FILLING STATIONS AND ASSOCIATED CONTAMINATION : REMEDIATION AND PROPOSED MITIGATION MEASURES

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DECLARATION

The work described in this research report was submitted in partial fulfilment of a Master of Science and was carried out in the School of Animal, Plant and Environmental Sciences, University of Witwatersrand, Johannesburg, under the supervision of Professor Mary Scholes of the University of Witwatersrand and Mr. Charles Mills of Mills and Otten Environmental Consultants.

This study represents original work undertaken by the author and has not otherwise been submitted in any form for any degree or diploma to any other tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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(Signature of Candidate) (Date)

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To my mum and dad, thank you for paving the way for my accomplishments. As always, your patience, guidance, encouragement and unwavering belief has carried me through another major milestone. All my accomplishments are truly yours - Thank you!

Finally, to my lovely husband, Ajen - Thank you for all your love and encouragement. You are an inspiration to me. This work is dedicated to you and our beautiful son Shivan.

ACRONYMS

BTEXN	Benzene, Toulene, Ethylene, Xylene and Naphthalene
DACET	Department of Agriculture, Conservation, Environment and Tourism
DAEA	Department of Agriculture and Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DNAPL	Dense Non Aqueous Phase Liquids
DWEA	Department of Water and Environmental Affairs
ECA	Environment Conservation Act, 73 of 1989
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EMP	Environmental Management Plan
EMPR	Environmental Management Programme Report
GAC	Granular Activated Carbon
HC	Hydrocarbon
I&APs	Interested and Affected Parties
IEM	Integrated Environmental Management
LCA	Life Cycle Assessment
LNAPL	Light Non Aqueous Phase Liquids
LPG	Liquefied Petroleum Gas
MNA	Monitored Natural Attenuation
NEMA	National Environmental Management Act, 107 of 1998
NEPA	United States National Environmental Policy Act
PAHs	Polyaromatic Hydrocarbons
RBCA	Risk Based Corrective Action
RBSLs	Risk Based Screening Levels
RoD	Record of Decision
RSA	Republic of South Africa
SANS	South African National Standards
SEA	Strategic Environmental Assessment
SVE	Soil Vapour Extraction
SVOCs	Semi Volatile Organic Compounds
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank

VER	Vacuum Enhanced Recovery
VOC	Volatile Organic Compound

ABSTRACT

This study involves a review of the Environmental Impact Assessment (EIA) legislation associated with the filling station industry. This is in order to determine if the South African EIA decision-making processes adequately evaluate new filling station developments. An additional objective of this study was to determine whether the local and provincial EIA decision-making structures and the filling station industry effectively evaluate the significance of filling station impacts and impose stringent enough mitigation measures.

A comprehensive literature review was undertaken on the various types of hydrocarbon contamination as well as the various hydrocarbon contamination assessment methods. In addition, the methods of remediation were also reviewed. This was in order to determine the ease and practicability of remediation at contaminated sites as well as the associated financial implications. Twenty six case studies were examined to determine the percentage of filling stations sites that are expected to be contaminated and individual analysis of two sites was undertaken to evaluate the success of remediation efforts.

This study indicates that a majority of filling station sites are associated with contamination. Remediation however is a long term process which does not fully eradicate contamination. The outcome of this investigation reveals that contamination must be prevented at the outset. Based on this it is determined that the Department of Environmental Affairs and Tourism (DEAT) needs to pose stricter measures on the filling station industry during the EIA phase of the development. Industry also needs to adopt more stringent mitigation measures during the design stage of projects to ensure protection of the environment.

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CHAPTER 1: INTRODUCTION

1.1 Background

The environmental impact assessment (EIA) process and its role leading to the authorisation of development activities is often much maligned and frequently misunderstood (Anonymous, 2008). At one end of the spectrum, the process is misinterpreted to be the panacea for environmental protection while at the other end as an obstacle to legitimate development objectives (Anonymous, 2008). In as much as it might be convenient to say that the truth lies somewhere in between, the practicalities involved in balancing environmental and development imperatives is fraught with difficulty.

Filling station developments are an essential part of the growing South African economy. The rapid upsurge in development and resultant increase in employment opportunities has resulted in a greater proportion of the population owning cars and utilising public transportation systems. This has resulted in more taxis and buses operating on our roads than ever before. New developments are continuously being constructed; this necessitates new roads and results in new residential areas being developed. Filling stations need to develop around these areas in order to cater for the needs of the people that now reside and work in the area. Filling station developments are therefore a vital and necessary part of the evolution of the area.

The need for development however must be balanced with the need to protect the environment. Due to the hydrocarbons on site, filling stations are notorious for their role in subsurface contamination, especially of groundwater resources. A site is referred to as contaminated when remediation (clean up) is required as a result of the hydrocarbon leak or spill. Contamination of groundwater by gasoline, diesel fuels and oil spills is a widespread environmental problem (Mbhele, 2007). The primary risks posed to humans and the environment are during the transporting, delivery, storage and dispensing of petroleum products. Spills and leaks during these activities could result in contamination of the surrounding land and water resources. The transport of organic pollutants is a function of various factors. In the mobile phase, i.e. the water or gas phases, transport is governed by advective and dispersive processes, whereas in the immobile phase, such as soil or natural organic matter, the dominant transport mechanism is diffusion (Mbhele, 2007). Once a liquid petroleum product is released into the ground, it partitions into three separate phases: dissolved, liquid and gas (Mbhele, 2007). A small fraction of the petroleum hydrocarbon dissolves in the soil moisture or groundwater, a portion of the product remains in soil pore space in its pure liquid form as residual saturation and some of it evaporates into the air of soil pores (Luthy *et al*, 1997). Residual liquid is held in soil pores either by capillary forces or as small pools of liquids over clay and silt lenses (Mbhele, 2007). If not removed, residual petroleum hydrocarbons act as a permanent source of contamination in the ground (Mbhele, 2007).

Leaks from underground storage tanks (UST's) and associated piping specifically are of most concern as they generally continue for significant periods of time prior to being detected. This therefore results in significant contamination of the subsurface soil and in some cases does cause contamination of the groundwater resources. When soil or water is affected by hydrocarbons, they lose their value to humans in terms of land and potable water supply (Mbhele, 2007). South Africa is a water scarce country with a large percentage of the population being dependant on borehole water supply. Contamination of this precious groundwater resource with toxic and carcinogenic compounds is therefore a serious concern for public health and environmental quality. Contamination of this life supporting source is not acceptable and for this reason, filling stations are considered to pose such a significant risk to the health and safety of both people and the environment (Mbhele, 2007).

Mitigation measures must therefore be sought that will prevent possible contamination as much as possible whilst simultaneously being practicable and cost effective to the filling station industry. Mitigation refers to methods to lessen the severity and significance or to reduce the risk of leaks and spills. In cases where mitigation measures were not applied or were found to be ineffective, remediation methods must be sought to alleviate any associated contamination.

Remediation refers to reducing the contamination to an acceptable level for the environment and the people.

The need for development must be balanced against an individual's right to clean water supply. For this reason, the filling station industry falls under the ambit of the National Environmental Management Act, Act 107 of 1998 (NEMA) and the associated regulations that are provided for in Regulations 385, 386 and 387 of 21 April 2006 (NEMA, 1998). New filling station developments trigger Activity 3 in the Second Schedule of NEMA regulations (NEMA, 1998). This stipulates that prior to the development of a filling station both a scoping and environmental impact assessment must be undertaken. These reports must be submitted to the provincial Department of Environmental Affairs and Tourism (DEAT) for approval or environmental authorisation prior to development.

1.2 Aim of the Study

The aim of this research report is to explore the success of current mitigation and rehabilitation measures taken by the petroleum industry in order to minimise the groundwater contamination associated with leaks from underground storage tanks (USTs) and associated pipework at filling stations.

This research report will investigate the effectiveness of implementing remediation measures at a site post-contamination as opposed to implementing effective BATNEEC (Best Available Technology Not Entailing Excessive Cost) mitigation measures pre-contamination. BATNEEC strikes a balance between the best available technology and management techniques with what the sector can generally afford (EPAW, 2002).

1.3 Objectives of the Study

The objectives of this research report are as follows:

- To review the legislation associated with environmental impact assessments with particular emphasis on filling stations
- To review the literature on the types of hydrocarbon contamination

- To review the literature on various hydrocarbon contamination assessment methods
- To review the literature on methods for remediation
- To analyze and interpret data from case studies on losses at filling stations
- To critically evaluate remediation and proposed mitigation measures

1.4 Literature Review

A comprehensive literature review was undertaken on the various types of hydrocarbon contamination and hydrocarbon contamination assessment methods as well as the methods of remediation. Three key pieces of literature have been utilised as the background research for this research report.

The first piece of literature is an unpublished Master of Science dissertation by Phelelani Phetheni Mbhele entitled "Remediation of Soil and Water Contaminated by Heavy Metals and Hydrocarbons Using Silica Encapsulation" (2007). This study evaluated the various methods utilised to remediate hydrocarbon contaminated soils. Silica encapsulation is currently the method utilised by mining houses to remediate hydrocarbon contamination however this method is costly and not effective as a long term solution. As a result, this method is not discussed as part of this research report.

A second unpublished Master of Science dissertation was utilised in the compilation of this research report entitled "The Occurrence and Evaluation of LNAPLs Contamination in Urban Areas of South Africa" (2004) by Thilivhali Samuel Phophi. This report provided an evaluation of the various types of hydrocarbon contamination and the various hydrocarbon assessment methods available.

The last piece of literature was a mini dissertation by Sylvia Raleru entitled "Geohydrological Remediation of Hydrocarbon Contaminated Soil at Johannesburg International Airport" (2005). This study provided the basis for the review of the available remediation technologies.

The case study aspect of the research is broadly based on analysis of existing data collected by Sasol Oil in the form of due diligence studies. The nature of the study, which focuses in part on the assessment of contamination within the filling station industry and the assessment of remediation measures within the filling station industry, dictated the choice of case studies.

1.5 Outline of Research Report

This research report is structured as follows:

Chapter one provides the background, aim, objectives, and the study area that is the focus of the report.

Chapter two provides a review of the EIA legislation. The principles, approaches, benefits and limitations of the EIA process are discussed. The purpose of this discussion serves as a basis to identify the current limitations of the EIA process in protecting the environment.

Chapter three focuses on types of Hydrocarbon Contamination and a review of the various assessment methods that are currently utilised.

Chapter four provides a review of the various remediation methods that can be implemented to rehabilitate hydrocarbon contaminated sites.

Chapter five documents the analysis of the identified case studies. The aim of this chapter is to determine the significance of hydrocarbon contamination to the filling station industry and to make recommendations to reduce the likelihood of hydrocarbon contamination.

Chapter six summarises the key results and presents a general discussion on remediation and mitigation measures.

CHAPTER 2: THE LEGISLATION

2.1 Introduction

In the South African context, the Environment Conservation Act (ECA), 73 of 1989, provided the key legislation for the implementation of the EIA process. This Act aimed to "provide for the effective protection and controlled utilisation of the environment" (ECA, 1989, p1). Section 2 of the Act described activities, which might have a detrimental impact on the environment, and therefore require an environmental impact assessment (Naidu, 2006).

The EIA regulations were promulgated in September 1997 as required by Sections 21, 22 and 26 of the ECA. These regulations described activities for which an EIA is required, and outlined the process to be followed (DEAT, 1998b). The EIA process calls for the application to undertake an activity together with the required stakeholder participation (DEAT, 1998b). This is necessary because the EIA process calls for an open and participatory approach in which the public is involved.

The National Environment Management Act (NEMA), 107 of 1998, also states that an environmental assessment process should take place for activities that have a potential impact on the environment (Naidu, 2006). Stakeholder participation and an independent review are required in the assessment of potential impacts. Furthermore, it is stipulated that the assessment processes must at a minimum investigate the affected environment, potential impacts (including cumulative effects) as well as proposed mitigation measures in order to ensure impacts are kept at a minimum (RSA, 1998a). NEMA has been amended to include regulations for the undertaking of an EIA. These regulations were promulgated in July 2006 and have superseded the ECA EIA regulations. Table 1 summarises the key policy interventions in the evolution of the EIA process in South Africa.

Table 1: Summary of Environmental Policy for EIA in South Africa (Adapted from Weaver *et al.*, 1999)

Date	Policy/Legislation	Comment
1982	Environment Conservation Act	Had limited scope, established the Council for the Environment, and contained provisions relating to natural areas.
1989	Environment Conservation Act (amended)	More comprehensive but specifically no requirements for EIAs.
1989	IEM process	IEM procedures were introduced. Compliance was voluntary.
1992	The IEM Procedure	Formal IEM process guidelines in 6 volumes. Compliance still voluntary but was gaining increasing credibility.
1992	Minerals and Mining Act	Introduced Environmental Management Programmes for mining industry. Compliance voluntary but was gaining credibility within the industry.
1995	Consultative National Environmental Policy Process (CONNEPP)	The purpose was to develop a new environmental policy for South Africa with emphasis on an integrated framework, which forms the basis for strategic action plans and a new framework for legislation through which the policy can be implemented.
1996	White Paper on Sustainable Forest Development in South Africa (now legislated)	Key implications for the forestry sector, in that, under the Afforestation Permit System, EIAs may be required.
1997	White Paper on a National Water Policy for South Africa (now legislated)	Key implications for EIAs in regard to water resource use and management as well as fostering the philosophy of both public good and sustainability.
1997	White Paper on Environmental Management Policy for South Africa	More comprehensive than the Environment Conservation Act of 1992, but still lacking in key areas.
1997	White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity	Policy pertaining to the use, management and preservation of genetic species, ecosystems and landscape diversity.
1997	EIA Regulations	Making EIAs mandatory for the first time in South Africa.
1998	Discussion Document: A National Strategy for IEM in South Africa	Major deficiency of the 1992 IEM procedure was a focus on discrete events. Most environmental impacts result from activities other than individual project level developments. Aimed at promoting legislation of

		integrated management approaches.
1998	NEMA	Seeks to promote co-operative governance among different levels of government involved in environmental management. Allows for enforcement of environmental laws by the public. Introduced the need for environmental considerations at a policy level.
1998	NEMA: National Water Act	To provide for the reform of law related to water resources
2004	NEMA: Biodiversity Act	Legislation pertaining to the importance of conserving biological diversity.
2004	NEMA: Air Quality Act	The aim of this Act is to reform the law regulating air quality to protect the environment by providing reasonable measures for the prevention of pollution and ecological degradation, and for securing ecologically sustainable development, whilst promoting justifiable economic and social development (RSA, 2004).
2005	Amendment of NEMA	Resulted in the Act becoming the overarching framework for environmental management in South Africa. A number of other pieces of legislation currently fall within the ambit of this framework.
2006	NEMA: EIA Regulations	Reiterates the importance of EIAs in promoting responsible business practices in South Africa.
2009	NEMA: Draft EIA Regulations	Promulgated due to interpretation problems with the old regulations and also because of the changing legal regime relating to mining and the environment. Changes were made to the procedural requirements of the EIA process. New definitions attempt to clarify previous uncertainties.

2.2 Environmental Impact Assessment (EIA)

2.2.1 Background to the EIA Process

The EIA process emerged at a time when there was increasing global awareness about humankind's detrimental impact on the environment. It was first introduced as a requirement in 1970 by the United States National Environmental

Policy Act (NEPA). Institutional milestones in the adoption of EIA internationally are reflected in Table 2 below (Weaver *et al.*, 1999).

Table 2: Milestones in the Development of the EIA Process (Adapted from Weaver *et al.*, 1999)

Year	Milestone
1970	NEPA introduced requirement and procedure for EIA
1973	Australia, Canada and New Zealand follow suit and start implementing the EIA process
Mid-late 70s	EIA process is established in developing countries
1985 and amended 1997	European Commission Directive on EIA in Member States
1989	World Bank establishes an operational Directive on Environmental Assessment
1991	Convention on EIA in a Transboundary Context (Espoo Convention)
1992	Principle 17 of Rio Declaration endorses the use of EIA as a national instrument for sustainable development

The EIA process is intended to facilitate decision-makers arriving at informed decisions based on objectively justifiable criteria. The process is designed to result in 'the abandonment of environmentally unacceptable actions and to the mitigation to the point of acceptability of the environmental effects of proposals which are approved' (Wood, 1995, p1). The process also lends legitimacy to the outcome by predicting outcomes and mitigating negative impacts (Wood, 1995). This made it mandatory for any development or project, which might have a detrimental impact on the environment, to investigate these effects (Avis, 1994).

An EIA takes place in a political context: it is therefore inevitable that economic, social and political factors will outweigh environmental factors in many instances. It is being applied to increasingly complex development problems and linked to broader planning and regulatory frameworks (Weaver *et al.*, 1999).

In South Africa, the EIA process applies scientific knowledge to assess the consequences of human activities on the biophysical, social and economic aspects of the environment. This process assists decision-makers by ensuring that the proposed project applies environmentally sound practices (Petts, 1999). Based on the EIA findings, decision-makers determine whether the proposed project will proceed or not. Table 3 reflects the core values and principles enshrined in the EIA process.

Table 3: EIA Core Values and Principles (CSIR, 2003)

Core Values	Principles
Sustainability	EIA process will result in environmental safeguards
Integrity	EIA process will conform to agreed standards
Utility	EIA process will provide balanced, credible information for decision-makers

2.2.2 Steps in the EIA Process

The EIA process, in South Africa, consists of the following steps (CSIR, 2003):

- Screening;
- Scoping;
- Specialist studies;
- Integration and report writing;
- Decision making; and
- Project implementation.

Screening is the process of determining whether an individual proposal requires detailed environmental assessment and what the level of assessment should be (CSIR, 2003). It is a decision-making process initiated at the earliest stage of the development or project process (DEAT, 2002a).

The scoping process identifies issues that are likely to be important during the EIA. The primary objective of this stage of the process is to focus the EIA to ensure that only significant issues and reasonable alternatives to the project are examined (Fuggle and Rabie, 1992). It is a process of interaction between the public, government departments and the client (CSIR, 2003) as well as involving relevant role-players, including the authorities and interested and affected parties (I&APS). These role-players assist in the process of identification and selection of alternatives and significant issues to be investigated in detail (Fuggle and Rabie, 1992).

The objective of the specialist study phase is to assess how the activities of the proposed development will potentially influence the identified issues. This phase of the process depends on the outcome of the scoping process, that is, if all issues raised during the scoping are addressed then it may not be necessary to proceed through to this phase of the process (Petts, 1999). During this phase, specialist studies are commissioned to provide the necessary information to respond to the key issues identified during scoping (Naidu, 2006). In this regard, specialists are appointed to assess the relevant issues (DEAT, 2002c). The aim of the specialist study phase is to provide information on the positive and negative impacts associated with the project (Naidu, 2006). The role of the specialist is to address the issues raised during the scoping phase and provide sufficient information for use by decision-makers (DEAT, 2002c).

The specialist undertakes this task by attaching an impact significance and magnitude to a potential impact. The following criteria are used to assign the magnitude and significance of an impact in a systematic manner (DEAT, 2002c):

- *Spatial scale of the impact*: Describes the extent of the area that the impact affects;
- *Intensity or severity of the impact*: Describes whether the impact has a high, medium or low intensity;
- *Duration of the impact*: Describes whether the impact will be short (0-5 years), medium (5-15 years) or long (more than 15 years) term;
- *Mitigatory potential*: Describes the possibility to be able to adequately mitigate the negative impacts and enhance the positive impacts;
- *Acceptability*: Determines the acceptability of an impact;
- *Degree of certainty*: Describes the likelihood of the impact occurring;
- *Status of the impact*: Describes the impact as being positive, negative or neutral; and
- *Legal Requirements*: Determines the legal requirements pertinent to the project.

Integration and report writing refer to the compilation of a single Environmental Impact Report (EIR) however; true integration should take place throughout the EIA process (CSIR, 2003). The decision-making phase refers to the final approval or authorisation of the proposed development by the regulatory authority (Naidu, 2006). The EIA process culminates in a political decision as to whether the project or development will proceed and under what circumstances (Sadler, 1996). This decision is issued in a Record of Decision (RoD).

Environmental decision-making occurs whenever a decision must be made that affects the present or future quality of the environment (Chechile, 1991). The decision-making phase involves trade-offs, and decisions are rarely a simple yes or no (Naidu, 2006). In most instances, decisions are made with conditions attached to it. The impact of an EIA on decision-making is influenced by the nature of the decision-making environment (Sadler, 1996). The objective of an EIA is not to force decision-makers to adopt the least environmentally damaging alternative but rather to seek a balance between the demands of development and environmental protection (Boden, 1980). As a decision-aiding tool, the EIA process provides the scientific and technical knowledge required by decision-makers to make an informed decision about a project or development proposal (Naidu, 2006).

A detailed representation of the EIA process and the various points where decision-making can take place is presented in Figure 1. After completion of the EIA, the project proponent may be required to prepare an Environmental Management Plan (EMP). This phase is referred to as project implementation (Sadler, 1996). An EMP is the tool used to ensure that the mitigation actions recommended by the specialist are implemented (CSIR, 2003).

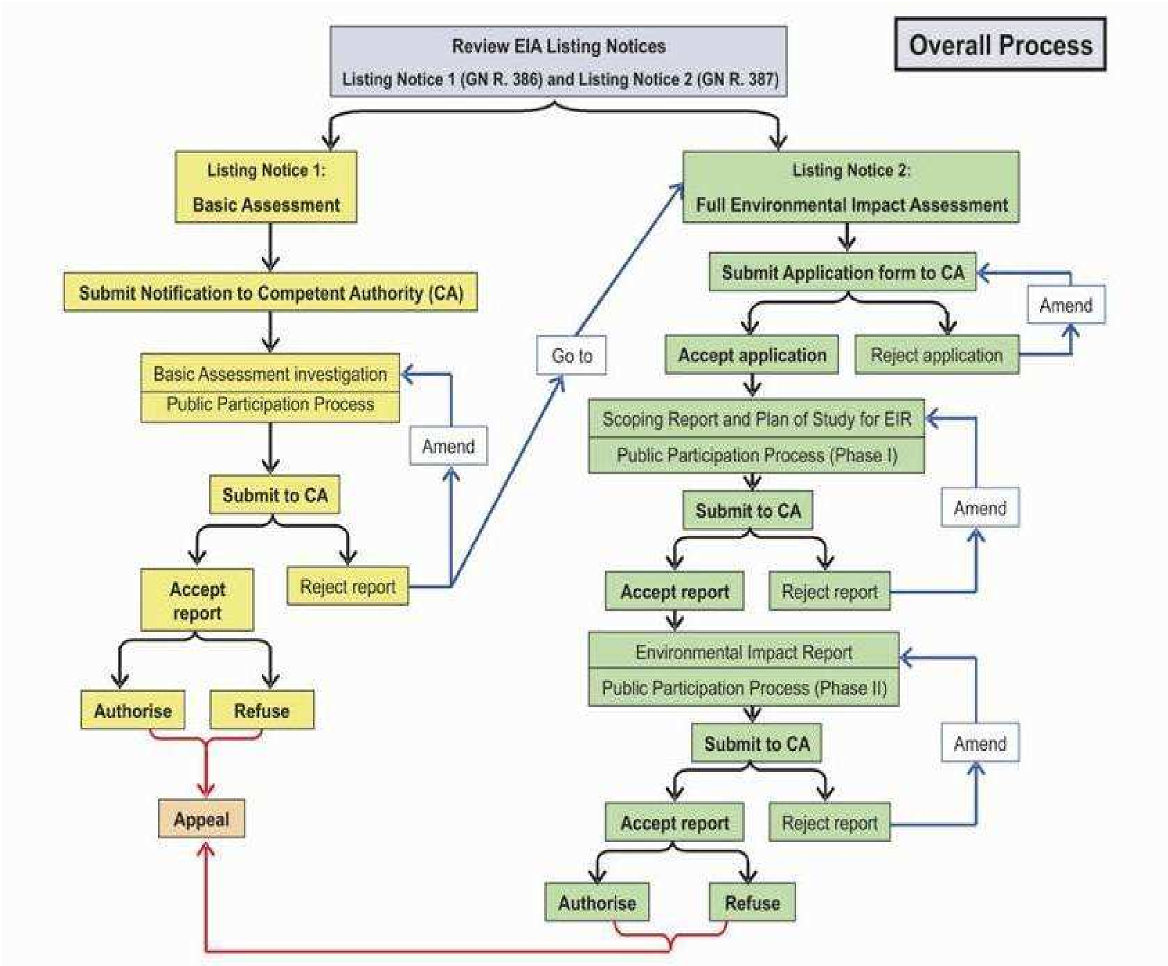

Figure 1: Schematic Representation of the South African EIA Process (Sasol, 2006)

2.3 Principals of NEMA

The National Environmental Management Act, Act 107 of 1998 (NEMA) is framework legislation that has a variety of applications for different industries and activities within a South African context. Through a number of legal actions and landmark cases, awareness of pollution is not just limited to soil and groundwater within government and civil society (Raleru, 2005). This Act requires the owners of properties to ensure that they take reasonable measures to assess and prevent pollution and to correct environmental degradation.

NEMA preamble (NEMA, 1998, p1) states that the intention of the Act is, *inter alia*, to provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment. Section 2 of NEMA details this set of principals, which act as guidelines that must be taken into account by the competent authority when making decisions that significantly affect the environment.

Principal two states that "environmental management must place people and their needs at the forefront of its concern, and serve their physical, psychological, developmental, cultural and social interests equitably" (NEMA, 1998, p14). This anthropocentric approach means that development both has to balance the need for humans to have an environment that is protected from pollution as well as to have ease of access to services e.g. filling stations.

Principal three of NEMA states "development must be socially, environmentally and economically sustainable" (NEMA, 1998, p14). This is further emphasised in Section 24 of the Constitution, which states that:

"Everyone has the right –

2. To have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –

3. Secure ecologically sustainable development and the use of natural resources while promoting justifiable economic and social development" (Act 108, 1996, p1251-1252)

The Constitution has therefore elevated the environment to a fundamental justifiable human right and in so doing, 'South Africa has irreversibly embarked on a road, which will lead to the goal of attaining a protected environment by an integrated approach, which takes into consideration, *inter alia*, socio-economic concerns and principles' (*BP South Africa*, op cit note 12 at 144) .

The need for protection of the environment must be balanced with the need for development. Mitigation measures must therefore be sought that will prevent possible contamination as much as possible whilst simultaneously being practicable and cost effective.

2.4 The Regulations

The Minister of Environmental Affairs and Tourism has, in terms of Section 24(5), read with Section 44 of NEMA, promulgated the Environmental Impact Assessment (EIA) Regulations, which are provided for in Regulations 385, 386 and 387 of 21 April 2006. Regulation 385 provides for the main administrative and procedural aspects of the EIA Regulations, whilst Regulations 386 and 387 contain the Schedule of Activities in respect of which assessment is required prior to commencement of the respective activities (NEMA, 1998).

The First Schedule published in Government Notice R386 in Government Gazette 28753 (2006) lists activities that require a basic assessment prior to the consideration of an application for environmental authorisation under section 24 of NEMA (NEMA, 1998).

The Second Schedule, published in Government Notice R387 in Government Gazette 28753 (2006) sets out the activities that require both Scoping and Environmental Impact Assessment (EIA) before an application for environmental authorisation may be considered (NEMA, 1998).

One of the declared purposes of NEMA is to establish principles that will guide organs of state in making decisions that may affect the environment. Many petroleum industry sites have been contaminated from previous activities or can become contaminated though accidental releases of various materials (Reis, 1996). For this reason, filling station developments are considered as highly hazardous installations and as a result, the Regulations have numerous implications for the filling station industry.

Activities, which could trigger a listed activity in the First Schedule, include:

- "Activity 7 – The above ground storage of a dangerous good, including petrol, diesel, liquid petroleum gas or paraffin, in containers with a combined capacity of more than 30 cubic meters but less than 1000 cubic meters at any one location or site" (GN, 28753, 2006, p141)

- Activity 24 – The recommissioning or use of any facility or infrastructure, excluding any facility or infrastructure that commenced under an environmental authorisation issued in terms of the Environmental Impact Assessment Regulations 2006, made under section 24(5) of the Act and published in Government Notice No. R. 385 of 2006, after a period of two years from closure or temporary closure, for –
  (c) facilities for any process or activity, which require permission or authorisation, or further authorisation, in terms of legislation governing the release of emissions, pollution, effluent or waste prior to the facility being recommissioned (GN 28753, 2006, p145)

Activities, which could trigger a listed activity in the Second Schedule, include:

- Activity 3 – The construction of filling stations, including associated structures and infrastructure, or any other facility for the underground storage of a dangerous good, including petrol, diesel, liquid petroleum gas or paraffin (GN 28753, 2006, p172).

The Regulations define the following terms as:

- Dangerous goods – means goods that are capable of posing a significant risk to the health and safety of people or the environment and which are listed in South African National Standard No. 10228 designated "The identification and classification of dangerous goods for transport", SANS 10228:2003, edition 3, published by Standards South Africa, ISBN 0-626-14417-5, as may be amended from time to time (GN R 387, 2006, p166)

- Filling station – means a site where petrol, diesel, liquid petroleum gas or paraffin is offered for sale, and includes shops and car washing facilities that are located on the same property or form part of the same development but excludes retail shops that sell gas or paraffin in small containers (GN R 387, 2006, p166)

- Petroleum – means any liquid, solid hydrocarbon or combustible gas as defined in section 1 of the Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002), as amended (GN R 387, 2006, p167)

As emphasised by the definitions, filling stations due the petroleum products stored on site in underground and aboveground tanks are considered to pose a significant risk to the health and safety of people and the environment. For this reason, the filling station industry falls under the ambit of NEMA and associated Regulations. Filling station developments therefore require environmental authorisations from the Provincial Department of Environment and Tourism (DEAT) prior to undertaking of the listed activities.

The primary risks posed to humans and the environment are during the delivery, storage and dispensing of petroleum products. Problems with these contaminations arise from disposal dumps, leaking storage tanks and accidental spills of hydrocarbons used in the petroleum industry (Essaid *et al.*, 1993; Kobus, 1996; Garg and Rixey, 1999; Tam and Byer, 2002). Spills and leaks during these activities could result in contamination of the surrounding land and water resources. Figure 2 below illustrates the groundwater ingestion and soil leaching to ground water exposure pathways that can exist at filling stations due to delivery, storage and dispensing of fuel.

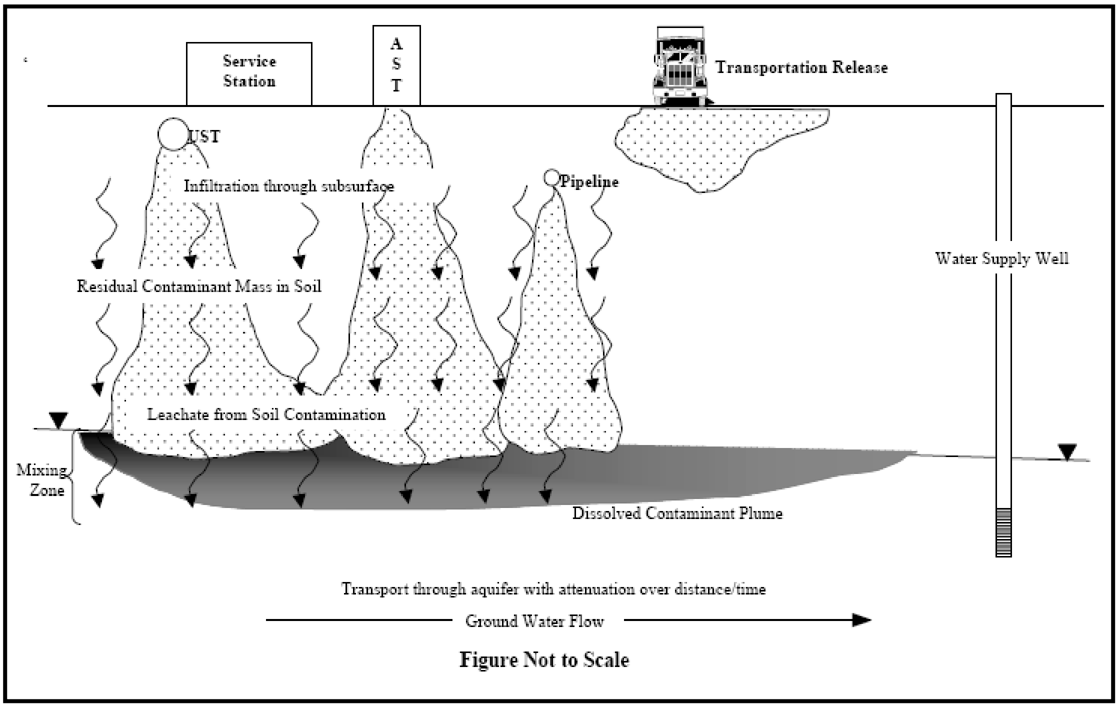

Figure 2: Idealized illustration of Ground Water Ingestion and Soil Leaching to Ground Water Exposure Pathways (NDEQ, 2004)

Figure 3 below illustrates the exposure pathways of hydrocarbon vapours. These vapours pose serious human health risks due to their carcinogenic properties.

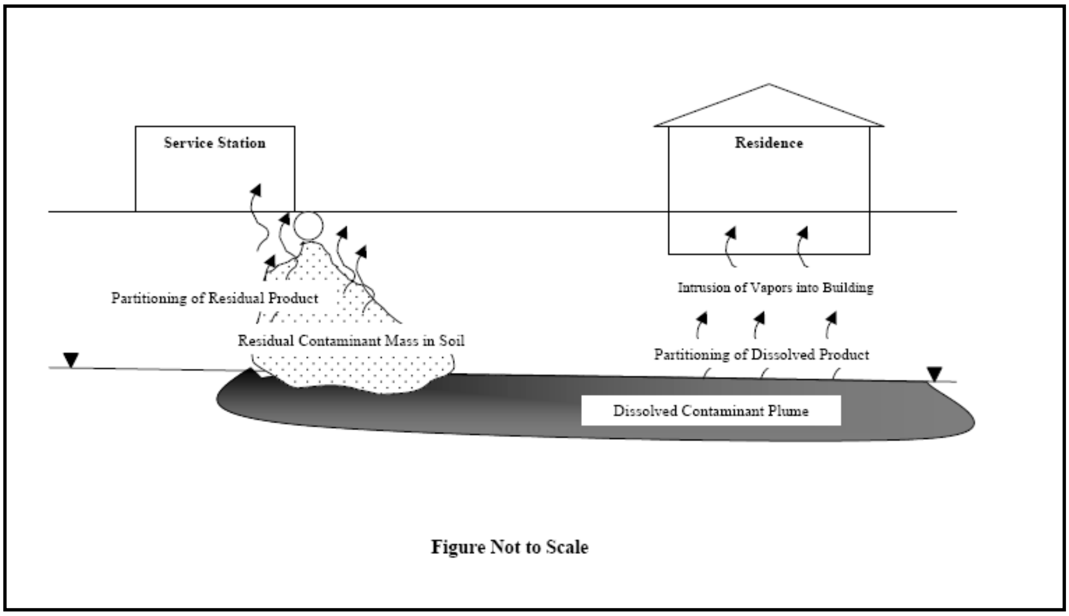

Figure 3: Idealized Illustration of Enclosed Space Inhalation Exposure Pathways (NDEQ, 2004)

2.5 EIA and Sustainable Development

Initially EIA was not an integrated appraisal process but restricted to a one-dimensional environmental appraisal (Field, 2006). This then changed with the emerging global consensus of concern about the state of the environment and the earth's ability to sustain the development needs of humankind. It was then determined that the key to the success of sustainable development is integration. This impetus led to the adoption of the sustainable development agenda (Brundtland Report, 1987). In simple terms, the problem statement of sustainable development is the management of the three 'mutually reinforcing pillars' of economic development, social development and environmental protection' (Field, 2006).

South Africa developed a 'home-grown' integrated environmental assessment (IEM) procedure, which pre-dates the National Environmental Management Act 107 of 1998 (NEMA). The IEM philosophy has spread across a broad spectrum of planning, development and industrial sectors in South Africa and this philosophy now underpins Chapter 5 of NEMA, which provides for "Integrated Environmental Management'. The concept is defined in NEMA as 'the integration of social, economic and environmental factors into planning, implementation and decision-making to ensure that development serves present and future generations' (NEMA, 1998, p1).

Section 23(1) provides that the purpose of the Chapter is 'to promote the application of appropriate environmental management tools in order to ensure the integrated environmental management of activities' (NEMA, 1998, p23)

In terms of Section 23(2) of NEMA, the general objectives of IEM are to, *inter alia*, 'promote the integration of the principles of environmental management set out in Section 2 into all decisions which may have a significant effect on the environment' (NEMA, 1998, p23), and to 'identify, predict and evaluate the actual and potential impact on the environment, socio-economic conditions and cultural heritage, the risks and consequences and alternatives and options for mitigation of activities, with a view to minimising negative impacts, maximising benefits, and promoting compliance with the principles of environmental management' (NEMA, 1998, p23). It is important here to note that the definition of 'activities' includes policies, programmes, plans and projects. This alludes to the fact that EIA, as a 'rigorous project-by-project evaluation' is not the only tool of IEM.

There have been a number of reported cases over the last few years involving the granting of authorisation by the environmental authorities for the construction of filling stations (Anonymous, 2006). These cases canvass the extent of the mandate of the environmental authorities in the process of deliberating applications for environmental authorisation. In so doing they consider how environmental, economic and social considerations intersect in the EIA process, the cumulative effect of impacts and matters relating to economic competition. At the heart of these cases is an engagement with the concept of sustainable development and consideration of how this concept has been transposed into our law as a legal norm.

The most authoritative decision on environmental authorisations is the Constitutional Court Judgement overturning the High Court and Supreme Court of Appeals (SCA) Judgements in the matter of the *Fuel Retailers Association (FRA) v Director-General Environmental Management, Department of Agriculture, Conservation and Environment, Mpumalanga Province and Others (DG Mpumalanga DACE)*. This case dealt with an application for the review and setting aside of a decision to grant an authorisation for the construction of a filling station in White River, Mpumalanga. Inama Trust applied to the Mpumalanga environmental authorities for authorisation to construct a filling station. The Fuel Retailers Association of Southern Africa (FRA) objected to the construction of the filling station on various grounds, including that the construction of the filling station will have an adverse impact on the environment. The FRA contended that the environmental authorities had failed to consider the socio-economic impact of the proposed filling station.

In reaching a decision, it was concluded that the environmental authorities were required to consider the impact on the environment of the proliferation of filling stations as well as the impact of the proposed filling station on exiting ones.

Accordingly, there was an obligation under NEMA to consider social, economic and environmental impacts of proposed developments. On this basis the decision fell to be reviewed under the Promotion of Administrative Justice Act 3 of 2000 (PAJA) in that the environmental authorities did not comply with a mandatory and material condition of NEMA.

The judgment states that the Constitution recognises the interrelationship between the protection of the environment and socio-economic development. The Constitution contemplates the integration of environmental protection and socio-economic development and envisages that the two will be balanced through the ideal of sustainable development. The judge held that sustainable development provides a framework for reconciling socio-economic development and environmental protection and thus acts as a mediating principle in reconciling environmental and developmental considerations. It is therefore the obligation of the environmental authorities to consider socio-economic factors, and this includes the obligation to consider the impact of the proliferation of filling stations and the impact of the proposed filling station on existing filling stations. This includes the obligation to assess the cumulative impact on the environment of the proposed development. The judge reasoned that unsustainable developments are in themselves detrimental to the environment, and a development such as a filling station may have a substantial negative impact on the environment. The proliferation of filling stations poses a potential threat to the environment, which arises from the limited end-use of filling stations upon their closure. The judge however stressed that the objective of considering the impact of a proposed developments on existing ones is not to stamp out competition; rather it is to ensure the economic, social and environmental sustainability of all developments.

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). The concept seeks to open a path through which economic development can progress, whilst both ensuring the enhancement of human development and the viability of natural systems (CSIR, 1998a).

It has been widely accepted that the environment and development are inseparable (CSIR, 1998a). This relationship has lead to different approaches to environmental assessment and management. In this regard, one of the most central roles of EIA is to achieve sustainable development by ensuring sustainable levels of economic activity within the carrying capacity of the Earth (Rees, 1998). This is recognised in the Rio Earth Summit Principle 17, which specifically calls for EIAs to be undertaken for proposed activities that are likely to have a significant adverse impact on the environment (George, 1999). At the Summit, a set of principles to guide future development were adopted in recognition of the integral and interdependent nature of the Earth. These principles defined the rights of people to development, and their responsibilities to safeguarding the environment (IISD, 2000a).

One of the key outputs was Agenda 21, which provides the options for combating degradation of the land, air and water, conserving forests and the climate and the diversity of the various species (Naidu, 2006). It predominantly focuses on poverty, excessive consumption, health, education and cities (IISD, 2000b). It identifies the link between population, consumption and technology, which are the primary driving forces of environmental change. It also stipulates the requirements for a reduction in wasteful and inefficient consumption patterns whilst encouraging increased but sustainable development (Naidu, 2006). It also offers policies and programmes to achieve a sustainable balance between consumption, population and the Earth’s life-supporting capacity (Wigan Council, 2003). This was translated into the Local Agenda 21, which calls on governments to adopt national strategies for sustainable development, which must be developed with wide participation, including non-governmental organisations and the public (USAID, 2005). It is through these local actions, which ultimately address issues at a global level, that the EIA process is advocated as the mechanism to assist in minimising the adverse effects on the environment (IISD, 2000b).

It was also determined at the European Union Fifth Community Action Programme Towards Sustainability, that the achievement of sustainable development will be controlled by EIA (which should operate within the framework of sustainable development) (Piper, 2002). However, despite advances in the practice of EIA, it is still falling short in meeting its full potential as a process that provides environmental sustainability assurance for environmental decision-making (Piper, 2002).

2.6 Weaknesses of the Legislation

Sites constructed prior to 1997 did not require environmental authorisations as NEMA regulations were only in place post 1997. This results in pre 1997 sites not being regulated. As a result pre 1997 sites did not have mitigation measures and monitoring in place (*pers comm* F de Gregorio). Because of this, underground storage tanks and associated pipework leaks are not contained or easily detected. Prior to the new regulations, UST's were constructed out of mild steel and therefore were susceptible to fatigue and corrosion – this lead to a loss of tank integrity and therefore subsurface contamination was commonplace (*pers comm* F de Gregorio). Precautions were generally not taken during the design stage of developments to avoid potential tank failure as is currently required by the legislation. Sites prior to 1997 are therefore associated with high levels of contamination as there was no legislation governing the industry (*pers comm* F de Gregorio).

Sites constructed post 1997 were required to undergo an EIA process. A part of this process involves listing proposed mitigation measures to avoid potential contamination. These mitigation measures then need to be approved by the provincial DEAT prior to being implemented on site. Provincial DEAT can also include additional mitigation measures as deemed appropriate to the final authorisation. A major weakness of this system is that some EIA consultants and environmental officers at DEAT are not familiar with the filling station environment (*pers comm* F de Gregorio). This results in proposed mitigation measures that are not feasible and sometimes not effective or practicable to implement. In addition to this, although Environmental Management Plans (EMP's) are in place to ensure that the proposed mitigation measures are being correctly implemented or practised on site, they are difficult to police (*pers comm* F de Gregorio).

This indicates that although the legislation has posed stricter measures on the filling station industry there are no controls in place to ensure that mitigation measures are suitable and site specific. The "green scorpions" are now beginning to play a more active role in ensuring compliance and are playing a role in policing developments. Due to NEMA, there is significant pressure on the filling station industry to show "Duty of Care" towards the environment – this duty ensures that filling stations do not adversely affect the environment. There is however still insufficient capacity at the provincial DEAT to ensure that all sites are targeted this therefore compromises protection of the environment (*pers comm* F de Gregorio).

In addition to this, the Constitutional Court judgement (FRA v DG, 2007) is being utilised as a delaying tactic by entities opposing proposed developments (*pers comm* F de Gregorio). Interested and affected parties are therefore now requesting socio-economic studies as a norm instead of as the exception. This results in increased costs and time delays to the project for the developer and does not necessarily add value to the project or benefit the environment (*pers comm* F de Gregorio).

The EIA authorisation process is therefore seen as more of a paper exercise than as a valuable tool in protecting the environment by preventing contamination.

2.7 Constraints on the Effectiveness of EIA

Previous sections of this chapter have highlighted that EIA is widely accepted, however it is important to note that there are problems with its application. These limitations range from the scope of projects to the manner in which cumulative effects are managed or mitigated (Naidu, 2006). The following sections provide a detailed review of some of the key problem areas within the assessment process.

2.7.1 Defining Significance

The concept of significance is central to impact identification, prediction, evaluation and decision-making. Deciding on whether an impact is going to cause significant environmental effects forms the core of the practice of EIA (DEAT, 2002d). Significance is primarily determined by prevailing societal values that are influenced by the associated social, economic, political and biophysical context (DEAT, 2002d). Assigning significance to an impact implies that the impact will have or is likely to have a considerable influence or effect on some aspect of human well-being (Fuggle and Rabie, 1992). This process is however attached to subjective judgement, as there are no objective measures that can be used to judge significance (Naidu, 2006). These judgements require the consideration of both context and intensity. Context has both a spatial and time dimension (Sadler, 1996). For example, an impact may not be significant on a national level, but at a regional or local level it may be regarded as very significant. Intensity refers to the severity of the impact resulting from an action and is judged by persons with special expertise in that area or by people affected by the impacts (Naidu, 2006).

A number of studies have criticised the quality of science in EIAs, with particular focus on the accuracy of impact prediction (CSIR, 1998b and DEAT, 2002b). All studies concluded that scientific quality was severely lacking (CSIR, 2001a). These studies have shown that impact prediction was very rarely quantified and not based on systematic methodologies and techniques but rather on expert opinion (Petts, 1999). Furthermore, there were no detailed indications or descriptions of the criteria used to assess and evaluate the impact and, in some cases, the specified criteria were not used to assess the impact (Woods, 1998).

2.7.2 Cumulative Impacts

Cumulative effects are changes to the environment that are caused by an action in combination with other past, present and future human actions (Tollefson and Wipond, 1998). It refers to the accumulation of changes in environmental systems over time and across space in an additive or interactive manner. In most instances, the impacts of a project are individually limited but cumulatively significant (Spaling, 1994). Inherent in the definition of cumulative effects is the concept that actions affecting an environmental resource are temporally connected, that is, the potential for a project to contribute to the cumulative impacts on a resource is determined by past, present and future actions on that common resource (Hochberg, 1993). According to the Council on Environmental Quality (1997), cumulative effects occur when the:

- impacts on the environment take place so frequently in time or so densely in space that the effects of individual impacts cannot be assimilated; or
- impacts of one activity combine with those of another to produce a greater impact or a different impact (synergistic effect).

In simple terms, cumulative effects may arise from single or multiple actions and may result in additive or interactive effects. This implies that an assessment of cumulative impacts must include all impacts, both direct and indirect, that might affect a resource. Table 4 reflects the types and characteristics of cumulative effects (CSIR, 1998b).

Table 4: Types and Characteristics of Cumulative Effects (CSIR, 1998b)

Type	Characteristic	Example
Time crowding	Frequent and repetitive effects	Forest harvesting rate exceeds re-growth
Time lags	Delayed effects	Bioaccumulation of mercury
Space crowding	High spatial density of effects	Pollution discharge into stream from non-point sources
Cross-boundary	Effects occur away from the source	Atmospheric pollution and acid rain
Fragmentation	Change in landscape pattern	Fragmentation of indigenous habitats
Compounding effects	Effects arising from multiple sources or pathways	Synergism among pesticides
Indirect effects	Secondary effects	Developments following construction of new highway

Triggers and thresholds	Fundamental changes in system functioning and structure	Climate change

Cumulative environmental changes are characterised by broad, often undefined spatial, temporal and media dimensions (Naidu, 2006). Changes occur over time scales much longer than forecasts and assessments normally utilised in policy and planning decisions (CSIR, 1998b). In this case, spatial changes transcend the fixed boundaries of local sites to include regional and global scales. Where the intensity of a development remains low, the environment can assimilate the impacts. Where the intensity is high, the environment is unable to assimilate the rapid build up of these impacts, resulting in the alteration of the structure and functioning of environmental systems (Naidu, 2006). This ultimately affects human activities and their functioning.

Due to the complex nature of cumulative effects, a co-ordinated institutional arrangement is required when dealing with these impacts. Most assessment approaches are not well adapted to cope with these problems because they are undertaken for specific developments and are therefore site specific (Fuggle and Rabie, 1992). In most cases, the impacts of a number of filling stations operating in the same area are not assessed.

In addition, cumulative impacts are also the consequence of social and economic policies, which are unable to be assessed at the project level. The limited scope of an EIA overlooks environmental change, which involves multiple perturbations, complex causation, higher-order impacts, interacting processes, time lags and extended spatial boundaries (CSIR, 1998b). Therefore, there was a clear and increasing need for decision-makers to look at projects in the context of other developments in the community or region (Naidu, 2006). The EIA process should take note that some impacts may be delayed, which will pose significant changes for future activities (Tollefson and Wipond, 1998).

2.8 Conclusion

This chapter critically reviewed the concept of environmental management as well as the legislative framework and implementation for EIA in South Africa. The emergence of environmental management, IEM and EIA, as well as the key constraints to the effectiveness of EIA was also discussed.

Environmental management is a multidisciplinary profession that attempts to find solutions for a human-altered environment by developing information co-ordinating skills (Naidu, 2006). The profession developed in South Africa because of the need to integrate environmental concerns into development actions. The process of environmental management culminated in the development of the IEM process. This process stresses the importance of considering environmental concerns from decommissioning of a project through to monitoring of the environmental impacts of a development (Naidu, 2006). Within the ambit of IEM, a number of tools have been developed to ensure the protection of the environment. The tool that was specifically addressed was EIA and its application in South Africa.

EIA is a systematic process that assists decision-makers in taking account of development impacts that affect the environment (Naidu, 2006). EIA emerged out of a need to understand the negative effects of development and in trying to fulfil the task a number of limitations of the process have emerged (Naidu, 2006). The effectiveness of the EIA within the filling station industry is proving to be ineffective in terms of preventing harm to the environment. EIA is being utilised to block and/or hinder developments instead of acting in the best interests of the environment and sustainable development. EIA authorities therefore need to:

- Revisit the legislation governing the filling station industry
- Increase the capacity at the provincial DEAT level in order to effectively manage developments to ensure that the goals of sustainable development are being met (Naidu, 2006).

CHAPTER 3: TYPES OF HYDROCARBON CONTAMINATION AND ASSESSMENT METHODS

3.1 Background to Surface and Subsurface Contamination

Surface contamination caused during petroleum delivery or dispensing is visible and therefore cleanup is immediate and uncomplicated. Spill kits are available at all sites and the spill is cleaned up using the material provided in the kit. This hydrocarbon contaminated material is then disposed of as hazardous waste.

Leakage and spill of petroleum hydrocarbons from underground storage tanks and pipelines have posed significant threats to groundwater resources across petroleum – contaminated sites (Qin *et al.*, 2009). As these leaks are underground, they generally continue for a significant period of time prior to being detected. This therefore results in significant contamination of the subsurface groundwater resources. Hydrocarbons will be carried to the water table with percolating meteoric water and some may migrate upward due to capillary action. In addition, not all of the hydrocarbons will move away from the immediate surroundings because the soils will have a residual hydrocarbon saturation, which is the amount adsorbed to the soil matrix (Raleru, 2005). This means that even if the soil is flushed via saturating waters, some of the hydrocarbon will remain within the matrix (Eslinger *et al.*, 1994). Flow and transport of petroleum-derived contaminants, commonly referred to as non-aqueous phase liquids (NAPLs) in the subsurface is of enormous importance (Qin *et al.*, 2009). This is due to the complex pore structures and fluid transport pathways of the soil, which also contribute towards making remediation difficult. Soil degradation results due to the fact that the soil structure, soil composition and its use is degraded to a less useful medium. The contamination sometimes causes some "clogging" in the soil due to the viscosity of the pollution substance (Raleru, 2005). Therefore, the soil is rendered useless unless it gets remediated physically, biologically or mechanically (Keller *et al.*, 1997).

Hydrocarbons are found in various places in the soil. Most are trapped by capillary pressure as a discrete liquid phase within the pores of the soil. If a sufficient volume of hydrocarbons has been released, it can exist in a separate, mobile phase that floats on top of the groundwater (Reis, 1996). The insoluble petroleum product that forms a floating lens above the water level in the boreholes or monitoring wells is referred to as free phase product. In addition to this hydrocarbons may also dissolve in the groundwater and be transported. Volatile hydrocarbons can be found as a vapour in air saturated pores whereas dissolved solids can be found in various places in the soil (Reis, 1996). Dissolved solids may remain dissolved and can therefore migrate with the groundwater or they can be adsorbed onto the soil solids (Phophi, 20004).

When petroleum enters the groundwater system, however remediation is difficult to implement. Contamination of groundwater with toxic and carcinogenic compounds is a serious concern for public health and environmental quality. Once petroleum enters, the groundwater system it is dispersed due to the natural migration of groundwater or groundwater flow patterns (James *et al*., 2000). This problem is commonly manifested as a contaminant plume migrating in the direction of groundwater flow from a point source (James *et al*., 2000). The distance that this contaminated plume can travel is dependant upon the surrounding geology, i.e. the permeability of the surrounding soil and rock formations (James *et al*., 2000). Groundwater remediation is therefore much more complex in comparison to surface contamination (*pers comm* F de Gregorio). Contamination of the groundwater is also caused when the ground water level is high and the tank excavation therefore intersects this level. Excavations may also intersect aquifers and perched aquifers that further contribute to contamination of groundwater resources. In areas not serviced by municipal water supply, the groundwater serves as a source of potable water for the surrounding community. This water supply source is then detrimentally affected in the event of a leaking underground storage tank (UST) or associated pipework (*pers comm* F de Gregorio).

Major sources of organic contaminants are mainly associated with human activities (i.e. industries and urban settlements). It is through these activities that the contaminants may get into contact with the subsurface and eventually migrate to the groundwater resources. The petroleum industry contributes to this phenomenon as filling stations are among the main potential urban sources of the contaminants. The contaminants entering the subsurface from a spill or leak often do so as constituents of non aqueous phase liquids (NAPL). NAPL are pure phase liquids that do not readily dissolve in water. NAPLs are subdivided into two classes: those with densities that are greater than water (dense non aqueous phase liquids, DNAPLs) or those with densities that are less than water (light non aqueous phase liquids, LNAPLs). LNAPLs and DNAPLs are the most common organic contaminants, which have the potential of causing soil and groundwater pollution (subsurface) (Phophi, 2004). LNAPLs and DNAPLs may be partially soluble in water, so that a dissolved phase as well as a non-aqueous phase (free phase) may be present (Schwille, 1981, 1984, 1988). These contaminants are released due to leaking of underground storage tanks (UGST's) and pipelines, thereby exposing the subsurface to hydrocarbons, which eventually leads to the deterioration of the groundwater resources. When soil or water is affected by hydrocarbons, they lose their value.

3.2 Non Aqueous Phase Liquid (NAPL)

3.2.1 Light Non Aqueous Phase Liquid (LNAPL)

Light Non Aqueous Phase Liquid (LNAPL) refers to petroleum liquids in soils and groundwater and is composed of mixtures of organic molecules. Hydrocarbon fuels such as gasoline, heating fuel, kerosene, jet fuel and aviation fuel are LNAPLs (Mbhele, 2007). LNAPLs have a specific gravity, which is less than water; they therefore tend to form a pool on top of the groundwater table. "Non Aqueous" highlights the fact that petroleum does not readily mix with water. When LNAPL meets groundwater, trace to low percent concentrations of the organic compounds dissolve into the groundwater. A benefit of this low solubility is that loading to the environment is typically small and natural processes often attenuate contaminants of concern over small distance. A disadvantage of low solubility is that LNAPL can persist as a source of groundwater contamination for extended periods (LNAPL Resource Centre, 2004). LNAPLs will generally move in the direction of groundwater movement. Dissolution of LNAPLs in groundwater often results in the exceedances of water quality close to the releases (Phophi, 2004).

Organic compounds differ widely in their solubility, from infinitely miscible polar compounds, such as methanol, to extremely low solubility nonpolar compounds, such as polynuclear aromatic hydrocarbons (PAHs) (Horvarth, 1982). The solubility represents the maximum concentration of the compound that will be dissolved in water under equilibrium conditions (Eckenfelder *et al*, 1993).
Benzene, toluene, ethylbenzene, and xylene (BTEX) are light aromatic hydrocarbons that have relative high water solubility (Silvers *et al.*, 2003). BTEX compounds also are the most volatile of the aromatic compounds and are considered to be volatile organic compounds. Benzene (10 times more soluble than ethylbenzne or xylenes) is the most water soluble of the BTEX compounds (Mbhele, 2007).

PAH are hydrophobic compounds and rapidly become associated with soil particles or sediments, where they may become buried or persist for long periods. As a result, transport of PAHs tends to be associated primarily with erosion of contaminated soils and sediments. PAHs sorbed to sediments may potentially affect aquatic communities downstream of contaminated sites (Mbhele, 2007). Some PAHs such as naphthalenes are more volatile and more water soluble than most PAHs and can pose a threat to ground-water resources (Goerlitz *et al.*, 1985). The possible fate of PAHs in the environment include volatilization, photo-oxidation, chemical oxidation, bioaccumulation, absorption onto soil particles or sediments, and leaching and microbial degradation (Mbhele, 2007). Due to the resistance of PAHs to decomposition processes, their high affinity for organic matter and their low water solubility, PAHs are highly persistent in the environment.

If large volumes of LNAPL are spilled, the LNAPL flows through the pore space to the top of the capillary fringe of the water table. Since LNAPLs are lighter than water, they will float on top of the capillary fringe (Phophi, 2004). If the source of the spilled LNAPLs is removed or contained, LNAPLs within the vadose zone continue to flow under the force of gravity until reaching residual saturation. Ground water passing through the area of residual saturation dissolves constituents of the residual LNAPLs, forming a contaminant plume. Water infiltrating from the surface also can dissolve the residual LNAPLs and add to the contaminant load of the aquifer. Decrease in the water table level from seasonal variations or groundwater pumping also causes dropping of the pool of LNAPLs. If the water table rises again, part of the LNAPLs may be pushed up, but a portion remains at residual saturation below the new water table (Phophi, 2004). Variations in the water table height, therefore, can spread LNAPLs over a greater thickness of the aquifer, causing larger volumes of aquifer materials to be contaminated (Palmer, *et al*, 1989b).

LNAPL contamination may differentiate into at least four distinct forms, each of which has unique chemical and geophysical characteristics. The four forms are discussed in detail below and are clearly illustrated in Figure 4, below.

1. The free phase product. This phase is mobile or free to migrate under gravitational pull.
2. The residual phase. This is that portion which is left behind after the free product has migrated.
3. The vapor phase plume. Comprises of volatile LNAPLs, which may have developed in the space above the free product and the residual product.
4. The dissolved phase. Small amounts of hydrocarbon may enter the aquifer in this phase (Phophi, 2004).

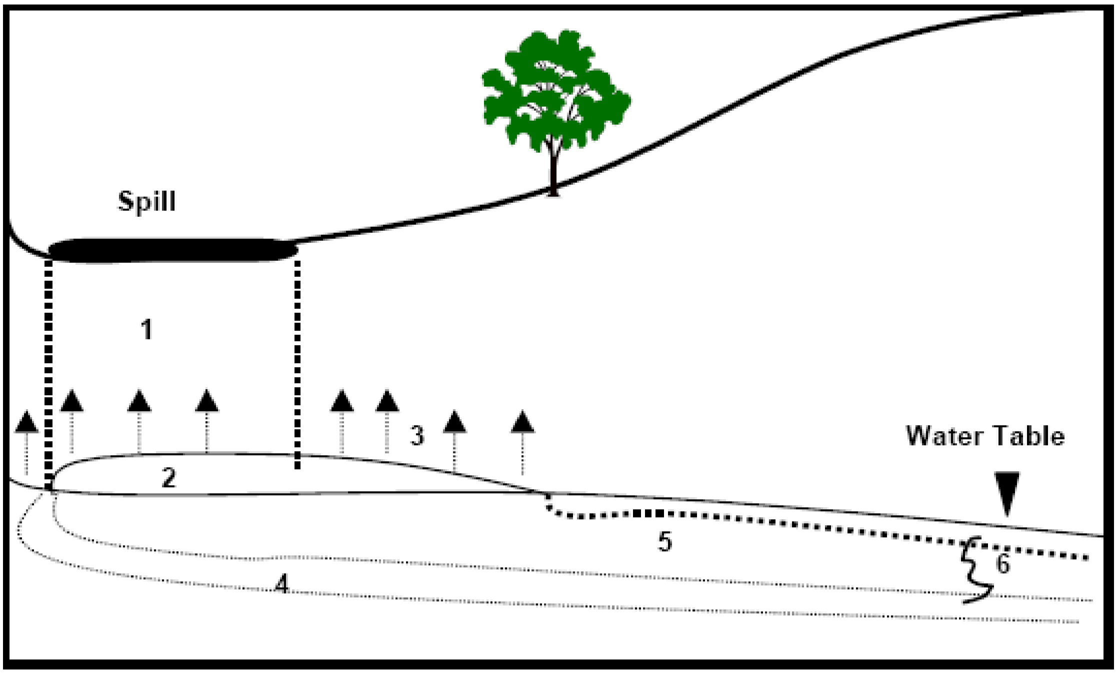

Figure 4: Cross-section diagram of zones around an LNAPL spill site, static water table case: 1– vadose zone directly beneath the spill, 2 – free (mobile) product and residual product zone, 3 – vadose zone directly above the free/residual product, 4 – reactive fringe around the dissolved plume, 5 – anaerobic core of the dissolved plume, 6 – distal end of the dissolved plume (Phophi, 2004).

3.2.2 Dense Non Aqueous Phase Liquids (DNAPL)

Dense Non Aqueous Phase Liquids (DNAPLs) are solvents which have a specific gravity, and are denser than water, and therefore they sink to the bottom of the aquifer. DNAPLs tend to sink through the water column and collect in depressions at the base of the aquifer. They flow along the bottom of the water table or aquifer and can move in directions that are different from the groundwater flow (Phophi, 2004). While these liquids do not go completely into solution in groundwater, they do contain compounds with limited solubilites in water (Mbhele, 2007).

Figure 5 below shows the behaviour of LNAPLs and DNAPLs in the subsurface (Phophi, 2004).

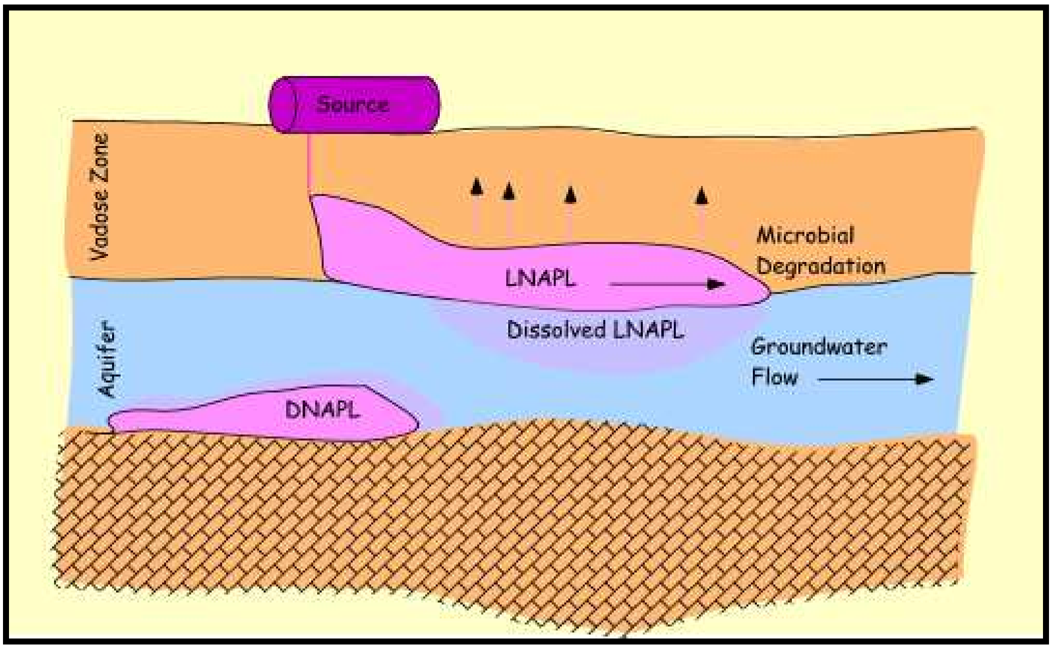

Figure 5: Behaviour of LNAPL and DNAPLs in the subsurface environment (Phophi, 2004).

3.3 Detection of Hydrocarbon Contaminants in the Subsurface Environment

There are various methods available which enable determination of the contamination of the soil or groundwater samples. Data gathering and analysis needs to be undertaken to determine the presence and concentration of hydrocarbon contaminants in the surface and in the groundwater and boreholes. The groundwater quality must be established so as to have a baseline to work from (Van der Linde, 2002). In addition, a hydrocensus should be conducted to establish background water quality.

Groundwater samples can be collected from percussion and auger boreholes for determining the baseline groundwater quality. The simplest determination is to check the odour and colour of the samples. Samples are then submitted for laboratory analysis for a more accurate diagnosis. At the same time, this gives an indication as to where the hotspots are and to determine reasons why there are high concentrations in one area as opposed to other areas. Modelling can then be undertaken to address the migration path of the plume and the volume and direction it will possibly follow in case no remediation processes take place (Phophi, 2004).

Chemical analysis is used to determine the presence of Benzene, Toulene, Ethyl-benzene, Xylene and Naphthalene i.e. the BTEXN compounds in soil and water samples (Phophi, 2004). The concentration of BTEXN compounds present in the samples is an indication of the presence of hydrocarbon contamination. Groundwater samples are also tested for the inorganic elements (major cation / anion concentrations - MO1 to MO8). These results are compared with those of the South African Bureau of Standards (SABS) drinking water standard in order to determine if the water is fit for human consumption.

Current methods of assessment of hydrocarbon-contaminated sites are the result of a gradual evolution of techniques which have been adapted from applications that were primarily exploratory in their scope. Hydrocarbon site assessment methods can be categorized broadly into those that merely attempt to detect the presence or absence of contamination and those that attempt to quantify the magnitude and extent of contamination (Phophi, 2004). Pedestrian survey and soil gas/vapour surveys fall into the qualitative category, while soil and groundwater sampling have a quantitative goal (Calabrese *et al*, 1991).

3.3.1 Hydrocarbon site assessment method

3.3.1.1 Pedestrian survey

Certainly the most common of all the assessment techniques is the pedestrian survey in which the investigator walks a site looking for visual signs of contamination or indicators of hydrocarbon presence. This quick and inexpensive technique allows for detection of both hydrocarbon odour and hydrocarbon stained soils. The appearance of an oily film on water surfaces is also an obvious sign of hydrocarbon contamination (Phophi, 2004). Seldom will a pedestrian survey be sufficient for site assessment, but it offers valuable guidance for planning of subsequent work (Calabrese *et al*, 1991).

3.3.1.2 Geophysical survey

Several geophysical site assessment techniques have been attempted on an experimental basis. One of these is ground penetrating radar. In theory this technique can identify free product plumes based upon the characteristics of return radar signals. A different geophysical method that has been utilised is induced polarization. When a current is applied to a conductive media, it alters the distribution of negative and positive ions, creating a gradient effect. When the current is terminated the gradient relaxes, resulting in a current flow and measurable voltage termed the induced polarization effect (Phophi, 2004). Electrical resistivity surveys have also been utilised to identify contamination by inorganic materials that causes an increase in the electrical conductivity of soils.

3.3.1.3 Soil Vapour Survey (SVS)

Once hydrocarbons have penetrated the soil they will break down into free, adsorbed, dissolved and vapour phases. The presence and distribution of the hydrocarbon vapour phase is detected using the Soil Vapour Survey (SVS) method. Gas from the pore space in soil and rock formations is commonly known as soil vapour and is analysed using a soil vapour detector. The main sources of hydrocarbon vapour are (Phophi, 2004):

- The vadose zone where an effluent petroleum product breaks down into a vapour phase that mixes with natural soil gas;
- Free substance floating on groundwater; and
- Dissolved contaminant in soil moisture and in groundwater

3.3.1.4 Soil sampling

The collection and analysis of soil samples has become a standard practice in site assessment. Soil and groundwater sampling has gained the wide acceptance of regulatory agencies. Due to the cost involved in the analysis of soil samples, organic vapour analyzers are used to screen samples in the field for evidence of contamination. Samples showing positive indicators of contamination are then submitted for laboratory analysis (Calabrese *et al*, 1991).

3.3.1.5 Groundwater sampling

Groundwater sampling is one of the most widely practiced methods of assessment because of the immediate threat of contamination of drinking water and the resulting public health concerns (Phophi, 2004). Groundwater samples are obtained from existing water supply boreholes, or most commonly from especially constructed monitoring boreholes. Monitoring boreholes used for hydrocarbon assessment require screening above the water table to be able to adequately detect free-phase product, but in construction are otherwise similar to small, shallow domestic water boreholes (Calabrese *et al*, 1991).

3.3.2 Evaluation of methods

An unbiased evaluation of assessment techniques must consider multiple factors ranging from site limitations to amount of money and time available for the survey (Phophi, 2004). The following evaluation (Table 5) is presented with the recognition that there are many varied approaches to each method, some of which effectively overcome limitations; however, most methods have the following characteristics:

Table 5: Evaluation of Survey Methods (Adapted from Phophi, 2004)

Type of Survey	**Positive Aspects**	**Limitations**	**General Comments**
Pedestrian survey	• Relatively Inexpensive • Rapid • Integration of many variables • No permits required • Unobtrusive • Good guidance for future work	• Dependant on experience of investigator • Subjective • Limited to surface assessment only • Personal protective equipment may limit sensitivity	During the pedestrian survey the investigator can assess hydrocarbon storage and housekeeping practices, identify utility trench locations which may be possible conduits for contamination migration, assess proximity of any

			sensitive neighbours, and examine any open excavations, manholes, or utility vaults, on-or offsite, to gain insight into subsurface condition (Phophi, 2004). Because this is a qualitative approach that relies on human sensory abilities and the judgment of the individual in the field, there is no way to critically assess this method other than to recognize that it cannot provide the type of data typically necessary to reach conclusions about the magnitude and extent of hydrocarbon contamination (Calabrese *et al*, 1991).
Soil Vapour Survey	• Inexpensive • Rapid • Quantitative • Immediate results • Limited regulatory permitting • Minimal disruption to operating facilities • Low public visibility • Does not generate	• Does not work well in wet or clayey soil • Limited depth penetration • Not accepted by regulatory agencies • Requires experienced field personnel • Results can be	The technique has proven to be reliable in determining the presence or absence of contamination in groundwater on the basis of a whole site survey with an accuracy of approximately 80% (Phophi, 2004). Analysis of field data

	waste • Excellent guidance for further investigation	over interpreted • Usually requires soil or water sampling to confirm results • Quality control often lacking	and observations by investigator indicate that water saturated and clay soils are not adequately sampled with this method, primarily due to lack of good vapour transport (Calabrese *et al*, 1991).
Geophysical Survey	• Rapid • Quantitative • Limited regulatory permitting • Low public visibility • Does not generate waste	• Expensive • Limited application • Not accepted by regulatory agencies • Requires experienced field personnel	In general, geophysical methods are at present, very limited in application to the assessment of hydrocarbon contamination, due to the difficulty in separating the subtle response of dissolved or sorbed hydrocarbon material from the natural variable background responses of native soils (Calabrese *et al*, 1991).
Soil sampling	• Quantitative • Direct measurement of contaminants of concern • Generally accepted by regulatory agencies	• Sample collection and analysis can be expensive • Sample numbers typically low due to cost per sample • Spatial distribution of contaminants in soils causes high sample variability • May require	This is commonly viewed as a definitive method of characterizing the magnitude and extent of contamination at a site. Soil sampling may be accomplished using a variety of methods ranging from simple hand augers to drill

		special regulatory permits • Generates waste soil necessitating special handling and disposal	rigs (Phophi, 2004). A notable limitation however is the fact that only a very small fraction of the total volume of soil at a site is sampled and an even smaller portion is actually analyzed.
Groundwater sampling	• Quantitative • Direct measurement of contaminants of concern • Provides essential data for risk assessment • Incorporate soil sampling • Accepted by regulatory agencies • Monitoring may be continued over time to evaluate trends	• Expensive (limited number of boreholes usually installed) • Analytical costs high • Special permits required • Generates waste for disposal • Time required for permits, drilling, analyses • Long-term monitoring commitment may be necessary • Highly visible to public • May be disruptive to operating facilities • Access for drill equipment may limit use	

3.4 Risk Based Corrective Action (RBCA)

Risk Based Corrective Action (RBCA – pronounced *Rebecca*) is a decision-making process for assessment and response to subsurface contamination associated with petroleum hydrocarbon releases that is utilised within the petroleum industry in South Africa. The guidelines for RBCA are published in the American Society for Testing Materials (ASTM-1739-95), the "*Standards Guide for Risk Based Corrective Action applied at Petroleum Releases Sites"* (Phophi, 2004). 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 resources. Under this integrated approach, petroleum release sites are characterised in terms of sources, transport mechanism and receptors (Phophi, 2004). Figure 6 below indicates the various parameters used in this evaluation. Remedial measures can then be applied as needed to prevent human health or environmental exposure to harmful levels. Risk Based Corrective Action can be used by addressing any step in the exposure process such as (Connor *et al*, 1995):

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

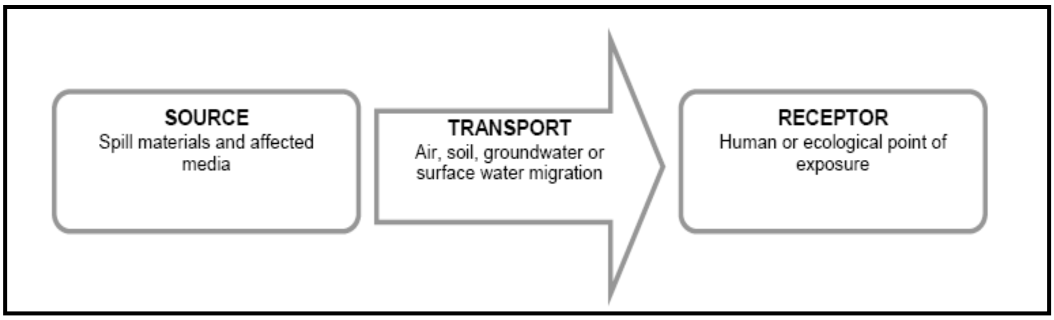

Figure 6: Conceptual Exposure Model (Phophi, 2004)

Under RBCA, risk management strategies are developed and implemented in accordance with the process flowchart as shown in Figure 7. This flowchart illustrates the general sequence of hazard characterization and response. Based on the available site information, a site classification step is completed to characterize the relative magnitude and immediacy of site risks and prescribe immediate response actions (Step 2 on Figure 7) (Phophi, 2004). After any acute or near-term hazards have been properly addressed, risk-based cleanup 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 7) (Phophi, 2004). To achieve the final risk management goals, the remedial action program may involve:

i. Source removal/treatment

ii. Containment measures

iii. Institutional controls and

iv. Some combination thereof

Release of petroleum products can results 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 (Phophi, 2004). 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 the EPA risk assessment protocol, the RBCA Tier 1, 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 levels of contaminants (Phophi, 2004). Such analysis is appropriate only after 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 7) prior to analysis of media cleanup standards (Phophi, 2004). 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 (Phophi, 2004). Interim stabilization measures may be applied to prevent incidences of short-term chronic impacts. Following completion of step 1 to 4 of the RBCA process (Figure 7), the procedures outlined in the ASTM Risk Based Corrective Action guideline can be used to define site-specific soil and groundwater cleanup levels necessary to protect against future health impacts. As shown, in some applications, other non-aesthetic considerations (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).

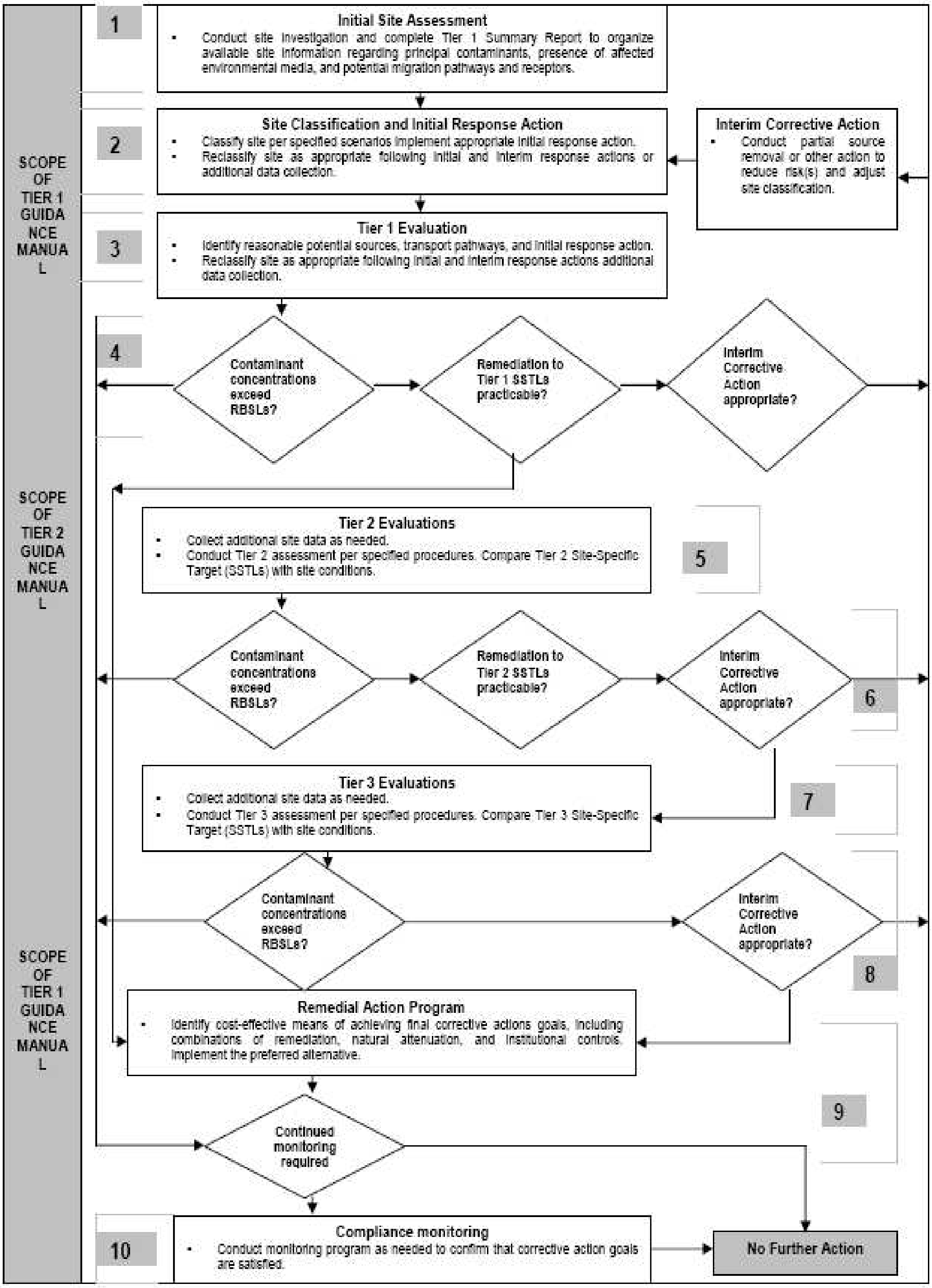

Figure 7: ASTM Risk-Based Corrective Action (RBCA) Flowchart (Connor *et al*, 1995)

Purchasing or selling of a site with environmental liabilities means that the buyer acquires at least a share in the liabilities as well. An Environmental Site Assessment (ESA) must be initiated by the buyer or the seller as a matter of good business principals. Even though an ESA is not a legal prerequisite, it does provide a good baseline in terms of site contamination and provides the buyer of a site with assurance against future legal action because of on site pollution.

Based on ASTM standards ESA's are divided into three phases:-

- *Phase 1*

Consists of gathering preliminary information to determine the probability of environmental contamination and the possible extent of environmental liabilities

- *Phase 2*

Involves undertaking a detailed site investigation including air, soil and/or water sampling and analysis for possible contamination as identified during Phase 1

- *Phase 3*

Occurs when certainty exists as to the intensity and extent of specific contaminants. In this phase, various remedial options are explored. Hazard and risk assessments are undertaken to determine cumulative impacts of the aspects identified (Raleru, 2005). Remediation is then planned and executed.

CHAPTER 4: METHODS FOR REMEDIATION

4.1 Introduction

The objective of any investigation into contamination is to identify and evaluate appropriate remediation technologies to rehabilitate the hydrocarbon affected zones. Determining the costs and practicability associated with implementing such preventative and corrective measures plays a vital role in deciding which technology to adopt.

The following questions should be asked to formulate a background understanding of the origin of the pollution (Raleru, 2005):

- How was the leak first detected?
- Where the leak was identified i.e. source of the pollution?
- How long has the leak been there i.e. pollution duration?
- What is the suspected cause of the leak?
- Which methods or tools were used to ascertain the pollution?
- What substances were identified as being contained in the pollution?
- What are preventative or remedial measures that can curb the problem from reoccurring?
- What are proactive measures to ensure that no similar incident reoccurs again?

It is crucial to ensure that once a leak has been identified, it is remediated and that mitigation measures are put in place as soon as possible. This is to prevent further contamination and possible migration of the pollution plume to non-affected areas. Non-action can result in underground aquifers being severely affected by hydrocarbon substances present in the subsurface.

4.2 Containment

One of the concerns that must be addressed when designing remediation projects is to prevent any further spread of the contaminant plume (Reis, 1996).

Containment of the contaminant plume is important for preventing further migration and localizing the plume for *in-situ* or *ex-situ* remediation (James *et al.*, 2000). Containment of the plume is of particular concern if remediation is expected to take a number of years, as it may for contaminated groundwater. Containment can be accomplished by placing physical or hydraulic barriers around the contaminant plume.

Physical barriers consist of an impermeable material that is placed around the contaminant plume to prevent its migration. Current containment methods include sheet pilings and grout curtains (James *et al.*, 2000). Grout curtains refers to grout which is injected into the soil and then solidifies to form an impermeable barrier. Sheet piling made of steel plates can be driven into the ground around the contaminant (Reis, 1996). Trenches can be dug and backfilled with an impermeable medium to form a slurry wall (Reis, 1996). These barriers require extensive physical manipulation of the site (e.g. excavation and back-filling) and are therefore expensive to construct.

Hydraulic barriers consist of a set of wells around the site from which fluid is withdrawn at a rate at least equal to the groundwater flow rate (Reis, 1996). The withdrawal point becomes a low point for the hydraulic pressure, inducing all groundwater in the immediate area, including the contaminant plume, to flow to the wells instead of away from the site (Reis, 1996). An alternative approach, biobarrier technology, involves the use of microbial biomass produced *in-situ* to manipulate the groundwater (James *et al.*, 2000). Biobarriers promise to be more cost effective and cause less surface disruption than conventional barrier technologies (James *et al.*, 2000).

Remediation technologies can then be employed at the contaminated sites. These various technologies are discussed below.

4.3 Remediation Technologies

There are a number of remediation technologies available to treat contaminated soil and groundwater. These options have been identified essentially using the

Federal Remediation Technology Roundtable (FRTR) screening matrix (FRTR, 2006) and US EPA documentation on Cleanup Technologies (USEPA, 2004). These remediation technologies can be subdivided into the following categories namely, physical, biological, chemical and thermal. These subcategories can be further broken down into the following specific technology type:

1. Physical remediation technologies
    a. Soil Vapour Extraction (SVE)
    b. Air sparging
    c. Vacuum Enhanced Recovery (VER)
    d. *In-Situ* Soil Venting
    e. Bio-enhanced Soil Aeration
    f. Pump and Skimmers
    g. Recovery Wells and Cut-off trenches
    h. Sprinkler Irrigation
    i. Air Stripping
    j. In Well Air Stripping
2. Biological Remediation Technologies
    a. Bioremediation (MNA)
    b. Phytoremediation
3. Chemical Remediation Technologies
    a. Pump and Treat – Carbon Adsorption
    b. Groundwater Pumping
    c. Chemical Oxidation
4. Thermal Technologies
    a. Thermal Treatment

4.4 Physical Remediation Technologies

4.4.1 Soil Vapour Extraction (SVE)

Soil vapour extraction (SVE), also known as soil venting or vacuum extraction, is an accepted, recognized, and cost effective technology for remediating soils contaminated with Volatile Organic Compounds (VOCs) and Semi Volatile Organic

Compounds (SVOCs). SVE involves the installation of vertical and horizontal wells in the area of soil contamination and air blowers are used to aid the evaporation process. Vacuums are applied through the wells near the source of contamination to evaporate the volatile constituents of the contaminated mass, which are subsequently withdrawn through an extraction well (Mbhele, 2007). Extracted vapours are then treated (commonly with carbon adsorption) before being released into the atmosphere. The increased airflow through the subsurface provided by SVE also stimulates the biodegradation of contaminants, especially those that are less volatile (Mbhele, 2007). This procedure is also used with groundwater pumping and air stripping for treating contaminated groundwater (Mulligan *et al*., 2001; Moutsatsou *et al*., 2006).

Benzene, toluene, xylene, naphthalene, biphenyl, perchloroethylene, trichloroethylene, trichloroethane, and gasoline are all effectively removed from contaminated soils by SVE systems (Mulligan *et al*., 2001; Moutsatsou *et al*., 2006).

Important observations related to the performance of SVE technology are (Mbhele, 2007):

- As SVE is an *in-situ* technology, the site disturbance is minimal, SVE can treat large volumes of soil at reasonable costs.
- It is effective at reducing VOCs in the vadose zone, thereby reducing the potential for further migration
- It has a short treatment time (usually a few months to 2 years under optimal conditions).
- Its applicability is limited to cases involving volatile compounds and sites with a shallow groundwater table.
- It is difficult, if not impossible to develop models that permit an accurate prediction of SVE cleanup times from the data collected in short-term pilot studies
- Concentration reductions greater than 90% are difficult to achieve.
- The permeability of the soil affects the rate of air and vapour movement through the soil. Therefore, the higher the permeability of the soil, the

more effective will be the SVE system at removing contaminants from the soil. Coarse-textured soils are therefore best suited for SVE.

- High moisture levels in the soil can reduce its permeability, and thus reduce the effectiveness of SVE by restricting the air flow through the soil pores.
- SVE is generally not appropriate for sites with a groundwater table located less than 0.9 m below the land surface (Mulligan *et al.*, 2001; Moutsatsou *et al.*, 2006).

4.4.2 Air Sparging

Air sparging is a relatively new *in-situ* remediation technique (Figure 8). Air is injected through the contaminated aquifer for the remediation of VOCs dissolved in groundwater, sorbed to the saturated zone soils, and trapped in the pores of the saturated zone. This technology is designed to operate at high flow rates to maintain increased contact between ground water and soil and strip more ground water.

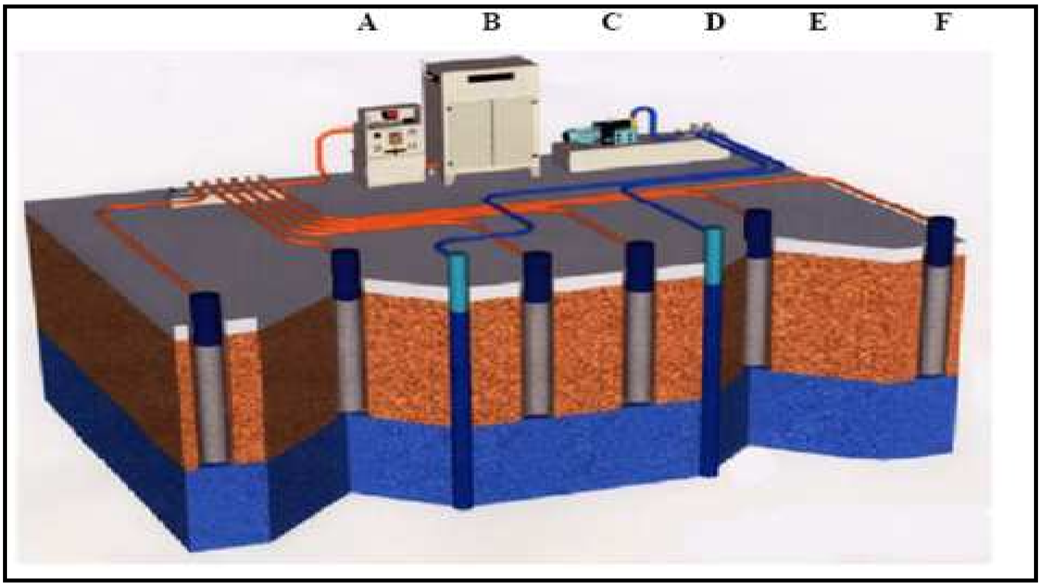

Figure 8: Air Sparging and Monitored Natural Attenuation (ABU GmbH Bad Saulgau – Germany)

Symbols as per Figure X above:

A – Airflow monitor

B – Airsparging main motor

C – Air compressor

D – Air inlet pipes

E – SVE pipe (outlet pipe)

F – Sparging point

The injected air forms channels through the contaminated plume as it flows upwards through the saturated zone and into the vadose zone. The injected air volatilizes the contaminants in the flow channels and transports them to the vadose zone where they are either biodegraded or removed by a SVE system (Figure 9).

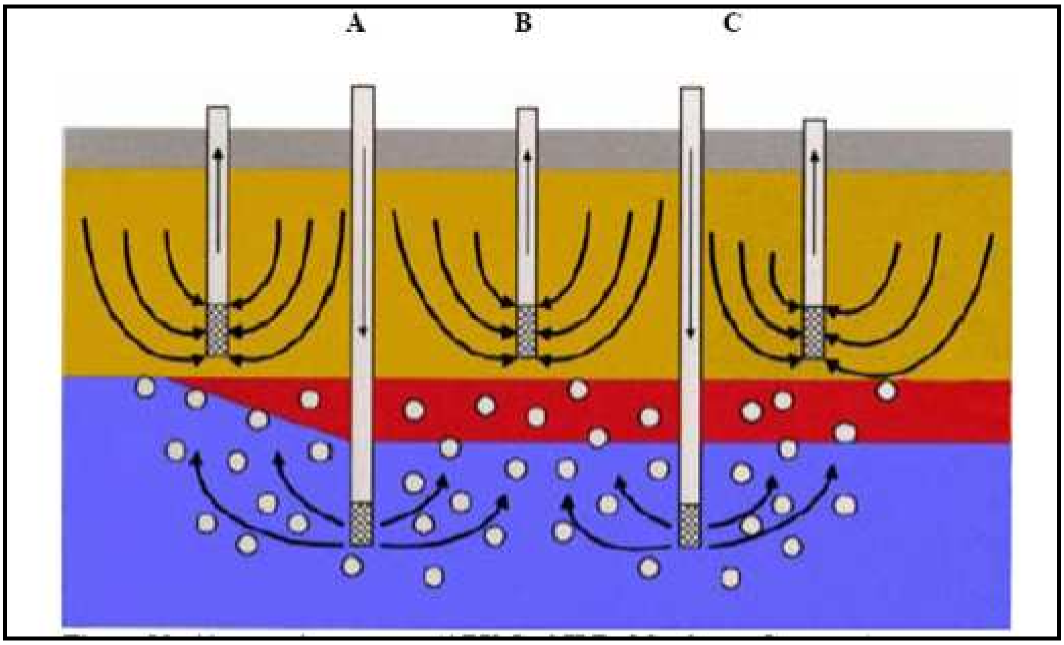

Figure 9: Air Sparging Process (ABU GmbH Bad Saulgau – Germany)

Symbols as per Figure X above:

A – Compressed air in

B – Air out

C – Air/water molecules centrifuge in the watertable

Air sparging offers a means of remediating contaminated soils and groundwater without the need for active groundwater pumping. This technology addresses a broad range of volatile and semi-volatile soil and groundwater contaminants including gasoline and other fuel components and chlorinated solvents (Mulligan *et al*., 2001; Moutsatsou *et al*., 2006). Figure 10, below indicates a SVE system where compressed water comes from underground to the surface. The water in the two beakers show how the darker material on the left is hydrocarbon contaminated before the remediation process (Raleru, 2005). The clearer water on the right is cleaned compressed water from underground vapours using the SVE system.

Figure 10: Air sparging analysis conducted before and after the remediation process (ABU GmbH Bad Saulgau – Germany)

Those sites with relatively permeable, homogeneous soil conditions favour the use of air sparging due to the greater effective contact between the injected air and the media being treated and the effective migration/extraction of volatilized vapours. Other site factors that influence the applicability of air sparging include the thickness of the saturated zone and the depth of the groundwater. For example, if the thickness of the saturated zone is small and the depth of groundwater is shallow, the number of wells required for adequate coverage could become expensive for such a remediation project (Mulligan *et al*., 2001; Moutsatsou *et al*., 2006). Air sparging has a medium to long duration, which may last, generally, up to a few years.

Important observations related to the performance of air sparging technology are:

- Silt and clay sediments are not appropriate for this technology
- Heterogeneous geologic conditions, reduces the effectiveness of the system
- This technology is ineffective in the case of non strippable and non-biodegradable contaminants
- This technology is inefficient if the vertical passage of air becomes hampered while the lateral movement is being increased

Factors that may limit the applicability and effectiveness of the process include:

- Airflow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapours.
- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions.
- Soil heterogeneity may cause some zones to be relatively unaffected.

4.4.3 Vacuum Enhanced Recovery System (VER)

VER, also commonly known as Single–pump Dual-Phase Extraction (DPE), is a commonly used and proven technology for the *in-situ* remediation of soils and groundwater in specific geological settings (Raleru, 2005). VER uses pumps to remove various combinations of contaminated groundwater; separate-phase petroleum product and hydrocarbon vapour from the subsurface. Extracted liquids and vapour are treated and collected for disposal. The DPE system is typically designed to maximize extraction rates; however, the technology also stimulates biodegradation (natural attenuation) of petroleum constituents in the unsaturated zone by increasing the supply of oxygen, in a manner similar to bio venting (USEPA, 1995).

VER is undertaken by installing a drop tube (slurp tube) into the free product/air interface and applying a vacuum enhanced pumping technique (Figure 11).

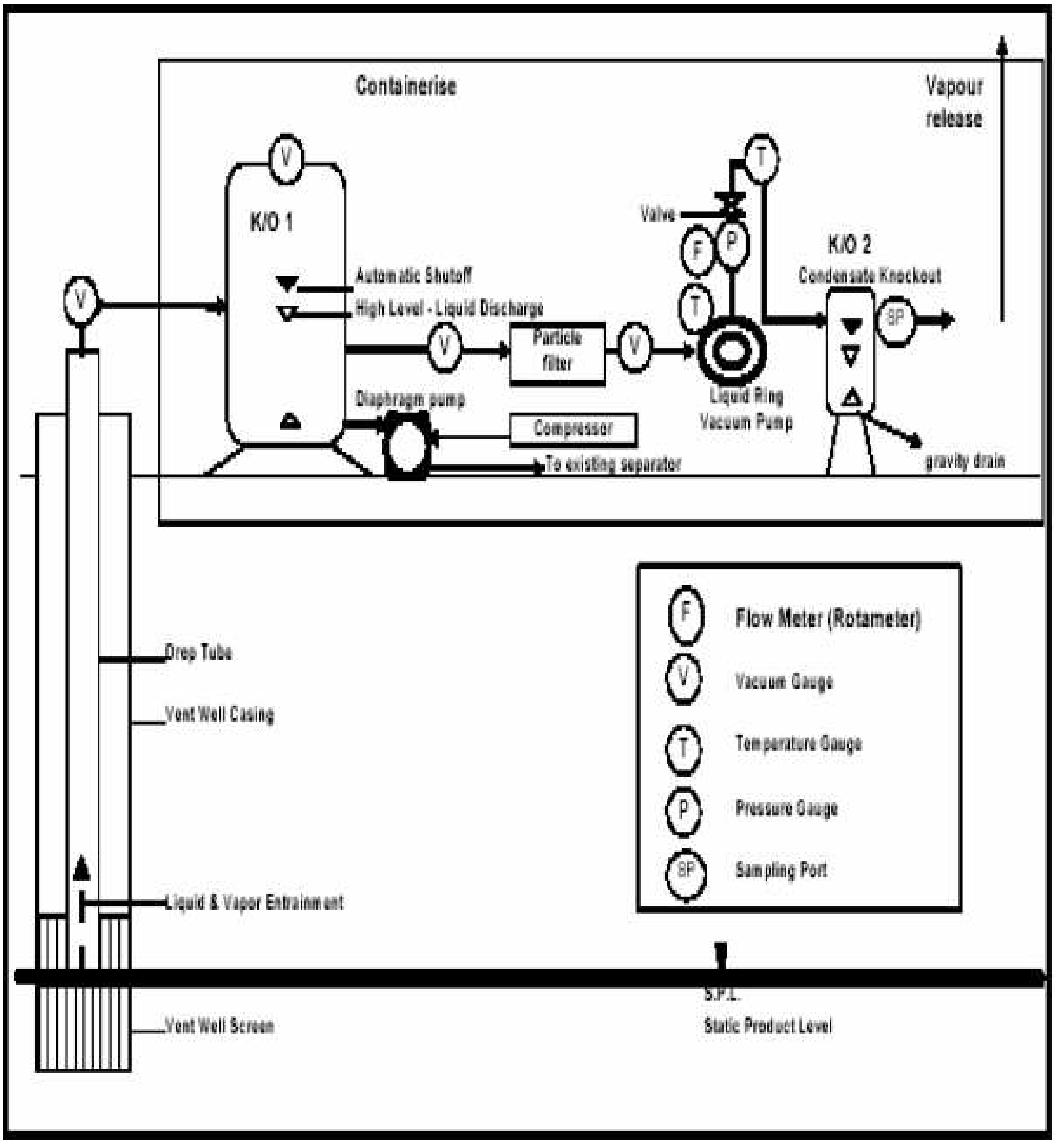

Figure 11: Process Flow Diagram of VER (Whitfield, 2002)

The success of VER depends on the nature, extent and depth of the contamination as well as the nature of the sub surface – vadose and saturated zones. High hydraulic gradients enhance the recovery rates of both water and LNAPL (Bruce *et al* 1992). The depressed groundwater table that results from these high recovery rates serves both to hydraulically control groundwater migration and to increase the efficiency of vapour extraction (Phophi, 2004).

Positive aspects about DPE technique (Phophi, 2004):

- Proven performance in low permeability soils. Requires no downhole pump.
- Can be applied at site with floating product, and can be combined with other technologies, such as air sparging and bioremediation.
- Intercept free product at higher recovery rate than pump and treat system (P&T).
- Can reduce the cost of groundwater treatment through air striping within the vacuum extraction tube.
- Removes free product, vapours and groundwater from the subsurface.
- Vents the soil and increases the percentages of oxygen in the subsurface resulting in the enhancement of biodegradation.
- Can be used under buildings and other locations that cannot be excavated.

Limitations of DPE technique (Phophi, 2004):

- Not efficient in low permeable soils (i.e. clay) due to low transmission of air
- Difficult to apply to sites where water table fluctuates
- Can extract a large volume of water that may require treatment
- Requires specialized equipment with sophisticated control capabilities
- Requires complex monitoring and control during operation
- Treatment may be expensive for extracted vapours and for oil-water separation
- Mostly efficient when dealing with petrol, diesel and jet fuel products due to their significant volatility

Table 6 below indicates an approximate cost estimate to undertake a VER installation.

Table 6: Cost estimate for VER installation for 2003 @ 6% annual inflation rate (Raleru, 2005)

Description	Rate	Quantity	Amount
Mobilisation Field monitoring & supervision Project management costs Data interpretation + report	R3.50/km R125.00/hr R10350.00/unit R175.00/hr	2000km 40hrs 1unit 48hrs	R7,000.00 R5000.00 R10,350.00 R8,400.00
Sub Total			**R30,750.00**
Containerised VER remediation unit Site establishment Installing and commissioning Drilling of three additional monitoring wells	R156871.25/unit R2750.00/unit R4500.00/unit R11163.50/unit	1 unit 1 unit 1 unit 1 unit	R156,871.25 R2,750.00 R4,500.00 R11,163.50
Laboratory			
Organic analyses of water VOC vapour measurements	**R390.00/sample** **R250.00/measurements**	**12 samples** **20 measurement**	R4,680.00 R5,000.00
Total Costs **VAT (14%)**			**R215,364.75** **R35,260.13**
Total			**R250,624.88**

4.4.4 In-Situ Soil Venting

Soil venting is accomplished by burying a slotted or perforated pipe or hose in the contaminated soil and then connecting a pipe to a fan or blower located on the surface so the soil gas is removed from the volume of soil surrounding the pipe (Angell, 1992). Typical soil vent systems for small sites of about 200m^2 and a contamination level which is of a primary nature, might be installed for US$2,000 to US$10,000 i.e. SA currency @ R6.50 on 11 June 2004 were R13 000 to R 65 000 (Raleru, 2005). Monitoring for such sites where the hydrocarbon contamination occurs consists of taking periodic photo ionization detector reading from the downstream side of the blower (Raleru, 2005). Ideally, the vapour should decrease with time (Eslinger *et al.*, 1994).

4.4.5 Bio Enhanced Soil Aeration

This technology involves excavation of the soil and then spreading it to a depth of no more than about 2m. It is a well-developed process in which the area of contact between the water and the air is increased (Mbhele, 2007). The contaminated soil is usually placed on an impermeable stiff liner or a plastic poly liner covered with a layer of sand (Raleru, 2005). The liner is then beamed in order to prevent runoff. The goal is to accelerate natural bioremediation via aeration and nutrient supply. A combination of evaporation and bioremediation stimulated by fertilizer nutrients results in both destruction and volitization of the contaminants (Eslinger *et al.*, 1994). The group of contaminants targeted by aeration includes SVOCs, pesticides, and fuels (Mbhele, 2007).

The disadvantage of this method is that it should not be employed in urban areas or other locations where organic vapours could cause health, fire, or nuisance hazards. The collected vapours also require further treatment. There are several limitations associated with the use of aeration (Mbhele, 2007):

- It cannot be used with contaminants with a high VOC content without some off- gas treatment;
- Vapours may cause health, fire, and nuisance hazards; and
- Aeration is often placed lower on the hierarchy of treatment technologies than those that destroy the contaminants.

4.4.6 Pumps and Skimmers

This refers to the pumping of water from the subsurface to the surface for treatment (Raleru, 2005). If free phase product is present, a skimmer pump can be used which only pumps the floating product. Pumps also exist which are dual purpose: free product is pumped from above the water to the surface, and water with dissolved hydrocarbons is simultaneously pumped to the surface from below the free product layer (Raleru, 2005). The water pump causes a drawdown which accelerates the movement of free product into the well (Eslinger *et al.*, 1994).

4.4.7 Recovery Wells and Cut off Trenches

A recovery well is a well containing a submersible pump or a water line leading to a pump on the surface (Raleru, 2005). The purpose of the pump is to pump groundwater to the surface for treatment. Typically, the recovery well will be close to, but slightly down gradient from, the location of maximum contamination (Raleru, 2005). Since the recovery well will be pumping water, it needs to be deep enough to produce a sufficient cone of depression to capture the contamination plume (Eslinger *et al.*, 1994).

In situations where it is imperative that the contamination be prevented from spreading offsite, an interceptor or cut off trench might be constructed (Raleru, 2005). The purpose of the trench is to intercept groundwater, and then to pump the intercepted groundwater to the surface for treatment (Raleru, 2005).

4.4.8 Sprinkler Irrigation

Sprinkler irrigation is a relatively simple treatment technology used to volatilize VOCs from contaminated wastewater. The process involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system (Mills and Otten, 1998). Sprinkler irrigation transfers VOCs from the dissolved aqueous phase to the vapour phase, whereby the VOCs are released directly to the atmosphere (Mills and Otten, 1998).

The following factors may limit the applicability and effectiveness of the process (Mills and Otten, 1998):

- Regulatory approval may be difficult to obtain because of the potential of direct release for contaminants to the atmosphere.
- Ponding of wastewater may result from heavy irrigation.
- Performance may be affected by temperature.
- As regulatory requirements become stricter, this technology may become obsolete.

4.4.9 Air Stripping

Air stripping is a full-scale technology, which involves the mass transfer of volatile contaminants from water to air by greatly increasing the surface area of the contaminated water exposed to air (Mills and Otten, 1998). Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

For ground water remediation, this process is typically conducted in a packed tower or an aeration tank. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air counter current to the water flow, and a sump at the bottom of the tower to collect decontaminated water (Mills and Otten, 1998). Aeration tanks strip volatile compounds by bubbling air into a tank through which contaminated water flows. The advantages offered by aeration tanks are considerably lower profiles (less than 2 meters high) than packed towers (5 to 12 meters high) where height may be a problem, and the ability to modify performance or adapt to changing feed composition by adding or removing trays or chambers (Mills and Otten, 1998). The discharge air from aeration tanks can be treated using the same technology as for packed tower air discharge treatment.

4.4.10 In-well Air Stripping

In-well air stripping technology involves the injection of air into a vertical well that has been screened at two depths (Mills and Otten, 1998). The lower screen is set in the groundwater saturated zone, and the upper screen is in the unsaturated zone, often called the vadose zone. Pressurized air is injected into the well below the water table, aerating the water (Mills and Otten, 1998). The aerated water rises in the well and flows out of the system at the upper screen. Contaminated groundwater is drawn into the system at the lower screen. The volatile organic compounds (VOCs) vaporize within the well at the top of the water table, as the air bubbles out of the water (Mills and Otten, 1998). The vapours are drawn off by a soil vapour extraction (SVE) system. The partially treated ground water is never brought to the surface; it is forced into the unsaturated zone, and the process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of ground water (Mills and Otten, 1998). As ground water circulates through the treatment system *in-situ*, contaminant concentrations are gradually reduced (Mills and Otten, 1998). In-well air stripping is a pilot-scale technology.

4.5 Biological Remediation Technologies

4.5.1 Monitored Natural Attenuation

Bioremediation or natural attenuation is a process in which naturally occurring micro organisms (i.e. yeast, fungi or bacteria) break down or degrade hazardous substances into less toxic or non-toxic substances (Mbhele, 2007). Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels. Consideration of this option usually requires modelling and evaluation of contaminant degradation rates and pathways and predicting contaminant concentration at down gradient receptor points, especially when the plume is still expanding/migrating. The primary objective of site modelling is to demonstrate that natural processes of contaminant degradation will reduce contaminant concentrations below risk-based levels before potential exposure pathways are completed. In addition, long term monitoring must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.
Natural attenuation processes can effectively clean soil and groundwater of hydrocarbon fuels, such as gasoline and BTEX compounds (U.S. Environmental Protection Agency, 1990, Khan et. al., 2004). The United States Environmental Protection Agency (USEPA) recognizes natural attenuation as a viable method of remediation for soil and groundwater, and its selection is often based on its ability to achieve remediation goals in a reasonable time frame whilst protecting human health and the environment (Mbhele, 2007). Natural attenuation is however recommended with specific reference to the dissolved pollution plume and not the free phase plume (Van der Linde, 2002).

Important observations related to the performance of natural attenuation technology are (Mbhele, 2007):

- It is a relatively simple technology compared to other remediation technologies.
- It can be carried out with little or no site disruption.

- It often requires more time to achieve cleanup goals than other conventional remediation methods.
- It requires a long-term monitoring program; program duration affects the cost.
- If natural attenuation rates are too slow, the plume could migrate.
- It is difficult to predict with high reliability the performance of natural attenuation.
- Sites must meet one or more of the following criteria:
    - It must be located in an area with little risk to human health or to the environment.
    - The contaminated soil or groundwater must be located at an adequate distance from potential receptors.
    - There must be evidence that natural attenuation is actually occurring at the site.
    - High permeability speeds contaminant spread, low permeability slows the breakdown.
    - Ideally, natural attenuation works best in soils whose permeability ranks somewhere between high and low (Khan et. al., 2004; Algarra et. al., 2004).

4.5.2 Enhanced Bioremediation

Enhanced bioremediation is a process in which indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in soil and/or ground water, converting them to innocuous products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. This is done by the addition of oxygen (either through sparging or oxygen releasing compounds) and nutrients (Raleru, 2005). A variety of other environmental factors may be manipulated to enhance the natural process breaking down pollutants (Raleru, 2005). Bioremediation designs can be divided into indigenous and exogenous systems, and into *in-situ* and *ex-situ* systems. An indigenous system uses the native bacterial population whereas an exogenous system introduces bacteria that have been collected or cultured specifically for the contaminant present (Raleru, 2005). *In-situ* means treatment of the contaminated soil in place and *ex-situ* means that contaminated soil is removed and treated elsewhere of its natural site (Eslinger *et al.*, 1994). *In-situ* bioremediation technologies are potentially effective in degrading or transforming a large number of organic compounds to environmentally acceptable or less mobile compounds (Mbhele, 2007). Fertile soil naturally contains up to one million hydrocarbon degrading bacteria per gram of dry soil (Testa and Winegardner, 1991). By adding nutrients and ensuring the availability of oxygen, *in-situ* bioremediation can effectively degrade many hydrocarbon contaminants (Reis, 1996). This process can take several months to several years to complete however, and is difficult to control (U.S. Environmental Protection Agency, 1990: American Petroleum Institute, 1986a and 1986b). A controlling factor in the effectiveness of *in-situ* bioremediation is the soil structure. Sandy soils with a high permeability allow higher levels of biological activity than do soils containing significant quantities of silt or clay (Reis, 1996). The more permeable soils permit a more rapid transport of air (oxygen), water and nutrients to the sites of biological activity (Reis, 1996). The availability of oxygen is another factor responsible for the degree of success during *in-situ* bioremediation. To help ensure an adequate supply of oxygen, air is commonly injected into the formation in a process called air sparging (Reis, 1996).

Natural bacteria in soil and ground water will use petroleum compounds as their primary source of energy, thus biodegrading the compounds during the process (Mbhele, 2007). There are three main processes by which microorganisms aid in the breakdown of hydrocarbons i.e. fermentation, aerobic respiration and anaerobic respiration.

Factors that may limit the applicability and effectiveness of these processes include (Mbhele, 2007):

- Where the subsurface is heterogeneous, it is very difficult to deliver the nitrate or hydrogen peroxide solution throughout every portion of the contaminated zone. Higher permeability zones will be cleaned up much faster because ground water flow rates are greater.

- Safety precautions must be used when handling hydrogen peroxide.
- Concentrations of hydrogen peroxide greater than 100 to 200 ppm in ground water are inhibiting to microorganisms.
- Microbial enzymes and high iron content of subsurface materials can rapidly reduce concentrations of hydrogen peroxide and reduce zones of influence.
- A ground water circulation system must be created so that contaminants do not escape from zones of active biodegradation.
- Because air sparging increases pressure in the vadose zone, vapours can build up in building basements, which are generally low pressure areas.
- Many states prohibit nitrate injection into ground water because nitrate is regulated through drinking water standards.
- A surface treatment system, such as air stripping or carbon adsorption, may be required to treat extracted ground water prior to re-injection or disposal.

Table 7 outlines the cost for one sampling event. Four sampling events are recommended over a twelve month period to obtain sufficient data for analysis (Raleru, 2005).

Table 7: Cost Enhanced Bioremediation (MNA) of one sampling event in 2002 @ 6% annual inflation (Raleru, 2005)

Qty		Unit	Total
Groundwater Sampling			
Mobilisation	400 samples	R3.00	R1,200.00
Sampling field work	32 samples	R225.00	R7,200.00
Reporting	10	R300.00	R3,000.00
Laboratory			
Organic analyses	30 (tests)	R650.00	R9,750.00
Inorganic analyses	30 (tests)	R350.00	R5,250.00
		Subtotal	**R26,400.00**
		VAT	**R3,696.00**
		Total	**R30,096.00**

4.5.3 Phytoremediation

Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. It is best applied with shallow contamination of organic nutrient, or metal pollutants that are amendable to the process. This process takes advantage of the ability of plants to take up, accumulate and degrade constituents that are present in soil and water environments (Mbhele, 2007). All plants extract necessary components, including nutrients and heavy metals, from these environments. Plants have also been known to take up various organics and either degrade or process them for use in physiological processes (Khan et. al., 2004, Mulligan *et al.*, 2001). These contaminants include heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, PCBs, PAHs, organophosphate insecticides, explosives, and surfactants (Khan et. al., 2004, Mulligan *et al.*, 2001). Phytoremediation is well suited for use at very large field sites where other methods of remediation are not cost effective or achievable (Gatliff, 1996). The process could consist of establishing plants in a contaminated area or irrigating plants using contaminated water. The mechanisms of phytoremediation include (Mbhele, 2007):

- Rhizofiltration or enhanced rhizosphere biodegradation, a water remediation technique in which contaminants are taken up by the plant's roots;
- Phytoextraction or phyto-accumulation, which involves the uptake of contaminant from the soil;
- Phytotransformation or phyto-degradation, which is applicable to both soil and water and involves the degradation of contaminants through plant metabolism;
- Phytostimulation or plant-assisted bioremediation, which involves the stimulation of microbial degradation through the activities of plants in the root zone (Mbhele, 2004); and
- Phytostabilization, which uses plants to reduce the migration of contaminants through the soil medium.

Important observations related to the performance of phytoremediation technology are (Mbhele, 2007):

- Remediation is accomplished with minimal environmental disturbance.
- It is an aesthetically pleasing and passive, solar energy driven technology.
- It can be used on a large range of contaminants.
- The generation of secondary wastes is minimal.
- Organic pollutants may be converted to CO_2 and H_2O instead of transferring toxicity.
- It is cost-effective for large contaminated sites (with a low concentration of contaminants).
- The topsoil is left in a usable condition and may be used in agriculture.
- The soil can remain at a site after the removal of the contaminant rather than being disposed of or isolated.
- The uptake of contaminated groundwater can prevent the migration of contaminants.
- Remediation usually requires more than one growing season.
- Treatment is limited to soils less than one meter from the surface and groundwater less than 3 m from the surface.
- Climate and hydrologic conditions such as flooding and drought may restrict plant growth and the type of plants that can be utilized (Khan et. al., 2004, Mulligan *et al.*, 2001).

There are a number of limitations to phytoremediation

- High concentrations of hazardous materials can be toxic to plants.
- It involves the same mass transfer limitations as other biotreatments.
- Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period.
- It can transfer contamination across media, e.g., from soil to air.
- It is not effective for strongly sorbed and weakly sorbed contaminants.
- Phytoremediation will likely require a large surface area of land for remediation.

Phytoremediation is a newly developed technology for soil remediation. In South Africa such remediation processes are not in place and still have to be researched further before they can be introduced (Raleru, 2005). The costing model on table 8, was changed to the SA currency @ R6.50; on the 11 June 2004, the cost was R 1 170 000.00 (Raleru, 2005). Such a huge cost can result in liquidation of a company.

Table 8: Costing model for Phytoremediation (Raleru, 2005)

Process	Costs
Design & implementation	US$ 50.000
Monitoring equipment	US$ 20.000
Installation	US$ 40.000
Replacement	US$ 20.000
Travel & administration	US$ 10.000
Data collection	US$ 10.000
Sample analysis	US$ 10.000
Consulting	US$ 10.000
Reports (bi-annual)	US$ 10.000
Total	US$ 150.000

4.6 Chemical Remediation Technologies

4.6.1 Pump and Treat System (P&T)

When contaminated groundwater is removed from the subsurface by pumping, it is often treated before it is discharged (Mbhele, 2007). Hence, these methods are referred to as pump and treat system. This is the most common form of groundwater remediation (USEPA, 1996). Possible objectives of ground water pumping include removal of dissolved contaminants from the subsurface, and containment of contaminated ground water to prevent migration. Pump and treat systems are ideal at sites where the contaminants are in a mobile, dissolved state and less sorption is likely to occur. A major component of any groundwater extraction system is a ground water monitoring program to verify its effectiveness (Mbhele, 2007). Monitoring the cleanup allows the operator to make adjustments to the system in response to changes in subsurface conditions (Mbhele, 2007).

A major component of a pump and treat system is determining when to turn the system off (Mbhele, 2007). Termination requirements are based on the cleanup objectives combined with site-specific aspects revealed during remedial operations (Mbhele, 2007)

Characteristics of P&T systems (Mbhele, 2007):

- It is the optimum tool for plume and hydraulic gradient control.
- Pump-and-treat systems often take a very long time (e.g. 50 -100 years) to meet cleanup goals.
- Pumping depresses the groundwater level, leaving residuals sorbed to the soil. After the groundwater level returns to its normal level, contaminants sorbed onto soil become dissolved. This phenomenon is called "rebound". Rebound tests should be performed frequently in the first few years after the system is turned off, and after major precipitation or flooding events.
- Generation of substantial amounts of secondary wastewater, high energy costs for pumping and moving large volumes of water, indiscriminate removal of all groundwater components, potential impacts on groundwater resources, and slow progress toward terminal regulatory goals due to technical limitations (Looney, 1994) are all limitations to the technology.

The following factors may limit the applicability and effectiveness of ground water pumping as part of the remedial process:

- The potentially long time necessary to achieve the remediation goal.
- System designs fail to contain the contaminant as predicted, allowing the plume to migrate and failure of the pumping equipment.
- Residual saturation of the contaminant in the soil pores cannot be removed by ground water pumping. Contaminants tend to be sorbed in the soil matrix. Ground water pumping is not applicable to contaminants with high residual saturation, contaminants with high sorption capabilities, and homogeneous aquifers with permeability less than 10^{-5} cm/sec.
- The cost of procuring and operating treatment systems is high. Additional cost may also be attributed to the disposal of treatment residuals and wastes.
- Biofouling of the extraction wells and associated treatment stream is a common problem, which can severely affect system performance.

- Drawdown pumping generally produces large volumes of water.
- The production of a cone depression in the water table can smear the free product or trap the fuel in the saturated zone when the water table returns to its original level.

4.6.2 Pump and Treat – Carbon Adsorption

Hydrocarbon contaminants dissolved in water (or present in a vapour) can be adsorbed by carbon (Raleru, 2005). Granular Activated Carbon (GAC) is a fine-grained carbon that has been "activated" so that it has a high surface area and will have excellent absorption properties. The contaminated groundwater is pumped to the surface and then through a container that holds the activated carbon (Eslinger *et al.*, 1994).

The up stream GAC container can be replaced after breakthrough to the second container is detected by sampling (Raleru, 2005). The second container is then moved to the upstream position and the first container replaced with fresh GAC and placed in the number 2 position (Raleru, 2005). The sediment filter prevents clogging of the GAC chamber. The separator aids in two ways: it prevents known or unknown free product pulse from entering the GAC chamber, and it separates low density emulsions from entering the GAC chamber (Raleru, 2005).

4.6.3 Chemical Oxidation

The chemical oxidants most commonly employed to date include peroxide, ozone, and permanganate (Mbhele, 2007). These oxidants have been able to cause the rapid and complete chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. In general the oxidants have been capable of achieving high treatment efficiencies (*e.g.*, > 90 percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, benzene), with very fast reaction rates (90 percent destruction in minutes) (Mbhele, 2007). Field applications have clearly affirmed that matching the oxidant and *in-situ* delivery system to the contaminants of concern (COCs) and the site conditions is the key to successful implementation and achieving performance goals.

The following factors may limit the applicability and effectiveness of chemical oxidation and include (Mbhele, 2007):

- The requirement for handling large quantities of hazardous oxidizing chemicals due to the oxidant demand of the target organic chemicals and the unproductive oxidant consumption of the formation.
- The potential for process-induced detrimental effects. Further research and development is ongoing to advance the science and engineering of *in-situ* chemical oxidation and to increase its overall cost effectiveness.

4.7 Thermal Technologies

4.7.1 Thermal Treatment

Thermal treatment has the distinct advantage of a permanent destruction of hazardous material (Raleru, 2005). This uses specialized retorting/desorption technology. It is an approved technology and is accepted by the US EPA as a mature and demonstrated technology. Figure 12 below illustrates the thermal treatment process.

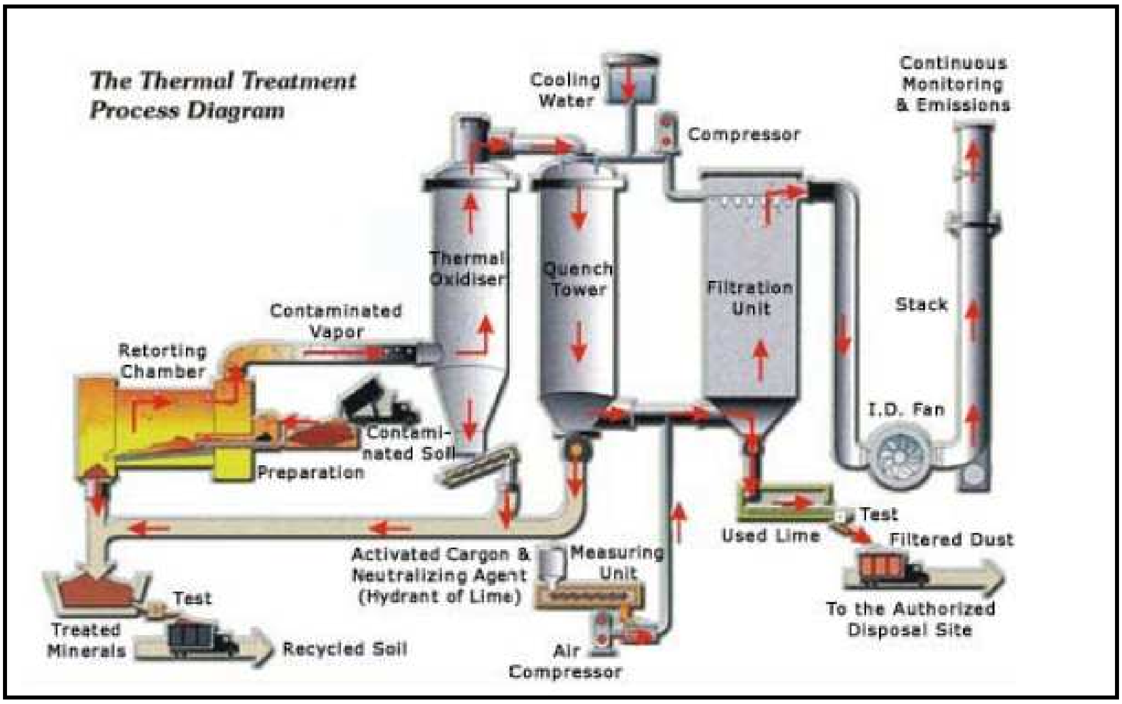

Figure 12: Thermopower Treatment Process (Raleru, 2005)

4.7.2 The functionality of a Thermal Treatment Plant

A gas clean up is used to remove heavy metals, particulates and unwanted pollutants from the gas stream. This enables compliance with the Basel Convention on the Control of Transboundary Movements of Hazardous Material to which South Africa is a signatory (Raleru, 2005). The Convention's article 4 No 9(a) specifically refers "The state shall take appropriate measures to ensure that the transboundary movement of hazardous material only be allowed if (it) does not have the technical capacity and the necessary facilities in order to dispose of the products/material/waste in question in an environmentally sound and efficient manner" (Tsinonis, 2003).

The thermal de-sorption plant is operated at a temperature of 95°C to 600°C (sometimes even higher) so that contaminants with low boiling points will vaporise and separate from the solid matrix (Raleru, 2005). Soil can be heated to volatilize HC's. The gaseous by products are then emitted into the atmosphere and the soil pollution now becomes air pollution i.e. the phase of the pollution has been changed from liquid to gaseous. This means that the pollution has not been properly resolved in terms of the Atmospheric Pollution Prevention Act 45 of 1965 (APPA, 1965). The treated soil passes out of the kiln and is then placed back into the hole from which it was excavated (Raleru, 2005)

Water is sprayed on the gases and air-entrained particulates in the quench chamber causing them to settle and the liquid is pumped back to the water supply (Raleru, 2005). The slightly cooled vapours continue to centrifuge where they are separated from any remaining liquids (Raleru, 2005). The vapours pass into the atmosphere and the liquids cycle back into the quench chamber (Raleru, 2005). The throughput of these systems varies from 5 – 30 kg per hour with the high temperature unit. This depends on the type of soil, nature of contamination and design of equipment. Cost for treating hydrocarbon fuel contaminated soils typically varies between US$ 40 and US$ 80, converted to SA currency on the 11 June 2004 i.e. R2600 and R5200 per 1000kg using this method (Raleru, 2005). Direct soil return to the original excavated site saves transportation and backfilling costs (Eslinger *et al.*, 1994).

4.8 Treatment Trains

The above options may be undertaken separately or as treatment trains. Treatment trains refer to the various options being implemented at different times or in different areas of the plume during the clean up.

4.9 Summary

Remediation i.e. cleanup activities generally take place once it is established that a site is or has been contaminated. Remediation of these sites is essential for protecting the soil and groundwater resources and reducing risks to local communities. The selected remediation measures must be appropriate depending on a case-by-case analysis with a possible mixture of remediation measures. Although many efforts have been made, effective design and management of various remediation systems are still challenging to practitioners (Qin *et al.*, 2009). A variety of technologies/methodologies are available and constant research into new technologies is being undertaken (Raleru, 2005).

Based on the remediation processes, VER subdivided into SVE and DPE as well as MNA, may be viable options for hydrocarbon chemicals that are quite mobile in the subsurface environment and not amenable to microbial degradation. SVE and VER are technically suitable and cost effective. The VER option is preferred based on the fact that it is locally based and the country is in the process of uplifting the proudly South African products and expertise (Raleru, 2005). The use of African trained and experienced staff ensures that such solutions are locally appropriate and competively priced (Raleru, 2005).

Phytoremediation is very competitive with other treatment alternatives as it is aesthetically pleasing and its public acceptability is high. Phytoremediation is far less expensive and versatile but it requires five years of operation rather than shorter periods for the competing technologies. It is most comparable to *in-situ* bioremediation and natural attenuation. In these technologies, mathematical modelling and monitoring are necessary to demonstrate the effectiveness of the technology to the regulatory agencies (Raleru, 2005). These technologies also exhibit further positive aspects as there are fewer disturbances to the environment because there are no ground excavations and infrastructural mechanisms required as compared to other technologies. The process is, however, too new to be approved by regulatory agencies in *pro forma* reviews. The main question that regulators will want answered is whether phytoremediation can remediate the site to recommended standards and reduce risk to human health and the environment (Raleru, 2005). Phytoremediation is not suitable for hazardous substances or waste problems, but it does show tremendous potential in several applications for treatment of metals and BTEX organics and VOC’s at sites where contamination is shallow. The technology has not been demonstrated conclusively at many sites to date, and it remains to be seen if it is effective at full scale.

Thermal treatment causes fugitive dust, with a high moisture content, which requires more treatment (Raleru, 2005). A certain percentage reduction of hydrocarbons that is present in the contaminated soil needs to be attained. The amount of reduction varies depending on the situation, but a typical efficiency required would vary between 95% and 99.9% reduction in total VOC's (Eslinger *et al.*, 1994).

A soil venting system might take months to years to remove sufficient contaminants from the soil and therefore the cost of routine maintenance and monitoring needs to be considered when deciding whether or not to install such a system.

GAC has the disadvantage of a container rusting if it is not made up of rustproof metal and clogging of the GAC by bacteria if a sediment filter is not used (Raleru, 2005). Carbon is not selective therefore; it will adsorb whatever is in the water solution even if the solute is not considered a contaminant. Thus, for instance, a high concentration of calcium in the water will decrease the effectiveness of the carbon in adsorbing any benzene in the water, as the carbon will absorb mostly the calcium from the water. A further significant drawback of GAC is the expense involved, which includes the continued cost of the GAC, the maintenance of the system (drums may require changing on a weekly or monthly basis), the analysis to detect breakthrough and the cost of disposing or regenerating the carbon once saturated. Disposal costs may be five times the original cost of the carbon, depending on the contaminant adsorbed (Raleru, 2005).

Air sparging does not bring water to the surface for treatment. It will most effectively remove those compounds that are most readily volatilized (Raleru, 2005).

Because of the complex distribution of contaminants in soil, a comprehensive site evaluation may be required before the optimum remediation process can be selected and properly implemented (Reis, 1996). Every site is unique and appropriate methodology needs to be applied accordingly. Methods are decided upon through consideration of the subsurface matrix, contaminant and cost implications (Raleru, 2005).

The best available technology or methodology must be selected and recommended to solve the hydrocarbon contamination in the best interests of the environment. These technologies should be selected based on the BATNEEC principal as well as the Best Practicable Environmental Option (BPEO) concept. These concepts must be applied without compromise on integrity and value. It is purely based on what is best available and practically viable by also taking cost implications into account (Raleru, 2005).

CHAPTER 5: DUE DILIGENCE REPORT AND CASE STUDY ANALYSIS

5.1 Introduction

This research report provides insight into the contamination associated with the filling station industry. The research focused on due diligence assessment studies that were conducted for Sasol Oil (Pty) Ltd between 2002 to March 2009. These due diligence reports were produced after the promulgation of the EIA regulations in 1997.

The aim of this study was to understand the contamination associated with the filling station industry. In addition to this, the current EIA decision-making processes are evaluated in order to determine their effectiveness in combating contamination associated with the filling station industry. Local and provincial EIA decision-making structures were analysed to determine whether they effectively evaluated the significance of filling station's and contamination impacts.

5.2 Study Area

The study area for this research report was restricted to the boundaries of South Africa. One of the research aims of this research report was to understand the effectiveness of EIA's in addressing contamination associated with the filling station industry. South African EIA legislation was utilised as the guideline and therefore South Africa was chosen as the study area.

The nature of the study, which focuses in part on the assessment of contamination within the filling station industry and the assessment of remediation measures within the filling station industry, dictated the choice of case studies. The filling station industry is a fiercely competitive field and as a result attaining information from competitor sites is not possible. As an employee of Sasol, I have access to information regarding sites that Sasol have been involved with. There is therefore a degree of self selection in this study which could cause the results to be skewed.

5.3 Data

Due diligence reports were used as a basis of the first leg of this study. Analysis of these reports were undertaken in order to determine the propensity for contamination within the filling station industry in South Africa. This was used to attain an approximate evaluation of the proportion of contaminated sites. The data however does not specify the source (tanks or pipework) of the contamination or the significance.

The second leg of this study involves the study of site characterisation reports undertaken on contaminated sites. This was used to determine the success of remediation efforts at contaminated sites.

Analysing both legs of the study allows a conclusion to be drawn regarding the role of EIA in mitigating against the associated filling station contamination.

5.4 Limitations of the Study

Initially, additional filling station operators were approached to assist in obtaining data. However, due to confidentiality issues the additional operators were unable to assist. Thereafter, data from Sasol Oil were solely utilised. This governed the number of case studies that could be used. Additionally data were only available on sites that Sasol Oil intended taking over from another oil company.

This compromised the study to some extent in that the findings were not based on a full set of filling station operators as was originally planned. Nonetheless, some interesting trends were detected.

5.5 Due Diligence Report Analysis

Due diligence studies are undertaken prior to site takeovers i.e. a site being taken over by another oil company, and during knock down and rebuild of sites. Knock down and rebuilds are undertaken on existing sites during either upgrading the site or converting the site to another oil company. These studies are undertaken at this point in order to determine the existing contamination on site for the purpose of remediation. The reason for these studies to be undertaken at this point is that the USTs are removed from the excavations and this therefore enables an accurate assessment of the contamination levels on site. It also allows the appropriate oil company to accept responsibility for the contamination on site. Table 9 below indicates the filling stations that were assessed as the basis of this study and the year in which the study was done.

Table 9: Filling Station Due Diligence Reports Assessed

Name of Service Station	Date of Due Diligence Study
Reynolds Brothers Service Station, Benoni	September 2002
Impala Service Station	October 2002
Lenesia Total Service Station	October 2002
East Auto, Witbank	February 2003
Exel Van Buuren Road Service Station	February 2003
Caltex Bonaero Park	March 2003
Mashala Motors, Bapsfontein	March 2003
Ruyssenaers Motors, Pretoria	March 2003
Sebenzile Motors, Soweto	March 2003
East Vaal Auto, Secunda	May 2003
Engineering Enterprise Motors, Pomona	May 2003
Raceway Motors, Turffontein	May 2003
V and M Motors, Wonderboom Agricultural Holdings	May 2003
IEMAS Service Station	July 2003
Rhoville Service Station, Brackenfell, Cape	July 2003
Rooihuiskraal Service Station	July 2003

Tableview Service Station, Tableview, Western Cape	October 2003
Amajuba Service Station	November 2003
Sasol Hill Street, Randburg	November 2003
FG Malinga Motors, Mpumalanga Township	May 2007
Lilianton Service Station	May 2007
Randjesfontein Filling Station, Randjesfontein	March 2008
CB Downes Service Station	October 2008
Mpophomeni Service Station	October 2008
Pat Duckhams, Pietermaritzburg	March 2009
Windsor Park, Durban	March 2009

5.6 Case Study Analysis

The due diligence assessment reports for each of the case studies were evaluated in terms of contamination levels on site. The contamination was assessed in terms of sites that displayed no contamination, sites with only soil contamination, sites with only groundwater contamination and sites with both types of contamination. The table below summarises the findings of the study (Table 10).

Table 10: Analysis of Case Studies

Name of Service Station	Date of Assessment	Approximate Age of Tanks (Years)	Soil Contamination	Groundwater Contamination
Reynolds Brothers Service Station, Benoni	September 2002	>60	No	No
Lenesia Total Service Station	October 2002	>30	No	No
Caltex Bonaero Park	March 2003	32	No	No
Mashala Motors, Bapsfontein	March 2003	12	No	No
Raceway Motors, Turffontein	May 2003	Unknown	No	No

Rooihuiskraal Service Station	July 2003	18	No	No
Tableview Service Station, Tableview, Western Cape	October 2003	20	No	No
Amajuba Service Station	November 2003	>20	No	No
FG Malinga Motors, Mpumalanga Township	May 2007	40	No	No
CB Downes Service Station	October 2008	25	No	No
Exel Van Buuren Road Service Station	February 2003	Unknown	No	Yes
Ruyssenaers Motors, Pretoria	March 2003	50	No	Yes
East Vaal Auto, Secunda	May 2003	21	No	Yes
V and M Motors, Wonderboom Agricultural Holdings	May 2003	46	Yes	No
Sasol Hill Street, Randburg	November 2003	Unknown	Yes	No
Windsor Park, Durban	March 2009	25	Yes	No
Impala Service Station	October 2002	30	Yes	Yes
East Auto, Witbank	February 2003	Unknown	Yes	Yes
Sebenzile Motors, Soweto	March 2003	14	Yes	Yes
Engineering Enterprise Motors, Pomona	May 2003	>40	Yes	Yes
IEMAS Service Station	July 2003	8	Yes	Yes
Rhoville Service Station, Brackenfell,	July 2003	>25	Yes	Yes

Cape				
Lilianton Service Station	May 2007	Unknown	Yes	Yes
Randjesfontein Filling Station, Randjesfontein	March 2008	13	Yes	Yes
Mpophomeni Service Station	October 2008	5	Yes	Yes
Pat Duckhams, Pietermaritzburg	March 2009	20	Yes	Yes

The total number of sites that were evaluated as part of this exercise was 26. Although this is a small sample size, it can be regarded as a representative sample and the results can be used to extrapolate information regarding the South African filling station industry as a whole (see table 11 below).

Table 11: Sites exhibiting Contamination

	No Contamination	**Soil Contamination**	**Groundwater Contamination**	**Soil and Groundwater Contamination**
Number of sites	10	3	3	10
% of Total	38	12	12	38

Figure 13 below indicates the percentage of filling stations exhibiting contamination. The results indicate that ten sites, i.e. 38%, exhibit no signs of contamination. Three sites each display either soil contamination or groundwater contamination. Ten sites i.e. 38% display both soil and groundwater contamination.

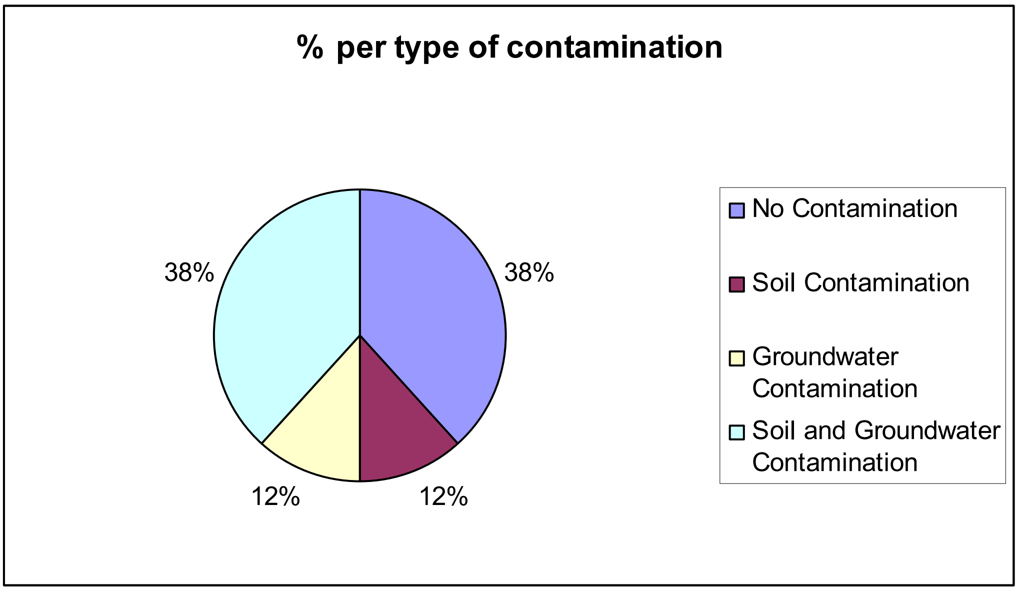

Figure 13: Graph indicating the percentage of sites by contamination type

The results indicate that 62% of sites display some form of contamination in comparison to 38% that display no contamination. It can therefore be inferred that a larger proportion of filling stations in South Africa are associated with soil and groundwater contamination i.e. six filling stations out of every ten.

Table 12 below indicates the age of the tanks in relation to the contamination exhibited on site. In some instances tanks that are 5 years old for example Mpophomeni Service Station have experienced integrity failure. In other instances, tanks that are in excess of 60 years for example Reynolds Brothers Service Station demonstrate no lose of integrity. There is therefore no direct correlation between the age of the tanks and contamination on site. This indicates that tank failure cannot be attributed to the age of tanks. It can therefore be inferred that tanks do not necessarily experience a failure (loss of integrity) due to age.

Table 12: Analysis of Age of Tanks

Criteria	No Contamination	Only Groundwater Contamination	Soil Contamination	Soil and Groundwater Contamination
Age of Tanks	Varies between 12 to >60 years	Varies between 21 to 50 years	Varies between 25 and 46 years	Varies between 5 to >40

In addition to this tank design has been significantly modernised to minimise risk of stress fatigue and corrosion risk. Underground Storage Tanks (UST's) are now constructed of double walled and fibreglass encased tanks and the risk of corrosion is significantly reduced. This therefore should prevent newer developments from leaks. As the case studies indicate however, this is not the case. There are not many other controllable factors to which the contamination can be attributed. For this reason, it is therefore essentially important that steps be taken by the filling station industry to mitigate potential contamination at the design stage of the project. Steps also need to be taken by the environmental authorities to avoid filling station related contamination.

Once contamination has taken place, however, the ease of remediation is an important factor. The following section discusses in detail two sites at which remediation efforts were undertaken.

5.7 Remediation at Sites

The sites that have been selected as part of this study to indicate the success of rehabilitation efforts are the Fairlands and Viljoenskroon sites. The reason for selection of these sites is that concentrated rehabilitation projects have been undertaken at these sites.

5.7.1 Fairlands

Below is a locality map of the Fairlands site (figure 14). The coloured square indicates the location of the site, i.e. tank location. Also indicated on the map are the borehole locations. Two aquifer units occur in the area, viz. unconsolidated sand or clay and fractured bedrock with water strikes and rest levels typically occurring in the fractured bedrock. Although the fractured rock aquifer extends from about 20 to 40m below surface, the water yielding fractures generally appear to be confined to the upper 5m of this aquifer. Groundwater in the area is generally used for garden irrigation but is also used for domestic purposes. Municipal water is available and groundwater is used to supplement this supply. Natural groundwater gradients are relatively flat with natural flow towards the north and northwest. However, pumping of boreholes has resulted in locally steep groundwater gradients and has reversed groundwater flow directions in places.

Figure 14: Site Location Map with Borehole (BH) locations indications (Mills and Otten, 2006a)

Groundwater contamination near Fairlands Auto was initially detected in a private borehole on a neighbouring property in August 1995. After integrity testing of all installations it was found that the Sasol installation was leaking. Potential alternative sources of contamination were leaks from the Total tanks reported in March 1999 and a Shell service station located 400m to the south. In general, no to slightly elevated soil vapour concentrations were recorded at the Fairlands Auto site, indicating limited residual, near surface contamination. Groundwater modelling using available information predicted an expanding contamination plume without concentration reduction for the first 5 years. After this the modelling predicted an expanding plume but with concentration reduction.

Pump and treat has been applied in the contaminated area since 1998. Pumped water was initially passed through a separator before being discharged to sewer. After approximately 23 000l of free phase product had been recovered, this separator was removed and water continued to be discharged directly to sewer (Mills and Otten, 2006a). Initial remediation measures have been successful with the groundwater showing acceptable levels. Contamination levels however began showing signs of increase in March 1999 (Mills and Otten, 2006a). Further monitoring has also indicated that groundwater contamination in the boreholes has generally decreased since peaking in May 2002 but is once again showing signs of increasing (Mills and Otten, 2006a).

The concentrations of targeted hydrocarbon compounds in boreholes at Fairlands Auto exceed applicable risk based screening levels (RBSLs), indicating that further corrective actions is required. This site is therefore still under investigation and remediation is still being undertaken in order to maintain and improve the groundwater quality. Reduced oxygen, nitrate and sulphate concentrations as well as increased iron in the contaminated boreholes indicate that natural bioremediation is taking place (Mills and Otten, 2006a). Oxygen however is the limiting parameter for effective bioremediation. At present, there is insufficient information available to rationally assess a preferred remediation method (Mills and Otten, 2006a). Monitored natural attenuation and ad-hoc management is essentially the method that is currently being applied to remediate the site. The method allows for only limited remedial action and for the management of complaints, incidents and other problems as and when they occur (Mills and Otten, 2006a).

This site is therefore classified as contaminated as it is not completely remediated and therefore currently remains as an active site for remediation efforts. The table below (table 13) is a summary of the case history.

Table 13: Summary of Case History (adapted from Mills and Otten, 2006a)

Date	Event
August 1995	Free phase product was noted in a borehole on an adjacent property (198 Market street) and it was found that the Sasol installation was leaking. Mills and Otten subsequently found other contaminated boreholes in the area. A loss of 4000l calculated from stock reconciliation. Sasol repaired the system and undertook remedial measures. Acceptable contamination levels were recorded in surrounding boreholes in February 1999.
March 1999	New dealer reported losses from Total installation. It was found that the ULP installation was probably leaking. Both the ULP and two Premium tanks were removed.
	Backfill soils around tanks were found to be contaminated, but not *in-situ* soils around excavation. Mills and Otten recommended that: 1) contaminated backfill be replaced with clean, coarse sand, 2) appropriate soil venting system is installed and 3) regular monitoring of on-site borehole be undertaken.
July 2001 to March 2003	Several monitoring runs were carried out during this period. Ozone tank installed in an attempt remediate groundwater. This installation was problematic and had to be abandoned. Contamination levels showed signs of decreasing but soon after began increasing.
August 2005 – March 2006	Water quality testing conducted. Results indicate significant levels of contamination still present. Modelling indicates that contamination will still be present in 2016.

April 2007	Site characterisation assessment carried out – results indicate elevated values in the vicinity of the tank. Numerous remediation options available. Pump and treat and MNA have been selected as the preferred option.
Current	Site still under investigation. From the initial contamination to present the surrounding landowners whose boreholes have been affected have received compensation for municipal water usage, painting and upkeep of boreholes. This site is therefore a financial liability to the company as well as a continual source of contamination.

5.7.2 Viljoenskroon

Below is a locality map of the Viljoenskroon site (figure 15). The crosshatch area indicates the location of the site i.e. tank location. Also indicated on the map are the borehole locations. Available information shows that the underlying aquifer occurs at an average depth of about 15,5m and extends from unconsolidated, weathered material into fractured bedrock. The yields of boreholes in the area are variable with a mean value of 0,76l/s.

Figure 15: Site Location (Mills and Otten 2006b)

The initial source of contamination was a leak in the Sasol tank at the Autovaria Service Station, which was reported in February 1998. Groundwater remediation was initiated in August 1998 after free phase product was detected in a private borehole located down gradient of the service station (Mills and Otten 2006b). Investigations revealed that the dissolved phase concentration of targeted hydrocarbon compounds was highest in the Forecourt Borehole at Autovaria with less elevated values recorded at Erf 206/207 as well as at Erf 203 and Erf 210 (See figure 15) (Mills and Otten 2006b). The concentrations in other private boreholes were close to or below detection limits (0,001mg/l). Corrective action was therefore required.

Pump and treat remediation method was applied in the contaminated area. Pumped water was initially passed through a separator before being discharged to sewer. After approximately 23 000l of free phase product had been recovered, this separator was removed and water continued to be discharged directly to sewer (Mills and Otten 2006b). Although a large quantity of free phase product was removed from the private boreholes, the dissolved phase plume continued to affect private borehole users (Mills and Otten 2006b). Detailed modelling of groundwater flow has shown that pumping of groundwater from private boreholes has contained the dissolved phase contamination in an area down gradient of the service station. The modelling showed that the contamination plume expanded to its maximum extent in April 1999 and then started to retract due to interventions by Sasol as well as due to natural attenuation (Mills and Otten 2006b).

During investigations in 2006, no free phase product was measured at any point, although it is possible that some free phase was still present close to the source. A risk assessment indicated that Benzene concentrations, in particular, exceeded applicable risk based screening levels in some private boreholes and that corrective action was still required (Mills and Otten 2006b). Dissolved oxygen concentrations, which are a good indicator of contamination, was depleted in boreholes even where the hydrocarbon contamination was below laboratory detection limits (Mills and Otten 2006b). The depleted oxygen concentrations indicate that aerobic biodegradation is currently the primary source of natural attenuation (Mills and Otten 2006b). Manganese staining at some properties is because of manganese dissolving in the *in-situ* groundwater due to the reduced oxygen levels and then precipitating out of the water because of aeration during irrigation. The incrustations of gel (biofouling) found in some of the private boreholes are as a result of pressure reduction and oxygen increase due to cascading in the boreholes causing an increase in biological activity (Mills and Otten 2006b). The biological activity is noted to be associated with low levels of hydrocarbon contamination.

The worst-case scenario-modelling scenario, i.e. no further intervention, predicts that the plume will reduce in extent by about 25% over 5 years with contaminant concentrations remaining approximately constant (Mills and Otten 2006b). The best case-modelling scenario, i.e. effective intervention predicts that the plume will reduce by more than 90% with contaminant concentrations reducing to negligible levels within 5 years (Mills and Otten 2006b). Monitored natural attenuation and ad-hoc management is essentially the remediation method that is currently being applied. This method allows for only limited remedial actions and for the management of complaints, incidents and other problems as and when they occur. Identified preferred remediation options consist of treatment trains which essentially comprise either of pumping for *ex-situ* treatment or of *in-situ* treatment with pumping to increase dispersion of treated groundwater (Mills and Otten 2006b). These methods are still being investigated however. This site is therefore considered as contaminated as it is not completely remediated and currently remains an active site for remediation efforts. The table below (table 14) is a summary of the case history.

Table 14: Summary of Case History (adapted from Mills and Otten, 2006b)

Date	Event
1996	Sasol upgraded installation at Autovaria with installation of leak detector.
Feb 1998	Stock losses of 36000L in 5 months noted by service station management. Reported to Sasol.
Aug 1998	Erf 206/207 - pure petrol was being pumped from borehole (110m south of filling station).
Sept 1998	Free phase, BTEX & Naphthalene detected at Erf206/207 Free phase (Erf203), not sampled. No BTEX observed in any other 8 sampled boreholes, but contamination indicators in several (e.g. Dräger, smell & bird deaths in aviary). Access denied to some properties.
Nov 1998 to Apr 1999 (approx period)	Approximately 23000l recovered, mostly at average rate of 200l/week
Mar 2000	Soil vapour survey found vapour plume confined to the Autovaria service station.
After Apr 2000	One borehole drilled at Autovaria but had lower Benzene concentrations than Erf206/207.
Apr 2000 to Jul 2001	Low level of dissolved phase pumped from Erf206/207 and discharged to sewer. Stopped when treatment works failed.
Mar 2002	Pumping resumed from Erf206/207 to sewerage.
Mar 2004	Site visit.
Jun 2005 to Nov 2005	Current investigation.
May 2006	Site characterisation assessment carried out. No free phase product was detected, however free phase can be present closer to the source. Dissolved phase concentration are still high on the forecourt borehole. MNA is currently being adopted with regular monitoring. Best case modelling scenario indicates a 90% decrease in contamination within 5 years. Worst case scenario indicates a 25% decrease in the plume in 5 years.
Current	Site presently under investigation. Company is currently liable for the municipal water that is used for irrigation and human consumption. In addition to this the company provides financial compensation to the surrounding landowners that have been affected by the contamination. Site is therefore a financial as well as environmental liability to the company.

5.8 Conclusion

As can be noted from the case study analysis regarding contamination associated with filling stations, six out of every 10 filling stations are associated with contamination. This contamination is not constrained by the age of the tanks. It can therefore be concluded that all filling station sites (no matter the age of the tanks) are predisposed to being associated with soil and groundwater contamination.

The second study focusing on the Fairlands and Viljoenskroon sites indicate that although contamination was detected early and a remediation program put in place, remediation efforts were not successful and are still currently ongoing. This reveals that remediation of hydrocarbon contaminated groundwater to pre contamination levels is extremely difficult to almost impossible. Rehabilitating these sites to these levels can prove to be unfeasible and unsustainable to the filling station industry.

The residual contamination levels however represent not only a financial liability but also pose a continued threat to the environment as well as possible negative publicity. Bearing in mind the propensity for contamination at filling station sites it is therefore of utmost importance that stricter mitigation measures be imposed on the filling station industry by the environmental authorities responsible for authorising developments, i.e. DEAT. In addition to this, DEAT officials must take into consideration any groundwater resources within the immediate vicinity to potential sites. Developments near groundwater resources should either not be authorised or mitigation measures should be put in place that will virtually eliminate the possibility of groundwater contamination. An example of such a measure is a requirement that, in areas of sensitive groundwater resources, that UST's be bunded below ground in a swimming pool type structure to contain any product that may leak. The other side to this is that the environmental authorities must not utilise such a requirement indiscriminately as it will impose extremely high costs on industry and therefore stymie the sustainable development concept. The costs associated with remediation of sites far outweigh the additional costs that are required at the design stage of the development to mitigate potential threats. Remediation efforts (pump and treat systems as well as additional monitoring) at both these sites have cost upwards of one million rands (*pers comm* F De Gregorio). In addition to this financial compensation to the surrounding landowners is ongoing and currently amounts to in excess of five hundred thousand (*pers comm* F De Gregorio). Installing greater mitigation measures at the project conception would have cost an additional two hundred and fifty thousand (*pers comm* F De Gregorio) and would have potentially saved the company millions of rands. The filling station industry therefore needs to adopt a more proactive approach to dealing with possible contamination instead of the current reactive approach.

CHAPTER 6: GENERAL DISCUSSION ON REMEDIATION AND MITIGATION METHODS

South Africa as a developing country is undergoing rapid transformation and growth. Hosting the 2010 World Cup as well as government's commitment to the reconstruction and development program by constructing low cost housing developments means that roads and residential areas are continually being constructed and or upgraded.

The filling station industry plays a vital role in this transformation and is critically important to its success. Filling station developments are an essential part of the development of towns and cities. In as much as they are a necessity, they also pose a serious hazard to the environment in terms of contamination. Spills and leaks of hydrocarbon products result in filling stations being associated with soil and groundwater contamination. Filling station developments cannot cease however, and therefore practicable mitigation measures must be put in place. This will ensure the continuance of the industry whilst simultaneously affording protection for the environment.

This study aimed to understand the contamination associated with the filling station industry utilising case study analysis as well as a study of the available literature. Key to this was a review of the EIA legislation governing filling station developments as well as a review of the methods for remediation and a discussion on proposed mitigation measures.

A study of several due diligence reports reveals a high percentage of contaminated sites. Extrapolating this information indicates that contamination is rife within the industry as a whole. This contamination however is not confined solely to the older sites. This therefore indicates that the newer technology utilised whilst constructing the tanks has not solved the problem of UST and associated pipework leaks and the ensuing contamination. The remediation of the resultant soil and groundwater contamination is an additional objective of this study.

A review of the current processes for filling station developments indicates that appropriate measures are not being put in place to counter the problems to begin with. Adopting stricter mitigation measures for the filling station industry therefore needs to be considered in the EIA process and design stage of the developments. Analysis has indicated that the potential for contamination is not being appropriately assessed by the EIA process or by the filling station industry.
Additionally environmental authorities are currently not imposing adequate measures to ensure protection of the environment whilst promoting sustainable development objectives. The impact of subsurface contamination poses a domestic and national threat and is likely to carry high economic costs if not properly mitigated. Industry as well as government therefore requires urgent intervention. DEAT requires capacity building with industry in order to understand the unique challenges facing the filling station environment. DEAT also require an increase in resources to adequately utilise the EIA legislation to protect the environment.

The Viljoenskroon and Fairlands case studies discussed were pre 1997 i.e. prior to the introduction of NEMA regulations. There were therefore few or no mitigation measures put in place to avoid contamination of the soil and groundwater. The remediation efforts at these sites have met with moderate success and are currently ongoing. From the contamination evidence at these sites and the difficulties with remediation efforts it is clear that prevention is better than cure i.e. avoiding the contamination is advantageous to remediation. From this it can be concluded that NEMA and subsequent EIA has been beneficial in terms of regulating the filling station industry in order to implement some mitigation measures.

Whilst EIA is important to regulate development activities, it is often misused in order to delay or halt filling station developments. EIA therefore is not completely fulfilling its intended role of protecting the environment from harm. The specialist studies aspect of the EIA is the most critical in terms of adding value to the EIA process as a whole. As the specialist studies provide information on the positive and negative impacts of the project, they need to be conducted by persons with an expert knowledge of the filling station industry. This is in order to ensure that the studies add value to the project and that the mitigation measures recommended are practicable. This ensures that the EIA process gives effect to NEMA by ensuring that filling station developments do not negatively impact on the health and wellbeing of the environment. Ensuring protection of the environment in turn gives effect to the Bill of Rights as stated in the Constitution of RSA.

It is self-evident that environmental degradation and resource depletion are significantly worse now than when EIA was introduced some 40 years ago. Project-specific EIA by itself is therefore clearly not sufficient to mitigate environmental problems associated with economic growth. The major limitations of the process occur when trying to decide whether an impact is going to result in a significant effect on the environment and in the assessment of impacts that cause cumulative pressures on the environment.

It was therefore determined that the South African EIA decision-making processes do not adequately evaluate new filling station developments. The local and provincial EIA decision-making structures and the filling station industry do not effectively evaluate the significance of filling station impacts and therefore do not impose stringent enough mitigation measures. EIA is not being properly utilised to promote the concept of sustainable development.

In addition, EIA at a project level is clearly reactive and has a limited response in that it is triggered by a proposed activity with the focus on mitigation of the effects of that proposed activity on the environment (Segger & Khalfan, 2004). DEAT officials must view filling station developments in the context of other filling station developments in the region. The EIA process must also take note of the impacts that may be delayed, as this will affect future activities.

Having regard to socio-economic conditions in South Africa, it would no doubt be reasonable to conclude that the environment stands a better chance of being protected through sustainable development. EIA ought then to advance the concept of sustainable development. EIA is said to be most effective where environmental values are 'implicit and consensual in the national culture … and are explicit in public law and policy'. In a developing country such as ours, the achievement of a consensus on environmental values will not be easily attainable.

The majority decision in Fuel Retailers Association clearly locates EIA in the paradigm of environmentalism. The judgment does not however seem to consider the efficiency of the environmental authorisation process as a whole, and instead focuses on clarifying the constitutional mandate of the environmental authorities. To import more efficiency into the EIA process it is submitted that a good place to start would be to refine the provisions of the IEM legislation and formulate its provisions in plain language.

Strategic Environmental Assessment (SEA) tends to be more proactive than EIA in that it 'facilitates the earlier consideration of environmental impacts, the examination of a wider range of potential alternatives, the generation of standard mitigation measures and the opportunity to address a wider range of impacts' (Glazewski, 2005). It should in theory then reduce the time and cost associated with an EIA at project level. Reflecting on international experience Segger and Khalfan note that SEAs extend the scope of project-level regulatory provisions to cover earlier stages in planning cycles, policies, plans and programmes and can apply to rolling national, regional or local development plans, or sectoral investment strategies.'

6.1 Changes required to the current process

6.1.1 Legislative Changes

Bearing in mind the propensity for contamination at filling station sites it is of utmost importance that stricter mitigation measures be imposed on the filling station industry by the environmental authorities responsible for authorising developments i.e. the DEAT. In addition to this, DEAT officials must take into consideration any groundwater resources within the immediate vicinity on potential sites. Developments near groundwater resources should then either not be authorised or mitigation measures should be put in place that will virtually eliminate the possibility of groundwater contamination. An example of such a measure is a requirement that, in areas of sensitive groundwater resources, that UST's be bunded below ground in a swimming pool type structure to contain any product that may leak. The other side to this is that the environmental authorities must not utilise such a requirement indiscriminately as it will impose extremely high costs on industry and therefore stymie the sustainable development concept.

At this juncture the Department of Water and Environmental Affairs (DWEA) does not have regulatory principles and frameworks for assessing the petroleum contamination within South Africa. DWEA and the South African Remediation Consortium (SARC) are currently focussing on a project called the "*Remediation of the Contaminated Land and Water Resources-Policy and strategy*". The Remediation Project is a DWAF (now DWEA) initiative to develop a holistic and integrated approach to remediation with appropriate management tools in the form of policy, strategies, assessment methodologies, procedural guidelines and appropriate legislative and financial tools to facilitate proper and consistent remediation of contaminated land and degraded water resources in terms of the appropriate legislation. In the interim the RBCA system is accepted by the DWEA to assess the petroleum contamination.

The other ways of keeping track of the extent of petroleum contamination in South Africa may be to set regulations where all the petrochemical industry and other potential occurrences of LNAPL submit an incident report to DWEA and DEAT (Phophi, 2004). This will assist, as there is currently little or no monitoring of the approved developments, all of which are potential sources of LNAPL contamination.

Therefore, if the petrochemical industries and service stations are forced to supply the department with the incident report and their monitoring program if available it will then help to locate areas where there is potential of groundwater contamination by the petroleum hydrocarbons (Phophi, 2004). The incident report should include and not limited to the following (Phophi, 2004):

- The type of incident (i.e., overfill, leakage from under and above ground product storage tanks etc.)
- Date, volume and type of product lost
- Date that the incident was reported to the authorities (i.e. the DWEA)
- The name of the regulatory officer allocated to be responsible for the reported incident
- Mitigation strategies taken to mitigate the problem in question
- Name of the consulting firm if there was any hired to assess the extent of the problem in question.

In order to avoid and/or minimize the LNAPL groundwater contamination in South Africa the following is required (Adapted from Phophi, 2004):

- The DWEA need to develop guidelines for assessing LNAPL contamination, risk assessment protocols as well as water quality standards with regard to the petroleum contamination.
- There needs to be a long-term formulation of guidelines for South Africa (i.e. minimum requirements or best practice guidelines for dealing with LNAPL contamination).
- There should also be consistency when it comes to the frameworks for assessing groundwater contamination.
- There should be an inter-departmental collaboration on reporting of incidents and progress reports to the DWEA.
- Petrochemical industries should supply the authorities with an incident report, which includes all the actions taken to mitigate the problem.
- An environmental awareness program should be implemented in order to make the public aware of the petroleum contamination in the subsurface environment. The public should know where to report incidents of petroleum contamination in their boreholes, more especially those who depends on groundwater for domestic and other use.
- The DWEA needs to enforce stringent water quality standards with regard to petroleum hydrocarbons to facilitate the implementation of a law, which will enforce the petroleum industry to allocate sufficient budgets for environmental management in South Africa.

6.1.2 Filling Station Industry Changes

Remediation of groundwater contaminated sites is an onerous and costly exercise. In addition to this, the levels of success are minimal. For this reason, and in order to show greater levels of environmental consciousness and responsibility it is recommended that the filling station industry adopt stricter standards during the design phase of filling station developments. It is suggested that mitigation measures adopted at this stage will limit future liability to the filling station industry in addition to protecting South Africa's limited groundwater resources. It must be borne in mind however that the chosen mitigation measures must be practicable. Mitigation measures that are not feasible will detrimentally affect new filling station developments. This once more highlights the problem of balancing the need for development with the need to protect the environment for present and future generations. Further mitigation measures therefore need to be implemented to reduce the possibility of UST and associated pipework failure. Some suggestions as to mitigation measures that can be adopted are:

- Although the risk of corrosion is significantly reduced with newer construction of tanks, the tanks are now brittle and extra care must be taken during installation of the tanks to ensure that the tanks are not damaged by sharp rocks/edges whilst being installed.
- The use of high-density polyurethane (HDPE) at the base of the tank excavation. This linear ensures that contamination is contained within the bounds of the excavation.
- Installation of leak condition sensors/monitors that alert site operators to leaks prior to environmental contamination.

6.2 Conclusion

Remediation efforts at contaminated sites needs to be upgraded to ensure that, when mitigation measures fail, sites can be successfully remediated to pre contamination levels. Barriers need to be utilised to contain contamination and in order to prevent the pollution plume from migrating. Hydraulic barriers serve a two-fold purpose because the wells drilled not only contain the contamination but also assist in the remediation. In addition to this, the wells can also serve as monitoring points. Hydraulic barriers are therefore the recommended barrier technology.

In severely contaminated sites contamination of the subsurface soil is remediated by excavating the contaminated material from the tank excavation and surrounds. The primary benefit of excavation is the insurance that all the contaminant has been removed, which lowers the potential for any future liability costs. The primary disadvantage of excavation however, is its high cost (Reis, 1996). Excavation and disposal at an off-site hazardous waste disposal facility may be the only economically viable cleanup option for severely contaminated sites. In instances where there is sufficient open areas on site, bioremediation technologies are employed on excavated soil. Contaminated groundwater is remediated utilising the pump and treat system however this system is very time consuming. Currently the most commonly utilised remediation technology in mild to moderately contaminated areas within the filling station industry is vacuum enhanced recovery (VER).

As noted from the case study analysis on Fairlands and Viljoenskroon; remediation is an onerous and time-consuming task. It is therefore recommended that detailed close out procedures be developed to assist in remediation. The close out procedure would detail the steps that need to be taken from initiation of the remediation program to the point when the site can officially be declared clear of all contamination. An example of this procedure is the RBCA system that is presently utilised at filling stations. Utilising the RBCA system to achieve the final risk management goals, the remedial action program may involve:

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

In addition, the results of water and soil samples should be submitted to the DWEA. The DWEA will then close out the site i.e. declare that the site clear of contamination. Once the site is closed out the filling station operator has no further environmental liability to the site.

The following presents the key findings of the study:

- The cost of remediation a site is far greater than the cost of implementing mitigation measures at the design stage when considering the implications for the environment.
- As the case studies indicate a large proportion of filling stations are associated with contamination.
- The contamination impacts negatively on the environment and it takes a number of years to remediate the environment to acceptable levels
- South Africa is a water scarce country and can therefore ill afford contamination to our sensitive groundwater resources.
- As the case studies indicate it is extremely difficult if not impossible to fully remediate groundwater
- For this reason, it is recommended that the DEAT officials insist on stricter mitigation measures for sites. Mitigation measures should be site specific as generic measures result in ineffective management of the environment. This causes industry to loose faith in the process and causes unnecessary additional costs to projects. This funding could be better utilised.
- DEAT officials must be empowered with filling station industry specific training in order to make meaningful requirements for industry to put in place for sites
- Capacity issues at DEAT also need to be addressed to ensure that staff is available to conduct regular audits in order to ensure that operators are complying with the requirements of the environmental authorisation.

- In terms of denying authorisation for developments, DEAT must first consider if the potential harm to the environment can be mitigated. If this is not possible then authorisations should be denied.
- In addition and in conclusion, American Society for Testing and Materials (ASTM) standard 1527, 1528 and 1903 must be modified to the South African context and applied to all future land and property acquisition. This process has to be pursued to ensure that processes or methods to investigate environmental issues are conducted prior to site take-overs.

The outcome of this investigation has determined that the contamination associated with the filling station industry poses a serious problem to the environment. For this reason the existing approach needs to be revised and mitigation measures need to be put in place proactively. Development is a necessity for economic growth and to ensure that sustainable development principles are met; potential pollutants need to be curbed. To be proactive in future, the monitoring of environmental aspects that may lead to the occurrence of significant impacts needs to be a critical component of risk management (Raleru, 2005). Management of these aspects through appropriate and regular monitoring reduces the business risk associated with undetected releases (Raleru, 2005). Through an early warning system, these risks may be reduced by means of quick and effective actions, which could also reduce the environmental liability and litigations (Raleru, 2005).

Greater precautionary measure needs to be placed on the industry by the national DEAT and the industry itself in order to counter contamination. From the study as presented in the previous chapters, it is recommended that industry adopt stronger mitigation measures in the design stage of projects to avoid contamination at the outset and that the DEAT play a more active role in policing these mitigation measures both during the EIA and operational phase of developments.

A more comprehensive analysis of filling stations and associated impacts is suggested to mitigate the increased threat of subsurface contamination.

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