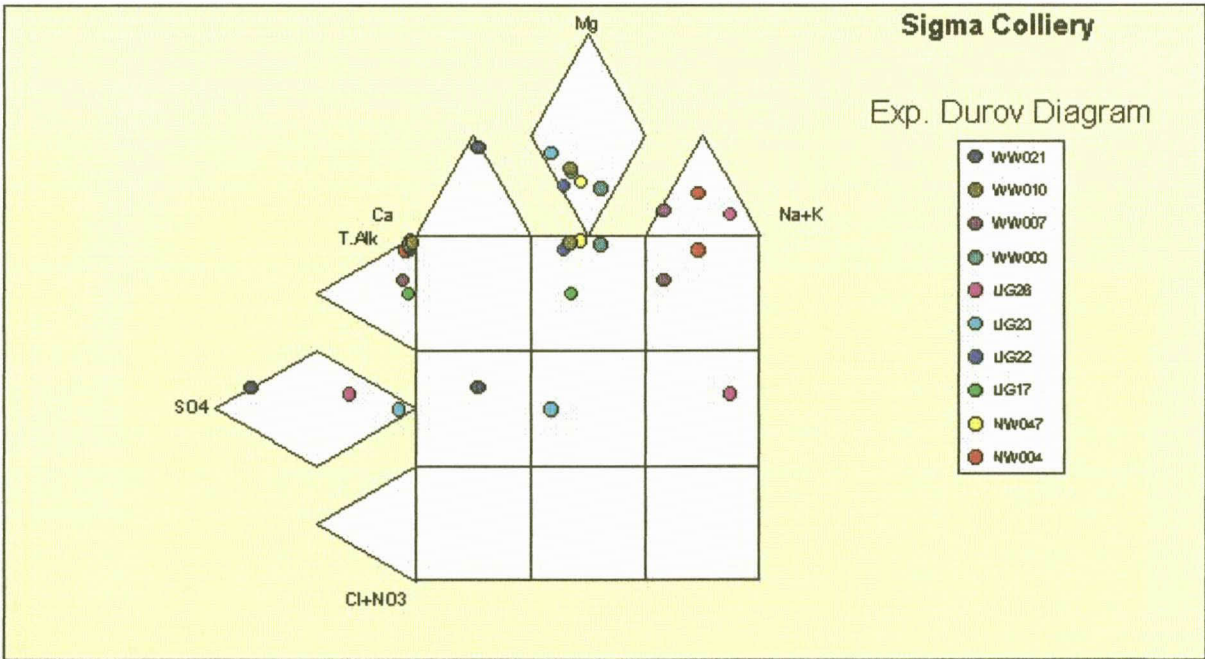
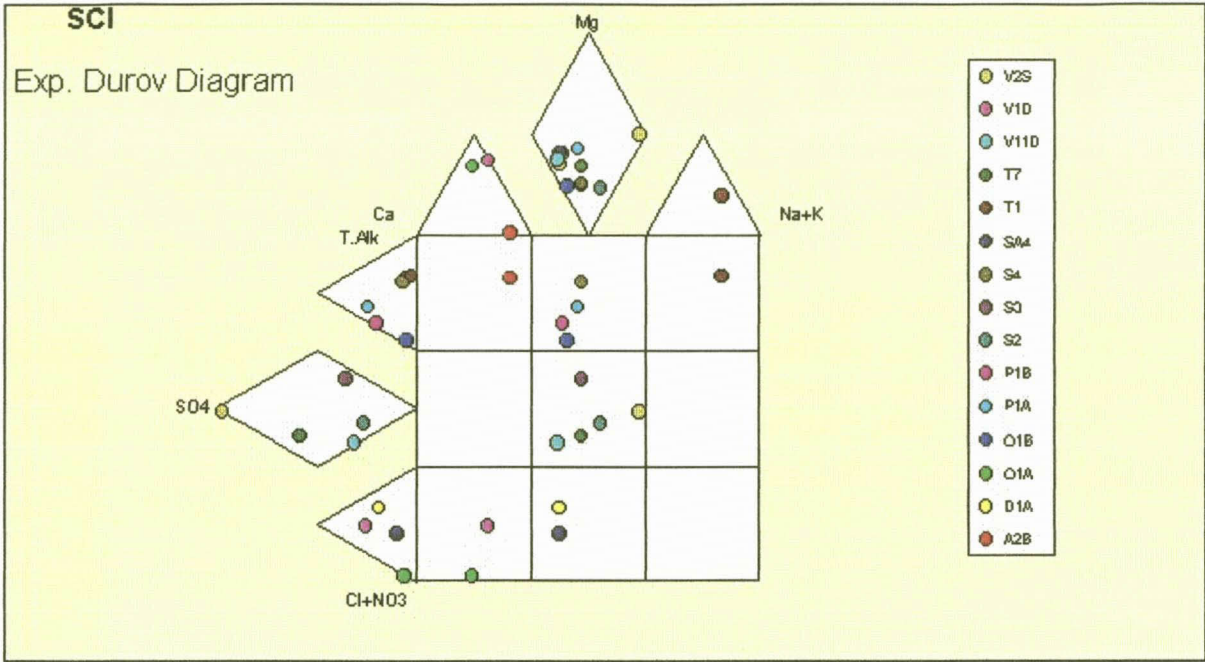
## NATREF

Exp. Durov Diagram



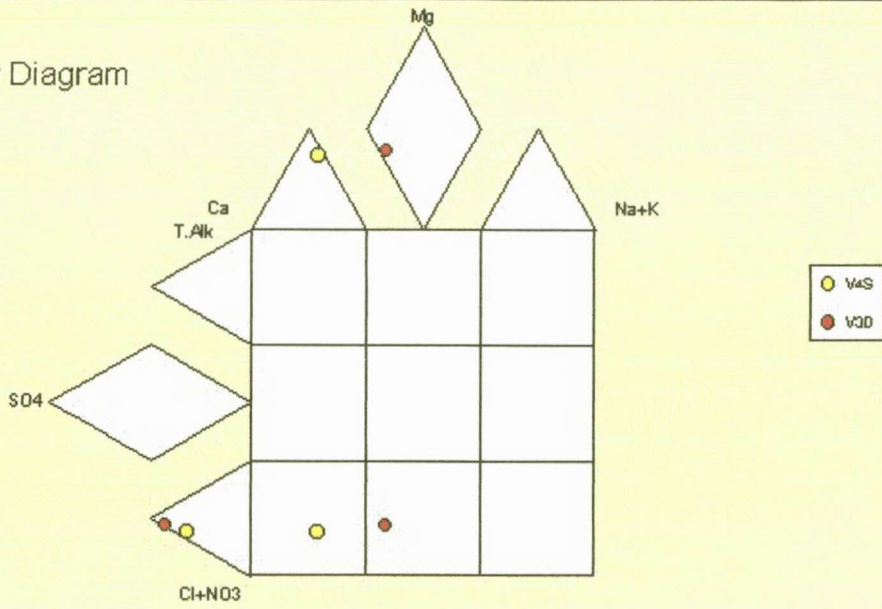






SMX

Exp. Durov Diagram



**APPENDIX D**  
**TOXICITY TEST RESULTS**



## DEPARTMENT OF WATER AFFAIRS AND FORESTRY

## INSTITUTE FOR WATER QUALITY STUDIES

## ACUTE TOXICITY TEST RESULTS

Test Report No. B98/11

V25

Programme:	AD HOC (Sasol)	Sample source id.:	V-25 (Supemate)
Sample date:	27/10/1998	Sampling depth:	0 m
Date sample received:	28/10/1998	Sampling time:	13 h 00
Date finalised:	04/11/1998	Sample description:	Water
		Preservative:	Cooling

TIME SPAN: 24 HOURS

Method no.	Test specie / age	Sample Concentration	Replicate beakers				% Mortality
			1	2	3	4	
3001001	<i>Daphnia pulex</i> / <24 h	100%	5	5	5	5	100 (After 10 min)
		50%	5	5	5	5	100 (After 10 min)
		25%	5	5	5	5	100 (After 1 hour)
		12.5%	3	3	2	1	45
		Control	0	0	0	0	0

V25: *Daphnia pulex* 24 h - LC50 = 13%

Method no.	Test specie / age	Time span	Sample concentration	Replicate beakers				% Mortality
				1	2	3	4	
3001002	<i>Poecilia reticulata</i> / ± 2 days	24 h	50%	5	5	-	-	100
		24 h	25%	0	0	-	-	0
		96 h	25%	1	0	-	-	10
		96 h	12,5%	0	0	-	-	0
		96 h	Control	0	0	-	-	0

V25: *Poecilia reticulata* 96 h - LC50 = 34%

## DEPARTMENT OF WATER AFFAIRS AND FORESTRY

## INSTITUTE FOR WATER QUALITY STUDIES

## ACUTE TOXICITY TEST RESULTS

Test Report No. B98/11

Programme:	AD HOC (Sasol)	Sample source id.:	W 3
Sample date:	27/10/1998	Sampling depth:	0 m
Date sample received:	28/10/1998	Sampling time:	15 h 10
Date finalised:	03/11/1998	Sample description:	Water
		Preservative:	Cooling

TIME SPAN: 24 HOURS

Method no.	Test specie / age	Sample Concentration	Replicate beakers				% Mortality
			1	2	3	4	
3001001	<i>Daphnia pulex</i> / <24 h	100%	1	1	1	1	20
		50%	0	0	0	0	0
		Control	0	0	0	0	0

TIME SPAN: 48 HOURS

Method no.	Test specie / age	Sample Concentration	Replicate beakers				% Mortality
			1	2	3	4	
3001001	<i>Daphnia pulex</i> / <24 h	100%	1	1	1	3	30
		50%	0	0	0	0	0
		Control	0	0	0	0	0

W 3: *Daphnia pulex* 48 h - LC50 = NA (Mortality must be >50%)

Method no.	Test specie / age	Time span	Sample concentration	Replicate beakers				% Mortality
				1	2	3	4	
3001002	<i>Poecilia reticulata</i> / ± 2 days	96 h	100%	0	0	-	-	0
		96 h	Control	0	0	-	-	0

DEPARTMENT OF WATER AFFAIRS AND FORESTRY  
INSTITUTE FOR WATER QUALITY STUDIES

## ACUTE TOXICITY TEST RESULTS

Test Report No. B98/11

Programme:	AD HOC (Sasol)	Sample source id.:	FB 95
Sample date:	27/10/1998	Sampling depth:	0 m
Date sample received:	28/10/1998	Sampling time:	14 h 15
Date finalised:	04/11/1998	Sample description:	Water
		Preservative:	Cooling

TIME SPAN: 24 HOURS

Method no.	Test specie / age	Sample Concentration	Replicate beakers				% Mortality
			1	2	3	4	
3001001	<i>Daphnia pulex</i> / 24 h	100%	2	3	1	2	40
		50%	0	0	0	0	0
		Control	0	0	0	0	0

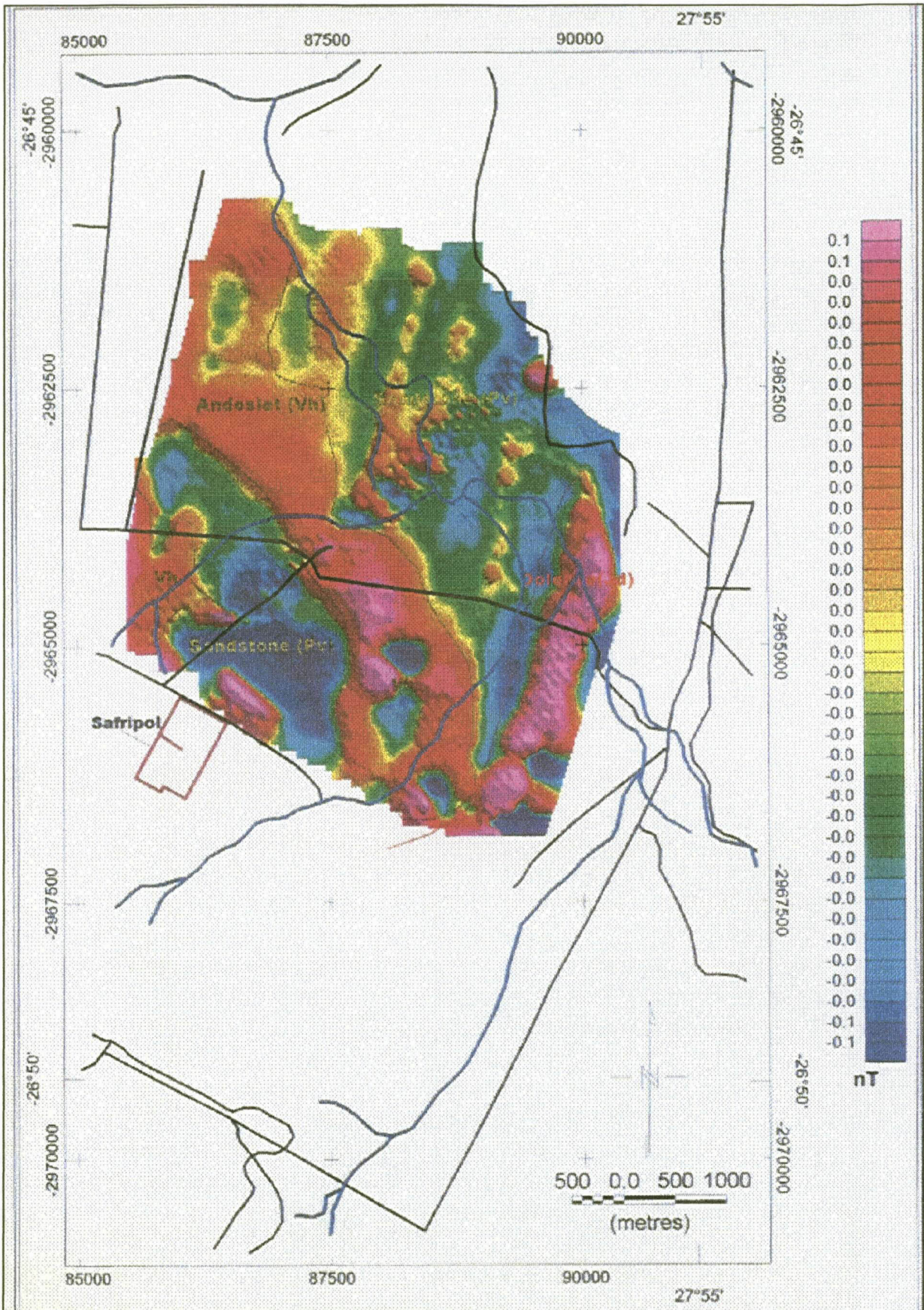
TIME SPAN: 48 HOURS

Method no.	Test specie / age	Sample Concentration	Replicate beakers				% Mortality
			1	2	3	4	
3001001	<i>Daphnia pulex</i> / 24 h	100%	3	4	1	3	55
		50%	0	0	0	0	0
		Control	0	0	0	0	0

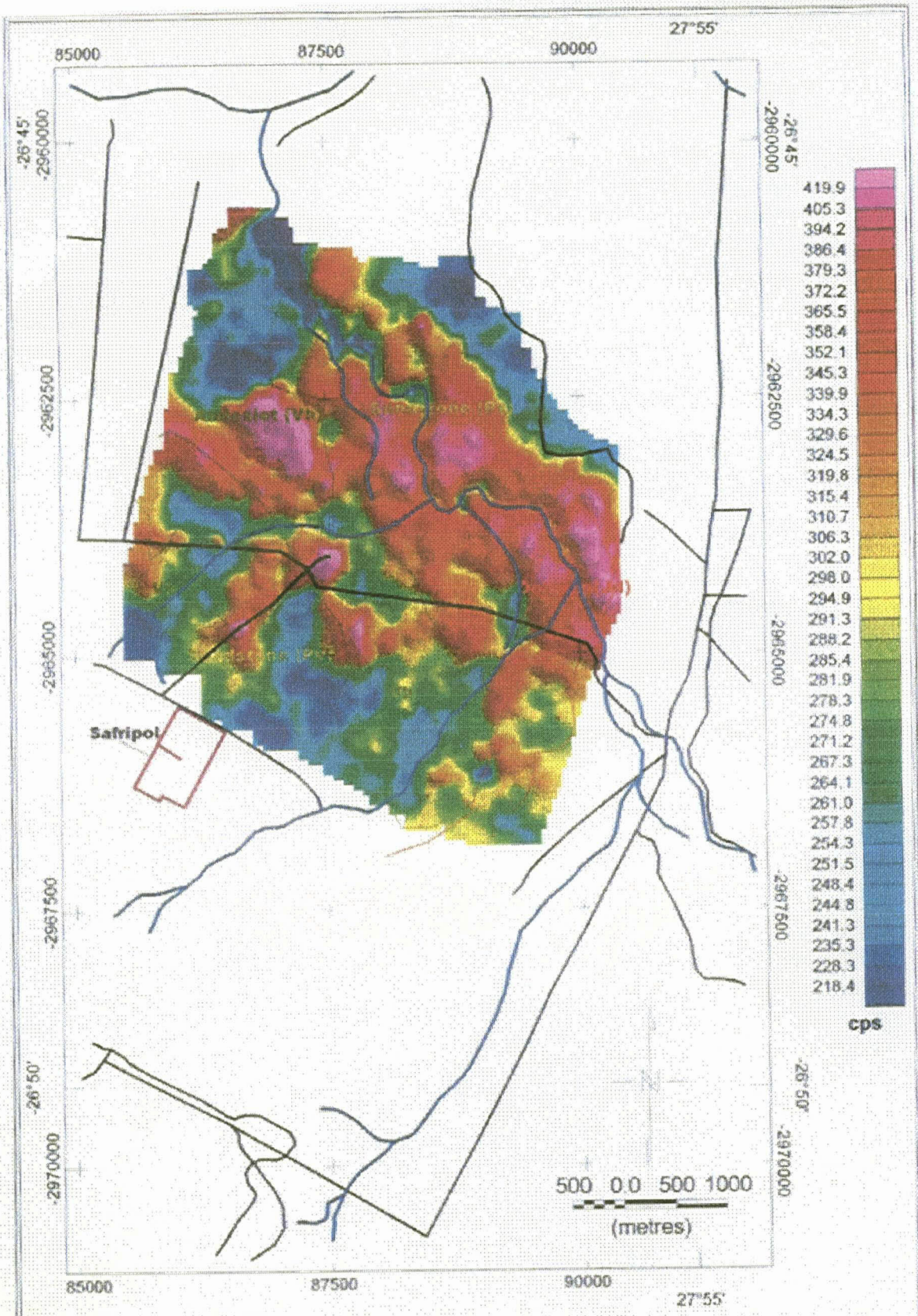
<sup>5</sup>  
FB 9: *Daphnia pulex*: 48 h - LC50 = 95%

Method no.	Test specie / age	Time span	Sample concentration	Replicate beakers				% Mortality
				1	2	3	4	
3001002	<i>Poecilia reticulata</i> / ± 2 days	96 h	100%	0	0	-	-	0
		96 h	Control	0	0	-	-	0

**APPENDIX E**  
**AERIAL GEOPHYSICS**  
**(From Groenewald & Smit, 1999)**



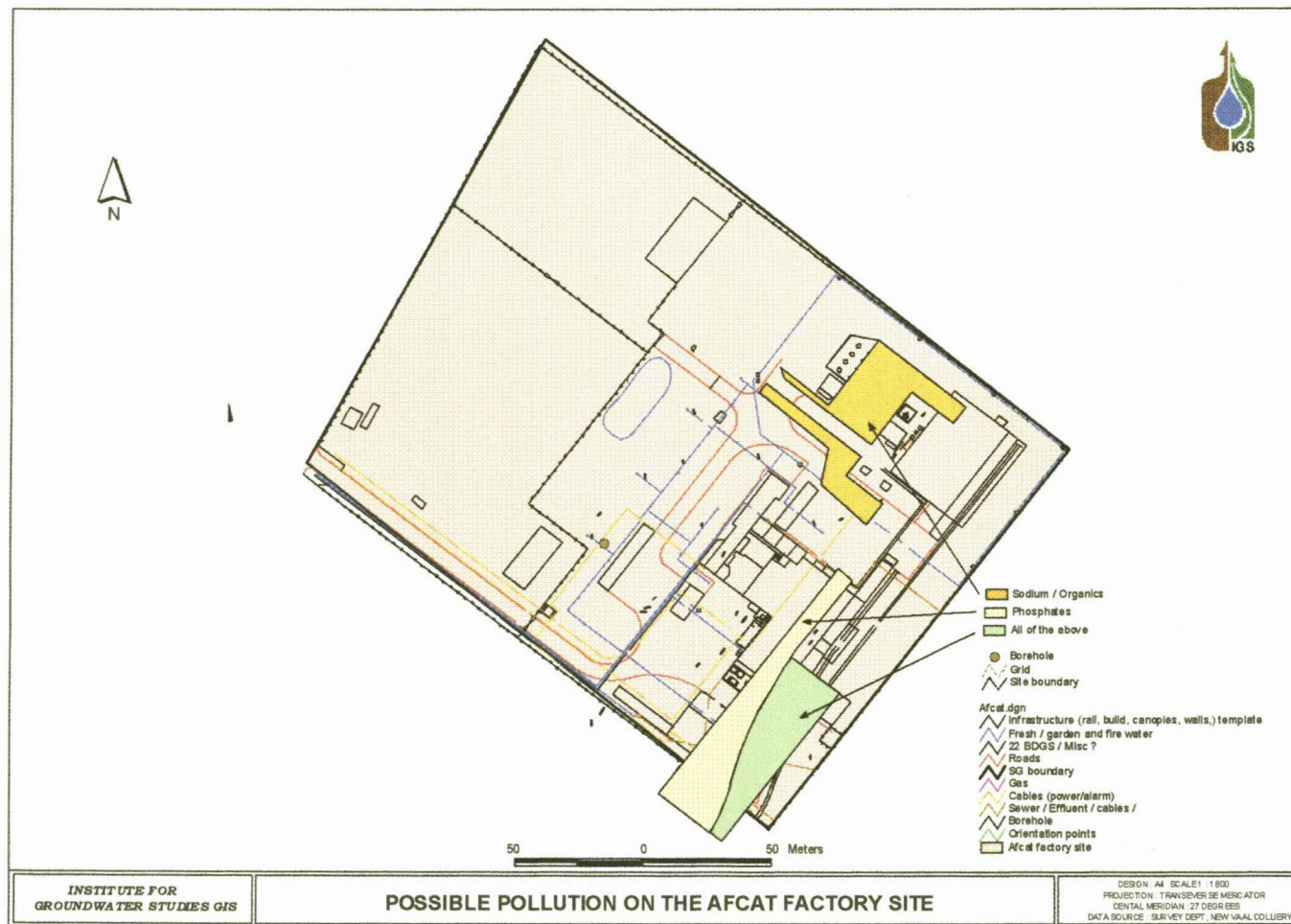
<b>TAAIBOS-LEEUSPRUIT PROJECT</b>	
TOTAL MAGNETIC FIELD Sasolburg Pollution Study	
Figure 1	Jacques Groenewald
<b>SYMBOL LEGEND</b>	
ROADS	Andesiet (Vh)
RIVERS	Shale, Sandstone (Pr)
SAFRIPOL	Dolerite (Jd)



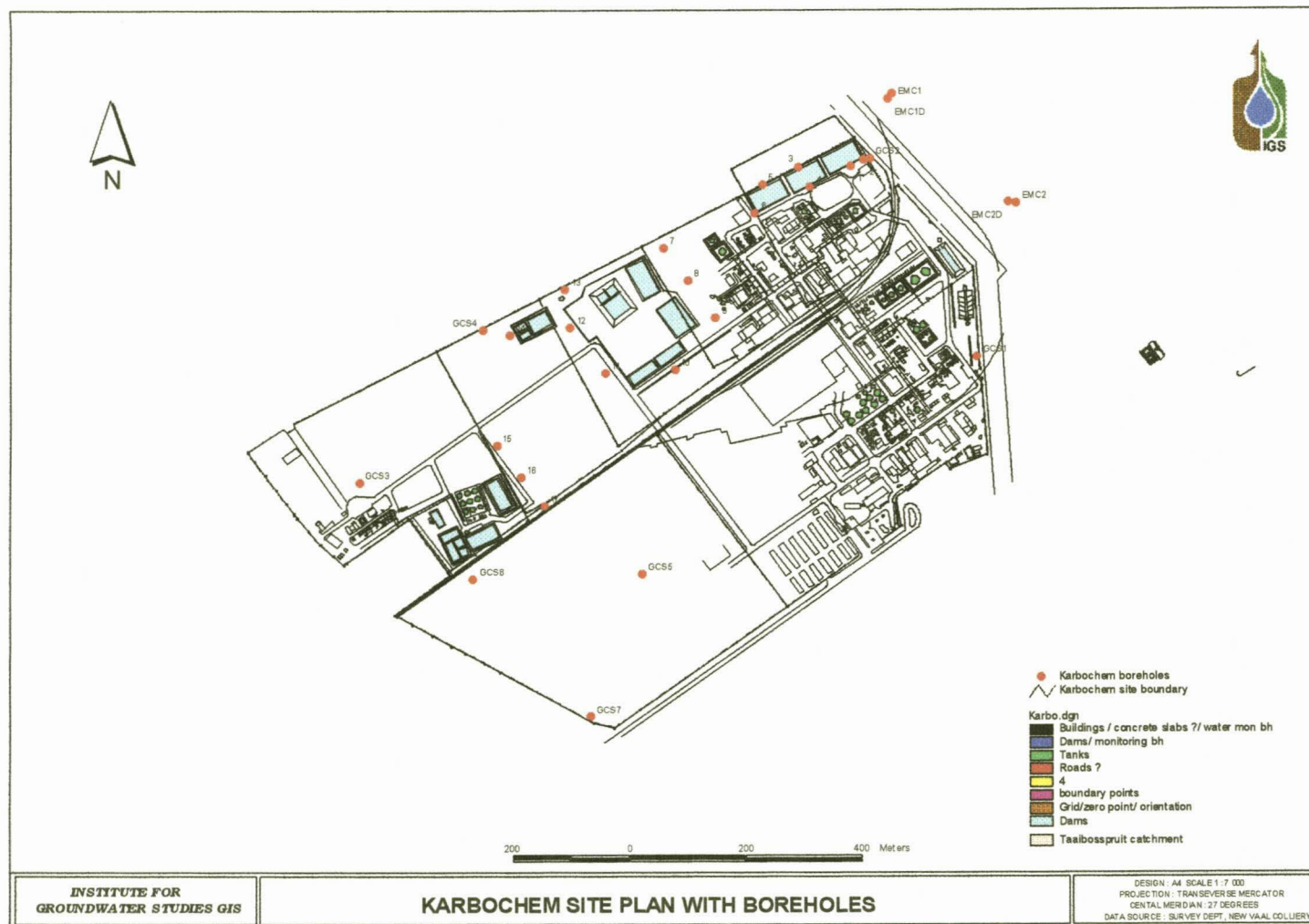
<b>TAAIBOS-LEEUSPRUIT PROJECT</b>	
Total Count-Radiometrics Sasolburg Pollution Study	
Figure 5	Jacques Groenewald
<b>SYMBOL LEGEND</b>	
ROADS	Andesiet (Vh)
RIVERS	Slate, Sandstone (Pv)
SAFRIPOL	Dolerite (Jd)

**APPENDIX F**  
**DETAILED SITE PLANS**

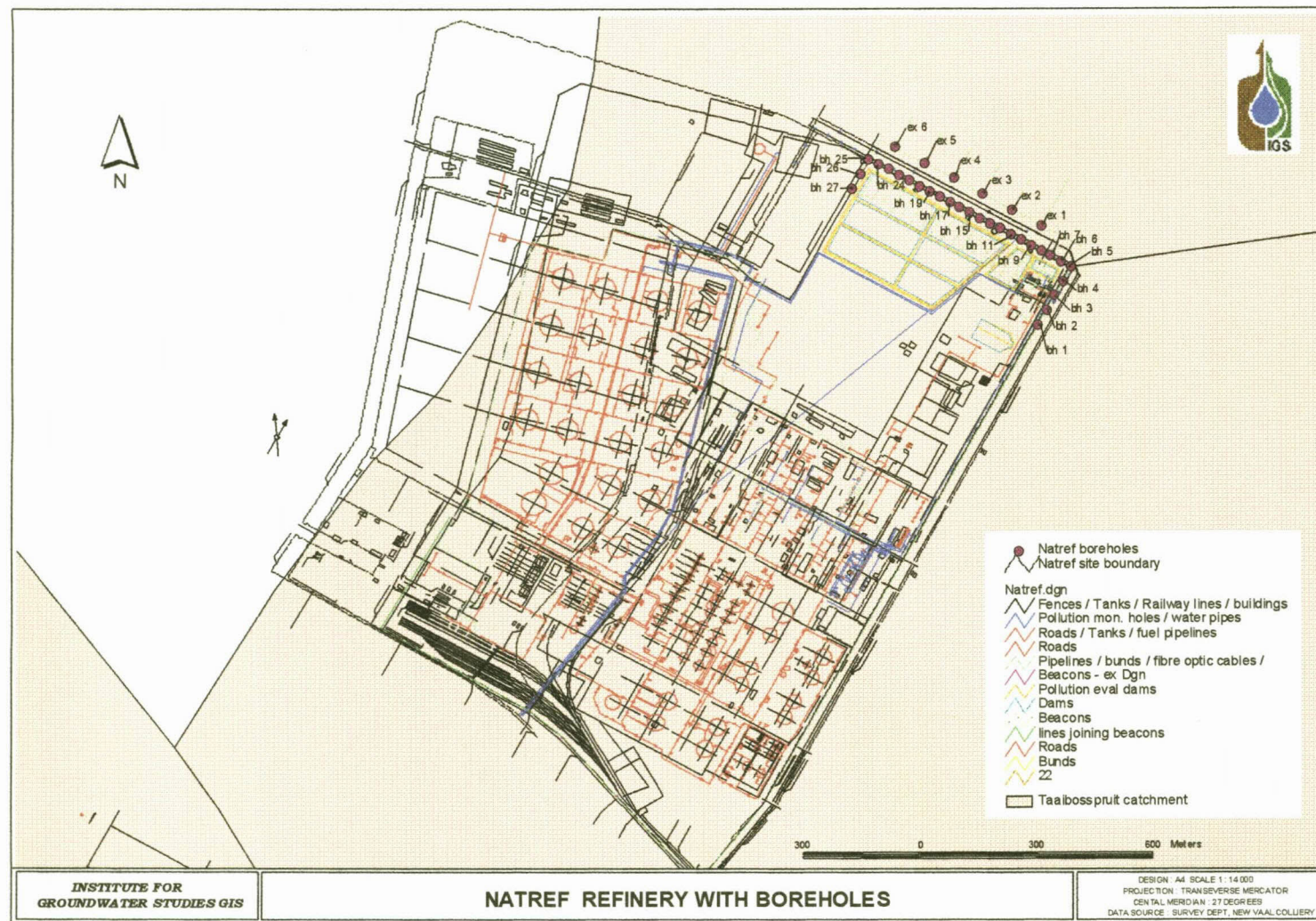
**AFRICAN CATALYSTS (PTY) LTD.**



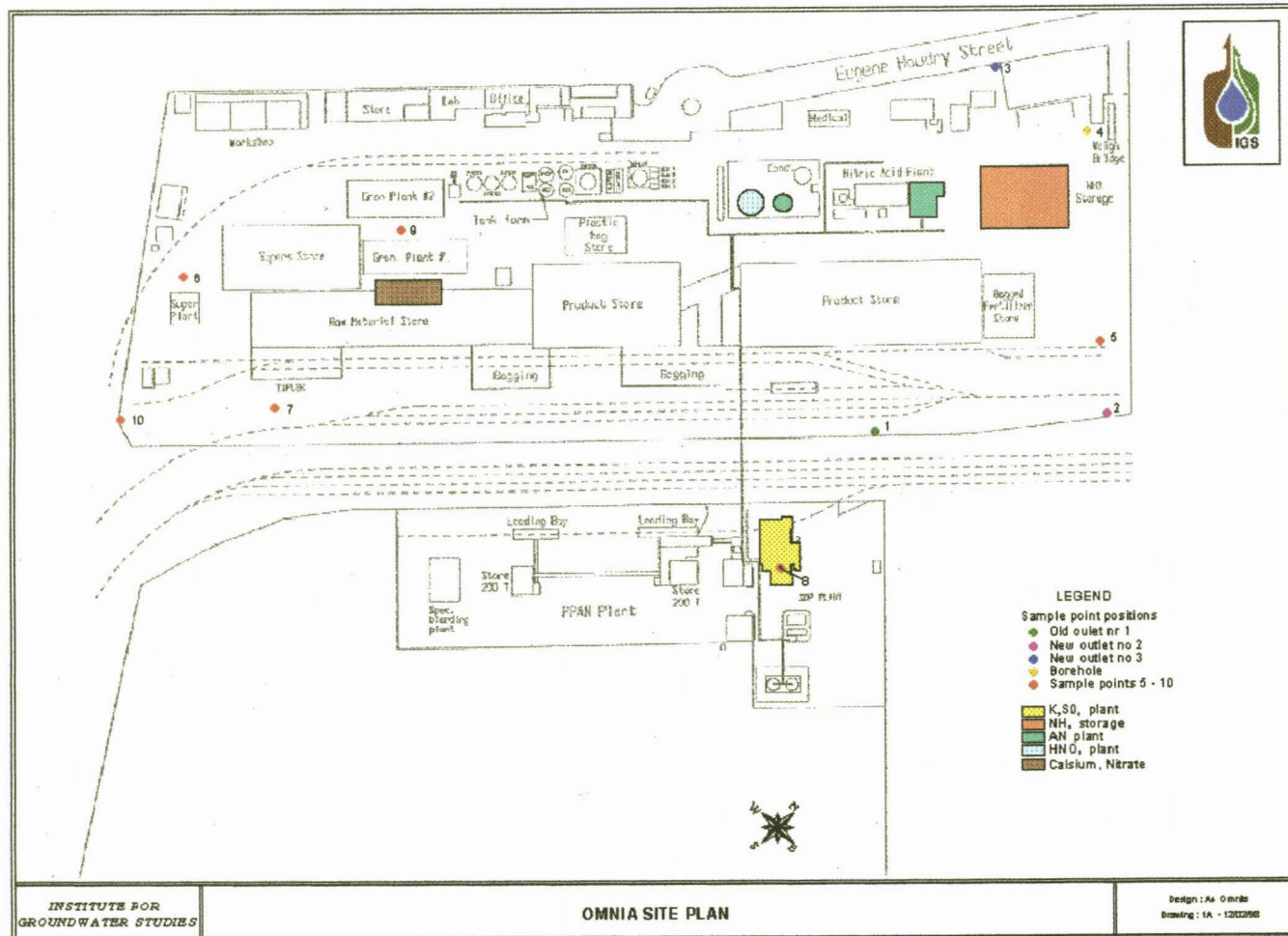
**KARBOCHEM (PTY) LTD. CHEMICAL PLANT.**



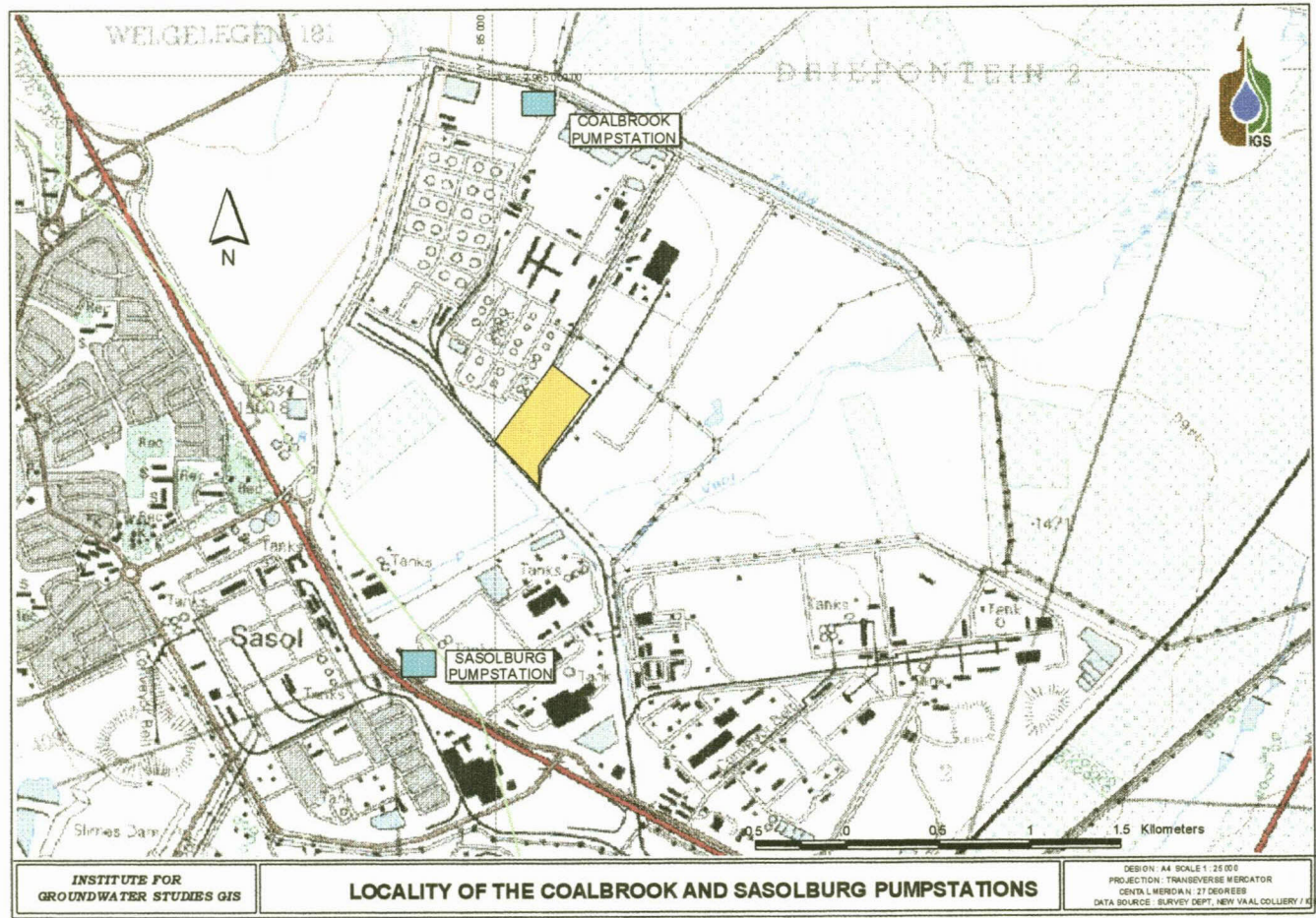
# NATURAL PETROLEUM REFINERS OF SOUTH AFRICA (PTY)LTD. (NATREF)



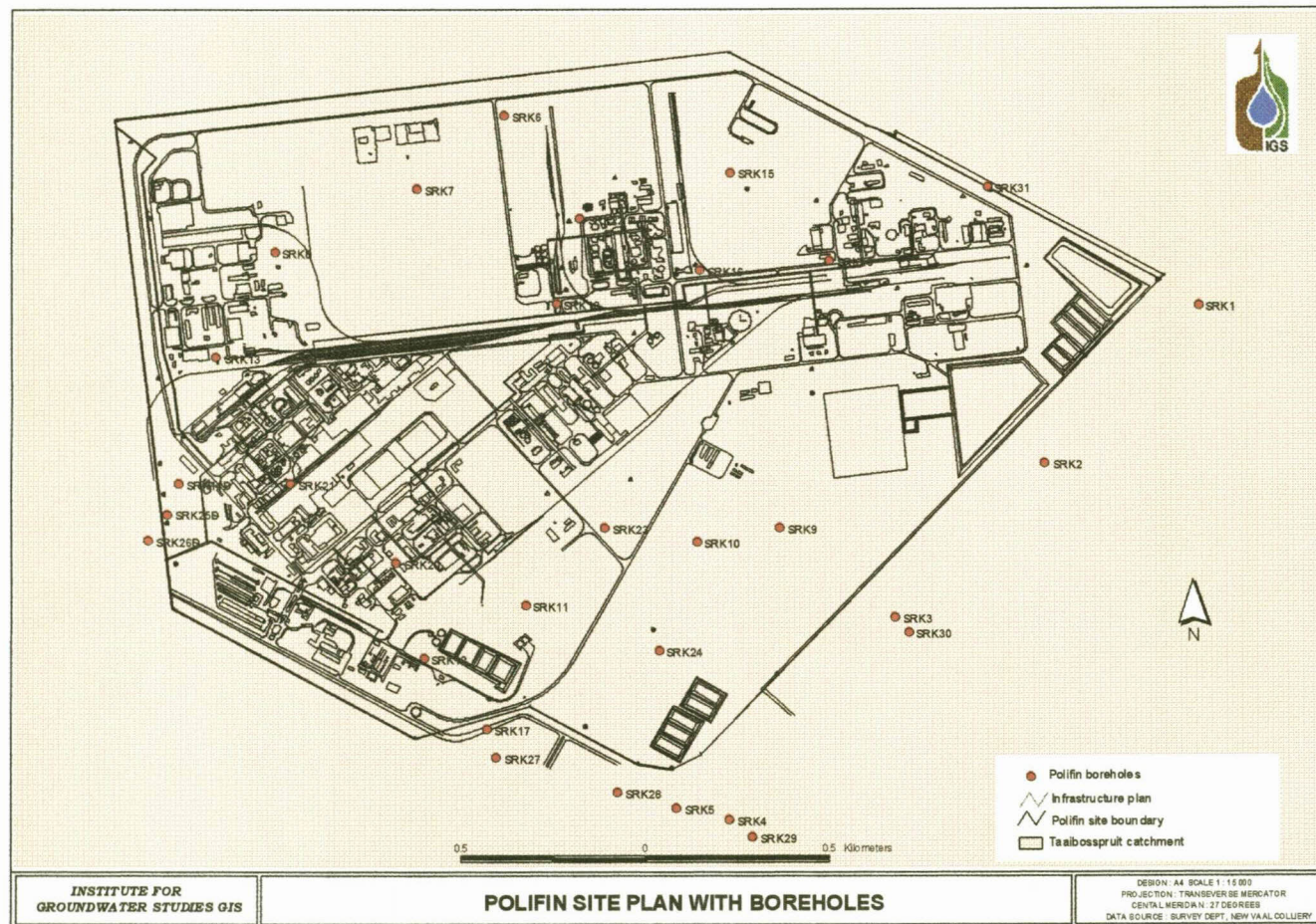
OMNIA FERTILIZERS



**PETRONET- SASOLBURG & COALBROOK PUMPSTATIONS**



POLIFIN

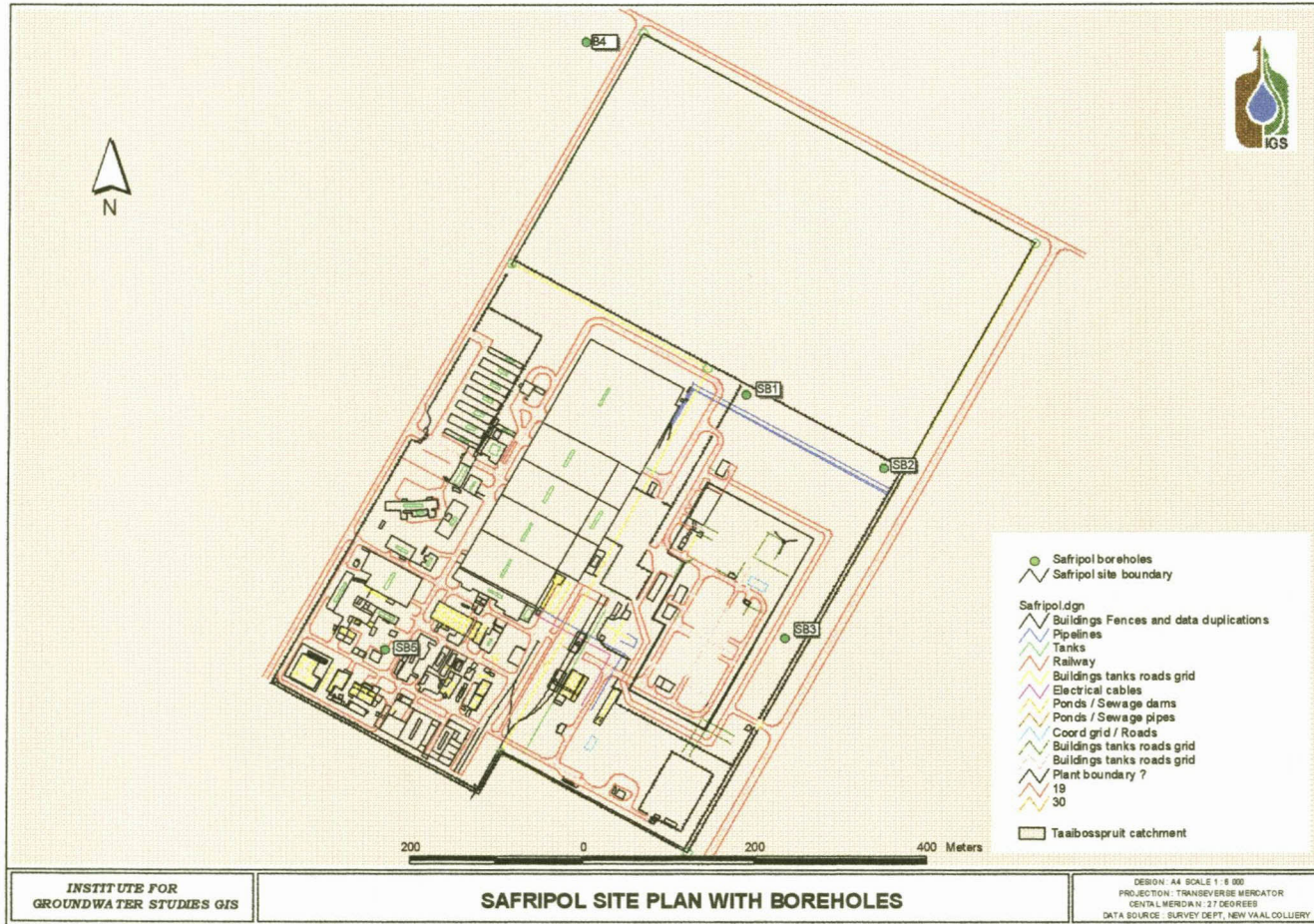


INSTITUTE FOR  
GROUNDWATER STUDIES GIS

POLIFIN SITE PLAN WITH BOREHOLES

DEBON: A4 SCALE 1:15 000  
PROJECTION: TRANSVERSE MERCATOR  
CENTAL MERIDIAN: 27 DEGREES  
DATA SOURCE: SURVEY DEPT, NEW VAAL COLLIERY

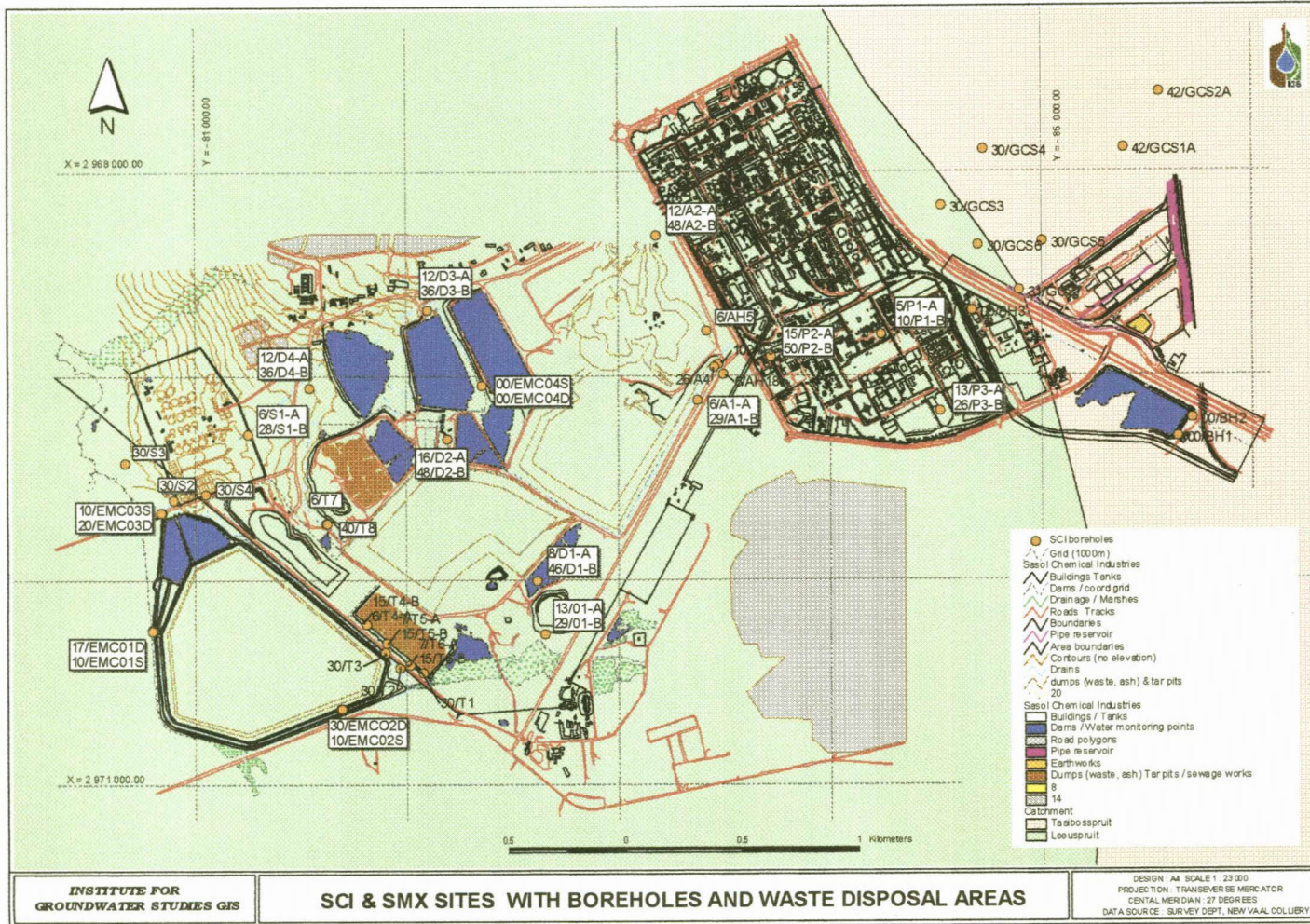
SAFRIPOL



INSTITUTE FOR  
GROUNDWATER STUDIES GIS

SAFRIPOL SITE PLAN WITH BOREHOLES

SCI

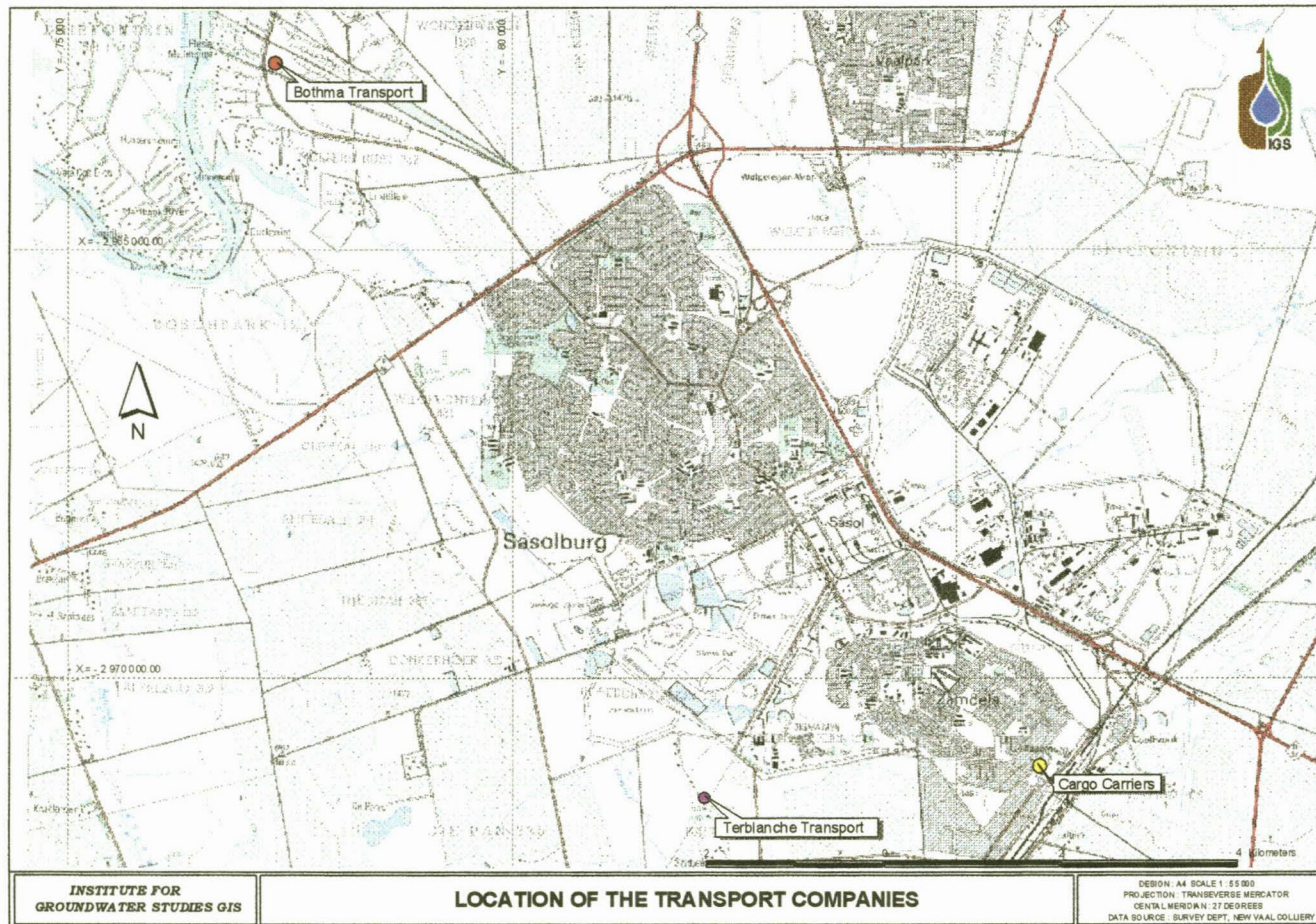


INSTITUTE FOR  
GROUNDWATER STUDIES GIS

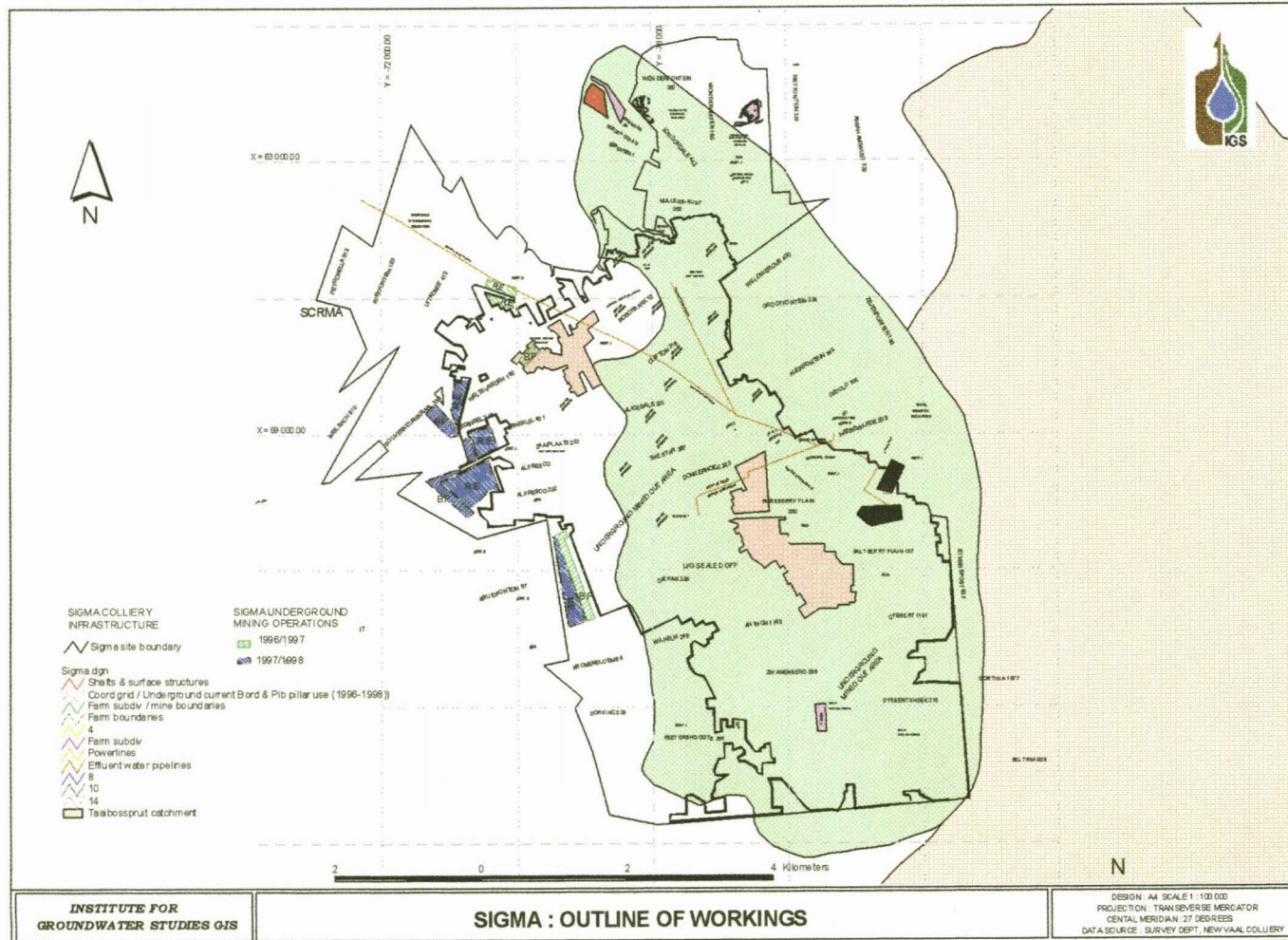
SCI & SMX SITES WITH BOREHOLES AND WASTE DISPOSAL AREAS

DESIGN: A4 SCALE: 1:23,000  
PROJECTION: TRANSVERSE MERCATOR  
CENTRAL MERIDIAN: 27 DEGREES  
DATA SOURCE: SURVEY DEPT., NEW VAAL COLLIERY

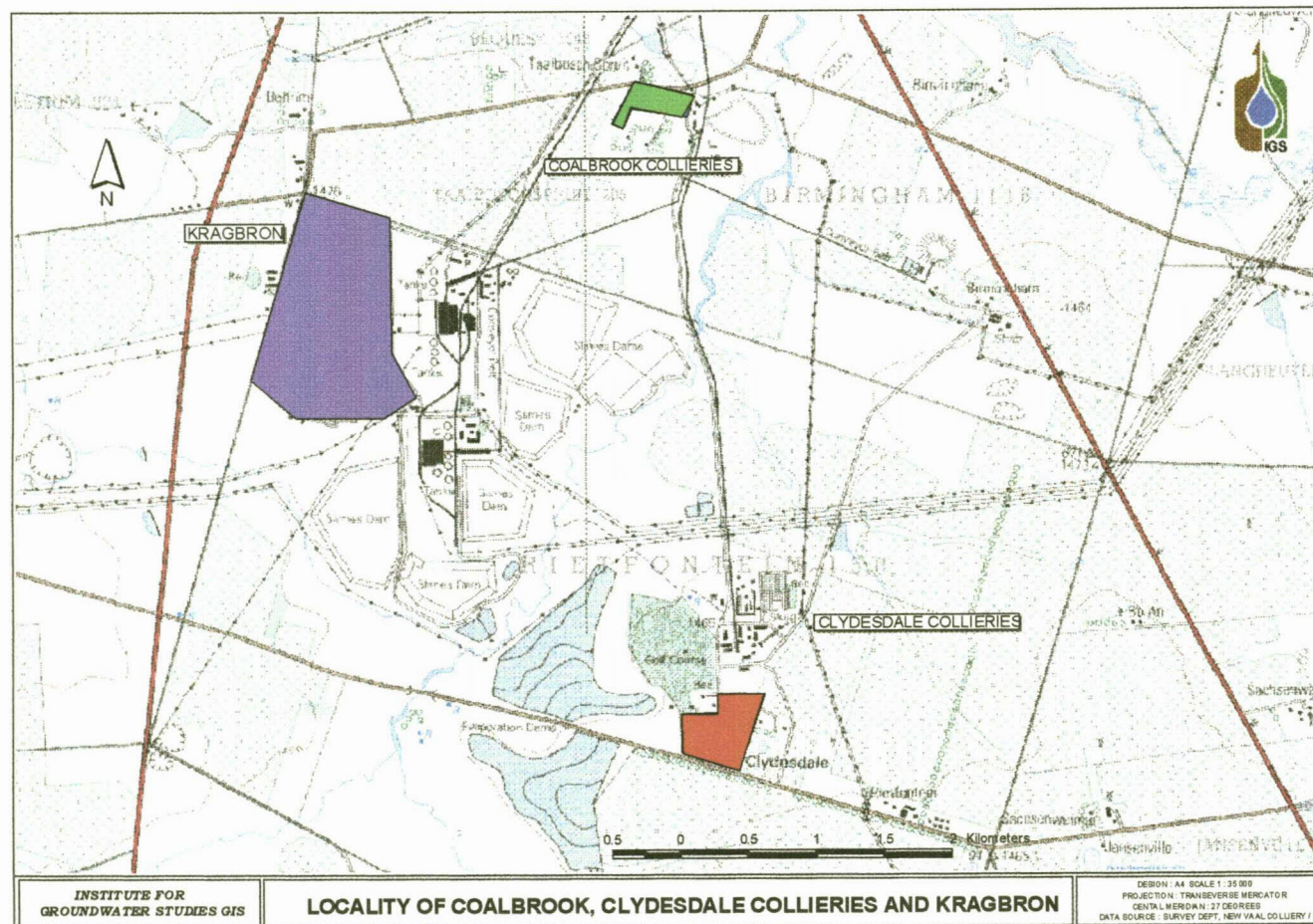
**TRANSPORT COMPANIES**



# SIGMA COLLIERY



### KRAGBRON POWER STATIONS



## SUMMARY

The Department of Water Affairs in South Africa has recently moved towards the management of regions on a catchment and subcatchment scale. The Taaibos and Leeu Spruit catchments were identified as catchments where groundwater research was needed. The final objective of this work would be the implementation of a Catchment Management Plan

These catchments house several influences on groundwater quality. These include the urban area of greater Sasolburg, several chemical industries (petrochemical, fertilizers, plastics etc), mining activities, power stations and agriculture.

A groundwater situation analysis was therefore undertaken to highlight all relevant groundwater components.

To achieve this, the study included a literature study, the creation of a database, fieldwork including sampling of 101 sites in the catchment for inorganic analysis, sampling of 10 sites for toxicity testing to indicate true toxicity of the water, aerial geophysics over a portion of the catchment and resistivity soundings at points surrounding the industries.

Based on information gathered by this work it was possible to identify the principal aquifers in the area and classify them according to methods set out by Parsons (1995). The chief controls on groundwater movement and pollution sources on each site were identified. It was found that a dolerite sill of variable depth and thickness was the main control of groundwater movement underlying the industrial areas.

The collected data and sampling highlighted the most important pollution sources. Use of toxicity testing showed the potential of these tests in indicating the true toxicity of samples. These results with, simplified numerical modelling in the area gave an indication of pollution migration and areas of concern.

The area was subdivided into groundwater management areas based on the activities in each area. Three zones were defined representing the industrial and mining areas, a buffer zone and the areas to be protected respectively. In each zone different quality guidelines were proposed.

A Threat Action Guide spreadsheet was developed to identify and prioritize areas of concern. It uses water quality data for different parameters, the aquifer classification, the water quality guideline for the zone and the distance to the nearest area of concern as inputs. A threat index is thereby calculated using various empirical equations and this index then suggests different generalized management options to be followed.

The situation analysis has provided an overview of this heterogeneous area and put a basic framework in place on which the eventual Groundwater Management Plan will be based.

## OPSOMMING

Die Departement van Waterwese en Bosbou het onlangs begin om die bestuur van grondwater op 'n opvangsgebied en sub-opvangsgebied sisteem te baseer in plaas van streke. Die Taaibosspruit en Leeuspruit opvangsgebiede was geïdentifiseer as opvangsgebiede waar grondwatervorsing nodig is. Die uiteinde van sulke werk sal lei tot die opstel van 'n grondwaterbestuursplan.

Daar is verskeie instansies wat 'n invloed op die grondwater kwaliteit in hierdie opvangsgebiede kan hê. Van hierdie instansies sluit die verskeie chemiese industrieë (petrochemies, kunsmis, plastiek, ens.), myne, kragstasies en landbou in.

'n Grondwatersituasie-analise is onderneem om al die relevante grondwater komponente aan te spreek.

Die studie het die volgende behels: (a) literatuurstudie; (b) opstel van 'n databasis; (c) veldwerk wat die neem van 101 grondwatermonsters vir anorganiese analise en 10 monsters vir toksisiteits toetse; asook grond- en lug geofisika ingesluit het.

Gebaseer op die inligting wat ingesamel was, is die hoof akwifere in die area geïdentifiseer en geklassifiseer volgens Parson (1995) se metode. Die hoof kontroles oor grondwaterbeweging en besoedelingsbronne was geïdentifiseer in al die areas. Daar is gevind dat 'n dolerietplaat van veranderlike diepte en dikte die hoof kontrole oor grondwaterbeweging in die industriële gebied is.

Die ingesamelde data en monsterneming het die belangrikste besoedelingsbronne geïdentifiseer. Toksisiteitstoetse het die potensiaal van hierdie tipe toetse uitgewys om die ware toksisiteit van monsters te weerspieël. Hierdie resultate tesame met vereenvoudigde numeriese modellering, het 'n indikasie van besoedelingsmigrasie en areas van kommer gegee.

Die area is in grondwaterbestuursareas ingedeel op grond van die verskillende aktiwiteite. Drie sones is gedefinieër wat die industriële en myn areas, 'n buffersone en areas wat beskerm moet word insluit. Vir elke sone was daar 'n verskillende waterkwaliteitriglyn voorgestel.

'n "Threat Action Guide" spreivel was ontwikkel om die areas van kommer uit te wys en te prioritiseer. Hierdie spreivel gebruik waterkwaliteitdata vir verskillende parameters, die akwifere klassifikasie, die waterkwaliteitriglyn vir 'n sone en die afstand na die naaste area van kommer, as insette. 'n "Threat" indeks word ook bepaal deur gebruik te maak van empiriese vergelykings en hierdie indeks gee dan moontlike bestuursopsies wat uitgevoer kan word.

Die situasie analise het 'n oorsig van 'n heterogene area gegee en het 'n basiese raamwerk daargestel vir die opstel van die uiteindelijke grondwaterbestuursplan.