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INVESTIGATION INTO THE IMPACT OF CHROMIUM CONTAMINATION IN THE SOILS AND GROUNDWATER UNDERLYING A MANUFACTURING PLANT ON A COASTAL AQUIFER

by

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In the Faculty of Natural and Agricultural Sciences

Institute for Groundwater Studies

University of the Free State

Bloemfontein

South Africa

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February 2010

DECLARATION

28 February 2010

I, Mokete Saladiel Makhutla, declare that the thesis hereby submitted by me for the Master of Science degree at the University of the Free State. Is my own independent work and has not previously been submitted by me at another University/faculty. I further cede copyright of the thesis in favour of the University of the Free State.

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ABSTRACT

The study area is located within the residential, commercial and industrial area, approximately 20km to the south west of the Durban CBD, between a turf club site and the international airport of Durban. Between 1945 and 1990, the site was used for the production of sodium dichromate (SDC), chromium tanning salts, chromic acid and sodium sulphate. In 1991, the production of sodium dichromate (SDC) was discontinued on the site, and manufacturing activities were limited to the production of chromium tanning salts. These salts are used in the production of leather where they are essential in converting perishable raw hides into durable leather.

In 2004, an investigation was initiated in the study area following the discovery of hexavalent chromium [Cr(VI)] in groundwater. Cr(VI) was detected in groundwater samples taken from an open pit excavated just outside the perimeter of the manufacturing plant site. It is considered that the actual main source of the groundwater plume are suspected hot spots in the soil within aquifer 1 and 2. It is most likely that the hot spots originated from SDC spills during former production and handling at certain locations within the manufacturing plant site. It is reasonable to assume that the SDC entered the groundwater from these production and handling locations and is still present in the soil voids within aquifer 1 and 2. SDC liquid slowly dissolved the groundwater flowing around the hot spots and would appear to be feeding the observed groundwater plume at present.

The specific aims of this research were to:

- Provide a literature overview of chromium contamination in the subsurface
- Establish the nature of geology and geohydrology underlying the manufacturing plant
- Quantify the levels and extent of chromium contamination in the soils and groundwater underlying the manufacturing plant
- Identify the source of chromium contamination in the soils and groundwater underlying the manufacturing plant and related potential pathways and exposure scenarios to the point of exposure of the receptors
- Conduct a risk assessment for the soils and groundwater

Field activities associated with this investigation included the following:

- Hydrocensus survey
- Installation of new boreholes
- Borehole pumping tests

- Groundwater level monitoring
- Groundwater sampling
- Soil sampling at test pits

A hydrocensus survey conducted within a 1 km radius of the plant site revealed that there were no private boreholes in or close to the affected area. The boreholes found were mainly industrial boreholes in other industries around the manufacturing plant including the turf club site. These boreholes were in the uncontaminated aquifer and most of them were either blocked or destroyed.

The investigations revealed that the fill underlying the site occurs from the surface to depths in the range of approximately 0.4 metres to 2.1 metres below existing ground level. The fill generally comprises brown to dark grey, silty sand to slightly clayey sand, and contains abundant gravel and rubble in places. The fill overlies the harbour bed sediments, which generally occur in four predominantly sandy aquifer horizons interlayered with clay layers of various composition and thickness. The harbour bed sediments overlie sandstone of the Natal Group or sandy siltstones of the St Lucia Formation at depths of between approximately 28 and 32 metres below existing ground level on the manufacturing plant site. The weathered sandstone immediately below the harbour beds generally comprises residual, highly weathered, orange brown, slightly clayey to silty sand. With depth the sandstone typically becomes less weathered, grading into pinkish maroon sandstone bedrock which extends to depths in excess of 100 metres below the site.

The hydraulic conductivity values of between 0.02 m/d to 2.23 m/d were estimated in various aquifers underlying the manufacturing plant site.

The depth to the groundwater table ranged from 0.0 m to 3.1 m across the manufacturing plant site area, as measured in the installed monitoring boreholes. The elevation of the groundwater table ranged from 13.5 mMSL to 17.5 mMSL, with an inferred direction of groundwater flow towards the east in aquifers 1 to 3. Within aquifer 4 and the Natal formation the groundwater flow was towards the south east in principle corresponding to the general regional groundwater flow at depth from the hills towards the sea.

The highest measured Cr(VI) concentrations in groundwater samples were found in aquifer 1 and aquifer 2 underlying closed or dismantled production facilities on the manufacturing plant site where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990. The highest measured Cr(VI) concentrations in soil samples taken at the manufacturing plant site coincide with the above mentioned locations.

Based on the site investigations, a risk assessment for the soils and groundwater underlying the study area was conducted using the RBCA approach in order to evaluate and assess the exposure scenarios. The risk assessment focused on the following exposure pathways:

- Soil to human - The potential exposure of humans by ingestion, dermal contact or inhalation of Cr(VI) or Cr(III) of contaminated soil.
- Soil to groundwater - The receptor or subject of protection is the groundwater with the point of exposure at the groundwater surface.
- Soil to plant - Concerns the potential uptake of Cr(VI) by the plants from contaminated soil/groundwater.
- Groundwater - Is the migration of the Cr(VI) contamination within the groundwater to any receptor. It is addressed in this context as groundwater plume or plume only.

The measured concentrations both for Cr(III) and Cr(VI) in the soil samples taken on the manufacturing plant site were always below the soil screening levels (SSL's) for ingestion and dermal contact for commercial/industrial areas. Beneath certain areas of the plant site, the Cr(VI) concentrations in the soil exceeded the SSL's for inhalation of fugitive particulates. These contaminant values do not pose a health risk to workers on the plant site or on neighbouring industrial sites, as in all instances the ground surface is covered by buildings and/or paved in concrete/asphalt. The measured concentrations of Cr (VI) and Cr(III) in the soil samples were well below the SSL's for ingestion and dermal contact in the neighbouring area. Hence neither of the concentrations of Cr(VI) and Cr(III) found in the soils of the neighbouring area pose risk to humans.

Based on the results of the risk assessment for the exposure scenario soil to groundwater, it is evident that on the manufacturing plant site outside the groundwater plume area, the Cr(VI) concentrations in the soils were below the screening levels. In the vicinity of the 'hot spots' (active sources) the Cr(VI) concentrations were above the screening levels. Therefore these contaminated soil areas have an impact on the groundwater plume. In the residential area and turf club site, the measured Cr(VI) concentrations in the soil samples outside the plume area and within the plume were all below the screening levels. Hence the migration of Cr(VI) from the soil to the groundwater in the neighbouring area is of no concern and does not pose a risk.

Numerous studies and scientific papers have indicated that the soluble Cr(VI) is not taken up easily by plants. If taken up by plants or in general by living tissue it is rapidly converted to Cr(III). Cr(III) in plants does not pose any risk to human health since it is an important component of a balanced human diet. Hence the exposure scenario soil to plant to human does not pose a risk.

The measured concentrations for Cr(VI) in the groundwater samples taken in the plume area exceeded all risk based screening levels for drinking water, irrigation and livestock, the contaminated groundwater is clearly not suitable for drinking, irrigation and livestock, as exposure to large quantities of the contamination could lead to serious health effects. The contaminated groundwater starts approximately 1 to 2 meters below the ground surface, provided a person does not come into direct contact with the contaminated groundwater through drinking or skin contact, there would be no risk of adverse health effects to the person.

Remediation of soil and groundwater contamination at the manufacturing plant site is not expected to be a simple matter that is likely to be achieved over a short period. Therefore, it has been important to establish the risks that have to be dealt with, and to set targets for remediation that will be realistic to achieve over time. In response to regulatory obligations, the risk assessment has been used as a basis to set short-term, medium-term, and long-term targets for cleanup. The assessment has also set preliminary remediation target concentrations for chromium contamination in the soils and groundwater on the site.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Objectives of the study	3
1.3 Methodology.....	3
CHAPTER 2 SITE DESCRIPTION	5
2.1 Location.....	5
2.2 Surrounding land use	6
2.3 Layout	7
2.4 Site history	8
2.4.1 General.....	8
2.4.2 Previous operation.....	9
2.4.3 Current operation	9
2.5 Topography	10
2.6 Climatic conditions	11
2.7 Surface run-off	13
2.8 Regional geology	13
2.8.1 Introduction	13
2.8.2 St Lucia formation	15
2.8.3 Bluff sandstone and Berea formations	15
2.8.4 Harbour beds.....	17
CHAPTER 3 CHROMIUM IN THE ENVIRONMENT:	
LITERATURE STUDY	18
3.1 Occurrence	18
3.2 Chromium chemistry	18
3.2.1 Aqueous chemistry and pH effect.....	19
3.2.2 Reactions and mechanisms in aquifer systems	21
3.2.2.1 Precipitation	23
3.2.2.2 Adsorption	24
3.2.2.3 Reduction and fixation	25
3.3 Toxicity.....	27
3.3.1 Human health.....	27
3.3.2 Ecological impacts	30
3.4 Site characterization requirements	31
3.5 Chromium treatment and remediation approaches	32
3.5.1 Introduction	32
3.5.2 Groundwater extraction and treatment method	33
3.5.3 In situ technologies	36

CHAPTER 4 FIELDWORK AND DISCUSSION OF RESULTS.....	37
4.1 Hydrocensus.....	37
4.2 Borehole installations	39
4.2.1 Introduction	39
4.2.2 Hand auger drilling	41
4.2.3 Rotary washbore drilling	42
4.3 Materials testing of soil samples	47
4.3.1 Hydraulic conductivity estimation based on grain size analysis	47
4.3.2 Hydraulic conductivity estimation based on laboratory tests	50
4.4 Borehole pumping tests	51
4.5 Groundwater level monitoring.....	55
4.6 Groundwater sampling.....	66
4.7 Soil sampling	72
 CHAPTER 5 CONCEPTUAL SITE MODEL.....	 78
5.1 Introduction	78
5.2 Sources of contamination.....	78
5.2.1 Primary sources.....	78
5.2.2 Secondary sources.....	79
5.3 Potential transport mechanisms	80
5.4 Exposure pathways	80
5.4.1 Air	80
5.4.2 Surface runoff.....	81
5.4.3 Soil	81
5.4.3.1 Hydraulic conductivity.....	81
5.4.4 Groundwater	83
5.4.4.1 Groundwater recharge.....	83
5.4.4.2 Groundwater levels	84
5.4.4.3 Groundwater flow directions	85
5.4.4.4 Seepage velocity.....	86
5.4.4.5 Retardation factors	87
5.4.5 Potential receptors and complete pathways	89
 CHAPTER 6 RISK ASSESSMENT	 91
6.1 Risk Based Corrective Action	91
6.1.1 Overview of Risk Based Corrective Action	91
6.1.2 Hazard characterization and response under RBCA	93
6.1.3 RBCA site classification.....	94
6.1.4 Tiered evaluation of Risk-Based standards	94
6.1.4.1 Tier 1: Generic Screening-Level Corrective Action Goal	95
6.1.4.2 Tier 2: Site-Specific Corrective Action Goals	95
6.1.4.3 Tier 3: Site-Specific Corrective Goals	96
6.2 Tier 1 evaluation.....	97
6.2.1 Introduction	97
6.2.2 Soil to human	97
6.2.3 Soil to groundwater.....	102
6.2.4 Soil to plant	105
6.2.5 Groundwater plume.....	105

6.2.5.1	<i>Excavation works</i>	107
6.2.5.2	<i>Groundwater extraction from shallow boreholes</i>	108
6.2.5.3	<i>Groundwater extraction from deep boreholes</i>	108
CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS		109
7.1	Conclusions	109
7.2	Recommendations	114
CHAPTER 8 REFERENCES		117
APPENDICES		120

LIST OF FIGURES

Figure 2.1: Locality of the site	5
Figure 2.2: Locality plan and land zoning	6
Figure 2.3: Layout of the site	8
Figure 2.4: Old production facilities	9
Figure 2.5: Manufacturing process of chromium tanning salts	10
Figure 2.6: General topography of the site	11
Figure 2.7: Average monthly temperatures for Durban	12
Figure 2.8: Average monthly rainfall for Durban	12
Figure 2.9: Geological map of the province of Kwazulu - Natal	14
Figure 3.1: Eh-pH diagram for chromium	20
Figure 3.2: The chromium cycle in the environment	22
Figure 3.3: Chromium reduction and fixation	26
Figure 3.4: Concentration versus pumping duration showing tailing and rebound effect	33
Figure 3.5: Conceptual geochemical model of zones in a contaminant plume	35
Figure 4.1: Boreholes found during hydrocensus survey	39
Figure 4.2: Borehole locations on the manufacturing plant site and neighbouring area	40
Figure 4.3: Hand auger hole with temporary casing	42
Figure 4.4: Rotary washbore drilling rig	44
Figure 4.5: Groundwater level monitoring using a dip meter	55
Figure 4.6: Groundwater levels in aquifer 1 boreholes	57
Figure 4.7: Groundwater levels in aquifer 2 boreholes	57
Figure 4.8: Groundwater levels in aquifer 3 boreholes	58
Figure 4.9: Groundwater levels in aquifer 4 boreholes	58
Figure 4.10: Groundwater levels in Natal Group aquifer boreholes	59
Figure 4.11: Correlation between topography and groundwater levels in aquifer 1	60
Figure 4.12: Groundwater levels and flow directions in aquifer 1	61
Figure 4.13: Groundwater levels and flow directions in aquifer 2	62
Figure 4.14: Groundwater levels and flow directions in aquifer 3	63
Figure 4.15: Groundwater levels and flow directions within aquifer 4	64
Figure 4.16: Groundwater levels and flow directions within sandstone aquifer	65
Figure 4.17: Groundwater sampling using peristaltic pump and flow through cell	66
Figure 4.18: Maximum Cr(VI) concentrations within aquifer 1	68
Figure 4.19: Maximum Cr(VI) concentrations within aquifer 2	69
Figure 4.20: Maximum Cr(VI) concentrations within aquifer 3	70
Figure 4.21: Maximum Cr(VI) concentrations within aquifer 4	71
Figure 4.22: Soil sampling locations on the manufacturing plant site and neighbouring area	72
Figure 4.23: Test pit excavated for shallow soil sampling	73
Figure 4.24: Cr(III) concentrations in the soils at the depth of 0.3m	74
Figure 4.25: Cr(III) concentrations in the soils at the depth 0.6 m	75
Figure 4.26: Cr(VI) concentrations in the soils at the depth of 0.3m	76
Figure 4.27: Cr(VI) concentrations in the soils at the depth of 0.6m	77
Figure 5.1: Suspected hot spot locations based on observed Cr(VI) concentrations in aquifer 1 and 2	79
Figure 5.2: Temperatures and rainfall in Durban	84
Figure 5.3: Sources, pathways, exposure scenarios and receptors of concern at the manufacturing plant site	90
Figure 6.1: ASTM risk based corrective action flowchart	92
Figure 6.2: Maximum Cr(VI) concentrations in the top soil on the manufacturing plant	99
Figure 6.3: Maximum Cr(III) concentrations in the top soil on the manufacturing plant	100

Figure 6.4: Maximum Cr(VI) concentrations in the top soil off the manufacturing plant101

Figure 6.5: Maximum Cr(III) concentrations in the top soil off the manufacturing plant102

Figure 6.6: Maximum Cr(VI) concentrations in the top soil on the manufacturing plant104

Figure 6.7: Projected extent of plume107

LIST OF TABLES

Table 2.1: Layout of the plant site.....	7
Table 2.2: Summary of the geology of the South Durban Basin Area.....	13
Table 3.1: CECs for soils.....	24
Table 4.1: Summary of hydrocensus results	38
Table 4.2: Summary of boreholes installed during this study.....	40
Table 4.3: Summary of geology underlying the manufacturing plant and neighbouring area	45
Table 4.4: Summary of particle size distribution analysis.....	49
Table 4.5: Hydraulic conductivities estimated from grain size analysis using empirical formulae	49
Table 4.6: Hydraulic conductivity of clayey soils based on laboratory tests.....	51
Table 4.7: Boreholes selected for pumping tests.....	51
Table 4.8: Summary of results of analysis of borehole pump tests.....	53
Table 4.9: Summary of estimated hydraulic conductivities for various aquifers underlying the Manufacturing plant	54
Table 4.10: Summary of measured groundwater levels in the boreholes.....	56
Table 5.1: Summary of estimated hydraulic conductivities for aquifers underlying the Manufacturing plant	82
Table 5.2: Summary of measured groundwater levels in the boreholes.....	84
Table 5.3: Summary of estimated seepage velocities for aquifers underlying the Manufacturing plant	86
Table 5.4: Estimated retardation factors for Cr(VI)	88
Table 6.1: RBCA site classification and response actions.....	94
Table 6.2: Exposure pathways and scenarios identified by CSM	97
Table 6.3: US EPA generic soil screening levels.....	98
Table 6.4: US EPA generic soil screening levels for migration to groundwater	104
Table 6.5: US EPA risk based screening levels for groundwater	105

LIST OF ACRONYMS

AEC	: Anion Exchange Capacity
ASTM	: American Society for Testing Materials
Cr(III)	: Trivalent chromium (reduced form)
Cr(VI)	: Hexavalent chromium (Oxidized form)
CEC	: Cation Exchange Model
CCA	: Copper Chromium Arsenate
CBD	: Central Business District
DOC	: Dissolved Organic Carbon
DAF	: Dilution Attenuation Factor
DWEA	: Department of Water and Environmental Affairs
ET	: Department of Environment and Tourism
MSL	: Mean Sea Level
mbgl	: metres below ground level
m	: metres
MCL	: Maximum Contaminant Level
NTC	: National Toxicology Program
N/A	: Not Available
PRB	: Permeable Reactive Barrier
POE	: Point of Exposure
RBCA	: Risk Based Corrective Action
RBSL	: Risk Based Screening Level
RME	: Reasonable Maximum Exposure
SDBA	: South Durban Basin Area
SPT	: Standard Penetration Test
SSTL	: Site Specific Target Level
SSL	: Soil Screening Level
SL	: Screening Level
SDC	: Sodium Dichromate
TOC	: Total Organic Carbon
US EPA	: United States Environmental Protection Agency

CHAPTER 1. INTRODUCTION

1.1 Background

Chromium is an important industrial metal used in diverse processes, including ore refining, production of steel and alloys, pigment manufacture, plating metal, corrosion inhibition, leather tanning, wood preservation, and combustion of coal and oil (Adriano 2001; Papp 2001). At many industrial and waste disposal locations, chromium has been released to the environment via leakage and poor storage during manufacturing or improper disposal practices (Palmer and Wittbrodt 1991; Calder 1988).

Fortunately, releases represent a very small fraction of total use and improvements of the infrastructure have dramatically reduced the potential for future releases. Nevertheless, a result of the utilization of chromium compounds is a legacy of soil and groundwater impacted by chromium. Over the last 30 years recognition of the need for better environmental stewardship has driven rapid evolution of science and technology associated with managing releases of chromium compounds.

In the environment, chromium is commonly found in two most stable oxidation states as trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)], each characterized by distinctly different chemical properties, bioavailability, and toxicity. Trivalent chromium is an essential element for living beings, has relatively low toxicity, immobile under moderately alkaline to slightly acidic conditions, and strongly partitioned into the solid phases, while hexavalent chromium is very toxic, carcinogenic, and mutagenic to both animals and humans and may cause liver and kidney damage and internal respiratory problems (Doisy et al. 1976; Yassi & Nieboer 1988; USDH 1991; Fendorf 1995). It is also very soluble, mobile, and moves at a rate essentially the same as the groundwater (Palmer and Puls, 1994). Industrial applications most commonly use chromium in the Cr(VI) form, which can introduce high concentrations of oxidized chromium (chromate) into the environment.

The study area is located within the residential, commercial and industrial area, approximately 20km to the south west of the Durban CBD, between a turf club site and the international airport of Durban. Between 1945 and 1990, the site was used for the production of sodium dichromate

(SDC), chromium tanning salts, chromic acid and sodium sulphate. In 1991, the production of sodium dichromate (SDC) was discontinued on the site, and manufacturing activities were limited to the production of chromium tanning salts. These salts are used in the production of leather where they are essential in converting perishable raw hides into durable leather. In 2004, an investigation was initiated in the study area following the discovery of Cr(VI) in groundwater. Cr(VI) was detected in groundwater samples taken from an open pit excavated just outside the perimeter of the manufacturing plant site. It is considered that the actual main source of the groundwater plume are suspected hot spots in the soil within aquifer 1 and 2. It is most likely that the hot spots originated from SDC spills during former production and handling at certain locations within the manufacturing plant site. It is reasonable to assume that the SDC entered the groundwater from these production and handling locations and is still present in the soil voids within aquifer 1 and 2. SDC liquid slowly dissolved the groundwater flowing around the hot spots and would appear to be feeding the observed groundwater plume at present.

Currently, most of the manufacturing plant site is covered in concrete or asphalt. However, the possibility that workers could come in contact with the impacted subsurface soils on the plant site at non-sealed surfaces cannot be ruled out completely. That scenario could cause a risk of inhalation of dust particles containing chromium or ingestion of chromium contaminated soils with concurrent skin contact. The residential stands in the area are small, mostly built up and exposed areas are either concreted or tiled. However, the possibility that the general public could come in contact with the impacted subsurface soils in the residential area at non-sealed surfaces cannot be ruled out completely. That scenario could cause a risk of inhalation of dust particles containing chromium or ingestion of chromium contaminated soils with concurrent skin contact.

The contaminated groundwater originating from the plant site could migrate into the residential area and downstream of the plant site, thus posing immediate danger or acute health risk to the population living in the residential area and downstream of the plant site. The movement of groundwater and dispersion within the aquifer spreads the contaminant over a wider area, which can then intersect with groundwater wells, making the water supplies unsafe. The use of groundwater for irrigation purposes and drinking would create the possibility that humans come into contact with Cr(VI)-contaminated groundwater. The most likely exposure route would be dermal contact and ingestion. Any excavations and below ground level construction within the plume area would potentially expose workers and members of the public to dermal contact with the contaminated groundwater.

Due to its adverse health effects, Cr(VI) poses a serious health risk to human health and that of the environment. Hence, Cr(VI) contamination of the soils and groundwater is considered a major environmental concern. This thesis aimed to investigate the processes leading to the scenario outline above.

1.2 Objectives of the study

- To provide a literature overview of chromium contamination in the subsurface
- To establish the nature of geology and geohydrology underlying the manufacturing plant.
- To quantify the level and extent of chromium contamination in the soils and groundwater underlying the manufacturing plant.
- To identify the source of chromium contamination in the soils and groundwater underlying the manufacturing plant and related potential pathways and exposure scenarios to the point of exposure of the receptors.
- To conduct a risk assessment for the soils and groundwater

1.3 Methodology

This project aimed to investigate the risk of chromium contamination in the soils and groundwater underlying the manufacturing plant. A hydrocensus survey was conducted in a 1 km radius of the plant site in order to establish if any groundwater extraction boreholes or wells occurred in the area, and to identify the usage of the groundwater extracted from such sources. Several new boreholes were drilled on the manufacturing plant site and neighbouring area. The boreholes were installed to establish the subsoil conditions and to facilitate the monitoring and sampling of the groundwater in the various aquifers underlying the study area. Certain aquifer parameters needed to be investigated by carrying out materials testing of soil samples, laboratory permeability tests and conducting pump tests.

The groundwater was accessed in order to study the geohydrology of the aquifers underlying the manufacturing plant and surrounding area. The groundwater levels needed to be measured over a

period of time in order to understand the processes taking place within the aquifers underlying the study area.

Chemical data was collected in order to quantify the levels and extent of chromium contamination in the soils and groundwater underlying the manufacturing plant and neighbouring area, and to gain a full understanding of the hydrochemistry.

Based on the results of site investigations, a risk assessment conceptual model was developed in order to identify the sources and related potential pathways and exposure scenarios to the point of exposure of the receptors. A risk assessment for the soils and groundwater underlying the study area was also conducted in order to evaluate and assess the exposure scenarios.

The methodology steps are listed as follows:

- Literature and background information study
- Hydrocensus survey
- Installation of new boreholes
- Materials testing of soil samples
- Borehole pumping tests
- Groundwater level monitoring
- Groundwater sampling
- Soil sampling at test pits
- Development of risk conceptual site model
- Risk assessment

CHAPTER 2. SITE DESCRIPTION

2.1 Location

The manufacturing plant is located within the residential, commercial and industrial area, approximately 20km to the south west of the Durban CBD, between a turf club site and the international airport of Durban, as shown in Figure 2.1.

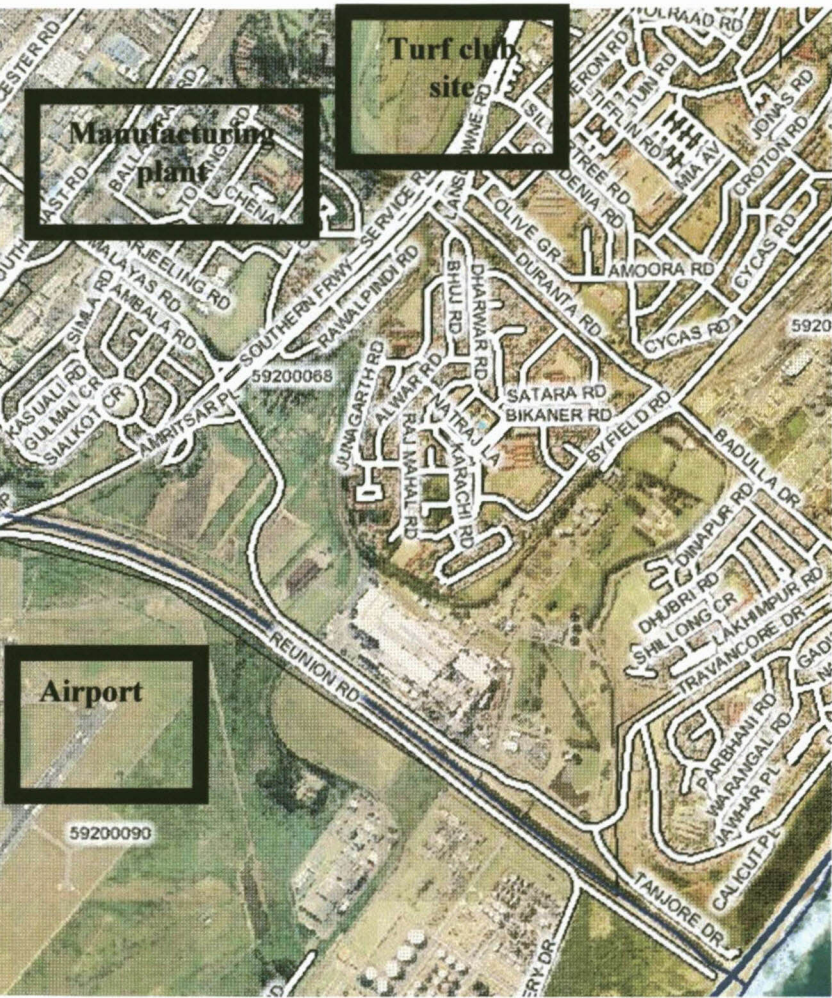


Figure 2.1: Locality of the site (not to scale).

2.2 Surrounding land use

In terms of urban planning the manufacturing plant is zoned noxious industrial, and the surrounding area is zoned special residential, educational, private open space, institutional, worship, special shopping and general industrial as shown in Figure 2.2.

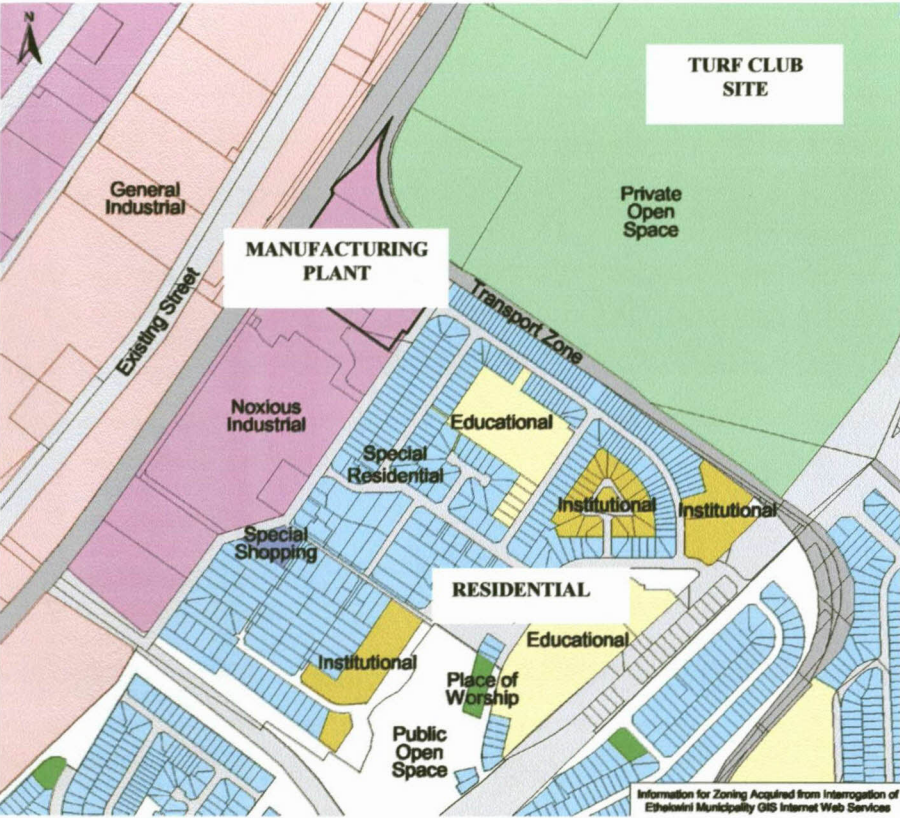


Figure 2.2: Locality plan and land zoning.

2.3 Layout

The site is roughly rhomboid in shape and covers an area of approximately 3.2 hectares. It is bounded on the north west and north east by a railway reserve. The south eastern periphery of the site is separated from the residential area by a municipal road, with an industrial site for Illovo sugar located immediately on the south western boundary of the site.

The site is occupied by a chromium tanning salts plant, laboratory, workshops, technical stores and administration offices, as detailed in Table 2.1 below. The plant site and surrounding area is served by paved roads and a municipal sewer and stormwater reticulation system. The layout of the plant site is shown in Figure 2. 3.

Table 2.1: Layout of the plant site

Building/Facility	Occupied area (m ²)	Location within the site
Major buildings		
Administration offices	200	Southeastern part
Laboratory	120	Southwestern part
Raw material storage	375	Eastern part
Raw material storage tanks	75	Southern part
Adsorption plant	125	Southern part
Chromium tanning salts plant (Mixing plant)	2436	Western part
Bagging, pelletising and shrink wrapping warehouse	400	Western part
Finished goods storage	3168	Central part
Container loading bay	150	Eastern part
Other buildings and facilities		
Workshop and technical stores	1125	Southeastern part
Guardhouse	16	Southeastern part
Canteen	150	Southern part
Car port	100	Southeastern part



Figure 2.3: Layout of the site.

2.4 Site history

2.4.1 General

The history of the site and the manufacturing activities are summarised below.

- Between 1945 and 1968, the site was used for the production of sodium dichromate (SDC), chromium tanning salts, chromic acid and sodium sulphate.
- Between 1985 and 1991, substantial improvements were implemented to address the stormwater drainage pathways. This included paving the process areas, lining the underground municipal stormwater pipe through the site.
- In 1991, the production of sodium dichromate (SDC) was discontinued on the site, and

manufacturing activities were limited to the production of chromium tanning salts.

- In 2004, an investigation was initiated in the study area following the detection of hexavalent chromium [Cr(VI)] in groundwater, in an open pit excavation just outside the perimeter of the manufacturing plant site.

2.4.2 Previous operation

Prior to 1991, Sodium Dichromate (SDC) was produced at the site from mono chromate liquor by acidifying it with sulphuric acid. After acidification the sulphate precipitate was centrifuged off and sold. The liquid dichromate was evaporated and centrifuged to a moist crystal state which was further dried before packing into containers. Figure 2.4 below shows the old production facilities.

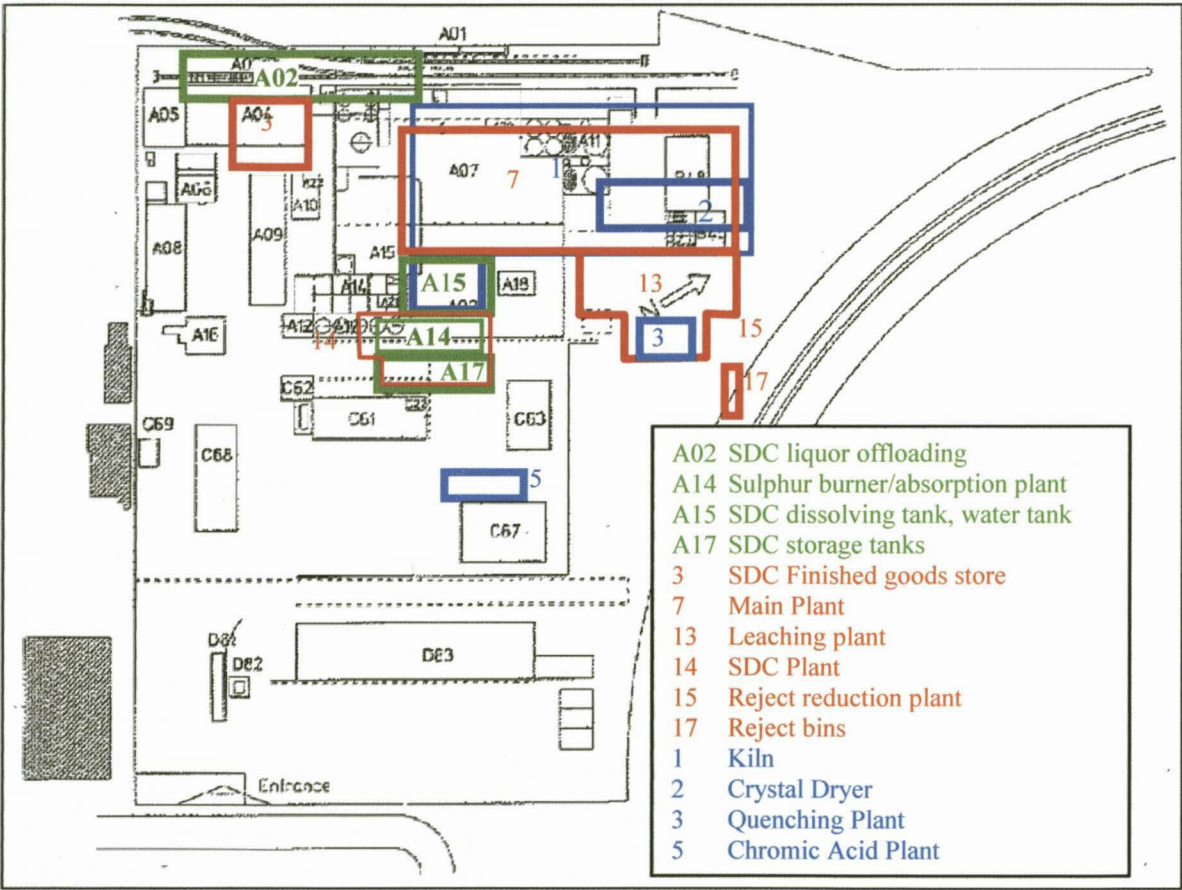


Figure 2.4: Old Production facilities.

2.4.3 Current operation

The manufacturing plant produces chromium tanning salts. These salts are used in the production of leather where they are essential in converting perishable raw hides into durable leather.

The plant currently produces, as its main product, a basic chromium sulphate called Chromosal B and two technically advanced products called Chromosal BF and Baychrom A. These products are in powder form and are supplied in paper bags, plastic drums or big bags.

Chromium tanning salt is produced by reacting sodium dichromate with sulphur dioxide on a continuous basis as shown in Figure 2.5 below. The resulting chromium tanning salt liquid is spray dried to yield Chromosal B powder which is conveyed to storage hoppers in the bagging plant. The sodium dichromate is imported to the plant site in liquid form. Sulphur dioxide is produced by heating liquid sulphur. The Baychrom product is produced by blending chromium tanning salts and various additives such as dolomite, sodium formate and sodium bicarbonate in order to achieve specific properties. The manufacture and blending takes place in a modern computer controlled mixing plant and a state of the art multi purpose bagging plant.

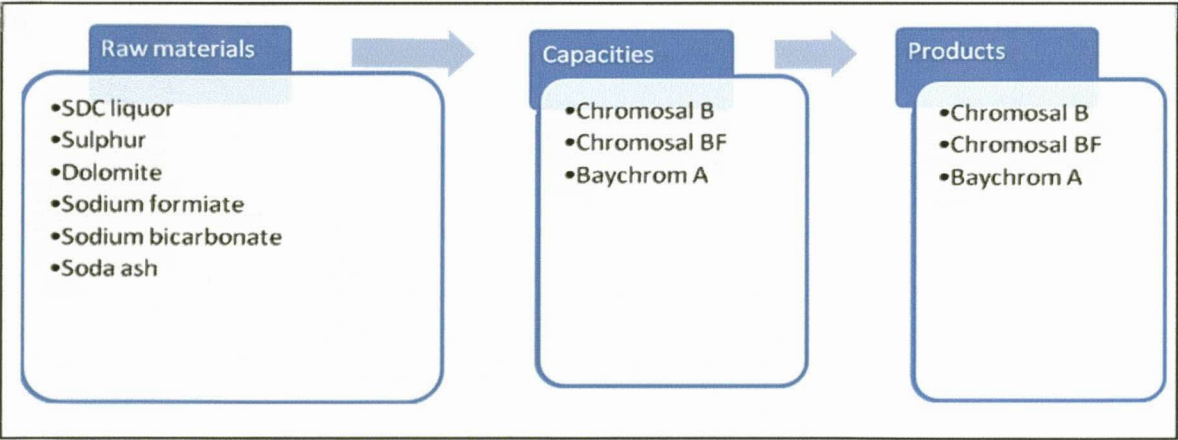


Figure 2.5: Manufacturing process of chromium tanning salts.

2.5 Topography

The manufacturing plant site is located on a gentle southeast facing slope, which generally grades towards the municipal road site boundary on the east. The elevation of the site varies between

approximately 17.5 m above MSL in the western corner to approximately 13.5 m above MSL in the eastern corner, as shown in Figure 2.6.

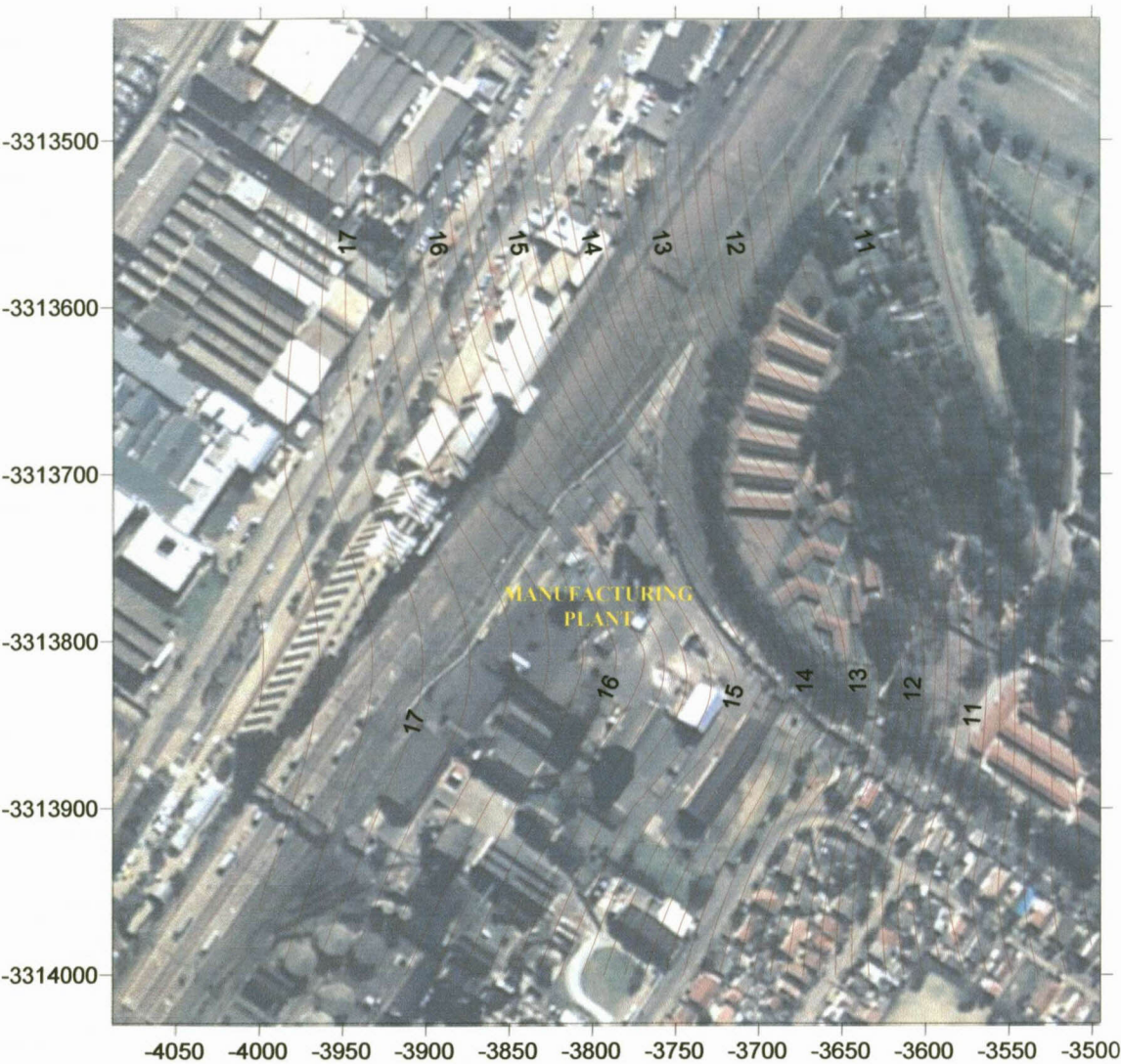


Figure 2.6: General topography of the site.

2.6 Climatic conditions

Durban’s climate is characterised by warm humid summers (October to March) during which the region receives most of it’s precipitation. Winters (April to September) are cool and relatively dry. Average monthly temperatures for the warmest month is 24.6°C (December) and for the coolest month it is 16.6°C (July). Average annual rainfall is approximately 1000mm.

Figures 2.7 and 2.8 below illustrate the average temperature and rainfall records for Durban for the period 2004 to 2007.

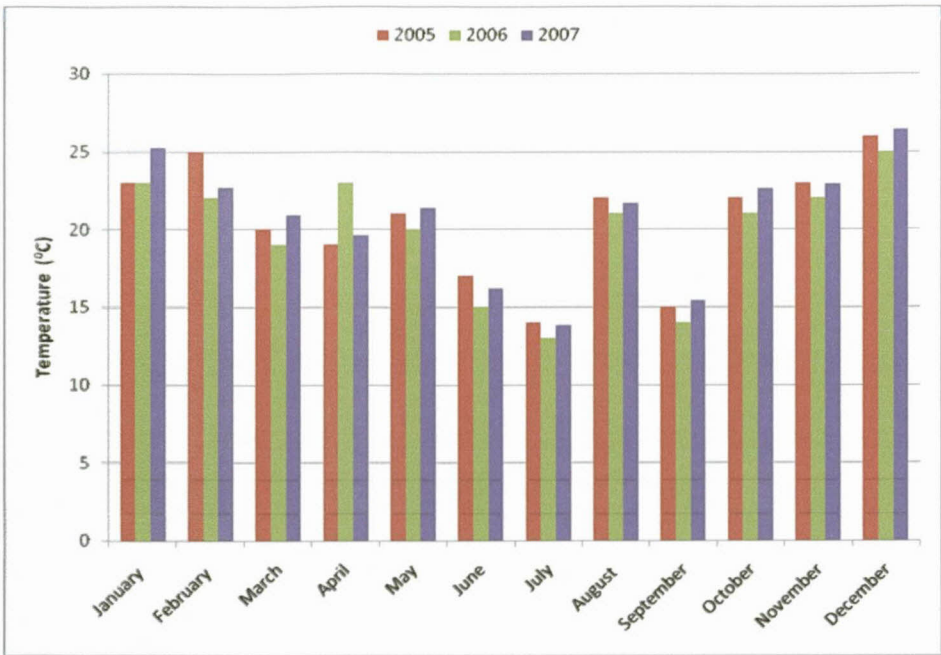


Figure 2.7: Average Monthly Temperatures for Durban – (2005 to 2007).

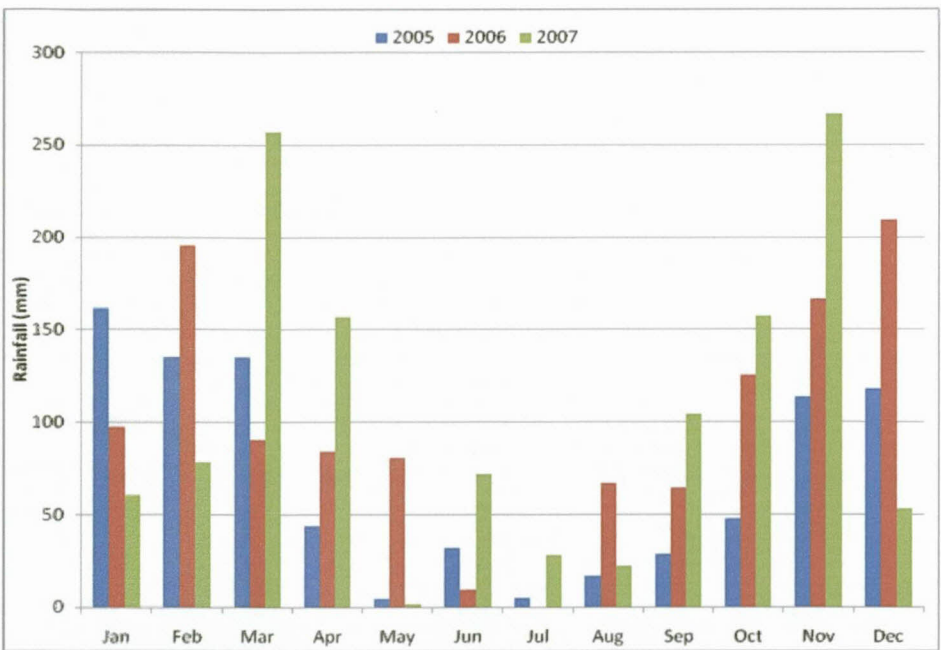


Figure 2.8 : Average Monthly Rainfall for Durban – (2004 to 2007).

2.7 Surface run-off

The majority of the manufacturing plant site is currently paved in concrete or asphalt, and all surface runoff is collected in surface drains before being discharged into the municipal stormwater reticulation system. The run-off that is collected in surface drains from the production area of the site is tested prior to being discharged to the municipal stormwater system. Where the test results exceed the discharge criteria, the water is pumped into holding tanks and used as process water in the plant.

2.8 Regional geology

2.8.1 Introduction

Regionally, the study area is located on the South Durban Basin Area (SDBA) and is underlain by recent alluvial soils and Quaternary sediments (Harbour Beds) flanked on both sides by aeolian sands of the Berea Formation. These sediments overlie Cretaceous bedrock of the St. Lucia Formation. The Cretaceous bedrock is, in turn, underlain by Sandstone of the Natal Formation and Tillite of the Dwyka Formation. The regional geology of the site is shown in Figures 2.9, and the stratigraphy of the SDBA is summarised in Table 2.2 below.

Table 2.2: Summary of geology in the South Durban Basin Area (Brink, 1986)

Formation	Age Mio. a	Name	Description	Thickness (m)
Recent		Alluvial sediments	Brown clayey sand	
Quaternary	0 1.5	Harbour Beds	Sand with clay layers	0 - 60
		Berea	Sandy clay	0 - 100
		Bluff Sandstone	Calcarenite	0 - 200
Cretaceous	~80	St. Lucia	Silty sandstone	0 - 60
Ordovician	>100	Natal	Sandstone	>100

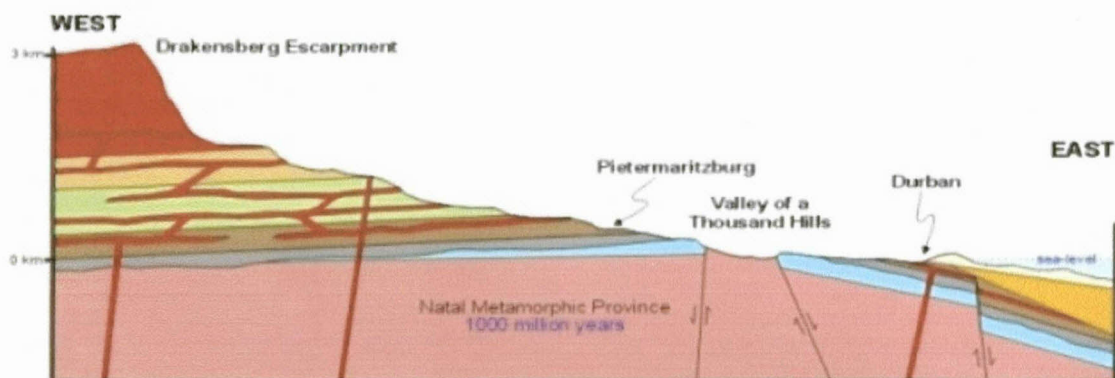
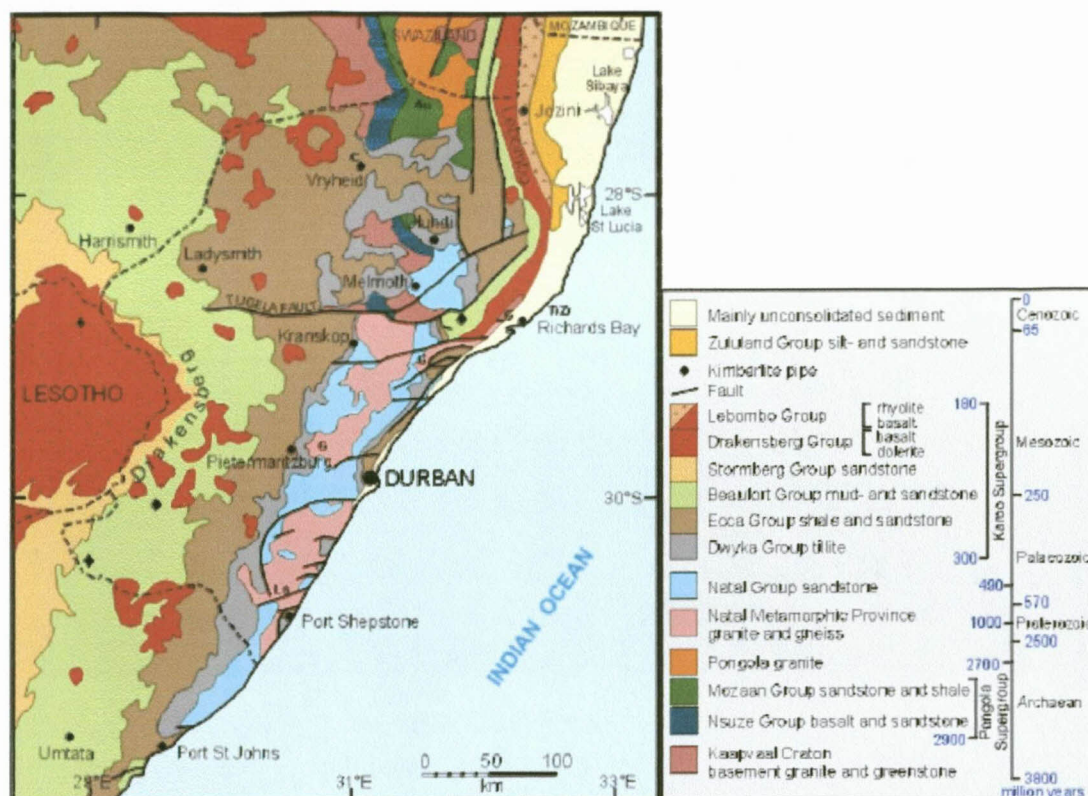


Figure 2.9: Geological Map of the province of KwaZulu-Natal.

2.8.2 St. Lucia formation

During the Cretaceous period approximately 80 million years ago, which followed the break up of Gondwanaland, this part of the KwaZulu Natal coastline was inundated by the sea, with a paleo-shoreline formed along the base of the Isipingo hills to the west. During this period of marine transgression, a thick deposit of silty fine sand was deposited in a marine environment on the drowned eroded bedrock surface. The bedrock surface comprised sandstone of the Natal Formation, tillite of the Dwyka Formation, and shales of the Ecca Group. The Dwyka Formation and Ecca Group forming part of the Karoo Sequence. The silty sands subsequently consolidated to form the very soft to soft rock, silty sandstone of Cretaceous Age. The Cretaceous bedrock occurs beneath the area at depths of between approximately 35 and 55 metres below existing ground level. These sediments are termed the St. Lucia Formation. As such the St. Lucia Formation rests unconformably on a very well-planed, inclined erosion surface on the underlying much faulted bedrock of the Natal Group and Karoo Sequence. The Cretaceous sediments form a wedge which thickens markedly in a seaward direction, with a corresponding decline in the elevation of the underlying bedrock surface. Formation thicknesses increase from zero at the sub-outcrop line along the toe of the Berea Ridge to some 3000m about 50km offshore. This stratum is weakly bedded and jointed, dipping a few degrees seaward, and shows no signs of disturbance since their deposition. Both faults and erosion of the underlying bedrock appear to pre-date the Cretaceous sediments of the St. Lucia Formation.

2.8.3 Bluff sandstone and Berea formations

During the Tertiary and Quaternary Periods that followed the Cretaceous Period, rivers flowing into the area deposited a mixture of boulders, gravel, sands and clays within the coastal estuarine environment that existed. In addition, aeolian coastal dunes also formed during this time, with the Bluff coastal dune thought to be a remnant of an early Quaternary dune. The Tertiary and Quaternary Periods have been characterised by repeated cycles of marine transgressions and regressions, with widely fluctuating sea levels. In particular, during the Quaternary Ice Ages, abstraction of sea water into Polar ice caps reduced sea levels world wide by 100 metres or more. As a result there was renewed erosion and down cutting by the rivers during periods of very low sea level. Consequently, much of the previously deposited alluvial and aeolian deposits were

eroded and in some cases new channels were carved into the soft sandstone of the St. Lucia Formation.

The Bluff Dune which encloses Durban harbour and the southern portions of Durban on their seaward side is underlain by the Bluff Sandstone Formation. This formation comprises up to about 200 metres of generally strongly bedded calcareous sandstone or calcarenite, mainly of aeolian origin deposited during the Quaternary period. The formation extends to a depth of about 100m below present sea level and rests unconformably on the Cretaceous sediments of the St. Lucia Formation.

The Bluff Sandstone Formation is the parent material of the Berea Formation, which was derived from the former by a process of insitu weathering. Outcrops of the Bluff Sandstone are common on the seaward side of the Bluff Dune along its entire length. The Berea Formation, or the Berea Red sand as it is locally known, occupies the upper and inner portions of the Durban Bluff Dune as well as the elevated Berea Ridges which parallel the coast. The Berea Ridge west of the central city and harbour areas is part of a compound coastal dune system of varying width which extends along the entire southeastern coast of Africa.

The Berea Formation has a thickness of up to about 100m and frequently overlies the bedrock surface. A basal boulder bed of water-worn pebbles and boulders in a clayey sandy matrix is often present where the Berea Formation overlies the bedrock surface. The Berea Formation has a marked variation in its clay content (mainly kaolin), which may range from 2 to 50%. The clay content being influenced particularly by the initial amount of weatherable feldspar. In general, the older the material the higher its clay content and the more red in colour. Wind and water redistribution of the surface material gives rise to a lighter coloured brown or grey sandy superficial horizon overlying more reddish brown clayey sand subsoil. With increasing depth into the dune cone, the material generally becomes progressively less weathered and thus less clayey and lighter in colour.

2.8.4 Harbour beds

As sea levels rose after the last ice age, the Harbour Beds were deposited within a lagoonal area that existed between the Bluff Coastal dunes and hillsides of the Isipingo area to the west. Many of the deep river channels were infilled initially with boulders and then with coarse sands and gravels. As the river gradients lessened coarse sediments gave way to fine sands, silts and clays deposited on the new still waters of the lagoon behind the windblown sands of the Bluff Dune. As a result of the changing depositional environment, the Harbour Beds are extremely variable both in depth and lateral distribution and comprise predominantly sands with layers and lenses of clay. These sediments rest unconformably on various older strata, and underlie the Central Business District (CBD) and Harbour areas of Durban and the low lying areas to the north and south thereof. Sediment thicknesses are variable. Beneath the CBD the Harbour Beds are on average about 30m thick. However, to the south and to the north of the CBD its thickness is in excess of 60m.

CHAPTER 3. CHROMIUM IN THE ENVIRONMENT:

LITERATUTURE REVIEW

3.1 Occurrence

Chromium is an ubiquitous contaminant of soils and groundwater and is derived from both natural and anthropogenic sources (Francoise & Alain 1991). It occurs in combination with other elements as chromium salts, some of which are soluble in water. The pure metallic form does not occur naturally. Chromium does not evaporate, but it can be present in air as particles.

Chromium is an important industrial metal used in diverse processes, including ore refining, production of steel and alloys, pigment manufacture, plating metal, corrosion inhibition, leather tanning, wood preservation, and combustion of coal and oil (Adriano 2001; Papp 2001). At many industrial and waste disposal locations, chromium has been released to the environment via leakage and poor storage during manufacturing or improper disposal practices (Palmer and Wittbrodt 1991; Calder 1988).

In the environment, chromium is commonly found in two most stable oxidation states as trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)], each characterized by distinctly different chemical properties, bioavailability, and toxicity. Cr(III) is an essential element for living beings, has relatively low toxicity, immobile under moderately alkaline to slightly acidic conditions, and strongly partitioned into the solid phases, while Cr(VI) is very toxic, carcinogenic, and mutagenic to both animals and humans and may cause liver and kidney damage and internal respiratory problems (Doisy et al. 1976; Yassi & Nieboer 1988; USDH 1991; Fendorf 1995). It is also very soluble, mobile, and moves at a rate essentially the same as the groundwater (Palmer and Puls, 1994). Industrial applications most commonly use chromium in the Cr(VI) form, which can introduce high concentrations of oxidized chromium (chromate) into the environment. Cr(VI) does not always readily reduce to Cr(III) and can exist over an extended period of time.

3.2 Chromium chemistry

The basic chemistry of chromium in the various oxidation states accounts for the behaviour of this metal in the natural environment, and links this information to in situ technologies discussed in the section 3.5.

3.2.1 Aqueous chemistry and pH effect

Chromium has a unique geochemical behaviour in natural water systems. Cr(III) is the most common form of naturally occurring chromium, but is largely immobile in the environment, with natural waters having only traces of chromium unless the pH is extremely low. Under strong oxidizing conditions, chromium is present in the Cr(VI) state and persists in an anionic form as chromate. Natural chromate are rare. However, the use of Cr(VI) in wood preserving CCA solutions, metal plating facilities, paint manufacturing, leather tanning, and other industrial applications has the potential to introduce high concentrations of oxidized chromium to the environment (Rouse and Pyrih 1990; Palmer and Wittbrodt 1991).

Redox potential Eh-pH diagrams present equilibrium data and indicate the oxidation states and chemical forms of the chemical substances which exist within specified Eh and pH ranges as shown in Figure 3.1.

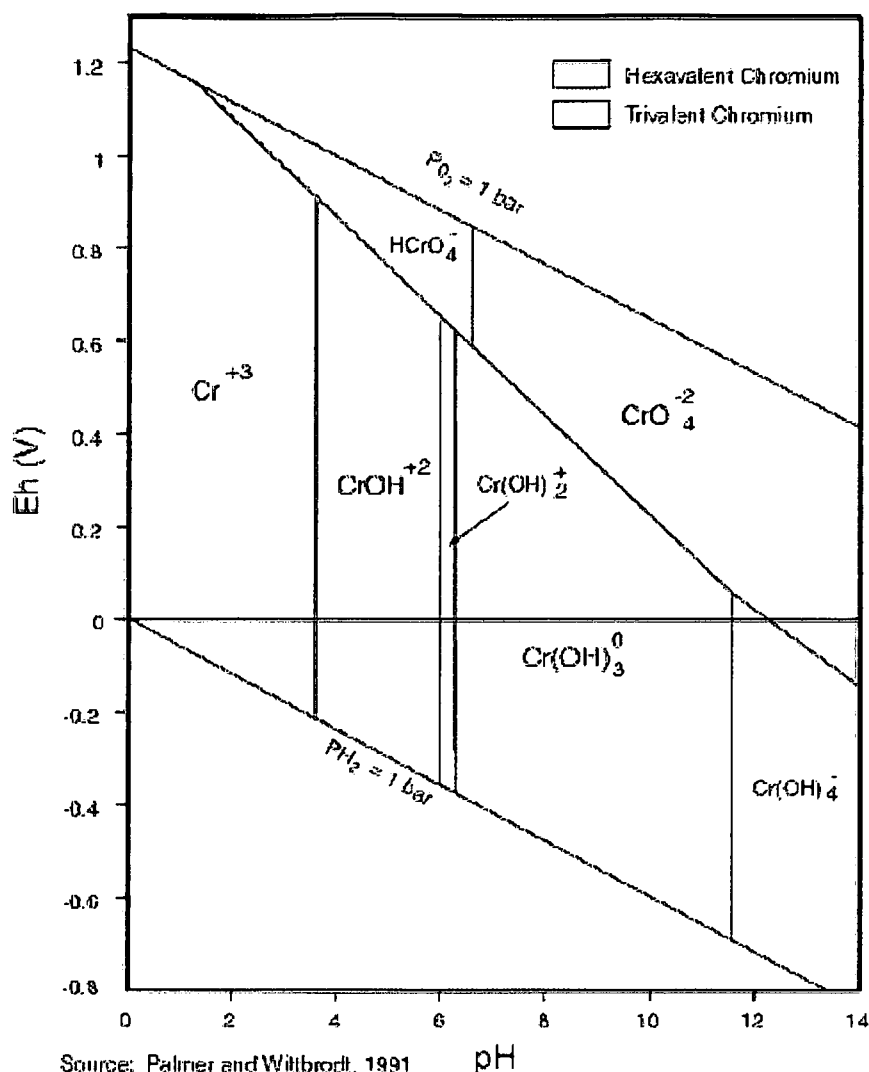


Figure 3.1: Eh-pH diagram for chromium.

The data presented in Figure 3.1 above are derived from parameters representing typical aqueous conditions. Although the diagram implies that the boundary separating one species from another is distinct, the transformation is so clear cut. Concentration, pressure, temperature, and the absence or presence of other aqueous ions can all affect which chromium species will exist. A measure of caution must be exercised when using this diagram as site-specific conditions can significantly alter actual Eh-pH boundaries. Palmer and Wittbrodt (1991) claim that chromium exists in several oxidation states ranging from 0 to 6. Under reducing conditions, Cr(III) is the most thermodynamically stable oxidation state. However, Cr(VI) can remain stable for significant periods of time.

In soils and aquifer systems, the most prevalent forms are the trivalent and hexavalent oxidation states.

Cr(III) exists in wide Eh and pH ranges. Palmer and Wittbrodt (1991) have determined that the following Cr(III) species exist with respect to pH. Cr(III) predominates as ionic (i.e., Cr^{+3}) at pH values less than 3.0. At pH values above 3.5, hydrolysis of Cr(III) in a Cr(III)-water system yields trivalent chromium hydroxyl species [CrOH^{+2} , Cr(OH)_2^+ , Cr(OH)_3^0 and Cr(OH)_4^-]. Cr(OH)_3^0 is the only solid species, existing as an amorphous precipitate. The existence of the Cr(OH)_3^0 species as the primary precipitated product in the process of reducing Cr(VI) to Cr(III) is paramount to the viability of in situ treatment using reactive zone technology, such as microbial bioreduction. Cr(III) can form stable, soluble (and thus mobile), organic complexes with low to moderate molecular weight organic acids (i.e., citric and fulvic acids) the significance of these is that they allow Cr(III) to remain in solution at pH levels above which Cr(III) would be expected to precipitate (Bartlett and Kimble 1976a ; James and Bartlett 1983a).

3.2.2 Reactions and mechanisms in aquifer systems

The chemistry of aqueous chromium in an aquifer is complicated, interactive between soil and water, and cyclic in the reactions that occur as they relate to solid and dissolved phases and various oxidation states present. The "Chromium Cycle" is presented in Figure 3.2 below. Understanding this chemical process is important in the decision-making process in determining which treatment technology (either singly or in combination) to use.

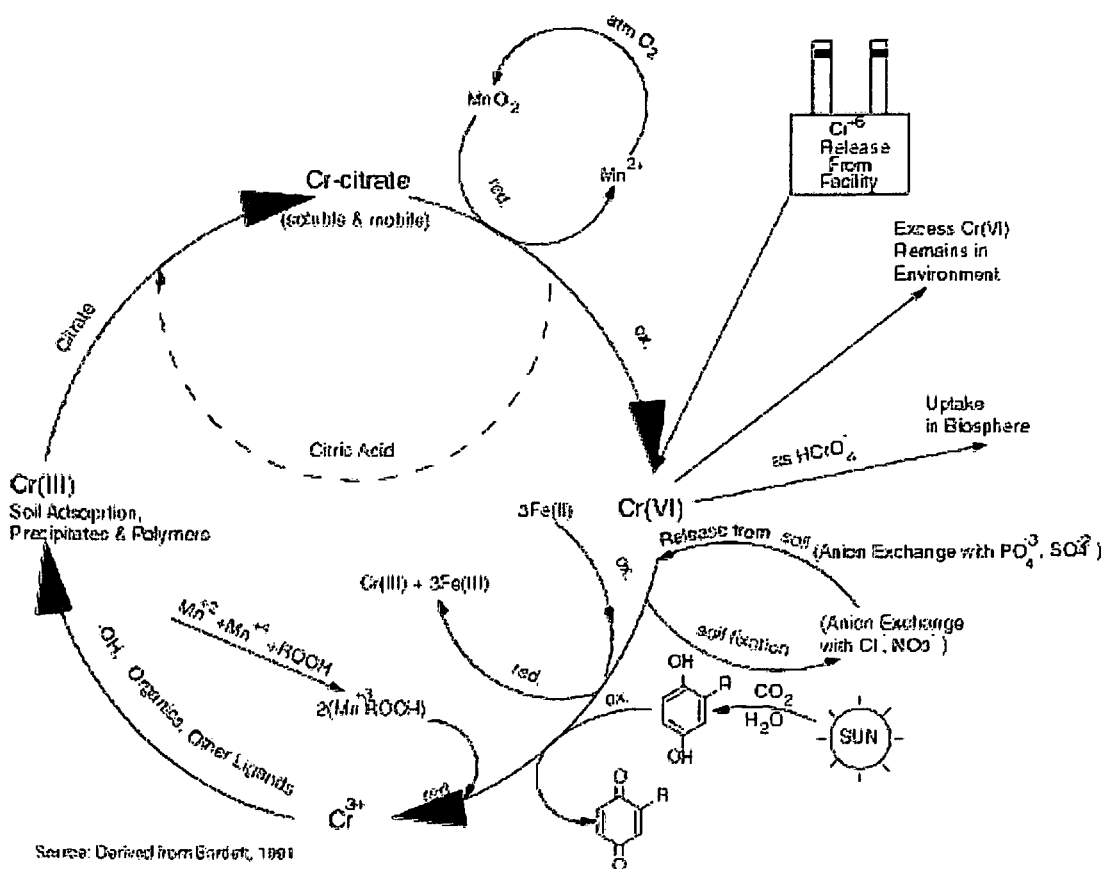


Figure 3.2: The chromium cycle in the environment.

The two major oxidation states of chromium which occur in the environment are Cr(III) and Cr(VI). According to Bartlett (1991), the following conditions exist, Cr(VI) is the most oxidized, mobile, reactive, and toxic chromium state. In general, under non-polluting conditions, only small concentrations of Cr(VI) species exist [the result of oxidation of natural Cr(III)], with Cr(III) species being the most prevalent forms. Most soils and sediments in partial equilibrium with atmospheric oxygen contain the conditions needed in which oxidation and reduction can occur simultaneously. Cr(III) species may be oxidized to Cr(VI) by oxidizing compounds that exist in the soil (i.e., manganese dioxide – MnO_2), while at the same time Cr(VI) species may be reduced to Cr(III) by MnO_2 in the presence of reduced manganese oxide (MnO) and organic acids from soil organic matter (including humic acid, fulvic acid, and humin), soluble ferrous [Fe(II)], and reduced sulphur compounds. Therefore, it is important to understand the geochemical environment of any site where Cr(VI) is likely to occur.

The success of geochemical fixation treatment techniques is based on forming insoluble non-reactive chemical species. Precipitation and adsorption result in fixation or solid-phase formation of Cr(III), each depending on the physical and chemical conditions existing in the aquifer system.

3.2.2.1 Precipitation

Precipitation reactions can be further divided into three types, pure solids such as $\text{Cr}(\text{OH})_3^0$ (amorphous precipitation), mixed solids or coprecipitates such as $\text{Cr}_x\text{Fe}_{1-x}(\text{OH})_3$, and high molecular weight organic acid complexes such as humic acid polymer (Palmer and Wittbrodt 1991 and James and Bartlett 1983b). Pure solid Cr(III) hydroxide precipitates result from changes in the Eh-pH parameters (Figure 3.1).

Chromium hydroxide solid solutions may precipitate as coprecipitates with other metals rather than $\text{Cr}(\text{OH})_3^0$. This is especially true if oxidized iron [Fe(II)] is present in the aquifer, it will generate an amorphous hydroxide coprecipitate in the $\text{Cr}_x\text{Fe}_{1-x}(\text{OH})_3$ form (Palmer and Wittbrodt 1991). This chemical reaction is particularly important due to the potential for Fe(II) to be oxidized to the ferric state as previously discussed. Fe(II) is the most common oxidation state of dissolved iron in natural subsurface waters as well as aquifer minerals. Advantage is taken of this chemical reaction when employing permeable reactive barrier (PRB) in situ treatment of groundwater. Zero-valent iron (Fe^0) metal is used to reduce Cr(VI) to Cr(III) and complex the Cr(III) as a Fe(III) hydroxide coprecipitate.

Insoluble organic acid complex precipitates with Cr(III) and soil humic acid polymers are generally quite stable and present a barrier to Cr(III) oxidation to Cr(VI). Cr(III) is slightly bound and immobilized by insoluble humic acid polymers. The name given to this complexation process is chrome tanning because chromium has replaced aluminium in the tanning of leather. The chrome tanning of soil organic matter limits the tendency for Cr(III) to become oxidized and for the organic matter to be decomposed (Ross et al., 1981).

3.2.2.2 Adsorption

Adsorption reactions generally consist of cation exchange capacity (CEC) mechanisms for Cr(III) species and anion exchange capacity (AEC) mechanisms for Cr(VI) species. Adsorption generally involves cation exchange of Cr(III) as Cr^{+3} or hydroxy ionic species onto hydrated iron manganese oxides located on the surface of clay soil particles. In CEC mechanisms, an aquifer mineral lattice or hydrated iron and manganese oxides located on the surfaces of fine-ingrained soil particles adsorb cations. Competition with other similar ions is possible and may limit the absorption of one particular species. Understanding CEC mechanisms is critical when considering in situ treatment technologies, such as soil flushing/chromium extraction and electrokinetic remediation. Generally, the lower the CEC of the soil, the better suited the soil for remediation by these technologies. Table 3.1 presents the CECs for various soil classifications (Dragun, 1988). The soil organic matter component of soil provides the greatest CEC, followed by the clay minerals vermiculite, saponite and montmorillonite. Clay offers the greatest CEC of all the soil types.

Table 3.1: CECs for soils – Components and types

	CEC (meq/100g)
Soil clays	
Chlorite	10-40
Illite	10-40
Kaolinite	3-15
Montmorillonite	80-150
Oxides and Oxyhydroxides	2-6
Saponite	80-120
Vermiculite	100-150
Soil types	
Soil Organic Matter	>200
Sand	2-7
Sandy Loam	2-18
Loam	8-22
Silt Loam	9-27
Car port	4-32
Clay	5-60

In addition to soil cation exchange mechanisms for Cr(III) species adsorption, soil anion exchange is possible for adsorption of Cr(VI) anions [i.e., hydrochromate (HCrO_4^-) and chromate (CrO_4^{2-})]. These species exchange with chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), and phosphate (PO_4^{3-}). Griffin et al. (1977) studied the effect of pH on the adsorption of Cr(VI) by the clay minerals kaolinite and montmorillonite, and found adsorption was highly pH dependent; the adsorption of Cr(VI) decreased as pH increased, and the predominant Cr(VI) species adsorbed was HCrO_4^- . Bartlett and Kimble (1976b) also found that while chromate is tightly bound compared with anions such as Cl^- or NO_3^- , it can be released by reaction of the soil with PO_4^{3-} . The presence of orthophosphate prevented the adsorption of Cr(VI) anions, presumably by competition for the adsorption sites. They concluded that the behaviour of Cr(VI) remaining in soils is similar to that of orthophosphate, but unlike phosphate, Cr(VI) is quickly reduced by soil organic matter, thus becoming immobilized. Cr(VI), they state, will remain mobile only if its concentration exceeds both the adsorbing and the reducing capacities of the soil.

Sulfate adsorption on kaolinite also varied with pH, although not as strongly as for chromate. Zachara et al. (1988) suggested that, although SO_4^{2-} and CrO_4^{2-} compete for adsorption sites on noncrystalline iron oxyhydroxide, SO_4^{2-} and CrO_4^{2-} bind to different sites on kaolinite and, thus, do not compete for the same site. Studies by Zachara et al. (1989) of the adsorption of chromate on soils found the following:

- Chromate adsorption increased with decreasing pH.
- Soils that contained higher concentrations of aluminium and iron oxides showed greater adsorption of Cr(VI).
- Chromate binding was depressed in the presence of dissolved SO_4^{2-} and inorganic carbon, which compete for adsorption sites.

3.2.2.3 Reduction and fixation

In situ treatment methods for chromium-contaminated soil and groundwater generally involve the reduction of Cr(VI) to Cr(III) with subsequent fixation of Cr(III).

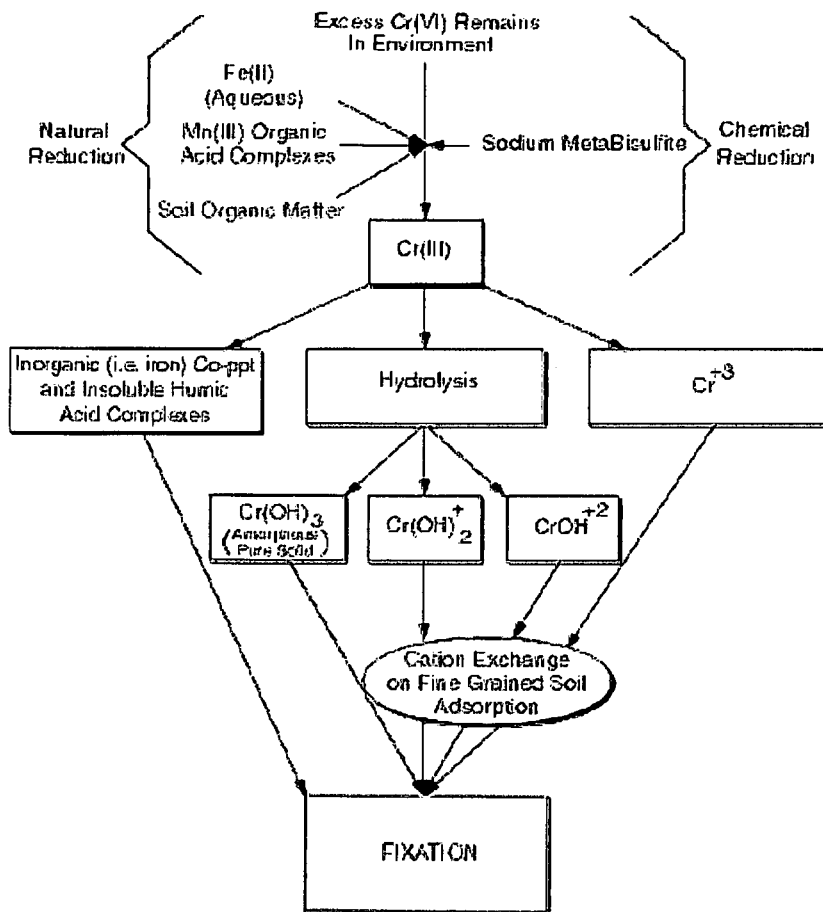


Figure 3.3: Chromium reduction and fixation.

Figure 3.3 presents examples of natural and chemical-induced reduction of Cr(VI) to Cr(III) and the mechanisms of subsequent fixation of Cr(III). The permanence of fixation must be evaluated since Cr(III) [as low molecular weight organic acid complexes (i.e chromium citrate)] can migrate to the surface and reoxidize to Cr(VI) in the presence of manganese dioxide. Manganese dioxide (MnO_2) forms naturally in the upper vadoze zone by reduced manganese oxide (MnO) reacting with atmospheric oxygen. Bartlett (1991) states “the marvel of the chromium cycle in soil is that oxidation and reduction can take place at the same time.” This is an important principle for the application of in situ technologies for the treatment (reduction) of Cr(VI) and permanent fixation of Cr(III).

Figure 3.2 illustrates the apparent paradox of simultaneous oxidation and reduction of chromium. As shown, Mn(IV) (as MnO_2) oxidizes Cr(III) to Cr(VI). However, under normal dry soil

conditions, mobile Cr(III) [i.e., Cr⁺³ or chromium citrate] will not oxidize to Cr(VI) in the presence of MnO₂. Mobile Cr(III) will not oxidize to Cr(VI) in the presence of MnO₂ unless the soil is moist and the MnO₂ surface present in the soil is fresh (i.e., amorphous rather than crystalline form) (Bartlett, 1991). Additionally, Mn(III)-organic acid complexes reduce Cr(IV) to its trivalent form. Mn(III) is formed when Mn(II) reacts with Mn(IV) in the presence of organic acids formed from soil organic matter (Bartlett, 1991). The cycle repeats itself as the Cr(III) formed may be chelated by low molecular weight organic acid complexes (e.g., citric acid) and thus, be mobile enough to migrate to the soil surface and consequently oxidize to Cr(VI).

Bartlett (1991) states that as long as all Cr(VI) has been reduced and all Cr(III) is bound by decay-resistant organic polymers, the chromium will remain inert and immobile, provided that oxygen is excluded. In other words, sealing of a landfill on the bottom to prevent leaching of chromium is unnecessary as long as the top is sealed.

3.3 Toxicity

3.3.1 Human health

Chromium, a metallic element, is naturally occurring in rocks and minerals, most usually in its trivalent state, Cr(III). Cr(III) is an essential nutrient, albeit in trace quantities. The element has a role in the metabolism of glucose, fat and protein, by making the action of the hormone, insulin, more effective. Chromium also exists in valence states other than Cr(III), and one of these forms, Cr(VI), has been released to the environment as a result of industrial processes. Cr(VI) is also known as hexavalent chromium, and the name may be abbreviated to Cr⁺⁶. There is wide industrial use of Cr(VI) compounds, and a few examples of the industries that utilize them include wood preservation; hard and soft chrome plating; pigment manufacture, the aerospace industry; leather tanning, and the textile industry. Cr(VI) was formerly in wide use as a corrosion inhibitor in wastewater systems and to prevent degradation of iron and steel pipe. Although decades have passed since its use as a corrosion inhibitor, it may still be found plated to treated pipes.

Occupational exposure to Cr(VI) generally occurs by inhalation and by skin (dermal) contact. However, when a substance is inhaled, a small amount is inevitably ingested. Workers may be exposed by inhalation to fumes and mists containing Cr(VI) when hot cutting or welding stainless steel, or other chromium-containing metal alloys. Portland cement contains Cr(VI) as an

impurity, and workers may be exposed by inhaling cement dust. Workers in the electroplating industry can be exposed to Cr(VI) by inhaling mists of electroplating solutions and by dermal contact with them. The production of Cr(VI) pigments, their use in sprayed-on coatings by aerospace industry, has exposed workers by skin contact and inhalation. The general public may be exposed to Cr(VI) by drinking from the contaminated groundwater wells, inhaling mists from cooling towers where water flows over treated timber, inhaling fugitive dusts from cement and chromate producing plants, and inhaling emissions from motor vehicles, catalytic converters.

Particulate Cr(VI) may be inhaled, and deposited in the lungs, but the pattern of deposition in the lungs is dependent on airflow patterns in the lungs. Some sites in the lung may preferentially build up Cr(VI) to create areas of high concentration. Cr(VI) is absorbed into the cells of the lung by facilitated diffusion through non-specific ion channels and is thence rapidly absorbed into the bloodstream. The readily soluble chromates reach the bloodstream more rapidly than less soluble compounds, but even Cr(VI) encapsulated in paint may be absorbed from the lung. Some inhaled Cr(VI) is removed from the lungs by mucociliary clearance. Mucociliary clearance and swallowing can move inhaled substances to the digestive tract. Ingested Cr(VI) is largely reduced to insoluble Cr(III) in the gastrointestinal tract. However, animal studies show that a proportion of ingested Cr(VI) is absorbed. Cr(VI) is absorbed through intact skin, easily crossing the epidermis to the underlying layer, the dermis, and from the dermis into deeper tissues. Once absorbed, Cr(VI) is distributed through the body via the bloodstream. Tissues retrieved from autopsies of chromate workers indicate high Cr(VI) concentrations in the lungs, and higher than background concentrations in liver, bladder, and bone. Cr(VI) is excreted in urine as low molecular weight Cr(III) complexes, and to a lesser extent by biliary excretion into faeces.

The toxicity Cr(VI) has been investigated in laboratory animal studies, and results have been reported from both short and long-term investigations. A recent National Toxicology Program (NTP) study, reported January 2007, examined the mid-term toxicity of Cr(VI) to rats and mice. The test animals were administered sodium dichromate in their drinking water for 3 months, and this exposure resulted in focal ulceration, metaplasia, and hyperplasia of the glandular stomach on both rats and mice. Evidence of histiocytic infiltration of the liver, duodenum, and pancreatic lymph nodes was also observed. Microcytic, hypochromic anemia was noted in rats, and, to a lesser extent, in mice. The development of anemia was considered a toxic response to the oral ingestion of Cr(VI). Other studies have demonstrated that rats exposed to Cr(VI) by inhalation for a period of 3 months show an increase in lung and spleen weight and in macrophage activity.

Long- term (chronic) animal studies have primarily focused on the potential of Cr(VI) to cause cancer. The results of a recent 2 year NTP study on the effects of Cr(VI) in drinking water in rats and mice found clear evidence of carcinogenicity of sodium dichromate. Carcinogenic effects of oral administration of Cr(VI) were seen in both rats and mice of both sexes. Squamous cell papillomas, or squamous cell carcinomas were seen in the oral mucosa or tongue of rats. Mice in the same investigation developed neoplasms, and adenomas or carcinomas of the duodenum, jejunum, or ileum. Lung implantation of Cr(VI) in rats has shown a statistically significant increase in squamous metaplasia, a condition that may progress to carcinoma of the lungs. Some investigations, but not all, have found statistically significant increases in bronchial carcinoma after intrabronchial instillation of Cr(VI) compounds. Subcutaneous, "site of injection," cancers have been reported for Cr(VI) .

Two animal studies show Cr(VI) to be toxic to the developing embryo. Mice and rats exposed to Cr(VI) in drinking water during gestation exhibited retarded fetal development, and embryo and fetotoxic effects that included reductions in the number of foetuses and fetal weight and a higher incidence of stillbirth and post-implantation loss. Both studies found significantly reduced bone ossification. However, a multigenerational dietary study performed by NTP observed no reproductive changes due to the toxicity of Cr(VI). There is no clear evidence that Cr(VI) is a human reproductive toxicant following occupational exposure. The only studies that address this issue are of poor quality and provide insufficient data to draw any conclusions about the reproductive toxicity of Cr(VI) in man.

Both soluble and insoluble Cr(VI) are able to cause structural damage to DNA, leading to genotoxicity. Cr(VI) compounds, such as sodium dichromate, are mutagenic in *Salmonella typhimurium* reverse mutation assays, and in *Escherichia coli* tests. Studies indicate that Cr(VI) induced DNA damage may result in clastogenesis, altered gene expression, and the inhibition of chromium replication and transcription. The genotoxic action of Cr(VI) is probably responsible for the induction of neoplastic change.

There are strong occupational health studies in chromate production workers from the USA, UK, Germany, Japan, and Italy. Chromate production plants in the USA and UK have been repeatedly studied for extended periods, one in Painsville, Ohio for 50 years. These studies evidence that Cr(VI) is carcinogenic to workers, as they report an elevated lung cancer mortality that is related to cumulative exposure, and length of employment. Occupational health studies also provide data for the non-cancer effects of Cr(VI). Inhalation of Cr(VI) leads to ulceration of nasal tissues to

nasal septum perforation. Cr(VI) is an airway sensitizer and can produce occupational asthma in sensitized individuals, and in addition, can cause allergy contact and irritant contact dermatitis. Skin ulcers, known as “chrome holes,” can occur on exposed skin. These ulcers are persistent, painful, and may result in deep penetration of tissues underlying the skin.

A study of villagers in China using Cr(VI)-contaminated well water (20 mg per liter) for domestic purposes reported the following effects of oral exposure: vomiting, oral ulcers, abdominal pain, indigestion, and diarrhea. Hematological effects such as leucocytosis and immature neutrophils were also noted. Cr(VI) has been classified by the US EPA under the 1986 cancer guidelines as Group A known human carcinogen by the inhalation route of exposure, and as Group D carcinogenicity cannot be determined by the oral route of exposure. Under the interim 1996 cancer guidelines EPA classifies Cr(VI) as a “known human carcinogen by the inhalation route of exposure.” The report on carcinogens (11th Edition) states that, “chromium hexavalent (VI) compounds are known to be human carcinogens”.

3.3.2 Ecological impacts

Chromium is an essential nutrient for human beings and chromium containing low molecular weight peptides (chromodulin) have been identified in many mammalian species. However, it is not known whether chromium is a dietary requirement for other terrestrial vertebrates. Although chromium does bioaccumulate, it is not reported to undergo biomagnification in the food chain. Many biotic and abiotic factors can modify the toxic effects of chromium in the environment. For example, Cr(VI) is more toxic to freshwater biota in soft, slightly acidic water. Early life stages are generally more sensitive to the effects of Cr(VI) than adults.

Cr(VI), at a concentration of 10 parts per billion (ppb) reduced fecundity and survival of the invertebrate *Daphnia magna* when the organisms were exposed to the metal for 32 days, but is also associated with adverse impact to other invertebrates from widely differing taxa. Cr(VI) is reported to be slightly to moderately toxic to aquatic polychaete and oligochaete worms in median lethal concentration (LC₅₀) studies. Some fish species are sensitive to Cr(VI), and relatively low concentrations (1621 ppb) reduced the growth of young rainbow trout and Chinook salmon during a 14 – 16 weeks exposure period. LC₅₀ studies have determined that Cr(VI) is not acutely toxic, to slightly toxic to amphibians (Indian toad and skipping frog under test).

Very little information is available for the effects of Cr(VI) on terrestrial mammals and birds. Laboratory animal studies have provided mammalian toxicity data. An egg injection study of the effects of Cr(VI) on the developing domestic fowl resulted in deformities that included twisted limbs, exencephaly, everted viscera, deformed beaks, and growth stunting. However, no effects were seen in adult chickens fed Cr(VI) at 100 ppm in their diet for 32 days.

Plants can be adversely affected by Cr(VI). It reduces the growth and chlorophylls a and b content of the small, floating aquatic fern *Azolla caroliniana* at concentrations of 1-2 ppm. Reduced germination, a decrease in root length and dry weight, reduction in plant height, number of flowers, leaf number, leaf area and biomass, and an up to 50% reduction in grain weight, with increased seed deformity have all been reported in response to Cr(VI).

3.4 Site characterization requirements

The remediation site should be characterized to determine how suitable it is for Cr(III) fixation or for other treatment application. Chemical characterization should include the following:

- Site characterization
- Groundwater
- Soil

Site characterization should include a determination of total organic carbon (TOC) and dissolved organic carbon (DOC) in the groundwater and soil. Both tests will indicate not only the availability of soluble organic ligands for Cr(III) complexing, which provides a mobilization vehicle for potential oxidation to Cr(VI), but also the availability of more complex organic matter which has the potential for reduction of Cr(VI) to Cr(III). The particulate (or solid fraction) of organic carbon in the aquifer can be determined by subtracting DOC from TOC. A total Cr(VI) reducing capacity of the soil should be determined to measure the portion of organic matter in the soil that is oxidizable by Cr(VI). The Cr(VI) not reduced is titrated with Fe(II). CEC should be measured to determine if sites are available for Cr(III)-hydroxyl cation complexes to adsorb onto the soil particles. Other tests that can be performed as needed are porosity, grain size, soil moisture and total manganese.

Both contaminated and treated groundwater should be analyzed for total chromium and Cr(VI); Cr(III) is determined by subtracting the results of the Cr(VI) from the total chromium values. Eh and pH should also be determined. Like the groundwater, both contaminated and treated aquifer solids and unsaturated soil should be analyzed for total and Cr(VI). Additional tests should be conducted for pH and the amount of dissolved Cr(III) that is mobile (not fixed). Further, in order to determine if, and how much of, the Cr(VI) was reduced, a mass balance should be performed. Other soil tests that can be performed as needed are the standard chromium oxidation test; Cr(III) oxidizable by excess MnO_2 ; and oxidizability of inert Cr(III). The methods for these tests, along with their rationale, are presented in Bartlett (1991). In addition to site chemistry, it is also critically important for in situ technology implementation to understand the contaminant distribution and geologic setting. This includes geologic structure, stratigraphy, and groundwater hydrogeology. Complicated geology and low permeability zones will influence how a technology is applied and its treatment effectiveness. Laboratory and pilot-scale tests can help to determine the effectiveness of the treatment on the contaminated matrix prior to full-scale application of the technology.

3.5 Chromium treatment and remediation approaches

3.5.1 Introduction

Groundwater extraction and treatment has traditionally been used to remediate chromium-contaminated plumes. This method, while providing interception and hydraulic containment of the plume, may require long-term application to meet Cr(VI) remediation goals and may not be effective at remediating source-zone Cr(VI). Treatment approaches have been developed for chromium-contaminated soil and groundwater treatment. A number of available in situ technologies or treatment approaches use chemical reduction and fixation for chromium remediation. These include geochemical fixation, permeable reactive barriers (PRBs), and reactive zones. Other types of in situ treatment that are under development include enhanced extraction, electrokinetics, biological processes that can be used with PRBs and reactive zones, natural attenuation, and phytoremediation.

3.5.2 Groundwater extraction and treatment method

Palmer and Wittbrodt (1991) discussed several remediation techniques for chromium-contaminated sites. Applicable to many sites is a pump-and-treat method. The technology works by extracting contaminated groundwater, usually over long time periods, and providing hydraulic control (containment) of a contaminant plume. Initially, the concentration of the contaminant is high in the affluent, but with continued pumping, the concentration decreases significantly. These residual concentrations remain above the MCLs, and can persist for long periods of time, called “tailing.” This same phenomenon was observed by Stollenwerk and Grove (1985) in their laboratory and batch column experiments.

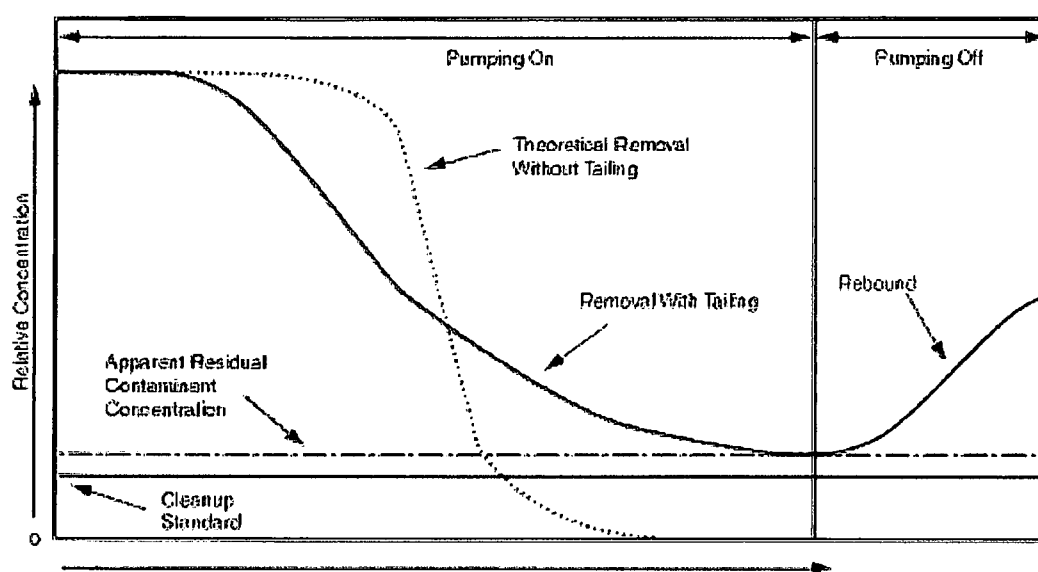


Figure 3.4: Concentration versus pumping duration showing tailing and rebound effect.

Figure 3.4 shows tailing and rebound effects during and after groundwater pumping. Tailing is the result of several physical and chemical processes:

- Differential time for contaminants to be advected from the boundary of the plume to an extraction well;
- Diffusive mass transport within spatially variable sediments;
- Mass transfer from residual solid phases in the aquifer;
- Sorption/desorption processes:

Differential time for contaminants to be advected from the boundary of the plume to an extraction well; Groundwater flows, not only in response to an extraction well, but also to the natural hydraulic gradient. As a result, not all of the water in the vicinity of an extraction well enters the well. There is a limited area, the capture zone, from which the water is captured, and a stagnation point, located downgradient from the well, where the velocity toward the well equals the velocity induced by the natural gradient. The net velocity is zero, and there is little change in the concentration of the contaminant during the pump-and-treat remediation. In addition, the groundwater velocity of a volume of water moving from the edge of the plume to the extraction well is greater than a volume of water travelling along a streamline on the outside of the capture zone. The time it takes the contaminated water to flow is controlled by the thickness of the aquifer, the rate of groundwater extraction, the natural groundwater gradient, and the gradient induced or impacted by other injection/extraction wells.

Diffusive mass transport within spatially variable sediments : Geologic materials are typically heterogeneous; groundwater moves through higher permeable layers while water in lower permeable layers remains immobile. Contaminants that have remained in the subsurface for extended periods of time migrate to the lower permeable layers by molecular diffusion. During pump-and-treat, clean water is moved through the more permeable layers at a relatively high rate, while removal of the contaminants from the lower permeable lenses is limited by the rate of diffusion into the higher permeable layers; thus maintaining the concentration of the contaminant, often above the established MCL.

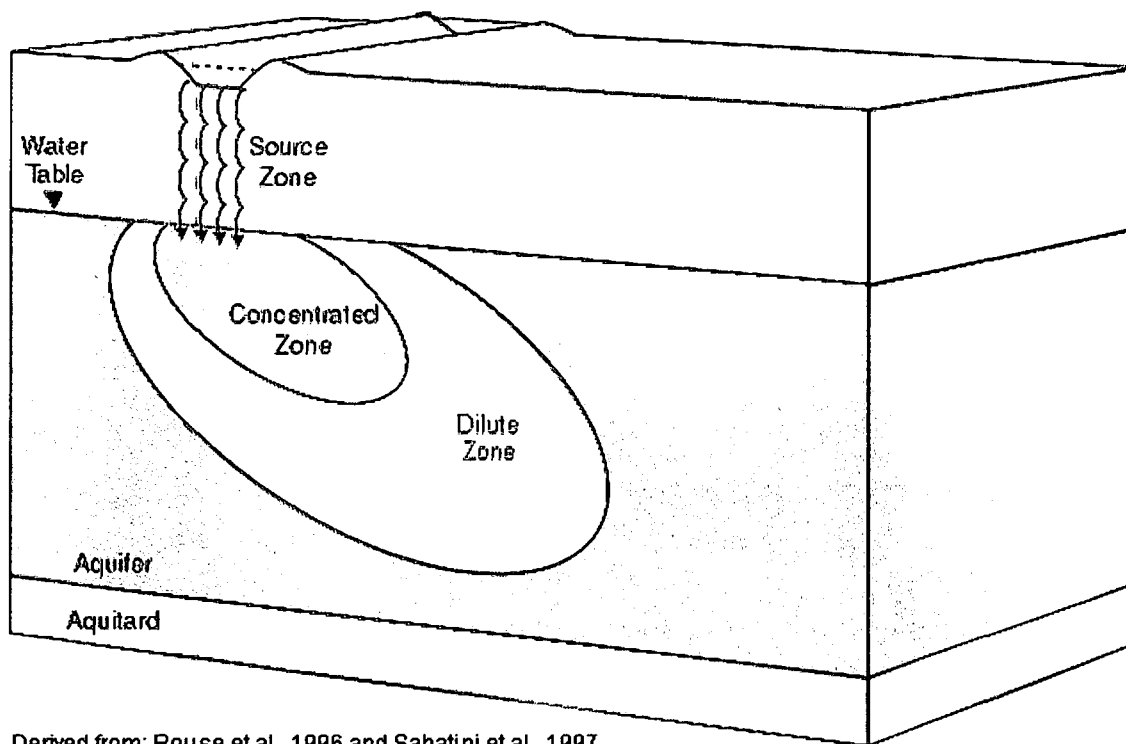
Mass transfer from residual solid phases in the aquifer: Contaminants can exist in the subsurface in relatively large reserves as solid phase precipitates. A likely reserve for chromium contaminated sites is barium chromate (BaCrO_4), the source of the barium either coming from contamination or from the natural soil.

Palmer and Wittbrodt (1991) conducted a study at a United Chrome Products site and suggested that the Cr(VI)-contaminated groundwater was in equilibrium with BaCrO_4 . Column leaching tests of the contaminated soil showed a significant levelling of the Cr(VI) concentrations, indicating that a solid phase may be controlling the concentration in the extraction water.

Sorption/desorption processes: As discussed previously, Cr(VI) exists in solution as the anions HCrO_4^- , CrO_4^{2-} , and dichromate ($\text{Cr}_2\text{O}_7^{2-}$), and is adsorbed onto the soil matrix. As the concentration of Cr(VI) decreases, it becomes more difficult to remove the Cr(VI).

The use of in situ technologies such as chemical enhancement of the pump-and-treat method (the addition of reductant or extracting agent) may be desirable to overcome the tailing phenomenon and reduce the overall time required for remediation. However, the cause of tailing at a given site needs to be determined and quantified. For example, if the tailing is controlled by physical processes such as differential travel time along streamlines, then chemical enhancement may not be advantageous. Further, regulatory agencies may require the removal of the chemical enhancer. This is especially true if the chemical enhancer or its byproducts exceeds the concentration(s) of applicable water quality standards. Typically, chromium-contaminated sites consist of three zones:

- source zone soils where the concentrated waste resides;
- the concentrated portion of the groundwater plume;
- the diluted portion of the groundwater plume (Sabatini et al., 1997).



Derived from: Rouse et al., 1996 and Sabatini et al., 1997.

Figure 3.5: Conceptual geochemical model of zones in a contaminant plume.

Figure 3.5 illustrates these three zones of contamination. Applying conventional pump-and-treat remediation methods to all three regions would be highly inefficient. An integrated technology approach would probably be best suited for full-scale site remediation.

3.5.3 In situ technologies

A number of in situ technologies or approaches use chemical reduction/fixation for chromium remediation. These include geochemical fixation, PRBs, reactive zones, and natural attenuation. Understanding the Chromium cycle presented in Section 3.2 and site characteristics presented in Section 3.4 is critical for the use of these approaches, especially natural attenuation. Chemical reduction/fixation remediation techniques do not remove chromium from the aquifer system, but are designed to immobilize chromium precipitates by fixing them onto aquifer solids or reactive media, thereby reducing chromium in groundwater. Other types of in situ treatment that are available or under development for remediation of chromium-contaminated sites include soil flushing/enhanced extraction, electrokinetics, and biological processes including phytoremediation. Biological processes include bioreduction, bioaccumulation, biomineralization, and bioprecipitation which use specific substrates to drive the treatment and effect the reduction, uptake, or precipitation of Cr(VI) based on the principles in Section 3.2. These processes can be utilized within PRBs and reactive zones. Phytoremediation utilizes plant uptake of chromium contamination as the in situ treatment approach.

CHAPTER 4. FIELDWORK AND DISCUSSION OF RESULTS

4.1 Hydrocensus

A hydrocensus survey was conducted in a 1 km radius of the manufacturing plant site between November 2004 and January 2005. The purpose of the hydrocensus was to establish if any groundwater extraction boreholes or wells occurred in the area, and to identify the usage of the groundwater extracted from such sources. Boreholes identified in the study area were sampled and the groundwater was analysed to determine the concentrations of hexavalent chromium [Cr(VI)], in order to ensure that there was no health risk to users from such sources.

The hydrocensus involved approaching landowners, tenants, residents or occupants of the properties, explaining the reason for the survey, completing a field questionnaire and gathering borehole information on the depth to groundwater, groundwater quantity and quality and drilling data. The following properties were surveyed in detail:

- Turf club site.
- Industrial and commercial properties to the south-west of the plant site.
- Residential properties and associated facilities (eg. Schools, religious institutions, sports facilities)

A multitude of boreholes were found during the hydrocensus survey as shown in Figure 4.1, and the information obtained is summarised in Table 4.1 below.

Table 4.1: Summary of hydrocensus results

Location	Borehole No.	Borehole depth (mbgl)*	Equipment	Pump depth (mbgl)*	Pump capacity (m3/hr)	Groundwater level (mbgl)*	Comments
Turf club site	BH_C4	70	None	35	N/A	0.902	Has not been pumped since 1998, presently not used
	BH_T	193	Submersible	48	9	0.506	Used for irrigation (7hrs/day)
	BH_DP	70	Submersible	40	6	6.374	Used for irrigation (7hrs/day)
	BH_CT	N/A	None	N/A	N/A	0.000	Presently not used
Industrial properties (southwest of plant site)	BH_Ar	43.46	None	N/A	2	1.579	Presently not used
	BH_Ca	80	None	N/A	N/A	N/A	Presently not used

N/A - Not Available

*mbgl - metres below ground level

Based on the results above, it is clear that there were no private boreholes found in or close to the affected area. The boreholes found were mainly industrial boreholes in other industries around the manufacturing plant including the turf club site. These boreholes were in the uncontaminated aquifer and most of them were either blocked or destroyed. Only two boreholes located on the turf club site were being utilized for irrigation. The reported groundwater levels in the identified boreholes ranged from 0.000 mbgl to 6.374 mbgl. The chemical results of the groundwater samples are discussed in section 4.6 below.

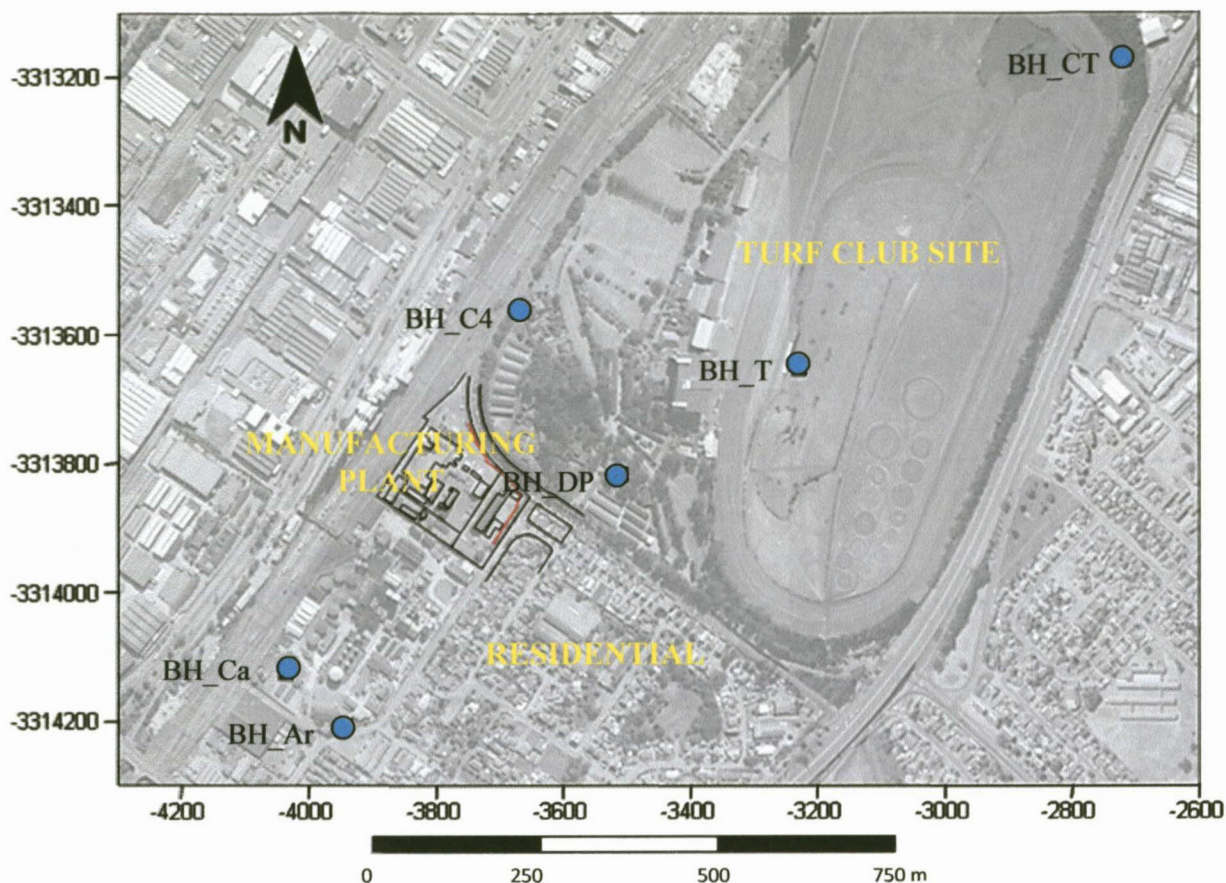


Figure 4.1: Boreholes found during hydrocensus survey.

4.2 Borehole installations

4.2.1 Introduction

A total of 113 hand auger holes and washbore drilled boreholes were put down in phases on the manufacturing plant site and neighbouring area over the period May 2004 to August 2005. The boreholes were installed to establish the subsoil conditions and to facilitate the monitoring and sampling of the groundwater in the various aquifers underlying the study area. The boreholes installed during this study are summarised in Table 4.2 below, and are shown on the site plan in Figure 4.2. The boreholes installed during this study are discussed separately in sections 4.2.2 and 4.2.3 below.

Table 4.2: Summary of boreholes installed during this study

Borehole Series	Borehole Numbers	Installation Date	Final Borehole Depths (m)
10	BH1 to BH39	May 2004 to March 2005	2,2 to 4,8
100	BH101 to BH121	September 2004 to December 2004	2,65 to 5,3
200	BH201A to BH225A	January 2005 to August 2005	6,5 to 11,0
	BH201 to BH225		9,0 to 16,0
300	BH301 to BH318	February 2005 to March 2005	1,6 to 3,9
400	BH401, BH402, BH403	June 2005 to July 2005	30,45 to 32,45
D	D1, D3, D5	November 2004 to March 2005	51,0 to 84,0

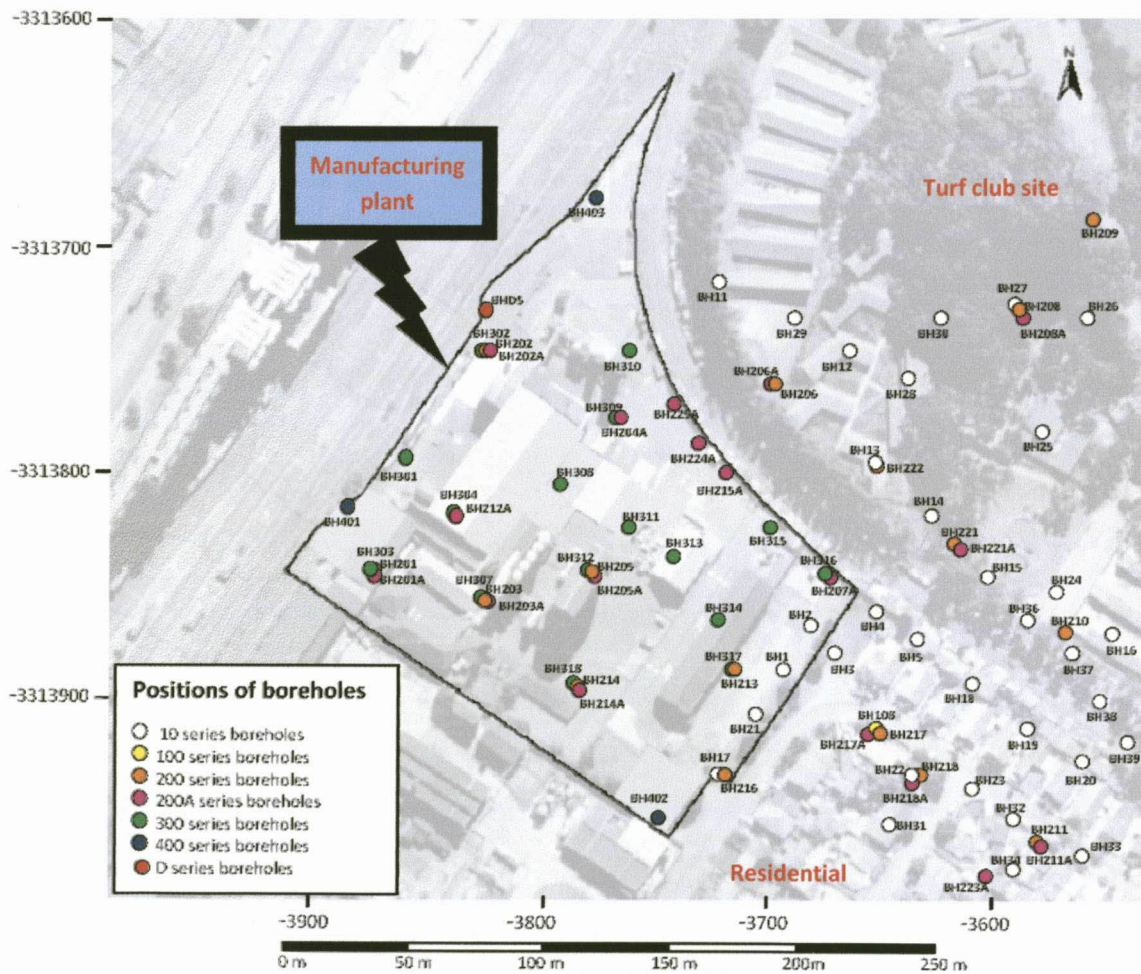


Figure 4.2: Boreholes locations on the manufacturing plant site and neighbouring area.

4.2.2 Hand auger drilling

A total of 74 hand auger holes designated BH1 to BH39, BH101 to BH121 and BH301 to BH318 were put down in phases on the manufacturing plant site and neighbouring area over the period May 2004 to August 2005. The locations of these boreholes are shown in Figure 4.2 above. The hand auger holes are discussed separately below.

- Boreholes designated BH1 to BH39 (“10 series”) were installed to investigate the subsoil conditions, and the levels and extent of the chromium contamination in the shallow aquifer beyond the boundaries of the manufacturing plant site. The “10 series” boreholes were installed over the period 14 May 2004 to 12 March 2005. They were installed on the southern portion of the turf club site and in the residential area to the south-east of the plant site.
- Boreholes designated BH101 to BH121 (“100 series”) were installed over a more widespread area than the “10 series” boreholes described above. These boreholes were put down to investigate the levels of chromium in the shallow groundwater aquifer beneath the area around the manufacturing plant and residential area, and turf club site, within an approximately 1km radius of the manufacturing plant site.
- Boreholes designated BH301 to BH318 (“300 series”) were installed on the manufacturing plant site to investigate the levels and extent of chromium contamination in the shallow aquifer beneath the site.

The hand auger holes discussed above were installed in the first sandy aquifer horizon using Eijkelkamp hand augering equipment of 110mm diameter and temporary steel casing, to depths shown in Table 4.2 above. The piezometers installed in these boreholes comprised 63mm diameter uPVC standpipes.



Figure 4.3: Hand auger hole with temporary casing.

4.2.3 Rotary washbore drilling

A total of 39 washbore drilled boreholes designated BH201 to BH225, BH201A to BH225A, BH401 to BH403, BHD1, BHD3 and BHD5 were put down in phases on the manufacturing plant site and neighbouring area over the period May 2004 to August 2005. The locations of these boreholes are shown in Figure 4.2 above. The washbore drilled boreholes are discussed separately below.

- Boreholes designated BH201 to BH225 and BH201A to BH225A (“200 series”) were installed over the manufacturing plant site, on the turf club site and in the adjacent residential area. These boreholes installed for the purpose of confirming the subsoil conditions down to the “hippo mud” clay, installing groundwater monitoring and sampling piezometers in sandy aquifers 2 and 3 m above the “hippo mud” clay and to conduct pump tests in order to determine deep aquifer parameters.

- Boreholes designated BH401 to BH403 (“400 series”) were put down on the manufacturing plant site, and were drilled down to the weathered sandstone bedrock underlying the Harbour Beds. These boreholes were put down to prove the nature of the subsoils underlying the “hippo mud” clay and depth to bedrock, to facilitate the installation of groundwater monitoring and sampling piezometers in aquifer 4 above the sandstone bedrock and to conduct pumping tests to determine the parameters and characteristics of aquifer 4.
- Boreholes designated BH D1, BH D3 and BH D5 (“D series”) were put down to the sandstone bedrock at the positions shown on the site plan in Figure 4.2. These boreholes were put down to confirm the stratigraphy beneath the manufacturing plant and neighbouring areas, to facilitate the installation of groundwater monitoring and sampling piezometers in the deep bedrock aquifers.

The “200” and “400” series boreholes discussed above were drilled using rotary washbore drilling techniques. After excavation of a test pit to prove the presence of underground services, a 200mm diameter temporary steel casing was installed and sealed into the first clay layer to prevent cross-contamination occurred between the upper aquifer above the first clay layer and the aquifers below. A second 150mm diameter casing was then advanced through the 200mm casing to the final depth of the borehole. The boreholes were drilled to depths shown in Table 4.2 above. A biodegradable drilling fluid was used during the washboring process. Standard Penetration Tests (SPT’s) were carried out at 1,0 metre depth intervals as the boreholes were advanced to determine the consistency of the soils.



Figure 4.4: Rotary washbore drilling rig.

Once the boreholes had been advanced to their final depths, the boreholes were flushed to remove the biodegradable drilling fluid and any sediment that had accumulated in the casing as a result of the drilling process. Piezometers were then installed in the boreholes and the temporary casing removed. The piezometers installed in these boreholes comprised 110mm diameter uPVC standpipes, with 0,3mm horizontal slotted screen sections which were wrapped in a nylon filter sock to prevent the ingress of fines.

The “D” series boreholes were also drilled using rotary drilling techniques. After excavation of a test pit to prove the presence of underground services, an HX size (114mm diameter) steel casing was advanced, together with washboring and Standard Penetration Tests (SPT’s) to a maximum depth of 10 metres. This temporary casing was used to prevent collapse of the shallow subsoils during drilling operations. A 150mm diameter casing was first sealed into the first clay layer to prevent cross-contamination between the upper and lower aquifers, before the HX casing was advanced to a depth of about 12 metres. SPT’s were carried out at 1,5 metre depth intervals as

the boreholes were advanced. Once SPT refusal occurred in the rock strata at certain depths, the boreholes were advanced into the bedrock by NX (75mm diameter) core drilling. Final depths of the boreholes ranged between 51 and 84 metres in the weathered Cretaceous silty sandstone or Natal Group Sandstone

The results of the borehole installations are displayed in geological logs included in Appendix A (selected borehole logs), and the geology underlying the site is summarized in Table 4.3 below.

Table 4.3: Summary of geology underlying the manufacturing plant site and neighbouring area

Depth Range of Top of Layer (mbgl*)	Range of Thickness of Layer (m)	Description	Layer
0	0.4 to 2.1	Brown to dark grey silty SAND, containing some gravel and rubble (FILL)	Fill
0.4 to 2.0	0.0 to 4.0	Yellowish brown / greyish brown fine to medium grained, slightly clayey sand to clayey SAND (Harbour Beds).	Aquifer 1
1.5 to 5.0	0.7 to 5.0	Grey mottled yellowish brown slightly sandy to sandy CLAY (Harbour Beds).	Clay Layer 1
2.4 to 7.4	1.0 to 6.3	Yellowish brown / greyish brown fine to medium grained, slightly clayey sand to clayey SAND (Harbour Beds).	Aquifer 2
7.0 to 13.3	1.0 to 3.0	Grey mottled yellowish brown slightly sandy to sandy CLAY (Harbour Beds).	Clay Layer 2
9.0 to 15.0	1.0 to 6.0	Yellowish brown / greyish brown fine to medium grained slightly clayey sand to clayey SAND. (Harbour Beds).	Aquifer 3
10.1 to 16.1	8.0 to 14.5	Dark grey silty CLAY, Hippo Mud (Harbour Beds).	Hippo Mud
24.0 to 29.5	1.0 to 7.7	Greyish brown fine to medium grained slightly clayey to clayey SAND. (Harbour Beds).	Aquifer 4
28.2 to 31.7	>100	SANDSTONE (Natal Group) / Cretaceous (St Lucia Formation)	Sandstone

*mbgl – metres below ground level

From the above it can be seen that the fill underlying the site occurs from the surface to depths in the range of approximately 0.4 metres to 2.1 metres below existing ground level. The fill generally comprises brown to dark grey, silty sand to slightly clayey sand, and contains abundant gravel and rubble in places. The fill overlies the harbour bed sediments, which generally occur in four predominantly sandy aquifer horizons interlayered with clay layers of various composition and thickness. The harbour beds beneath the site may be described as follows:-

- Aquifer 1 – This aquifer directly underlies the fill, and generally comprises yellowish brown to greyish brown, slightly clayey to clayey sand. This subsoil

horizon extends to a maximum thickness of about 4.0 metres, and is underlain by a clay layer, designated clay layer 1.

- Clay Layer 1 – This clay layer appears to be continuous beneath the site, occurring at depths ranging between approximately 1.5 to 5.0 metres below existing ground level, with a layer thickness ranging from approximately 0.7 to 5.0 metres. This layer generally comprises grey mottled yellow brown, slightly sandy to sandy clay, and is underlain by the sandy soils of Aquifer 2.
- Aquifer 2 – This aquifer generally comprises yellow brown to greyish brown, slightly clayey sands and clayey sands, occurring below the base of clay layer 1 at depths of between approximately 2.4 to 7.4 metres. The Aquifer 2 subsoils range in thickness between approximately 1.0 and 6.3 metres. Aquifer 2 contains occasional localized thin lenses of clay.
- Clay Layer 2 – This layer, comprising grey mottled yellow brown, slightly sandy to sandy clay, occurs between Aquifers 2 and 3 at depths of between approximately 7.0 and 13.3 metres. The thickness of this clay layer ranges between approximately 1.0 to 3.0 metres.
- Aquifer 3 – This aquifer comprises yellowish brown to greyish brown, slightly clayey to clayey sand, and occurs at depths in the range of approximately 9.0 to 15.0 metres, below Clay Layer 2. Occasional localized silty clay lenses occur within this aquifer. The thickness of the Aquifer 3 horizon ranges between approximately 1.0 and 6.0 metres. Aquifer 3 is underlain by the “hippo mud” clays.
- Hippo Mud – These typically soft, dark grey silty clay deposits range in thickness between approximately 8.0 to 14.5 metres, occurring at depths of between approximately 10.1 and 16.1 metres below existing ground level beneath the manufacturing plant site. The “hippo muds” form a relatively impermeable aquitard between Aquifer 3 and Aquifer 4.
- Aquifer 4 – This aquifer occurs below the “hippo mud” clays at depths of approximately 24.0 to 29.5 metres. Aquifer 4 comprises greyish brown slightly clayey to clayey sand, interlayered with localised clay lenses in places. The thickness of Aquifer 4, which represents the deepest harbour bed deposits, ranges between approximately 1.0 and 7.7 metres.

The harbour bed sediments described above, overlie sandstone of the Natal Group or sandy siltstones of the St Lucia Formation at depths of between approximately 28 and 32 metres below existing ground level on the manufacturing plant site. The weathered sandstone immediately below the harbour beds generally comprises residual, highly weathered, orange brown, slightly clayey to silty sand. With depth the sandstone typically becomes less weathered, grading into pinkish maroon sandstone bedrock which extends to depths in excess of 100 metres below the site.

4.3 Materials testing of soil samples

4.3.1 Hydraulic conductivity estimation based on grain size analysis

Eighteen representative soil samples recovered during the installation of boreholes on the plant site and surrounding area were selected and submitted to commercial materials testing laboratory for grading analysis. This was done in order to characterize the soils in terms of their particle size distribution and clay content and to compare the results to the soil profile given on the borehole logs. Soils samples were taken at selected depths from the Standard Penetrometer Test (SPT) split spoon sampling carried out during the installation of boreholes.

Based on the grain-size analysis, hydraulic conductivities of soils were estimated using various empirical equations discussed below. Kozeny-Carman empirical equation:

$$K = \frac{g}{\nu} \times 8.3 \times 10^{-3} \left[\frac{n^3}{(1-n)^2} \right] d_{10}^2$$

Where:

K = hydraulic conductivity (m/day)

g = acceleration due to gravity (m/sec^2)

ν = kinematic viscosity (m^2/day)

n = porosity (dimensionless)

d_{10} = effective grain diameter (mm)

porosity (n) may be derived from the empirical relationship with the coefficient of grain uniformity (U) as follows:

$$n = 0.255(1 + 0.83^U)$$

where U is the coefficient of grain uniformity and is given by:

$$U = \left(\frac{d_{60}}{d_{10}} \right)$$

The Kozeny-Carman equation is one of the most widely accepted and used derivations of hydraulic conductivity as a function of the characteristics of the soil medium. This equation was originally proposed by Kozeny (1927) and was then modified by Carman (1937, 1956) to become the Kozeny-Carman equation. It is not appropriate for either soil with effective size above 3mm or for clayey soils (Carrier 2003).

Sherard et al (1984) developed the following equation:

$$K = 0.35(d_{15})^2$$

Where:

K = hydraulic conductivity (m/day)

d_{15} = represents the size at which 15% of the sample is smaller (mm)

Alyamani and Sen (1993) proposed calculating the hydraulic conductivity using the following equation:

$$K = 0.015[I_0 + 0.025(d_{50} - d_{10})]^2$$

Where:

K = hydraulic conductivity (m/sec)

I_0 = intercept of the line formed by d_{50} and d_{10} with the grain size axis (mm)

d_{50} = median grain diameter (mm)

d_{10} = effective grain diameter (mm)

The results of the particle size distribution analysis of the soil samples are given in Appendix B, and summarized in Table 4.4 below. The results of the estimated hydraulic conductivities from the grain size analysis using the three empirical formulae discussed above are summarized in Table 4.5 below.

Table 4.4: Summary of particle size distribution analysis

Sample No.	Unit	Soil type	Soil origin	Particle size (%)			
				Clay	Silt	Sand	Gravel
BH202 (1m)	Aquifer 1	SAND	Harbour bed sediments	8	3	87	2
BH210 (3m)		Silty SAND		8	5	72	16
BH209 (4m)		SAND		4	2	86	8
BH202 (2m)	Aquitard 1	Sandy CLAY		24	6	70	0
BH201 (5m)		Sandy CLAY		29	13	58	0
BH204 (5m)		Sandy CLAY		53	14	33	0
BH204 (7m)	Aquifer 2	SAND		8	2	86	4
BH205 (7m)		SAND		6	8	84	2
BH202 (8m)		SAND		11	5	81	3
BH204 (10m)	Aquitard 2	Silty Sandy CLAY		23	12	65	0
BH205 (10m)		Sandy Silty CLAY		31	18	51	0
BH202 (11m)		Sandy CLAY		30	11	59	0
BH201 (11m)	Aquifer 3	SAND		10	6	81	3
BH203 (13m)		Silty SAND		10	16	68	5
BH202 (16m)		Silty SAND		9	22	61	8
BH205 (12m)	Aquitard 3	Silty Sandy CLAY		21	10	69	0
BH201 (14m)		Sandy CLAY		19	21	60	0
BH202 (16m)		SlightlySandy Silty CLAY		9	22	68	1
BH401 (27m)	Aquifer 4	SAND	Natal Group	0	13	81	6
BH403 (27m)		SAND		2	14	84	0
BHD1 (27m)		SAND		9	6	85	0
BHD5 (27m)	Sandstone Aquifer	SAND		2	2	95	1
BHD3 (30m)		SAND		6	3	86	5
BHD1 (31m)		SAND		6	0	94	0

Table 4.5: Hydraulic conductivities estimated from grain size analysis using empirical formulae

Sample No.	d ₁₀ (mm)	d ₁₅ (mm)	d ₅₀ (mm)	d ₆₀ (mm)	(U)	(n)	I ₀ (mm)	Hydraulic conductivity (m/d)		
								K-C	Sherard	A/S
BH202 (1m)	0.007	0.07	0.16	0.19	27.142	0.257	0.0034	0.010	0.015	0.068
BH210 (3m)	0.01	0.07	0.18	0.23	23	0.259	0.0049	0.022	0.015	0.109
BH209 (4m)	0.08	0.09	0.19	0.23	2.875	0.404	0.068	8.275	0.024	6.487
BH204 (7m)	0.005	0.08	0.17	0.2	40	0.255	0.0022	0.005	0.019	0.052
BH205 (7m)	0.013	0.065	0.155	0.18	13.846	0.274	0.0063	0.046	0.013	0.126
BH202 (8m)	0.0016	0.055	0.15	0.18	112.5	0.255	NA	0.001	0.009	NA
BH201 (11m)	0.002	0.04	0.17	0.18	90	0.255	NA	0.001	0.005	NA
BH203 (13m)	0.001	0.004	0.15	0.17	170	0.255	NA	0.0002	0.00005	NA
BH202 (16m)	0.004	0.015	0.07	0.085	21.25	0.260	0.0016	0.004	0.001	0.014
BH401 (27m)	0.02	0.065	0.157	0.19	9.5	0.298	0.013	0.150	0.013	0.350
BH403 (27m)	0.015	0.05	0.156	0.19	12.667	0.279	0.0085	0.065	0.008	0.187
BHD1 (27m)	0.006	0.015	0.065	0.07	11.667	0.284	0.0033	0.011	0.001	0.030
BHD5 (27m)	0.03	0.035	0.065	0.065	6	0.338	0.025	0.553	0.004	0.868
BHD3 (30m)	0.07	0.08	0.18	0.21	0.929	0.469	0.05	12.517	0.019	3.606
BHD1 (31m)	0.04	0.055	0.07	0.07	5.25	0.351	0.032	1.140	0.009	1.390

K-C = Kozeny-Carman; A/S = Alyamani & Sen; NA = Not Available

Based on Table 4.4 above, it can be seen that the aquifer layers typically have higher sand contents than the clay layers, whilst the clay layers generally show higher contents of soil fines i.e. clay and silt, as expected. However, the variation of the various soil fractions identified in the laboratory tests within specific soil layers is substantial, particularly within the clay layers where clay contents range between 9 and 53% and sand content between 33 and 95%, although these layers were identified from field samples to comprise predominantly clays. Such occurrences of lower than expected clay content, and higher than expected sand contents within the clay layers, resulting from the laboratory particle size distribution analysis, can be attributed to the following :

- The erratic occurrence of sand lenses within the clay sediments, as is typical of the harbour bed sedimentary deposits.
- The characteristic under-estimation of the clay content of such estuarine sediments, as is often experienced in the hydrometer analysis of soil fines on such materials, presumably due to the soil particle characteristics and behaviour under dispersion. This is particularly relevant to the hippo mud clays, where the test results reflect a clay content in the range 9 to 21%, considered to be a severe underestimation.

4.3.2 Hydraulic conductivity estimation based on laboratory tests

The empirical formulae discussed in section 4.3.1 above are not appropriate for estimating hydraulic conductivity of clayey soils. Therefore the hydraulic conductivity of clayey soils, were estimated using the laboratory tests. The recovered continuous samples were consolidated and recompacted in the laboratory to densities approximating the insitu densities. These samples were then subjected to constant head permeability tests. The results of the estimated hydraulic conductivities from the laboratory tests are summarized in Table 4.6 below.

Table 4.6: Hydraulic conductivity of clayey soils based on laboratory tests

Sample No.	Unit	Soil type	Particle size (%)				Bulk** density ρ_b (kg/m ³)	Hydraulic conductivity K (m/d)
			Clay	Silt	Sand	Gravel		
BH202 (2m)	Aquitard 1	Sandy CLAY	24	6	70	0	1566	0.0000963
BH204 (5m)		Sandy CLAY	53	14	33	0	1587	0.0000422
BH201 (5m)		Sandy CLAY	29	13	58	0	1594	0.0000865
BH204 (10m)	Aquitard 2	Silty Sandy CLAY	23	12	65	0	1619	0.0000960
BH205 (10m)		Sandy Silty CLAY	31	18	51	0	1618	0.0000958
BH202 (11m)		Sandy CLAY	30	11	59	0	1625	0.0000964
BH205 (12m)	Aquitard 3	Silty Sandy CLAY	21	10	69	0	1630	0.000864
BH201 (14m)		Sandy CLAY	19	21	60	0	1646	0.000874
BH202 (16m)		Slightly Sandy Silty CLAY	9	22	68	1	1660	0.000996

mbgl = meters below ground level

*Samples consolidated from consecutive Standard Penetration Test (SPT) recoveries at approximate depths given

**Laboratory recompaction to approximate insitu densities based on SPT results

The results of the laboratory tests in Table 4.6 above show a general reduction in hydraulic conductivity with an increase in density (and depth) as could be expected.

4.4 Borehole pumping tests

A total of sixteen "200 series" boreholes were selected for pumping tests in order to determine the aquifer parameters and groundwater flow characteristics in the intermediate and deep aquifers, referred to as Aquifer 2 and 3, respectively. Of the 16 pumping tests, 9 tests were conducted in the "200A series" boreholes to target aquifer 2. The remaining 7 pumping tests targeted aquifer 3 in the "200 series" boreholes. In addition, a pumping test was conducted in borehole BH403.

This test was conducted to target the aquifer below the "hippo mud clay" (Aquifer 4). The boreholes selected for the pumping tests are shown in Table 4.7 below.

Table 4.7: Boreholes selected for pumping tests

Aquifer	Borehole number
2	BH203A, BH212A, BH204A, BH205A, BH215A, BH207A, BH206A, BH221A and BH217A
3	BH203, BH205, BH207, BH213, BH206, BH208 and BH217
4	BH403

All pumping tests were conducted as follows:

- Prior to the test, the final depth and static groundwater level were measured in the borehole using a Heron interface probe.

- The test pump was installed in each borehole at the maximum depth possible to optimise the available drawdown. This was influenced by the final depth of each borehole and the set lengths of rods connecting the line shaft pump to the motor. Step drawdown tests, which generally comprised four 1 hour steps at incremental increases in pump discharge rates were conducted. The purpose of the step test was to predict a constant discharge pumping rate, based on the observed drawdown curves obtained during the steps. Ideally a drawdown of between 60% and 75% of the available drawdown should be achieved at the end of the constant discharge pumping phase.
- The step tests were followed by monitoring the recovery of the groundwater in the borehole to the original static groundwater level measured prior to commencing the test.
- Following the recovery stage of the pumping test, the boreholes were pumped for a period of 24 hours at the constant discharge rate. The constant discharge rate was predicted from the step test stage.
- Following the constant discharge pumping stage, the pump was switched off and the recovery of the groundwater was monitored in the pumped wells. The recovery was monitored generally to within 90% to 100% of the original static groundwater level measured in the boreholes prior to testing. For most boreholes, the recovery to this condition took the same amount of time as the period of constant discharge pumping.

The results of the pump test data were analysed to determine the transmissivity of the respective pumped aquifers, and hence the hydraulic conductivities. The transmissivity of an aquifer is a measure of how much water can be transmitted horizontally, and is directly proportional to hydraulic conductivity and aquifer thickness.

Transmissivity : $T = KD$ (Kruseman et al 1991)

Solving for K gives,

$$K = T/D$$

Where :

T = Transmissivity (m^2/d)

K = Hydraulic conductivity (m/d)

D = Aquifer thickness (m)

The transmissivity values were estimated from the pump test data that was captured into the Flow Characteristic Method (Van Tonder et al 2001). The results of the analysis of the pump test data are given in Appendix C, and are summarized in Table 4.8 below.

Table 4.8: Summary of results of analysis of borehole pump tests

Borehole No.	Unit	Pump rate (l/hr)	Maximum drawdown (m)	Transmissivity (m ² /d)	Hydraulic conductivity (m/d)
BH204A	Aquifer 2	90	2.3	0.55	0.18
BH205A		36	2.3	0.25	0.04
BH206A		36	4.8	0.05	0.02
BH207A		54	3.3	0.24	0.05
BH212A		288	5.1	0.67	0.12
BH215A		90	3.4	0.40	0.14
BH221A		216	2.8	1.05	0.29
Mean hydraulic conductivity					0.12
BH203	Aquifer 3	252	6.7	0.92	0.12
BH205		108	5.7	0.47	0.12
BH206		216	5.1	0.95	0.16
BH207		324	4.7	1.45	0.48
BH208		792	6.4	2.32	0.33
BH213		648	6.7	1.54	0.5
BH217		288	4.5	1.81	0.3
Mean hydraulic conductivity					0.29
BH403	Aquifer 4	180	5.8	0.14	0.02

From the above it can be seen that the estimated aquifer transmissivities ranged between the values of 0.05 m²/d to 1.05 m²/d in aquifer 2 and 0.47m²/d to 2.32 m²/d in aquifer 3. The estimated aquifer transmissivity value of 0.14 m²/d was reported in aquifer 4. The estimated hydraulic conductivities ranged between the values of 0.04 m/d to 0.29 m/d in aquifer 2 and 0.12 m/d to 0.48 m/d in aquifer 3. The hydraulic conductivity value of 0.14 m/d was estimated in aquifer 4. The average results of the estimated hydraulic conductivities using the three methods mentioned above (section 4.3 and 4.4) are summarized in Table 4.9 and discussed below.

Table 4.9: Summary of estimated hydraulic conductivities for various aquifers underlying the manufacturing plant

Sample No.	Unit	Soil type	Soil origin	Particle size (%)				Average Hydraulic conductivity (m/d)
				Clay	Silt	Sand	Gravel	
BH202 (1m)	Aquifer 1	SAND	Harbour bed sediments	8	3	87	2	1.67
BH210 (3m)		Silty SAND		8	5	72	16	
BH209 (4m)		SAND		4	2	86	8	
BH202 (2m)	Aquitard 1	Sandy CLAY		24	6	70	0	0.000082
BH201 (5m)		Sandy CLAY		29	13	58	0	
BH204 (5m)		Sandy CLAY		53	14	33	0	
BH204 (7m)	Aquifer 2	SAND		8	2	86	4	0.12
BH205 (7m)		SAND		6	8	84	2	
BH202 (8m)		SAND		11	5	81	3	
BH204 (10m)	Aquitard 2	Silty Sandy CLAY		23	12	65	0	0.000097
BH202 (11m)		Sandy CLAY		30	11	59	0	
BH205 (10m)		Sandy Silty CLAY		31	18	51	0	
BH201 (11m)	Aquifer 3	SAND		10	6	81	3	0.29
BH203 (13m)		Silty SAND		10	16	68	5	
BH202 (16m)		Silty SAND		9	22	61	8	
BH205 (12m)	Aquitard 3	Silty Sandy CLAY		21	10	69	0	0.000911
BH201 (14m)		Sandy CLAY		19	21	60	0	
BH202 (16m)		Slightly Sandy Silty CLAY		9	22	68	1	
BH401 (27m)	Aquifer 4	SAND		0	13	81	6	0.02
BH403 (27m)		SAND		2	14	84	0	
BHD1 (27m)		SAND		9	6	85	0	
BHD5 (27m)	Sandstone Aquifer	SAND	Natal Group	2	2	95	1	2.23
BHD3 (30m)		SAND		6	3	86	5	
BHD1 (31m)		SAND		6	0	94	0	

Based on the estimated hydraulic conductivities in Table 4.9 above, it is clear that the sandstone aquifer had higher hydraulic conductivity than the harbour bed sediments which generally occur in four predominantly sandy aquifer horizons (aquifers 1,2,3 and 4). This means that the movement of groundwater in the sandstone aquifer would be faster than in the harbour bed sediments. Of the harbour bed sediments, aquifer 1 had higher hydraulic conductivity, suggesting that it would easily transmit water more than the other sandy aquifer horizons (aquifers 2,3 and 4).

The aquitards interlayering different sandy aquifer horizons had very low hydraulic conductivities and this implies that groundwater movement through these layers would be very slow hence it is suspected that contamination could diffuse through these layers.

4.5 Groundwater level monitoring

Groundwater levels (piezometric levels) were monitored in the existing boreholes and new boreholes put down on the manufacturing plant site and surrounding area on a monthly basis. The purpose of the groundwater level monitoring was to establish groundwater flow patterns within the manufacturing plant site and the surrounding area. The groundwater levels were measured using a dip meter as shown in Figure 4.5 below.



Figure 4.5: Groundwater level monitoring using a dip meter.

The recorded groundwater levels in the boreholes are included in Appendix D, and summarized in Table 4.10 below. Graphical plots of groundwater level monitoring data are presented in Figures 4.6 to 4.10, and categorize boreholes per aquifer.

Table 4.10: Summary of measured groundwater levels in the boreholes

Unit	Soil type	Soil origin	Borehole Numbers	Piezometric level (mbgl)	
				Average	Range
Aquifer 1	Sand	Harbour bed sediments	BH301 to BH318	1.597	0 to 3.321
Aquifer 2	Sand		BH201A to BH225A	1.248	0 to 2.093
Aquifer 3	Sand		BH201 to BH225	1.626	0 to 3.286
Aquifer 4	Sand		BH401, BH402, BH403	2.125	1.361 to 3.474
Sandstone Aquifer	Sand	Natal Group	D1, D3, D5	14.322	1.354 to 36.07

mbgl = meters below ground level

Based on Table 4.10 above, it is evident that shallow groundwater levels occurred at the average depths of approximately 1.2 mbgl and 1.6 mbgl in aquifer 2 and aquifer 1 respectively. Deep groundwater level occurred at an average depth of approximately 14 mbgl in the sandstone aquifer. This suggests that aquifer 1 and aquifer 2 could be more vulnerable to hexavalent chromium [Cr(VI)] contamination through washout of soluble Cr(VI) in the soils by high groundwater table, than aquifers 3,4 and sandstone aquifer.

Based on the chemical results of Cr(VI) (refer to Appendix E), it is evident that Cr(VI) concentrations were always higher in aquifer 1 and aquifer 2 as compared to the concentrations of Cr(VI) in aquifer 3, 4 and sandstone aquifer.

The graphical plots of monitoring data (Figures 4.6 to 4.10) indicate that the groundwater levels have remained relatively constant throughout the study period of approximately 5 years, and in most boreholes the groundwater level fluctuations were less than 0.5 meters. This clearly suggests that the groundwater flow could be close to steady state. The graphical plots of monitoring data also indicate that the notable response in some boreholes could be associated with seasonal groundwater fluctuations.

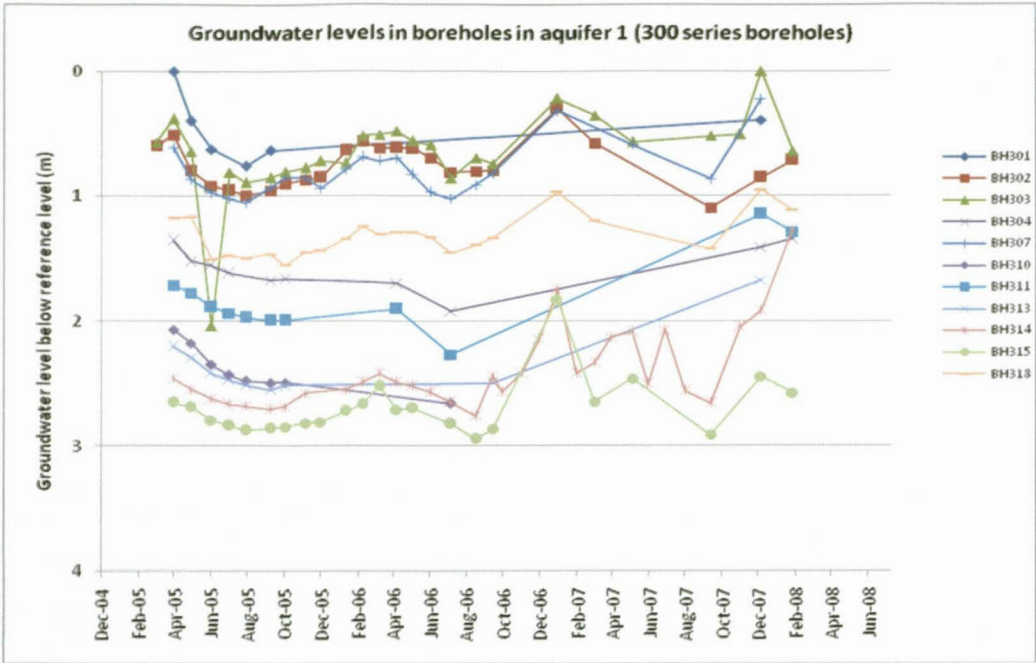


Figure 4.6: Groundwater levels in aquifer 1 boreholes.

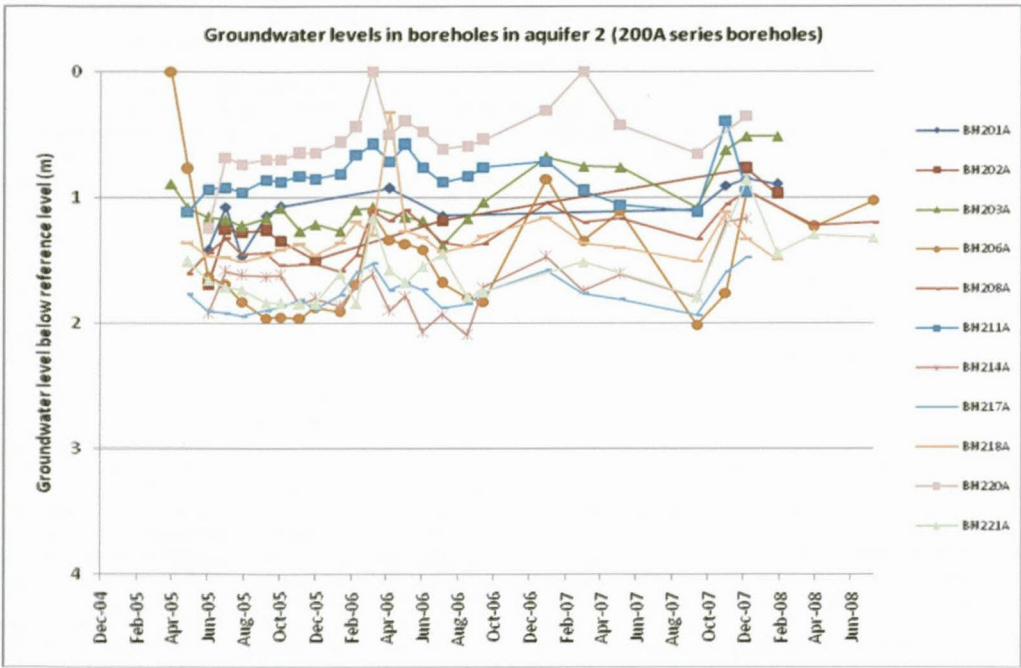


Figure 4.7: Groundwater levels in aquifer 2 boreholes.

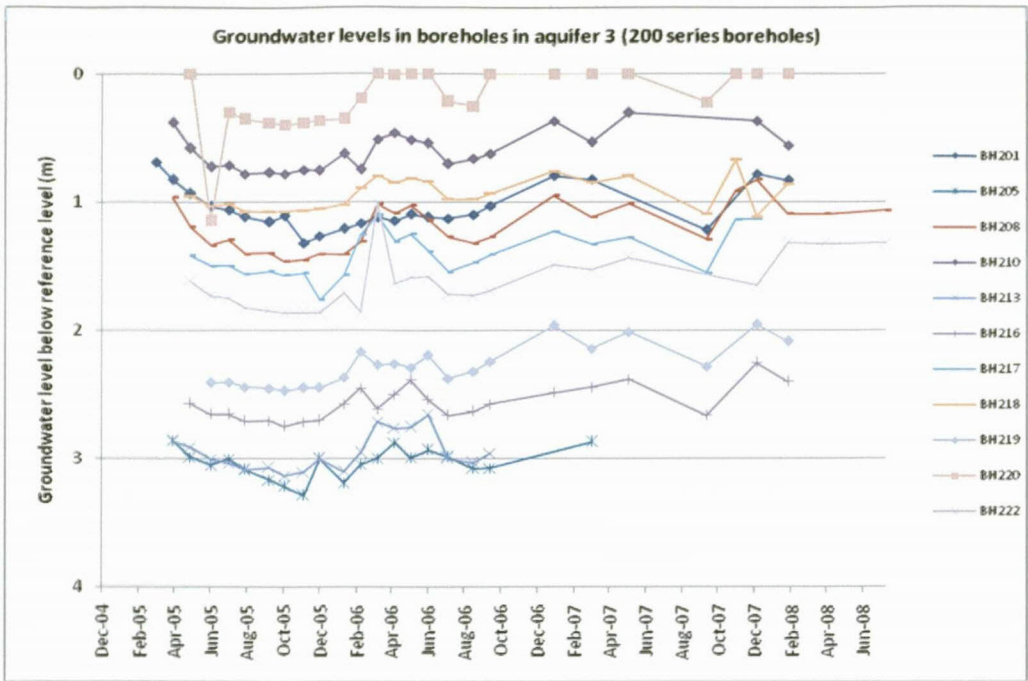


Figure 4.8: Groundwater levels in aquifer 3 boreholes.

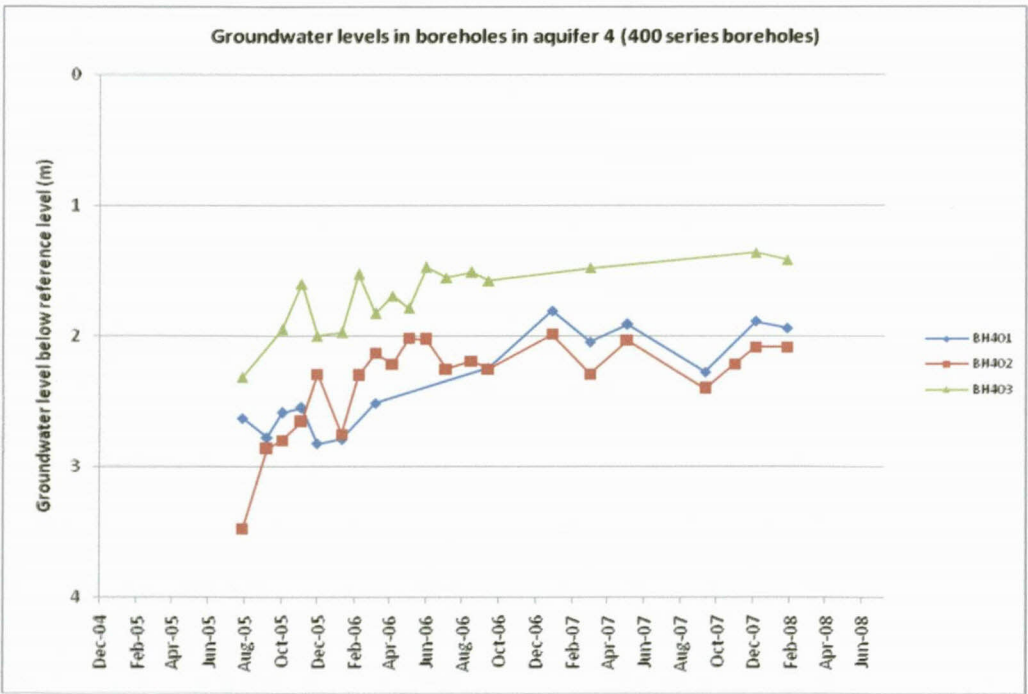


Figure 4.9: Groundwater levels in aquifer 4 boreholes.

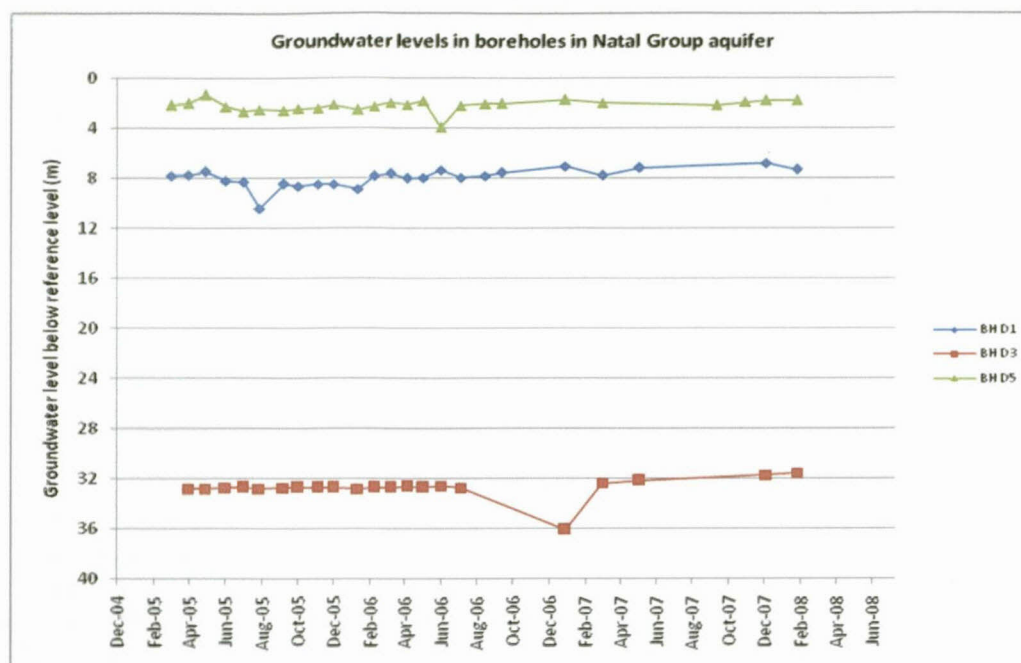


Figure 4.10: Groundwater levels in Natal Group aquifer boreholes.

Based on the recorded groundwater levels (piezometric levels) in the boreholes (see Appendix D), the standing water elevations were determined. It was assumed that the groundwater level distribution generally emulates the surface topography and therefore the contaminated groundwater would flow from a topographic high to a topographic low. The Bayesian interpolation technique, which uses the possible relationship between the topography and groundwater levels, was used to interpolate groundwater levels and therefore the groundwater flow directions. Figure 4.11 presents the topography against the groundwater elevations.

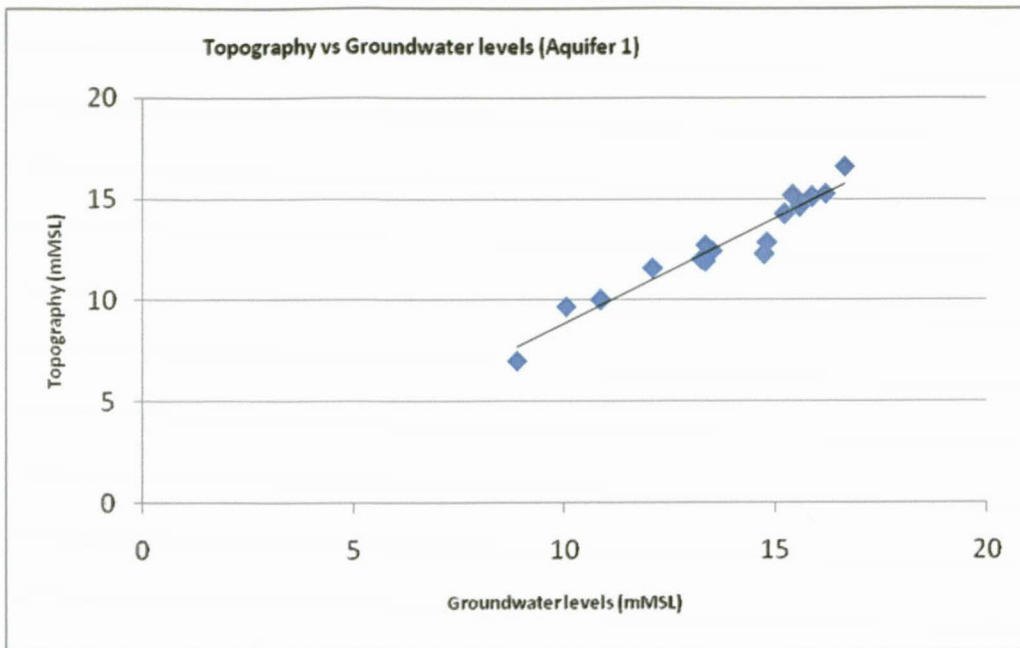


Figure 4.11: Correlation between topography and groundwater levels in aquifer 1.

The interpolated groundwater levels in various aquifers underlying the manufacturing plant and the surrounding area are presented diagrammatically in Figures 4.12 to 4.16 as contours with flow directions (based on monitoring data of December 2007). From the groundwater level contour plots, it is evident that the direction of groundwater flow in aquifers 1 to 3 was from the west to the east. Within Aquifer 4 and the sandstone formation the groundwater flow was from the north west to the south east in principle corresponding to the general regional groundwater flow at depth from the hills toward the sea.

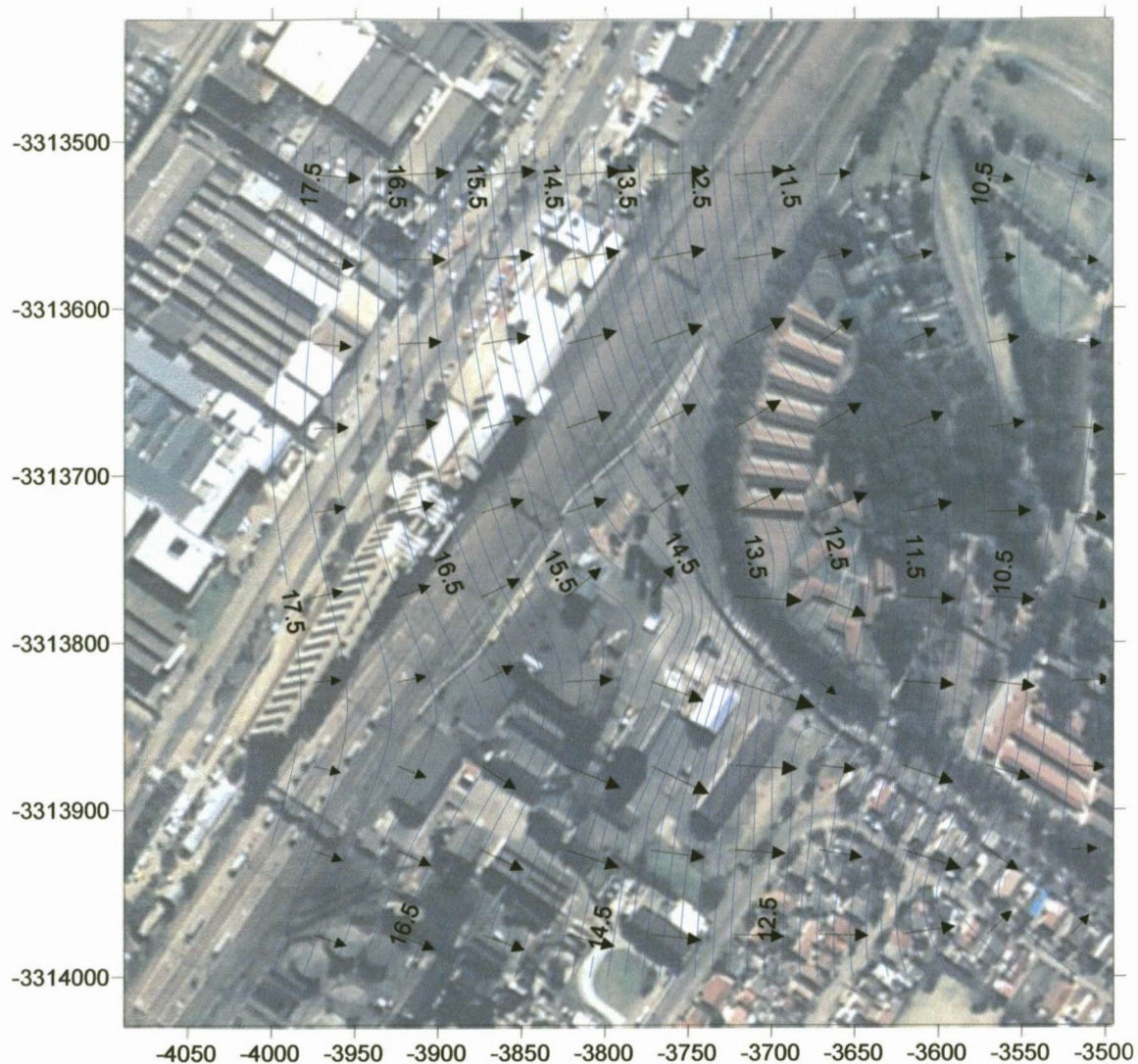


Figure 4.12: Groundwater levels and flow directions within aquifer 1.

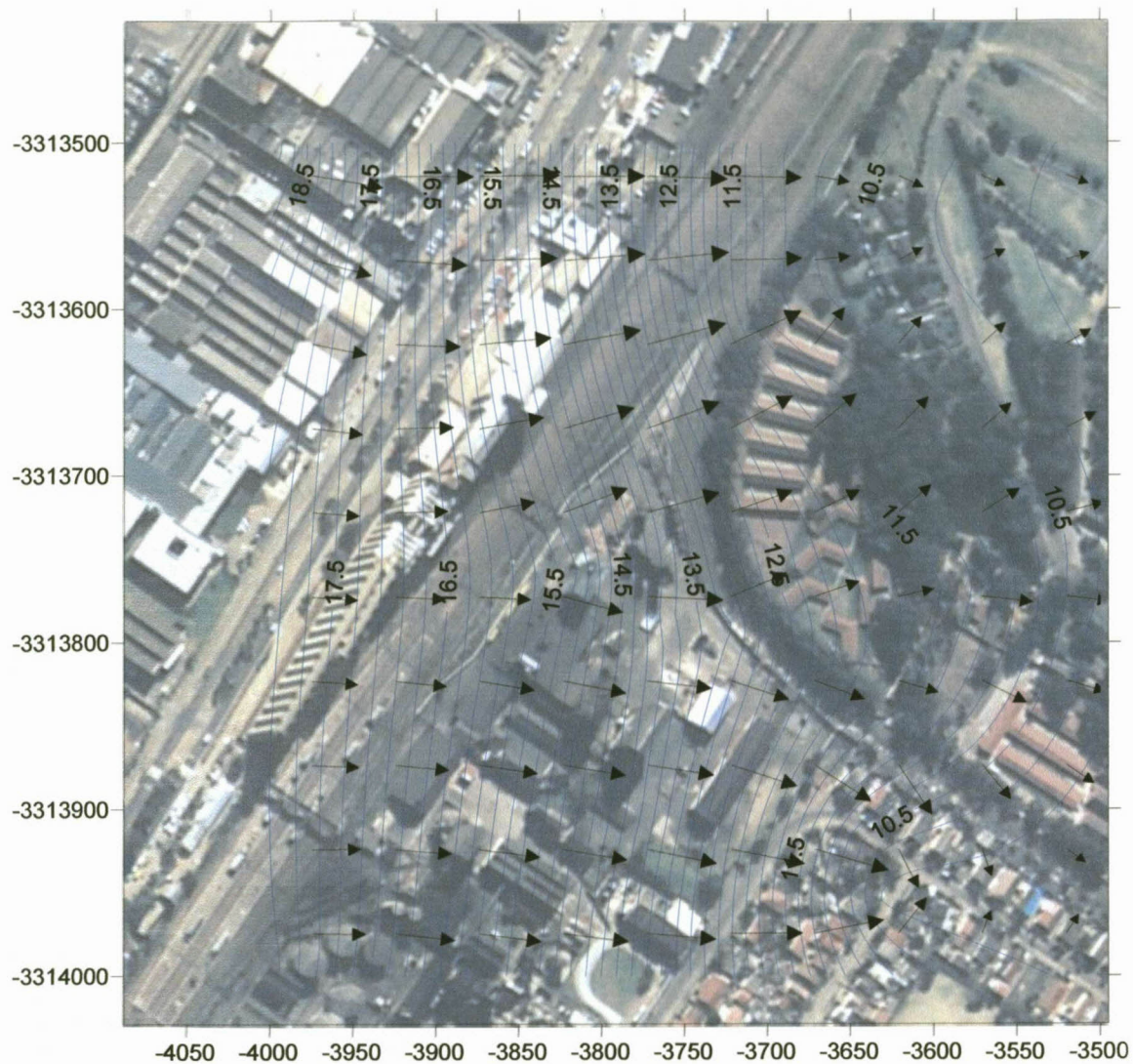


Figure 4.13: Groundwater levels and flow directions within aquifer 2.

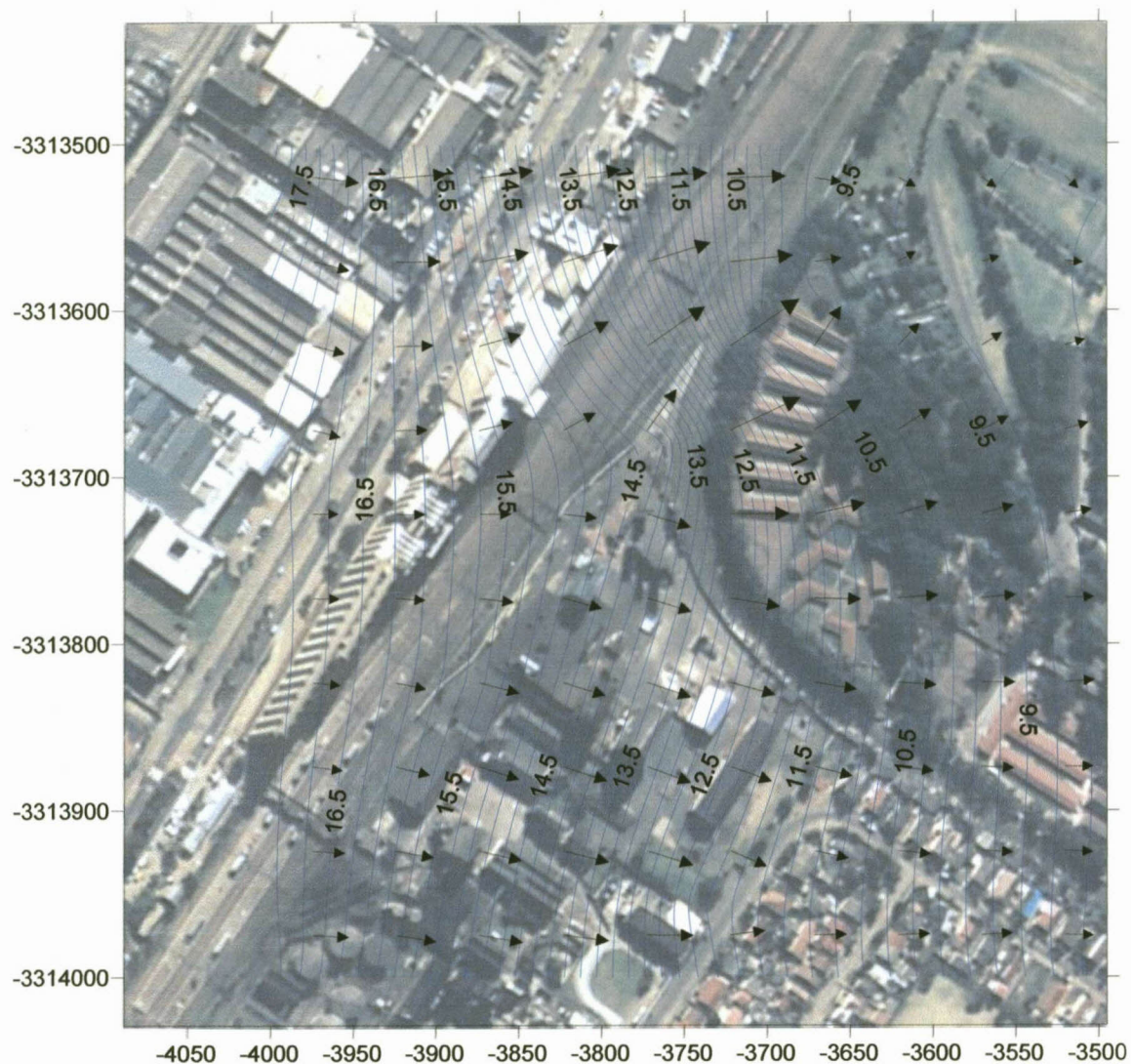


Figure 4.15: Groundwater levels and flow directions within aquifer 4.

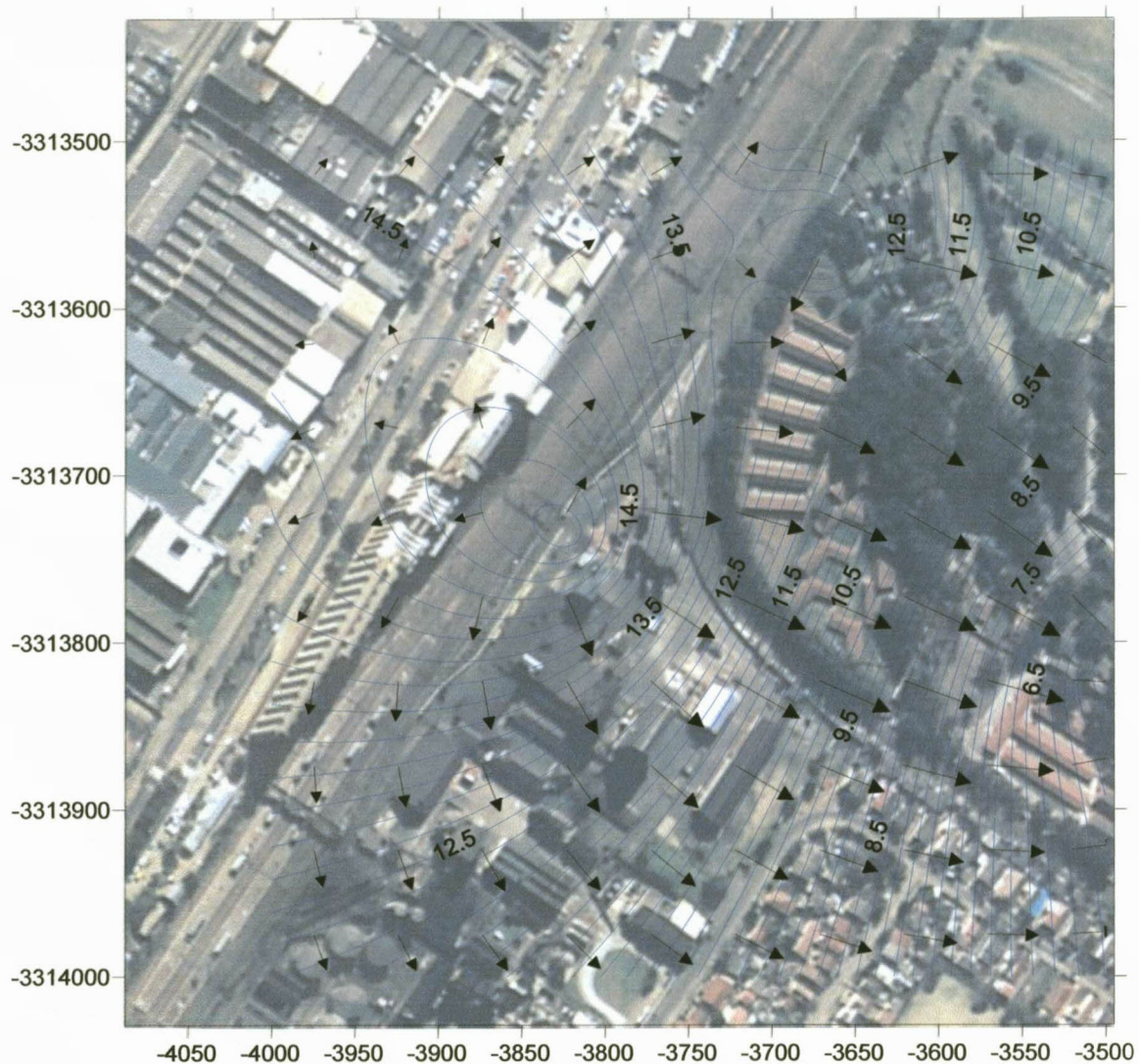


Figure 4.16: Groundwater levels and flow directions within sandstone aquifer.

4.6 Groundwater sampling

The sampling of the groundwater from both existing and new boreholes was carried out in various sampling events over the period June 2004 to December 2007, in order to determine the levels and extent of chromium contamination in the groundwater underlying the manufacturing plant and neighbouring area. The locations of boreholes are shown in Figure 4.2. The boreholes were purged and sampled using a peristaltic pump and flow through cell for the determination of well head parameters in accordance with the US EPA (1996) Low Flow sampling procedure.

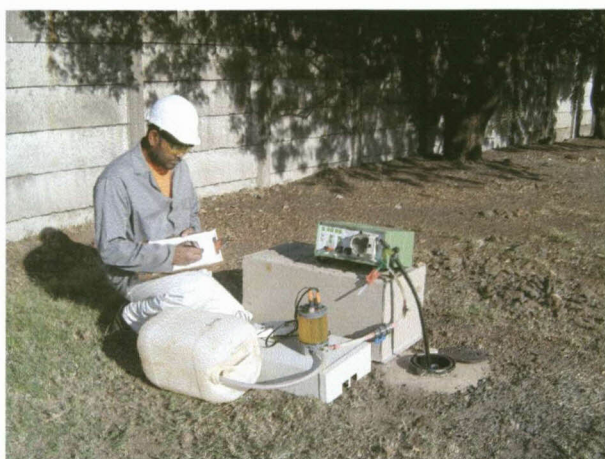


Figure 4.17: Groundwater sampling using peristaltic pump and flow through cell

Groundwater sampling was carried out as follows:

- The standing water levels in all of the boreholes were measured and recorded prior to the commencement of any work on each borehole.
- The boreholes were then purged by pumping a volume of groundwater that was equal to three times the measured volume of water present in the borehole. Purging is necessary because a groundwater sample must be representative of the formation (aquifer) water. This is because water that has been standing in the borehole above the borehole is
 - Not free to interact with water formation
 - In contact with borehole construction material (i.e., casing) for long period of time
 - In direct contact with the atmosphere which is then subject to different chemical equilibria.

- The boreholes were purged at a very low rate in order to avoid:
 - Cone of depression (caused by lowering the water table)
 - Turbulence that would cause dilution in the water and then mask the presence of contamination
 - Exposure of portion of formation (aquifer) materials to air and other gases
 - Drawing of contamination to boreholes which do not intersect contamination plume, since this causes wide spreading of contamination.
- The boreholes were purged until the pH, EC, Redox potential and temperature stabilised in accordance with the specified range for each parameter given in the sampling procedure.
- When the water quality parameters of three conservative measurements met the set criteria, samples of adequate volume were collected and sent to the selected laboratory for analysis.
- The analysis of groundwater samples included the determination of the pH, total chromium and hexavalent chromium [Cr(VI)] .

The results of the analysis carried out on the groundwater samples are given in Appendix E, and the maximum concentrations of hexavalent chromium reported in the groundwater in the individual boreholes installed in aquifers 1,2,3,4 and Natal Group aquifer are indicated in colour coded dots in Figures 4.18 to 4.21 below. Note that some of the private boreholes could not be sampled during the sampling events due to the absence of the owners. The sampling events were done in a frequency of a one monthly basis.

Based on the chemical results in Appendix D and colour coded dots indicated in Figures 4.18 to 4.21 below, it is evident that significant concentrations of hexavalent chromium were detected in aquifers 1 and 2 underlying old closed or dismantled production facilities on the manufacturing plant site where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1991. Hexavalent chromium was only detected in aquifer 3, in the limited area underlying the manufacturing plant, immediately above the “Hippo mud” clay. In the aquifers below the “Hippo mud” clay, aquifer 4 within the harbour bed sediments and especially within the sandstone bedrock where groundwater is extracted for irrigation at the turf club site, no hexavalent chromium was detected.

It is therefore clear that the dissolved groundwater plume in the area underlying the manufacturing plant was identified as a secondary source of chromium contamination.

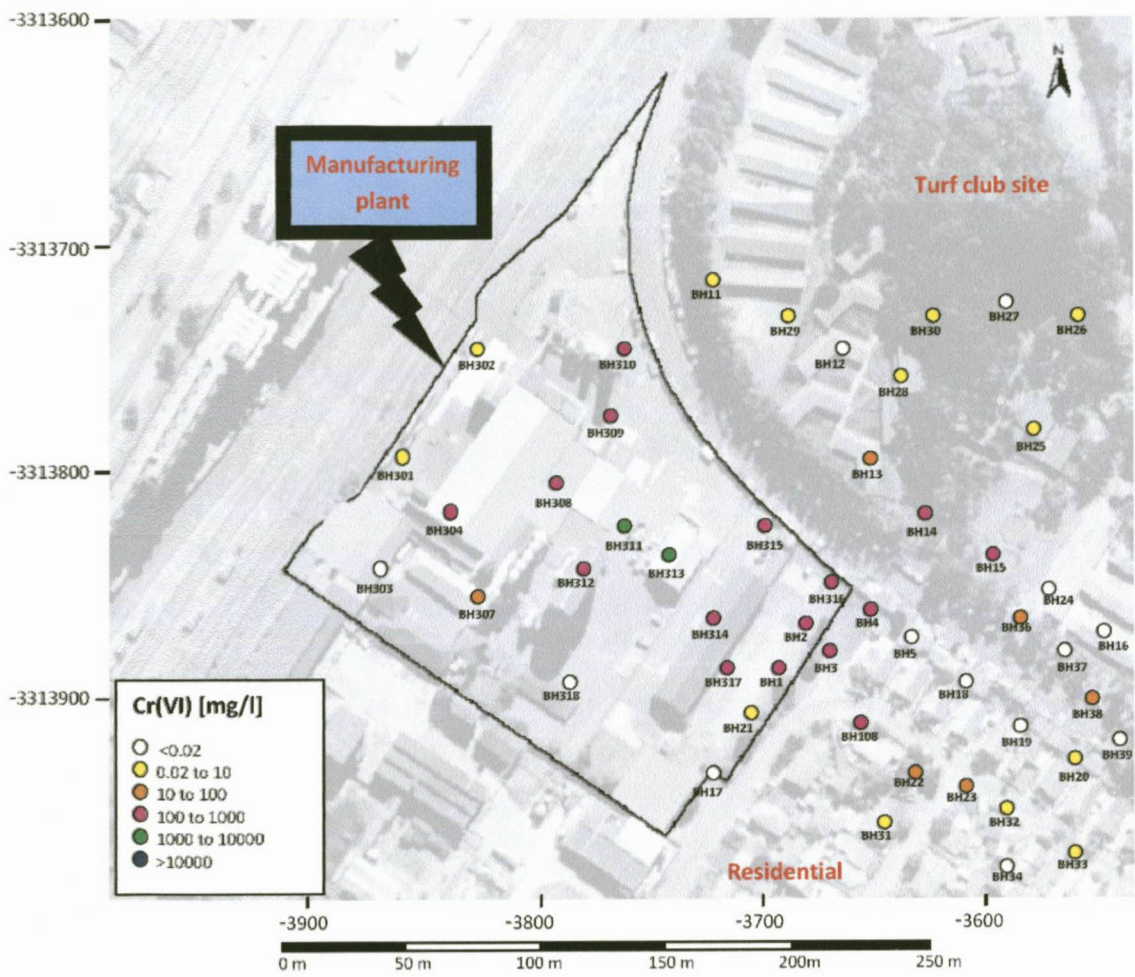


Figure 4.18: Maximum hexavalent chromium concentrations within aquifer 1 for the sampling events 14 to 24.

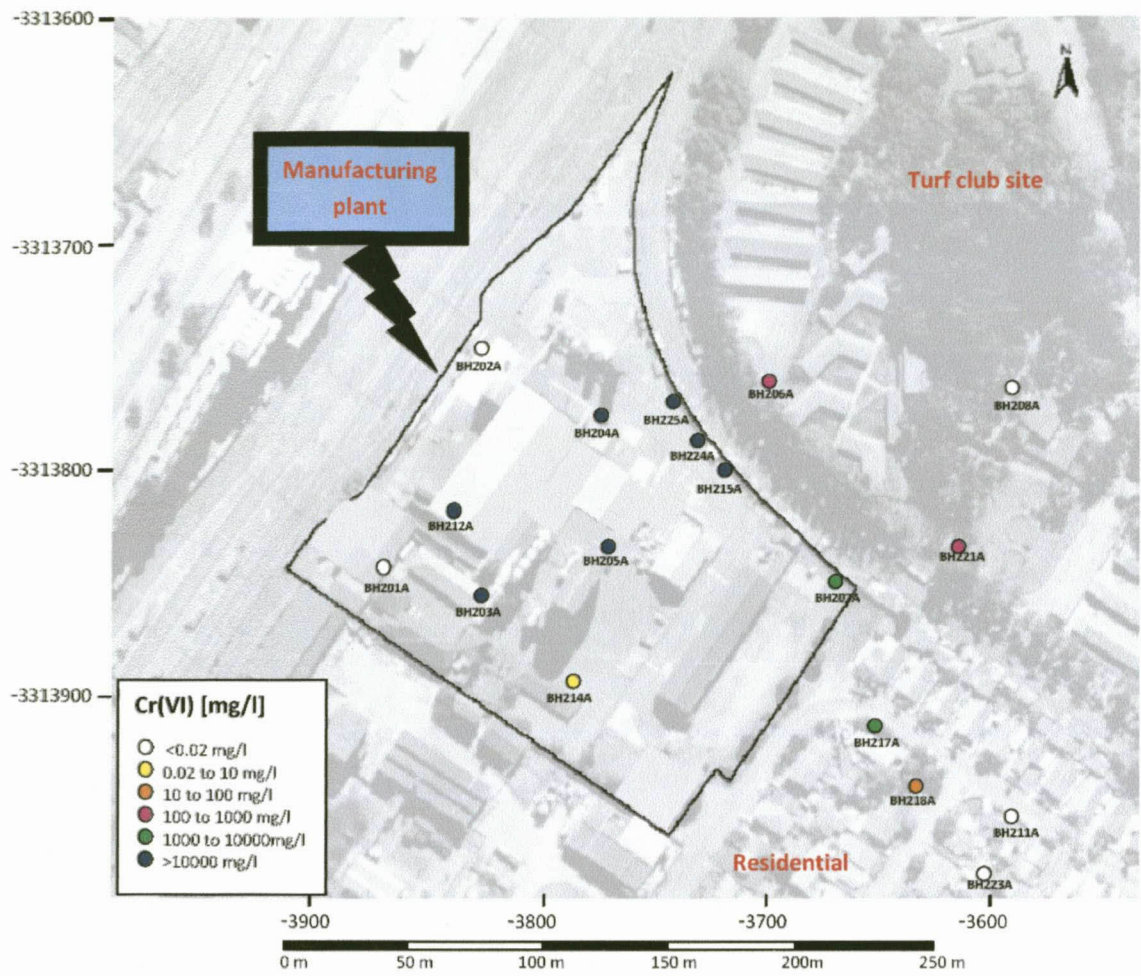


Figure 4.19: Maximum hexavalent chromium concentrations within aquifer 2 for the sampling events 14 to 24.

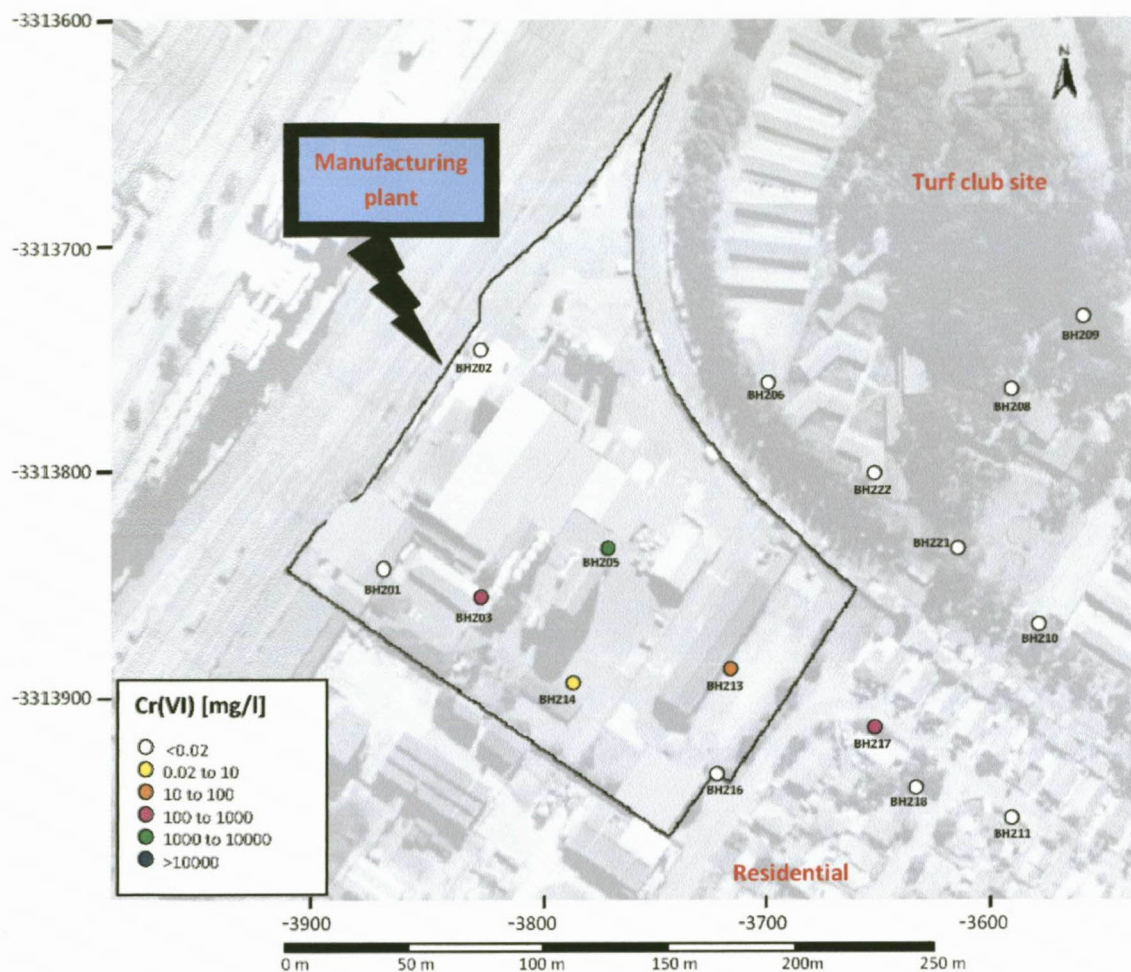


Figure 4.20: Maximum hexavalent chromium concentrations within aquifer 3 for the sampling events 14 to 24.

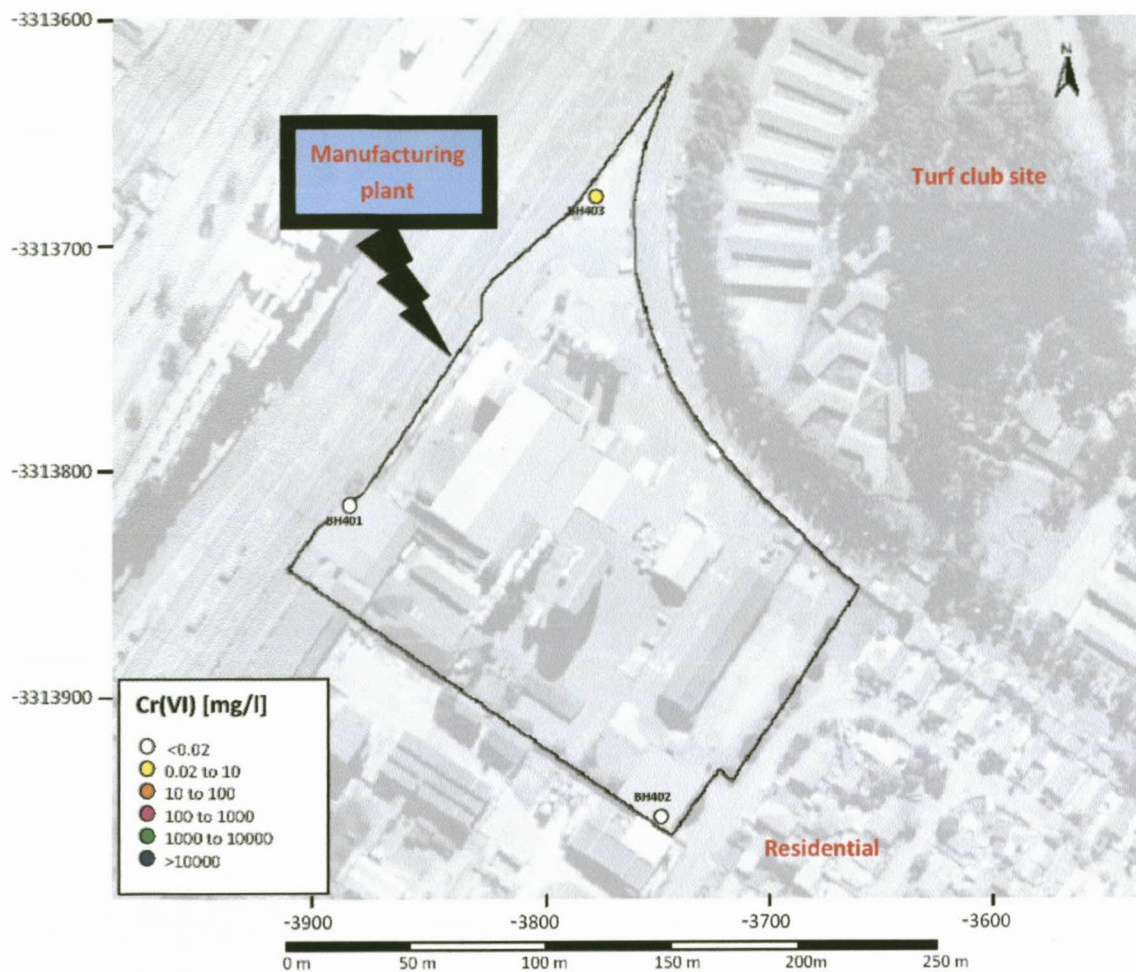


Figure 4.21: Maximum hexavalent chromium concentrations within aquifer 4 for the sampling events 14 to 24.

4.7 Soil sampling

The soils underlying the manufacturing plant site and neighbouring area were sampled in order to investigate the nature of the shallow subsoil materials and to determine the levels and extent of chromium contamination. A total of 41 test pits, designated TP1 to TP45, were excavated across the manufacturing plant site, and 12 test pits, designated S01 to S12 were excavated in the neighbouring area adjacent to the manufacturing plant. The locations of test pits are shown in Figure 4.22.

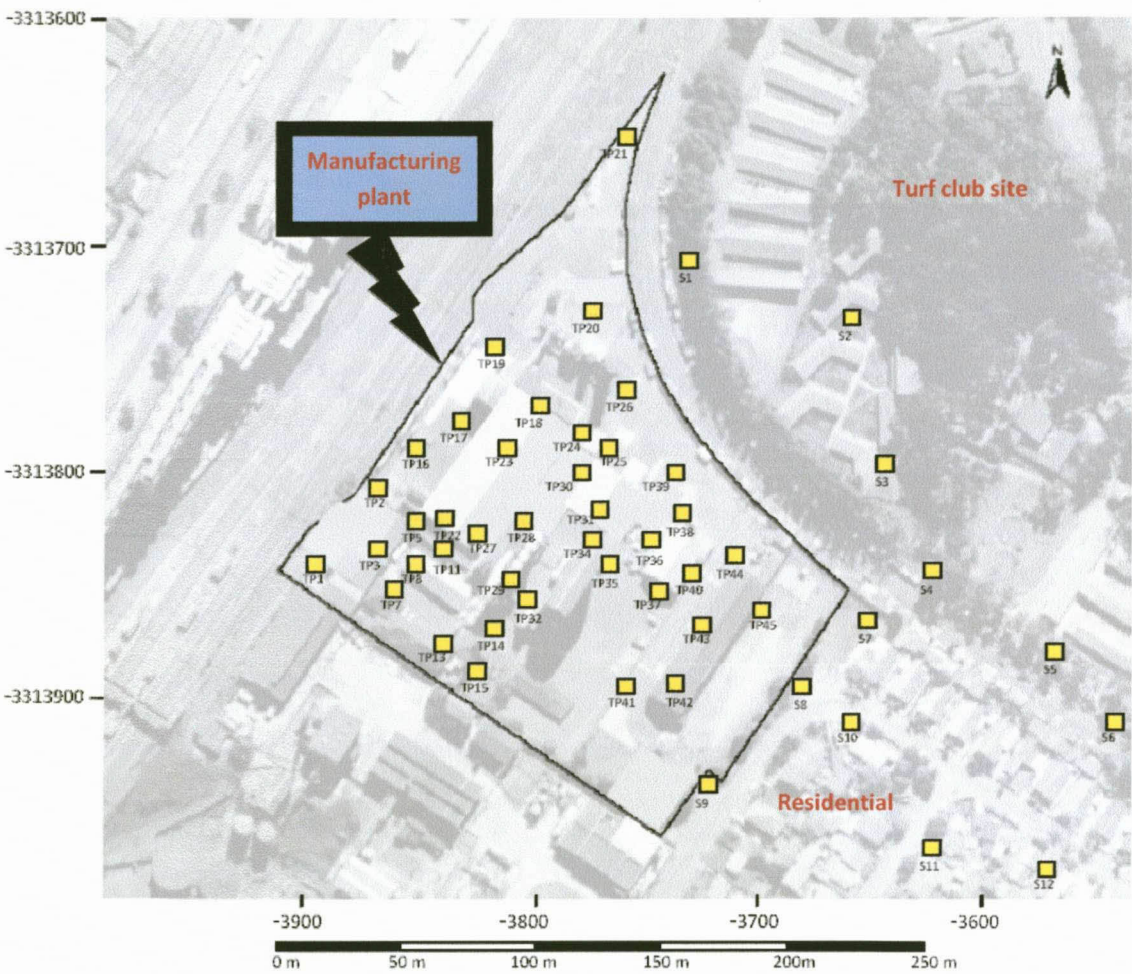


Figure 4.22: Soil sampling locations on the manufacturing plant site and neighbouring area.

The test pits were excavated by hand to depths of 1.0 metres below existing ground level or to a depth where the groundwater was encountered. Some of the test pits were located in paved areas, necessitating the removal of the concrete or asphalt paving by saw cutting and breaking out of the surfacing. The soil samples were taken at 0.3 metres (“shallow samples”) and at 0.6 metres (“deep samples”) in each test pit. The soil samples were then submitted to the selected laboratory for analysis, and the analysis generally included the determination of the pH, total chromium and hexavalent chromium [Cr(VI)] content of the soil. The trivalent chromium [Cr(III)] results were then computed by subtracting the analytical results for hexavalent chromium [Cr(VI)] from total chromium (Total Chromium – Hexavalent Chromium).

The results of the analysis carried out on the soil samples are given in Appendix F, and the concentrations of Cr(III) and Cr(VI) reported in the individual test pits at different depths are indicated in colour coded dots in Figures 4.24 to 4.27 below.



Figure 4.23: Test pit excavated for shallow soil sampling.

Based on the results of the analysis carried out on the soil samples in Appendix F, and the colour coded dots in Figures 4.24 to 4.27 below, it is evident that significant concentrations of Cr(III) and Cr(VI) were detected in the soils underlying the old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1991 at the manufacturing plant site. Within the residential area and turf club site, low levels of Cr(III) and Cr(VI) were detected in the soil samples and this contamination could be due to the historical surface run-off from the manufacturing plant site. It is therefore clear that the impacted subsurface soils (>0.3m) in the area underlying the manufacturing plant site were found to be the secondary source of contamination.

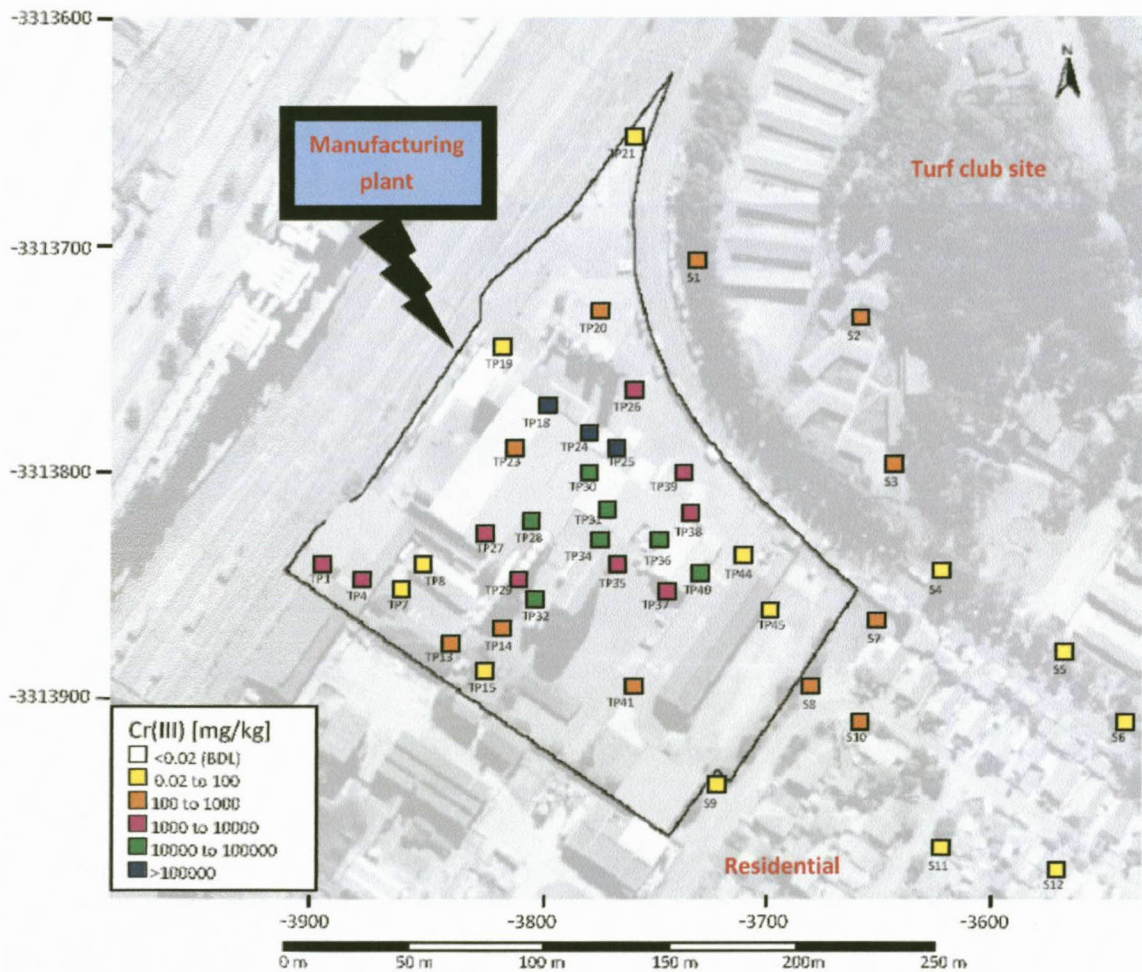


Figure 4.24: Trivalent chromium concentrations in the soils at the depth of 0.3m.

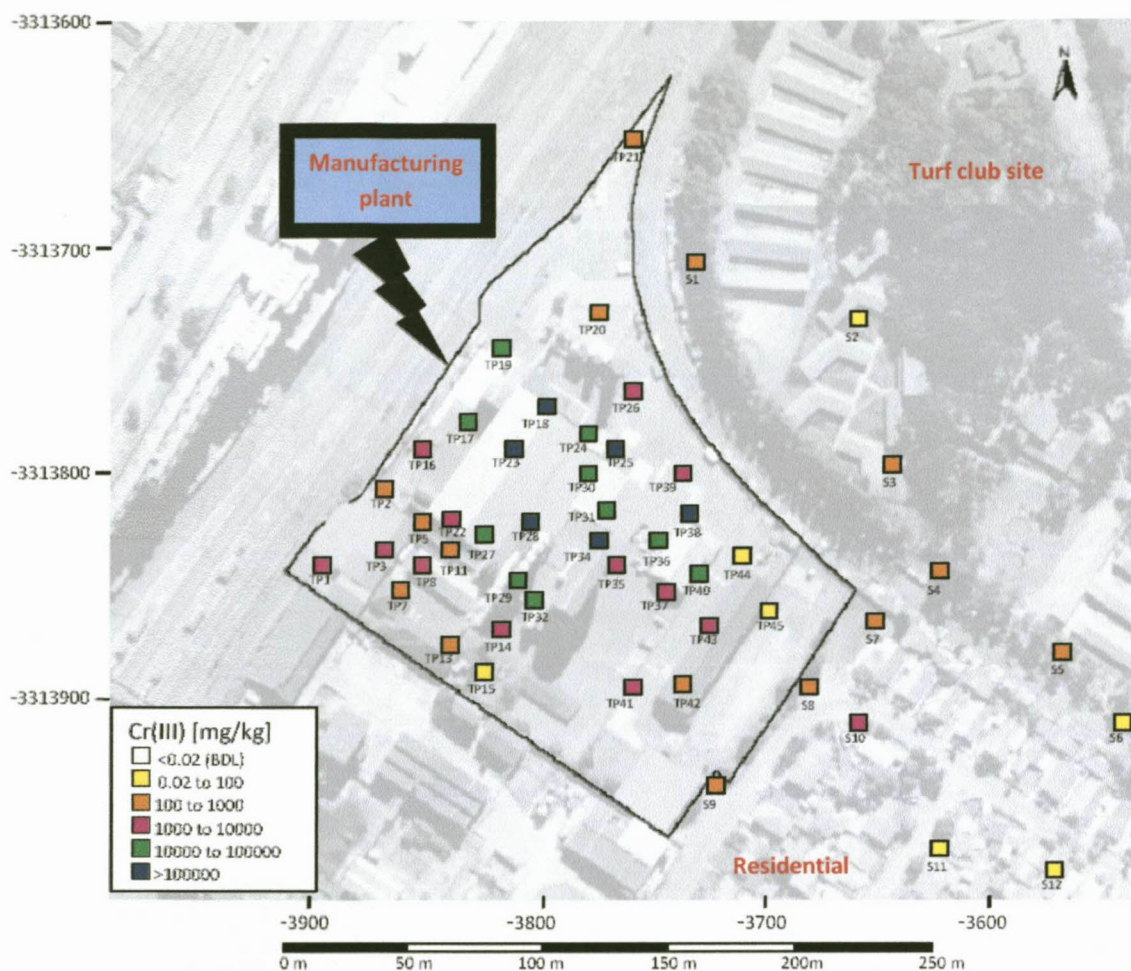


Figure 4.25: Trivalent chromium concentrations in the soils at the depth of 0.6m.

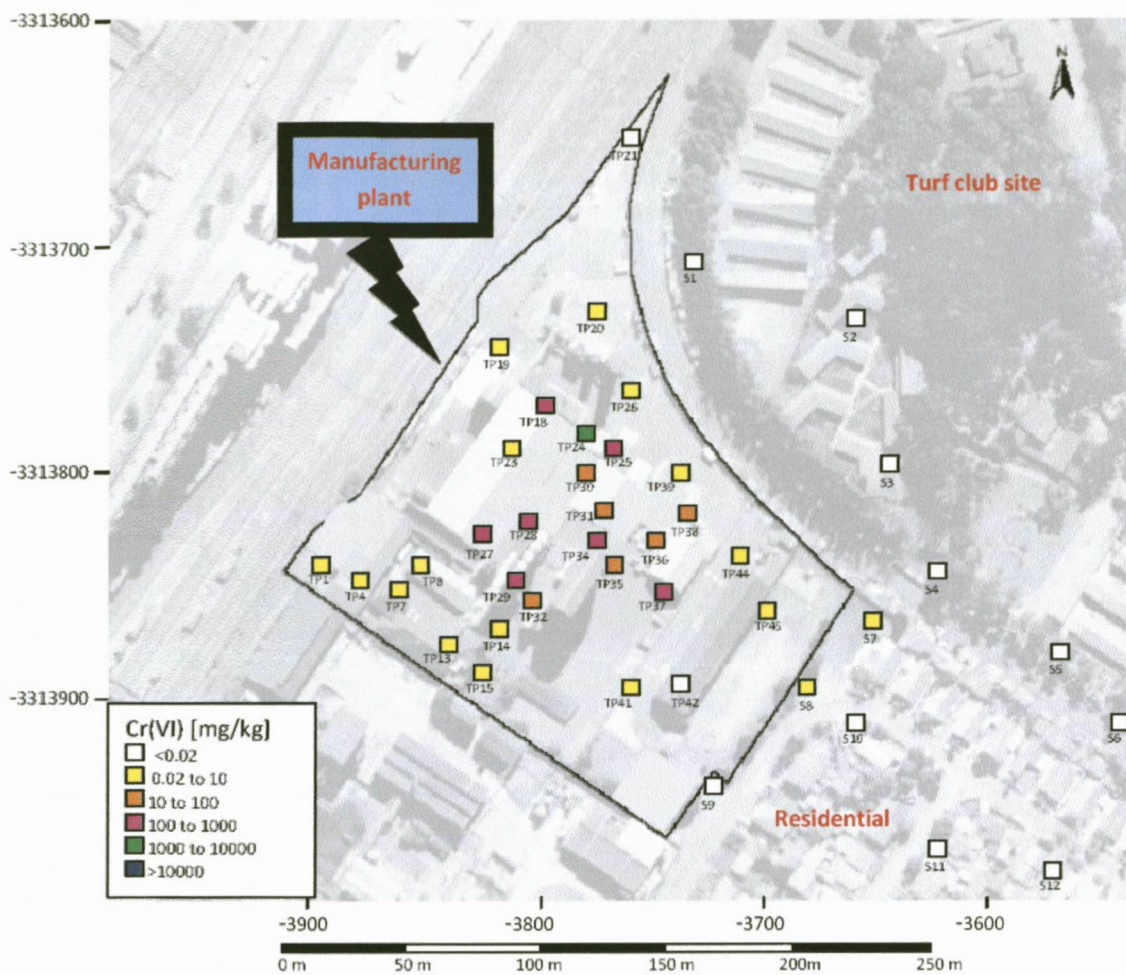


Figure 4.26: Hexavalent chromium concentrations in the soils at the depth of 0.3.

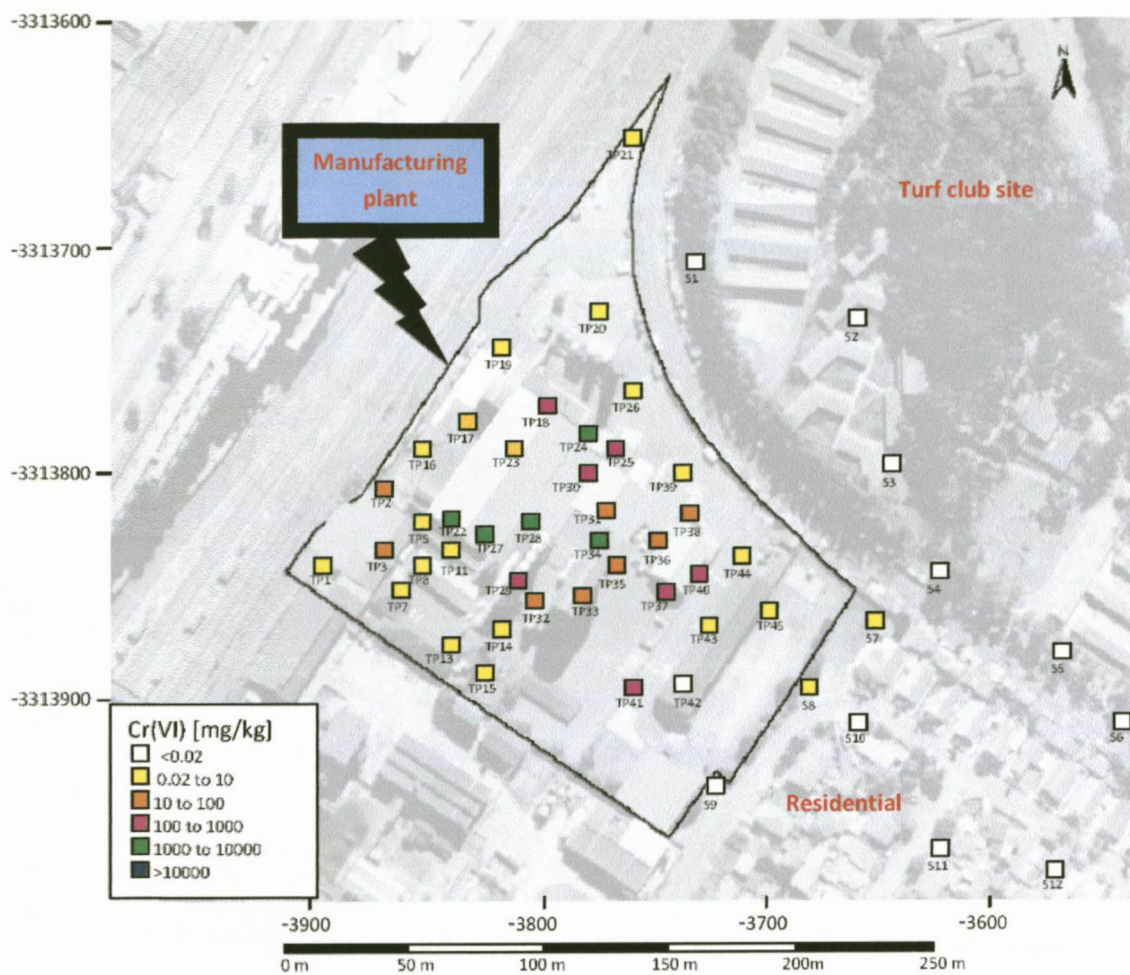


Figure 4.27: Hexavalent chromium concentrations in the soils at the depth of 0.6m.

CHAPTER 5. CONCEPTUAL SITE MODEL

5.1 Introduction

The Conceptual Site Model (CSM) developed for the site has been used to evaluate the relevant pathways from the potential sources of contamination identified to points of exposure and the receptors. It has been developed from information gathered during site investigations carried out at the manufacturing plant site. The CSM describes all known or potential sources of contamination, and considers how and where the contamination is likely to move (pathways) and identifies who or what is most likely to be affected by the contaminants (receptors).

Here the relevant chromium contamination is hexavalent chromium[Cr(VI)] in groundwater and soil to a much lesser extent trivalent chromium[Cr(III)] in the soil. The CSM is shown diagrammatically in Figure 5.3, and is discussed under the following headings:

- Sources: Primary and secondary sources of contamination
- Transport mechanisms: Pathways
- Receptors: The exposure pathways and other end users who may be impacted by contaminants in soil or groundwater

5.2 Sources of contamination

5.2.1 Primary sources

The primary source of chromium contamination in the soils and groundwater underlying the manufacturing plant is considered to be the previous sodium dichromate (SDC) spills during production and handling at certain locations within the manufacturing plant between 1945 and 1991. It is suspected that the ingress of liquid SDC into the soils and underlying groundwater in these areas has caused the contamination. The historic activities have lead to high concentrations of contamination, so called “hot spots”, which have subsequently acted as active sources of the contamination plume that is now observed in aquifers 1, 2 and 3. In 1991, the production of sodium dichromate (SDC) was discontinued on the site, and manufacturing activities were limited to the manufacture of chromium tanning salts. The production facilities of SDC were closed and dismantled.

5.2.2 Secondary sources

Soil and groundwater sampling was conducted in order to identify the secondary sources at the site. The highest measured Cr(VI) concentrations in groundwater were found in aquifer 1 and aquifer 2 underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990 as shown in Figure 5.1. The highest measured Cr(VI) concentrations in soil samples taken at the manufacturing plant site coincide with the above mentioned locations. The secondary sources of contamination at the manufacturing plant site were found to be the following:

- Affected subsurface soil (>0.3m) and
- Dissolved groundwater plume

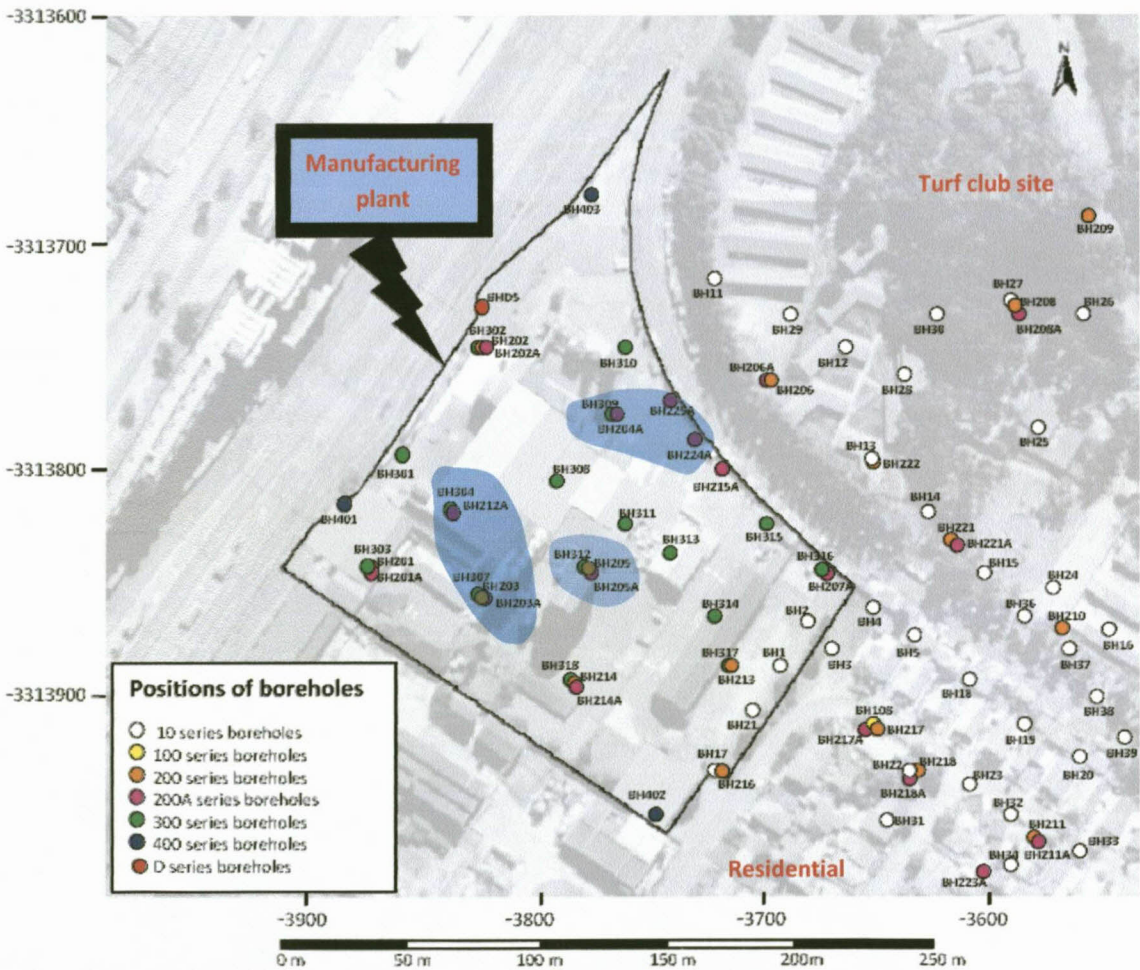


Figure 5.1: Suspected hot spot locations based on observed Cr(VI) concentrations in aquifer 1 and 2.

5.3 Potential transport mechanisms

Having identified secondary sources the next step was to determine the different transport mechanisms at the manufacturing plant. Based on the results of groundwater sampling (refer to chapter 4, section 4.6), significant concentrations of Cr(VI) were detected in aquifers 1 and 2, in the area underlying the manufacturing plant and neighbouring areas. Cr(VI) was only detected in aquifer 3, in the limited area underlying the manufacturing plant, immediately above the hippo mud" clay. In the aquifer below the "hippo mud" clay, especially within the sandstone bedrock where groundwater is extracted for irrigation at the turf club site, no Cr(VI) was detected.

The results of soil sampling carried out at the manufacturing plant and its surroundings (refer to chapter 4, section 4.7) indicate that significant concentrations of Cr(III) and Cr(VI) were detected in the soils underlying the manufacturing plant. Within the residential area and turf club site, low levels of Cr(VI) were detected in the soil samples. Thus potential transport media for the contaminants at the site are soil (through leaching to groundwater) and groundwater (through dissolved plume migration).

5.4 Exposure pathways

Four possible pathways are defined by the RBCA methodology, i.e soil, air, groundwater and surface water. The relevant pathways in the study area are air, soil and groundwater.

5.4.1 Air

Air is a potential pathway through inhalation of dust particles containing chromium from possible wind erosion and atmospheric dispersion of chromium-contaminated surface soils on the site. However the significance of air pathway in this study is limited due to the fact that most of the manufacturing plant site is covered in concrete or asphalt, and the residential stands in the area are small, mostly built up and exposed areas are either concreted or tiled.

Air is also a potential pathway through inhalation of vapours from dissolved chromium plume, especially where groundwater is used for irrigation e.g groundwater extraction from the Natal formation is undertaken on the turf club site for irrigation. However, based on the results of site

investigations (refer to chapter 4, section 4.6), no Cr(VI) was detected in samples from pumped groundwater on the turf club site. Hence the extraction of groundwater from the rock aquifer revealed no risk at the point of exposure to potential receptors. This pathway was then not investigated further.

5.4.2 Surface runoff

The majority of the manufacturing plant site is currently paved in concrete or asphalt, and all surface runoff is collected in surface drains before being discharged into the municipal stormwater reticulation system. The run-off that is collected in surface drains from the production area of the site is tested prior to being discharged to the municipal stormwater system. Where the test results exceed the discharge criteria, the water is pumped into holding tanks and used as process water in the plant. Hence the present site surface drainage can be ruled out as primary source for the identified groundwater plume.

5.4.3 Soil

The highest measured chromium concentrations in the soils underlying the manufacturing plant were found in areas underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1991. (refer to chapter 4, section 4.7). It is suspected that the ingress of chromium into the soils from these areas led to the contamination. Chromium contamination released into the subsurface can work its way down into groundwater. Therefore the soil properties through which chromium contamination has to pass through to reach the aquifer play an important role in determining the transport and fate of chromium contamination. Below is the discussion of some of the soil characteristics.

5.4.3.1 Hydraulic conductivity

Hydraulic conductivity defines the rate of movement of water through a porous medium such as a soil or aquifer. It is a constant of proportionality in Darcy's law and is defined as the flow volume per unit cross-sectional area of porous medium under the influence of a unit hydraulic gradient.

Darcy equation:

$$Q = KiA \quad (\text{Kruseman et al 1991})$$

Solving for K gives,

$$K = Q/iA$$

Where:

Q = Volume rate of flow (m³/d)

K = Hydraulic conductivity (m/d)

i = Gradient (dimensionless)

A = Area (m²)

The hydraulic conductivities of the aquifers underlying the manufacturing plant and neighbouring areas were estimated using grain-size distribution analysis, laboratory tests and borehole pumping tests (refer to chapter 4, section 4.3). The results of the estimated hydraulic conductivities using the three methods mentioned above are summarized in Table 5.1 and discussed below.

Table 5.1: Summary of estimated hydraulic conductivities in aquifers underlying the manufacturing plant

Sample No.	Unit	Soil type	Soil origin	Particle size (%)				Average Hydraulic conductivity (m/d)
				Clay	Silt	Sand	Gravel	
BH202 (1m)	Aquifer 1	SAND	Harbour bed sediments	8	3	87	2	1.67
BH210 (3m)		Silty SAND		8	5	72	16	
BH209 (4m)		SAND		4	2	86	8	
BH202 (2m)	Aquitard 1	Sandy CLAY		24	6	70	0	0.000082
BH201 (5m)		Sandy CLAY		29	13	58	0	
BH204 (5m)		Sandy CLAY		53	14	33	0	
BH204 (7m)	Aquifer 2	SAND		8	2	86	4	0.12
BH205 (7m)		SAND		6	8	84	2	
BH202 (8m)		SAND		11	5	81	3	
BH204 (10m)	Aquitard 2	Silty Sandy CLAY		23	12	65	0	0.000097
BH202 (11m)		Sandy CLAY		30	11	59	0	
BH205 (10m)		Sandy Silty CLAY		31	18	51	0	
BH201 (11m)	Aquifer 3	SAND		10	6	81	3	0.29
BH203 (13m)		Silty SAND		10	16	68	5	
BH202 (16m)		Silty SAND		9	22	61	8	
BH205 (12m)	Aquitard 3	Silty Sandy CLAY		21	10	69	0	0.000911
BH201 (14m)		Sandy CLAY		19	21	60	0	
BH202 (16m)		Slightly Sandy Silty CLAY		9	22	68	1	
BH401 (27m)	Aquifer 4	SAND		0	13	81	6	0.02
BH403 (27m)		SAND		2	14	84	0	
BHD1 (27m)		SAND		9	6	85	0	
BHD5 (27m)	Sandstone Aquifer	SAND	Natal Group	2	2	95	1	2.23
BHD3 (30m)		SAND		6	3	86	5	
BHD1 (31m)		SAND		6	0	94	0	

Based on the obtained hydraulic conductivities in Table 5.1 above, it is clear that the sandstone aquifer had higher hydraulic conductivity than the harbour bed sediments which generally occur

in four predominantly sandy aquifer horizons (aquifers 1,2,3 and 4). This means that the movement of groundwater in the sandstone aquifer would be faster than in the harbour bed sediments. Of the harbour bed sediments, aquifer 1 had higher hydraulic conductivity, suggesting that it would easily transmit water more than the other sandy aquifer horizons (aquifers 2,3 and 4).

The aquitards interlayering different sandy aquifer horizons had very low hydraulic conductivities and this implies that groundwater movement through these layers would be very slow hence it is suspected that contamination could diffuse through these layers.

5.4.4 Groundwater

The highest measured Cr(VI) concentrations in groundwater were found in aquifer 1 and aquifer 2 underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1991 (refer to chapter 4, section 4.6). The contaminated groundwater originating from the plant site could migrate into the residential area and downstream of the plant site, thus posing immediate danger or acute health risk to the population living in the residential area and downstream of the plant site. The movement of groundwater and dispersion within the aquifer spreads the contaminant over a wider area, which can then intersect with groundwater wells, making the water supplies unsafe. Below is the discussion of some of the groundwater flow characteristics.

5.4.4.1 Groundwater recharge

Durban's climate is characterised by warm humid summers (October to March) during which the region receives most of its precipitation. Winters (April to September) are cool and relatively dry. Average monthly temperatures for the warmest month is 24.6°C (December) and for the coolest month it is 16.6°C (July). Average annual rainfall is approximately 1000mm.

Due to evaporation and surface runoff the recharge to the groundwater will be lower. The recharge rate for this area was taken from the Royal Haskoning report (2008) which focused on the South Durban Basin Area (SDBA), similar to that of the manufacturing plant. According to the Royal Haskoning report, the study area has a recharge rate of 13% of the mean annual

precipitation (MAP) using the chloride method. Figures 5.2 below illustrates the minimum and maximum temperatures and rainfall records for Durban

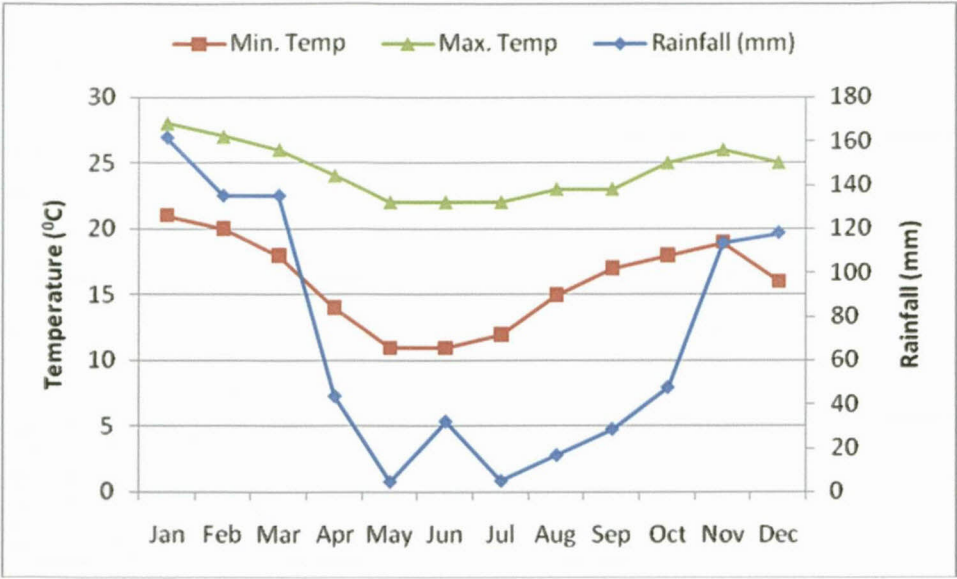


Figure 5.2: Temperatures and rainfall in Durban.

5.4.4.2 Groundwater levels

Groundwater levels (piezometric levels) were monitored in the existing boreholes and new boreholes put down on the manufacturing plant site and surrounding area on a monthly basis. The purpose of the groundwater level monitoring was to establish groundwater flow patterns within the manufacturing plant site and the surrounding area. The recorded groundwater levels in the boreholes are included in Appendix D, and summarized in Table 5.2 below.

Table 5.2: Summary of measured groundwater levels in the boreholes

Unit	Soil type	Soil origin	Borehole Numbers	Piezometric level (mbgl)	
				Average	Range
Aquifer 1	Sand	Harbour bed sediments	BH301 to BH318	1.597	0 to 3.321
Aquifer 2	Sand		BH201A to BH225A	1.248	0 to 2.093
Aquifer 3	Sand		BH201 to BH225	1.626	0 to 3.286
Aquifer 4	Sand		BH401, BH402, BH403	2.125	1.361 to 3.474
Sandstone Aquifer	Sand	Natal Group	D1, D3, D5	14.322	1.354 to 36.07

mbgl = meters below ground level

Based on Table 5.2 above, it is evident that shallow groundwater levels occurred at the approximate depths of 1.2 mbgl and 1.6 mbgl in aquifer 2 and aquifer 1 respectively. Deep groundwater level occurred at an approximate depth of 14 mbgl in the sandstone aquifer. This suggests that aquifer 1 and aquifer 2 could be more vulnerable to hexavalent chromium [Cr(VI)] contamination through washout of soluble Cr(VI) in the soils by high groundwater table, than aquifers 3,4 and sandstone aquifer.

Based on the chemical results of Cr(VI) (refer to Appendix E), it is evident that Cr(VI) concentrations were always higher in aquifer 1 and aquifer 2 as compared to the concentrations of Cr(VI) in aquifer 3, 4 and sandstone aquifer.

The graphical plots of monitoring data (Figures 4.6 to 4.10) indicate that the groundwater levels have remained relatively constant throughout the study period of approximately 5 years, and in most boreholes the groundwater level fluctuations were less than 0.5 meters. This clearly suggests that the groundwater flow could be close to steady state. The graphical plots of monitoring data also indicate that the notable response in some boreholes could be associated with seasonal groundwater fluctuations.

5.4.4.3 Groundwater flow directions

Based on the recorded groundwater levels (piezometric levels) in the boreholes (see Appendix D), the standing water elevations were determined. It was assumed that the groundwater level distribution generally emulates the surface topography and therefore the contaminated groundwater would flow from a topographic high to a topographic low. The Bayesian interpolation technique, which uses the possible relationship between the topography and groundwater levels, was used to interpolate groundwater levels and therefore the groundwater flow directions.

The groundwater level contour plots (Figures 4.12 to 4.16) indicate that the direction of groundwater flow in aquifers 1 to 3 was from the west to the east. Within Aquifer 4 and the sandstone formation the groundwater flow was from the north west to the south east in principle corresponding to the regional groundwater flow at depth from the hills towards the sea.

5.4.4.4 Seepage velocity

The movement of water through a soil mass is generally termed seepage. On a microscopic scale the water when flowing follows a tortuous route through the voids in the soil. From a practical point of view, however, it is assumed to follow a straight-line path. In Darcy’s equation, the velocity v is interpreted as the apparent or superficial velocity i.e the velocity of flow relative to a soil section area A . The actual velocity through pores will be greater, and this is termed seepage velocity (v_s).

Seepage velocity: $v_s = Q/nA = Ki/n$ (Kruseman et al 1991)

Where :

- Q = volume rate of flow (m^3/d)
- n = porosity (dimensionless)
- A = Area (m^2)
- K = Hydraulic conductivity (m/d)
- i = Gradient

The equation mentioned above was used to calculate the seepage velocities using the available hydraulic conductivity, hydraulic gradient and porosity data from field investigations (refer to chapter 4, section 4.3). The results are presented in Table 5.3 below.

Table 5.3: Summary of estimated seepage velocities for aquifers underlying the manufacturing plant

Sample No.	Unit	Soil type	Soil origin	Average Hydraulic conductivity $K(m/d)$	Average Hydraulic gradient i	Average Porosity n	Average Seepage velocity $v_s(m/d)$
BH202 (1m)	Aquifer 1	SAND	Harbour bed sediments	1.67	0.0159	0.306	0.0864
BH210 (3m)		Silty SAND					
BH209 (4m)		SAND					
BH204 (7m)	Aquifer 2	SAND		0.12	0.0173	0.261	0.0079
BH205 (7m)		SAND					
BH202 (8m)		SAND					
BH201 (11m)	Aquifer 3	SAND		0.29	0.0443	0.257	0.0501
BH203 (13m)		Silty SAND					
BH202 (16m)		Silty SAND					
BH401 (27m)	Aquifer 4	SAND		0.02	0.0084	0.287	0.0006
BH403 (27m)		SAND					
BHD1 (27m)		SAND					
BHD5 (27m)	Sandstone Aquifer	SAND	Natal Group	2.23	0.0068	0.386	0.0391
BHD3 (30m)		SAND					
BHD1 (31m)		SAND					

Based on the obtained seepage velocities in Table 5.3 above, it is clear that the harbour bed sediments which occur in four predominantly sandy aquifer horizons (aquifers 1,2,3 and 4) generally had higher seepage velocities than the sandstone aquifer. This means that the rate of movement of Cr(VI) in harbour bed sediments would be faster than in the sandstone aquifer. Of the harbour bed sediments, aquifer 1 and aquifer 3 had higher seepage velocities than aquifers 2 and 4. This suggests that the rate of movement of Cr(VI) in aquifer 1 and aquifer 3 would be faster than in the other sandy aquifer horizons (aquifers 2 and 4).

Assuming a cross-section of 100m length, the travel times for Cr(VI) in various aquifers underlying the manufacturing plant were approximated. According to the results presented above it would take 1157 days for Cr(VI) to travel through 100m of aquifer 1, 1996 days in aquifer 3, 2558 days in sandstone aquifer, 12592 days in aquifer 2 and 169237 in aquifer 4.

Based on the chemical results of Cr(VI) (refer to Appendix E), it is evident that Cr(VI) concentrations were always higher in aquifer 1 and aquifer 2 as compared to the concentrations of Cr(VI) in aquifer 3, 4 and sandstone aquifer. However, the observed high Cr(VI) concentrations in aquifers 1 and 2 could not be determined whether it was due to the rate of movement (seepage velocities) of chromium-contaminated groundwater in the sandy materials.

5.4.4.5 Retardation

If contaminants undergo chemical reactions while being transported through an aquifer, their movement rate may be less than the average groundwater flow rate, this effect is called Retardation (Palmer, 1989a). Such chemical reactions that slow movement of contaminants in an aquifer include sorption (i.e. adsorption, and ion exchange). Adsorption includes the processes by which a solute clings to a solid. Ion exchange is when the cation/anion are attracted to the region close to a positively/negatively charged clay-minerals surface and held there by electrostatic forces.

Retardation is simply the ratio of the velocity of a dissolved contaminant plume in relation to the bulk velocity of the groundwater. It can be described by the conventional retardation equation (Lyman et al., 1992):

Rf = Vw/Vc = 1 + Kdρb/n

Where:

- Rf = retardation factor (dimensionless)
- Vw = the average velocity of water (cm/sec)
- Vc = the average velocity of chemical contaminant (cm/sec)
- Kd = distribution coefficient (cm³/g)
- ρb = bulk density of the aquifer (g/cm³)
- n = soil porosity (dimensionless)

The equation mentioned above was used to estimate Cr(VI) retardation factors using the available data from field investigations (refer to chapter 4, section 4.3). The results are presented in Table 5.1 below.

Table 5.4: Estimated retardation factors for hexavalent chromium [Cr(VI)]

Sample No.	Unit	Description	Soil origin	pH	Average Bulk density ρb ¹ (g/cm ³)	Average Distribution coefficient Kd ² (cm ³ /g)	Average Porosity n	Average Retardation factor Rf
BH202 (1m)	Aquifer 1	SAND	Harbour bed sediments	6.32	1.52	19	0.306	100
BH210 (3m)		Silty SAND		6.35				
BH209 (4m)		SAND		6.42				
BH204 (7m)	Aquifer 2	SAND		7.08	1.52	17	0.261	102
BH205 (7m)		SAND		12.16				
BH202 (8m)		SAND		6.32				
BH201 (11m)	Aquifer 3	SAND		6.71	1.52	19	0.257	114
BH203 (13m)		Silty SAND		6.21				
BH202 (16m)		Silty SAND		6.32				
BH401 (27m)	Aquifer 4	SAND		6.24	1.52	19	0.287	102
BH403 (27m)		SAND		6.02				
BHD1 (27m)		SAND		7.74				
BHD5 (27m)	Sandstone Aquifer	SAND	Natal Group	6.78	1.52	19	0.386	77
BHD3 (30m)		SAND		7.05				
BHD1 (31m)		SAND		7.74				

¹ Typical values of dry density of various soil types, Linsley et al. (1992); Proffijn (1998).
² Distribution coefficient for metals, 1996 EPA soil screening guidance. Technical background document

According to the results presented in Table 5.4 above, it is evident that the harbour bed sediments which occur in four predominantly sandy aquifer horizons (aquifers 1,2,3 and 4) had higher retardation factors than the sandstone aquifer. This implies that Cr(VI) would be adsorbed more in the sandy materials (aquifers 1,2,3 and 4) than in the sandstone aquifer. This suggests that the sandstone aquifer is expected to have high concentrations of Cr(VI) as compared to the sandy materials (aquifers 1,2,3 and 4) .

Based on the chemical results of Cr(VI) in Appendix E, it is evident that Cr(VI) concentrations were always higher in aquifer 1 and aquifer 2 as compared to the concentrations of Cr(VI) in aquifer 3 and aquifer 4. Within the sandstone bedrock where groundwater is extracted for irrigation at the turf club site, no Cr(VI) was detected. Clearly the estimated retardation factors were found to be not consistent with the chemical results, indicating that chromium contamination could not be explained by retardation process only.

5.4.5 Potential receptors and complete pathways

Based on the results of the field investigations (refer to chapter 4, sections 4.6 and 4.7), The following potential exposure pathways of contamination from the source to the point of exposure and receptors have been identified in the study area.

- Soil to human - Is the potential exposure of humans by ingestion, dermal contact or inhalation of Cr(VI) or Cr(III) of contaminated soil. For inhalation, exposure is via the top 30cm of soil. For ingestion and dermal contact, exposure is via the top 60cm of soil.
- Soil to groundwater - The receptor or subject of protection is the groundwater with the point of exposure at the groundwater surface.
- Soil to plant - Concerns the potential uptake of Cr(VI) by the plants from contaminated soil/groundwater.
- Groundwater - Is the migration of the Cr(VI) contamination within the groundwater to any receptor. It is addressed in this context as groundwater plume or plume only.
- Groundwater to construction worker - Addresses the potential exposure of construction workers by dermal contact and involuntarily ingestion of contaminated groundwater during below ground level construction work.
- Groundwater to shallow boreholes - Addresses the potential exposure of receptors by groundwater extracted for use from shallow aquifers above the Hippo Mud. Potential receptors could be humans (drinking water), livestock or plants (irrigation).
- Groundwater to deep boreholes - Addresses the potential exposure of receptors by groundwater extracted for use from the fractured rock aquifer (Natal Sandstone formation) below the Hippo Mud. Potential receptors could be humans (drinking water), livestock or plants (irrigation).

The identified exposure scenarios and potential pathways of the contaminant from the source to the point of exposure of the receptors are shown diagrammatically in Figure 5.3 below.

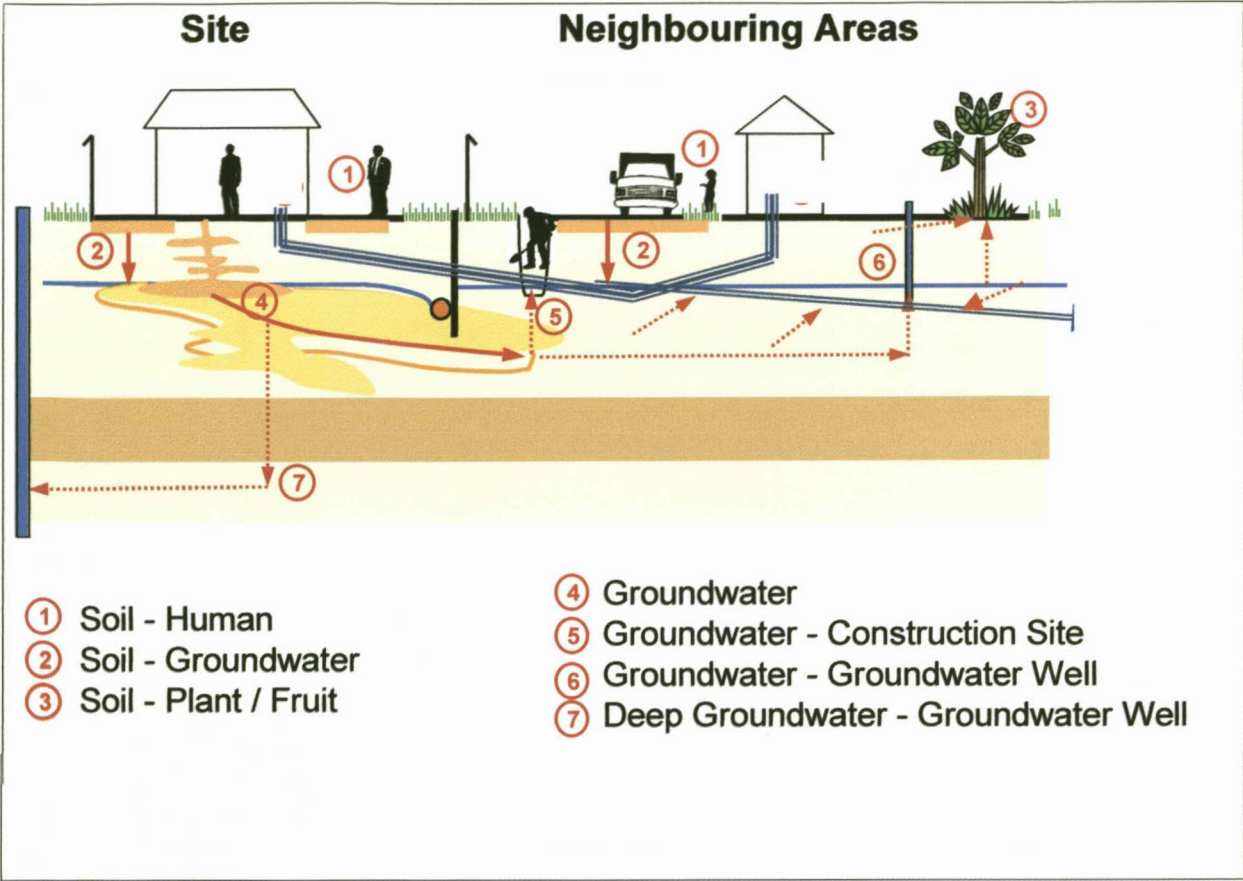


Figure 5.3: Sources, pathways, exposure scenarios and receptors of concern at the manufacturing plant site.

CHAPTER 6. RISK ASSESSMENT

6.1 Risk Based Corrective Action

6.1.1 Overview of Risk Based Corrective Action

Risk Based Corrective Action (RBCA) is a decision-making process for assessment and response to subsurface contamination associated with chemical substance releases. The guidelines for RBCA are published in American Society for Testing Materials (ASTM E-1739-95). RBCA integrates Environmental Protection Act (EPA) risk assessment practices with traditional site investigation and remedy selection activities in order to determine the cost-effective measures for protection of human health and environmental measures. Under this integrated approach, chemical substance release sites are characterized in terms of sources, transport mechanism and receptors. Remedial measures are then applied as needed to human health or environmental exposure to harmful levels of site constituent. Risk Based Corrective Action can be used by addressing any step in the exposure process such as (Connor et al, 1995):

- i. Removing or treating the source
- ii. Interrupting contaminant transport mechanism or
- iii. Controlling activities at the point of exposure.

Under RBCA, risk management strategies are developed and implemented in accordance with the process flowchart as shown in Figure 6.1 below. Based on the available site information, a site classification step is completed to characterize the relative magnitude immediacy of site risks and prescribe immediate response actions (Step 2 on figure 5.2). After any acute or near-term hazards have been properly addressed, risk-based clean-up standards are developed to protect against potential chronic health or environmental impacts associated with long-term exposure to low levels of contaminants (Step 3-7 on figure 5.2). To achieve the final risk management goals, the remedial action program may involve:

- i. Source removal/treatment
- ii. Contaminant measures
- iii. Institutional controls and
- iv. Some combination thereof.

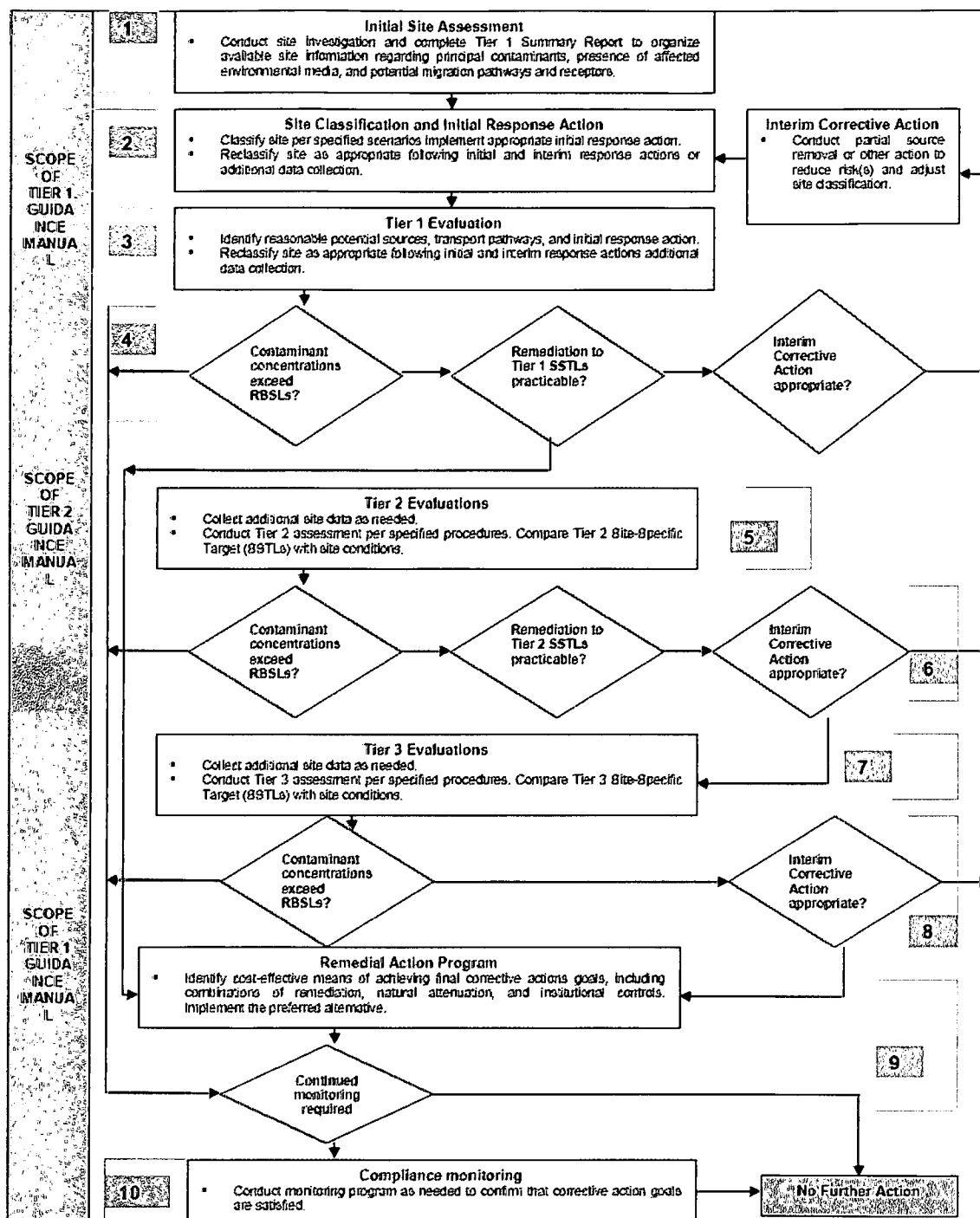


Figure 6.1: ASTM Risk-Based Corrective Action (RBCA) flowchart (Connor et al, 1995).

Further discussion of the underlying concepts of the RBCA process, as well as the specific tasks involved in site classification and development of risk-based remediation goals are provided below.

6.1.2. Hazard characterization and response under RBCA.

Release of petroleum products or other chemical substances can result in an acute (i.e. , immediate) or a chronic (i.e. , long-term) hazard to life or health. In general, chronic hazards are associated with long-term exposure to relatively low levels of the site constituents, whereas acute hazards involve high concentrations sufficient to pose an immediate risk of fire, explosion, or health impairment. The presence of an acute hazard can be ascertained based on established threshold criteria (e.g. , lower explosive limit, vapour IDLH). However, chronic health effects are not immediately evident and therefore require a more careful evaluation of long-term, future exposure patterns in order to establish appropriate site cleanup (Connor et al, 1995).

Consistent with EPA risk assessment protocol, the RBCA Tier1, 2, and 3 evaluations address source zone cleanup standards that will protect against chronic health or environmental impacts, i.e. , carcinogenic or toxic effects caused by long-term exposure to low level of contaminants. Such analysis is appropriate only after any and all acute hazards associated with the site have been identified and properly controlled. For this purpose, the RBCA evaluation process requires site classification and implementation of appropriate interim response actions (see step 2 on Figure 6.1) prior to analysis of media cleanup standards. Types of acute hazards to be addressed in the site classification-response phase include explosive vapour levels, utility impacts, or the presence of free phase hydrocarbon liquid in the groundwater. In addition, interim stabilization measure may be applied to prevent incidence of short-term chronic impacts.

Following completion of step 1 to 4 of RBCA process (Figure 6.1), the procedures outlined in this ASTM Risk Based Corrective Action can be used to define site-specific soil and groundwater cleanup levels necessary to protect against future health impacts. The general sequence of hazard characterization and response under RBCA is illustrated on Figure 6.1. As shown, in some applications, other non-aesthetic consideration (i.e. , odour, appearance and taste) may affect the future use of a property or resources even after constituent concentrations have been reduced to levels posing no further health concern (Connor et al, 1995).

6.1.3 RBCA Site Classification

Under the RBCA planning process, sites are first classified with regard to the current magnitude and immediacy of human health and environmental risks. Appropriate emergency actions are then implemented without delay to address acute hazards or near term-term impacts. Under the classification scheme outlined in ASTM E-1739, applicable exposure scenarios are reviewed to match the site with one of the four qualitative risk categories indicated in Table 6.1 below. For each classification, an appropriate response action is prescribed to effectively manage the potential site hazards as the site evaluation and remediation process. As shown on Table 6.1, remedial actions are expected at near-term high-risk sites, while interim monitoring systems are required to long-term, low-risk sites. This site classification represents a “snapshot” in time, addressing hazards associated with current site conditions and land use.

Table 6.1: RBCA site classification and response actions (Connor et al, 1995)

Current Hazard	Site Classification	Initial Response Action
Acute	Class 1: Immediate threat	Abate release
Chronic	Class 2: Near-term threat (0-2years)	Monitor/Remediate
	Class 3: Future threat (>2years)	Monitor/Investigate
Aesthetic	Class 4: No current demonstrate risk	Monitor only

6.1.4. Tiered Evaluation of Risk-Based Standards

To address the chronic human health or environmental hazards, site remediation requirements are evaluated on the basis of risk-based soil and groundwater cleanup goals, developed in accordance with U.S.EPA risk assessment guidelines. To provide an economical use at both small and large facilities, the RBCA process has been designed to match the site evaluation effort to the relative risk or complexity of each site. For this purpose, a tiered approach is employed for determination of risk-based cleanup goals, involving increasingly sophisticated levels of data collection and analysis. Upon completion of each sequential tier, the user reviews the results to determine whether further data collection and evaluation is warranted. For purpose of efficiency, the site investigation steps and decisions involved in this process are indicated on the RBCA flowchart

(Figure 6.1). The scope of Tiers 1, 2, and 3 are as follows (Connors et al, 1995):

6.1.4.1. Tier 1: Generic Screening-Level Corrective Action Goals

Tier 1 of the RBCA process involves comparison of site constituent concentration to generic Risk Based Screening Levels (RBSLs) to determine whether further evaluation is required. RBSL values are derived from standard exposure equations and reasonable maximum exposure (RME) estimates per U.S.EPA guidelines. RBSL concentration limits are designed to be protective of human health even if exposure occurs directly within the on-site area of affected soil or groundwater (i.e., the source zone).

If Tier 1 limits are not exceeded, the user may proceed directly to compliance monitoring and/or no further action (see Figure 6.1). However, if these generic levels are exceeded, the affected media may be addressed by:

- i. Remediating the generic Tier 1 limits, if applicable
- ii. Conducting a Tier 2 evaluation to develop site-specific remediation goals
- iii. Implementing an interim action to abate risk "hotspots".

In general, the Tier 1 evaluation serves to identify sites requiring no further action. For most sites exceeding Tier 1 limits, a Tier 2 analysis will provide a more cost-efficient basis for evaluation of appropriate remedial measures.

6.1.4.2. Tier 2: Site-Specific Corrective Action Goals

Under Tier 2, Site-Specific Target Levels (SSTLs) for soil and groundwater cleanup goals are determined on the basis of site-specific information and/or points of exposure. Simple analytical models are employed in conjunction with additional site data to calculate Tier 2 SSTL values in a manner consistent with EPA-recommended practices. Modelling and calculation procedures are streamlined so as to represent a minor incremental effort relative to Tier 1. Both the Tier 1 RBSL and Tier 2 SSTL values represent concentration limits for constituents within the source zone. However, SSTLs differ from RBSLs in three significant ways:

- i. Site-specific data are used to calculate the risk-based cleanup goals
- ii. Human exposure to affected media may be assumed to occur not at the source zone, but at the separate "point of exposure" (POE) and

The effects of natural attenuation of constituent concentration during lateral transport from the source to an off-site POE may be considered in the SSTL calculation (Figure 5.3).

If site constituent concentrations exceed SSTL values, subsequent actions may involve the following:

- i. Remediation to site-specific Tier 2 cleanup goals
- ii. Further evaluation per Tier 3 of the RBCA process
- iii. Interim response measures targeted at principal risk sources (see Step 6 on Figure 6.1)

6.1.4.3. Tier 3: Site-Specific Corrective Goals

If Tier 2 results are judged inappropriate or impracticable, a Tier 3 evaluation can be conducted to refine Tier 2 corrective action goals on the basis of a more complex risk and exposure assessment, involving more detailed site information, probabilistic data analysis, and/or numerical fate and transport modelling. Such Tier 3 evaluation will typically entail significant additional data and expense relative to Tiers 1 and 2 should therefore be reserved for highly complex, cost-significant sites. Tier analysis may be warranted at sites for which Tier 2 modeling methods are non-conservative or detailed ecological impact assessment are required. Similar to Tier 2, the Tier 3 evaluation provides source zone cleanup levels designed to protect against health or environmental impacts at a site-specific POE. The tiered evaluation process concludes upon derivation of applicable and remediation standards. It should be noted that the soil and groundwater standards developed under Tier 1, 2, and 3 are equally protective of human health and the environment, based on applicable target risks and exposure criteria. However, with each tier upgrade, the degree of uncertainty and conservatism involved in the cleanup standard calculation is reduced based upon a more detailed characterization of actual site condition. As indicated on the RBCA process flowchart (Figure 6.1), the user reviews the results of each tier to determine if further evaluation is necessary (Connor et al, 1995).

6.2 Tier 1 evaluation: Generic screening-level corrective action goals

6.2.1 Introduction

In the course of the Tier 1 risk assessment the potential pathways and exposure scenarios identified by the Conceptual Site Model (CSM) were evaluated. The identified potential pathways and exposure scenarios are summarised in Table 6.2 and discussed below.

Table 6.2: Exposure pathways and scenarios identified by CSM

Exposure pathway	Exposure scenario
Soil	Soil to human
	Soil to groundwater
	Soil to plant
Groundwater	Groundwater to construction worker
	Groundwater to shallow boreholes
	Groundwater to deep boreholes

The Tier 1 evaluation was done by comparing the detected contamination at the point of exposure with internationally accepted general risk-based screening levels (RBSLs). Screening levels are conservative concentrations below which an exposure would not pose a health risk to the most sensitive exposed receptor. Where contaminant concentrations are below screening levels, no corrective actions are required.

If concentrations at the point of exposure exceed screening levels, the receptors might be exposed to an unacceptable risk. In such a case a detailed risk assessment (Tier 2) for the site specific exposure/receptor relationship is needed to quantify the actual risk or corrective, mitigation or remediation actions which are necessary. Furthermore, if general screening levels do not exist or if they are not appropriate/applicable for the situation at hand, pathway and receptor specific risk assessments are carried out to assess the actual risk and to deduce appropriate actions.

6.2.2 Soil to human

Most of the manufacturing plant site is covered in concrete or asphalt. However, the possibility that workers could come in contact with the impacted subsurface soils on the plant site at non-sealed surfaces cannot be ruled out completely. That scenario could cause a risk of inhalation of

dust particles containing chromium or ingestion of chromium contaminated soils with concurrent skin contact.

The residential stands in the area are small, mostly built up and exposed areas are either concreted or tiled. However, the possibility that the general public could come in contact with the impacted subsurface soils in the residential area at non-sealed surfaces cannot be ruled out completely. That scenario could cause a risk of inhalation of dust particles containing chromium or ingestion of chromium contaminated soils with concurrent skin contact.

The Tier 1 risk assessment for the exposure scenario soil to human considered exposures to Cr(III) and Cr(VI). The risk was assessed by comparing the soil contamination with the appropriate soil screening levels (SSL). Generally, inhalation, ingestion and dermal contact are considered relevant routes of exposure for soil at all depths. Inhalation is only regarded as a relevant route of exposure for near surface soils at depths of less than 30 cm below ground level.

The analytical results for Cr(VI) and Cr(III) were compared to the US EPA soil screening levels for Cr(VI) and Cr(III) as listed in Table 6.3. The results of the risk assessment for the exposure scenario soil to human are given in Appendix G and discussed below.

Table 6.3: US EPA Generic Soil Screening Levels

Compound	Residential Scenario		Commercial/Industrial Scenario: Outdoor Worker Receptor	
	Ingestion / Dermal (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Ingestion/ Dermal (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)
Trivalent Chromium Cr (III)	120 000	Low toxicity; no guideline	1 000 000	Low toxicity; no guideline
Hexavalent Chromium Cr (VI)	230	260	3400	510

Based on the results of the risk assessment for the exposure scenario soil to human in Appendix G, it is evident that the measured concentrations both for Cr(III) and Cr(VI) in the soil samples taken on the manufacturing plant site were always below the SSL's for ingestion and dermal contact for commercial/industrial areas. Beneath certain areas of the plant site, the Cr(VI) concentrations in the soil exceeded the SSL's for inhalation of fugitive particulates. These

contaminant values do not pose a health risk to workers on the plant site or on neighbouring industrial sites, as in all instances the ground surface is covered by buildings and/or paved in concrete/asphalt. Special safe working procedures should be established and applied where infrequent excavations on the plant site are required. Further corrective actions concerning the potential exposure of workers to soil on the plant site are not deemed necessary. In Figure 6.2 the maximum measured Cr(VI) concentrations in the soil samples taken on manufacturing plant site are visualized.

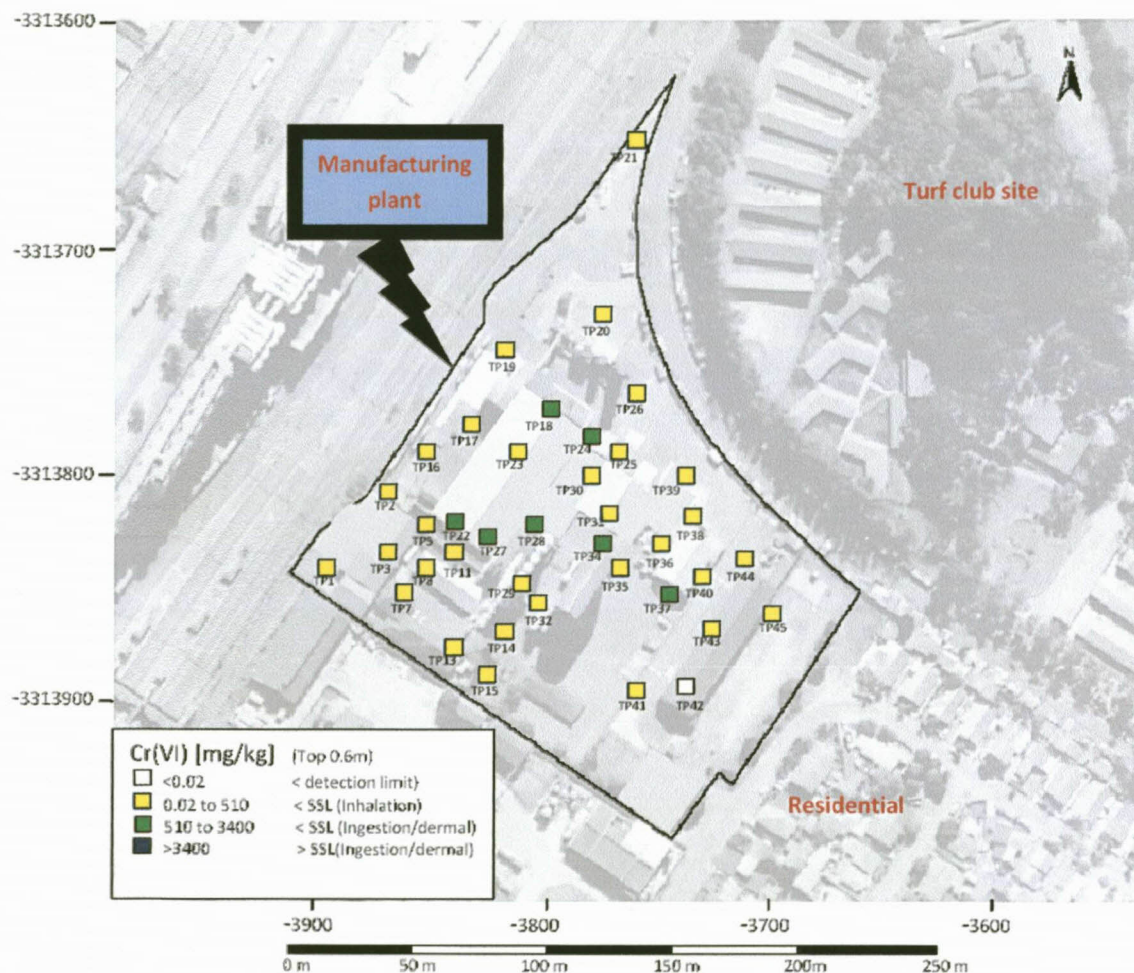


Figure 6.2: Maximum Cr(VI) concentrations in the top soil on the manufacturing plant.

In Figure 6.3 the maximum measured Cr(III) concentrations in the soil samples taken on the manufacturing plant site are shown.

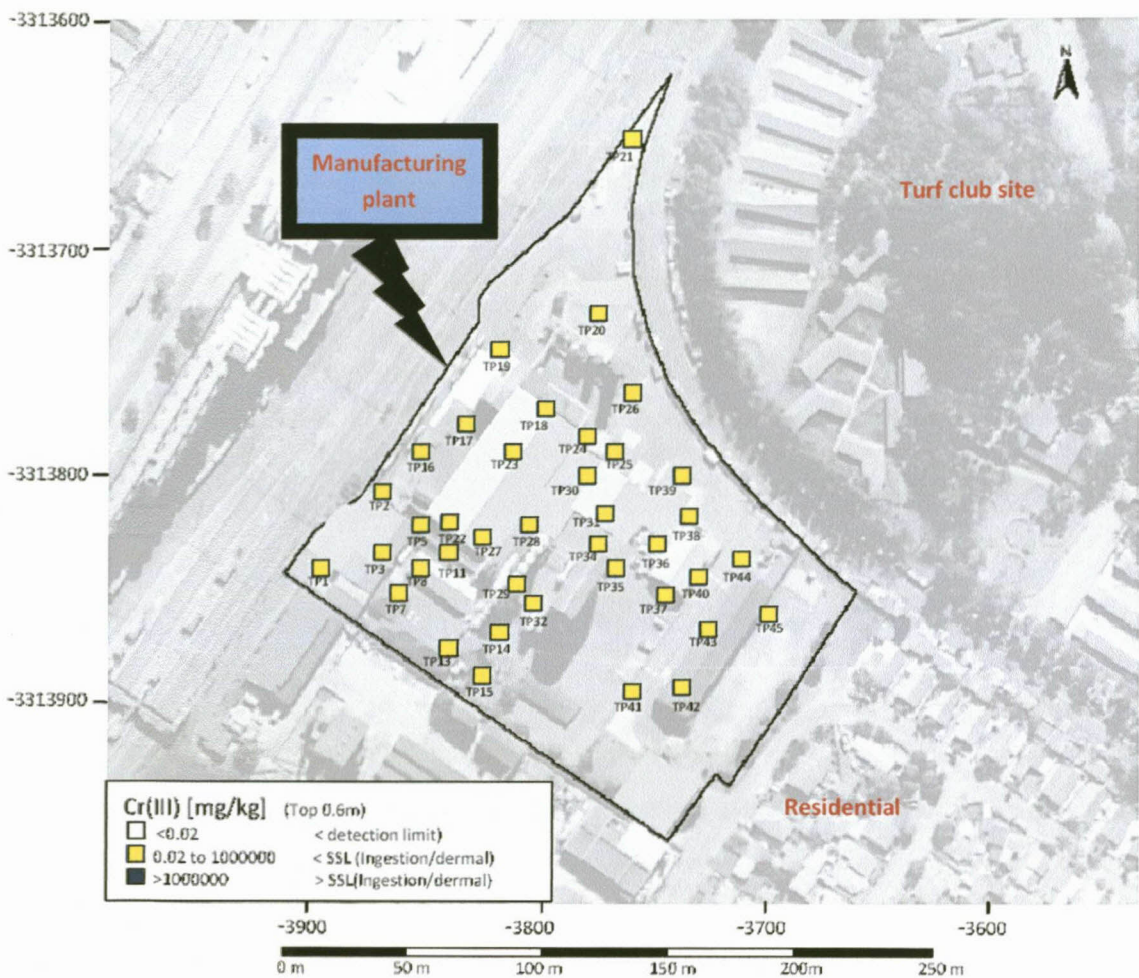


Figure 6.3: Maximum Cr(III) concentrations in the top soil on the manufacturing plant.

The measured concentrations of Cr (VI) in the upper 30cm of soil in the residential area and turf club site were much lower than SSL's for inhalation as well as ingestion/dermal contact of 260 mg/kg and 230 mg/kg respectively. Similarly, the concentrations of Cr(VI) in the unsaturated soils at greater depths were below the SSL's for ingestion and dermal contact. The majority of the soil samples in the residential area and turf club site reported Cr (VI) concentrations at levels below the method detection limit of 0,02mg/kg.

All deduced Cr(III) concentrations of the soil samples were well below the SSL of 120000 mg/kg in the neighbouring area. Hence neither of the concentrations of Cr(VI) and Cr(III) found in the soils of the neighbouring area pose risk to humans.

Figure 6.4 gives an overview of the maximum measured Cr(VI) concentrations in the soil samples outside of the manufacturing plant site in the top 60 cm.

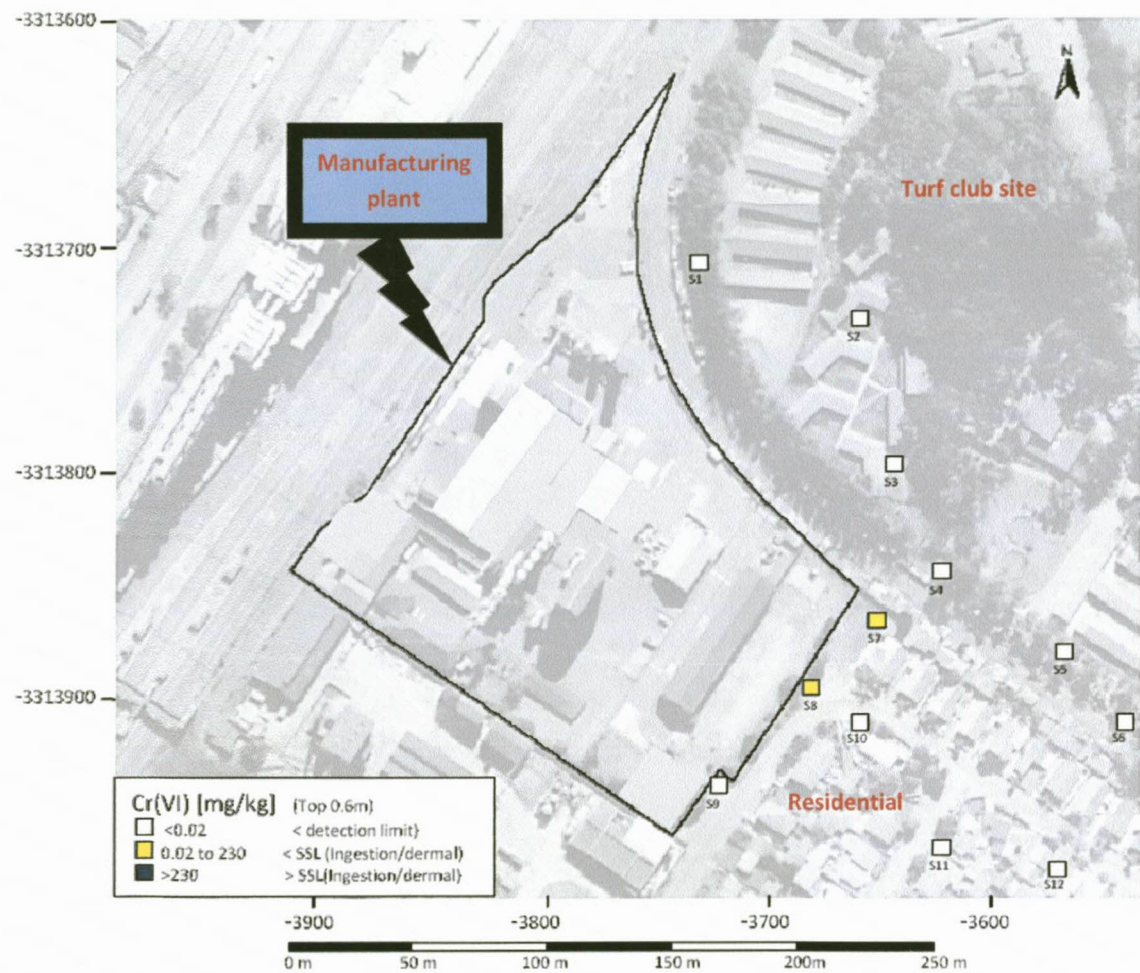


Figure 6.4: Maximum Cr(VI) concentrations in the top soil off the manufacturing plant.

In Figure 6.5 the maximum measured Cr(III) concentrations in the soil samples off the manufacturing plant site in the top 60 cm are shown.

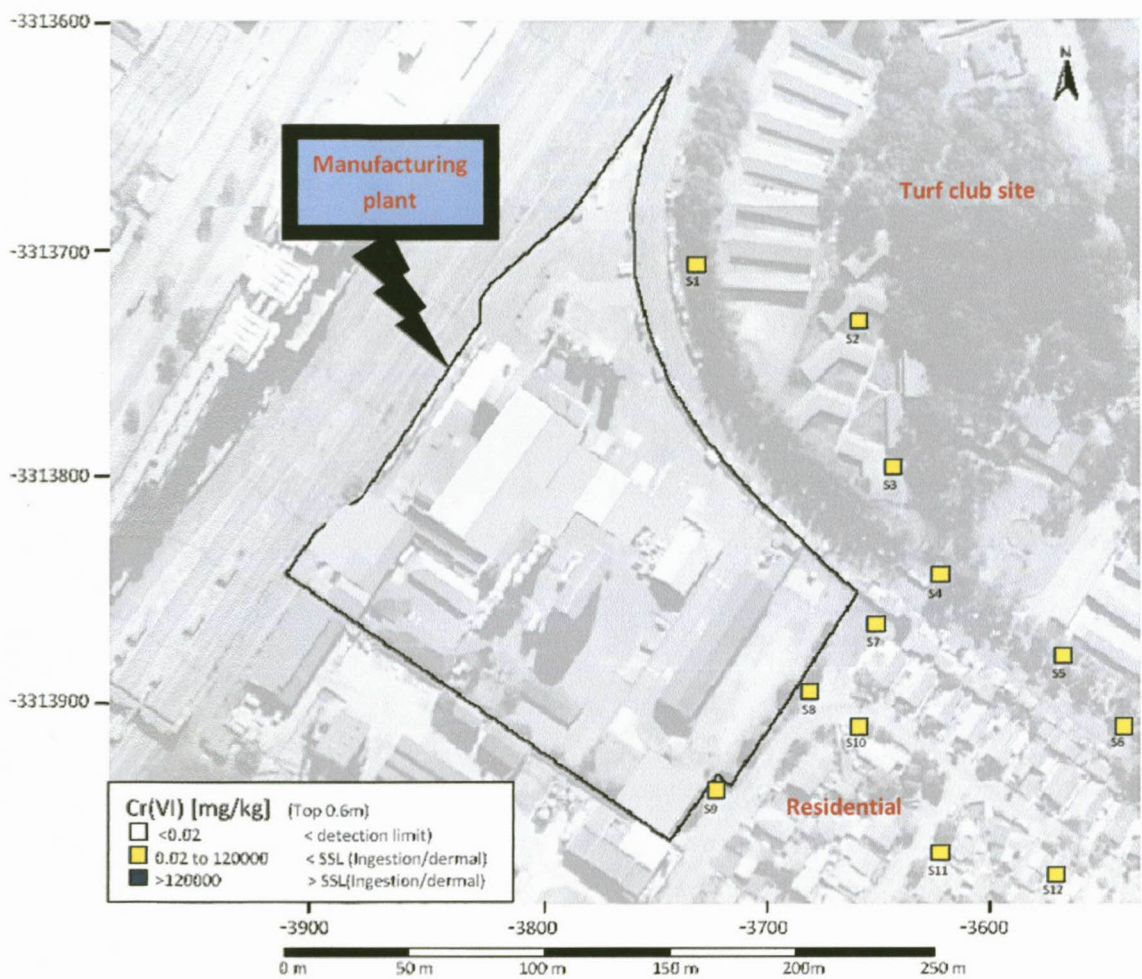


Figure 6.5: Maximum Cr(III) concentrations in the top soil off the manufacturing plant.

6.2.3 Soil to groundwater

The highest measured chromium concentrations in the soils underlying the manufacturing plant were found in areas underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990. (refer to chapter 4, section 4.6). Besides the ‘hot spots’ (active sources), the site investigations revealed Cr(VI)

concentrations in the soil on parts of the manufacturing plant site and at some locations in the neighbouring area.

It is suspected that the ingress of chromium into the soils from these areas led to the contamination. Chromium contamination released into the subsurface can work its way down into groundwater. This exposure pathway indicates whether an established soil contamination poses a risk to the groundwater as a protected natural resource. The contaminant of concern for this pathway is Cr(VI) only. Cr(III) need not be considered due to its low solubility in water and its general transport behaviour in groundwater.

It is believed Cr(VI) containing process residuals were used in the past for backfilling on the manufacturing plant site. This might be an additional limited source for groundwater contamination through washout of soluble Cr(VI) by infiltrating rain or high groundwater table. However, the observed high Cr(VI) concentrations in aquifers 1 and 2 cannot be explained by the latter processes only.

To assess the risk of soil contamination, US EPA generic soil screening levels for the migration to groundwater were applied as shown in Table 6.4. The results of the risk assessment for the exposure scenario soil to groundwater are given in Appendix G and discussed below.

Table 6.4: US EPA generic soil screening levels for migration to groundwater

Compound	Migration to groundwater	Migration to groundwater
	DAF =20 (mg/kg)	DAF =1 (mg/kg)
Trivalent Chromium Cr (III)	No concern	No concern
Hexavalent Chromium Cr (VI)	38	2

DAF: Dilution Attenuation Factor

Based on the results of the risk assessment for the exposure scenario soil to groundwater in Appendix G, it is evident that on the manufacturing plant site outside the groundwater plume area, the Cr(VI) concentrations in the soils were below the SL of 38 mg/kg. In the vicinity of the ‘hot spots’ the Cr(VI) concentrations were above the SL. Therefore these contaminated soil areas have an impact on the groundwater plume. It is therefore considered a priority to take measures that would further reduce the possibility of contact with the contaminated groundwater and to implement a strategy of corrective action to reduce the levels of contamination. Members of the

community should be made aware that deep excavations into the plume area should be avoided. Corrective action concerning the groundwater plume is necessary

In the residential area and turf club site, the measured Cr(VI) concentrations in the soil samples outside the plume area and within the plume were all below the SL of 38 mg/kg. Hence the migration of Cr(VI) from the soil to the groundwater in the neighbouring area is of no concern and does not pose a risk. Figure 6.6 shows the maximum measured Cr(VI) concentrations in soil samples on and off the manufacturing plant site.

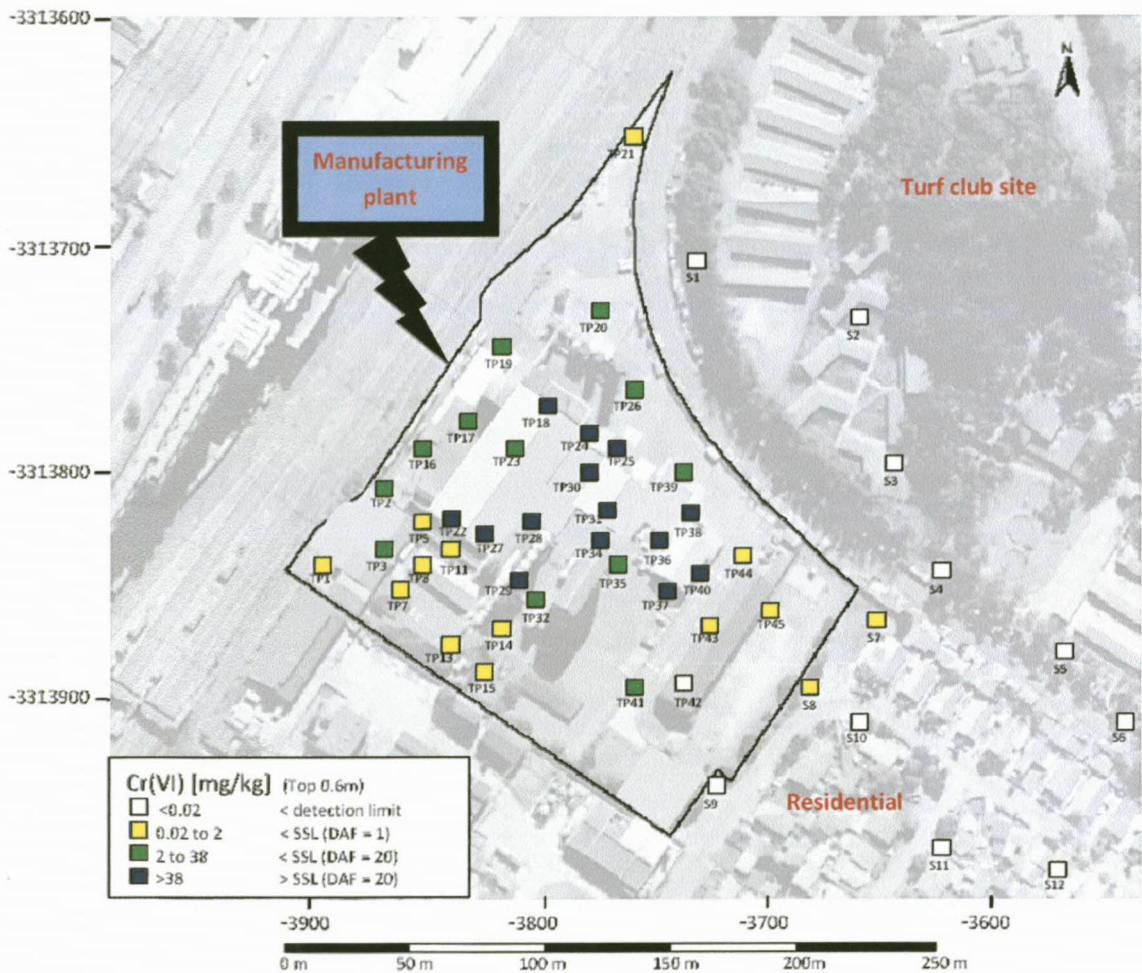


Figure 6.6: Maximum Cr(VI) concentrations in the top soil on the manufacturing plant.

6.2.4 Soil to plant

The potential pathway of Cr(VI) from soil (and groundwater) to plants is of concern to the residents of the neighbouring residential area adjacent to the manufacturing plant. Numerous studies and scientific papers, i.e. Lytle et. al. 1998 or Zayed & Terry, 2003, clearly indicated that the soluble Cr(VI) is not taken up easily by plants. If taken up by plants or in general by living tissue it is rapidly converted to Cr(III). Cr(III) in plants does not pose any risk to human health since it is an important component of a balanced human diet. Hence the exposure scenario soil to plant to human does not pose a risk.

6.2.5 Groundwater plume

Based on the site investigation results (refer to chapter 4, section 4.6) the extent of the Cr(VI) plume is well documented in aquifers 1,2 and 3. In aquifer 4 and within the underlying fractured rock aquifer of the Natal Sandstone formation no Cr(VI) was detected. The main portion of the actual plume is located within aquifer 1 and aquifer 2 where the maximum Cr(VI) concentrations were observed. In aquifer 3, Cr(VI) was detected within a limited area at the manufacturing plant site. In aquifer 4 and within the Natal Sandstone formation, where groundwater is extracted for irrigation at the adjacent turf club site, no Cr(VI) was detected. Figure 6.7 shows the projected extent of the Cr(VI) plume. Outside this area all the analysed Cr(VI) concentrations of the groundwater samples were below the detection level of 0.02 mg/l.

To assess the risk of groundwater contamination in terms of the potential use of the groundwater in the area, the analytical results for Cr(VI) were compared to the generally accepted Tier 1 risk-based screening levels (RBSLs) for Cr(VI) in groundwater as shown in Table 6.5 . The results of the risk assessment for the groundwater contamination are given in Appendix G and discussed below

Table 6.5: US EPA risk based screening levels for groundwater

Compound	Potential use of groundwater		
	Drinking water (mg/l)	Irrigation (mg/l)	Livestock (mg/l)
Hexavalent Chromium Cr (VI)	0.05	0.1	1.0

Based on the results of the risk assessment for the groundwater contamination in Appendix G, it is clear that the amount of the Cr(VI) concentrations in the groundwater plume exceeded all risk based screening levels for drinking water, irrigation and livestock. The groundwater within the plume is not fit for any use. It should be appreciated that the contaminated groundwater starts approximately 1 to 2 meters below the ground surface. Provided a person does not come into direct contact with the contaminated water, for example through drinking or skin contact, there would be no risk of adverse health effects to the person. The contaminated groundwater is clearly not suitable for drinking, irrigation and livestock, as exposure to large quantities of the contamination could lead to serious health effects.

It is therefore considered a priority to take measures that would further reduce the possibility of contact with the contaminated groundwater and to implement a strategy of corrective action to reduce the levels of contamination. Members of the community should be made aware that deep excavations into the plume area should be avoided. Corrective action concerning the groundwater plume is necessary.

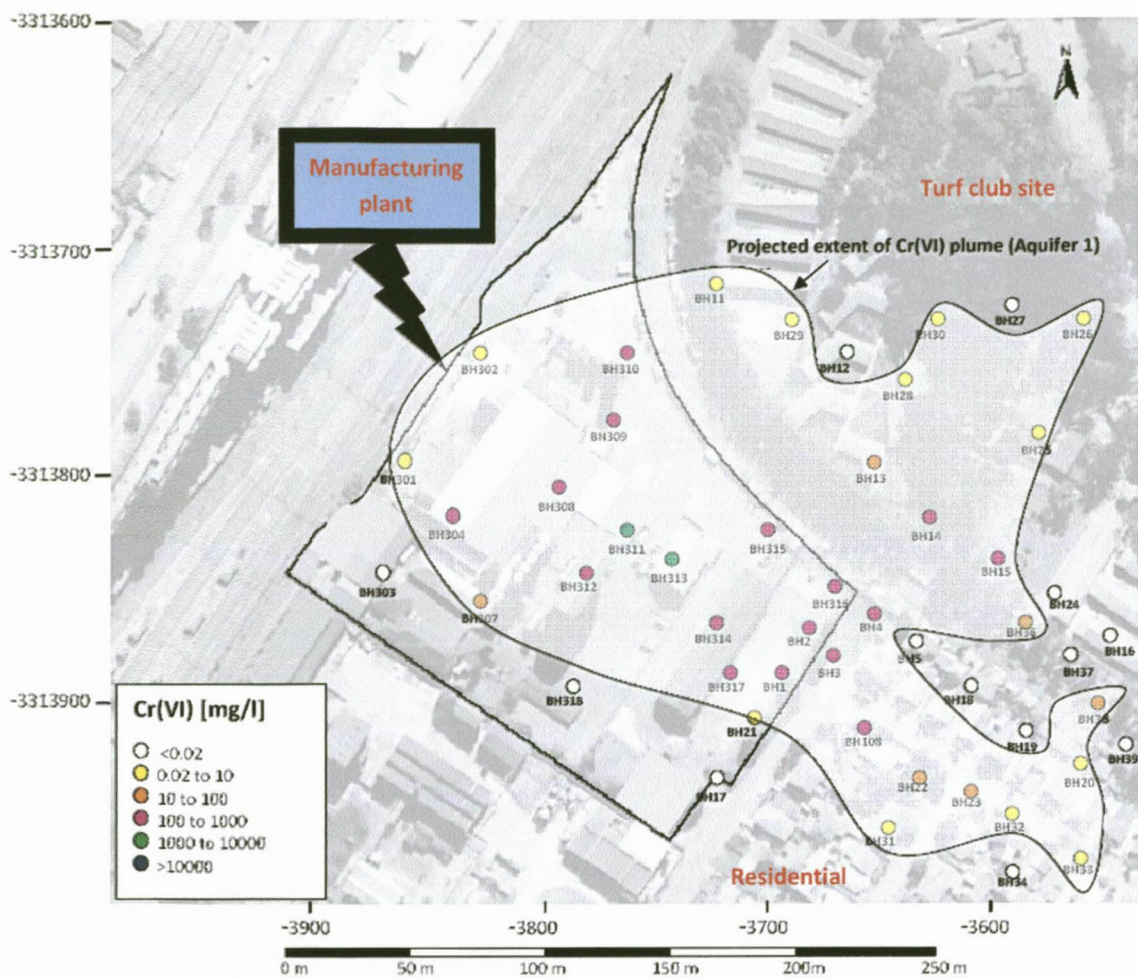


Figure 6.7: Projected extent of plume.

6.2.5.1 Excavation Works

The groundwater within the plume is not fit for any use (refer to section 6.2.5). It should be appreciated that the contaminated groundwater starts approximately 1 to 2 meters below the ground surface. Any excavations and below ground level construction within the plume area would potentially expose workers and members of the public to dermal contact with the contaminated groundwater.

Therefore in a scenario of dermal contact with small quantities of contaminated groundwater with concurrent ingestion, slight adverse systemic health effects may be possible, e.g. various degrees of gastrointestinal effects, depending on the chromium concentration and volume ingested, as

well as the sensitivity of the exposed individual. Dermal allergic reactions, as well as dermatitis, may be observed in chromium sensitive individuals exposed to chromium in the groundwater, especially where levels of contamination are high.

Appropriate work procedures should be developed and applied during all future excavations and below ground level construction within the plume area. These procedures should comprise protective and safety measures to prevent worker exposure to the Cr(VI) contaminated groundwater.

6.2.5.2 Groundwater extraction from shallow boreholes

Based on the results of the hydrocensus, it was revealed that there was no groundwater extraction from the shallow boreholes on the manufacturing plant and the neighbouring areas. Hence the potential exposure pathway does not exist and currently poses no risk to potential receptors. Groundwater extraction boreholes or wells must not be installed within the plume area except for remedial actions. The Department of Water Affairs and Forestry should be requested to assist in this regard by applying the necessary controls.

6.2.5.3 Groundwater extraction from deep boreholes

Based on the results of the hydrocensus, it was revealed that groundwater extraction from the deep fractured rock aquifer was being undertaken on the turf club site for irrigation. The use of groundwater for irrigation purposes would create the possibility that humans come into contact with Cr(VI) - contaminated groundwater. The most likely exposure route would be dermal contact or accidental ingestion. However, based on the results of the site investigations (refer to chapter 4, section 4.6), no Cr(VI) was detected in samples from pumped groundwater on the turf club site. Hence the extraction of groundwater from the rock aquifer revealed no risk at the point of exposure to potential receptors. It is recommended to regularly monitor the extracted groundwater on the turf club site.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the theoretical research the following conclusions can be made:

- Chromium is an important industrial metal used in diverse processes. At many industrial and waste disposal locations, chromium has been released to the environment via leakage and poor storage during manufacturing or improper disposal practices
- In the environment, chromium is commonly found in two most stable oxidation states as trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)], each characterized by distinctly different chemical properties, bioavailability, and toxicity.
- Trivalent chromium is an essential element for living beings, has relatively low toxicity, immobile under moderately alkaline to slightly acidic conditions, and strongly partitioned into the solid phases, while hexavalent chromium is very toxic, carcinogenic, and mutagenic to both animals and humans. It is also very soluble, mobile, and moves at a rate essentially the same as the groundwater (Palmer and Puls, 1994). Industrial applications most commonly use chromium in the Cr(VI) form, which can introduce high concentrations of oxidized chromium (chromate) into the environment.

Based on the results of the case study the following conclusions can be made:

- An investigation was initiated in the study area following the discovery of hexavalent chromium in groundwater. Hexavalent chromium was detected in groundwater, in an open pit just outside the perimeter of the manufacturing plant. The historical source of this chromium contamination in the groundwater is considered to be the old sodium dichromate production and handling areas. It is suspected that the ingress of chromium into the soils from these areas led to the contamination.
- A hydrocensus survey was conducted in a 1 km radius of the manufacturing plant site in order to establish if any groundwater extraction boreholes or wells occurred in the area, and to identify the usage of the groundwater extracted from such sources. Boreholes identified in the study area were sampled and the groundwater was analysed to determine

the concentrations of hexavalent chromium, in order to ensure that there was no health risk to users from such sources.

- There were no private boreholes found in or close to the affected area. The boreholes found were mainly industrial boreholes in other industries around the manufacturing plant including the turf club site. These boreholes were in the uncontaminated aquifer and most of them were either blocked or destroyed.
- A total of 113 hand auger holes and washbore drilled boreholes were put down in phases on the manufacturing plant site and neighbouring area over the period May 2004 to August 2005. The boreholes were installed to establish the subsoil conditions and to facilitate the monitoring and sampling of the groundwater in the various aquifers underlying the study area.
- The fill underlying the site occurs from the surface to depths in the range of approximately 0.4 metres to 2.1 metres below existing ground level. The fill generally comprises brown to dark grey, silty sand to slightly clayey sand, and contains abundant gravel and rubble in places. The fill overlies the harbour bed sediments, which generally occur in four predominantly sandy aquifer horizons interlayered with clay layers of various composition and thickness. The harbour bed sediments overlie sandstone of the Natal Group or sandy siltstones of the St Lucia Formation at depths of between approximately 28 and 32 metres below existing ground level on the manufacturing plant site. The weathered sandstone immediately below the harbour beds generally comprises residual, highly weathered, orange brown, slightly clayey to silty sand. With depth the sandstone typically becomes less weathered, grading into pinkish maroon sandstone bedrock which extends to depths in excess of 100 metres below the site.
- The aquifer parameter tests were conducted to determine the transmissivities and the hydraulic conductivities of the aquifers underlying the manufacturing plant site. The transmissivities of $0.12 \text{ m}^2/\text{d}$, $0.29 \text{ m}^2/\text{d}$ and $0.02 \text{ m}^2/\text{d}$ were estimated in aquifer 2, aquifer 3 and aquifer 4 respectively. This implies that the ease with which the water moves through aquifers 3 would be faster than in aquifer 2 and aquifer 4.
- The hydraulic conductivities of 1.67 m/d , 0.12 m/d , 0.29 m/d , 0.02 m/d and 2.23 m/d were estimated in aquifer 1, aquifer 2, aquifer 3, aquifer 4 and sandstone aquifer respectively, indicating the rate of movement of water through the sandstone aquifer and aquifer 1 would be faster than in aquifer 2, aquifer 3 and aquifer 4.

- Groundwater occurred at the approximate depth of 1.25 mbgl, 1.60 mbgl, 1.63 mbgl, 2.13 mbgl and 14.32 mbgl in aquifer 2, aquifer 1, aquifer 3, aquifer 4 and sandstone aquifer respectively. The shallow groundwater levels in aquifer 1 and aquifer 2 suggested that these aquifers could be vulnerable to contamination through washout of soluble Cr(VI) in the soils by high groundwater table. However, the observed high Cr(VI)-concentrations in aquifer 1 and 2 could not be explained by the latter process only.
- Groundwater levels have remained relatively constant throughout the study period of 5 years, indicating the historical groundwater level in the area. The graphical plots of monitoring data showed that the notable response in some boreholes could be associated with seasonal groundwater fluctuations.
- Based on the groundwater level contour plots, it is evident that the direction of groundwater flow in aquifers 1 to 3 was from the west to the east. Within Aquifer 4 and the Natal formation the groundwater flow was from the north west to the south east in principle corresponding to the regional groundwater flow at depth from the hills toward the sea.
- The highest measured Cr(VI) concentrations in groundwater were found in aquifer 1 and aquifer 2 underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990. Cr(VI) was only detected in aquifer 3, in the limited area underlying the manufacturing plant, immediately above the "Hippo mud" clay. In the aquifers below the "Hippo mud" clay, aquifer 4 within the harbour bed sediments and especially within the sandstone bedrock where groundwater is extracted for irrigation at the turf club site, no hexavalent chromium was detected.
- The highest measured Cr(III) and Cr(VI) concentrations in soils were found on the manufacturing plant in areas underlying old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990.
- Within the residential area and turf club site, low levels of Cr(III) and Cr(VI) were detected in the soil samples and this could be associated with the historical surface run-off from the plant site.
- As part of risk assessment the primary source at the manufacturing plant was addressed by removing old closed or dismantled production facilities where sodium dichromate (SDC) liquid was produced or handled between 1945 and 1990.

Soil and groundwater sampling was conducted and revealed the secondary sources to be the affected surface soils (<0.3m), affected subsurface soils (>0.3m) and dissolved groundwater plume. The potential transport media for the contaminants at the site were found to be the soil (through leaching to groundwater) and groundwater (through dissolved plume migration).

- The exposure pathways of concern in the study area were found to be soil, air and groundwater.
- Seepage velocity values of 0.0864 m/d, 0.079 m/d, 0.0501 m/d, 0.0006 m/d and 0.0391 m/d were estimated in aquifer 1, aquifer 2, aquifer 3, aquifer 4 and sandstone aquifer respectively. This suggests that the rate of movement of hexavalent chromium in sandy aquifer 1 and aquifer 2 would be faster than in the sandy aquifer horizons aquifers 2 and 4, and sandstone aquifer.
- Based on the calculated retardation factors it is clear that retardation of the Cr(VI) was expected to occur at the investigated site. The retardation factors of 77, 100, 102, 102, and 114 were calculated in sandstone aquifer, aquifer 1, aquifer 2, aquifer 4 and aquifer 3 respectively. This implies that Cr(VI) would be adsorbed the most in aquifer 3 as compared to the other aquifers. Based on the chemical results of Cr(VI), it was evident that low levels of Cr(VI) in aquifer 3 were detected away the manufacturing plant as compared to the concentrations in aquifer 1 and aquifer 2, suggesting that Cr(VI) was retarded the most in aquifer 3.
- Based on the results of the risk assessment for the exposure scenario soil to human in, it is evident that the measured concentrations both for Cr(III) and Cr(VI) in the soil samples taken on the manufacturing plant site were always below the SSL's for ingestion and dermal contact for commercial/industrial areas. Beneath certain areas of the plant site, the Cr(VI) concentrations in the soil exceeded the SSL's for inhalation of fugitive particulates. These contaminant values do not pose a health risk to workers on the plant site or on neighbouring industrial sites, as in all instances the ground surface is covered by buildings and/or paved in concrete/asphalt.
- The measured concentrations of Cr (VI) in the upper 30cm of soil in the residential area and turf club site were much lower than SSL's for inhalation as well as ingestion/dermal. Similarly, the concentrations of Cr(VI) in the unsaturated soils at greater depths were below the SSL's for ingestion and dermal contact.

The majority of the soil samples in the residential area and turf club site reported Cr (VI) concentrations at levels below the method detection limit of 0,02mg/kg. All deduced Cr(III) concentrations of the soil samples were well below the SSL in the neighbouring area. Hence neither of the concentrations of Cr(VI) and Cr(III) found in the soils of the neighbouring area pose risk to humans.

- Based on the results of the risk assessment for the exposure scenario soil to groundwater in, it is evident that on the manufacturing plant site outside the groundwater plume area, the Cr(VI) concentrations in the soils were below the SL. In the vicinity of the 'hot spots' (active sources) the Cr(VI) concentrations were above the SL. Therefore these contaminated soil areas have an impact on the groundwater plume.
- In the residential area and turf club site, the measured Cr(VI) concentrations in the soil samples outside the plume area and within the plume were all below the SL of 38 mg/kg. Hence the migration of Cr(VI) from the soil to the groundwater in the neighbouring area is of no concern and does not pose a risk.
- Numerous studies and scientific papers have indicated that the soluble Cr(VI) is not taken up easily by plants. If taken up by plants or in general by living tissue it is rapidly converted to Cr(III). Cr(III) in plants does not pose any risk to human health since it is an important component of a balanced human diet. Hence the exposure scenario soil to plant to human does not pose a risk.
- Based on the results of the risk assessment for the groundwater contamination, it is clear that the amount of the Cr(VI) concentrations in the groundwater plume exceeded all risk based screening levels for drinking water, irrigation and livestock. The contaminated groundwater is clearly not suitable for drinking, irrigation and livestock, as exposure to large quantities of the contamination could lead to serious health effects. However, the contaminated groundwater starts approximately 1 to 2 meters below the ground surface., provided a person does not come into direct contact with the contaminated water through drinking or skin contact, there would be no risk of adverse health effects to the person.

7.2 Recommendations

Based on the findings of this research, and theoretical models, it becomes obvious that there is need for further research, as recommended below:

- From the launched project Department of Water and Environmental Affairs have to establish the guidelines of assessing the chromium contamination, formulation of the water quality standards with regard to chromium and finally generate the law which will then enforce the industries to allocate enough budgets for environmental management in South Africa.
- The authorities (i.e. DWEA, ET) have to be fully involved during the investigation of the chromium contamination since their involvement can then help in the disclosure of the research findings to the interested and affected parties. This is because most of the contamination which is induced in the groundwater ends up with the negative impacts to the public.
- An environmental awareness should be implemented in order to make the public aware of the chromium in the subsurface environment. This awareness can be done through workshops, by simply inviting the public as well as knowledgeable people who can then discuss the issue of chromium contamination in the subsurface focusing on its detrimental consequences to the environment.
- In terms of risk-based approach, DWEA accepts RBCA until South African risk assessment protocols are developed. This should be communicated to all officials likely to deal with chromium risk assessment. Eventually, DWEA should write an official protocol about the acceptance of RBCA so that there is consistency until South African risk-based approach has been established.

In order to avoid and/or minimize the chromium soil and groundwater contamination in the subsurface there should be:

- An inter-departmental collaboration as well as reporting incidents and progress reports to both DWEA and DET. This means that there should be a close relation between the departments as well as the consistency when it comes to the frameworks of assessing the groundwater contamination. Industries and consultants should supply the authorities

with the incident report which include all the actions taken to mitigate the problem in question. The progress and pitfalls should be forwarded to the authorities in the form of a report.

- An acceptance of some interim standard/approach for evaluating and monitoring the contamination. Consultants should always keep in touch with the authorities in order to be able to know if there is any interim approach developed to be used for conducting contamination assessments.

Based on the results, findings and conclusions drawn from the Conceptual Site Model (CSM) and the preliminary risk assessment it is recommended that the following corrective actions or mitigation measure be implemented and administered:

- Appropriate work procedures should be developed and applied during all future excavations and below ground level construction within the plume area. These procedures should comprise protective and safety measures to prevent worker exposure to the Cr(VI) contaminated groundwater.
- Residents and owners of neighbouring properties must continue to be made aware of the extent of the chromium contamination in the groundwater beneath the study area, and the need to avoid excavations and contact with the groundwater in the designated precautionary area.
- Groundwater extraction boreholes or wells must not be installed within the plume area except for remedial actions. The relevant authorities (DWEA) should be requested to assist in this regard by applying the necessary controls to eliminate any future risk to workers and residents.
- A detailed remediation plan to treat the “hot spots” (active sources) beneath the manufacturing plant site should be developed. This plan should include selected excavation and removal of contaminated soil and groundwater to landfill, and replace with clean soil/concrete/or treated soil.
- Groundwater containment system should be designed and implemented to prevent contaminants in the groundwater migrating off site.
- Groundwater extraction system at the hot spots should be designed and implemented in order to lower the groundwater table and reduce chromium concentrations in the 1st and 2nd aquifers.

- The effectiveness of the groundwater extraction and containment system should be monitored in reducing chromium concentrations.
- Site-specific target levels (SSTL's) for soil and groundwater cleanup goals should be established.

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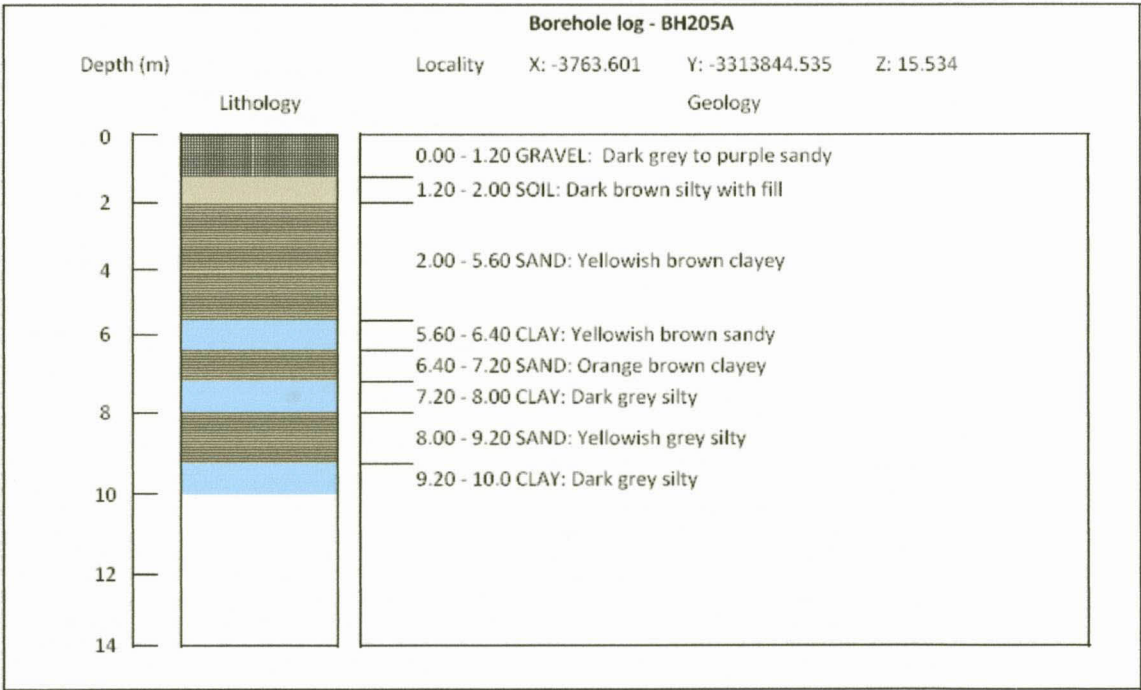
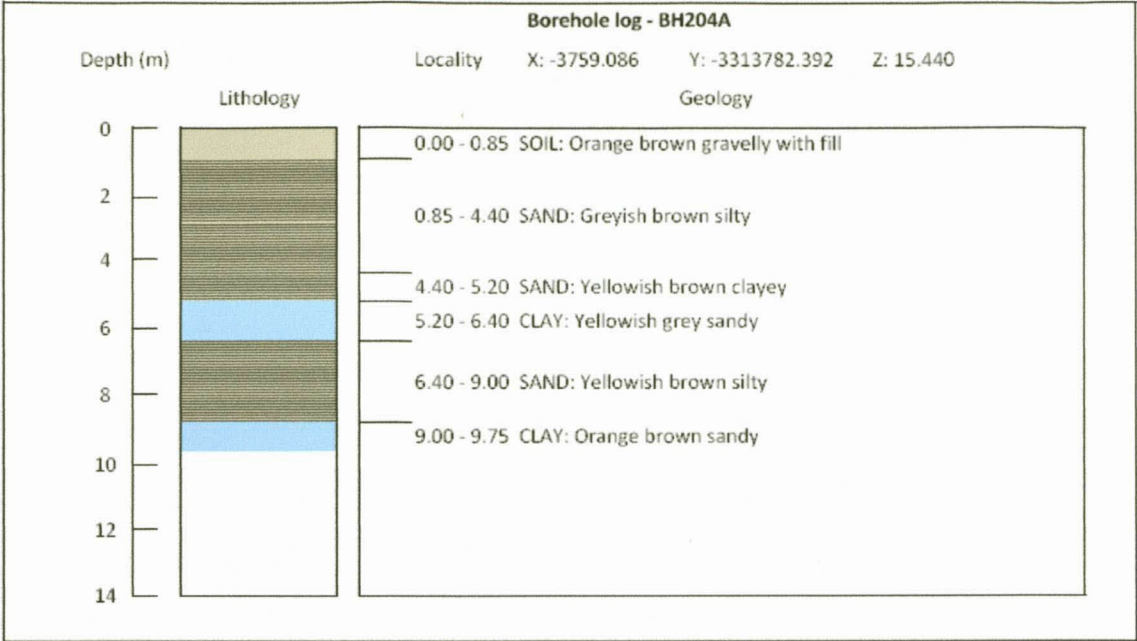
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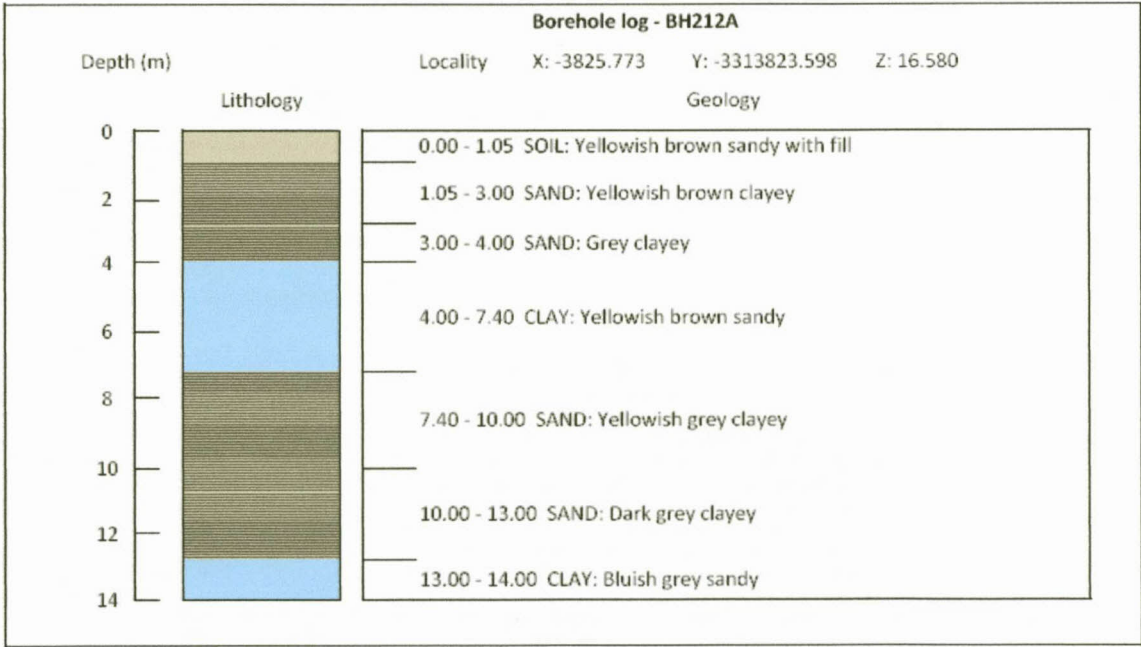
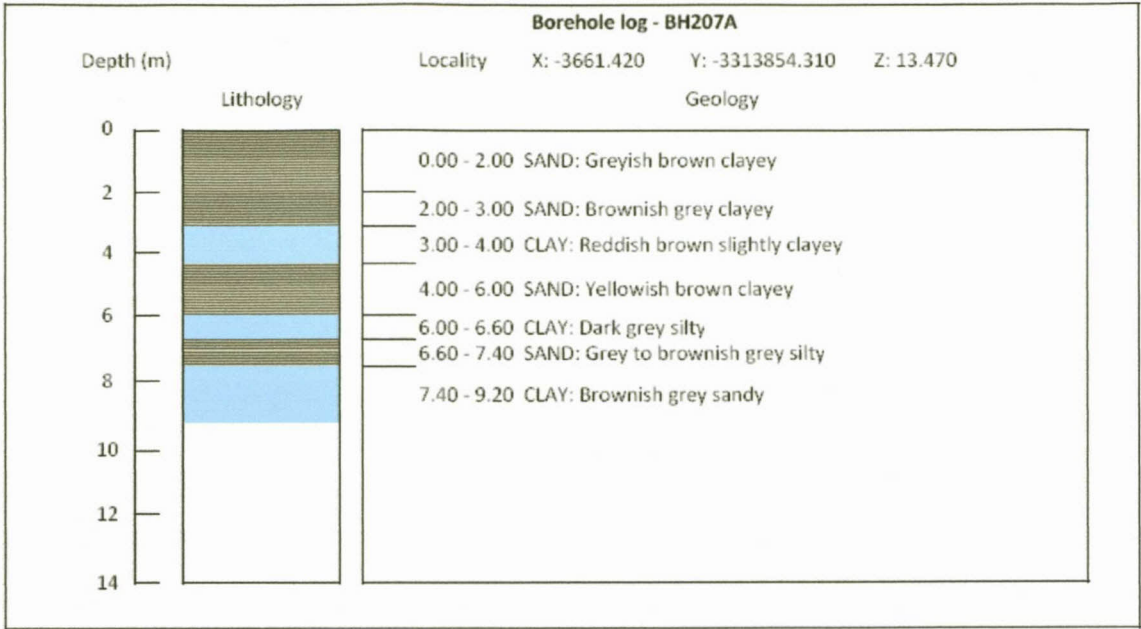
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APPENDIX A

Borehole logs (selected)





Borehole log - BH215A

Depth (m)

Locality X: -3723.200 Y: -3313789.933 Z: 14.490

Lithology

Geology



Borehole log - BH208

Depth (m)

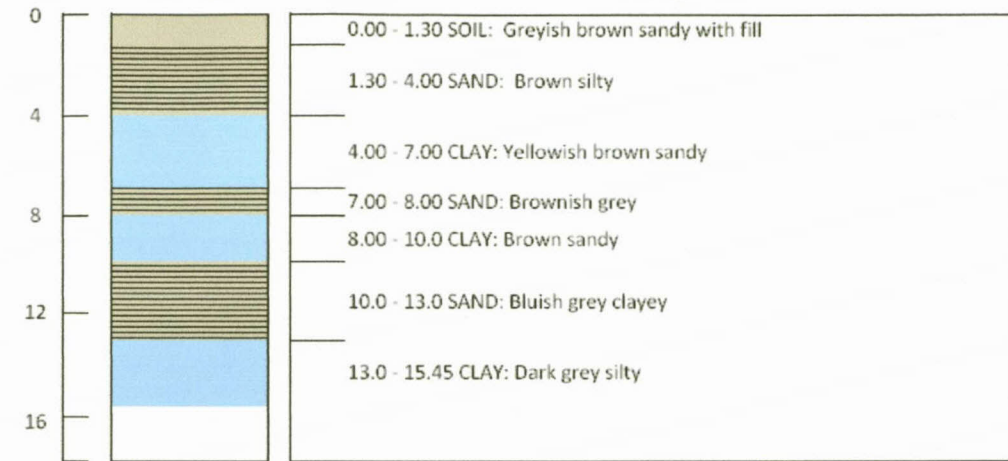
Locality - X: 3585.732 - Y: 3313763.598 Z: 12.071

Lithology

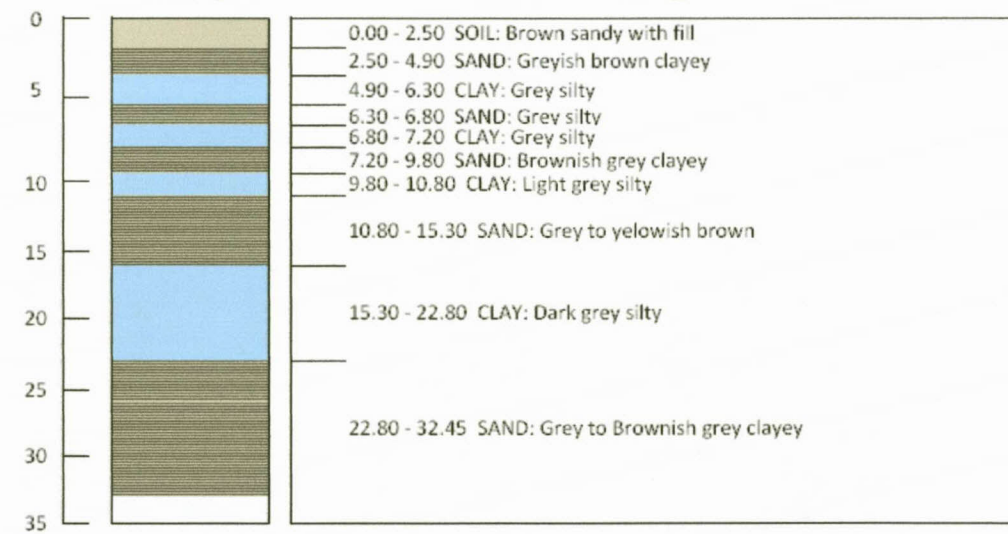
Geology



Depth (m)	Locality	X: -3706.579	Y: -3313882.941	Z: 13.923
Lithology	Geology			



Depth (m)	Locality	X: -3762.451	Y: -3313679.372	Z: 15.721
Lithology			Geology	



Borehole log - BHD5

Depth (m)

Locality

- X: 12345678

Y: 12333

Z: 1234

Lithology

Geology

0

10

20

30

40

50

60

70

0.00 - 2.40 SOIL: Brown sandy with fill

2.40 - 6.40 SAND: Yellowish brown clayey

6.40 - 7.70 SAND: Yellowish brown clayey

7.70 - 11.50 SAND: Brownish grey silty

11.50 - 13.60 CLAY: Light grey silty

13.60 - 16.00 SAND: Light grey clayey

16.00 - 24.00 CLAY: Dark brown silty

24.00 - 32.20 SAND: Yellowish brown clayey

32.20 - 51.00 SANDSTONE: Pinkish maroon weathered

APPENDIX B

Results of particle size distribution analysis

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

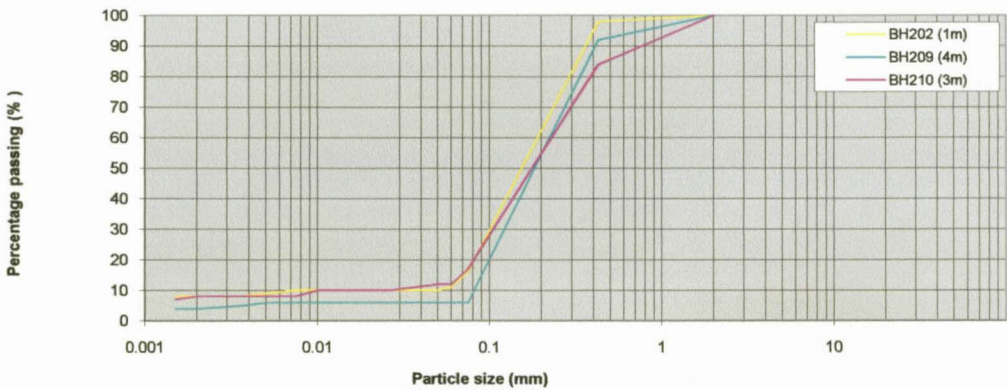
Sample No.
Depth (m)

BH202	BH210	BH209
1	3	4

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(% passing)		
100	100	100
98	84	96
16	17	10
11	12	8
10	12	8
10	10	8
10	10	8
10	10	8
10	8	8
9	8	6
8	8	6
8	8	6
8	7	6

Figure 1: Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BH202	BH210	BH209
1	3	4

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification		
2	16	8
87	72	86
3	5	2
8	8	4
SAND	Silty SAND	SAND

d_{10}
d_{15}
d_{50}
d_{60}
I_0

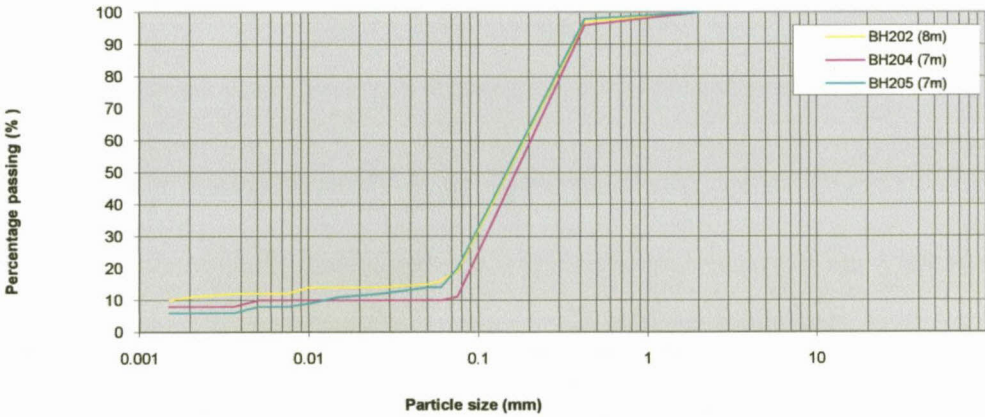
0.007	0.01	0.08
0.07	0.07	0.09
0.16	0.18	0.19
0.19	0.23	0.23
0.0034	0.0049	0.068

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

Sample No.	BH204	BH205	BH202
Depth (m)	7	7	8

Particle size (mm)	(% passing)		
19	100	100	100
13.2	96	98	97
4.75	11	20	19
2	10	14	16
0.425	10	14	15
0.075	10	12	14
0.06	10	11	14
0.05	10	9	14
0.026	10	8	12
0.015	10	8	12
0.01	10	6	12
0.0074	8	6	12
0.005	8	6	11
0.0036	8	6	10
0.002			
0.0015			

Figure 2 : Grain-size distribution curves for soil samples



Sample No.	BH204	BH205	BH202
Depth (m)	7	7	8

BS 5930 Classification	BS 5930 Classification		
Gravel (%)	4	2	2
Sand (%)	86	84	81
Silt (%)	2	8	5
Clay (%)	8	6	11
Material description	SAND	SAND	SAND

d_{10}	0.005	0.013	0.0016
d_{15}	0.08	0.065	0.055
d_{50}	0.17	0.155	0.15
d_{60}	0.2	0.18	0.18
I_g	0.0022	0.0063	-

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

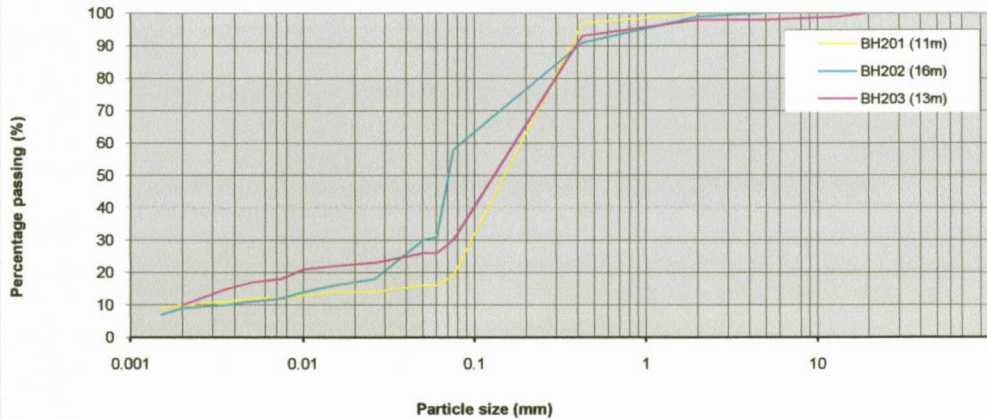
Sample No.
Depth (m)

BH201	BH203	BH202
11	13	16

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(%) passing		
	100	
	99	
	98	100
100	98	99
97	93	91
19	30	58
16	26	31
16	26	30
14	23	18
14	22	16
13	21	14
12	18	12
12	17	11
11	15	10
10	10	9
9	8	7

Figure 3 : Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BH201	BH203	BH202
11	13	16

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification		
3	5	8
81	68	61
6	16	22
10	10	9
SAND	Silty SAND	Silty SAND

d_{10}
d_{15}
d_{50}
d_{60}
I_0

0.002	0.001	0.004
0.04	0.004	0.015
0.17	0.15	0.07
0.18	0.17	0.085
-	-	0.0016

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

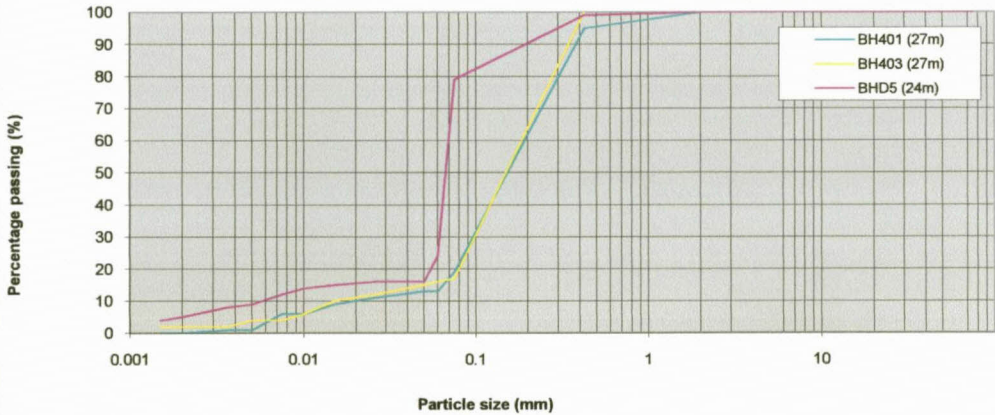
Sample No.
Depth (m)

BH401	BH403	BHD5
27	27	24

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(% passing)		
		100
		100
		100
100		100
95	100	99
19	17	79
13	16	24
13	15	16
11	12	16
9	10	15
6	6	14
6	4	12
1	4	9
1	2	8
0	2	5
0	2	4

Figure 4 : Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BH401	BH403	BHD5
27	27	24

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification		
6	0	0
81	84	85
13	14	6
0	2	9
SAND	SAND	SAND

d ₁₀
d ₁₅
d ₅₀
d ₆₀
I ₀

0.02	0.015	0.006
0.065	0.005	0.015
0.157	0.156	0.065
0.19	0.19	0.07
0.013	0.0085	0.0033

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

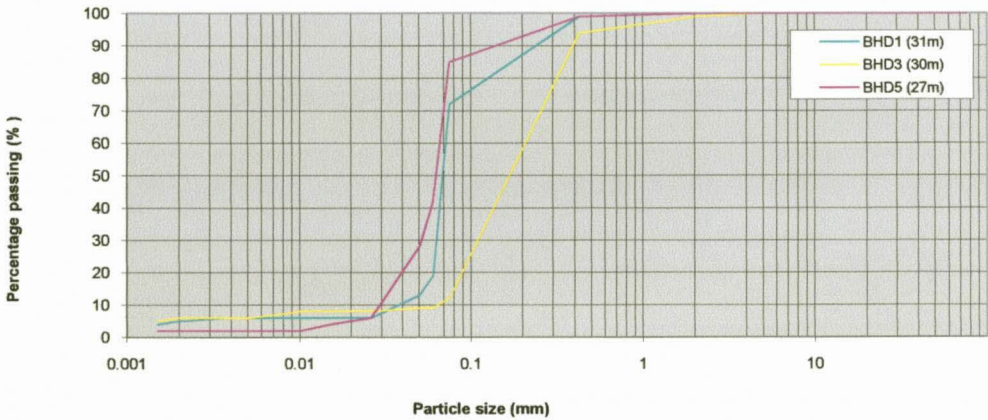
Sample No.
Depth (m)

BHD5	BHD3	BHD1
27	30	31

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(% passing)		
100		100
100		100
100	100	100
100	99	100
99	94	99
85	12	72
42	9	19
28	9	13
6	8	6
4	8	6
2	8	6
2	7	6
2	6	6
2	6	6
2	6	5
2	5	4

Figure 5 : Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BHD5	BHD3	BHD1
27	30	31

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification		
1	5	0
95	86	94
2	3	0
2	6	6
SAND	SAND	SAND

d ₁₀
d ₁₅
d ₅₀
d ₆₀
I ₀

0.03	0.07	0.04
0.035	0.08	0.055
0.065	0.18	0.07
0.065	0.21	0.07
0.025	0.05	0.032

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

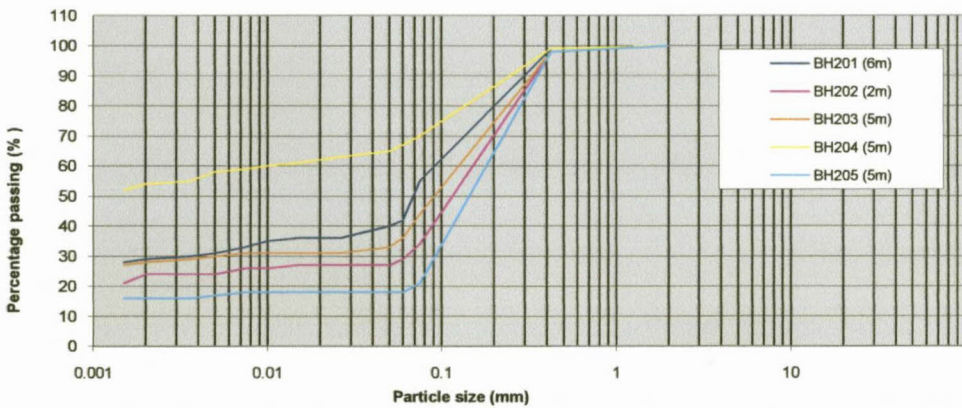
Sample No.
Depth (m)

BH202	BH203	BH204	BH205	BH201
2	5	5	5	6

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(%) passing				
100	100	100	100	100
98	98	99	98	99
34	44	70	21	55
29	36	67	18	42
27	33	65	18	40
27	31	63	18	36
27	31	61	18	36
26	31	60	18	35
26	31	59	18	33
24	30	58	17	31
24	29	55	16	30
24	28	54	16	29
21	27	52	16	28

Figure 6 : Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BH202	BH203	BH204	BH205	BH201
2	5	5	5	6

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification				
0	0	0	0	0
70	64	33	82	58
6	8	14	2	13
24	28	53	16	29
SAND	Clay SAND	CLAY	Clay SAND	Clay SAND

d_{10}
d_{15}
d_{50}
d_{60}
I_0

-	-	-	-	-
-	-	-	-	-
0.12	0.019	-	0.15	0.017
0.15	0.14	0.0017	0.175	0.019
-	-	-	-	-

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

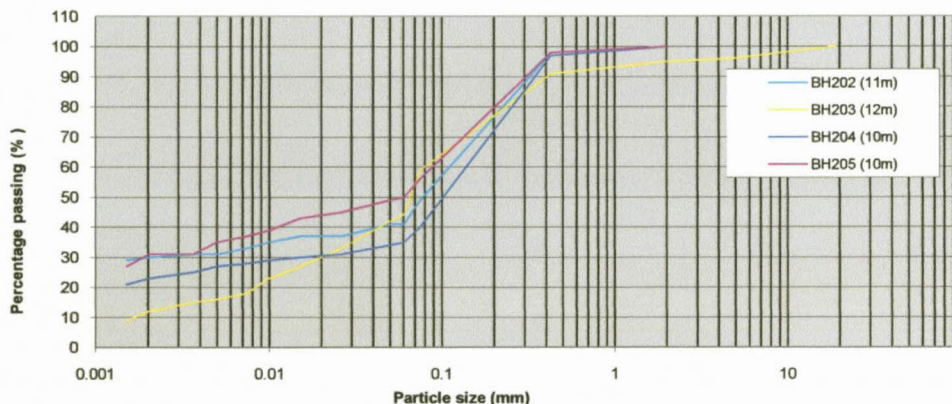
Sample No.
Depth (m)

BH204	BH205	BH202	BH203
10	10	11	12

Particle size (mm)
19
13.2
4.75
2
0.425
0.075
0.06
0.05
0.026
0.015
0.01
0.0074
0.005
0.0036
0.002
0.0015

(% passing)			
			100
			99
			96
100	100	100	95
97	98	98	91
40	56	49	59
35	50	41	44
34	49	41	42
31	45	37	33
30	43	37	27
29	39	35	23
28	37	33	18
27	35	31	16
25	31	31	15
23	31	30	12
21	27	29	9

Figure 7 : Grain-size distribution curves for soil samples



Sample No.
Depth (m)

BH204	BH205	BH202	BH203
10	10	11	12

BS 5930 Classification
Gravel (%)
Sand (%)
Silt (%)
Clay (%)
Material description

BS 5930 Classification			
0	0	0	5
65	51	59	49
12	18	11	34
23	31	30	12
Clay SAND	Clay SAND	Clay SAND	Silty SAND

d_{10}
d_{15}
d_{50}
d_{60}
I_0

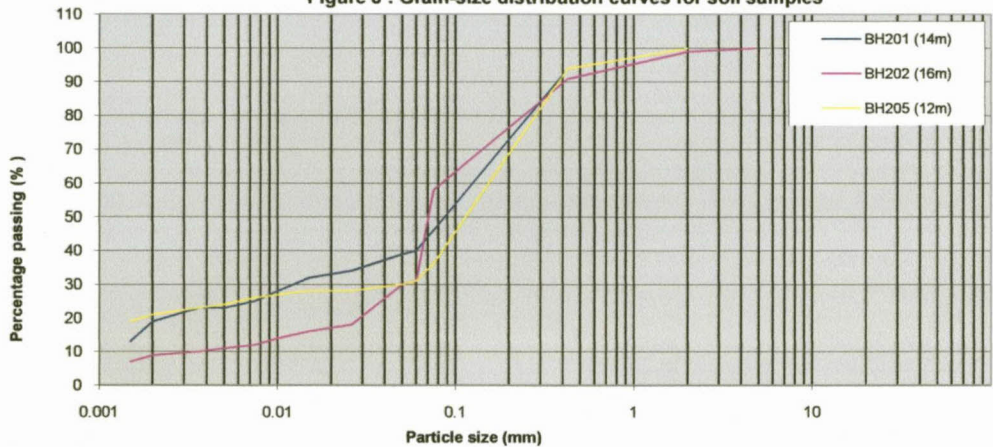
-	-	-	0.00155
-	-	-	0.0013
0.1	0.06	0.08	0.065
0.15	0.09	0.12	0.075
-	-	-	-

DETERMINATION OF SOIL PARTICLE SIZE DISTRIBUTION

Sample No.	BH205	BH201	BH202
Depth (m)	12	14	16

Particle size (mm)	(% passing)		
19	100	100	100
13.2	94	94	99
4.75	36	46	91
2	31	40	58
0.425	30	39	31
0.075	28	34	30
0.06	28	32	18
0.05	27	28	16
0.026	26	25	14
0.015	24	23	12
0.01	23	23	11
0.0074	21	19	10
0.005	19	13	9
0.0036			7
0.002			
0.0015			

Figure 8 : Grain-size distribution curves for soil samples



Sample No.	BH205	BH201	BH202
Depth (m)	12	14	16

BS 5930 Classification	BS 5930 Classification		
Gravel (%)	0	0	1
Sand (%)	69	60	68
Silt (%)	10	21	22
Clay (%)	21	19	9
Material description	Clay SAND	Silty clayey SANC	Silty SAND

d_{10}	-	-	0.004
d_{15}	-	0.00175	0.015
d_{50}	0.12	0.09	0.07
d_{60}	0.165	0.13	0.08
I_0	-	-	0.002

APPENDIX C

FC-Method (Data sheets and T-value estimation)

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	9.45
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH204A								Other info:		
Distance from Rest WL to main water strike (m) =		3.48	S _{max} =	2.33	Recom. AD =		2.8					
Q (l/s)=	0.025						Recovery data					T (m ² /d): Logan eq.
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T	1.1
0.01	0.00					0.01	2.33	1E+05	0			
0.50	0.19					0.5	1.96	2881	0.37	0.21		
1.00	0.32	####	#NUM!			1	1.92	1441	0.41	0.13		
1.50	0.41	####	#NUM!	0.65	1.11E-03	1.5	1.9	961	0.43	0.16	2.1	
2.00	0.51	0.70	#NUM!	0.56	3.36E-04	2	1.87	721	0.46	0.31	1.1	
2.50	0.56	0.80	0.50	0.49	3.36E-04	2.5	1.83	577	0.5	1.00	0.6	
3.00	0.65	0.88	0.37	0.44	3.36E-04	3	1.69	481	0.64	1.09	0.4	
4.00	0.76	0.94	0.20	0.41	3.36E-04	4	1.6	361	0.73	0.76	0.4	
5.00	0.85	0.98	0.07	0.41	3.36E-04	5	1.52	289	0.81	0.91	0.5	
6.00	0.93	0.97	-0.13	0.40	3.36E-04	6	1.44	241	0.89	0.83	0.5	
7.00	1.00	0.94	-0.40	0.41	3.36E-04	7	1.4	206.7	0.93	0.80	0.5	
8.00	1.05	0.87	-0.72	0.45	3.36E-04	8	1.34	181	0.99	0.92	0.5	
9.00	1.09	0.79	-0.87	0.50	3.36E-04	9	1.3	161	1.03	0.62	0.5	
10.00	1.13	0.70	-0.83	0.56	3.36E-04	10	1.28	145	1.05	0.65	0.6	
12.00	1.18	0.62	-0.64	0.64	3.36E-04	12	1.22	121	1.11	0.74	0.6	
15.00	1.24	0.55	-0.59	0.72	3.36E-04	15	1.15	97	1.18	0.58	0.6	
20.00	1.30	0.47	-0.97	0.81	3.36E-04	20	1.09	73	1.24	0.54	0.7	
25.00	1.35	0.35	-1.20	1.04	3.36E-04	25	1.03	58.6	1.3	0.57	0.8	
30.00	1.37	0.27	-0.82	1.66	3.36E-04	30	0.99	49	1.34	0.39	1.0	
40.00	1.39	0.25	0.33	1.84	3.36E-04	40	0.95	37	1.38	0.27	1.2	
50.00	1.41	0.30	1.27	1.31	3.36E-04	50	0.93	29.8	1.4	0.34	1.0	
60.00	1.44	0.41	1.40	0.92	3.36E-04	60	0.89	25	1.44	0.61	0.7	
70.00	1.48	0.50	0.75	0.75	3.36E-04	70	0.84	21.57	1.49	0.88	0.5	
80.00	1.51	0.52	0.05	0.73	3.36E-04	80	0.78	19	1.55	0.92	0.5	
90.00	1.54	0.51	-0.24	0.73	3.36E-04	90	0.74	17	1.59	0.62	0.6	
100.00	1.56	0.49	-0.15	0.73	3.36E-04	100	0.72	15.4	1.61	0.40	0.8	
120.00	1.59	0.50	0.05	0.73	3.36E-04	120	0.69	13	1.64	0.52	0.8	
150.00	1.66	0.51	0.18	0.73	3.36E-04	150	0.63	10.6	1.7	0.54	0.8	
200.00	1.70	0.54	0.39	0.73	3.36E-04	200	0.57	8.2	1.76	0.50	0.8	
250.00	1.76	0.61	0.45	0.66	3.36E-04	250	0.52	6.76	1.81	0.46	0.9	
300.00	1.82	0.67	0.36	0.57	3.36E-04	300	0.49	5.8	1.84	0.34	1.0	
400.00	1.90	0.71	0.14	0.55	3.36E-04	400	0.45	4.6	1.88	0.36	1.1	
500.00	1.98	0.72	-0.02	0.55	3.36E-04	500	0.41	3.88	1.92	0.40	1.0	
600.00	2.03	0.71	-0.08	0.55	3.36E-04	600	0.38	3.4	1.95	0.48	0.8	
700.00	2.08	0.70	-0.02	0.55	3.36E-04	700	0.34	3.057	1.99	0.72	0.6	
800.00	2.12	0.70	0.16	0.55	3.36E-04	800	0.29	2.8	2.04	0.74	0.6	
900.00	2.15	0.72	0.37	0.55	3.36E-04	900	0.26	2.6	2.07	0.62	0.6	
1000.00	2.19	0.76	0.52	0.52	3.36E-04	1000	0.23	2.44	2.1	0.80	0.5	
1100.00	2.22	0.80	#NUM!	0.50	3.36E-04	1100	0.19	2.309	2.14	0.76	0.6	
1200.00	2.25	####	#NUM!	0.46	3.36E-04	1200	0.17	2.2	2.16	0.42	#DIV/0!	
1300.00	2.28	####	#NUM!	0.46	3.36E-04	1300	0.16	2.108	2.17	####	#DIV/0!	
1440.00	2.33	####	#NUM!	0.46	3.36E-04			####	####	####	#DIV/0!	

FC-METHOD : Estimation of the sustainable yield of a borehole					
BH204A					
Extrapolation time in years = (enter)	2	1051200	Extrapol. time in minutes		
Effective borehole radius (r _e) = (enter)	0.50	#DIV/0!	← Est. r _e	From r(e) sheet	
Q (l/s) from pumping test =	0.025	1.11E-03	← S-late	← Change r _e	
s _a (available drawdown), sigma _s = (enter)	3.5		← Sigma _s from risk		
Annual effective recharge (mm) =		3.48	s _a available working drawdown(m)		
t(end) and s(end) of pumping test =	1440	2.33	End time and drawdown of test		
Average maximum derivative = (enter)	0.7	0.8	Estimate of average of max deriv		
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv		
Derivative at radial flow period = (enter)	0.50	#NUM!	Read from derivative graph		
T and S estimates from derivatives	T-early[m ² /d] =	0.79	Aqui. thick (m)		3.05
(To obtain correct S-value, use program RPTSOLV)	T-late [m ² /d] =	0.55	Est. S-late =		1.68E-04
	S-late =	3.36E-04	S-estimate could be wrong		
BASIC SOLUTION					
(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time			
(No values of T and S are necessary)		No boundaries	1: no-flow	2: no-flow	Closed: no-flow
sWell (Extrapol. time) =	4.39	6.45	8.51	14.70	
Q _{sust} (l/s) =	0.02	0.01	0.01	0.01	
	Best case	Worst case			
Average Q _{sust} (l/s) =	0.01				
with standard deviation =	0.01				
(If no information exists about boundaries skip advanced solution and go to final recommendation)					
ADVANCED SOLUTION					
(Using derivatives+ knowledge on boundaries and other boreholes)					
(Late T-and S-values a priori + distance to boundary)					
T-late [m ² /d] = (enter)	→	0.55			
S-late = (enter)	→	1.00E-03			
1. BOUNDARY INFORMATION (choose a or b)		(Code =9999 = dummy value if not applicable)			
(a) Barrier (no-flow) boundaries		Closed Square	Single Barrier	Intersect. 90°	2: Parallel Barriers
Bound. distance a[meter] : (enter)	→	9999	9999	9999	9999
Bound. distance b[meter] : (enter)	→		9999	9999	9999
s _{Bound} (t = Extrapol. time) [m] =	→	0.00	0.00	0.00	#NUM!
(b) Fix head boundary + no-flow		Closed Fix	Single Fix	90° Fix+no-flow	// Fix+no-flow
Bound. distance to fix head a[meter] : (enter)	→	9999	9999	9999	9999
Bound. distance to no-flow b[meter] : (enter)	→		9999	9999	9999
s _{Bound} (t = Extrapol. time) [m] =	→	0.00	0.00	0.00	#NUM!
2. INFLUENCE OF OTHER BOREHOLES		Q (l/s)	r (m)	u _r	W(u,r)
BH1	→			0.00E+00	#NUM!
BH2	→			0.00E+00	#NUM!
s _(influence of BH1,BH2) =	→	0.00	0.00	1.56E-07	15.10
SOLUTION INCLUDING BOUNDS AND BH's					
Fix head + No-flow : Q _{sust} (l/s) =	→	9999.00	9999.00	9999.00	9999.00
No-flow : Q _{sust} (l/s) =	→	9999.00	9999.00	9999.00	9999.00
Enter selected Q for risk analysis = (enter)	→		Sigma _s = 0.000		
(Go to Risk sheet and perform risk analysis from which sigma _s will be estimated : only for barrier boundaries)					
FINAL RECOMMENDED ABSTRACTION RATE					
Abstraction rate (l/s) for 24 hr/d = (enter)	→				
Total amount of water allowed to be abstracted per month (m ³) =	→	0			
COMMENTS					
Q _{sust} with 68% safety =					
Q _{sust} with 95% safety =					

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	9.5
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH205A										Other info:	
Distance from Rest WL to main water strike (m) =		3.46	S _{max} =	2.33	Recom. AD =		2.8						
Q (l/s)=	0.01	Recovery data										T (m ² /d) : Logan eq.	
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T	0.5	
0.01	0					0.01	2.33	1E+05	0				
0.50	0.17					0.5	2.3	2881	0.03	0.04			
1.00	0.22	#####	#NUM!			1	2.23	1441	0.1	0.25			
1.50	0.26	#####	#NUM!	0.60	4.75E-04	1.5	2.18	961	0.15	0.30	0.5		
2.00	0.29	0.38	#NUM!	0.40	3.41E-04	2	2.14	721	0.19	0.49	0.4		
2.50	0.35	0.52	1.05	0.29	3.41E-04	2.5	2.07	577	0.26	0.63	0.3		
3.00	0.4	0.62	0.72	0.24	3.41E-04	3	2.03	481	0.3	0.54	0.3		
4.00	0.48	0.71	0.53	0.23	3.41E-04	4	1.96	361	0.37	0.67	0.2		
5.00	0.55	0.80	0.63	0.20	3.41E-04	5	1.88	289	0.45	1.01	0.2		
6.00	0.62	0.92	0.86	0.17	3.41E-04	6	1.78	241	0.55	1.10	0.2		
7.00	0.69	1.06	0.92	0.15	3.41E-04	7	1.72	206.7	0.61	0.96	0.1		
8.00	0.74	1.20	0.58	0.13	3.41E-04	8	1.66	181	0.67	1.19	0.1		
9.00	0.83	1.25	0.07	0.12	3.41E-04	9	1.59	161	0.74	1.14	0.1		
10.00	0.89	1.21	-0.17	0.13	3.41E-04	10	1.55	145	0.78	1.22	0.1		
12.00	0.96	1.19	-0.01	0.14	3.41E-04	12	1.44	121	0.89	1.48	0.1		
15.00	1.09	1.24	0.15	0.13	3.41E-04	15	1.29	97	1.04	1.49	0.1		
20.00	1.25	1.28	-0.09	0.12	3.41E-04	20	1.11	73	1.22	1.40	0.1		
25.00	1.38	1.20	-0.41	0.13	3.41E-04	25	0.98	58.6	1.35	0.87	0.1		
30.00	1.48	1.06	-0.65	0.15	3.41E-04	30	0.96	49	1.37	1.12	0.1		
40.00	1.6	0.89	-0.76	0.18	3.41E-04	40	0.76	37	1.57	1.28	0.2		
50.00	1.67	0.75	-0.81	0.18	3.41E-04	50	0.68	29.8	1.65	0.74	0.2		
60.00	1.72	0.63	-0.89	0.18	3.41E-04	60	0.63	25	1.7	0.62	0.3		
70.00	1.76	0.55	-0.86	0.18	3.41E-04	70	0.59	21.57	1.74	0.48	0.3		
80.00	1.79	0.49	-0.76	0.18	3.41E-04	80	0.57	19	1.76	0.37	0.4		
90.00	1.81	0.45	-0.57	0.18	3.41E-04	90	0.55	17	1.78	0.31	0.5		
100.00	1.83	0.43	-0.37	0.18	3.41E-04	100	0.54	15.4	1.79	0.24	0.4		
120.00	1.87	0.41	-0.25	0.18	3.41E-04	120	0.52	13	1.81	0.58	0.4		
150.00	1.9	0.39	-0.25	0.18	3.41E-04	150	0.44	10.6	1.89	0.53	0.4		
200.00	1.95	0.36	-0.51	0.18	3.41E-04	200	0.4	8.2	1.93	0.27	0.5		
250.00	1.99	0.31	-0.63	0.18	3.41E-04	250	0.38	6.76	1.95	0.23	0.6		
300.00	2.01	0.27	-0.35	0.18	3.41E-04	300	0.36	5.8	1.97	0.30	0.6		
400.00	2.03	0.27	0.44	0.18	3.41E-04	400	0.32	4.6	2.01	0.32	0.5		
500.00	2.06	0.32	1.13	0.18	3.41E-04	500	0.29	3.88	2.04	0.28	0.5		
600.00	2.09	0.42	1.36	0.18	3.41E-04	600	0.27	3.4	2.06	0.27	0.5		
700.00	2.12	0.52	1.18	0.18	3.41E-04	700	0.25	3.057	2.08	0.32	0.5		
800.00	2.16	0.59	0.68	0.18	3.41E-04	800	0.23	2.8	2.1	0.28	0.6		
900.00	2.19	0.62	-0.02	0.18	3.41E-04	900	0.22	2.6	2.11	0.21	0.7		
1000.00	2.22	0.60	-0.63	0.18	3.41E-04	1000	0.21	2.44	2.12	0.23	0.7		
1100.00	2.25	0.55	-0.17	0.18	3.41E-04	1100	0.2	2.309	2.13	0.25	0.6		
1200.00	2.26	0.57	#NUM!	0.18	3.41E-04	1200	0.19	2.2	2.14	0.28	0.6		
1300.00	2.28	#####	#NUM!	0.18	3.41E-04	1300	0.18	2.108	2.15	0.30	0.5		
1400.00	2.3	#####	#NUM!	0.18	3.41E-04	1400	0.17	2.029	2.16	0.42	#DIV/0!		
1440.00	2.33	#####	#NUM!	0.18	3.41E-04	1440	0.16	2	2.17	#####	#DIV/0!		

FC-METHOD: Estimation of the sustainable yield of a borehole									
BH205A									
Extrapolation time in years = (enter)	2	1051200	Extrapol. time in minutes						
Effective borehole radius (r _e) = (enter)	0.50	#DIV/0!	← Est. r _e	From r(e) sheet					
Q (l/s) from pumping test =	0.01	4.75E-04	← S-late	← Change r _e					
s _a (available drawdown), sigma_s = (enter)	3.4		← Sigma_s from risk						
Annual effective recharge (mm) =		3.40	s _a available working drawdown(m)						
t(end) and s(end) of pumping test =	1440	2.33	End time and drawdown of test						
Average maximum derivative = (enter)	0.6	1.3	Estimate of average of max deriv						
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv						
Derivative at radial flow period = (enter)	0.00	#NUM!	Read from derivative graph						
T and S estimates from derivatives		T-early[m ² /d] =	#DIV/0!	Aqui. thick (m)		3.1			
(To obtain correct S-value, use program RPTSOLV)		T-late [m ² /d] =	0.25	Est. S-late =		1.71E-04			
		S-late =	3.41E-04	S-estimate could be wrong					
BASIC SOLUTION									
(Using derivatives + subjective information about boundaries)									
(No values of T and S are necessary)									
		No boundaries	1: no flow	2: no flow	Closed: no flow				
sWell (Extrapol. time) =		4.04	5.85	7.65	13.06				
Q _{sust} (l/s) =		0.01	0.01	0.00	0.00				
		Best case			Worst case				
Average Q _{sust} (l/s) =		0.00							
		with standard deviation =		0.00					
(If no information exists about boundaries skip advanced solution and go to final recommendation)									
ADVANCED SOLUTION									
(Using derivatives+ knowledge on boundaries and other boreholes)									
(Late T-and S-values a priori + distance to boundary)									
T-late [m ² /d] = (enter)		0.25							
S-late = (enter)		1.00E-03							
1. BOUNDARY INFORMATION (choose a or b)									
(a) Barrier (no-flow) boundaries									
Bound. distance a[meter] : (enter)		Closed/Square	Single Barrier	Intersect 90°	2 Parallel Barriers				
Bound. distance b[meter] : (enter)		9999	9999	9999	9999				
s _{Bound} (t = Extrapol. time) [m] =		#NUM!	0.00	#NUM!	#NUM!				
(b) Fix head boundary + no-flow									
Bound. distance to fix head a[meter] : (enter)		Closed/Fix	Single/Fix	90°Fix+no-flow	//Fix+no-flow				
Bound. distance to no-flow b[meter] : (enter)		9999	9999	9999	9999				
s _{Bound} (t = Extrapol. time) [m] =		#NUM!	0.00	#NUM!	#NUM!				
2. INFLUENCE OF OTHER BOREHOLES									
s _(influence of BH1, BH2) =		Q (l/s)	r (m)	u _r	W(u,r)				
BH1				0.00E+00	#NUM!				
BH2				0.00E+00	#NUM!				
		0.00	0.00	3.41E-07	14.31				
SOLUTION INCLUDING BOUNDS AND BH's									
Fix head + No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00				
No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00				
Enter selected Q for risk analysis = (enter)		Sigma_s = 0.000							
(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)									
FINAL RECOMMENDED ABSTRACTION RATE									
Abstraction rate (l/s) for 24 hr/d = (enter)									
Total amount of water allowed to be abstracted per month (m ³) =		0							
COMMENTS									
Q _{sust} with 68% safety =									
Q _{sust} with 95% safety =									

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	7.8
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH207A										Other info:
Distance from Rest WL to main water strike (m) =		4.2	S _{max} =	3.29	Recom. AD =	3.7						
Q (l/s)=	0.015	Recovery data										T (m ² /d) : Logan eq.
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	W'	Wl rise	s'	Rec_T	0.5
1.00	0.19					0.5	3.18	2881	0.11			
1.50	0.23					1	2.93	1441	0.36	0.65		
2.00	0.26	0.43	-0.80			1.5	2.88	961	0.41	0.83		
2.50	0.29	0.31	-0.28	0.75	1.28E-03	2	2.67	721	0.62	1.93	0.2	
3.00	0.32	0.37	0.91	0.68	3.58E-04	2.5	2.45	577	0.84	2.27	0.1	
4.00	0.36	0.49	1.57	0.53	3.58E-04	3	2.27	481	1.02	2.46	0.1	
5.00	0.4	0.74	2.26	0.32	3.58E-04	4	1.95	361	1.34	2.78	0.1	
6.00	0.49	1.21	2.49	0.19	3.58E-04	5	1.65	289	1.64	3.18	0.1	
7.00	0.59	1.76	1.83	0.12	3.58E-04	6	1.39	241	1.9	3.02	0.1	
8.00	0.73	2.12	0.58	0.10	3.58E-04	7	1.21	206.7	2.08	2.56	0.1	
9.00	0.89	2.10	-0.29	0.11	3.58E-04	8	1.07	181	2.22	2.29	0.1	
10.00	0.93	1.96	-0.39	0.13	3.58E-04	9	0.96	161	2.33	1.66	0.2	
12.00	1.07	1.91	-0.10	0.13	3.58E-04	10	0.91	145	2.38	0.70	0.2	
15.00	1.32	1.91	-0.14	0.12	3.58E-04	12	0.87	121	2.42	0.75	0.3	
20.00	1.52	1.77	-0.66	0.13	3.58E-04	15	0.78	97	2.51	0.71	0.4	
25.00	1.73	1.43	-1.01	0.16	3.58E-04	20	0.71	73	2.58	0.58	0.3	
30.00	1.77	1.11	-1.07	0.22	3.58E-04	25	0.65	58.6	2.64	0.90	0.3	
40.00	1.92	0.87	-1.06	0.27	3.58E-04	30	0.55	49	2.74	0.70	0.4	
50.00	1.99	0.68	-0.90	0.27	3.58E-04	40	0.5	37	2.79	0.49	0.4	
60.00	2.03	0.60	-0.05	0.27	3.58E-04	50	0.44	29.8	2.85	0.57	0.5	
70.00	2.05	0.64	1.23	0.27	3.58E-04	60	0.4	25	2.89	0.48	0.5	
80.00	2.09	0.82	1.95	0.27	3.58E-04	70	0.37	21.57	2.92	0.40	0.5	
90.00	2.15	1.04	1.31	0.21	3.58E-04	80	0.35	19	2.94	0.46	0.5	
100.00	2.21	1.13	0.23	0.20	3.58E-04	90	0.32	17	2.97	0.72	0.4	
120.00	2.3	1.05	-0.52	0.20	3.58E-04	100	0.28	15.4	3.01	0.54	0.5	
150.00	2.42	0.90	-0.78	0.20	3.58E-04	120	0.25	13	3.04	0.34	0.6	
200.00	2.5	0.72	-1.06	0.20	3.58E-04	150	0.22	10.6	3.07	0.36	0.7	
250.00	2.57	0.55	-1.02	0.20	3.58E-04	200	0.17	8.2	3.12	0.32	0.9	
300.00	2.61	0.45	-0.57	0.20	3.58E-04	250	0.15	6.76	3.14	0.17	1.0	
400.00	2.63	0.44	0.74	0.20	3.58E-04	300	0.14	5.8	3.15	0.25	1.0	
500.00	2.69	0.61	2.21	0.20	3.58E-04	400	0.1	4.6	3.19	0.32	0.8	
600.00	2.74	1.00	2.77	0.20	3.58E-04	500	0.07	3.88	3.22	0.28	0.8	
700.00	2.77	1.59	1.73	0.13	3.58E-04	600	0.05	3.4	3.24	0.27	0.8	
800.00	3.04	1.76	-0.83	0.12	3.58E-04	700	0.03	3.057	3.26	0.40	#DIV/0!	
900.00	3.07	1.36	-2.28	0.12	3.58E-04	800	0	2.8	3.29	#####	#DIV/0!	
1000.00	3.1	1.07	-1.52	0.12	3.58E-04			#####	#####	#####	#DIV/0!	
1100.00	3.15	0.97	#NUM!	0.12	3.58E-04			#####	#####	#####	#DIV/0!	
1200.00	3.18	#####	#NUM!	0.12	3.58E-04			#####	#####	#####	#DIV/0!	
1300.00	3.22	#####	#NUM!	0.12	3.58E-04			#####	#####	#####	#DIV/0!	
1440.00	3.29	#####	#NUM!	0.12	3.58E-04			#####	#####	#####	#DIV/0!	

FC-METHOD : Estimation of the sustainable yield of a borehole						
BH207A						
Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes			
Effective borehole radius (r _e) = (enter)	0.50	#DIV/0!	← Est. r _e	From r(e) sheet		
Q (l/s) from pumping test =	0.015	1.28E-03	← S-late	← Change r _e		
s _a (available drawdown), sigma _s = (enter)	4.2		← Sigma _s from risk			
Annual effective recharge (mm) =		4.20	s _{available} working drawdown(m)			
t(end) and s(end) of pumping test =	1440	3.29	End time and drawdown of test			
Average maximum derivative = (enter)	1.0	1.9	Estimate of average of max deriv			
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv			
Derivative at radial flow period = (enter)	0.00	1.06	Read from derivative graph			
T and S estimates from derivatives (To obtain correct S-value, use program RPTSOLV)	T-early[m ² /d] =	#DIV/0!	Aqui. thick (m)	3.25		
	T-late [m ² /d] =	0.24	Est. S-late =	1.79E-04		
	S-late =	3.58E-04	S-estimate could be wrong			
BASIC SOLUTION						
(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time				
(No values of T and S are necessary)		No boundaries	1 no-flow	2 no-flow	Closed no-flow	
sWell (Extrapol.time) =	6.12	8.99	11.85	20.44		
Q _{sust} (l/s) =	0.01	0.01	0.01	0.00		
	Best case		Worst case			
Average Q _{sust} (l/s) =	0.01					
with standard deviation=	0.00					
(If no information exists about boundaries skip advanced solution and go to final recommendation)						
ADVANCED SOLUTION						
(Using derivatives+ knowledge on boundaries and other boreholes)						
(Late T-and S-values a priori + distance to boundary)						
T-late [m ² /d] = (enter)	→	0.24				
S-late = (enter)	→	1.00E-03				
1. BOUNDARY INFORMATION (choose a or b)		(Code =9999 = dummy value if not applicable)				
(a) Barrier (no-flow) boundaries	→	Closed Square	Single Barrier	Intersect 90°	2 Parallel Barriers	
Bound. distance a[meter] : (enter)		9999	9999	9999	9999	
Bound. distance b[meter] : (enter)			9999	9999	9999	
s _{Bound} (t = Extrapol.time) [m] =		#NUM!	0.00	#NUM!	#NUM!	
(b) Fix head boundary + no-flow	→	Closed Fix	Single Fix	90°Fix+no-flow	// Fix+no-flow	
Bound. distance to fix head a[meter] : (enter)		9999	9999	9999	9999	
Bound. distance to no-flow b[meter] : (enter)				9999	9999	
s _{Bound} (t = Extrapol.time) [m] =		#NUM!	0.00	#NUM!	#NUM!	
2. INFLUENCE OF OTHER BOREHOLES		→	Q (l/s)	r (m)	u _r	W(u,r)
BH1					0.00E+00	#NUM!
BH2					0.00E+00	#NUM!
s _(influence of BH1,BH2) =		0.00	0.00		3.61E-07	14.26
SOLUTION INCLUDING BOUNDS AND BH's						
Fix head + No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00	
No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00	
Enter selected Q for risk analysis = (enter)	→		Sigma _s =	0.000		
(Go to Risk sheet and perform risk analysis from which sigma _s will be estimated : only for barrier boundaries)						
FINAL RECOMMENDED ABSTRACTION RATE						
Abstraction rate (l/s) for 24 hr/d = (enter)						
Total amount of water allowed to be abstracted per month (m ³) =		0				
COMMENTS						
Q _{sust} with 68% safety =						
Q _{sust} with 95% safety =						

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA		Geology:	Harbour beds
Region:	Durban		Depth of BH:	11.17
Owner:			Water strikes:	
X-coord:			Date of Test:	
Y-coord:			Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH212A										Other info:	
Distance from Rest WL to main water strike (m) =		5.3		S _{max} =		5.14		Recom. AD =		5.2			
Q (l/s) =		0.08		Recovery data								T (m ² /d) : Logan eq.	
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	WL rise	s'	Rec_T	1.6	
0.50	0.09					0.5	4.83	801	0.31				
1.00	0.29					1	4.52	401	0.62	1.27			
1.50	0.35	0.77	1.47			1.5	4.21	267.7	0.93	1.26			
2.00	0.4	1.10	1.91	1.19	4.74E-03	2	4.15	201	0.99	0.67	1.2		
2.50	0.48	1.95	2.01	0.60	6.38E-04	2.5	4.06	161	1.08	1.57	1.0		
3.00	0.99	2.80	0.99	0.39	6.38E-04	3	3.87	134.3	1.27	2.14	0.7		
4.00	1.26	2.93	-0.14	0.40	6.38E-04	4	3.62	101	1.52	2.11	0.6		
5.00	1.49	2.67	-0.45	0.52	6.38E-04	5	3.4	81	1.74	2.27	0.6		
6.00	1.69	2.39	-0.61	0.51	6.38E-04	6	3.22	67.67	1.92	2.26	0.6		
7.00	1.84	2.18	-1.20	0.55	6.38E-04	7	3.07	58.14	2.07	1.93	0.6		
8.00	2	1.74	-1.88	0.69	6.38E-04	8	2.98	51	2.16	2.63	0.4		
9.00	2.04	1.37	-1.45	1.01	6.38E-04	9	2.78	45.44	2.36	5.64	0.3		
10.00	2.09	1.23	-0.45	1.13	6.38E-04	10	2.43	41	2.71	4.11	0.4		
12.00	2.15	1.29	0.43	0.97	6.38E-04	12	2.24	34.33	2.9	1.51	0.7		
15.00	2.34	1.46	0.51	0.87	6.38E-04	15	2.16	27.67	2.98	0.95	0.9		
20.00	2.51	1.64	0.50	0.77	6.38E-04	20	2.03	21	3.11	1.72	0.8		
25.00	2.63	1.84	0.41	0.68	6.38E-04	25	1.77	17	3.37	2.34	0.6		
30.00	2.87	1.98	0.19	0.61	6.38E-04	30	1.62	14.33	3.52	1.86	0.6		
40.00	3.11	1.99	0.01	0.63	6.38E-04	40	1.39	11	3.75	2.02	0.7		
50.00	3.28	1.99	0.12	0.63	6.38E-04	50	1.17	9	3.97	1.67	0.7		
60.00	3.41	2.08	0.24	0.61	6.38E-04	60	1.1	7.667	4.04	2.08	0.6		
70.00	3.59	2.16	0.09	0.57	6.38E-04	70	0.86	6.714	4.28	3.13	0.6		
80.00	3.72	2.14	-0.25	0.57	6.38E-04	80	0.71	6	4.43	1.76	0.8		
90.00	3.81	2.04	-0.32	0.57	6.38E-04	90	0.67	5.444	4.47	0.72	1.4		
100.00	3.91	1.97	-0.09	0.57	6.38E-04	100	0.64	5	4.5	0.64	2.1		
120.00	4.07	2.03	0.23	0.57	6.38E-04	120	0.59	4.333	4.55	0.45	3.2		
150.00	4.23	2.20	0.31	0.57	6.38E-04	150	0.56	3.667	4.58	0.22	4.5		
200.00	4.53	2.35	#NUM!	0.52	6.38E-04	200	0.54	3	4.6	0.22	5.2		
250.00	4.81	####	#NUM!	0.52	6.38E-04	250	0.51	2.6	4.63	0.28	5.5		
300.00	5.02	####	#NUM!	0.52	6.38E-04	300	0.49	2.333	4.65	0.19	5.5		
400.00	5.14	####	#NUM!	0.52	6.38E-04	400	0.47	2	4.67	0.22	#DIV/0!		
		####	#NUM!	0.52	6.38E-04	500	0.44	1.8	4.7	####	#DIV/0!		

FC-METHOD : Estimation of the sustainable yield of a borehole

BH212A

Extrapolation time in years = (enter)	2	1051200	Extrapol time in minutes
Effective borehole radius (r_e) = (enter)	0.50	23.33	Est. r_e From r(e) sheet
Q (l/s) from pumping test =	0.08	4.74E-03	S-late Change r_e
s_a (available drawdown), sigma_s = (enter)	5.2		Sigma_s from risk
Annual effective recharge (mm) =		5.20	$s_{available}$ working drawdown(m)
t(end) and s(end) of pumping test =	400	5.14	End time and drawdown of test
Average maximum derivative = (enter)	1.9	2.3	Estimate of average of max deriv
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	1.22	1.70	Read from derivative graph
T and S estimates from derivatives (To obtain correct S-value, use program RPTSOLV)	T-early[m ² /d] =	1.04	Aqui. thick (m) 5.8
	T-late [m ² /d] =	0.67	Est. S-late = 3.19E-04
	S-late =	6.38E-04	S-estimate could be wrong

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)
(No values of T and S are necessary)

Maximum influence of boundaries at long time

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	11.70	18.20	24.69	44.18
Q_sust (l/s) =	0.04	0.02	0.02	0.01
Best case		Worst case		
Average Q_sust (l/s) =	0.02			
with standard deviation=	0.01			

(If no information exists about boundaries skip advanced solution and go to final recommendation)

ADVANCED SOLUTION

(Using derivatives+ knowledge on boundaries and other boreholes)

(Late T-and S-values a priori + distance to boundary)

T-late [m ² /d] = (enter)	0.67
S-late = (enter)	1.00E-03

1. BOUNDARY INFORMATION (choose a or b)

(a) Barrier (no-flow) boundaries

Bound. distance a[meter] : (enter)

Bound. distance b[meter] : (enter)

s_Bound(t = Extrapol.time) [m] =

(b) Fix head boundary + no-flow

Bound. distance to fix head a[meter] : (enter)

Bound. distance to no-flow b[meter] : (enter)

s_Bound(t = Extrapol.time) [m] =

2. INFLUENCE OF OTHER BOREHOLES

(Code =9999 = dummy value if not applicable)			
Closed Square	Single Barrier	Intersect. 90°	2 Parallel Barriers
9999	9999	9999	9999
9999	9999	9999	9999
0.00	0.00	0.00	#NUM!
0.00	0.00	0.00	#NUM!
Closed Fix	Single Fix	90°Fix+no-flow	// Fix+no-flow
9999	9999	9999	9999
9999	9999	9999	9999
0.00	0.00	0.00	#NUM!
0.00	0.00	0.00	#NUM!
Q (l/s)	r (m)	u_r	W(u,r)
BH1		0.00E+00	#NUM!
BH2		0.00E+00	#NUM!
s_(influence of BH1,BH2) =	0.00	0.00	1.29E-07
			15.29

SOLUTION INCLUDING BOUNDS AND BH's

Fix head + No-flow : Q_sust (l/s) = 9999.00 9999.00 9999.00 9999.00

No-flow : Q_sust (l/s) = 9999.00 9999.00 9999.00 9999.00

Enter selected Q for risk analysis = (enter) → Sigma_s = 0.000

(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)

FINAL RECOMMENDED ABSTRACTION RATE

Abstraction rate (l/s) for 24 hr/d = (enter)	
Total amount of water allowed to be abstracted per month (m ³) =	0

COMMENTS

Q_sust with 68% safety =

Q_sust with 95% safety =

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	9.75
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH215A										Other info:	
Distance from Rest WL to main water strike (m) =		5.03		S _{max} = 3.81		Recom. AD =		4.4					
Q (l/s)=	0.025	Recovery data										T (m ² /d) : Logan eq.	
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	WI rise	s'	Rec_T	0.7	
0.50	0.32					0.5	3.78	2881	0.03				
1.00	0.36					1	3.75	1441	0.06	0.14			
1.50	0.4	0.33	-0.12			1.5	3.71	961	0.1	0.26			
2.00	0.41	0.26	0.77	1.59	3.57E-04	2	3.67	721	0.14	0.40	0.8		
2.50	0.44	0.42	1.90	0.95	3.19E-04	2.5	3.62	577	0.19	1.22	0.4		
3.00	0.49	0.63	1.56	0.56	3.19E-04	3	3.45	481	0.36	1.43	0.4		
4.00	0.59	0.84	0.85	0.46	3.19E-04	4	3.32	361	0.49	0.78	0.4		
5.00	0.68	0.95	0.35	0.40	3.19E-04	5	3.28	289	0.53	1.22	0.3		
6.00	0.77	0.99	0.22	0.40	3.19E-04	6	3.1	241	0.71	1.66	0.3		
7.00	0.84	1.02	0.53	0.40	3.19E-04	7	3.04	206.7	0.77	1.19	0.3		
8.00	0.87	1.14	1.21	0.36	3.19E-04	8	2.95	181	0.86	1.38	0.3		
9.00	0.95	1.37	1.36	0.29	3.19E-04	9	2.89	161	0.92	1.54	0.2		
10.00	1.02	1.60	0.99	0.23	3.19E-04	10	2.8	145	1.01	2.00	0.2		
12.00	1.16	1.77	0.44	0.23	3.19E-04	12	2.64	121	1.17	1.93	0.2		
15.00	1.36	1.89	0.32	0.21	3.19E-04	15	2.46	97	1.35	1.89	0.2		
20.00	1.54	2.07	0.21	0.19	3.19E-04	20	2.22	73	1.59	1.98	0.2		
25.00	1.8	2.11	-0.19	0.17	3.19E-04	25	2.02	58.6	1.79	2.81	0.2		
30.00	2.02	1.90	-0.76	0.20	3.19E-04	30	1.72	49	2.09	2.53	0.2		
40.00	2.23	1.45	-1.34	0.26	3.19E-04	40	1.49	37	2.32	1.46	0.2		
50.00	2.32	1.03	-1.57	0.26	3.19E-04	50	1.4	29.8	2.41	1.18	0.3		
60.00	2.38	0.76	-1.45	0.26	3.19E-04	60	1.28	25	2.53	1.37	0.3		
70.00	2.42	0.62	-0.51	0.26	3.19E-04	70	1.2	21.57	2.61	1.28	0.3		
80.00	2.45	0.63	1.49	0.26	3.19E-04	80	1.12	19	2.69	1.37	0.3		
90.00	2.48	0.85	2.65	0.26	3.19E-04	90	1.05	17	2.76	1.34	0.3		
100.00	2.5	1.25	2.35	0.26	3.19E-04	100	0.99	15.4	2.82	1.19	0.3		
120.00	2.65	1.57	0.63	0.23	3.19E-04	120	0.9	13	2.91	1.02	0.4		
150.00	2.88	1.46	-0.62	0.23	3.19E-04	150	0.81	10.6	3	0.99	0.4		
200.00	3.01	1.14	-1.05	0.23	3.19E-04	200	0.68	8.2	3.13	1.17	0.4		
250.00	3.09	0.89	-0.85	0.23	3.19E-04	250	0.55	6.76	3.26	0.92	0.6		
300.00	3.16	0.77	-0.31	0.23	3.19E-04	300	0.52	5.8	3.29	0.29	0.8		
400.00	3.21	0.80	0.31	0.23	3.19E-04	400	0.49	4.6	3.32	0.53	0.8		
500.00	3.33	0.88	0.33	0.23	3.19E-04	500	0.4	3.88	3.41	0.80	0.6		
600.00	3.39	0.93	-0.03	0.23	3.19E-04	600	0.35	3.4	3.46	0.62	0.5		
700.00	3.47	0.90	-0.19	0.23	3.19E-04	700	0.31	3.057	3.5	0.80	0.5		
800.00	3.51	0.88	0.33	0.23	3.19E-04	800	0.25	2.8	3.56	0.83	0.5		
900.00	3.55	0.95	1.00	0.23	3.19E-04	900	0.22	2.6	3.59	0.62	0.6		
1000.00	3.58	1.09	1.10	0.23	3.19E-04	1000	0.19	2.44	3.62	0.69	0.7		
1100.00	3.67	1.20	#NUM!	0.23	3.19E-04	1100	0.16	2.309	3.65	0.51	0.8		
1200.00	3.69	#####	#NUM!	0.23	3.19E-04	1200	0.15	2.2	3.66	0.41	0.7		
1300.00	3.73	#####	#NUM!	0.23	3.19E-04	1300	0.13	2.108	3.68	1.03	#DIV/0!		
1440.00	3.81	#####	#NUM!	0.23	3.19E-04	1440	0.07	2	3.74	#####	#DIV/0!		

FC-METHOD: Estimation of the sustainable yield of a borehole					
BH215A					
Extrapolation time in years = (enter)	2	1051200	Extrapol. time in minutes		
Effective borehole radius (r_e) = (enter)	0.50	#DIV/0!	← Est. r_e	From r(e) sheet	
Q (l/s) from pumping test =	0.025	3.57E-04	← S-late	← Change r_e	
s_o (available drawdown), sigma_s = (enter)	5.0		← Sigma_s from risk		
Annual effective recharge (mm) =		5.00	s_available working drawdown(m)		
t(end) and s(end) of pumping test =	1440	3.81	End time and drawdown of test		
Average maximum derivative = (enter)	1.0	2.1	Estimate of average of max deriv		
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv		
Derivative at radial flow period = (enter)	0.00	0.87	Read from derivative graph		
T and S estimates from derivatives		T-early[m ² /d] = #DIV/0!	Aqui. thick (m)	2.9	
(To obtain correct S-value, use program RPTSOLV)		T-late [m ² /d] = 0.40	Est. S-late =	1.60E-04	
		S-late = 3.19E-04	S-estimate could be wrong		
BASIC SOLUTION					
(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time			
(No values of T and S are necessary)		No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	6.75	9.61	12.47	21.06	
Q_sust (l/s) =	0.02	0.01	0.01	0.01	
		Best case	Worst case		
Average Q_sust (l/s) =	0.01				
with standard deviation=		0.01			
(If no information exists about boundaries skip advanced solution and go to final recommendation)					
ADVANCED SOLUTION					
(Using derivatives+ knowledge on boundaries and other boreholes)					
(Late T-and S-values a priori + distance to boundary)					
T-late [m ² /d] = (enter)	→	0.40			
S-late = (enter)	→	1.00E-03			
1. BOUNDARY INFORMATION (choose a or b)		(Code =9999 = dummy value if not applicable)			
(a) Barrier (no-flow) boundaries		Closed/Square	Single/Barrier	Intersect/90°	2/Parallel/Barriers
Bound. distance a[meter] : (enter)	→	9999	9999	9999	9999
Bound. distance b[meter] : (enter)	→		9999	9999	9999
s_Bound(t = Extrapol.time) [m] =	→	0.00	0.00	0.00	#NUM!
(b) Fix head boundary + no-flow		Closed/Fix	Single/Fix	90°Fix+no-flow	//Fix+no-flow
Bound. distance to fix head a[meter] : (enter)	→	9999	9999	9999	9999
Bound. distance to no-flow b[meter] : (enter)	→		9999	9999	9999
s_Bound(t = Extrapol.time) [m] =	→	0.00	0.00	0.00	#NUM!
2. INFLUENCE OF OTHER BOREHOLES		Q (l/s)	r (m)	u_r	W(u,r)
BH1	→			0.00E+00	#NUM!
BH2	→			0.00E+00	#NUM!
s_(influence of BH1,BH2) =	→	0.00	0.00	2.17E-07	14.77
SOLUTION INCLUDING BOUNDS AND BH's					
Fix head + No-flow : Q_sust (l/s) =	→	9999.00	9999.00	9999.00	9999.00
No-flow : Q_sust (l/s) =	→	9999.00	9999.00	9999.00	9999.00
Enter selected Q for risk analysis = (enter)	→		Sigma_s = 0.000		
(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)					
FINAL RECOMMENDED ABSTRACTION RATE					
Abstraction rate (l/s) for 24 hr/d = (enter)	→				
Total amount of water allowed to be abstracted per month (m ³) =	→	0			
COMMENTS					
Q_sust with 68% safety =					
Q_sust with 95% safety =					

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	12
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH208										Other info:	
Distance from Rest WL to main water strike (m) =		8.3	S _{max} =	6.44	Recom. AD =	7.3							
Q (l/s)=	0.22	Recovery data										T (m ² /d) : Logan eq.	
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T	3.6	
0.50	0.5					0.5	5.79	2881	0.65				
1.00	0.99					1	5.24	1441	1.2	2.37			
1.50	1.4	2.78	-0.11			1.5	4.63	961	1.81	3.92			
2.00	1.81	2.60	-0.33	1.26	3.32E-03	2	4.05	721	2.39	4.04	0.9		
2.50	2.03	2.40	-0.39	1.42	3.30E-04	2.5	3.74	577	2.7	3.13	1.0		
3.00	2.2	2.17	-0.30	1.71	3.30E-04	3	3.5	481	2.94	3.04	1.2		
4.00	2.42	2.11	0.03	1.68	3.30E-04	4	3.12	361	3.32	2.81	1.4		
5.00	2.65	2.19	0.05	1.56	3.30E-04	5	2.88	289	3.56	2.01	1.7		
6.00	2.83	2.18	-0.39	1.53	3.30E-04	6	2.77	241	3.67	1.50	2.1		
7.00	2.99	1.96	-1.24	1.71	3.30E-04	7	2.66	206.7	3.78	1.45	2.6		
8.00	3.09	1.56	-2.31	2.13	3.30E-04	8	2.59	181	3.85	1.10	3.2		
9.00	3.16	1.11	-2.51	3.05	3.30E-04	9	2.54	161	3.9	0.83	4.6		
10.00	3.2	0.83	-1.71	4.67	3.30E-04	10	2.51	145	3.93	0.47	5.9		
12.00	3.24	0.73	-0.13	5.26	3.30E-04	12	2.48	121	3.96	0.52	6.0		
15.00	3.31	0.86	1.04	4.47	3.30E-04	15	2.42	97	4.02	0.82	4.6		
20.00	3.4	1.23	1.55	2.83	3.30E-04	20	2.3	73	4.14	1.03	3.6		
25.00	3.52	1.78	1.29	1.81	3.30E-04	25	2.19	58.6	4.25	1.08	3.3		
30.00	3.81	2.24	0.76	1.45	3.30E-04	30	2.11	49	4.33	1.03	3.3		
40.00	4.09	2.48	0.36	1.43	3.30E-04	40	1.98	37	4.46	1.04	3.6		
50.00	4.27	2.65	0.20	1.33	3.30E-04	50	1.88	29.8	4.56	0.86	3.5		
60.00	4.5	2.70	-0.58	1.18	3.30E-04	60	1.83	25	4.61	1.08	3.2		
70.00	4.8	2.27	-2.34	1.18	3.30E-04	70	1.72	21.57	4.72	1.37	2.9		
80.00	4.86	1.45	-3.38	1.18	3.30E-04	80	1.66	19	4.78	1.19	2.7		
90.00	4.89	0.97	-2.53	1.18	3.30E-04	90	1.59	17	4.85	1.34	2.6		
100.00	4.93	0.79	-0.61	1.18	3.30E-04	100	1.53	15.4	4.91	1.53	2.4		
120.00	4.98	0.91	0.83	1.18	3.30E-04	120	1.4	13	5.04	1.41	2.8		
150.00	5.08	1.14	1.04	1.18	3.30E-04	150	1.28	10.6	5.16	0.84	3.9		
200.00	5.19	1.49	0.90	1.18	3.30E-04	200	1.21	8.2	5.23	0.58	4.5		
250.00	5.42	1.77	0.41	1.18	3.30E-04	250	1.15	6.76	5.29	0.95	4.2		
300.00	5.61	1.83	-0.04	1.18	3.30E-04	300	1.04	5.8	5.4	0.99	3.5		
370.00	5.72	1.72	-0.37	1.18	3.30E-04	370	0.98	4.892	5.46	1.01	3.5		
500.00	5.97	1.53	-0.61	1.18	3.30E-04	500	0.82	3.88	5.62	0.98	3.9		
600.00	6.08	1.33	-0.89	1.18	3.30E-04	600	0.78	3.4	5.66	0.75	3.8		
700.00	6.15	1.13	-0.94	1.18	3.30E-04	700	0.71	3.057	5.73	1.04	3.9		
800.00	6.21	1.01	-0.81	1.18	3.30E-04	800	0.65	2.8	5.79	0.92	3.9		
900.00	6.26	0.96	-0.28	1.18	3.30E-04	900	0.61	2.6	5.83	0.72	4.5		
1000.00	6.29	0.94	-0.26	1.18	3.30E-04	1000	0.58	2.44	5.86	0.69	5.1		
1100.00	6.35	0.91	#NUM!	1.18	3.30E-04	1100	0.55	2.309	5.89	0.63	5.2		
1200.00	6.37	####	#NUM!	1.18	3.30E-04	1200	0.53	2.2	5.91	0.69	5.0		
1300.00	6.4	####	#NUM!	1.18	3.30E-04	1300	0.5	2.108	5.94	0.75	#DIV/0!		
1440.00	6.44	####	#NUM!	1.18	3.30E-04	1440	0.47	2	5.97	####	#DIV/0!		

FC-METHOD : Estimation of the sustainable yield of a borehole					
BH208					
Extrapolation time in years = (enter)	2	1051200	Extrapol time in minutes		
Effective borehole radius (r _e) = (enter)	0.50	#DIV/0!	← Est. r _e	From r(e) sheet	
Q (l/s) from pumping test =	0.22	3.32E-03	← S-late	← Change r _e	
s _a (available drawdown), sigma_s = (enter)	8.3		← Sigma_s from risk		
Annual effective recharge (mm) =		8.30	s _a available working drawdown(m)		
t(end) and s(end) of pumping test =	1440	6.44	End time and drawdown of test		
Average maximum derivative = (enter)	1.5	2.7	Estimate of average of max deriv		
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv		
Derivative at radial flow period = (enter)	0.00	1.65	Read from derivative graph		
T and S estimates from derivatives		T-early[m ² /d] =	#DIV/0!	Aqui. thick (m)	3
(To obtain correct S-value, use program RPTSOLV)		T-late [m ² /d] =	2.32	Est. S-late =	1.65E-04
		S-late =	3.30E-04	S-estimate could be wrong	
BASIC SOLUTION					
(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time			
(No values of T and S are necessary)		No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =		10.58	14.88	19.17	32.06
Q _{sust} (l/s) =		0.17	0.12	0.10	0.06
		Best case		Worst case	
Average Q _{sust} (l/s) =		0.10			
with standard deviation=		0.05			
(If no information exists about boundaries skip advanced solution and go to final recommendation)					
ADVANCED SOLUTION					
(Using derivatives+ knowledge on boundaries and other boreholes)					
(Late T-and S-values a priori + distance to boundary)					
T-late [m ² /d] = (enter)		2.32			
S-late = (enter)		1.00E-03			
1. BOUNDARY INFORMATION (choose a or b)		(Code =9999 = dummy value if not applicable)			
(a) Barrier (no-flow) boundaries		Closed Square	Single Barrier	Intersect. 90°	2 Parallel Barriers
Bound. distance a[meter] : (enter)		9999	9999	9999	9999
Bound. distance b[meter] : (enter)				9999	9999
s _{Bound} (t = Extrapol.time) [m] =		0.00	0.00	0.00	#NUM!
(b) Fix head boundary + no-flow		Closed Fix	Single Fix	90°Fix+no-flow	// Fix+no-flow
Bound. distance to fix head a[meter] : (enter)		9999	9999	9999	9999
Bound. distance to no-flow b[meter] : (enter)				9999	9999
s _{Bound} (t = Extrapol.time) [m] =		0.00	0.00	0.00	0.00
2. INFLUENCE OF OTHER BOREHOLES		Q (l/s)	r (m)	u _r	W(u,r)
BH1				0.00E+00	#NUM!
BH2				0.00E+00	#NUM!
s _(influence of BH1,BH2) =		0.00	0.00	3.69E-08	16.54
SOLUTION INCLUDING BOUNDS AND BH's					
Fix head + No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00
No-flow : Q _{sust} (l/s) =		9999.00	9999.00	9999.00	9999.00
Enter selected Q for risk analysis = (enter)			Sigma_s =		0.000
(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)					
FINAL RECOMMENDED ABSTRACTION RATE					
Abstraction rate (l/s) for 24 hr/d = (enter)					
Total amount of water allowed to be abstracted per month (m ³) =		0			
COMMENTS					
Q _{sust} with 68% safety =					
Q _{sust} with 95% safety =					

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	16.22
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH213										Other info:
Distance from Rest WL to main water strike (m) =		8.25	S _{max} =	6.74	Recom. AD =	7.5						
Q (l/s) =	0.18	Recovery data										T (m ² /d) : Logan eq.
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res. s	t/t'	Wl rise	s'	Rec. T	2.8
0.50	0.53					0.5	5.89	2881	0.85			
1.00	0.79					1	5.12	1441	1.62	2.71		
1.50	1.02	1.58	-0.33			1.5	4.59	961	2.15	2.93		
2.00	1.2	1.33	-0.43	2.02	3.27E-03	2	4.24	721	2.5	2.15	1.5	
2.50	1.33	1.26	-0.21	2.19	3.41E-04	2.5	4.12	577	2.62	1.14	2.0	
3.00	1.43	1.21	0.19	2.63	3.41E-04	3	4.04	481	2.7	1.24	2.2	
4.00	1.55	1.41	1.19	2.27	3.41E-04	4	3.87	361	2.87	1.61	1.6	
5.00	1.64	2.04	1.86	1.38	3.41E-04	5	3.68	289	3.06	2.59	1.3	
6.00	1.89	3.00	1.53	0.86	3.41E-04	6	3.41	241	3.33	2.49	1.5	
7.00	2.2	3.59	0.49	0.72	3.41E-04	7	3.32	206.7	3.42	0.97	2.2	
8.00	2.46	3.58	-0.31	0.81	3.41E-04	8	3.29	181	3.45	0.91	2.7	
9.00	2.55	3.34	-0.58	0.87	3.41E-04	9	3.22	161	3.52	1.34	2.5	
10.00	2.69	3.09	-0.68	0.89	3.41E-04	10	3.16	145	3.58	1.28	2.4	
12.00	3.11	2.67	-0.73	1.02	3.41E-04	12	3.06	121	3.68	0.96	2.8	
15.00	3.19	2.30	-0.47	1.34	3.41E-04	15	2.99	97	3.75	0.86	3.0	
20.00	3.4	2.18	-0.10	1.39	3.41E-04	20	2.87	73	3.87	1.08	2.6	
25.00	3.7	2.17	-0.11	1.18	3.41E-04	25	2.75	58.6	3.99	1.36	2.3	
30.00	3.89	2.07	-0.38	1.37	3.41E-04	30	2.63	49	4.11	1.26	2.3	
40.00	4.12	1.79	-0.57	1.61	3.41E-04	40	2.49	37	4.25	1.17	2.5	
50.00	4.26	1.59	-0.39	1.61	3.41E-04	50	2.37	29.8	4.37	0.98	2.9	
60.00	4.38	1.50	-0.10	1.61	3.41E-04	60	2.32	25	4.42	0.82	3.0	
70.00	4.47	1.51	0.17	1.61	3.41E-04	70	2.25	21.57	4.49	1.12	2.8	
80.00	4.56	1.57	0.27	1.61	3.41E-04	80	2.18	19	4.56	1.19	2.5	
90.00	4.65	1.62	0.07	1.61	3.41E-04	90	2.12	17	4.62	1.14	2.4	
100.00	4.72	1.59	-0.07	1.61	3.41E-04	100	2.07	15.4	4.67	1.29	2.2	
120.00	4.85	1.57	-0.04	1.61	3.41E-04	120	1.96	13	4.78	1.42	2.1	
150.00	5.02	1.60	0.15	1.61	3.41E-04	150	1.82	10.6	4.92	1.40	2.0	
200.00	5.13	1.70	0.23	1.61	3.41E-04	200	1.65	8.2	5.09	1.44	2.0	
250.00	5.41	1.79	0.14	1.57	3.41E-04	250	1.5	6.76	5.24	1.37	2.3	
300.00	5.54	1.82	0.08	1.56	3.41E-04	300	1.41	5.8	5.33	1.02	2.3	
400.00	5.67	1.85	-0.02	1.56	3.41E-04	400	1.29	4.6	5.45	1.38	2.1	
500.00	5.98	1.81	-0.32	1.49	3.41E-04	500	1.1	3.88	5.64	1.71	1.9	
600.00	6.09	1.66	-0.55	1.49	3.41E-04	600	0.99	3.4	5.75	1.44	1.9	
700.00	6.16	1.52	-0.09	1.49	3.41E-04	700	0.89	3.057	5.85	1.44	2.1	
800.00	6.26	1.57	0.97	1.49	3.41E-04	800	0.81	2.8	5.93	1.28	2.5	
900.00	6.34	1.89	1.53	1.49	3.41E-04	900	0.75	2.6	5.99	0.83	3.2	
1000.00	6.39	2.22	0.63	1.18	3.41E-04	1000	0.73	2.44	6.01	0.68	3.8	
1100.00	6.59	2.19	#NUM!	1.18	3.41E-04	1100	0.69	2.309	6.05	0.78	3.6	
1200.00	6.64	####	#NUM!	1.18	3.41E-04	1200	0.67	2.2	6.07	0.96	2.7	
1300.00	6.66	####	#NUM!	1.18	3.41E-04	1300	0.62	2.108	6.12	1.65	#DIV/0!	
1440.00	6.74	####	#NUM!	1.18	3.41E-04	1440	0.54	2	8.2	####	#DIV/0!	

FC-METHOD : Estimation of the sustainable yield of a borehole
BH213

Extrapolation time in years = (enter)	4320	2270592000	Extrapol time in minutes	
Effective borehole radius (r _e) = (enter)	0.50	37.03	← Est. r _e	From r(e) sheet
Q (l/s) from pumping test =	0.18	3.27E-03	← S-late	← Change r _e
s _a (available drawdown), sigma _s = (enter)	8.2	8	← Sigma _s from risk	
Annual effective recharge (mm) =		8.20	s _a available working drawdown(m)	
t(end) and s(end) of pumping test =	1440	6.74	End time and drawdown of test	
Average maximum derivative = (enter)	1.9	3.1	Estimate of average of max deriv	
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	1.50	2.16	Read from derivative graph	
T and S estimates from derivatives	T-early[m ² /d] = 1.90	Aqui. thick (m)		3.1
(To obtain correct S-value, use program RPTSOLV)	T-late [m ² /d] = 1.54	Est. S-late =		1.71E-04
	S-late = 3.41E-04	S-estimate could be wrong		

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)
(No values of T and S are necessary)

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	18.17	29.63	41.10	75.50
Q _{sust} (l/s) =	0.08	0.05	0.04	0.02
	Best case		Worst case	
Average Q _{sust} (l/s) =	0.04			
with standard deviation=	0.03			

(If no information exists about boundaries skip advanced solution and go to final recommendation)

ADVANCED SOLUTION

(Using derivatives+ knowledge on boundaries and other boreholes)
(Late T-and S-values a priori + distance to boundary)

T-late [m ² /d] = (enter)	1.54			
S-late = (enter)	1.00E-03			
1. BOUNDARY INFORMATION (choose a or b)	(Code =9999 = dummy value if not applicable)			
(a) Barrier (no-flow) boundaries	Closed Square	Single Barrier	Intersect. 90°	2 Parallel Barriers
Bound. distance a[meter] : (enter)	9999	9999	9999	9999
Bound. distance b[meter] : (enter)			9999	9999
s _{Bound} (t = Extrapol.time) [m] =	57.12	2.13	5.88	8.36
(b) Fix head boundary + no-flow	Closed Fix	Single Fix	90°Fix+no-flow	// Fix+no-flow
Bound. distance to fix head a[meter] : (enter)	9999	9999	9999	9999
Bound. distance to no-flow b[meter] : (enter)			9999	9999
s _{Bound} (t = Extrapol.time) [m] =	-3.39	-2.13	-3.22	-2.83
2. INFLUENCE OF OTHER BOREHOLES	Q (l/s)	r (m)	u _r	W(u,r)
BH1			0.00E+00	#NUM!
BH2			0.00E+00	#NUM!
s _(influence of BH1,BH2) =	0.00	0.00	2.58E-11	23.80

SOLUTION INCLUDING BOUNDS AND BH's

Fix head + No-flow : Q_{sust} (l/s) = 9999.00
No-flow : Q_{sust} (l/s) = 9999.00

Enter selected Q for risk analysis = (enter) → Sigma_s = 0.000

(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)

FINAL RECOMMENDED ABSTRACTION RATE

Abstraction rate (l/s) for 24 hr/d = (enter)	
Total amount of water allowed to be abstracted per month (m ³) =	0

COMMENTS

Q_{sust} with 68% safety =
Q_{sust} with 95% safety =

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	SA	Geology:	Harbour beds
Region:	Durban	Depth of BH:	25.8
Owner:		Water strikes:	
X-coord:		Date of Test:	
Y-coord:		Contractor:	

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole:		BH403										Other info:	
Distance from Rest WL to main water strike (m) =		19		S _{max} = 6.88		Recom. AD =		11.4					
Q (l/s) =	0.05	Recovery data										T (m ² /d) : Logan eq.	
t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res. s	t/t'	Wl rise	s'	Rec. T	0.8	
0.01	0					0.01	7.29	1E+06	-0.41				
0.50	0.38					0.5	7.02	29921	-0.14	0.23			
1.00	0.48	#####	#NUM!			1	6.76	14961	0.12	0.93			
1.50	0.69	#####	#NUM!	0.87	3.52E-03	1.5	6.57	9974	0.31	1.34	0.6		
2.00	0.8	1.12	#NUM!	0.68	6.60E-04	2	6.35	7481	0.53	2.32	0.4		
2.50	0.91	1.36	0.77	0.60	6.60E-04	2.5	6.05	5985	0.83	2.79	0.3		
3.00	1.04	1.60	0.67	0.48	6.60E-04	3	5.86	4988	1.02	2.87	0.3		
4.00	1.27	1.86	0.56	0.42	6.60E-04	4	5.47	3741	1.41	3.45	0.2		
5.00	1.44	2.08	0.56	0.38	6.60E-04	5	5.09	2993	1.79	3.68	0.2		
6.00	1.63	2.34	0.70	0.34	6.60E-04	6	4.79	2494	2.09	4.23	0.2		
7.00	1.79	2.63	0.75	0.30	6.60E-04	7	4.47	2135	2.41	4.72	0.2		
8.00	1.94	2.91	0.64	0.27	6.60E-04	8	4.2	1871	2.68	4.76	0.2		
9.00	2.13	3.11	0.44	0.25	6.60E-04	9	3.95	1663	2.93	5.15	0.2		
10.00	2.26	3.25	0.29	0.25	6.60E-04	10	3.7	1497	3.18	5.70	0.1		
12.00	2.51	3.38	0.17	0.23	6.60E-04	12	3.24	1248	3.64	5.67	0.1		
15.00	2.87	3.45	-0.08	0.22	6.60E-04	15	2.7	998.3	4.16	5.45	0.1		
20.00	3.35	3.22	-0.73	0.23	6.60E-04	20	2.03	749	4.85	5.15	0.1		
25.00	3.63	2.51	-1.17	0.29	6.60E-04	25	1.56	599.4	5.32	5.32	0.2		
30.00	3.84	1.88	-1.06	0.47	6.60E-04	30	1.09	499.7	5.79	4.01	0.2		
40.00	3.93	1.56	-0.28	0.55	6.60E-04	40	0.72	375	6.16	2.29	0.3		
50.00	4.1	1.61	0.22	0.51	6.60E-04	50	0.59	300.2	6.29	1.36	0.5		
60.00	4.23	1.69	0.04	0.43	6.60E-04	60	0.48	250.3	6.4	1.50	0.6		
70.00	4.38	1.67	-0.52	0.43	6.60E-04	70	0.37	214.7	6.51	1.45	0.5		
80.00	4.47	1.48	-1.13	0.43	6.60E-04	80	0.3	188	6.58	1.46	0.5		
90.00	4.5	1.26	-1.44	0.43	6.60E-04	90	0.21	167.2	6.67	1.75	0.5		
100.00	4.61	1.02	-1.50	0.43	6.60E-04	100	0.13	150.6	6.75	1.17	0.7		
120.00	4.66	0.81	-0.85	0.43	6.60E-04	120	0.06	125.7	6.82	0.73	#DIV/0!		
150.00	4.72	0.77	0.19	0.43	6.60E-04	150	0	100.7	6.88	#####	#DIV/0!		
200.00	4.79	0.92	0.93	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
250.00	4.87	1.19	0.12	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
300.00	5.09	1.06	-1.10	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
350.00	5.13	0.71	-1.78	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
500.00	5.19	0.46	-1.04	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
600.00	5.22	0.40	-0.01	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
700.00	5.24	0.43	0.60	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
800.00	5.27	0.47	0.74	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
900.00	5.3	0.52	0.71	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1000.00	5.32	0.56	1.12	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1140.00	5.35	0.66	1.49	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1200.00	5.37	0.74	1.04	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1300.00	5.41	0.79	0.06	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1440.00	5.43	0.74	-1.13	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1500.00	5.45	0.68	-1.71	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1600.00	5.47	0.60	-1.36	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1700.00	5.48	0.58	0.29	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1800.00	5.49	0.62	1.36	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
1900.00	5.51	0.68	0.46	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2000.00	5.53	0.65	-1.07	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2100.00	5.54	0.61	-0.55	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2200.00	5.55	0.62	1.14	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2300.00	5.56	0.67	1.46	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2400.00	5.58	0.70	0.41	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2500	5.59	0.70	0.50	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2600	5.6	0.73	2.17	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2700	5.61	0.82	3.75	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2800	5.63	0.96	4.14	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
2900	5.64	1.11	3.48	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3000	5.66	1.23	1.95	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3100	5.68	1.27	0.47	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3200	5.7	1.27	0.01	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3300	5.71	1.27	-0.10	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3400	5.73	1.26	-2.59	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3500	5.75	1.09	-7.47	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3600	5.76	0.83	-9.33	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3700	5.77	0.65	-6.33	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3800	5.77	0.58	-1.49	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
3900	5.78	0.60	0.70	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
4000	5.79	0.60	2.46	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
4100	5.79	0.68	7.69	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
4200	5.8	0.90	17.24	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
4320	5.81	1.53	26.33	0.43	6.60E-04			#####	#####	#####	#DIV/0!		
4380	5.82	2.49	20.52	0.26	6.60E-04			#####	#####	#####	#DIV/0!		
4440	5.85	3.11	2.46	0.22	6.60E-04			#####	#####	#####	#DIV/0!		
4470	5.86	2.83	-15.85	0.22	6.60E-04			#####	#####	#####	#DIV/0!		

4520	5.87	2.23	-24.81	0.22	6.60E-04			####	####	####	#DIV/0!
4570	5.88	1.69	-28.82	0.22	6.60E-04			####	####	####	#DIV/0!
4620	5.89	1.19	-24.17	0.22	6.60E-04			####	####	####	#DIV/0!
4670	5.89	0.92	-13.11	0.22	6.60E-04			####	####	####	#DIV/0!
4820	5.9	0.87	2.26	0.22	6.60E-04			####	####	####	#DIV/0!
4920	5.91	1.00	5.66	0.22	6.60E-04			####	####	####	#DIV/0!
5020	5.92	1.13	4.87	0.22	6.60E-04			####	####	####	#DIV/0!
5120	5.93	1.21	4.46	0.22	6.60E-04			####	####	####	#DIV/0!
5220	5.94	1.34	5.30	0.22	6.60E-04			####	####	####	#DIV/0!
5320	5.95	1.51	3.77	0.22	6.60E-04			####	####	####	#DIV/0!
5460	5.97	1.56	0.67	0.22	6.60E-04			####	####	####	#DIV/0!
5520	5.98	1.55	0.05	0.22	6.60E-04			####	####	####	#DIV/0!
5620	5.99	1.58	3.83	0.22	6.60E-04			####	####	####	#DIV/0!
5760	6	1.80	8.48	0.22	6.60E-04			####	####	####	#DIV/0!
5820	6.02	2.10	7.59	0.22	6.60E-04			####	####	####	#DIV/0!
5920	6.03	2.33	3.06	0.22	6.60E-04			####	####	####	#DIV/0!
6020	6.05	2.28	-4.50	0.22	6.60E-04			####	####	####	#DIV/0!
6120	6.07	2.01	-8.61	0.22	6.60E-04			####	####	####	#DIV/0!
6220	6.08	1.72	-8.46	0.22	6.60E-04			####	####	####	#DIV/0!
6320	6.09	1.53	-6.77	0.22	6.60E-04			####	####	####	#DIV/0!
6420	6.1	1.39	-7.00	0.22	6.60E-04			####	####	####	#DIV/0!
6520	6.11	1.23	-7.82	0.22	6.60E-04			####	####	####	#DIV/0!
6620	6.12	1.09	-3.34	0.22	6.60E-04			####	####	####	#DIV/0!
6720	6.12	1.11	5.87	0.22	6.60E-04			####	####	####	#DIV/0!
6820	6.13	1.29	10.21	0.22	6.60E-04			####	####	####	#DIV/0!
6920	6.14	1.50	7.69	0.22	6.60E-04			####	####	####	#DIV/0!
7020	6.15	1.62	3.10	0.22	6.60E-04			####	####	####	#DIV/0!
7120	6.16	1.64	1.00	0.22	6.60E-04			####	####	####	#DIV/0!
7220	6.17	1.68	1.00	0.22	6.60E-04			####	####	####	#DIV/0!
7320	6.18	1.69	-1.26	0.22	6.60E-04			####	####	####	#DIV/0!
7420	6.19	1.61	-6.36	0.22	6.60E-04			####	####	####	#DIV/0!
7520	6.2	1.42	-9.17	0.22	6.60E-04			####	####	####	#DIV/0!
7620	6.21	1.26	-4.02	0.22	6.60E-04			####	####	####	#DIV/0!
7720	6.21	1.28	6.34	0.22	6.60E-04			####	####	####	#DIV/0!
7820	6.22	1.48	13.60	0.22	6.60E-04			####	####	####	#DIV/0!
7920	6.23	1.81	14.56	0.22	6.60E-04			####	####	####	#DIV/0!
8020	6.24	2.14	11.09	0.22	6.60E-04			####	####	####	#DIV/0!
8120	6.25	2.38	4.82	0.22	6.60E-04			####	####	####	#DIV/0!
8220	6.27	2.41	-3.44	0.22	6.60E-04			####	####	####	#DIV/0!
8320	6.28	2.20	-7.28	0.22	6.60E-04			####	####	####	#DIV/0!
8420	6.29	2.03	-3.46	0.22	6.60E-04			####	####	####	#DIV/0!
8520	6.3	2.03	4.85	0.22	6.60E-04			####	####	####	#DIV/0!
8640	6.31	2.27	11.58	0.22	6.60E-04			####	####	####	#DIV/0!
8700	6.32	2.53	14.09	0.22	6.60E-04			####	####	####	#DIV/0!
8760	6.33	2.81	19.23	0.22	6.60E-04			####	####	####	#DIV/0!
8790	6.33	3.12	22.63	0.22	6.60E-04			####	####	####	#DIV/0!
8840	6.34	3.58	14.24	0.22	6.60E-04			####	####	####	#DIV/0!
8890	6.35	3.59	-27.27	0.19	6.60E-04			####	####	####	#DIV/0!
8940	6.36	2.62	-47.30	0.19	6.60E-04			####	####	####	#DIV/0!
8990	6.37	1.76	-41.66	0.19	6.60E-04			####	####	####	#DIV/0!
9140	6.37	1.43	-0.89	0.19	6.60E-04			####	####	####	#DIV/0!
9240	6.38	1.65	14.48	0.19	6.60E-04			####	####	####	#DIV/0!
9340	6.39	2.00	11.86	0.19	6.60E-04			####	####	####	#DIV/0!
9440	6.4	2.13	-1.05	0.19	6.60E-04			####	####	####	#DIV/0!
9540	6.41	1.96	-8.97	0.19	6.60E-04			####	####	####	#DIV/0!
9640	6.42	1.73	-9.95	0.19	6.60E-04			####	####	####	#DIV/0!
9780	6.43	1.57	-0.26	0.19	6.60E-04			####	####	####	#DIV/0!
9840	6.43	1.65	9.13	0.19	6.60E-04			####	####	####	#DIV/0!
9940	6.44	1.88	15.17	0.19	6.60E-04			####	####	####	#DIV/0!
10080	6.45	2.24	12.12	0.19	6.60E-04			####	####	####	#DIV/0!
10140	6.46	2.45	5.58	0.19	6.60E-04			####	####	####	#DIV/0!
10240	6.47	2.50	0.03	0.19	6.60E-04			####	####	####	#DIV/0!
10340	6.48	2.44	-5.20	0.19	6.60E-04			####	####	####	#DIV/0!
10440	6.49	2.26	-10.68	0.19	6.60E-04			####	####	####	#DIV/0!
10540	6.5	1.99	-9.30	0.19	6.60E-04			####	####	####	#DIV/0!
10640	6.51	1.89	3.92	0.19	6.60E-04			####	####	####	#DIV/0!
10740	6.51	2.14	19.53	0.19	6.60E-04			####	####	####	#DIV/0!
10840	6.52	2.72	19.51	0.19	6.60E-04			####	####	####	#DIV/0!
10940	6.54	3.07	4.18	0.19	6.60E-04			####	####	####	#DIV/0!
11040	6.55	2.94	-7.16	0.19	6.60E-04			####	####	####	#DIV/0!
11140	6.56	2.70	-4.26	0.19	6.60E-04			####	####	####	#DIV/0!
11240	6.57	2.72	6.47	0.19	6.60E-04			####	####	####	#DIV/0!
11340	6.58	3.03	11.87	0.19	6.60E-04			####	####	####	#DIV/0!
11440	6.59	3.36	3.45	0.19	6.60E-04			####	####	####	#DIV/0!
11540	6.61	3.22	-15.45	0.19	6.60E-04			####	####	####	#DIV/0!
11640	6.62	2.58	-25.91	0.19	6.60E-04			####	####	####	#DIV/0!
11740	6.63	2.06	-15.95	0.19	6.60E-04			####	####	####	#DIV/0!
11840	6.63	1.96	5.55	0.19	6.60E-04			####	####	####	#DIV/0!
11940	6.64	2.26	13.47	0.19	6.60E-04			####	####	####	#DIV/0!
12040	6.65	2.45	0.83	0.19	6.60E-04			####	####	####	#DIV/0!
12140	6.66	2.30	-11.76	0.19	6.60E-04			####	####	####	#DIV/0!
12240	6.67	2.02	-7.15	0.19	6.60E-04			####	####	####	#DIV/0!
12340	6.67	2.04	5.88	0.19	6.60E-04			####	####	####	#DIV/0!
12440	6.68	2.22	5.54	0.19	6.60E-04			####	####	####	#DIV/0!
12540	6.69	2.23	-4.73	0.19	6.60E-04			####	####	####	#DIV/0!
12640	6.7	2.06	-9.47	0.19	6.60E-04			####	####	####	#DIV/0!
12740	6.7	1.92	-1.27	0.19	6.60E-04			####	####	####	#DIV/0!
12840	6.71	2.03	9.81	0.19	6.60E-04			####	####	####	#DIV/0!
12960	6.72	2.23	18.66	0.19	6.60E-04			####	####	####	#DIV/0!
13020	6.72	2.55	41.87	0.19	6.60E-04			####	####	####	#DIV/0!
13080	6.73	3.23	66.65	0.19	6.60E-04			####	####	####	#DIV/0!
13110	6.73	4.15	69.61	0.17	6.60E-04			####	####	####	#DIV/0!

13160	6.74	5.29	41.69	0.15	6.60E-04			#####	#####	#####	#DIV/0!
13210	6.75	5.51	-17.13	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13260	6.76	4.65	-43.85	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13310	6.77	3.45	-57.42	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13460	6.78	2.21	-48.65	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13560	6.79	1.52	-30.73	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13660	6.79	1.31	3.90	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13760	6.79	1.60	33.06	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13860	6.8	2.12	23.54	0.13	6.60E-04			#####	#####	#####	#DIV/0!
13960	6.81	2.23	-35.12	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14100	6.82	1.18	-70.31	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14160	6.82	0.74	-37.92	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14260	6.82	0.66	37.90	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14400	6.82	1.41	91.22	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14460	6.83	2.52	65.19	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14560	6.84	3.44	26.64	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14660	6.85	3.47	#NUM!	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14760	6.86	#####	#NUM!	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14860	6.87	#####	#NUM!	0.13	6.60E-04			#####	#####	#####	#DIV/0!
14960	6.88	#####	#NUM!	0.13	6.60E-04			#####	#####	#####	#DIV/0!

FC-METHOD : Estimation of the sustainable yield of a borehole BH403

Extrapolation time in years = (enter)	2	1051200	Extrapol. time in minutes
Effective borehole radius (r_e) = (enter)	0.30	#NUM!	Est. r_e From r(e) sheet
Q (l/s) from pumping test =	0.05	3.52E-03	S-late Change r_e
s_a (available drawdown), sigma_s = (enter)	11.4		Sigma_s from risk
Annual effective recharge (mm) =		11.43	$s_{\text{available working drawdown(m)}}$
t(end) and s(end) of pumping test =	14960	6.88	End time and drawdown of test
Average maximum derivative = (enter)	5.5	5.5	Estimate of average of max deriv
Average second derivative = (enter)	1.0	1.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	#NUM!	#NUM!	Read from derivative graph
T and S estimates from derivatives (To obtain correct S-value, use program RPTSOLV)	T-early[m ² /d] =	#NUM!	Aqui. thick (m) 6
	T-late [m ² /d] =	0.14	Est. S-late = 3.30E-04
	S-late =	6.60E-04	S-estimate could be wrong

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time			
(No values of T and S are necessary)		No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =		18.73	28.90	39.08	69.60
Q_sust (l/s) =		0.03	0.02	0.01	0.01
		Best case		Worst case	
Average Q_sust (l/s) =		0.02			
with standard deviation=		0.01			
(If no information exists about boundaries skip advanced solution and go to final recommendation)					

ADVANCED SOLUTION

(Using derivatives+ knowledge on boundaries and other boreholes)

(Late T-and S-values a priori + distance to boundary)

T-late [m²/d] = (enter)

S-late = (enter)

1. BOUNDARY INFORMATION (choose a or b)

(a) Barrier (no-flow) boundaries

Bound. distance a[meter] : (enter)

Bound. distance b[meter] : (enter)

s_Bound(t = Extrapol.time) [m] =

(b) Fix head boundary + no-flow

Bound. distance to fix head a[meter] : (enter)

Bound. distance to no-flow b[meter] : (enter)

s_Bound(t = Extrapol.time) [m] =

2. INFLUENCE OF OTHER BOREHOLES

BH1

BH2

s_(influence of BH1,BH2) =

SOLUTION INCLUDING BOUNDS AND BH's

Fix head + No-flow : Q_sust (l/s) =

No-flow : Q_sust (l/s) =

Enter selected Q for risk analysis = (enter)

0.14

1.00E-03

(Code =9999 = dummy value if not applicable)

Closed Square

Single Barrier

Intersect. 90°

2 Parallel Barriers

9999

9999

9999

9999

9999

9999

#NUM!

#NUM!

#NUM!

#NUM!

Closed Fix

Single Fix

90°Fix+no-flow

// Fix+no-flow

9999

9999

9999

9999

9999

9999

#NUM!

#NUM!

#NUM!

#NUM!

Q (l/s)

r (m)

u_r

W(u,r)

0.00E+00

#NUM!

0.00E+00

#NUM!

0.00

0.00

2.15E-07

14.78

9999.00

9999.00

9999.00

9999.00

9999.00

9999.00

9999.00

9999.00

Sigma_s =

0.000

(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)

FINAL RECOMMENDED ABSTRACTION RATE

Abstraction rate (l/s) for 24 hr/d = (enter)	
Total amount of water allowed to be abstracted per month (m ³) =	0

COMMENTS

Q_sust with 68% safety =
Q_sust with 95% safety =

APPENDIX D

Groundwater level monitoring results

Parameter	Groundwater level (mbgl)*																				
Borehole number	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14	BH15	BH16	BH17	BH18	BH19	BH20	BH21
Monitoring date																					
2004/12/06	2.224	2.115	2.136	1.348	2.527	2.123	2.94	1.697	2.43	2.154	2.417	1.78	1.63	1.647	1.158	0.863	1.798	2.681	2.835	3.503	#N/A
2005/01/03	2.178	1.912	2.09	2.252	2.449	2.967	1.48	1.512	2.096	2.039	2.346	1.685	1.563	1.625	1.187	0.744	1.745	2.678	2.804	3.479	#N/A
2005/02/07	2.157	1.967	2.062	2.233	2.471	#N/A	1.51	1.556	2.134	1.986	2.292	1.687	1.634	1.709	1.268	0.923	1.642	2.707	2.842	3.462	1.519
2005/03/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/06/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/07/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.256	2.126	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/08/02	2.76	2.145	2.122	2.31	2.632	#N/A	1.72	1.754	2.289	2.184	2.525	1.525	1.7	1.685	1.316	0.84	1.81	2.823	2.916	2.551	1.637
2005/09/12	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.365	2.268	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/10/07	2.277	2.205	2.181	2.459	2.621	#N/A	1.82	1.763	2.351	2.259	2.652	1.684	1.849	1.826	1.386	0.819	1.866	2.775	2.898	3.595	1.534
2005/11/09	1.285	#N/A	#N/A	2.509	#N/A	#N/A	#N/A	1.629	2.232	#N/A	#N/A	1.638	#N/A	#N/A	#N/A	#N/A	1.869	2.755	2.863	3.587	#N/A
2005/12/05	1.234	#N/A	#N/A	2.418	#N/A	#N/A	#N/A	1.679	2.287	#N/A	#N/A	1.629	#N/A	#N/A	#N/A	#N/A	1.871	2.775	2.899	3.591	#N/A
2006/01/16	2.127	#N/A	#N/A	1.894	#N/A	#N/A	#N/A	1.579	2.197	#N/A	#N/A	1.601	#N/A	#N/A	#N/A	#N/A	1.852	2.617	2.779	3.516	#N/A
2006/02/13	2.074	#N/A	#N/A	1.843	#N/A	#N/A	#N/A	1.652	2.269	#N/A	#N/A	1.614	#N/A	#N/A	#N/A	#N/A	1.422	2.761	2.862	3.586	#N/A
2006/03/13	1.181	#N/A	#N/A	2.271	#N/A	#N/A	#N/A	1.031	1.872	#N/A	#N/A	0.865	#N/A	#N/A	#N/A	#N/A	1.671	2.346	2.546	2.962	#N/A
2006/04/11	2.039	#N/A	#N/A	2.114	#N/A	#N/A	#N/A	1.585	2.202	#N/A	#N/A	1.264	#N/A	#N/A	#N/A	#N/A	1.519	2.549	2.758	3.105	#N/A
2006/05/08	2.126	#N/A	#N/A	2.106	#N/A	#N/A	#N/A	1.284	2.039	#N/A	#N/A	1.259	#N/A	#N/A	#N/A	#N/A	1.497	2.451	2.664	3.071	#N/A
2006/06/06	2.072	#N/A	#N/A	1.871	#N/A	#N/A	#N/A	1.442	2.142	#N/A	#N/A	1.346	#N/A	#N/A	#N/A	#N/A	1.557	2.524	2.697	3.018	#N/A
2006/07/10	2.174	2.056	1.987	2.291	2.358	1.969	1.67	1.713	2.383	2.394	2.515	1.599	1.589	1.806	1.984	0.82	1.701	2.68	2.831	3.181	2.02
2006/08/21	2.312	#N/A	#N/A	2.454	#N/A	#N/A	#N/A	1.808	2.489	#N/A	#N/A	1.507	#N/A	#N/A	#N/A	#N/A	1.709	2.675	2.835	3.397	#N/A
2006/09/18	2.186	#N/A	#N/A	2.309	#N/A	#N/A	#N/A	2.351	2.398	#N/A	#N/A	1.438	#N/A	#N/A	#N/A	#N/A	1.647	2.641	2.808	3.238	#N/A
2006/10/04	2.169	#N/A	1.864	#N/A	#N/A	#N/A	#N/A	#N/A	2.397	#N/A	#N/A	1.442	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	1.993	#N/A	1.761	#N/A	#N/A	#N/A	#N/A	#N/A	2.037	#N/A	#N/A	1.719	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	1.751	#N/A	1.461	#N/A	#N/A	#N/A	#N/A	#N/A	1.774	#N/A	#N/A	0.938	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	1.27	#N/A	#N/A	1.82	#N/A	#N/A	#N/A	0.81	1.679	#N/A	#N/A	0.775	#N/A	#N/A	#N/A	#N/A	1.81	2.689	2.555	2.905	#N/A
2007/02/05	2.131	#N/A	1.942	#N/A	#N/A	#N/A	#N/A	#N/A	2.172	#N/A	#N/A	1.403	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	2.005	#N/A	1.863	2.025	#N/A	#N/A	#N/A	1.19	2.065	#N/A	#N/A	1.215	#N/A	#N/A	#N/A	#N/A	1.469	#N/A	#N/A	3.045	#N/A
2007/04/03	1.865	#N/A	1.368	#N/A	#N/A	#N/A	#N/A	#N/A	1.994	#N/A	#N/A	0.952	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	1.693	#N/A	#N/A	1.96	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/06/04	1.928	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.645	#N/A	#N/A	1.518	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	1.928	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.954	#N/A	#N/A	1.558	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.341	#N/A	#N/A	1.56	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	#N/A	#N/A	#N/A	2.332	#N/A	#N/A	#N/A	1.814	2.614	#N/A	#N/A	1.594	#N/A	#N/A	#N/A	#N/A	1.784	#N/A	#N/A	#N/A	#N/A
2007/11/05	1.324	#N/A	#N/A	1.801	#N/A	#N/A	#N/A	#N/A	1.825	#N/A	#N/A	0.847	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/12/10	1.105	1.427	1.326	1.554	#N/A	1.175	0.49	0.709	1.634	1.885	2.498	0.634	0.864	1.011	0.714	0.546	0.851	#N/A	#N/A	2.586	1.465
2008/02/01	#N/A	1.744	#N/A	#N/A	#N/A	1.916	#N/A	1.312	2.015	1.873	2.178	#N/A	1.169	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.791
2008/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.127	1.211	1.092	#N/A	0.934	0.561	#N/A	#N/A	#N/A	#N/A	#N/A
2008/07/14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.803	1.054	1.025	#N/A	0.774	0.596	#N/A	#N/A	#N/A	#N/A	#N/A

N/A = Not available

Parameter	Groundwater level(mbgf)*																		
Borehole number	BH22	BH23	BH24	BH25	BH26	BH27	BH28	BH29	BH30	BH31	BH32	BH33	BH34	BH35	BH36	BH37	BH38	BH39	BH40
Monitoring date																			
2004/12/06	#N/A	#N/A	0.893	1.062	1.134	1.669	1.668	2.354	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/01/03	#N/A	#N/A	0.842	1.033	1.038	1.489	1.516	2.302	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/02/07	1.519	1.015	0.929	1.091	1.167	1.624	1.643	2.253	1.531	1.488	1.151	1.311	1.312	0.603	#N/A	#N/A	#N/A	#N/A	#N/A
2005/03/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.173	0.945	1.193	1.027	0.503	2.197	1.837	1.863	#N/A	#N/A
2005/04/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/06/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/07/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/08/02	1.637	1.11	0.99	1.203	1.185	1.631	1.666	2.261	1.562	1.621	1.209	1.405	1.358	0.526	2.4	1.975	2.047	2.211	#N/A
2005/09/12	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/10/07	1.534	0.985	0.987	1.306	1.245	1.802	1.799	2.495	1.665	1.493	1.146	1.228	1.236	0.492	2.431	1.992	2.065	#N/A	#N/A
2005/11/09	#N/A	0.964	#N/A	#N/A	1.194	#N/A	#N/A	#N/A	#N/A	#N/A	1.002	1.208	1.905	0.475	2.408	#N/A	#N/A	#N/A	#N/A
2005/12/05	#N/A	0.936	#N/A	#N/A	1.201	#N/A	#N/A	#N/A	#N/A	#N/A	1	1.201	1.899	0.472	2.406	#N/A	#N/A	#N/A	#N/A
2006/01/16	#N/A	0.899	#N/A	#N/A	1.181	#N/A	#N/A	#N/A	#N/A	#N/A	0.989	1.119	1.887	0.451	2.382	#N/A	#N/A	#N/A	#N/A
2006/02/13	#N/A	0.784	#N/A	#N/A	1.201	#N/A	#N/A	#N/A	#N/A	#N/A	0.863	1.117	1.828	0.409	2.396	#N/A	#N/A	#N/A	#N/A
2006/03/13	#N/A	0.721	#N/A	#N/A	1.002	#N/A	#N/A	#N/A	#N/A	#N/A	0.971	1.012	1.622	0.217	1.948	#N/A	#N/A	1.917	#N/A
2006/04/11	#N/A	0.932	#N/A	#N/A	0.971	#N/A	#N/A	#N/A	#N/A	#N/A	1.106	1.226	1.252	1.364	2.396	#N/A	#N/A	#N/A	#N/A
2006/05/08	#N/A	0.846	#N/A	#N/A	0.989	#N/A	#N/A	#N/A	#N/A	#N/A	1.109	1.178	1.369	1.401	2.139	#N/A	#N/A	#N/A	#N/A
2006/06/06	#N/A	0.885	#N/A	#N/A	0.959	#N/A	#N/A	#N/A	#N/A	#N/A	0.991	1.246	1.158	0.449	2.184	#N/A	#N/A	#N/A	#N/A
2006/07/10	0.986	0.971	0.916	0.987	1.549	1.583	1.558	1.705	1.419	1.525	1.238	1.323	1.321	0.529	2.23	2.016	1.947	#N/A	#N/A
2006/08/21	#N/A	0.949	#N/A	#N/A	1.098	#N/A	#N/A	#N/A	#N/A	#N/A	1.051	1.288	1.16	0.453	2.304	#N/A	#N/A	#N/A	#N/A
2006/09/18	#N/A	0.857	#N/A	#N/A	1.065	#N/A	#N/A	#N/A	#N/A	#N/A	0.964	1.176	1.053	0.426	2.306	#N/A	#N/A	1.963	#N/A
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	#N/A	0.885	#N/A	#N/A	0.799	#N/A	#N/A	#N/A	#N/A	#N/A	0.885	#N/A	#N/A	0.94	0.39	1.81	#N/A	#N/A	1.739
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	#N/A	0.975	#N/A	#N/A	0.919	#N/A	#N/A	#N/A	#N/A	#N/A	1.05	1.115	0.96	0.478	2.19	#N/A	#N/A	1.89	#N/A
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	#N/A	1.009	#N/A	#N/A	0.884	#N/A	#N/A	#N/A	#N/A	#N/A	1.162	#N/A	1.174	0.513	1.88	#N/A	#N/A	1.75	#N/A
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	#N/A	1.084	#N/A	#N/A	2.371	#N/A	#N/A	#N/A	#N/A	#N/A	1.23	1.251	1.176	0.389	2.4	#N/A	#N/A	#N/A	#N/A
2007/11/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/12/10	1.221	0.835	0.453	0.378	0.726	0.97	0.816	1.097	0.364	0.691	0.782	1.077	1.008	0.428	1.854	1.525	1.574	1.679	#N/A
2008/02/01	1.607	#N/A	0.686	#N/A	0.926	#N/A	#N/A	#N/A	0.771	#N/A	1.193	#N/A	1.425	#N/A	#N/A	#N/A	#N/A	1.874	#N/A
2008/04/03	#N/A	#N/A	0.57	0.739	0.943	#N/A	#N/A	#N/A	0.838	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2008/07/14	#N/A	#N/A	0.534	0.672	0.836	#N/A	#N/A	#N/A	0.735	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

N/A = Not available

Parameter	Groundwater level (mbgl)*																				
Borehole number	BH101	BH102	BH103	BH104	BH105	BH106	BH107	BH108	BH109	BH110	BH111	BH112	BH113	BH114	BH115	BH116	BH117	BH118	BH119	BH120	BH121
Monitoring date																					
2004/12/06	1.429	0.062	1.632	2.882	2.128	3.384	0.628	1.462	1.741	1.657	2.623	1.326	1.094	1.479	1.381	0.851	0.711	0.726	1.143	2.294	0.997
2005/01/03	1.346	0.01	1.57	2.798	2.103	3.337	#N/A	1.389	1.607	1.467	2.577	1.118	0.908	1.391	1.204	#N/A	#N/A	#N/A	#N/A	2.249	0.725
2005/02/07	1.368	0	1.579	2.817	2.169	3.372	0.588	1.431	1.615	1.278	2.389	1.095	0.946	1.317	1.21	0.821	0.692	0.72	1.152	2.235	0.889
2005/03/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	#N/A	#N/A	#N/A	2.795	#N/A	#N/A	0.533	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/06/06	#N/A	#N/A	#N/A	2.86	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/07/06	#N/A	#N/A	#N/A	2.835	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/08/02	1.635	0	1.525	2.792	2.085	3.568	0.745	1.582	1.718	#N/A	2.682	1.381	1.17	#N/A	1.456	0.912	0.859	0.775	1.216	2.344	0.927
2005/09/12	#N/A	#N/A	#N/A	2.643	#N/A	#N/A	0.671	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/10/07	1.713	0	1.599	2.816	2.031	3.686	0.641	1.459	1.337	#N/A	1.942	1.487	1.347	1.596	1.661	0.796	0.817	0.706	1.229	2.339	0.995
2005/11/09	#N/A	0	1.551	2.772	#N/A	3.693	0.529	1.145	1.886	1.669	3.007	#N/A	1.346	#N/A	1.194	#N/A	#N/A	0.632	1.216	1.414	1.01
2005/12/05	#N/A	0	1.55	2.917	2.036	3.685	0.503	1.152	1.889	#N/A	3	#N/A	1.329	#N/A	1.191	#N/A	#N/A	0.63	1.219	1.401	1.01
2006/01/16	#N/A	0	1.506	2.916	1.264	3.682	0.516	1.121	1.795	1.629	2.997	#N/A	1.321	#N/A	1.184	#N/A	#N/A	0.619	1.197	1.362	0.997
2006/02/13	#N/A	0	1.462	2.652	2.019	3.616	0.329	0.919	1.881	1.652	2.998	#N/A	1.316	#N/A	1.182	#N/A	#N/A	0.482	0.936	2.233	0.685
2006/03/13	#N/A	0	1.782	1.961	1.971	3.189	0	1.042	1.116	1.271	1.454	#N/A	1.269	1.481	1.162	#N/A	#N/A	0.512	1.146	1.521	1.187
2006/04/11	#N/A	0	1.428	2.624	0.863	3.401	0.01	1.251	1.099	1.134	1.164	#N/A	1.876	#N/A	0.174	#N/A	#N/A	0.996	0.942	2.04	0.659
2006/05/08	#N/A	0	1.516	2.268	0.896	3.359	0.06	1.172	1.11	1.159	1.216	#N/A	1.899	#N/A	0.206	#N/A	#N/A	1.006	1.001	2.02	0.598
2006/06/06	#N/A	0.04	1.425	2.764	#N/A	3.267	0.07	1.231	0.942	1.029	1.724	#N/A	0.634	#N/A	0.886	#N/A	#N/A	0.622	0.891	2.051	0.664
2006/07/10	1.653	0.026	2.119	2.562	#N/A	3.465	0.023	1.429	0.997	1.274	1.643	1.599	1.368	#N/A	1.235	0.876	0.794	0.715	1.029	2.659	2.806
2006/08/21	#N/A	0.004	1.545	2.899	#N/A	3.058	0.541	1.427	#N/A	1.248	2.469	#N/A	0.941	1.138	1.234	#N/A	#N/A	0.661	1.031	2.154	0.802
2006/09/18	#N/A	0	1.521	2.85	#N/A	3.42	0.391	1.314	1.299	1.175	2.453	#N/A	#N/A	#N/A	1.103	#N/A	#N/A	0.665	0.99	2.14	0.634
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	#N/A	0	1.22	2.54	1.48	2.889	0	0.852	0.459	0.69	1.095	#N/A	#N/A	#N/A	0.558	#N/A	#N/A	0.686	0.639	1.645	0.405
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	#N/A	0	1.41	2.675	1.678	2.948	0	1.209	0.756	0.77	1.87	#N/A	#N/A	#N/A	0.786	#N/A	#N/A	0.548	0.82	1.91	0.658
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	#N/A	0	1.23	2.71	1.602	2.62	0	1.125	0.514	0.995	1.259	#N/A	#N/A	1.248	0.778	#N/A	#N/A	0.65	0.714	1.553	0.334
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	#N/A	#N/A	#N/A	2.803	#N/A	#N/A	0.396	1.376	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.826	#N/A	#N/A	0.69	#N/A	#N/A	#N/A
2007/11/05	#N/A	#N/A	#N/A	1.347	#N/A	#N/A	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/12/10	0.67	0	1.099	1.234	1.413	2.396	0	0.555	0.337	0.724	0.985	0.276	#N/A	#N/A	0.603	1.004	0.411	0.478	0.523	1.145	0.01
2008/02/01	1.223	0	1.295	#N/A	1.64	#N/A	#N/A	#N/A	0.612	1.015	#N/A	0.487	#N/A	#N/A	#N/A	#N/A	0.498	#N/A	#N/A	#N/A	#N/A
2008/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.885	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2008/07/14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.559	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

N/A = Not available
mbgl = metres below ground level

Parameter	Groundwater level (mbgl)*											
Borehole number	BH201A	BH202A	BH203A	BH206A	BH208A	BH211A	BH212A	BH214A	BH217A	BH218A	BH220A	BH221A
Monitoring date												
2004/12/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/01/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/02/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/03/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	#N/A	#N/A	0.894	0	#N/A	#N/A	2.072	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	#N/A	#N/A	1.088	0.774	1.605	1.114	2.031	#N/A	1.769	1.361	#N/A	1.512
2005/06/06	1.416	1.695	1.156	1.63	1.442	0.938	2.032	1.926	1.906	1.469	1.249	1.659
2005/07/06	1.075	1.258	1.178	1.693	1.325	0.924	2.065	1.589	1.923	1.479	0.685	1.714
2005/08/02	1.47	1.275	1.226	1.831	1.454	0.96	#N/A	1.618	1.945	1.51	0.739	1.736
2005/09/12	1.149	1.265	1.166	1.958	1.442	0.862	#N/A	1.631	1.899	1.465	0.7	1.836
2005/10/07	1.074	1.344	1.084	1.951	1.541	0.877	#N/A	1.619	1.872	1.416	0.701	1.841
2005/11/09	#N/A	#N/A	1.269	1.962	1.534	0.832	4.514	1.848	1.815	1.372	0.649	1.849
2005/12/05	#N/A	1.498	1.214	1.875	1.526	0.852	3.096	1.801	1.889	1.462	0.647	1.846
2006/01/16	#N/A	#N/A	1.27	1.909	1.589	0.814	5.432	1.865	1.779	1.364	0.565	1.61
2006/02/13	#N/A	#N/A	1.101	1.692	1.459	0.662	#N/A	1.701	1.596	1.197	0.444	1.846
2006/03/13	#N/A	#N/A	1.082	1.118	1.102	0.581	9.51	1.609	1.524	1.301	0	1.162
2006/04/11	0.928	#N/A	#N/A	1.34	1.189	0.714	#N/A	1.903	1.738	0.326	0.502	1.579
2006/05/08	#N/A	#N/A	1.156	1.368	1.101	0.581	#N/A	1.784	1.681	1.269	0.396	1.681
2006/06/06	#N/A	#N/A	1.185	1.416	1.214	0.762	#N/A	2.069	1.734	1.314	0.476	1.549
2006/07/10	1.144	1.185	1.384	1.679	1.355	0.879	#N/A	1.928	1.878	1.435	0.615	1.45
2006/08/21	#N/A	#N/A	1.171	1.799	1.387	0.833	2.965	2.093	1.848	1.391	0.591	1.789
2006/09/18	#N/A	#N/A	1.038	1.831	1.368	0.76	#N/A	1.714	1.752	1.308	0.542	1.752
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	#N/A	#N/A	0.68	0.855	1.042	0.715	#N/A	1.472	1.579	1.16	0.309	#N/A
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	#N/A	#N/A	0.755	1.345	1.2	0.95	#N/A	1.739	1.762	1.365	0	1.513
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	#N/A	#N/A	0.76	1.11	1.17	1.06	#N/A	1.61	1.81	1.4	0.426	#N/A
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	1.098	#N/A	1.085	2.013	1.335	1.114	#N/A	1.799	1.938	1.51	0.654	1.786
2007/11/05	0.91	#N/A	0.623	1.762	1.057	0.395	#N/A	1.196	1.595	1.118	#N/A	#N/A
2007/12/10	0.854	0.773	0.516	0.944	0.955	0.956	#N/A	1.168	1.476	1.328	0.355	0.856
2008/02/01	0.897	0.973	0.514	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.494	#N/A	1.44
2008/04/03	#N/A	#N/A	#N/A	1.234	1.218	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.294
2008/07/14	#N/A	#N/A	#N/A	1.025	1.199	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.322

N/A = Not available

mbgl = metres below ground level

Parameter	Groundwater level (mbgl)*																		
Borehole number	BH201	BH202	BH203	BH205	BH206	BH208	BH209	BH210	BH211	BH213	BH214	BH216	BH217	BH218	BH219	BH220	BH221	BH222	BH223
Monitoring date																			
2004/12/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/01/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/02/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/03/07	0.694	1.012	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	0.828	0.948	0.406	2.859	0.515	0.967	0.468	0.383	0	2.861	2.505	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	0.935	1.012	0.465	2.99	1.868	1.196	0.62	0.581	0	2.913	2.538	2.571	1.418	0.952	#N/A	0	1.349	1.619	#N/A
2005/06/06	1.035	1.126	0.547	3.05	0.779	1.338	0.715	0.726	1.56	3.003	2.671	2.655	1.5	1.035	2.41	1.15	1.479	1.734	1.21
2005/07/06	1.065	1.204	0.617	3.005	0.83	1.294	0.647	0.716	0.445	3.035	2.677	2.655	1.498	1.019	2.407	0.3	1.472	1.747	0.543
2005/08/02	1.119	1.279	0.675	3.085	0.923	1.407	0.767	0.785	0.511	3.089	2.701	2.71	1.565	1.075	2.445	0.359	1.544	1.83	0.59
2005/09/12	1.158	1.329	0.748	3.164	1.022	1.398	0.756	0.772	0.501	3.069	2.759	2.703	1.542	1.081	2.453	0.385	1.583	1.849	0.531
2005/10/07	1.11	1.262	0.74	3.217	1.025	1.463	#N/A	0.786	0.495	3.135	2.778	2.747	1.573	1.076	2.471	0.403	1.582	1.864	0.532
2005/11/09	1.321	1.857	1.521	3.286	1.145	1.452	#N/A	0.755	0.494	3.105	2.899	2.714	1.556	1.067	2.449	0.384	1.592	1.864	0.457
2005/12/05	1.271	1.799	1.498	3.001	1.099	1.406	#N/A	0.757	0.469	3	2.951	2.701	1.762	1.056	2.448	0.371	1.59	1.864	0.452
2006/01/16	1.212	1.875	1.742	3.187	1.876	1.41	#N/A	0.628	0.473	3.099	2.945	2.573	1.57	1.024	2.369	0.36	1.441	1.709	0.446
2006/02/13	1.171	1.779	1.675	3.045	0.944	1.309	#N/A	0.749	0.256	2.956	2.746	2.453	1.258	0.895	2.169	0.195	1.586	1.859	0.285
2006/03/13	1.121	1.633	1.641	2.995	0.522	1.02	#N/A	0.517	0.09	2.713	2.611	2.614	1.102	0.801	2.271	0	1.017	1.016	0.341
2006/04/11	1.148	1.524	1.371	2.872	0.681	1.089	#N/A	0.464	0.324	2.761	2.823	2.499	1.307	0.849	2.261	0.01	1.351	1.639	0.956
2006/05/08	1.096	1.521	1.169	2.991	0.561	1.026	#N/A	0.516	0.189	2.754	2.617	2.386	1.25	0.817	2.289	0	1.529	1.587	0.991
2006/06/06	1.119	1.331	0.994	2.931	0.714	1.137	#N/A	0.542	0.389	2.653	2.831	2.538	1.385	0.843	2.194	0	1.314	1.584	0.37
2006/07/10	1.132	1.295	0.917	2.986	0.941	1.271	#N/A	0.705	0.482	3.002	2.827	2.664	1.545	0.982	2.375	0.22	1.805	1.723	0.492
2006/08/21	1.099	1.326	0.813	3.079	0.956	1.324	#N/A	0.664	0.437	3.032	2.965	2.632	1.473	0.982	2.319	0.254	1.463	1.728	0.446
2006/09/18	1.032	1.225	0.667	3.075	0.882	1.272	#N/A	0.625	0.376	2.959	2.996	2.575	1.411	0.934	2.244	0	1.397	1.689	0.395
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	0.797	1.112	#N/A	#N/A	0.48	0.95	#N/A	0.37	0.22	#N/A	2.979	2.485	1.23	0.761	1.964	0	#N/A	1.493	0.259
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	0.825	1.105	0.579	2.87	0.65	1.119	#N/A	0.535	0.33	#N/A	1.575	2.445	1.328	0.85	2.145	0	1.523	1.528	0.387
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	#N/A	0.966	#N/A	#N/A	0.62	1.01	#N/A	0.305	0.305	#N/A	2.493	2.384	1.275	0.795	2.015	0	#N/A	1.435	0.468
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	1.219	#N/A	#N/A	#N/A	1.105	1.29	#N/A	#N/A	0.541	#N/A	2.635	2.661	1.552	1.097	2.281	0.224	#N/A	#N/A	0.568
2007/11/05	#N/A	#N/A	#N/A	#N/A	0.563	0.915	0.394	#N/A	0	#N/A	2.114	#N/A	1.137	0.674	#N/A	0	#N/A	#N/A	#N/A
2007/12/10	0.786	0.945	#N/A	#N/A	0.43	0.825	0.375	0.37	0	#N/A	2.143	2.257	1.134	1.114	1.956	0	0.826	1.654	0.631
2008/02/01	0.834	1.008	#N/A	#N/A	#N/A	1.095	0.54	0.562	0.373	#N/A	2.403	#N/A	#N/A	0.862	2.086	0	1.02	1.32	#N/A
2008/04/03	#N/A	#N/A	#N/A	#N/A	0.506	1.096	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.097	1.327	#N/A
2008/07/14	#N/A	#N/A	#N/A	#N/A	0.424	1.068	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1.119	1.324	#N/A

N/A = Not available
mbgl = metres below ground level

Parameter	Groundwater level (mbgl)*															
Borehole number	BH301	BH302	BH303	BH304	BH307	BH308	BH309	BH310	BH311	BH312	BH313	BH314	BH315	BH316	BH317	BH318
Monitoring date																
2004/12/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/01/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/02/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/03/07	#N/A	0.597	0.57	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	0	0.51	0.382	1.354	0.61	1.546	1.755	2.067	1.713	1.896	2.201	2.455	2.651	1.584	1.762	1.172
2005/05/03	0.399	0.798	0.64	1.519	0.869	1.676	1.801	2.174	1.775	1.896	2.29	2.547	2.689	1.929	1.885	1.169
2005/06/06	0.625	0.92	2.039	1.556	0.973	1.77	1.937	2.347	1.885	1.976	2.418	2.622	2.793	2.116	1.959	1.505
2005/07/06	#N/A	0.952	0.809	1.617	1.023	1.875	2.039	2.435	1.935	2.065	2.472	2.666	2.835	2.223	2.013	1.479
2005/08/02	0.762	0.997	0.892	#N/A	1.055	1.886	2.079	2.479	1.971	2.059	2.512	2.679	2.875	#N/A	2.03	1.496
2005/09/12	0.636	0.959	0.852	1.676	0.932	1.917	1.995	2.491	1.995	2.079	2.548	2.702	2.857	3.321	2.074	1.465
2005/10/07	#N/A	0.903	0.805	1.661	0.851	1.924	1.998	2.493	1.993	2.075	2.516	2.684	2.845	2.342	2.085	1.556
2005/11/09	#N/A	0.872	0.775	#N/A	0.856	#N/A	2.502	#N/A	#N/A	2.106	#N/A	2.575	2.815	2.403	#N/A	1.452
2005/12/05	#N/A	0.852	0.723	#N/A	0.941	#N/A	2.439	#N/A	#N/A	2.069	#N/A	#N/A	2.809	2.374	#N/A	1.439
2006/01/16	#N/A	0.637	0.739	#N/A	0.789	#N/A	2.389	#N/A	#N/A	2.091	#N/A	2.547	2.719	2.356	#N/A	1.343
2006/02/13	#N/A	0.569	0.519	#N/A	0.692	#N/A	2.356	#N/A	#N/A	1.99	#N/A	2.487	2.664	1.681	#N/A	1.248
2006/03/13	#N/A	0.617	0.511	#N/A	0.721	#N/A	2.209	#N/A	#N/A	1.893	#N/A	2.417	2.518	1.401	#N/A	1.307
2006/04/11	#N/A	0.613	0.481	1.697	0.693	1.952	2.487	#N/A	1.903	1.914	#N/A	2.487	2.708	1.712	#N/A	1.29
2006/05/08	#N/A	0.619	0.561	#N/A	0.829	#N/A	2.581	#N/A	#N/A	2.164	#N/A	2.519	2.695	2.001	#N/A	1.287
2006/06/06	#N/A	0.694	0.59	#N/A	0.968	#N/A	2.59	#N/A	#N/A	2.152	#N/A	2.564	#N/A	1.904	#N/A	1.327
2006/07/10	#N/A	0.81	0.855	1.921	1.021	#N/A	2.789	2.659	2.267	NA	#N/A	2.651	2.818	2.148	1.97	1.455
2006/08/21	#N/A	0.804	0.695	#N/A	0.91	#N/A	1.574	#N/A	#N/A	1.985	#N/A	2.756	2.944	2.355	#N/A	1.394
2006/09/18	#N/A	0.796	0.742	#N/A	0.817	#N/A	1.275	#N/A	#N/A	1.803	2.496	2.439	2.864	2.226	#N/A	1.335
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	1.371	#N/A	#N/A	#N/A	#N/A	#N/A	2.563	#N/A	2.16	1.964	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	0.884	#N/A	#N/A	#N/A	#N/A	#N/A	2.414	#N/A	1.873	1.752	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	0.667	#N/A	#N/A	#N/A	#N/A	#N/A	2.148	#N/A	1.498	1.646	#N/A
2007/01/03	#N/A	0.299	0.22	#N/A	0.317	#N/A	0.575	#N/A	#N/A	1.169	#N/A	1.749	1.83	1.219	#N/A	0.97
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	1.246	#N/A	#N/A	#N/A	#N/A	#N/A	2.418	#N/A	1.993	1.865	#N/A
2007/03/07	#N/A	0.58	0.355	#N/A	#N/A	0.859	0.595	#N/A	#N/A	1.425	#N/A	2.332	2.644	1.79	#N/A	1.2
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	0.79	#N/A	#N/A	#N/A	#N/A	#N/A	2.13	#N/A	1.758	#N/A	#N/A
2007/05/09	#N/A	#N/A	0.569	#N/A	0.59	#N/A	0.999	#N/A	#N/A	1.55	#N/A	2.086	2.46	#N/A	#N/A	#N/A
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	1.268	#N/A	#N/A	#N/A	#N/A	#N/A	2.504	#N/A	1.964	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	1.359	#N/A	#N/A	#N/A	#N/A	#N/A	2.067	#N/A	1.822	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	0.795	#N/A	#N/A	#N/A	#N/A	#N/A	2.558	#N/A	2.089	#N/A	#N/A
2007/09/17	#N/A	1.095	0.52	#N/A	0.865	1.183	0.579	#N/A	#N/A	1.986	#N/A	2.658	2.91	2.251	#N/A	1.423
2007/11/05	#N/A	#N/A	0.507	#N/A	#N/A	0.914	0.554	#N/A	#N/A	1.114	#N/A	2.047	#N/A	1.168	#N/A	#N/A
2007/12/10	0.395	0.854	0	1.41	0.225	0.753	0.23	#N/A	1.146	0.924	1.674	1.916	2.445	1.069	#N/A	0.948
2008/02/01	#N/A	0.715	0.639	1.342	#N/A	0.895	#N/A	#N/A	1.29	1.421	#N/A	1.265	2.576	1.764	#N/A	1.114
2008/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2008/07/14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

N/A = Not available

mbgl = metres below ground level

Parameter	Groundwater level (mbgl)*											
Borehole number	BH401	BH402	BH403	BHD1	BHD3	BHD5	BH_T	BH_CT	BH_C4	BH_DP	BH_Ar	BH_Ca
Monitoring date												
2004/12/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/01/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/02/07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/03/07	#N/A	#N/A	#N/A	7.862	#N/A	2.194	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/04/04	#N/A	#N/A	#N/A	7.793	32.788	2.049	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/05/03	#N/A	#N/A	#N/A	7.519	32.808	1.354	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/06/06	#N/A	#N/A	#N/A	8.242	32.731	2.326	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/07/06	#N/A	#N/A	#N/A	8.355	32.705	2.717	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/08/02	2.626	3.474	2.313	10.466	32.809	2.535	#N/A	0.000	0.871	#N/A	1.495	#N/A
2005/09/12	2.773	2.863	#N/A	8.505	32.747	2.637	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2005/10/07	2.586	2.798	1.947	8.676	32.704	2.492	#N/A	0.000	0.761	#N/A	1.390	#N/A
2005/11/09	2.546	2.654	1.599	8.546	32.686	2.456	#N/A	0	0.764	#N/A	1.579	#N/A
2005/12/05	2.822	2.291	1.997	8.529	32.681	2.185	#N/A	0.000	0.760	#N/A	1.456	#N/A
2006/01/16	2.791	2.751	1.972	8.906	32.791	2.579	#N/A	0.000	0.791	#N/A	1.334	#N/A
2006/02/13	#N/A	2.302	1.526	7.896	32.695	2.334	#N/A	0.000	0.741	#N/A	1.019	#N/A
2006/03/13	2.511	2.131	1.827	7.642	32.694	2.012	#N/A	0.000	0.613	#N/A	0.769	#N/A
2006/04/11	#N/A	2.214	1.692	8.056	32.625	2.147	#N/A	0.000	0.619	#N/A	1.001	#N/A
2006/05/08	#N/A	2.016	1.785	7.995	32.699	1.867	#N/A	0.000	0.583	#N/A	0.989	#N/A
2006/06/06	#N/A	2.026	1.472	7.378	32.594	3.978	#N/A	0.000	0.366	#N/A	0.996	#N/A
2006/07/10	#N/A	2.253	1.551	7.998	32.749	2.227	#N/A	0.000	0.459	#N/A	1.24	#N/A
2006/08/21	#N/A	2.192	1.51	7.861	#N/A	2.087	#N/A	0.000	0.393	#N/A	0.994	#N/A
2006/09/18	2.243	2.253	1.574	7.585	#N/A	2.052	#N/A	0.000	0.000	#N/A	1.195	#N/A
2006/10/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/11/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2006/12/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/01/03	1.805	1.985	#N/A	7.07	36.07	1.739	#N/A	0.000	0.080	#N/A	0.849	#N/A
2007/02/05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/03/07	2.045	2.289	1.478	7.81	32.37	1.99	0.462	0.000	0.425	#N/A	1.648	#N/A
2007/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/05/09	1.909	2.031	#N/A	7.183	32.164	#N/A	0.506	0.000	0.295	#N/A	0.941	#N/A
2007/06/04	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/07/02	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/08/06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/09/17	2.274	2.403	#N/A	#N/A	#N/A	2.197	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/11/05	#N/A	2.213	#N/A	#N/A	#N/A	1.955	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2007/12/10	1.885	2.084	1.361	6.84	31.744	1.824	#N/A	0.000	#N/A	6.045	1.02	0.894
2008/02/01	1.938	2.081	1.415	7.356	31.56	1.831	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2008/04/03	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2008/07/14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

N/A = Not available

mbgl = metres below ground level

APPENDIX E

Analytical results of groundwater samples

Sample type		Groundwater chemistry																	
Aquifer		Aquifer 1																	
Borehole number		BH1	BH2	BH3	BH4	BH5	BH11	BH12	BH13	BH14	BH15	BH16	BH17	BH18	BH19	BH20	BH21	BH22	
Chemical substance		Hexavalent chromium concentration (mg/l)																	
Sampling Event	Date																		
1	2004/11/03	342.00	503.00	862.00	269.00	NT	NT	NT	70.00	936.00	142.00	NT	NT	NT	NT	NT	10.40	25.80	
2	2005/05/05	321.00	482.00	618.00	NT	0.01	0.01	0.01	60.00	847.00	181.00	0.02	0.03	0.01	0.04	0.84	10.40	23.00	
3	2006/02/03	NT	NT	NT	31.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
4	2006/03/13	279.00	NT	700.00	245.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	8.80	14.00	
5	2006/04/05	NT	NT	NT	32.10	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
6	2006/05/03	306.00	NT	781.00	36.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	4.90	21.00	
7	2006/06/13	NT	NT	NT	21.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
8	2006/07/10	140.00	NT	731.00	30.90	<0.02	<0.02	<0.02	74.00	915.00	123.00	<0.02	<0.02	<0.02	<0.02	<0.02	6.00	17.00	
9	2006/08/30	292.00	NT	552.00	23.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	5.60	24.00	
10	2006/09/27	NT	NT	NT	48.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
11	2006/10/20	278.00	NT	693.00	32.00	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	2.70	19.00	
12	2006/11/21	NT	NT	NT	12.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
13	2006/12/07	260.00	194.00	705.00	7.50	<0.02	<0.02	<0.02	69.00	920.00	129.00	<0.02	<0.02	0.07	<0.02	<0.02	6.60	19.00	
14	2007/01/24	270.00	NT	780.00	217.00	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	6.30	NT	
15	2007/02/06	NT	NT	NT	18.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
16	2007/03/22	NT	NT	560.00	5.60	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	4.80	8.30	
17	2007/04/16	NT	NT	NT	9.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
18	2007/05/31	216.00	NT	NT	15.00	<0.02	<0.02	<0.02	32.00	721.00	109.00	<0.02	NT	<0.02	<0.02	<0.02	7.00	19.30	
19	2007/06/11	NT	NT	NT	19.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
20	2007/07/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	7.00	19.00	
21	2007/08/20	NT	NT	NT	25.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
22	2007/09/17	NT	NT	NT	20.00	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	NT	
23	2007/10/30	NT	NT	NT	7.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
24	2007/11/30	212.00	108.00	350.00	11.00	<0.02	0.05	<0.02	15.00	322.00	104.00	<0.02	<0.02	<0.02	<0.02	0.03	4.00	3.00	
25	2008/03/03	NT	NT	625.00	NT	NT	NT	NT	NT	NT	NT	NT	0.25	NT	NT	NT	NT	15.00	
26	2008/04/02	NT	NT	NT	NT	NT	0.05	0.05	10.50	NT	208.00	0.12	NT	NT	0.10	NT	NT	NT	
27	2008/05/13	165.00	150.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	5.40	NT	
28	2008/06/09	NT	NT	457.00	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	14.00	
29	2008/07/23	NT	NT	NT	5.00	NT	0.03	0.02	10.60	NT	164.00	<0.02	NT	NT	0.27	NT	NT	NT	
30	2008/08/05	185.00	348.00	NT	NT	NT	0.05	NT	NT	NT	NT	NT	NT	NT	NT	NT	2.80	NT	
31	2008/09/04	NT	NT	395.00	NT	NT	0.02	NT	NT	NT	213.00	NT	NT	NT	NT	NT	NT	38.00	
32	2008/10/14	NT	NT	NT	5.50	NT	<0.02	<0.02	8.30	NT	36.00	<0.02	NT	NT	<0.02	NT	NT	NT	
33	2008/11/17	304.00	152.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	3.13	NT	
34	2008/12/18	192.00	242.00	329.00	8.10	NT	NT	NT	8.80	NT	113.00	<0.02	<0.02	NT	0.32	NT	7.30	18.00	

NT = Not Tested

Sample type		Groundwater chemistry																
Aquifer		Aquifer 1																
Borehole number		BH23	BH24	BH25	BH26	BH27	BH28	BH29	BH30	BH31	BH32	BH33	BH34	BH36	BH38	BH39	BH108	
Chemical substance		Hexavalent chromium concentration (mg/l)																
Sampling Event	Date																	
1	2004/11/03	68.90	0.08	0.03	0.07	0.02	NT	0.79	0.08	0.07	3.60	0.05	0.05	194.00	45.00	0.02	162.00	
2	2005/05/05	107.00	0.02	0.02	0.02	0.05	36.00	0.56	0.04	0.04	1.34	0.01	0.01	239.00	29.00	0.02	173.00	
3	2006/02/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
4	2006/03/13	7.00	NT	NT	NT	NT	28.00	0.28	NT	NT	2.60	NT	NT	74.00	88.00	NT	157.00	
5	2006/04/05	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
6	2006/05/03	2.10	NT	NT	NT	NT	14.00	0.06	NT	NT	0.10	NT	NT	116.00	60.00	NT	188.00	
7	2006/06/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
8	2006/07/10	0.90	<0.02	<0.02	NT	NT	7.00	<0.02	42.00	<0.02	0.02	<0.02	<0.02	128.00	<0.02	<0.02	179.00	
9	2006/08/30	0.70	NT	NT	NT	NT	17.00	0.09	NT	NT	0.04	NT	NT	125.00	17.00	NT	176.00	
10	2006/09/27	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
11	2006/10/20	<0.02	NT	NT	NT	NT	8.80	<0.02	<0.02	0.10	NT	<0.02	<0.02	89.00	21.00	NT	186.00	
12	2006/11/21	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
13	2006/12/07	<0.02	<0.02	<0.02	NT	NT	1.00	<0.02	<0.02	<0.02	0.40	<0.02	<0.02	113.00	104.00	<0.02	188.00	
14	2007/01/24	1.90	NT	NT	NT	NT	0.80	0.20	<0.02	<0.02	0.08	NT	<0.02	44.00	78.00	NT	169.00	
15	2007/02/06	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
16	2007/03/22	<0.02	NT	NT	NT	NT	0.20	1.00	<0.02	<0.02	<0.02	<0.02	<0.02	42.00	83.00	NT	38.00	
17	2007/04/16	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
18	2007/05/31	9.00	<0.02	<0.02	NT	NT	<0.02	<0.02	0.03	<0.02	0.10	<0.02	NT	49.00	52.00	<0.02	163.00	
19	2007/06/11	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
20	2007/07/30	26.00	NT	NT	NT	NT	0.60	<0.02	<0.02	0.50	<0.02	<0.02	<0.02	47.00	24.00	NT	167.00	
21	2007/08/20	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
22	2007/09/17	NT	NT	NT	NT	NT	0.40	<0.02	NT	NT	NT	0.03	<0.02	44.00	21.00	NT	172.00	
23	2007/10/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
24	2007/11/30	0.90	<0.02	2.00	0.50	<0.02	0.20	0.09	<0.02	<0.02	0.05	<0.02	<0.02	2.00	30.00	<0.02	102.00	
25	2008/03/03	15.65	NT	NT	NT	NT	NT	NT	NT	0.17	0.34	0.16	0.17	NT	NT	NT	113.00	
26	2008/04/02	NT	<0.02	0.75	2.66	NT	NT	NT	<0.02	NT	NT	NT	NT	NT	NT	NT	NT	
27	2008/05/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
28	2008/06/09	10.50	NT	NT	NT	NT	NT	NT	NT	<0.02	0.12	<0.02	<0.02	NT	NT	NT	123.00	
29	2008/07/23	NT	<0.02	12.40	12.40	NT	NT	NT	<0.02	NT	NT	NT	NT	NT	NT	<0.02	NT	
30	2008/08/05	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
31	2008/09/04	16.40	NT	NT	<0.02	NT	NT	NT	NT	<0.02	<0.02	<0.02	<0.02	NT	NT	NT	151.00	
32	2008/10/14	16.40	<0.02	8.80	2.90	NT	NT	NT	<0.02	NT	NT	<0.02	NT	NT	NT	<0.02	NT	
33	2008/11/17	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	
34	2008/12/18	3.50	<0.02	26.70	6.60	NT	NT	NT	<0.02	<0.02	0.17	<0.02	<0.02	NT	NT	<0.02	142.00	

NT = Not Tested

Sample type		Groundwater chemistry															
Aquifer		Aquifer 1															
Borehole number		BH301	BH302	BH303	BH304	BH307	BH308	BH309	BH310	BH311	BH312	BH313	BH314	BH315	BH316	BH317	BH318
Chemical substance		Hexavalent chromium concentration (mg/l)															
Sampling Event	Date																
1	2004/11/03	7.06	0.59	0.03	404.00	0.06	247.00	459.00	4592.00	3886.00	3515.00	3886.00	1406.00	422.00	257.00	237.00	0.08
2	2005/05/05	8.90	0.87	0.03	332.00	0.03	464.00	696.00	3838.00	7320.00	3819.00	3392.00	1428.00	446.00	267.00	178.00	0.03
3	2006/02/28	2.60	NT	NT	173.00	NT	1057.00	443.00	NT	6580.00	2597.00	5887.00	520.00	NT	121.00	130.00	NT
4	2006/03/13	NT	0.17	NT	192.00	1.80	944.00	525.00	192.00	4058.00	2099.00	5596.00	525.00	595.00	78.00	122.00	NT
5	2006/04/21	NT	NT	NT	169.00	NT	1121.00	646.00	NT	2436.00	978.00	9750.00	920.00	NT	195.00	337.00	NT
6	2006/05/03	NT	3.30	NT	155.00	2.00	1218.00	729.00	377.00	2425.00	649.00	NT	1009.00	724.00	181.00	329.00	NT
7	2006/06/13	NT	NT	NT	151.00	NT	1297.00	1100.00	NT	2772.00	984.00	NT	1170.00	NT	220.00	320.00	NT
8	2006/07/10	NT	<0.02	0.66	156.00	0.40	NT	1285.00	295.00	3405.00	NT	NT	1220.00	654.00	206.00	299.00	<0.02
9	2006/08/30	NT	<0.02	NT	151.00	1.30	809.00	80.00	NT	4185.00	1361.00	NT	920.00	NT	194.00	195.00	NT
10	2006/09/27	NT	NT	NT	161.00	NT	394.00	118.00	NT	NT	195.00	8160.00	994.00	NT	186.00	274.00	NT
11	2006/10/20	NT	<0.02	NT	167.00	5.40	221.00	136.00	97.00	7050.00	190.00	7180.00	715.00	679.00	177.00	NT	NT
12	2006/11/21	NT	NT	NT	175.00	NT	250.00	95.00	NT	7350.00	283.00	NT	725.00	NT	252.00	232.00	NT
13	2006/12/07	NT	<0.02	<0.02	183.00	2.30	103.00	74.00	21.00	2265.00	190.00	NT	523.00	714.00	179.00	125.00	<0.02
14	2007/01/24	NT	NT	<0.02	196.00	1.70	33.00	58.00	330.00	735.00	80.00	7080.00	590.00	670.00	57.00	15.00	NT
15	2007/02/19	5.00	NT	NT	240.00	NT	100.00	260.00	NT	530.00	420.00	7000.00	680.00	NT	160.00	250.00	NT
16	2007/03/22	NT	<0.02	<0.02	280.00	80.00	160.00	480.00	NT	820.00	NT	NT	720.00	710.00	81.00	NT	NT
17	2007/04/16	NT	NT	NT	370.00	NT	140.00	400.00	NT	670.00	590.00	7000.00	670.00	NT	99.00	NT	NT
18	2007/05/31	NT	<0.02	<0.02	252.00	1.70	123.00	567.00	NT	885.00	274.00	9260.00	730.00	690.00	79.00	NT	<0.02
19	2007/06/11	NT	NT	NT	206.00	1.00	117.00	700.00	NT	1118.00	440.00	6830.00	820.00	NT	89.00	NT	NT
20	2007/07/30	NT	<0.02	<0.02	173.00	NT	152.00	497.00	NT	1758.00	315.00	5945.00	928.00	NT	93.00	NT	NT
21	2007/08/20	4.00	NT	NT	202.00	NT	204.00	391.00	NT	1413.00	486.00	6437.00	543.00	NT	102.00	NT	NT
22	2007/09/17	NT	NT	NT	252.00	NT	NT	303.00	NT	1372.00	319.00	NT	865.00	NT	96.00	NT	NT
23	2007/10/30	NT	NT	NT	543.00	NT	326.00	320.00	NT	4630.00	430.00	NT	924.00	NT	39.00	NT	NT
24	2007/11/30	2.91	0.30	<0.02	337.00	3.00	347.00	170.00	NT	4050.00	289.00	4150.00	910.00	448.00	48.00	NT	0.02
25	2008/03/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
26	2008/04/02	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	760.00	NT	NT	NT
27	2008/05/13	2.87	0.19	<0.02	242.00	0.51	244.00	31.00	NT	3572.00	140.00	6518.00	1179.00	402.00	32.00	NT	<0.02
28	2008/06/09	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
29	2008/07/23	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	164.00	NT	NT	NT
30	2008/08/05	2.61	0.38	<0.02	254.00	0.21	218.00	65.00	NT	2499.00	334.00	5938.00	1282.00	498.00	34.00	NT	<0.02
31	2008/09/04	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
32	2008/10/14	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
33	2008/11/17	2.64	0.28	0.10	143.00	1.22	162.00	143.00	NT	784.00	218.00	5907.00	1458.00	624.00	62.00	NT	0.02
34	2008/12/18	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT

NT = Not Tested

Sample type		Groundwater chemistry																	
Aquifer		Aquifer 2																	
Borehole number		BH201A	BH202A	BH203A	BH204A	BH205A	BH206A	BH207A	BH208A	BH211A	BH212A	BH214A	BH215A	BH217A	BH218A	BH221A	BH223A	BH224A	BH225A
Chemical substance		Hexavalent chromium concentration (mg/l)																	
Sampling Event	Date																		
1	2004/11/03	0.50	0.90	14981.00	23668.00	16249.00	95.00	5634.00	0.04	NT	66764.00	0.03	25939.00	3429.00	31.00	402.00	NT	NT	NT
2	2005/05/05	NT	NT	31623.00	24872.00	20964.00	51.00	4961.00	NT	0.02	64313.00	NT	18701.00	3731.00	50.00	427.00	0.03	11600.00	14763.00
3	2006/02/28	NT	NT	42770.00	26320.00	23550.00	NT	3809.00	NT	NT	15930.00	NT	17547.00	NT	NT	NT	NT	23878.00	40252.00
4	2006/03/13	NT	NT	41624.00	25424.00	22918.00	53.00	3580.00	NT	NT	15756.00	NT	NT	3497.00	42.00	700.00	NT	22386.00	39525.00
5	2006/04/21	NT	NT	35500.00	23435.00	21337.00	NT	3847.00	NT	NT	18888.00	NT	NT	NT	NT	NT	NT	19900.00	38600.00
6	2006/05/03	NT	NT	41500.00	22735.00	20287.00	83.00	3847.00	NT	NT	18538.00	NT	15506.00	2690.00	79.00	530.00	NT	17200.00	29750.00
7	2006/06/13	NT	NT	36600.00	22053.00	20158.00	NT	3704.00	NT	NT	20158.00	NT	15130.00	NT	NT	NT	NT	16100.00	32300.00
8	2006/07/10	<0.02	<0.02	40880.00	22429.00	20382.00	76.00	4183.00	NT	<0.02	NT	NT	14236.00	NT	NT	414.00	NT	15800.00	36300.00
9	2006/08/30	NT	NT	34700.00	20563.00	19860.00	63.00	4393.00	NT	NT	26363.00	NT	13467.00	3175.00	49.00	NT	NT	11650.00	18350.00
10	2006/09/11	NT	NT	17750.00	18713.00	20462.00	19.00	4372.00	NT	NT	NT	<0.02	14660.00	1360.00	NT	NT	NT	12400.00	16600.00
11	2006/10/20	NT	NT	22750.00	18369.00	22785.00	80.00	3356.00	NT	<0.02	25257.00	NT	15134.00	3220.00	108.00	NT	NT	11250.00	10450.00
12	2006/11/06	NT	NT	23360.00	NT	NT	NT	3647.00	NT	NT	NT	NT	14910.00	NT	NT	NT	NT	12345.00	11965.00
13	2006/12/07	<0.02	<0.02	NT	19490.00	21610.00	122.00	3170.00	<0.02	<0.02	21300.00	<0.02	12880.00	3680.00	51.00	290.00	<0.02	16910.00	14770.00
14	2007/01/24	NT	NT	30000.00	18790.00	20210.00	130.00	4320.00	NT	NT	21980.00	NT	13000.00	3500.00	80.00	510.00	NT	15000.00	15070.00
15	2007/02/19	NT	NT	33000.00	16000.00	20000.00	NT	4000.00	NT	NT	18000.00	NT	11000.00	NT	NT	NT	NT	15000.00	22000.00
16	2007/03/22	NT	NT	32000.00	14000.00	17000.00	130.00	3500.00	NT	<0.02	18000.00	NT	12000.00	3500.00	44.00	300.00	NT	13000.00	18000.00
17	2007/04/16	NT	NT	34000.00	16000.00	17000.00	NT	4000.00	NT	NT	19000.00	NT	10760.00	NT	NT	NT	NT	13000.00	13000.00
18	2007/05/31	<0.02	<0.02	40900.00	17110.00	18580.00	132.00	4000.00	<0.02	<0.02	21710.00	<0.02	10510.00	3100.00	33.00	448.00	<0.02	17120.00	13400.00
19	2007/06/11	NT	NT	41300.00	15870.00	17800.00	NT	2804.00	NT	NT	20740.00	NT	10520.00	NT	NT	NT	NT	15780.00	11220.00
20	2007/07/30	NT	NT	34250.00	15970.00	NT	157.00	3670.00	NT	<0.02	20260.00	NT	10460.00	3410.00	49.00	502.00	NT	10470.00	10450.00
21	2007/08/20	NT	NT	41080.00	15550.00	19130.00	NT	3605.00	NT	NT	19950.00	NT	10170.00	NT	NT	NT	NT	11420.00	10630.00
22	2007/09/17	NT	NT	NT	15640.00	18190.00	NT	4060.00	NT	<0.02	18710.00	NT	9859.00	3040.00	31.00	498.00	NT	11330.00	10810.00
23	2007/10/03	NT	NT	36480.00	14910.00	16540.00	31.00	3736.00	<0.02	NT	19600.00	NT	NT	NT	NT	NT	NT	12030.00	11330.00
24	2007/11/30	<0.02	<0.02	34300.00	9808.00	21589.00	254.00	3676.00	<0.02	<0.02	21000.00	1.82	2932.00	3200.00	26.00	545.00	<0.02	10920.00	9069.00
25	2008/03/03	NT	NT	NT	NT	NT	NT	NT	NT	0.16	NT	NT	NT	2952.00	19.00	NT	0.16	NT	NT
26	2008/04/02	NT	NT	NT	NT	NT	212.00	NT	<0.02	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
27	2008/05/13	0.10	0.59	232.00	12980.00	11604.00	NT	4655.00	NT	NT	19054.00	<0.02	7876.00	NT	NT	NT	NT	9755.00	7894.00
28	2008/06/09	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	2812.00	15.80	NT	<0.02	NT	NT
29	2008/07/23	NT	NT	NT	NT	NT	218.00	NT	<0.02	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
30	2008/08/05	<0.02	<0.02	17823.00	11913.00	14207.00	NT	3792.00	NT	NT	18909.00	<0.02	232.00	NT	NT	NT	NT	8748.00	9876.00
31	2008/09/04	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	1634.00	38.00	NT	<0.02	NT	NT
32	2008/10/14	NT	NT	NT	NT	NT	344.00	NT	<0.02	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
33	2008/11/17	0.10	0.27	28807.00	11485.00	12946.00	NT	1899.00	NT	NT	NT	0.10	251.00	NT	NT	NT	NT	7293.00	9117.00
34	2008/12/18	<0.02	<0.02	NT	10970.00	2490.00	320.00	624.00	<0.02	<0.02	NT	<0.02	243.00	4236.00	21.00	0.12	<0.02	NT	NT

NT = Not Tested

Sample type		Groundwater chemistry															
Aquifer		Aquifer 3															
Borehole number		BH201	BH202	BH203	BH205	BH206	BH208	BH209	BH210	BH211	BH213	BH214	BH216	BH217	BH218	BH221	BH222
Chemical substance		Hexavalent chromium concentration (mg/l)															
Sampling Event	Date																
1	2004/11/03	0.10	0.06	0.03	371.00	0.11	0.02	0.03	0.03	0.05	0.03	0.02	0.01	0.02	0.04	0.02	0.02
2	2005/05/05	0.25	0.02	0.03	408.00	0.03	0.01	0.01	0.03	0.01	0.01	0.16	0.02	0.06	0.04	0.03	0.03
3	2006/02/28	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
4	2006/03/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
5	2006/04/21	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6	2006/05/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
7	2006/06/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT
8	2006/07/10	<0.02	<0.02	1085.00	NT	<0.02	<0.02	<0.02	<0.02	<0.02	46.00	<0.02	<0.02	<0.02	<0.02	NT	<0.02
9	2006/08/30	NT	NT	685.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
10	2006/09/11	<0.02	<0.02	478.00	2990.00	NT	NT	NT	NT	NT	18.00	<0.02	<0.02	NT	NT	NT	NT
11	2006/10/20	NT	NT	463.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
12	2006/11/06	NT	NT	97.00	3200.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
13	2006/12/07	<0.02	<0.02	50.00	42	<0.02	<0.02	<0.02	<0.02	<0.02	NT	<0.02	NT	NT	NT	<0.02	<0.02
14	2007/01/24	NT	NT	218.00	79	NT	NT	NT	NT	<0.02	14.00	NT	<0.02	NT	NT	NT	NT
15	2007/02/19	NT	NT	NT	87	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
16	2007/03/22	NT	NT	NT	1500.00	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
17	2007/04/16	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
18	2007/05/31	<0.02	<0.02	NT	NT	<0.02	<0.02	<0.02	<0.02	<0.02	12.00	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
19	2007/06/11	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
20	2007/07/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
21	2007/08/20	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
22	2007/09/17	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	172.00	NT	NT	NT
23	2007/10/03	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	NT	NT	NT
24	2007/11/30	<0.02	<0.02	NT	NT	<0.02	<0.02	<0.02	<0.02	<0.02	11.00	0.11	<0.02	<0.02	<0.02	<0.02	<0.02
25	2008/03/03	NT	NT	NT	NT	NT	NT	NT	NT	0.16	NT	NT	<0.02	0.21	0.14	NT	NT
26	2008/04/02	NT	NT	NT	NT	0.10	<0.02	NT	<0.02	NT	NT	NT	NT	NT	NT	<0.02	<0.02
27	2008/05/13	<0.02	<0.02	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	NT
28	2008/06/09	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	<0.02	<0.02	<0.02	NT	NT
29	2008/07/23	NT	NT	NT	NT	<0.02	<0.02	<0.02	<0.02	NT	NT	NT	NT	NT	NT	<0.02	<0.02
30	2008/08/05	<0.02	<0.02	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT	NT	NT
31	2008/09/04	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	<0.02	<0.02	<0.02	NT	NT
32	2008/10/14	NT	NT	NT	NT	0.10	0.10	NT	0.10	NT	NT	NT	NT	NT	NT	<0.02	<0.02
33	2008/11/17	0.10	0.10	NT	NT	NT	NT	NT	NT	NT	NT	0.10	NT	NT	NT	NT	NT
34	2008/12/18	<0.02	<0.02	NT	NT	<0.02	<0.02	<0.02	<0.02	<0.02	NT	<0.02	<0.02	<0.02	0.17	0.12	<0.02

NT = Not Tested

Sample type		Groundwater chemistry											
Aquifer		Aquifer 4			Sandstone								
Borehole number		BH401	BH402	BH403	BH D1	BH D3	BH D5	BH C4	BH T	BH DP	BH CT	BH Ar	BH Ca
Chemical substance		Hexavalent chromium concentration (mg/l)											
Sampling Event	Date												
1	2004/11/03	NT	0.04	0.03	<0.02	0.04	0.03	NT	NT	NT	NT	NT	NT
2	2005/05/05	0.06	0.01	0.04	0.06	0.08	0.06	<0.02	0.01	NT	<0.02	NT	NT
3	2006/02/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
4	2006/03/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
5	2006/04/05	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
6	2006/05/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
7	2006/06/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
8	2006/07/10	NT	<0.02	<0.02	NT	NT	NT	NT	NT	NT	NT	<0.02	NT
9	2006/08/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
10	2006/09/27	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
11	2006/10/20	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
12	2006/11/21	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
13	2006/12/07	NT	<0.02	<0.02	NT	NT	NT	NT	NT	<0.02	<0.02	<0.02	NT
14	2007/01/24	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
15	2007/02/06	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
16	2007/03/22	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT	NT	NT
17	2007/04/16	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
18	2007/05/31	NT	<0.02	0.20	NT	NT	NT	NT	NT	NT	NT	NT	NT
19	2007/06/11	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	NT
20	2007/07/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
21	2007/08/20	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
22	2007/09/17	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
23	2007/10/30	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
24	2007/11/30	<0.02	<0.02	<0.02	NT	NT	NT	NT	NT	NT	NT	NT	NT
25	2008/03/03	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
26	2008/04/02	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	<0.02	<0.02
27	2008/05/13	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
28	2008/06/09	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
29	2008/07/23	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
30	2008/08/05	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
31	2008/09/04	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
32	2008/10/14	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
33	2008/11/17	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
34	2008/12/18	<0.02	<0.02	0.05	<0.02	<0.02	<0.02	NT	NT	NT	NT	NT	NT

NT = Not Tested

APPENDIX F

Analytical results of soil samples

Test pit No.	Description	Depth (mbgl)	Soil chemistry			
			pH	Total Chromium (mg/kg)	Chromium (VI) (mg/kg)	Chromium (III) (mg/kg)
TP1	Sand with ash gravel	0 - 0.3	8.28	4357	9.82	4347.18
	Sand	0.3 - 0.6	8.11	1273	1.22	1271.78
	Sand	0.6 - 0.9	7.93	273	0.98	272.02
TP2	Sand	0.3 - 0.6	8.51	819	3.46	815.54
	Sand	0.6 - 0.9	8.29	1249	13.5	1235.5
TP3	Ash gravel	0.3 - 0.6	9.01	8171	10.7	8160.3
	Sand	0.6 - 0.9	8.02	2248	0.87	2247.13
TP4	Sand	0 - 0.3	8.42	1468	3.25	1464.75
TP5	Sand	0.3 - 0.6	8.02	701	0.7	700.3
	Sand	0.6 - 0.9	8.07	472	4.69	467.31
	Sand	0.9 - 1.2	9.42	2462	7.31	2454.69
TP7	Sandy gravel	0 - 0.3	5.69	40.7	1.29	39.41
	Sand	0.3 - 0.6	8.34	241	0.91	240.09
	Sand	0.6 - 0.9	8.15	162	0.56	161.44
TP8	Sandy gravel	0 - 0.3	6.8	30	0.13	29.87
	Sand with chrome reject	0.3 - 0.6	8.51	1008	1.75	1006.25
	Sand	0.6 - 0.9	8.57	95	0.13	94.87
TP11	Sand	0.3 - 0.6	8.43	208	1.46	206.54
	Sand	0.6 - 0.9	8.49	225	0.2	224.8
TP13	Gravel and sand	0 - 0.3	8.39	316	0.52	315.48
	Sand	0.3 - 0.6	7.01	286	0.36	285.64
TP14	Sand	0 - 0.3	7.47	857	0.7	856.3
	Sand	0.3 - 0.6	7.1	1284	0.77	1283.23
TP15	Sand with some reject	0 - 0.3	7.35	54.5	0.73	53.77
	Sand	0.3 - 0.6	7.17	48	0.23	47.77
	Sand	0.6 - 0.9	7.15	109	0.7	108.3
TP16	Sand	0.3 - 0.6	4.02	7338	6.4	7331.6
	Sand	0.6 - 0.9	4.09	8663	27.6	8635.4
TP17	Chrome reject	0.3 - 0.6	10.2	10729	8.39	10720.61
	Chrome reject	0.6 - 0.9	10.2	7376	10.5	7365.5
TP18	Sand with gravel	0 - 0.3	9.75	129900	376	129524
	Gravel	0.3 - 0.6	9.61	189700	720	188980
	Sand	0.6 - 0.9	9.97	122900	257	122643
	Sand	0.9 - 1.2	10.2	24981	210	24771
TP19	Ash gravel	0 - 0.3	7.79	7258	4.22	7253.78
	Sand	0.3 - 0.6	7.76	93560	3.31	93556.69
	Sand	0.6 - 0.9	8.17	243200	0.22	243199.78
	Sand	0.9 - 1.2	8.6	13975	4.86	13970.14
TP20	Gravel with ash	0 - 0.3	8.05	400	3.76	396.24
	Clayey sand	0.3 - 0.6	7.74	634	7.53	626.47
	Ash gravel	0.6 - 0.9	8.38	132	5.39	126.61
	Sandy ash gravel	0.9 - 1.2	7.93	2875	11.1	2863.9
	Sandy ash gravel	1.2 - 1.9	7.14	562	2.45	559.55
TP21	Ash gravel	0 - 0.3	6.52	5.18	<0.02	5.16
	Ash gravel	0.3 - 0.6	6.63	168	0.33	167.67
	Sand	0.6 - 0.9	7.58	260	1.58	258.42
	Sand	0.9 - 1.2	8.34	2287	2.05	2284.95
	Slightly clayey sand	1.2 - 2.0	7.58	225	0.06	224.94
TP22	Sand to gravel	0.3 - 0.6	7.92	4339	2799	1540
	Gravel to sand	0.6 - 0.9	8.95	4644	11	4633
	Sandy clay	0.9 - 1.2	7.58	10546	27	10519
TP23	Sand	0 - 0.3	5.95	877	1.78	875.22
	Sand with gravel	0.3 - 0.6	8.41	393100	24	393076
TP24	Sand with gravel	0 - 0.3	9.69	309900	1815	308085
	Sand	0.3 - 0.6	9.97	48830	1178	47652
	Sand	0.6 - 0.9	9.98	91729	979	90750
	Sand with gravel	0.9 - 1.2	10.3	48260	190	48070
	Sand	1.2 - 1.8	10.2	17512	236	17276

Test pit No.	Description	Depth (mbgl)	Soil chemistry			
			pH	Total Chromium (mg/kg)	Chromium (VI) (mg/kg)	Chromium (III) (mg/kg)
TP25	Sand with gravel	0 - 0.3	10	169600	454	169146
	Sand with gravel	0.3 - 0.6	9.94	380900	164	380736
	Sand with gravel	0.6 - 0.9	9.87	4873	126	4747
	Sand with gravel	0.9 - 1.2	9.91	75697	27	75670
	Sand with gravel	1.2 - 2.0	9.89	22650	221	22429
TP26	Sandy ash gravel	0 - 0.3	10.5	1193	3.07	1189.93
	Sandy gravel and reject	0.3 - 0.6	9.02	4180	24.7	4155.3
	Sand with rubble	0.6 - 0.9	8.96	3537	128	3409
	Sand	0.9 - 1.2	9.55	31550	219	31331
	Sand to slightly clayey sand	1.2 - 2.0	9.82	5696	150	5546
TP27	Sand	0 - 0.3	8.2	2578	421	2157
	Sand and gravel	0.3 - 0.6	7.39	43064	3188	39876
	Sand	0.6 - 0.9	7.56	33008	649	32359
TP28	Sand with gravel	0 - 0.3	10.4	14180	787	13393
	Sand with rubble	0.3 - 0.6	9.91	164208	1340	162868
	Sand	0.6 - 0.9	9.93	46946	772	46174
TP29	Sand with gravel	0 - 0.3	8.88	8267	915	7352
	Sand with gravel	0.3 - 0.6	8.04	20647	140	20507
	Sand	0.6 - 0.9	9.3	327	1.34	325.66
	Sand	0.9 - 1.2	9.06	50817	121	50696
TP30	Sand	0 - 0.3	8.31	42292	17.7	42274.3
	Sandy gravel	0.3 - 0.6	8.96	13699	221	13478
	Sand	0.6 - 0.9	8.78	23555	154	23401
TP31	Sandy gravel	0 - 0.3	8.33	18813	23.4	18789.6
	Sandy silt	0.3 - 0.6	9.06	72013	62.2	71950.8
	Gravel	0.6 - 0.9	9.23	3384	54.5	3329.5
	Sand	0.9 - 1.2	9.74	164892	29	164863
	Sand	1.2 - 1.7	9.8	45369	4.18	45364.82
TP32	Sand	0 - 0.3	7.81	35413	17.9	35395.1
	Sand	0.3 - 0.6	8.09	28617	25.2	28591.8
	Sand	0.6 - 0.9	7.9	25011	7.87	25003.13
TP33	Sand with gravel	0.6 - 0.9	5.67	51435	3.52	51431.48
	Sand with chrome reject	0.9 - 1.2	7.24	20921	20	20901
	Sand with gravel	1.2 - 1.5	5.07	20456	98.2	20357.8
	Sand	1.5 - 2.1	5.64	24969	78.8	24890.2
TP34	Chrome reject with gravel	0 - 0.3	7.36	86157	536	85621
	Chrome reject with gravel	0.3 - 0.6	6.88	134271	1827	132444
	Sand	0.6 - 0.9	4.79	9035	0.96	9034.04
	Sand	0.9 - 1.2	3.84	66089	272	65817
TP35	Chrome reject with rubble	0 - 0.3	6.98	1424	11.3	1412.7
	Chrome reject with rubble	0.3 - 0.6	12.1	4441	27.1	4413.9
	Chrome reject with rubble	0.6 - 0.9	12.1	851	28.9	822.1
	Chrome reject with gravel	0.9 - 1.2	3.81	116939	1.32	116937.68
TP36	Chrome reject with gravel	0 - 0.3	7.05	62058	50.1	62007.9
	Chrome reject with gravel	0.3 - 0.6	7.56	58585	77.8	58507.2
	Slightly clayey gravel	0.6 - 0.9	7.18	49163	115	49048
	Slightly clayey gravel	0.9 - 1.2	7.09	17199	14.8	17184.2
TP37	Chrome reject with ash gravel	0 - 0.3	7.33	4511	330	4181
	Chrome reject with ash gravel	0.3 - 0.6	6.83	9563	623	8940
	Chrome reject with ash gravel	0.6 - 0.9	7.29	7760	136	7624
	Chrome reject with ash gravel	0.9 - 1.2	7.33	188412	306	188106
TP38	Gravel	0 - 0.3	9.2	6589	19.9	6569.1
	Gravel	0.3 - 0.6	8.77	152788	58.4	152729.6
	Gravel	0.6 - 0.9	9.85	9567	91.8	9475.2
	Sand with gravel and reject	0.9 - 1.2	8.06	53390	28.2	53361.8
TP39	Sand	0 - 0.3	8.29	2316	2.99	2313.01
	Sand	0.3 - 0.6	8.23	1765	2.03	1762.97
	Sand	0.6 - 0.9	9.42	209	23.5	185.5
	Sand with ash and reject	0.9 - 1.2	8.73	2071	68.9	2002.1
TP40	Gravel	0.3 - 0.6	8.66	60498	96.5	60401.5
	Sand with gravel	0.6 - 0.9	8.13	109420	121	109299
	Sand with gravel	0.9 - 1.2	9.15	140071	243	139828

Test pit No.	Description	Depth (mbgl)	Soil chemistry			
			pH	Total Chromium (mg/kg)	Chromium (VI) (mg/kg)	Chromium (III) (mg/kg)
TP41	Sand	0 - 0.3	8.32	432	4.34	427.66
	Sand with reject	0.3 - 0.6	8.04	1950	3.11	1946.89
	Sand to sandy gravel	0.6 - 0.9	8.19	187	9.05	177.95
	Sand	0.9 - 1.2	7.8	21764	15.8	21748.2
	Sand	1.2 - 1.6	8.03	3281	108	3173
TP42	Sand with gravel	0.3 - 0.6	8.53	621	<0.02	620.98
	Sand with gravel	0.6 - 0.9	8.4	1099	<0.02	1098.98
	Sand with gravel	0.9 - 1.2	8.22	3855	0.1	3854.9
	Sand with gravel	1.2 - 1.6	8.64	4836	1.98	4834.02
	Sand with gravel	0.3 - 0.6	8.47	2484	0.68	2483.32
TP43	Sand with gravel	0.6 - 0.9	8.58	4792	2.52	4789.48
	Sand with gravel	0.9 - 1.2	8.27	12168	8.65	12159.35
	Gravel	1.2 - 1.6	8.43	15289	3.99	15285.01
	Sand with some boulders	0 - 0.3	8.51	9.56	0.16	9.4
	Sand with some boulders	0.3 - 0.6	8.33	13.3	1.03	12.27
TP44	Sand with some boulders	0.6 - 0.9	7.73	59.4	0.32	59.08
	Sand	0.9 - 1.2	5.39	3161	35.4	3125.6
	Sand	1.2 - 2.2	7.36	10918	242	10676
	Sand	0 - 0.3	6.99	111	2.74	108.26
	Gravel	0.3 - 0.6	6.76	106	1.15	104.85
TP45	Sand	0.6 - 0.9	7.72	735	3.43	731.57
	Sand	0.9 - 1.2	7.27	12242	19.9	12222.1
	Silty clay	1.2 - 2.0	6.38	19640	0.43	19639.57
	Sand	0 - 0.3	8.72	168	<0.02	167.98
	Sand	0.3 - 0.6	8.05	121	<0.02	120.98
S01	Sand	0 - 0.3	7.68	129	<0.02	128.98
	Sand	0.3 - 0.6	8.08	53	<0.02	52.98
S02	Sand	0 - 0.3	6.91	122	<0.02	121.98
	Sand	0.3 - 0.6	8.05	167	<0.02	166.98
S03	Gravel	0 - 0.3	7.48	81	<0.02	80.98
	Sand	0.3 - 0.6	7.61	825	<0.02	824.98
S04	Sand	0 - 0.3	8.36	56	<0.02	55.98
	Sand	0.3 - 0.6	7.91	240	<0.02	239.98
S05	Gravel	0 - 0.3	6.44	8	<0.02	7.98
	Sand	0.3 - 0.6	5.47	30	<0.02	29.98
S06	Sand	0 - 0.3	7.81	611	0.02	610.98
	Sand	0.3 - 0.6	7.69	559	0.02	558.98
S07	Sand	0 - 0.3	7.69	659	0.02	658.98
	Sand	0.3 - 0.6	7.7	625	0.05	624.98
S08	Sand	0 - 0.3	7.22	39	<0.02	38.98
	Gravel	0.3 - 0.6	6.86	508	<0.02	507.98
S09	Sand	0 - 0.3	7.25	356	<0.02	355.98
	Sand	0.3 - 0.6	7.77	1027	<0.02	1026.98
S10	Sand	0 - 0.3	7.36	21	<0.02	20.98
	Sand	0.3 - 0.6	6.16	2	<0.02	1.98
S11	Sand	0 - 0.3	7.41	44	<0.02	43.98
	Sand	0.3 - 0.6	6.71	30	<0.02	29.98

mbgl = meters below ground level

APPENDIX G

Preliminary risk assessment (Tier 1 evaluation)

Test pit No.	Depth (mbgl)*	Chromium (VI) (mg/kg)	Tier 1 Evaluation			
			US EPA Soil screening guidelines			
			Commercial/Industrial scenario		Migration to groundwater	
			Outdoor worker receptor		DAF=20 (mg/kg)	DAF=1 (mg/kg)
			Ingestion/Dermal (mg/kg)	Inhalation of fugitive particulates (mg/kg)		
TP1	0 - 0.3	9.82	3400	510	38	2
	0.3 - 0.6	1.22	3400	510	38	2
TP2	0.3 - 0.6	3.46	3400	510	38	2
TP3	0.3 - 0.6	10.7	3400	510	38	2
TP4	0 - 0.3	3.25	3400	510	38	2
TP5	0.3 - 0.6	0.7	3400	510	38	2
TP7	0 - 0.3	1.29	3400	510	38	2
	0.3 - 0.6	0.91	3400	510	38	2
TP8	0 - 0.3	0.13	3400	510	38	2
	0.3 - 0.6	1.75	3400	510	38	2
TP11	0.3 - 0.6	1.46	3400	510	38	2
TP13	0 - 0.3	0.52	3400	510	38	2
	0.3 - 0.6	0.36	3400	510	38	2
TP14	0 - 0.3	0.7	3400	510	38	2
	0.3 - 0.6	0.77	3400	510	38	2
TP15	0 - 0.3	0.73	3400	510	38	2
	0.3 - 0.6	0.23	3400	510	38	2
TP16	0.3 - 0.6	6.4	3400	510	38	2
TP17	0.3 - 0.6	8.39	3400	510	38	2
TP18	0 - 0.3	376	3400	510	38	2
	0.3 - 0.6	720	3400	510	38	2
TP19	0 - 0.3	4.22	3400	510	38	2
	0.3 - 0.6	3.31	3400	510	38	2
TP20	0 - 0.3	3.76	3400	510	38	2
	0.3 - 0.6	7.53	3400	510	38	2
TP21	0 - 0.3	<0.02	3400	510	38	2
	0.3 - 0.6	0.33	3400	510	38	2
TP22	0.3 - 0.6	2799	3400	510	38	2
TP23	0 - 0.3	1.78	3400	510	38	2
	0.3 - 0.6	24	3400	510	38	2
TP24	0 - 0.3	1815	3400	510	38	2
	0.3 - 0.6	1178	3400	510	38	2
TP25	0 - 0.3	454	3400	510	38	2
	0.3 - 0.6	164	3400	510	38	2
TP26	0 - 0.3	3.07	3400	510	38	2
	0.3 - 0.6	24.7	3400	510	38	2
TP27	0 - 0.3	421	3400	510	38	2
	0.3 - 0.6	3188	3400	510	38	2
TP28	0 - 0.3	787	3400	510	38	2
	0.3 - 0.6	1340	3400	510	38	2
TP29	0 - 0.3	915	3400	510	38	2
	0.3 - 0.6	140	3400	510	38	2
TP30	0 - 0.3	17.7	3400	510	38	2
	0.3 - 0.6	221	3400	510	38	2
TP31	0 - 0.3	23.4	3400	510	38	2
	0.3 - 0.6	62.2	3400	510	38	2
TP32	0 - 0.3	17.9	3400	510	38	2
	0.3 - 0.6	25.2	3400	510	38	2
TP34	0 - 0.3	536	3400	510	38	2
	0.3 - 0.6	1827	3400	510	38	2
TP35	0 - 0.3	11.3	3400	510	38	2
	0.3 - 0.6	27.1	3400	510	38	2
TP36	0 - 0.3	50.1	3400	510	38	2
	0.3 - 0.6	77.8	3400	510	38	2
TP37	0 - 0.3	330	3400	510	38	2
	0.3 - 0.6	623	3400	510	38	2
TP38	0 - 0.3	19.9	3400	510	38	2
	0.3 - 0.6	58.4	3400	510	38	2
TP39	0 - 0.3	2.99	3400	510	38	2
	0.3 - 0.6	2.03	3400	510	38	2
TP40	0.3 - 0.6	96.5	3400	510	38	2
TP41	0 - 0.3	4.34	3400	510	38	2
	0.3 - 0.6	3.11	3400	510	38	2
TP42	0.3 - 0.6	<0.02	3400	510	38	2
TP43	0.3 - 0.6	0.68	3400	510	38	2
TP44	0 - 0.3	0.16	3400	510	38	2
	0.3 - 0.6	1.03	3400	510	38	2
TP45	0 - 0.3	2.74	3400	510	38	2
	0.3 - 0.6	1.15	3400	510	38	2

mbgl* = meters below ground level

DAF = Dilution Attenuation Factor

Tier 1 Evaluation						
Test pit No.	Depth (mbgl)*	Chromium (III) (mg/kg)	US EPA Soil screening guidelines			
			Commercial/Industrial scenario		Migration to groundwater	
			Ingestion/Dermal (mg/kg)	Inhalation of fugitive particulates (mg/kg)	DAF=20 (mg/kg)	DAF=1 (mg/kg)
TP1	0 - 0.3	4347.18	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	1271.78	1000000	Low toxicity, no guideline	No concern	No concern
TP2	0.3 - 0.6	815.54	1000000	Low toxicity, no guideline	No concern	No concern
TP3	0.3 - 0.6	8160.3	1000000	Low toxicity, no guideline	No concern	No concern
TP4	0 - 0.3	1464.75	1000000	Low toxicity, no guideline	No concern	No concern
TP5	0.3 - 0.6	700.3	1000000	Low toxicity, no guideline	No concern	No concern
TP7	0 - 0.3	39.41	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	240.09	1000000	Low toxicity, no guideline	No concern	No concern
TP8	0 - 0.3	29.87	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	1006.25	1000000	Low toxicity, no guideline	No concern	No concern
TP11	0.3 - 0.6	206.54	1000000	Low toxicity, no guideline	No concern	No concern
TP13	0 - 0.3	315.48	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	285.64	1000000	Low toxicity, no guideline	No concern	No concern
TP14	0 - 0.3	856.3	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	1283.23	1000000	Low toxicity, no guideline	No concern	No concern
TP15	0 - 0.3	53.77	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	47.77	1000000	Low toxicity, no guideline	No concern	No concern
TP16	0.3 - 0.6	7331.6	1000000	Low toxicity, no guideline	No concern	No concern
TP17	0.3 - 0.6	10720.61	1000000	Low toxicity, no guideline	No concern	No concern
TP18	0 - 0.3	129524	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	188980	1000000	Low toxicity, no guideline	No concern	No concern
TP19	0 - 0.3	7253.78	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	93556.69	1000000	Low toxicity, no guideline	No concern	No concern
TP20	0 - 0.3	396.24	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	626.47	1000000	Low toxicity, no guideline	No concern	No concern
TP21	0 - 0.3	5.16	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	167.67	1000000	Low toxicity, no guideline	No concern	No concern
TP22	0.3 - 0.6	1540	1000000	Low toxicity, no guideline	No concern	No concern
TP23	0 - 0.3	875.22	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	393076	1000000	Low toxicity, no guideline	No concern	No concern
TP24	0 - 0.3	308085	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	47652	1000000	Low toxicity, no guideline	No concern	No concern
TP25	0 - 0.3	169146	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	380736	1000000	Low toxicity, no guideline	No concern	No concern
TP26	0 - 0.3	1189.93	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	4155.3	1000000	Low toxicity, no guideline	No concern	No concern
TP27	0 - 0.3	2157	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	39876	1000000	Low toxicity, no guideline	No concern	No concern
TP28	0 - 0.3	13393	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	162868	1000000	Low toxicity, no guideline	No concern	No concern
TP29	0 - 0.3	7352	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	20507	1000000	Low toxicity, no guideline	No concern	No concern
TP30	0 - 0.3	42274.3	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	13478	1000000	Low toxicity, no guideline	No concern	No concern
TP31	0 - 0.3	18789.6	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	71950.8	1000000	Low toxicity, no guideline	No concern	No concern
TP32	0 - 0.3	35395.1	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	28591.8	1000000	Low toxicity, no guideline	No concern	No concern
TP34	0 - 0.3	85621	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	132444	1000000	Low toxicity, no guideline	No concern	No concern
TP35	0 - 0.3	1412.7	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	4413.9	1000000	Low toxicity, no guideline	No concern	No concern
TP36	0 - 0.3	62007.9	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	58507.2	1000000	Low toxicity, no guideline	No concern	No concern
TP37	0 - 0.3	4181	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	8940	1000000	Low toxicity, no guideline	No concern	No concern
TP38	0 - 0.3	6569.1	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	152729.6	1000000	Low toxicity, no guideline	No concern	No concern
TP39	0 - 0.3	2313.01	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	1762.97	1000000	Low toxicity, no guideline	No concern	No concern
TP40	0.3 - 0.6	60401.5	1000000	Low toxicity, no guideline	No concern	No concern
TP41	0 - 0.3	427.66	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	1946.89	1000000	Low toxicity, no guideline	No concern	No concern
TP42	0.3 - 0.6	620.98	1000000	Low toxicity, no guideline	No concern	No concern
TP43	0.3 - 0.6	2483.32	1000000	Low toxicity, no guideline	No concern	No concern
TP44	0 - 0.3	9.4	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	12.27	1000000	Low toxicity, no guideline	No concern	No concern
TP45	0 - 0.3	108.26	1000000	Low toxicity, no guideline	No concern	No concern
	0.3 - 0.6	104.85	1000000	Low toxicity, no guideline	No concern	No concern

mbgl* = meters below ground level
DAF = Dilution Attenuation Factor

Tier 1 Evaluation						
Test pit No.	Depth (mbgl)*	Chromium (VI) (mg/kg)	US EPA Soil screening guidelines			
			Residential scenario		Migration to groundwater	
			Ingestion/Dermal (mg/kg)	Inhalation of fugitive particulates (mg/kg)	DAF=20 (mg/kg)	DAF=1 (mg/kg)
S01	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S02	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S03	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S04	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S05	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S06	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S07	0 - 0.3	0.02	230	260	38	2
	0.3 - 0.6	0.02	230	260	38	2
S08	0 - 0.3	0.02	230	260	38	2
	0.3 - 0.6	0.05	230	260	38	2
S09	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S10	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S11	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2
S12	0 - 0.3	<0.02	230	260	38	2
	0.3 - 0.6	<0.02	230	260	38	2

mbgl* = meters below ground level

DAF = Dilution Attenuation Factor

Tier 1 Evaluation						
Test pit No.	Depth (mbgl)*	Chromium (III) (mg/kg)	US EPA Soil screening guidelines			
			Residential scenario		Migration to groundwater	
			Ingestion/Dermal (mg/kg)	Inhalation of fugitive particulates (mg/kg)	DAF=20 (mg/kg)	DAF=1 (mg/kg)
S01	0 - 0.3	167.98	120000	NS	No concern	No concern
	0.3 - 0.6	120.98	120000	NS	No concern	No concern
S02	0 - 0.3	128.98	120000	NS	No concern	No concern
	0.3 - 0.6	52.98	120000	NS	No concern	No concern
S03	0 - 0.3	121.98	120000	NS	No concern	No concern
	0.3 - 0.6	166.98	120000	NS	No concern	No concern
S04	0 - 0.3	80.98	120000	NS	No concern	No concern
	0.3 - 0.6	824.98	120000	NS	No concern	No concern
S05	0 - 0.3	55.98	120000	NS	No concern	No concern
	0.3 - 0.6	239.98	120000	NS	No concern	No concern
S06	0 - 0.3	7.98	120000	NS	No concern	No concern
	0.3 - 0.6	29.98	120000	NS	No concern	No concern
S07	0 - 0.3	610.98	120000	NS	No concern	No concern
	0.3 - 0.6	558.98	120000	NS	No concern	No concern
S08	0 - 0.3	658.98	120000	NS	No concern	No concern
	0.3 - 0.6	624.98	120000	NS	No concern	No concern
S09	0 - 0.3	38.98	120000	NS	No concern	No concern
	0.3 - 0.6	507.98	120000	NS	No concern	No concern
S10	0 - 0.3	355.98	120000	NS	No concern	No concern
	0.3 - 0.6	1026.98	120000	NS	No concern	No concern
S11	0 - 0.3	20.98	120000	NS	No concern	No concern
	0.3 - 0.6	1.98	120000	NS	No concern	No concern
S12	0 - 0.3	43.98	120000	NS	No concern	No concern
	0.3 - 0.6	29.98	120000	NS	No concern	No concern

mbgl* = meters below ground level

DAF = Dilution Attenuation Factor

Tier 1 Evaluation				
Borehole number	Maximum Cr(VI) (mg/l)	Groundwater- Risk based Screening Levels		
		Drinking water (mg/l)	Irrigation (mg/l)	Livestock (mg/l)
BH1	342.00	0.05	0.10	1.00
BH2	503.00	0.05	0.10	1.00
BH3	862.00	0.05	0.10	1.00
BH4	269.00	0.05	0.10	1.00
BH5	0.01	0.05	0.10	1.00
BH11	0.05	0.05	0.10	1.00
BH12	0.05	0.05	0.10	1.00
BH13	74.00	0.05	0.10	1.00
BH14	936.00	0.05	0.10	1.00
BH15	213.00	0.05	0.10	1.00
BH16	0.12	0.05	0.10	1.00
BH17	0.25	0.05	0.10	1.00
BH18	0.07	0.05	0.10	1.00
BH19	0.32	0.05	0.10	1.00
BH20	0.84	0.05	0.10	1.00
BH21	10.40	0.05	0.10	1.00
BH22	38.00	0.05	0.10	1.00
BH23	107.00	0.05	0.10	1.00
BH24	0.08	0.05	0.10	1.00
BH25	26.70	0.05	0.10	1.00
BH26	12.40	0.05	0.10	1.00
BH27	0.05	0.05	0.10	1.00
BH28	36.00	0.05	0.10	1.00
BH29	1.00	0.05	0.10	1.00
BH30	42.00	0.05	0.10	1.00
BH31	0.50	0.05	0.10	1.00
BH32	3.60	0.05	0.10	1.00
BH33	0.16	0.05	0.10	1.00
BH34	0.17	0.05	0.10	1.00
BH36	239.00	0.05	0.10	1.00
BH38	104.00	0.05	0.10	1.00
BH39	0.02	0.05	0.10	1.00
BH108	188.00	0.05	0.10	1.00
BH301	8.90	0.05	0.10	1.00
BH302	3.30	0.05	0.10	1.00
BH303	0.66	0.05	0.10	1.00
BH304	543.00	0.05	0.10	1.00
BH307	80.00	0.05	0.10	1.00
BH308	1297.00	0.05	0.10	1.00
BH309	1285.00	0.05	0.10	1.00
BH310	4592.00	0.05	0.10	1.00
BH311	7350.00	0.05	0.10	1.00
BH312	3819.00	0.05	0.10	1.00
BH313	9750.00	0.05	0.10	1.00
BH314	1458.00	0.05	0.10	1.00
BH315	724.00	0.05	0.10	1.00
BH316	267.00	0.05	0.10	1.00
BH317	337.00	0.05	0.10	1.00
BH318	0.08	0.05	0.10	1.00
BH201A	0.50	0.05	0.10	1.00
BH202A	0.90	0.05	0.10	1.00
BH203A	42770.00	0.05	0.10	1.00
BH204A	26320.00	0.05	0.10	1.00
BH205A	23550.00	0.05	0.10	1.00
BH206A	344.00	0.05	0.10	1.00
BH207A	5634.00	0.05	0.10	1.00
BH208A	0.04	0.05	0.10	1.00
BH211A	0.16	0.05	0.10	1.00
BH212A	66764.00	0.05	0.10	1.00
BH214A	1.82	0.05	0.10	1.00
BH215A	25939.00	0.05	0.10	1.00
BH217A	4236.00	0.05	0.10	1.00
BH218A	108.00	0.05	0.10	1.00
BH221A	700.00	0.05	0.10	1.00
BH223A	0.16	0.05	0.10	1.00
BH224A	23878.00	0.05	0.10	1.00
BH225A	40252.00	0.05	0.10	1.00

Tier 1 Evaluation				
Borehole number	Maximum Cr(VI) (mg/l)	Groundwater- Risk based Screening Levels		
		Drinking water (mg/l)	Irrigation (mg/l)	Livestock (mg/l)
BH201	0.25	0.05	0.10	1.00
BH202	0.10	0.05	0.10	1.00
BH203	1085.00	0.05	0.10	1.00
BH205	3200.00	0.05	0.10	1.00
BH206	0.11	0.05	0.10	1.00
BH208	0.10	0.05	0.10	1.00
BH209	0.03	0.05	0.10	1.00
BH210	0.10	0.05	0.10	1.00
BH211	0.16	0.05	0.10	1.00
BH213	46.00	0.05	0.10	1.00
BH214	0.16	0.05	0.10	1.00
BH216	0.02	0.05	0.10	1.00
BH217	172.00	0.05	0.10	1.00
BH218	0.17	0.05	0.10	1.00
BH221	0.12	0.05	0.10	1.00
BH222	0.03	0.05	0.10	1.00
BH401	0.06	0.05	0.10	1.00
BH402	0.04	0.05	0.10	1.00
BH403	0.20	0.05	0.10	1.00
BH D1	0.06	0.05	0.10	1.00
BH D3	0.08	0.05	0.10	1.00
BH D5	0.06	0.05	0.10	1.00
BH C4	<0.02	0.05	0.10	1.00
BH T	0.01	0.05	0.10	1.00
BH DP	<0.02	0.05	0.10	1.00
BH CT	<0.02	0.05	0.10	1.00
BH Ar	<0.02	0.05	0.10	1.00
BH Ca	<0.02	0.05	0.10	1.00