1. INTRODUCTION

1.1 General Introduction

Society is increasingly becoming conscious of the harm that its activities can cause to the environment, and the harm to people or the loss of the quality of life that can result from environmental degradation. The need to manage our activities in a way that minimizes the risks of environmental damage, at the same time ensuring economic growth and social progress has been recognized. The interaction between human activity and the environment (e.g. the landfilling of waste on a particular site and the resultant effects of this activity on ground and surface water) is complicated and difficult to quantify and it is not easy to judge where the balance should lie between environmental protection and economic and technical progress. According to Zondi (2000), the concept of environmental liability and risk management is a key element in the appraisal of these complex problems and for formulating and communicating the issues so that transparent and equitable policy, regulatory or other decisions can be taken.

1.2 Aims and Objectives

The aim of this research is to highlight the importance of undertaking risk assessment and introducing the issue of environmental liability when dealing with groundwater quality monitoring, which leads to a more proactive and effective way of risk management by landfill operators. Risk management is a tool of risk management and should be the key factor to pay attention to because it is through the risk assessment of the site (e.g. soil, geology, etc) that decisions can be made on the continued operations, proposed applications and management of the site.

The problems related to the land filling of waste include the pollution of ground and surface water, emission of landfill gases, blown litter, infestation by vermin, etc and the extent to which these problems can happen also depends on the landfill design, standards and monitoring. The Department of Water Affairs and Forestry’s Minimum Requirements for landfill designs was considered extensively in the research as they are the regulators who would enforce the usage of the concept of environmental liability and risk management in the running of South African landfills. A case study was also considered of a general waste landfill situated in Gauteng, South Africa. The case study presented a good opportunity to look into a real life situation in order to have an idea on the procedure of designing a groundwater quality monitoring system. From this, the report then introduces the concept of including environmental liability parameters in South African legislation and also propose a risk management approach to landfill management with regards to groundwater monitoring.

1.3 Methodology

This research was conducted in four phases:

Phase 1. Initial Literature Review on Risk Assessment, Environmental Liability and Landfill Legislation in South Africa.

Phase 2. A Case Study (Landfill X in Gauteng, South Africa)

Phase 3. Review of the current analytical variables used in monitoring groundwater quality (DWAF, 1998) and propose a new list of liability parameters if necessary that can be used in the proposed Risk Management procedure for landfill groundwater quality monitoring in South Africa.

Phase 4. Based on the current DWAF (1998) requirements, propose a Risk Management approach to Groundwater Quality Management in South Africa that is based on the concept of Environmental Liability.

For the Landfill X case study, documents were obtained from the managing company and they included their water quality monitoring protocol and a review of their groundwater monitoring network report, which contains almost all the issues concerned with the groundwater monitoring at the landfill. If one would have conducted a risk assessment of all the environmental effects of a landfill i.e. gas emissions, odour, ground and surface water pollution, etc, the activities concerned would have gone beyond the time frame for this research project. Therefore, the research focused mainly on the risk assessment of one parameter, which was groundwater.

2. RISK ASSESSMENT

2.1 Introduction

Environmental contamination problems have far outreaching implications impacting on health, environmental, political and socio-economic spheres. This highlights the importance of using systematic and technically sound methods of approach in the relevant environmental management programs. As an example, a systematic and accurate assessment of current and future risks associated with contamination due to landfilling activities is very important towards the development and implementation of a cost-effective mitigation plan.

Risk assessment is a management tool that aids decision-making and is used widely within regulation, business and finance. It involves the separate consideration of the likelihood and the consequences of an event, for the purposes of making decisions about the nature and significance of any risks, and how best to manage any unacceptable risks (Zondi, 2000; Hope, 2006; Gorrick, 2002)

2.2 Protecting the Environment using a Risk Assessment Approach

Environmental risk assessment is fundamental to all phases of development of waste management facilities, from the strategic planning level through to the licensing of an individual facility.

At strategic level, risk assessment informs decisions about land use, and subsequently underpins assessment of the environmental impact associated with the site location that is considered through the development planning process. In the context of waste management licensing, environmental risk assessment is used to enable the landfill operator and the government's environment custodian (DEAT) to identify whether and what risk management options, or mitigation measures, are required to adequately prevent, control, minimize and/or mitigate the identified risks to the environment from that site. These measures are normally stipulated as license conditions or are included in the landfill operation plan (Furuichi, 1993; Tixier, 2006; Sdao, 2006).

2.3 Risk Assessment for Landfills in South Africa

Risk Assessment of a landfill is a minimum requirement to determine the risk of water becoming polluted. This is done before installation of the monitoring system to ensure the adequacy of monitoring system design (DWAF, 1998). It is through the risk assessment of a landfill site that the potential for the activity to cause adverse environmental effects is detected and after doing so, the preventative mechanisms are put in place and a financial provision for the activity is made for clean-up activities, just in case, the predicted risk happens.

According to the DWAF Minimum Requirements (1998), a groundwater risk assessment serves two valuable purposes:

- It provides a numerical value or visual aid with respect to the groundwater pollution potential for a particular waste management facility. Existing or potential sites evaluated by these means can therefore be ranked in terms of suitability or remedial priorities.
- Monitoring facilities can be prescribed according to the results of the risk assessment. Particularly, the density and locality of monitoring points should be in relation to the rating obtained from the risk assessment procedures.

The Minimum Requirements document argues that South African groundwater systems differ in many ways from those overseas. Monitoring methodologies and requirements that have been developed overseas do not necessarily apply to the South African situation. The principle of “batneec” (best available technology, not entailing excessive cost) is the foundation for the minimum requirements for water monitoring document. Other policies considered in the document include the Environmental Conservation Act, Act 73 of 1989, dealing with general and hazardous waste and activities under the EIA regulations, the EMPR (Environmental Management Programme Report) of the mining industry, the Water Services Act, Act 108 of 1997 and the National Water Bill of 1998 to be discussed in chapter 4.

2.4 Landfill Effects on the Environment

Environmental risks posed by landfill activities can range from local (e.g. the pollution of surface and groundwater) to global (e.g. the release of methane which contributes to global warming). This diversity does not necessarily require a change in risk assessment methodology, although the requirements can be very different.

The risk management strategy based on the risk assessment however will reflect the scale of the problem, for example, since methane gas contributes to global warming, this problem requires a global solution as detailed by the United Nations Framework on Climate Change (www.unfcc.de). Therefore, whilst South Africa engages in landfill practices, the country also has to consider its contributions to some environmental effects, which can ultimately impact the world.

The risk assessment of a landfill site is therefore considered as necessary since some of the consequences of its activities do not only pollute the local environment but affect people in other parts of the world. The diagram below gives an idea on the complexity of a landfill risk assessment and indicates that some of the effects are not just local.

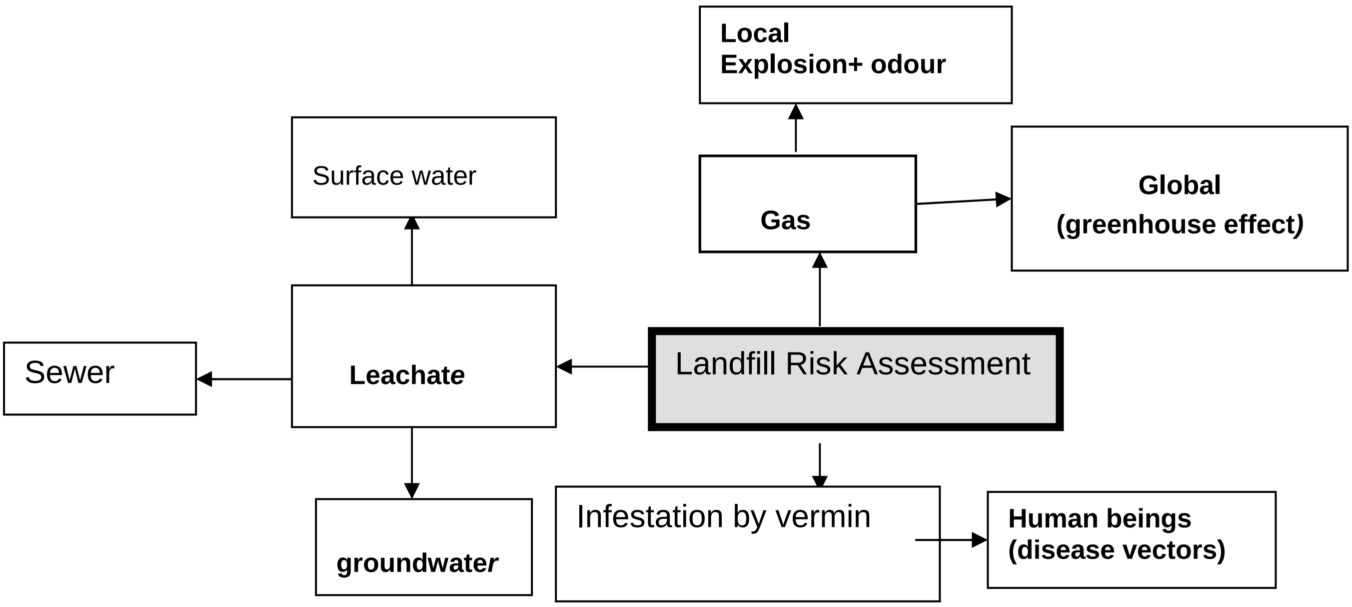


Figure 2.1:Environmental Impacts of Landfill as Addressed by risk assessment
Source: (Zondi, 2001; Calvo, 2007; Lisk, 1991)

2.5 General Risk Assessment Process

It is important to look at the steps and terminology involved in the process of risk assessment in order to have a common idea on the application of the concept in land filling of waste. Before applying risk management procedures, the process of risk assessment first needs to be undertaken. According to the European Environment Agency (2000), risk assessment consists of three components being hazard identification, exposure assessment and dose-response assessment. Once these components are covered, this report suggests that these components be followed by risk estimation and modeling, risk characterization and finally the risk management stage (Murphy, 1982).

2.5.1 Hazard Identification

In hazard identification, inferences are made from human epidemiological studies, animal studies, or short-term in vitro tests to identify whether there is a hazard posed by the substance (Reichard, 1990). In landfills (see fig. 2.2), the substances in question could be the different constituents of a leachate e.g. heavy metals, emitted gas, etc. Hazard identification requires reviewing and analyzing toxicity data, weighing the evidence that a substance causes various toxic effects and evaluating whether the toxic effects in one setting will occur in other settings (Reichard, 1990 ; Iscan, 2004).

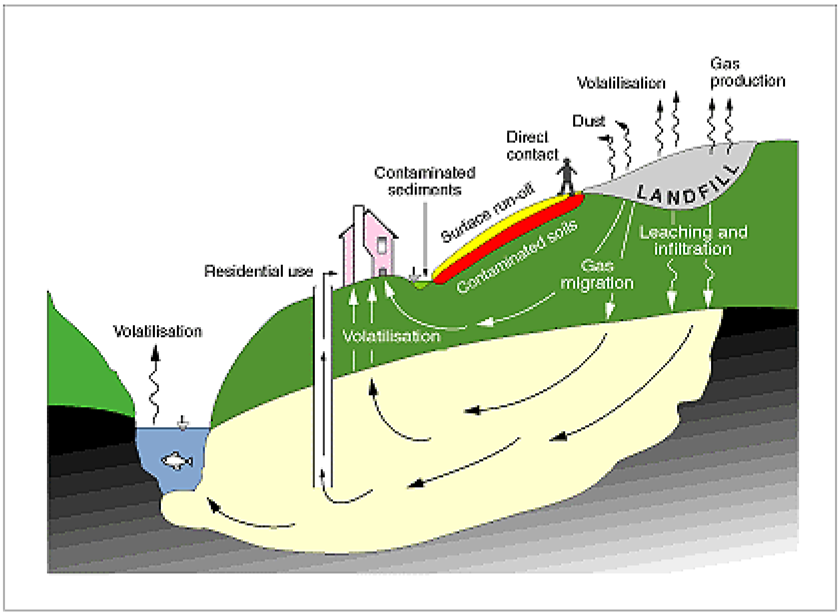


Figure 2.2: Groundwater contamination from a landfill
Source: www.eea.eu.int

2.5.2 Exposure Assessment

This step is conducted to estimate the magnitude of the actual and/or potential receptor exposures to environmental contaminants, the frequency and duration of these exposures, the nature and size of the populations potentially at risk (i.e. the risk group) and the pathways by which the risk group may be exposed (Reichard, 1990). In the case of a landfill, the pathway to receptors (ground or surface water) is determined through the use of models like Aquamod mentioned in the DWAF Minimum Requirements (1998). To complete a typical exposure analysis for an environmental contamination problem, populations potentially at risk are identified and concentrations of the chemicals or substances of concern are determined in each medium to which potential receptors may be exposed. Using the appropriate case-specific exposure parameter values, the intake of the chemicals or substances are then estimated (Reichard, 1990; Nyambe, 2004; Kakkar, 2006; Luis, 2006).

2.5.3 Dose Response Assessment

The main objective of this step is to estimate the extent to which the hazard increases with increasing exposure. The higher the leachate concentration, the more the groundwater could be contaminated and this increases the hazard to human beings or other life-forms dependent on the water. This process is the estimation of the relationship between dose or level of exposure to a substance and the incidence and severity of an effect (Asante-Duah, 1998). The type of adverse effects associated with contaminant exposures, the relationship between magnitude of exposure and adverse effects and related uncertainties (such as the weight-of-evidence of a particular chemical's carcinogenicity in humans) in humans are considered.

Reichard (1990) recognised the fact that while data from epidemiological studies and supporting information such as metabolic studies and short-term mutanic tests may be used, the most typical source of information for dose-response assessments is the long-term animal laboratory study. For example, rodents, typically mice, are exposed to very high doses of a substance, doses much higher than those to which human beings would be exposed in the general environment and workplace. This is true in the case of environmental contamination due to landfill activities because vermin infestation is one of the consequences of land filling of waste and these creatures are directly exposed to the contaminants which are at a higher concentration that when they reach the targets (e.g. surface water). Humans are, then, at a lower dose exposure than them. It is therefore necessary to make some inference from this high-dose exposure and its effects to those that would be produced at the much lower doses to which human beings would be exposed.

2.5.4 Risk Estimation and Modelling

It is important to note that risk cannot be calculated precisely and that all methods, whether subjective or numerical, will produce results with degrees of uncertainty, further more all numerical methods have shortcomings that may distort the information produced by their use (Reichard, 1990). The limitations and uncertainties associated with the estimation of risk must be identified and addressed when carrying out the subsequent risk characterization (evaluating the acceptability and significance of the risks with reference to standards, targets, background risks, cost benefit criteria, etc) (European Environment Agency, 1999).

Since this chapter is focused on risk assessment as a component of the process of risk management, it is therefore important to discuss the AquaMod software, which was suggested in the DWAF Minimum Requirements Document for assessment of risk in groundwater due to landfill activities (DWAF, 1998) and the Monte-Carlo approach technique. There are a number of modeling tools available to assist with the estimation of risk associated with discharge to groundwater, ranging from simple spreadsheets, through AquaMod mass transport model and the monte-carlo approach technique to highly complex three-dimensional time-variant contaminant transport models. Any simulator may be used to model pollution transportation although it is a DWAF requirement that modellers should demonstrate their competence in the modeling of the groundwater systems, otherwise the DWAF will not accept results from simulations (DWAF, 1998; Serrano, 1989).

AquaMod

According to the DWAF (1998), this model deals with mass transportation and is capable of simulating pollution transport through an aquifer. Extensive field surveys are necessary to generate data of sufficient quality and magnitude for input into models of this kind. Output from this model is in the form of a particle- tracking vector or contour that shows concentrations of various elements within the leachate plumes. Since these predictions are time dependent, simulations of the propagation of the pollution plumes may be done many years in advance (DWAF, 1998). Just like other numerical models, this model provides good data on probable leakage rates from a landfill site. Simulators like Landsim and Aquamod are user-friendly probabilistic assessment risk assessment tools with a number of potential uses (Calow, 1998):

a. selection of initial liner and leachate management systems to achieve performance objectives within the site-specific geological and hydrogeological setting.
b. fine tuning of designs to achieve required mitigation of potential impacts.
c. evaluation of the relative risks from different potential designs.
d. review of the appropriateness of site investigation data and identification of outstanding information requirements.
e. assessment of old landfills, which may pose a future risk.

The Monte Carlo Approach

In this approach, according to Reichard (1990), probability distributions are assigned to each of the uncertain parameters, with values selected from these distributions by a computer-based simulation programme in determining the sensitivity in a risk assessment. The simulations are repeated many times, with probabilistically assigned combinations of parameter values inserted for each "realization" of the model. With sufficient numbers of realizations, one ends up with a probability distribution of the final benefit-cost calculations.

Reichard (1990) states that the approach creates statistical confidence limits around the outcomes, accounting for error propagation and the outcomes are only valid as the value ranges and probability distributions assigned to the relevant variables.

Reichard (1990) mentions an example where there was an investigation into the uncertainties in a benefit-cost assessment of the options available for premeditating groundwater contamination impacting two community water supply wells at Massachusetts, USA. The investigation evaluated four remediation strategies with Monte-Carlo simulations that addressed uncertainties in three critical areas:

a. the solute transport model used for predicting contaminant concentration at the wells over a 40-year planning period.
b. the health risk assessment indicating the potency (slope of the dose response function) of the contaminant of concern.
c. the economic valuation component used to value statistical lives and to estimate the cost to individuals of avoiding contaminated water (absent remediation).

Reichard (1990) writes that these three areas interact with each other in important ways to affect benefit and cost calculations, for example, the solute transport uncertainties (parameter values for hydraulic conductivity, longitudinal dispersion, and transverse dispersion) alter the predicted contaminant concentrations at the well at each point in time and this determines the number of years it would take for remediation strategies to reduce the concentrations to drinking water standards. This in turn determines the level of human exposure and the effectiveness (duration and cost) of remediation alternatives. The exposure levels then interact with the dose-response uncertainties to indicate the potential level of health risk (statistical number of cancer cases) and this then interacts with valuation issues in terms of measuring the monetary value of the risk reduction benefits (Balousa, 2004; Emery, 2006; Benedini, 1982).

2.5.5 Risk Characterisation

The integration of information from the first three steps to develop a qualitative or quantitative estimate of the likelihood that any hazards associated with the agent of concern will be realized in exposed people (Chen, 2006; Van der Heijde, 1987; Baum, 1993). This is the step in which risk assessment results are expressed and should include a full discussion of the uncertainties associated with the estimates of risks. In the landfills scenario, these could include the findings about the underlying geological or hydro geological conditions of the site, thereby enabling the decision on the type of liner material to be used.

2.5.6 Risk Management

Risk characterization leads into risk management by providing the basis for discussions between the risk assessor and the risk manager. These discussions are held to ensure that the results of the risk assessment are presented clearly and completely and in an unbiased manner. Risk management, according to Calow (1998) is a policy-based activity that defines end-points and questions from risk assessment so as to protect human health and the environment. It is a decision making process that attempts to minimize risks without harm to other societal values and, as a result of these discussions, timely regulatory decision-making and mitigation measures may then occur. Follow-on activities to the risk assessment may be identified (e.g. monitoring, collection of additional data to reduce uncertainty, stakeholder meetings). In its application to landfills, risk management includes, for example, deciding that composite liners should be installed, if the site is a quarry, wall liners are taken into consideration (Sorensen, 2004).

2.6 Conclusion

This chapter has given a general overview of the concept of risk assessment in landfills and explained how the risk assessment approach is used to protect the environment. A brief summary of the legislation governing landfill risk assessment was also covered. It has also emerged that risk assessment of a landfill site is an estimation of the chances of the leachate escaping through the landfill liner, through the ground and reaching targets.

3. WASTE LEGISLATION IN SOUTH AFRICA

3.1 Introduction

Effective environmental protection, either in a person's own or in the public interest, requires that a person or association have the ability to enforce it. One important means of enforcement is litigation, hence the importance of environmental liability. South Africa has a number of pieces of legislation that are being utilized to protect the environment although it should be noted that this chapter will only discuss the legislation concerned with solid waste operations and groundwater pollution. The legislation to be covered includes the Constitution of South Africa (CoSA), Environment Conservation (EC) Act, National Environmental Management (NEM) Act, Water Act, the Minimum Requirements from the Department of Water Affairs and Forestry (DWAF-MR) and the draft Waste Management Bill currently being debated in parliament. Other documents also include the green and white paper on environmental management policy.

3.2 Relevant Legislation

3.2.1 Constitution of South Africa (1996)

According to Kidd (1997), before the establishment of the constitution it was difficult to take judicial action in order to protect the environment. The only situation in which the polluter was found guilty was when there was the simultaneous violation of the environment and of personal rights like property or health. As in other countries, the constitution is the supreme law of South Africa so any law or conduct inconsistent with it is invalid, and the obligations imposed by it must be fulfilled. Two sections are relevant to this discussion.

According to section 24 regarding the environment, everyone has the right -

(a) to an environment that is not harmful to their health or well-being; and

(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that -

(i) prevent pollution and ecological degradation;

(ii) promote conservation; and

(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

According to section 32 regarding access to information, (CoSA, 1996)

(1) Everyone has the right of access to -

(a) any information held by the state; and

(b) any information that is held by another person and that is required for the exercise or protection of any rights.

(2) National legislation must be enacted to give effect to this right, and may provide for reasonable measures to alleviate the administrative and financial burden on the state.

3.2.2 Environment Conservation Act (No.73 of 1989)

This Act prohibits littering; identifies activities which have a detrimental effect on the environment; prohibits the undertaking of these activities without the appropriate permit; and regulates waste management, environmental impact assessment reports, noise, vibration, and shock, and limits development areas.

The EC Act regulates the activity and the permitting processes regarding (ECA, 1989):

a. The protection of ecological processes, biophysical systems and the biophysical beauty as well as the preservation of biotic diversity in the biophysical environment;
b. The promotion of sustained utilization of species and ecosystems and the effective application and reuse of biophysical processes;
c. The protection of the environment against disturbance, deterioration, defacement, poisoning or destruction as a result of man-made structures, installation, processes of products or human activity; and
d. The establishment, maintenance and improvement of environments which contribute to a general acceptable quality of life with the inhabitants of the Republic of South Africa.

Prior to 2004, the administration of waste disposal sites fell under the department of Water Affairs and Forestry. In 2004, section 20 of the EC Act No. 73 of 1989 was amended so as to enable the Minister of Environmental Affairs and Tourism to make regulations regarding financial matters relating to identified waste types and regarding product control for waste management; to provide for the transfer of the administration of waste disposal sites from the Minister of Water Affairs and Forestry to the Minister of Environmental Affairs and Tourism; and to provide for matters connected therewith.

3.2.3 National Environment Management Act (No. 107 of 1998)

The aim of this act is to provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment. The act defines environment as the following:

> "Environment" means the surroundings within which humans exist and that are made up of -
>
> (i) the land, water and atmosphere of the earth;
>
> (ii) micro-organisms, plant and animal life;
>
> (iii) any part or combination of (i) and (ii) and the inter-relationships among and between them; and
>
> (iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being.

In terms of compliance regarding duty of care and remediation of environmental damage, section 28 of the NEM Act states the following

> "Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment." (NEMA, 1998)

Two principles are drawn from section 2 of the NEM Act and they form the core of this report, being placing people first in environmental management and the principle of the polluter paying;

> Subsection (2) 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).
>
> Subsection (4p) states that the costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment (NEMA, 1998).

According to the NEM Act (1998), after site preparation, the disposal site must be operated in accordance with the Permit conditions. Any applicable Minimum Requirements not specifically stipulated in the Permit conditions should also be adhered to. During operation, the site may be inspected by Competent Authority officials and representatives of the IAPs on an *ad hoc* basis.

Any infringements of the permit conditions are noted and the permit holder is notified accordingly in writing. If there are any major transgressions or continued infringements, the Permit Holder may be prosecuted. If a disposal site pollutes or is likely to cause pollution of the surface water or ground water, the Permit Holder must, in terms of Sections 19 and 20 of the National Water Act, 1998 (No. 36 of 1998) take reasonable measures to prevent or remediate any further pollution. If the Permit Holder fails to comply with the directives, a Catchment Management Agency or the Minister of Department of Water Affairs and Forestry or his delegate may intervene and recover any expenses that the Department may have incurred.

Section 28 of NEM Act (No.107 of 1998) stipulates that every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation. Anyone who contravenes the act or who fails to fulfil a condition of a Permit issued to him under Section 20(1) of the Environmental Conservation Act, 1989, (No.73 of 1989) shall be considered guilty of an offence. In the case of the Environmental Conservation Act, on conviction, a person may be liable to a fine not exceeding R100 000 or to imprisonment for a period not exceeding 10 years.

3.2.4 National Water Act (No.36 of 1998)

The aim of this Act is to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors;

- protecting aquatic and associated ecosystems and their biological diversity
- reducing and preventing pollution and degradation of water resources

Section 19 of the NW Act states that;

> An owner of a land, a person in control of the land or a person who occupies or uses the land on which any activity is performed or undertaken or a situation exists which causes, has caused or is likely to cause pollution of a water resource, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring. The list of measures that can be undertaken to prevent or control the pollution is contained under subsection 19 (2) (NWA, 1998).

In terms of liability under the NW Act, if found guilty the courts may award damages for the loss or harm suffered or may order the accused to pay for any remedial measures implemented or if not done yet, the court may order that remedial action be undertake.

3.2.5 DWAF Minimum Requirements (1998)

The DWAF-MR (1998) consists of three documents, which are; Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, Minimum Requirements for Waste Disposal by Landfill, and Minimum Requirements for Water Quality Monitoring at Waste Disposal Facilities. As this document deals only with groundwater, only the Minimum Requirements dealing with Water Quality Monitoring at and around waste management facilities will be discussed.

The Minimum Requirement for water quality monitoring document lists monitoring requirements and is intended to explain (DWAF, 1998):

- Groundwater behaviour
- Reasoning behind monitoring
- Principles of risk assessment
- Installation of a monitoring system
- Principles of water sampling
- Principles of indicator variables
- Principles of data evaluation

All the above steps assist in the designing of a water quality monitoring system for the landfill facility.

3.2.6 National Environmental Management: Waste Management Bill (draft)(2006)

The Waste Management Bill is currently being debated in Parliament. It is meant to repeal or amend the Environment Conservation Act (1989), the Environment Conservation Act (1992) and the National Environmental Management Act (1998). The purpose of the bill is:

- To protect the health, well-being and the environment by providing a list of reasonable measures.
- To ensure that people are aware of the impacts of waste on health and the environment.
- To provide for compliance with the measures provided.
- Generally to give effect to section 24 of the constitution in order to secure an environment that is not harmful to the health and well-being of people.

The establishment of a national waste management strategy is covered under part 1 of Chapter 2 of this bill. The aim of the national waste management strategy is to help achieve the objectives of the bill and the strategy must take effect by notice in a Gazette within two years of the date that the bill is passed into an Act.

Part 2 of Chapter 2 states that the Minister must establish national standards and also lists the different powers that are conferred upon the Minister in the establishment of these standards. The provinces and municipalities are not allowed to alter the national standards, except to make the requirements more stringent.

Part 3 of Chapter 3 introduces the concept of Integrated Waste Management Plans. According to the bill, each national department and province responsible for preparing an environmental implementation plan or environmental management plan in terms of Chapter 3 of the NEM Act must include in that plan an integrated waste management plan. In addition, each municipality must include in its integrated development plan in Chapter 5 of the Municipal Systems Act, an integrated waste management plan that is consistent with the relevant provincial integrated waste management plan. An annual performance report must be prepared by the municipalities and it must contain information on the implementation of the municipal integrated waste management plan.

Chapter 4 of the bill covers the issuing, transfer, review, variation, renewal, revocation, suspension and surrender of waste management licences. According to Chapter 5 of the bill, the Minister is supposed to establish a waste information system for the recording, collection, management and analysis of data and information. The aim of this waste information system is to provide information to the public and organs of state as well as for the development and implementation of any integrated waste management plans required in the bill. This will be done through the storage, verification, analysis, evaluation and provision of data and information for the protection of the environment and management of waste.

Compliance and enforcement is covered under Chapter 6 of the bill. It gives the waste management officer the power to require any person to submit a waste impact report in a specified form and within a specified period. The costs incurred in compiling this report are the liability of the person required to submit the report. The waste management officer has the power to appoint an independent person to compile this report and costs are still borne by the person required to submit the report.

3.2.7 Green Paper on an Environmental Policy (1996)

The purpose of the green paper was to provide a basis for developing an environmental policy, which would lead South Africa along a path of sustainable development, whilst ensuring that all the citizens have an environment catering for their well-being. It entailed the Consultative National Environmental Policy Process (CONNEPP), which was being used to develop the South African National Environmental Policy. The green paper was therefore part of the process of making sure that all Stakeholders in the country are given an opportunity to contribute towards the development of a new environmental policy. Once the copies of the green paper were distributed countrywide, responses were captured electronically which led to the white paper being drafted (DEAT, 1997).

In summary, the green paper merely launched a broad framework for an integrated and holistic approach to environmental management in all areas of government. It proposed a framework of principles, structures, processes and mechanisms to integrate environmental governance and enable the development of policy, strategy and action to address specific issues and sectors (DEAT, 1996).

3.2.8 White Paper on Environmental Management Policy (1997)

This document contains the government's environmental management policy and describes the context in which it has been developed (DEAT, 1997). In drafting this document, government took into account all the comments made on the green paper and the views expressed at the CONNEPP II (DEAT, 1997).

According to DEAT (1997), this new approach model to sustainable development was based on integrated and coordinated environmental management that addressed:

- people's quality of life and their daily living and working environments
- equitable access to land and natural resources
- the integration of economic development, social justice and environmental sustainability
- more efficient use of energy resources
- the sustainable use of social, cultural and natural resources
- public participation in environmental governance

In addition to implementing this policy, the Department of Environmental Affairs and Tourism also undertook to develop a National Environmental Strategy and Action Plans (DEAT, 1997) as stated in Chapter 4 of the white paper. This strategy would focus and prioritize goals and objectives requiring action by government. The strategy would further more do the following:

- ensure the development and implementation of integrated environmental management systems in both public and private sectors.
- develop and implement effective education and information strategies to increase public awareness and understanding of environmental issues
- develop structures, processes and procedures and implement programmes to ensure effective and appropriate participation in environmental governance
- develop mechanisms to deal effectively with international cooperation on environmental governance

The white paper has 7 goals contained in Chapter 4, which deals with the policy's strategic goals and objectives:

Goal 1 Effective Institutional Framework and Legislation

Goal 2 Sustainable Resource Use and Impact Management

Goal 3 Holistic and Integrated Planning

Goal 4 Participation and Partnerships in Environmental Governance

Goal 5 Empowerment and Environmental Education

Goal 6 Information Management

Goal 7 International Cooperation

In his introductory statement of this document, the Honourable Peter Mokaba says "this policy gives us a formidable framework to interact with the world and our own past, present and future". His statement reflected the input that went into the creation of this document including the participatory process and the continued implementation partnership (DEAT, 1997).

3.2.9 White Paper on Integrated Pollution and Waste Management (2000)

This is a policy on pollution prevention, waste minimization, impact management and remediation. It outlined government's new thinking in relation to pollution and waste management in line with international trends and South Africa's national objectives of efficient and effective management of the country's resources and priority towards prevention (DEAT, 2000).

There are two main purposes served by this white paper (DEAT, 2000):

- To inform the public of the governments objectives, and how the government intends to achieve them, and
- to inform government agencies and State organs of these objectives, and their roles in achieving them.

According to the DEAT (2000), all along waste was only dealt with once it is generated known as the “end-of-pipe” way of thinking. The intention of this white paper was to facilitate a paradigm shift towards the following:

- pollution prevention
- waste minimization
- cross media integration
- institutional integration; and
- involvement of all sectors of society in pollution and waste management.

The National Waste Management Strategy and short-term priority Action Plans were developed in order to translate the goals and objectives of this policy into practice.

3.3 Conclusion

This chapter has demonstrated how comprehensive the South African legislation is with regard to the solid waste management permitting and operations. The different Acts, Green and White papers have shown how South Africa has been building up its legislative since the introduction of the new democratic era. This seems to have culminated with the birth of the Waste Management Bill (2006), which when passed will be the most comprehensive pieces of legislation in terms of waste management. There is also a draft update to the DWAF Minimum Requirements series currently under review. Some of its content has been utilized in this report. The DWAF- MR document is further discussed in chapter 6.

4. ENVIRONMENTAL LIABILITY

4.1 Introduction

In legal terms, the word liability refers to fault. The person who is at fault is liable to another because of his or her actions or failure to act (Salvador, 2000). One example is in the case of a crime. The liability of the offending party may include providing restitution for damage to property or paying medical bills in the case of physical injury. It simply describes some form of obligation or responsibility. It represents an outstanding debt, products or services that have yet to be provided, or acknowledgment of responsibility and payment provided for damage caused through actions or negligence (ICMA, 2001).

4.2 Environmental Liability

It is the obligation to compensate or restore the environmental damage caused by the past, use, release, or threatened release of a particular substance; or by other activities that adversely affect the environment and/or human health (Salvador, 2000; Dixon, 2005; Linsley, 2006; Sanders, 1995).

4.3 Categories of Environmental Liability

According to the U.S. Environmental Protection Agency (EPA, 1996), there are six major environmental liability types. Another source of liability can be the common law (i.e. judge-made law or case law), which may provide the basis for a cause of action even if an institution has complied with the country's laws and regulations. The following terms are used to denote categories of environmental liability:

4.3.1 Compliance obligations

Obligations prescribed by laws and regulations that apply to the manufacture, use, waste disposal, and release of chemical substances and to other activities recognized under environmental laws and regulations as adversely affecting the environment, such as releasing toxic substances into a river (ICMA, 2001; Rahman, 2004; Read, 2001; Petersen, 1999).

4.3.2 Remediation obligations

Obligations to clean up a site and/or pay for the cleanup of a site contaminated by chemicals and other wastes considered under law, regulations, and by science to pose adverse health risks to humans and the environment. Such sites could include old or previously undiscovered landfills (ICMA, 2001; Rivette, 2002; Bolan, 2005).

4.3.3 Fine and penalty obligations

Obligations to pay fines or penalties under civil or criminal law for non-compliance and/or expenses for supplementary environmental projects agreed to as part of a settlement for non-compliance (ICMA, 2001).

4.3.4 Compensation obligations

Obligations under some state and federal statutes (as well as under common law), to pay (or "make whole") individuals and businesses for damages suffered by them or their property from the use or release of toxic substances or other pollutants. Commonly known as "compensatory damages," these liabilities may occur even if a local government is in compliance with all applicable environmental standards (ICMA, 2001; Mason, 2003).

4.3.5 Punitive damage obligation

Obligations to pay damages, which are punitive in nature and are imposed in addition to compensatory damages; to punish and deter conduct viewed as showing callous disregard of others or as being grossly negligent. Punitive damages are typically awarded in addition to compensatory damages, thus dramatically increasing the potential overall costs of environmental liability (ICMA, 2001).

4.3.6 Natural resource damages obligation

Obligations (normally in the form of fines) arising from natural resources liability. Natural resource liability arises from injury, destruction, or loss of natural resources that do not constitute private property. Federal, state, local, foreign, or tribal governments must control natural resources, which include plants, wildlife, land, air, and water. Natural resource damages can be imposed for accidental releases (e.g., during transport) as well as lawful releases (ICMA, 2001; Deis, 1998).

4.4 White Paper on Environmental Liability (EC, 2000)

This European White Paper aims to explore how the ‘polluter pays’ principle can best serve the aims of the European Community’s environmental policy, keeping in mind that avoiding environmental damage is the anchor aim of the policy (EC, 2000). The white paper also explores how an EC environmental liability regime can help to improve the implementation of EC environmental laws, and also examines the economic effects of the liability regime.

The White Paper (2000) sets out what types of environmental damage can be remedied through environmental liability:

- there needs to be one or more identifiable actors (polluters);
- the damage needs to be concrete and quantifiable; and
- a causal link needs to be established between the damage and the identified polluters.

Instances where damage results from industrial accidents or from gradual pollution caused by hazardous substances or waste coming into the environment from identifiable sources qualify as environmental liability cases (EC, 2000). It therefore can be inferred that environmental liability legislation are relevant to solid waste management. According to the White Paper (2000), environment liability results in prevention of damage and in the internalisation of environmental costs. Liability can also lead to the application of more precaution, resulting in avoidance of risk and damage, and may encourage investment in research and development for improving knowledge and technologies (EC, 2000; ICMA, 2001).

The White Paper (2000), highlights insurability as an important mechanism to ensure that the goals of environmental liability regime are met. Insurance availability reduces the risks to which companies are exposed by the transfer of some of that risk to the insurers. The probability of them being exposed to environmental liability prosecution is also reduced because a company that is able to insure against the damages it can potentially cause to the environment still has to go through annual environmental audits. These companies are also required to have an effective risk-management system in place, and they also have to carry part of the liability penalty (EC, 2000).

4.5 Liability in South African Waste Legislation

In South Africa, section 24 of the Constitution (1996) provides the foundation for environmental liability. It creates general national obligations with respect to the protection of the environment and liability for environmental damage.

4.5.1 National Environment Management Act (1998)

According to the National Environment Management Act (1998), if a person fails to comply with the act regarding compliance, the director general or provincial head of department may take reasonable measures to remedy the situation. The liability costs according to the NEM Act (1998) may be recovered as a result of the measures taken in remedying the situation from any or all of the following persons:

(a) any person who is or was responsible for, or who directly or indirectly contributed to, the pollution or degradation or the potential pollution or degradation;

(b) the owner of the land at the time when the pollution or degradation or the potential for pollution or degradation occurred, or that owner's successor in title;

(c) the person in control of the land or any person who has or had a right to use the land at the time when—

- (i) the activity or the process is or was performed or undertaken; or
- (ii) the situation came about; or

(d) any person who negligently failed to prevent—

- (i) the activity or the process being performed or undertaken; or
- (ii) the situation from coming about

Furthermore, the act states that the state may in respect of cost recovery claim proportionally from any other persons who benefited from the activity that led to the degradation of the environment. These costs must be reasonable and may include labour, administrative and overhead costs. If more than one person is liable, the liability must be apportioned among the persons concerned according to the degree to which each was responsible for the harm to the environment (DEAT, 1998).

4.5.2 National Water Act (1998)

According to the National Water Act (1998), no person may unlawfully and intentionally or negligently commit any act or omission, which pollutes or is likely to pollute a water resource. Any person who is found to have contravened this act is guilty of an offence and liable, on the first conviction, to a fine or imprisonment for a period not exceeding five years, or to both a fine and such imprisonment and, in the case of a second or subsequent conviction, to a fine or imprisonment for a period not exceeding ten years or to both a fine and such imprisonment.

If a person has been convicted under this act and another person has suffered harm or loss as a result of the harm to the environment, the courts may award damages as follows:

- award damages for the loss or harm suffered by a complainant;
- order the accused to pay for the cost of any remedial measures implemented or to be implemented; and
- order that the remedial measures to be implemented, be undertaken either by the accused or the relevant water management institution.

4.5.3 National Environmental Management: Waste Management Bill (draft)(2006)

The Waste Management Bill (2006) uses part 2 of chapter 7 of the National Environment Management Act (1998) concerning compliance and enforcement. Furthermore, the bill empowers a waste management officer to request a waste impact report if deemed necessary. The costs incurred in compiling the waste impact report, including any costs of an independent person, are the liability of the person required to submit the report (DEAT, 2006).

If a person is convicted of harming the environment, that person is liable to a fine not exceeding ten million rands, or to imprisonment for a period not exceeding ten years, or both a fine and such imprisonment (DEAT, 2006). The Waste bill (2006) states that the determination of the fine depends on the severity of the offence, its impact and the benefits accrued during the commission of the offence.

4.5.4 Environment Conservation Act (1989)

According to this act, any person who contravenes the sections relating to waste management and any other activity listed under section 29(4) shall be guilty of an offence and liable on conviction to a fine not exceeding R100,000 or to imprisonment for a period not exceeding 10 years or to both fine and imprisonment, and the fine should not exceed three times the commercial value of any thing in respect of which the offence was committed.

If a person is convicted, the court may order that any damage to the environment resulting from the offence be repaired until the Minister, competent authority or local authority concerned is satisfied (DWAF, 1989).

4.6 Conclusion

This chapter has introduced the topic of environmental liability, which will be utilised in this research when proposing the risk management approach. In South Africa, environmental liability is an instrument utilised currently by the waste management legislation The author feels that the expansion of the environmental liability concepts including the introduction of environmental liability insurance and incentives would further entrench the ‘polluter pays’ principle, which when not applied to covering restoration costs of environmental damage leads to permanently damaged environment or ultimately the taxpayer ends up paying for this restoration. The author also feels that the current environmental liability aspects of the South African legislation are generalised and do not take into consideration that some pollutants do not carry the same level of environmental impact. The author therefore feels that the environmental liability aspects should differentiate the conviction or liability as a result of either high, medium or low risk pollutants as well as the differentiate the receptor environment e.g geology, hydrogeology, aquifer type, etc.

5. AQUIFER CLASSIFICATION IN SOUTH AFRICA

5.1 Introduction

According to Linsley (1992), Aquifers are geologic formations that contain and transmit groundwater. Before developing a risk management approach for groundwater pollution in landfills, it is important to first understand the nature and occurrence of groundwater in aquifers. Three types of classifying aquifers are discussed in this chapter, namely aquifer yield classification, flow mechanism classification and potential value classification.

5.2 Aquifer Yield Classification

5.2.1 Unconfined Aquifers

This type of aquifer is usually the most accessible groundwater resource, but they are also the most vulnerable to contamination. They are often the uppermost resource in a system of aquifers underlying an area. The most important aquifers economically are deposits of sand and gravel because they can gravitationally drain more water per unit volume of the aquifer, known as the specific yield. The specific yield of fine-grained material is much less than coarse material (Linsley, 1992).

5.2.2 Confined Aquifers

These are usually groundwater resources that need to be drilled for the water to reach the surface and are under pressure. A well piercing the confining stratum allows water to rise to the level of the local static pressure, similar to a piezometer measuring pressure in a pipe (Chadwick, 1999). If the pressure is sufficient to raise water above the ground, the well is called a flowing well. Confined aquifers usually have relatively small recharge areas as compared with unconfined aquifers and generally yield less water. Confined have an economical importance in that they transmit water substantial distances and deliver it above the level of the aquifer, thus minimizing pumping costs (Linsley, 1992).

The DWAF-MR (1998) splits aquifers into primary, secondary and dolomitic, although each of them can either show confined or unconfined behaviour.

5.3 Flow Mechanism Classification

5.3.1 Primary (Porous Flow) Aquifers

The main type of flow mechanism in this type of aquifer is porous flow. The flow is around grains of sand and clay, which make up the aquifer. Some of the characteristics usually shown by this type of aquifer include (DWAF, 1998):

- Usually shallow, unconfined systems.
- Mostly consist of unconsolidated material, less than 30m thick.
- Normally contain 1 – 20% water by aquifer volume.
- Pollutant transport through this aquifer is comparatively slow because of the high effective porosity.
- Significant attenuation of pollutants could occur within the clayey portion of the aquifer

5.3.2 Secondary (Fracture Flow) Aquifers

The main type of flow mechanism in this type of aquifer is fracture flow, which generally refers to groundwater movement through a variety of secondary structures in rock. In South Africa, the degree of fracturing of rocks is a function of the tectonic history of the rocks and its composition (DWAF, 1998). Some of the characteristics usually shown by this type of aquifer include:

- They show either unconfined or confined behaviour.
- Usually shallow systems, usually less than 60 m thick, with a maximum of 200m in exceptional.
- Pollutant transport through fracture flow aquifers is comparatively fast.
- Hardly any attenuation of pollutants occurs in the fractures.

5.3.3 Dolomitic (Karst) Aquifers

Dolomite is a crystalline rock that is unstable in acid environments. The dissolution channels occurring along the dolomite fractures may extend to the surface resulting in a karst topography, which influences the recharge characteristics of the aquifer. Dolomitic aquifers with overlying geologic formations are less vulnerable to pollution (DWAF, 1998; Jaquet, 2004)

The DWAF-MR (2005) further classifies aquifers in terms of their existing and/or potential value as a resource, and hence their sensitivity to pollution. The criteria relevant to this discussion are potential sustained yield and significance.

5.4 Potential Value Classification

5.4.1 Potential Yield

The potential yields from boreholes are used as a basis for a quantitative aquifer classification. The table below shows the index:

Yield	Low	Medium	High	Very High
Range	< 1*L* / sec	1 - 5 *L* / sec	5 - 20 *L* / sec	> 20 *L* / sec
Potential Usage	Stock, garden, domestic	Limited development potential	Small community	Large scale water supply

Table 5.1: Aquifer Potential Yield Classification

Source: DWAF-MR (2005)

5.4.2 Potential Significance

The significance or potential significance of the aquifer is assessed using the table below:

Sole source aquifer	An aquifer that is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major aquifer	High yielding aquifer of acceptable quality water.
Minor aquifer	Moderately yielding aquifer of acceptable quality or high yielding aquifer of poor quality water.
Poor / Non aquifer	Insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special aquifer	An aquifer designated as such by the Minister of Water Affairs after due process.

Table 5.2: Aquifer Potential Significance Classification

Source: DWAF-MR (2005)

The potential value classification will be utilised in the formulation of the risk management approach later in this document.

6. DWAF MINIMUM REQUIREMENTS

6.1 Introduction

The current minimum requirements have a classification system with three main objectives (DWAF, 1998):

- To consider waste disposal situations and needs in terms of waste type, size of waste stream and potential for significant leachate generation.
- To develop landfill classes that reflect the spectrum of waste disposal needs.
- To use the landfill classes as the basis for setting graded minimum requirements for the cost-effective selection, investigation, design, operation and closure of landfills.

This disposal site classification system cannot address factors specific to a particular site, such as sensitivity of receiving environment. These factors are covered in the site selection, investigation and environmental impact assessment. It should be noted that the DWAF-MR document is extensive but this section will only focus on the issues relevant to groundwater quality monitoring.

6.2 Landfill Classification

Landfills are grouped according to three factors:

- Types of waste involved
- Size of the waste stream, and
- Potential for significant leachate generation (water balance).

6.2.1 Waste Class

Waste is classified as either General or Hazardous. General waste is a generic term for waste that because of its composition and characteristics, does not pose a significant threat to public health or the environment if properly managed. Hazardous waste is waste that can, even in low concentrations, have a significant adverse effect on public health and/or the environment.

6.2.2 Size of Waste-stream / Operation

The size classification focuses on the size of the waste stream and the consequent size of the operation. This is because the immediate impacts of a disposal site, the resources required to control them and, consequently, the DWAF-MR applicable to the site will be dictated by the size of the operation. The size of operation depends on the daily rate of waste deposition. This in turn relates to, amongst other things, the size of the population served. To take time and growth into account, disposal sites are classified using the 'Maximum Rate of Deposition' or 'MRD'. This is simply the projected maximum average annual rate of waste deposition, expressed in tonnes per day, during the expected life of the site.

Disposal Site Size Class		Maximum Rate of Deposition (MRD) (Tonnes per day)	
Communal	**C**		< 25
Small	**S**	> 25	<150
Medium	**M**	> 150	< 500
Large	**L**	> 500	

Table 6.1: Landfill Size Classification
Source: DWAF-MR (2005).

It should be noted that classification of hazardous waste disposal sites does not take size into account, but is based solely on the hazard rating of the waste.

6.2.3 Potential for significant leachate generation

To avoid water pollution, it is essential that significant leachate generation from landfills be managed by means of leachate collection and treatment systems. All hazardous waste disposal sites are assumed to require leachate management systems. Waste treatment plants (that produce effluence). General waste landfills are classified in terms of their potential to generate leachate. This ensures that the risk of water pollution from leachate is identified at the earliest opportunity, even before a landfill site has been selected.

The potential for leachate to be generated by a landfill depends on the water balance associated with the site, i.e., the Site Water Balance. This is affected by such factors as rainfall, evaporation, moisture content of incoming waste and water ingress into the waste body on account of poor landfill site selection, design and operation (Albaiges, 1986).

According to the DWAF-MR (1998), ambient climate is the major uncontrollable cause of significant leachate generation at a landfill, a Climatic Water Balance is used as the first step in determining the potential for significant leachate generation. The Climatic Water Balance indicates whether the climate in which a landfill is located will cause it to generate significant leachate or not. It is thus a tool to alert the developer, as early as possible, to the need to address leachate management in the disposal site design and costing. In many instances, this may be applied even before the site is selected. Thereafter, Site-Specific Factors, such as waste moisture content, and ingress of runoff and ground water into the waste body, must be taken into account. The relationship between the three factors is shown in the figure below.

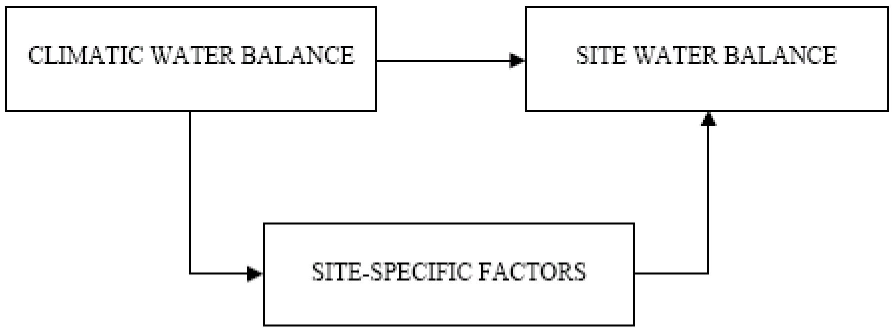


Figure 6.1: Water Balance Factors
Source: DWAF-MR (2005).

The Climatic Water Balance (B) is determined using only two climatic components of a full water balance, namely average annual Rainfall (*R*) and average annual Evaporation (E). The data used are the average annual values of precipitation and A-pan evaporation or S-pan evaporation for that region.

The Climatic Water Balance is determined by selecting *R* and E_A for A-pan evaporation and plotting the values on the chart shown below. If the data plots to the left of the line then the site is B^- otherwise it's classified as a B^+ meaning there will probably be significant leachate generated in the landfill.

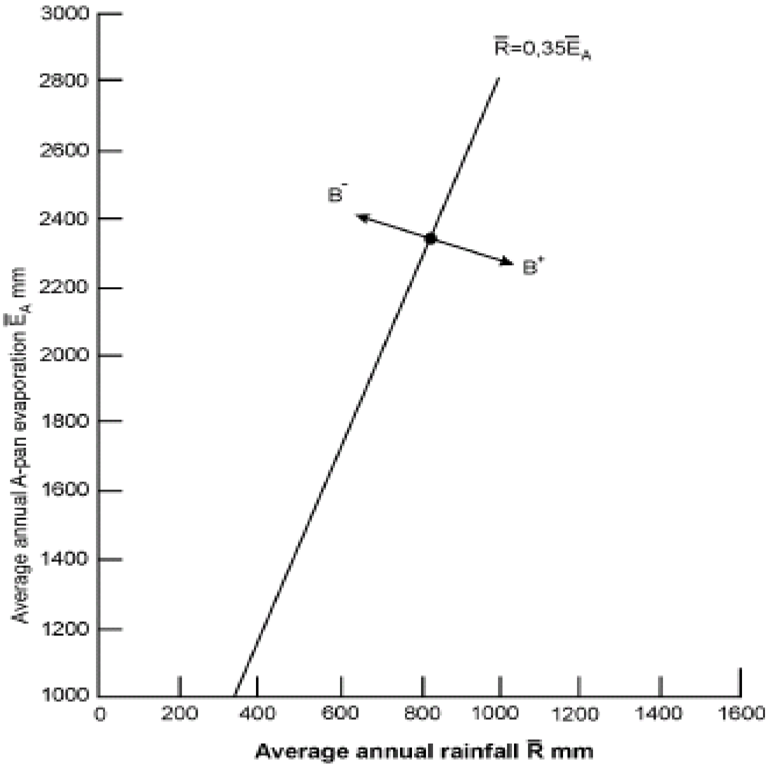


Figure 6.2: Climatic Water Balance Determination Graph
Source: DWAF-MR (2005).

<u>6.2.4 Landfill Classes</u>

The format used in the landfill classification system is based on the three parameters discussed above i.e. waste type, size of operation and site water balance. There are 10 different types of landfills, which are G:C:B^-, G:C:B^+, G:S: B^-, G:S: B^+, G:M: B^-, G:M: B^+, G:L: B^-, G:L: B^+, H:h and H:H. Of these, only the last two classes cater for hazardous waste.

6.3 Landfill Lining System

A mandatory physical separation between the waste body and the surface and ground water regimes is fundamental to all landfill designs. As leachate can be potentially toxic, all leachate producing landfills (B^+) are required to construct liners (DWAF, 1998).

The DWAF-MR (1998) require at least minimal liners at B^- landfills. This is, however, not to manage, but to detect the presence of leachate. In the case of all hazardous waste sites and lagoons, however, the DWAF-MR require a substantial composite liner and leachate management system to be provided, regardless of the Climatic Water Balance.

Every liner system is made up of a series of elements that can be assembled in various ways to provide the necessary degree of protection to the ground water system. The detail and variation associated with each liner component is described in the table and figures below, which depict the liner systems for each class of landfill, as well as the specifications for the various component liner layers.

LEGEND	CLASSIFICATION SYSTEM										
B^- = No significant leachate produced B^+ = Significant leachate produced R = Requirement N = Not a requirement	G General Waste								H Hazardous Waste		
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill				
3 1 mm geo-membrane liner	N	N	N	N	N	N	N	N	N	N	R
2 Compacted clay liner	N	N	N	R	R	R	R	R	R	R	R
1 Base preparation layer	N	N	R	R	R	R	R	R	R	R	R

Table 6.2: Landfill Liner System Design Requirements
Source: DWAF-MR (1998).

LEGEND	CLASSIFICATION SYSTEM										
B⁻ = No significant leachate produced B⁺ = Significant leachate produced R = Requirement N = Not a requirement	G General Waste								H Hazardous Waste		
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4	Lagoons
LINER COMPONENTS	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+			
14 Geotextile separation layer	N	N	N	F	N	F	N	F	F	F	N
13 Waste body	R	R	R	R	R	R	R	R	R	R	R
12 Leachate detection system (finger drains)	N	N	R	N	R	N	R	N	N	N	N
11 Dessication protection	N	N	N	N	R	N	R	N	N	N	N
10 Leachate collection layer	N	N	N	R	N	R	N	R	R	R	N
9 Cushion layer	N	N	N	N	N	N	N	N	R	R	R
8 1,5 mm or 2 mm geomembrane	N	N	N	N	N	N	N	N	R	R	R
7 Compacted clay liner or equivalent GCL on sand support layer	N	N	N	N	N	R	N	R	R	R	R
6 Geotextile layer	N	N	N	N	N	R	N	R	R	R	R
5 Leakage detection layer	N	N	N	N	N	R	N	R	R	R	R
4 Cushion layer	N	N	N	N	N	N	N	N	N	N	R

Table 6.3: Landfill Liner System Design Requirements
Source: DWAF-MR (1998).

Depending on the nature of the waste, it may be necessary to install an appropriate geotextile separation layer between the leachate collection layer and the waste body during construction, to protect the long-term performance of the leachate collection layer. This separation layer could be necessary to reduce the risk of biochemical clogging of the drainage media, or to prevent ingress of fines from the waste into the drainage media.

Figure 6.3: Construction of Weltevreden Landfill Liners in Gauteng

Source: SAICE, 2003

This section will only consider general waste B+ and hazardous sites as liner designs only apply to them. See appendix J for layer descriptions.

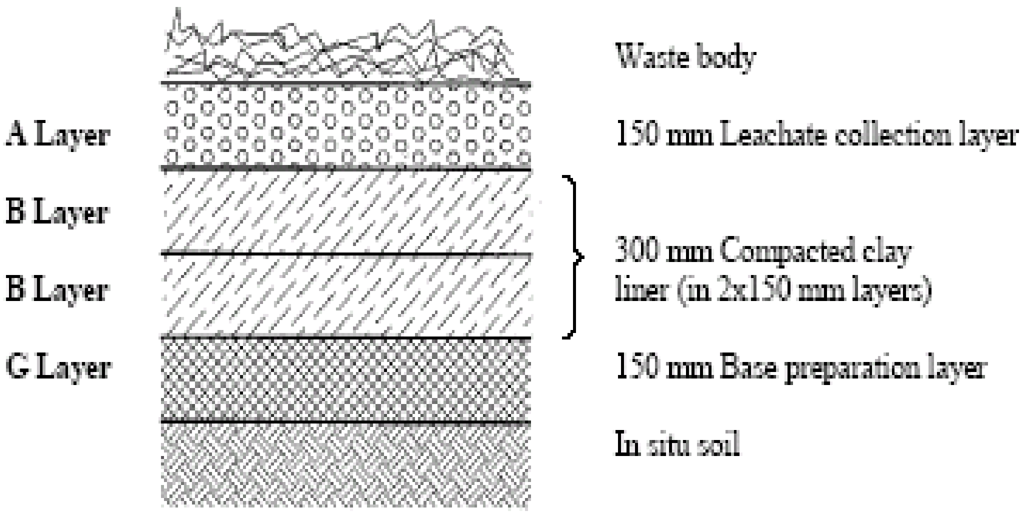


Figure 6.4: Liners - G:S:B+ Landfills

Source: DWAF-MR (1998).

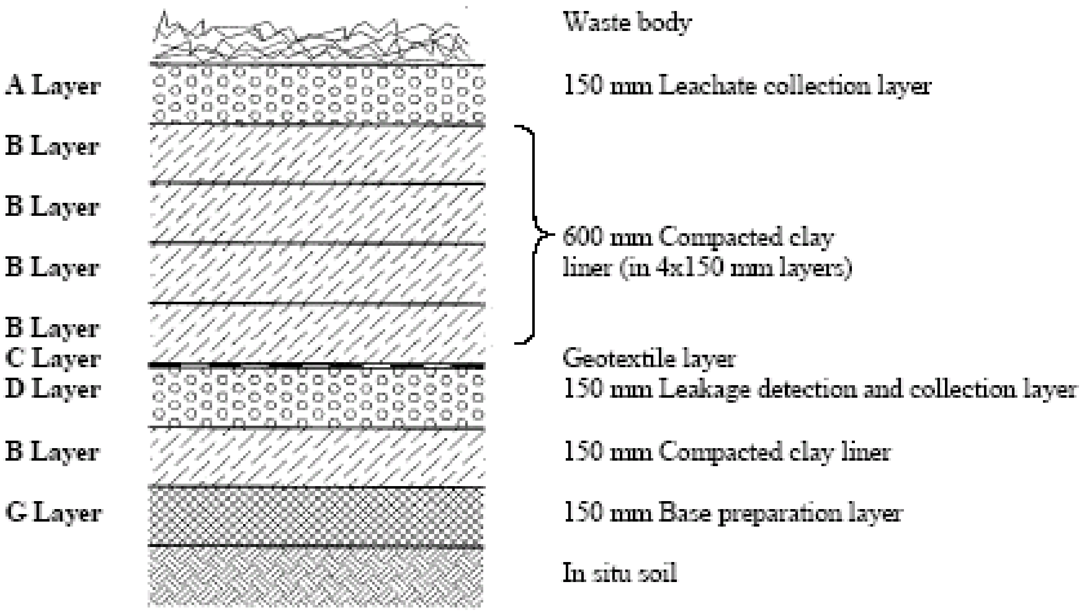


Figure 6.5: Liners- G:M:B+ and G:L:B+ Landfills

Source: DWAF-MR (1998).

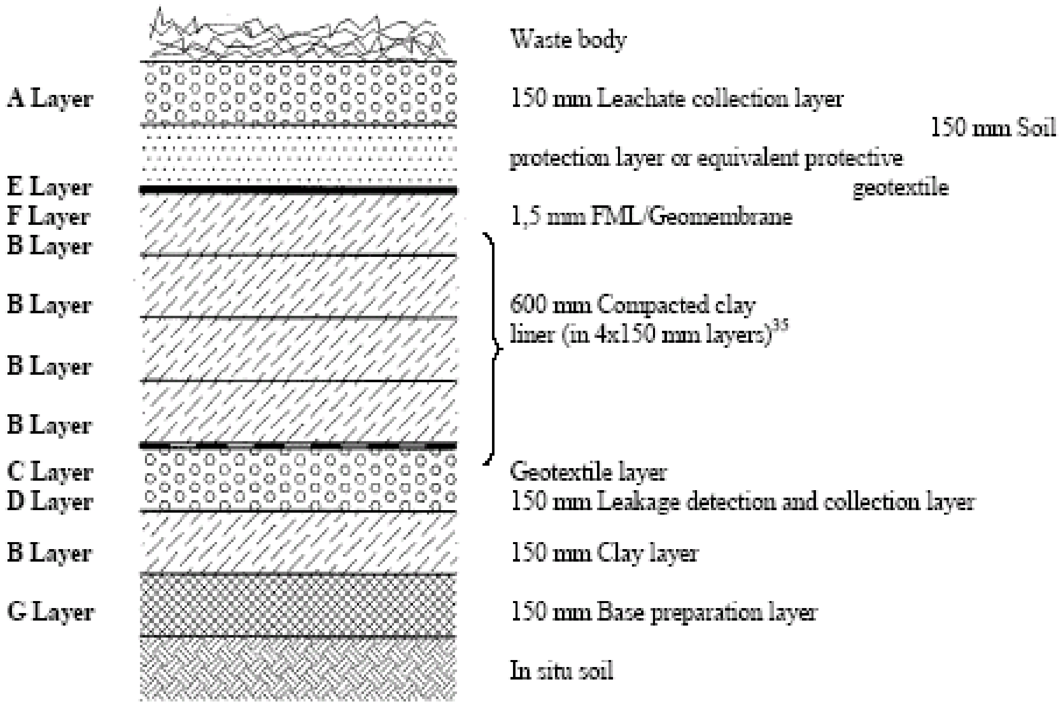


Figure 6.6: Liners - H:h Landfills

Source: DWAF-MR (1998).

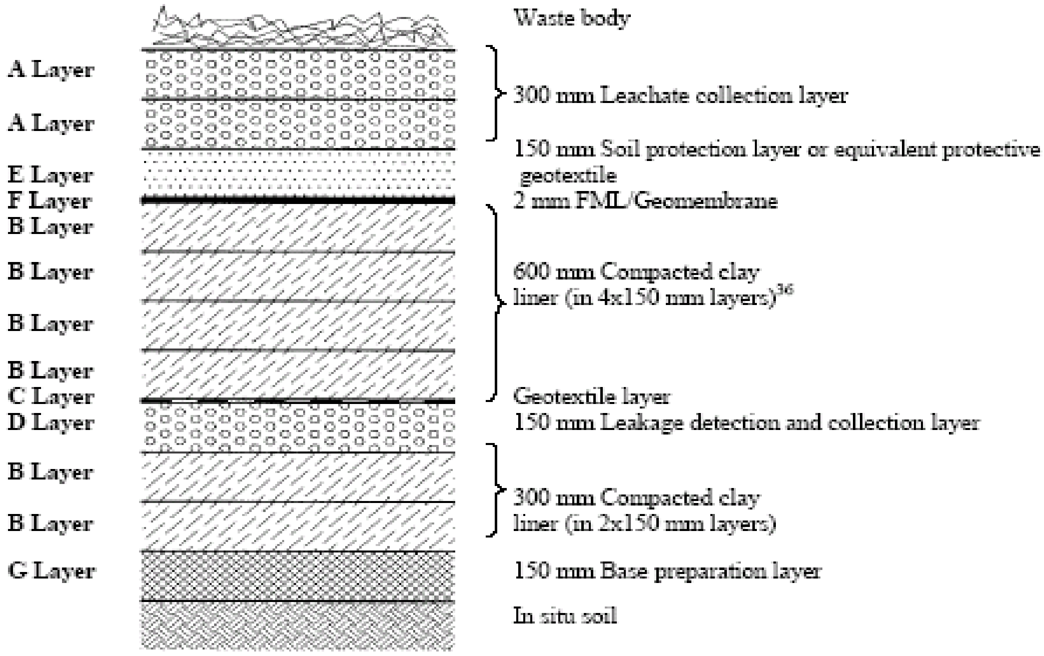


Figure 6.7: Liners - H:H Landfills
Source: DWAF-MR (1998).

6.4 Water Quality Monitoring System

According to the DWAF-MR (1998), regulatory controls will be focused on those activities that represent the most significant threat to the groundwater resources of the country. These activities include:

- Groundwater abstraction and dewatering.
- Disturbance and damage to aquifers.
- Waste disposal from urban, commercial farming, industrial and mining sectors.
- Diffuse sources of pollution associated with urban and rural development, specifically around boreholes.
- Underground storage tanks.

Water quality monitoring at a landfill site begins before the commissioning of a landfill site and continues throughout and beyond its operation. Post-closure water quality monitoring may continue for up to 30 years after the closure of a landfill, it can be viewed as the final step in the landfill process (DWAF, 1998).

According to the DWAF-MR (1998), the objectives of water quality monitoring are:

- To enable the Permit Holder to comply with the relevant Permit conditions and legislation.
- To indicate any escape of leachate into the water environment.
- To serve as an early warning system, so that any pollution problems that arise can be identified and rectified.
- To quantify any effect that the disposal site, including any leachate treatment systems, has on the water regime.

LEGEND

B^- = No significant leachate produced
B^+ = Significant leachate produced
R = Requirement
N = Not a requirement
F = Flag: special consideration to be given by expert or representative(s) of the Competent Authority and/or the Department

	CLASSIFICATION SYSTEM									
	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4
MINIMUM REQUIREMENTS	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+		
Designate a Responsible Person	F	F	F	R	R	R	R	R	R	
Pre-operation Monitoring Surface water monitoring	F	F	F	R	R	R	R	R	R	R
Ground water monitoring	N	N	F	R	F	R	R	R	R	R
Background results reported in Permit Application Report	F	F	F	R	R	R	R	R	R	R
Water analysed in accordance with parameters in *Table 13.1*	F	F	F	R	R	R	R	R	R	R
Sample analysis in accord with SABS methodology or equivalent	F	F	F	R	R	R	R	R	R	R
Operation Monitoring Surface water monitoring	F	F	F	R	R	R	R	R	R	R
Ground water monitoring	N	F	R	F	R	R	R	R	R	R
Leachate treatment effluent/sludge/concentrate monitoring	N	F	N	R	N	R	N	R	R	R
Report sporadic leachate	F	F	F	R	R	R	R	R	R	R
Post-Closure Monitoring Post-closure surface water monitoring	N	F	N	R	F	R	R	R	R	R

Table 6.4: Water Quality Monitoring System Requirements
Source: DWAF-MR (1998).

It is therefore recommended that a Water Quality Monitoring Plan be set up to ensure that the water quality in the vicinity of a disposal site is regularly monitored and reported throughout its life to enable immediate remedial action where necessary (DWAF, 1998). Below are the minimum requirements for water quality monitoring.

The DWAF-MR (1998) lists some sequential steps that are to be followed in the design of a water quality monitoring system. These steps include a preliminary site investigation as well as a risk assessment.

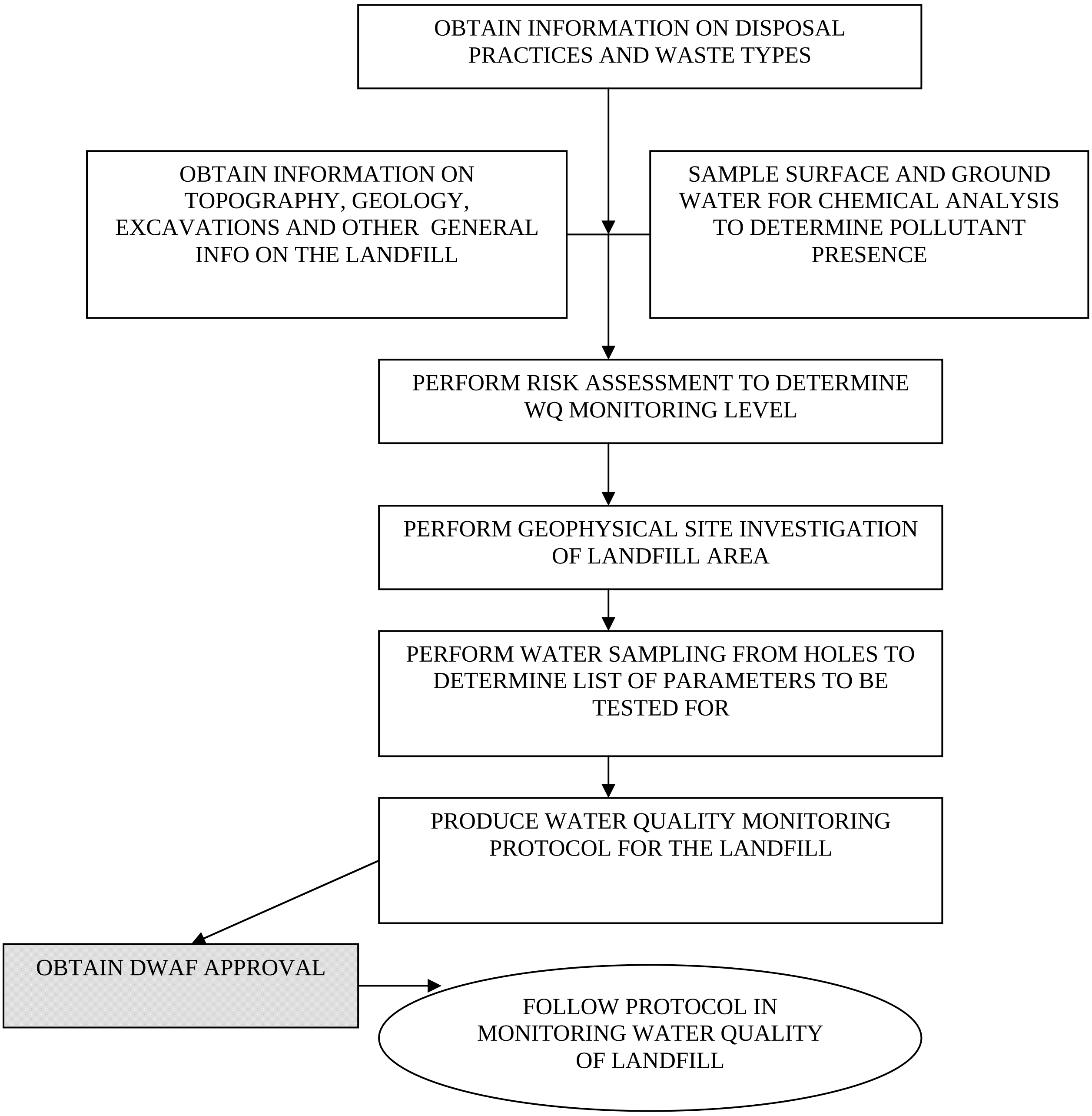


Figure 6.8: Sequential Steps for a Water Quality Monitoring System Design
Source: DWAF-MR (1998).

6.5 Conclusion

This section discusses the DWAF-MR document, which is a practical manual on 'minimum' requirements for landfill license application, construction and water quality monitoring. According to the DWAF-MR (1998), the term minimum refers to the lower limit that must be complied with. Monitoring refers to the meaningful measurement of a variable(s) on a once-off basis during initial impact assessments or on a routine basis thereafter. The author feels that the document seems highly comprehensive yet a few areas need to be highlighted.

Section 2 of the document states that a proposed new waste site must be within a "Poor Aquifer Region" as described in chapter 5 of this research document. The document states that major, minor and poor aquifers are relative and not yield specific, meaning there is no fixed criteria on this classification. It relies mostly on assumptions as the poor aquifer region should contain an aquifer which will never be utilized for water supply and which will not contaminate other aquifers. The author feels that including such form of criteria in waste site selection is too general. What if the conditions of the major and minor aquifers deteriorate drastically through unpredicted events like diversion of acid mine drainage flow-paths because of unfavourable ? It must be noted that although groundwater is not currently fully utilized in South Africa, its importance will increase with time (DWAF, 1998).

The author feels that the current minimum monitoring requirements for general and hazardous waste should be re-considered. Currently the minimum monitoring requirements are as follows:

	Special monitoring holes	Groundwater levels	Groundwater chemistry
General Waste: Large	Yes	3 months	3 months
General Waste: Medium	Yes	1 year	3 months
General Waste: Small	Yes	1 year	3 months
General Waste: Communal	No	1 year	3 months
Hazardous Waste	Yes	1 month	1 month

Table 6.5: Selected minimum monitoring requirements (DWAF, 1998)

The monitoring requirements for groundwater levels seem to be only dependent on the waste type as well as the landfill size in the case of general waste. As expected, the hazardous waste landfill monitoring period is the most stringent with a monthly sequence. The sequence for a large general waste landfill is 3 months and the remaining general waste landfills have a yearly sequence for groundwater levels. In terms of groundwater chemistry monitoring, the monitoring requirements only depend on the waste type. The most stringent period of 1 month applies to hazardous waste and the general waste landfills are expected to monitor quarterly (DWAF, 1998).

The DWAF-MR document highlights that flow through aquifers can happen through fracture flow, porous flow or through dolomitic flow systems. Fracture flow systems are capable of transmitting contaminants at rates of between 10 – 1000 times faster than porous flow systems (DWAF, 1998). The geology of the aquifer also helps understand the typical yield of the aquifer as well as its recharge behaviour. The author therefore feels that the groundwater monitoring requirements have been generalized and should include the geological characteristics of that aquifer to determine the monitoring periods and not only depend on the size and waste type of the landfill. This further highlights the need for a policy of differentiated protection for South African aquifers as highlighted by the DWAF-MR document (1998).

7. LANDFILL WATER QUALITY MONITORING

A Case Study on Landfill X

7.1 Introduction

The DWAF-MR (1998) requires a Water Quality Monitoring Plan as part of its permitting requirements. The Water Quality Monitoring Plan ensures that the water quality in the vicinity of the landfill is regularly monitored and reported throughout its life, so that, where necessary, remedial action can be taken. As explained in chapter 4, once a landfill is operational, water monitoring for level and quantity must take place in accordance with the permit conditions stated by the relevant permit-licensing department. The managing company and engineering consultants for the landfill used in the case study have requested that their identity remains anonymous hence the landfill will be referred to as Landfill X.

7.2 Methodology

This section was done through consultation with the Landfill X engineering consultants. Literature review includes the water quality monitoring reports for Landfill X from July 2004 to February 2006. The aim of this section is to highlight a practical case of how the water quality monitoring protocol is carried out. The proposed environmental liability and risk management approach will therefore build up from this monitoring approach whilst introducing the aspect of environmental liability and integrating it into the current DWAF (1998) procedure for designing and implementing a groundwater quality monitoring plan.

7.3 Landfill X

7.3.1 Location

Landfill X Waste Disposal Site is an operational class GLB- landfill site situated in the Gauteng area on the north eastern side of Johannesburg. The site is owned and operated by a Waste Management company also based in Johannesburg.

Water quality monitoring is the responsibility of the permit holder, who must ensure that the level and the extent of the monitoring are relevant to the landfill class (DWAF, 1998). Landfill X management produce a water quality monitoring report on a quarterly basis, through a joint effort between Consulting Civil Engineers and Groundwater Consultants.

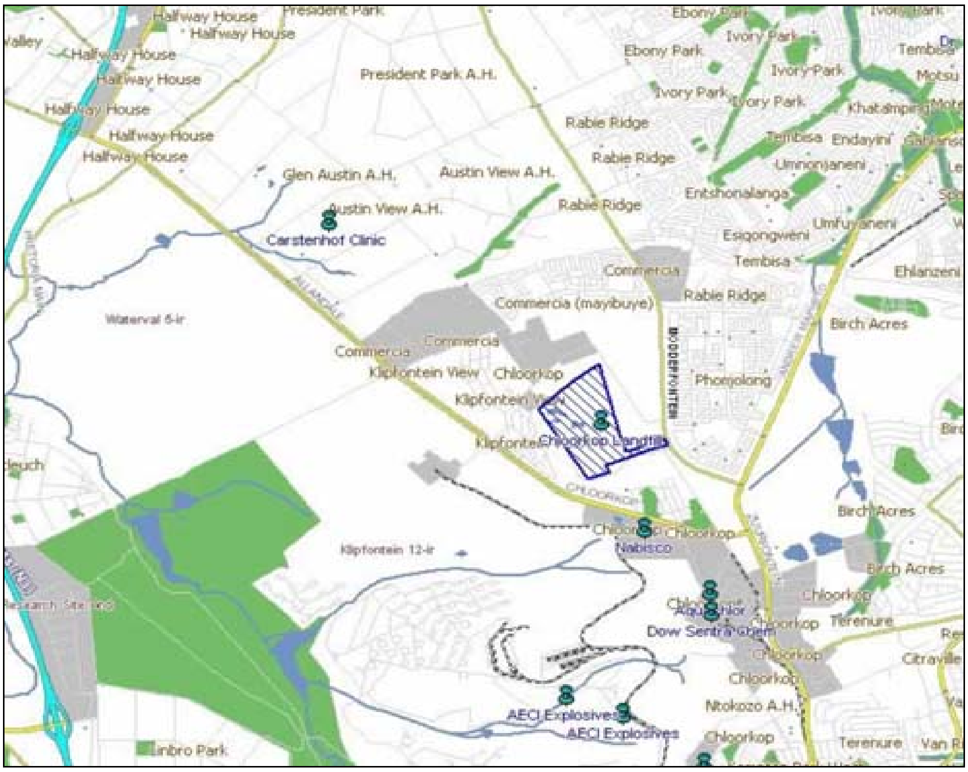


Figure 7.1: Location of Landfill X, Johannesburg

Source: Landfill X Management Website

7.3.2 Site Geology

Landfill X is situated within an old sand quarry, located on the Halfway House Granite Suite and is underlain by two aquifers. These aquifers include a shallow, weathered aquifer and a deeper fractured aquifer. The weathered aquifer is a primary aquifer and classified as unconfined. The aquifer is well developed across the site and varies in thickness between 5m and 42m. The fractured aquifer directly underlies the weathered aquifer and appears to be hydraulically connected to the shallower aquifer (Engineers Report, 2005).

The geology of the area consists predominantly of the Halfway House Granite Suite, also known as the Johannesburg Dome Basement Granites. The landfill's geological profile consists of soil, weathered granite, slightly weathered granite and fresh granite with occasional fracturing and joints. The structural geology in the landfill area includes quarts veining, joints, faults and foliations within the gneissic bands. Of importance are the dolerite dykes, which have an east-west orientation. This orientation impacts on the groundwater flow and hence contaminant migration, especially on a large scale (Engineers Report, 2005).

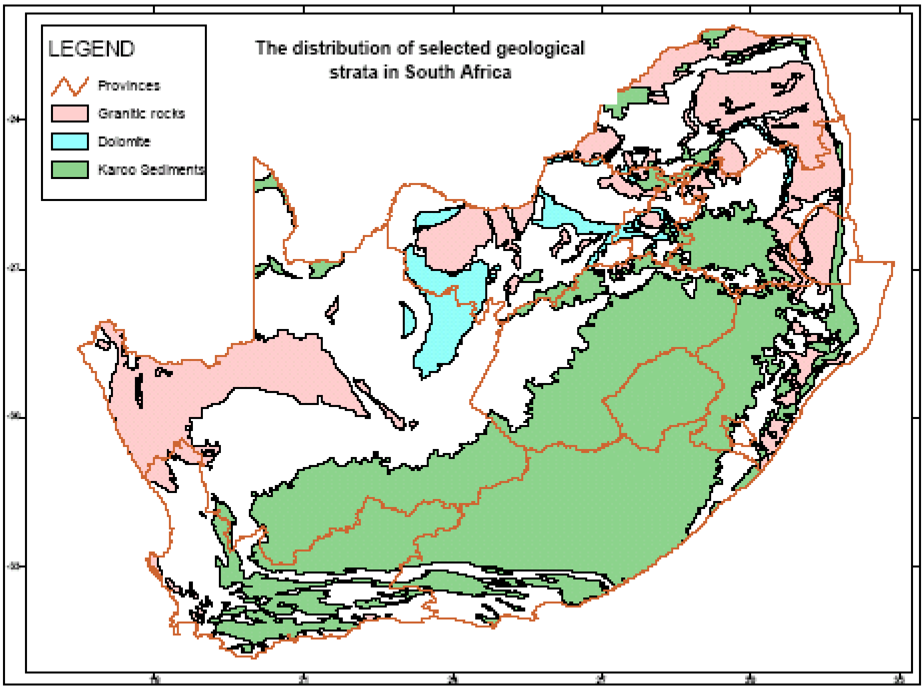


Figure 7.2: Selected Geological Strata Distribution in South Africa

Source: DWAF-MR (2005).

7.3.3 Groundwater Monitoring Boreholes

The Landfill X water quality monitoring report contains information on the groundwater monitoring network, which consists of 14 boreholes ranging in depth from 20m to 56m.

Borehole Number	Depth
CL-02	20m
CL-07	50m
CL-12	46m
CL-13	51m
CL-14	51m
CL-19	36m
CL-21	56m
CL-22	44m
CL-24	50m
CL-25	50m
CL-26	50m
CL-37	37.18m
CL-38	19.15m
CL-39	50.72m

Table 7.1: Landfill X Monitoring Borehole Depths

Source: Engineers Report, 2005.

7.3.4 Groundwater Quality Monitoring Parameters

Inorganic Constituents

The parameters monitored in the Landfill X water quality monitoring report are compared to the DWAF Insignificant Risk guideline which were published by DWAF as an appendix in the 1992 water quality guidelines, they were developed by the old Department of Health and Population Development. These guidelines were not retained by DWAF in the 1998 minimum requirements and are therefore not official guidelines although they are still regarded by the engineers report as very useful for contaminated sites. The guidelines corresponds to levels similar to values described as "maximum permissible" or "maximum allowable" in other guidelines as seen in the table below.

The guideline represents the maximum concentration, which poses negligible risk to human health even for lifetime consumption. It is the lowest quality of water accepted by health authorities under normal circumstances.

	DWAF Guidelines Domestic Use	Maximum Limit for No Risk	Maximum Limit for Insignificant Risk	Maximum Limit for Low Risk
PH	6.0 - 9.0	6.0 - 9.0	6.0 - 9.0	>4 or <11
EC (Ms/m)	70	70	300	400
TDS	450	450	2000	2600
NH_4 as N	1.0	1.0	2.0	4.0
NO_3 as N	6.0	6.0	10	20
Cl	100	250	600	1200
SO_4	200	200	600	1200
B		0.5	2.0	4.0
F	1.0	1.0	1.5	3.0
Na	100	100	400	800
K	50	200	400	800
Ca	32	150	200	400
Mg	30	70	100	200
As	0.010	0.10	0.30	0.60
Ba		0.50	1.0	2.0
Cd	0.050	0.010	0.020	0.040
Hexavalent Cr		0.10	0.20	0.40
Cu	1.0	0.50	1.0	2.0
Fe	0.10	0.10	1.0	2.0
Pb	0.010	0.050	0.10	0.20
Mn	0.050	0.050	1.0	2.0
Hg	0.0010	0.0050	0.010	0.020
Al	0.15	0.15	0.50	1.0
Ni		0.25	0.50	1.0
Zn	3.0	1.0	5.0	10

Table 7.2: Guidelines for Domestic Water Use (µg / L)

Source: Engineers Report, 2005.

Organic Constituents

South Africa currently does not have health risk based screening guidelines for organic constituents, therefore this section of the water quality monitoring report was derived by Landill X management who used a combination of international sources. This approach resulted in a hazard assessment that indicates the magnitude of potential risks, should the groundwater be used for domestic purposes. Some of the organic constituents measured and their guidelines are shown below. A full list of the organic constituents measured can be seen in the appendix.

Vinyl Chloride	0.015
cis-1,2-Dichloroethene	61
Carbon Tetrachloride	0.160
Trichloroethene	5.0
Toluene	750
Tetrachloroethene	40
m,p-Xylene	1500
o-Xylene	1500
1,2,4-Trimethylbenzene	3.0

Table 7.3: Landfill X Organic Constituents (µg / L)

Source: Engineers Report, 2005

7.3.5 Groundwater Quality Monitoring Process

The process followed to design a monitoring system is shown in the diagram in appendix D. After a review of the groundwater monitoring process currently being used, Landfill X management further customised their water quality monitoring protocol whereby, water level measurements and groundwater samples are to be taken on a quarterly basis by contractors. A detailed analysis is to be undertaken once a year in July, with only PH, EC and COD analysed during the other three sampling exercises.

7.4 Review of the Groundwater Monitoring Protocol

7.4.1 Aim of Review

A geohydrological assessment was undertaken of Landfill X to evaluate the groundwater regime and assess the effectiveness of the current groundwater monitoring network at the site. The assessment was based on data collected during the previous investigations and monitoring of the existing boreholes. It is very important to understand the groundwater flow patterns of a site in order to successfully assess the effectiveness of the monitoring network.

7.4.2 Geological Setting

The landfill area has a geology dominated by the Halfway House Granite Suite also known as the Johannesburg Dome Basement Granites (Fig 7.3). A geological profile in the landfill area consists of soil (decomposed granite), weathered granite, slightly weathered granite and fresh granite with occasional fracturing and joints (Fig 7.4). Structural geology of the site comprise of the fractured aquifer and also includes features like quartz veining, joints, faults and foliations within the gneissic bands. There are two dolerite dykes at the landfill site that have a huge impact on the groundwater flow and contaminant migration on a local scale.

7.4.3 Hydrogeological Setting

The site features both a shallow unconfined sandy aquifer as well as a deeper confined fractured aquifer. The unconfined aquifer is well developed across the site and varies in thickness between 5m and 42m. The confined aquifer lies directly below the unconfined sandy aquifer and the two aquifers are hydraulically connected. Contamination of the unconfined aquifer will lead to contamination of the confined fractured aquifer below it.

7.4.4 Groundwater Flow

The regional groundwater table was estimated based on Bayesian interpolation. The Bayesian relationship looks at the correlation between the topography and the groundwater table. A linear relationship will indicate a correlation between the topography and the groundwater table (Fig 7.5).

Figure 7.3 – **Regional Geology**

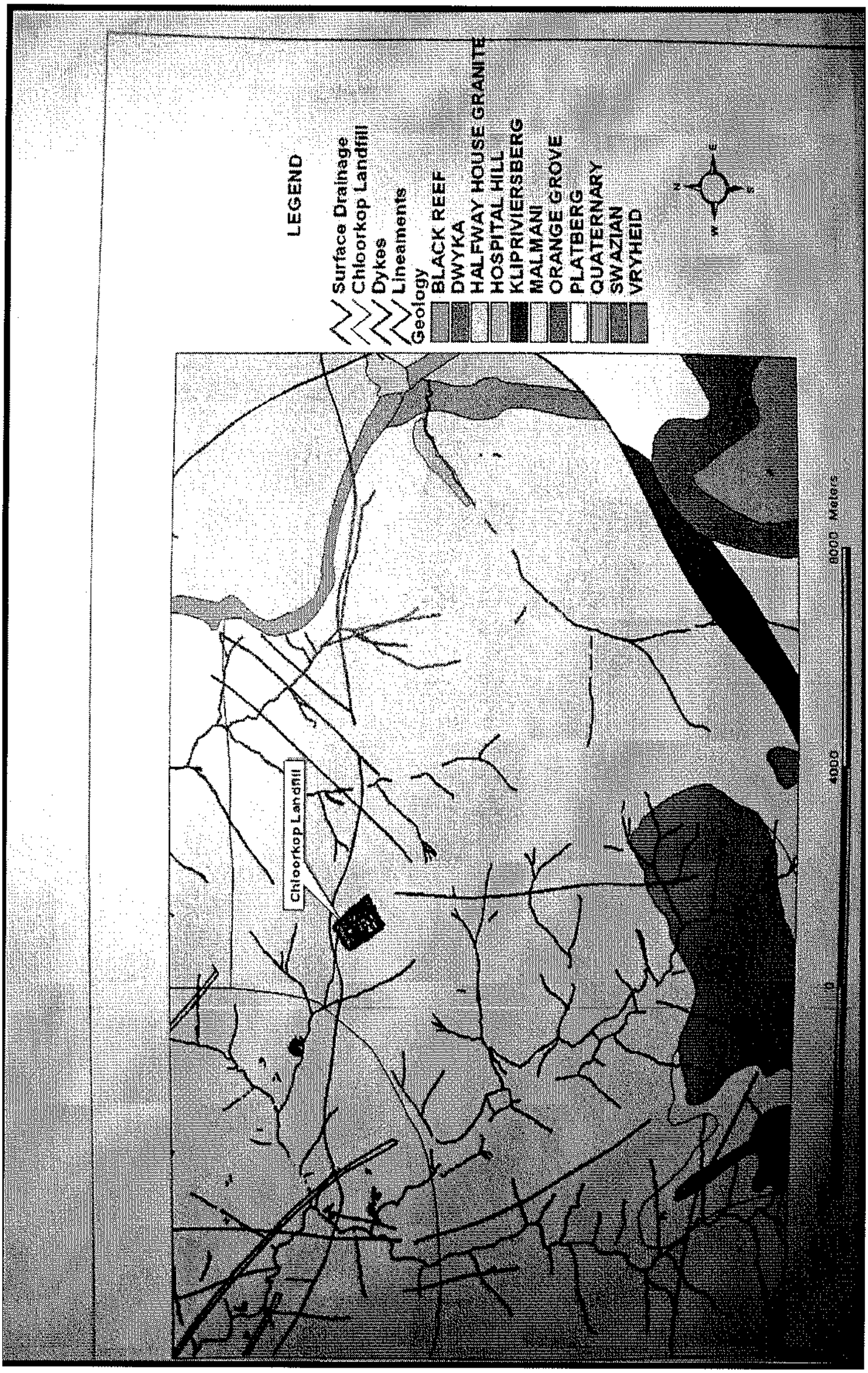


Figure 7.4 – **North-South Geological Profile through the Landfill**

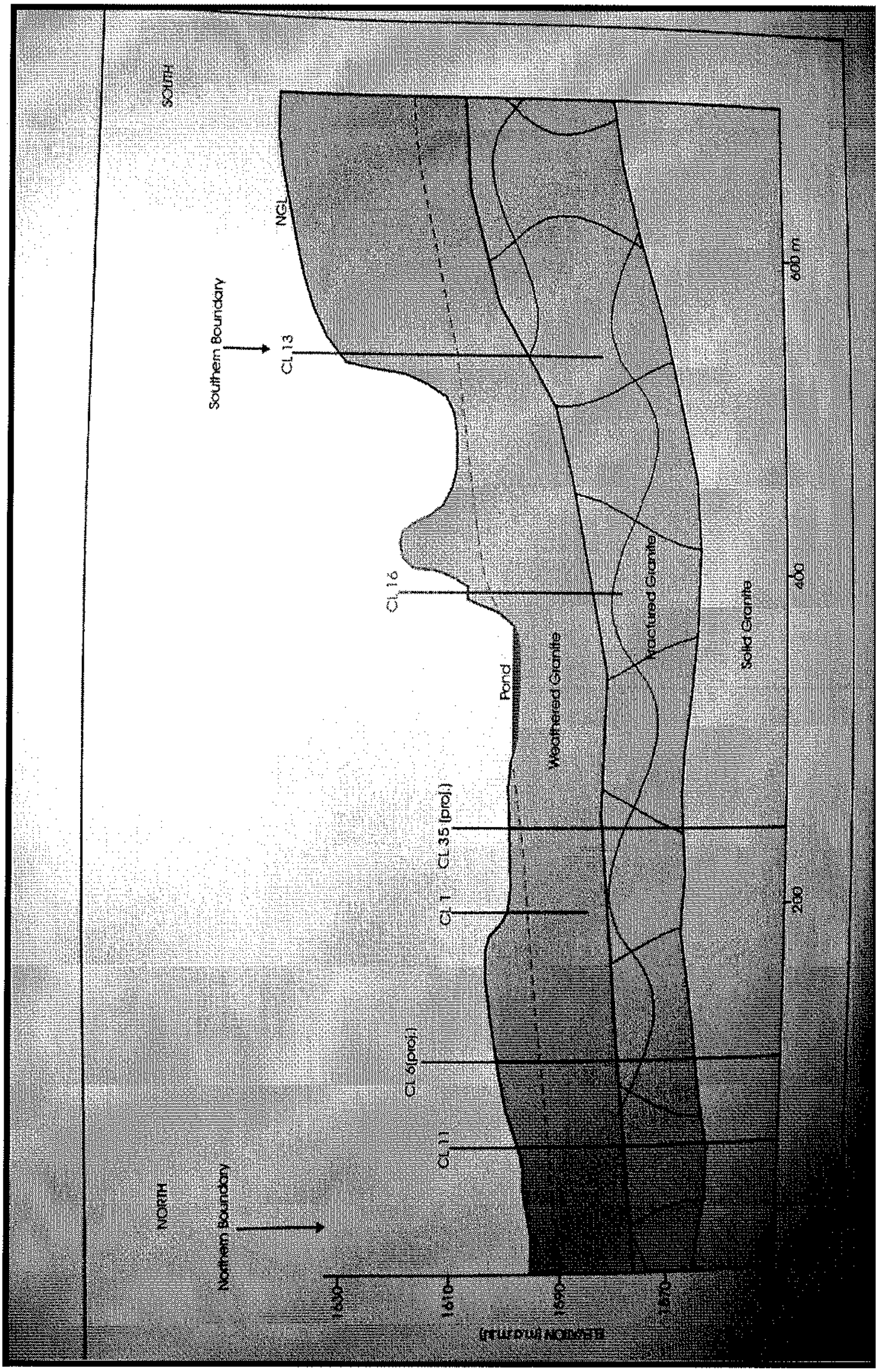
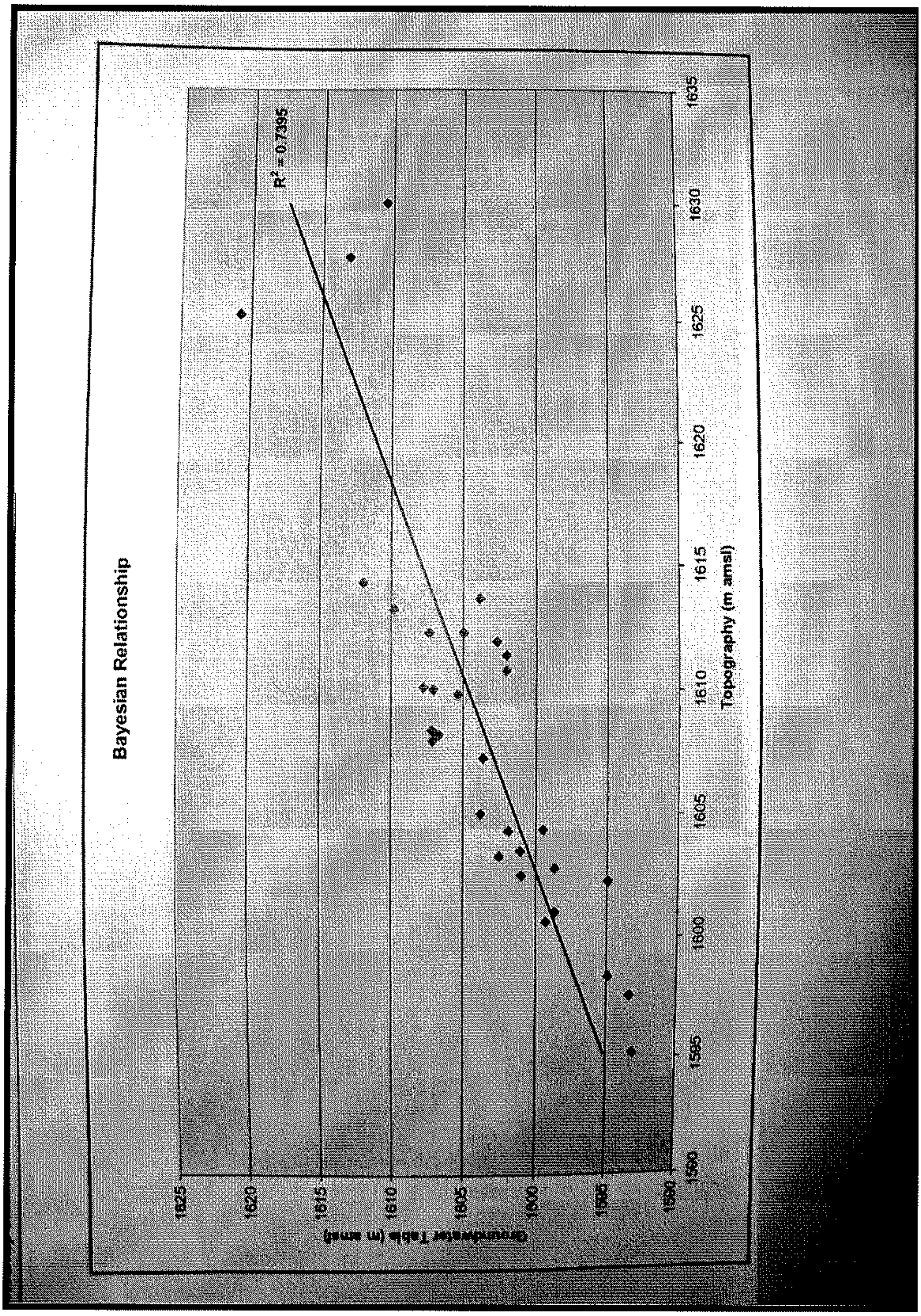


Figure 7.5 – **Relationship between Topography and GW Table**



Groundwater flow at the landfill site is generally towards the north-west at an average angle of 4.7%. The groundwater flow direction was then established using a conceptual MODFLOW groundwater flow model. Although MODFLOW was originally intended for simulations of flow through porous medium like sandy aquifers, it was used in this case because of flow through dense fractured strata, which will exhibit similar behaviour. This is because the degree of fracturing and fracture spacing is dense enough to result in flow similar to porous media flow. For modelling purposes, it was assumed that the groundwater table flow is mainly towards the north-west at an angle of 4.7%. Furthermore, the aquifer parameters were tested through a series of pump and packer tests.

- Horizontal Hydraulic Conductivity (K) of 0.86 m/day
- Transmissivity (T) of 34 m^2/day
- Storage Coefficient of 0.001 (Driscol, 1986)
- Porosity of 10% (Driscol, 1986)

Particle tracking was then used to trace out the groundwater flowlines (Fig 7.6). These flow paths indicate the direction of the groundwater flow, under natural conditions prior to setting up the landfill. Groundwater flow will be diverted around the landfill site because of the lining and no groundwater will enter the waste pile (Fig 7.7).

Once the flow direction was determined, the flow rate was then calculated. This is done because contaminants move at the speed of the average linear velocity of groundwater called advection. The formula used is:

$$\nu = \frac{K \text{ X } i}{n}$$

where

ν	=	velocity in m / day
K	=	Hydraulic Conductivity in m / day
i	=	Gradient as a %
n	=	Porosity as a %

From the above formula, the groundwater velocity average is 0.4 m / day or 147 m per year. This is if K is estimated to be 0.86 m / day, I estimated to be 4.7% from the Bayesian relationship and n is 10%.

7.4.5 Effectiveness of Groundwater Monitoring Network

The assessment was aimed at evaluating the current groundwater monitoring network and it was found that the existing monitoring network did not distinguish between the weathered and fractured aquifer underlying the landfill site. It was therefore recommended that the monitoring boreholes should bear geology in mind and not assume that groundwater flow through the weathered and fractured part of the aquifer will be the same. It was therefore recommended that a number of boreholes be reconstructed on the site.

7.4.6 Risk Estimation and Modelling

The author feels that this assessment exercise should not have ended there. A risk assessment of the landfill should have been conducted before undertaking the geohydrological assessment to determine the risk level and the monitoring facilities required before developing a risk management strategy as stated by the sequential steps for the design of a monitoring system (DWAF, 1998). The author feels this would have assisted in determining how many monitoring boreholes should have been placed at the site. This would then help determine how many boreholes should be sealed and how many should be reconstructed.

7.4.5 Groundwater Monitoring Design

A number of monitoring boreholes had to be sealed and new ones reconstructed because monitoring them led to repetitive work. That was mainly because the existing monitoring network wouldn’t distinguish between the weathered and fractured aquifer underlying the site for both the granite and dolerite. Groundwater intersections are mainly confined to the weathered / fresh bedrock interface.

Figure 7.6 – **Groundwater Flow Paths**

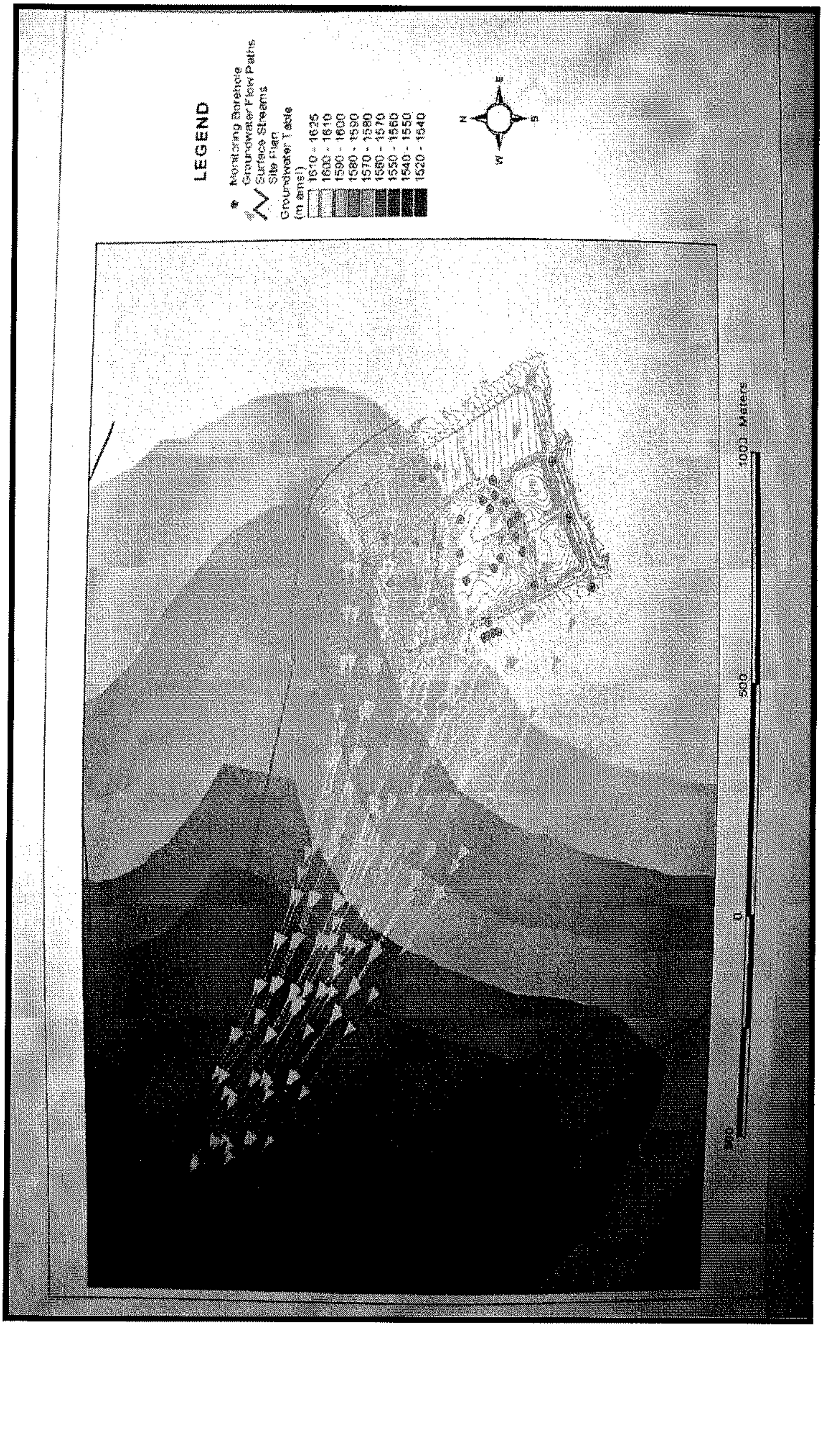
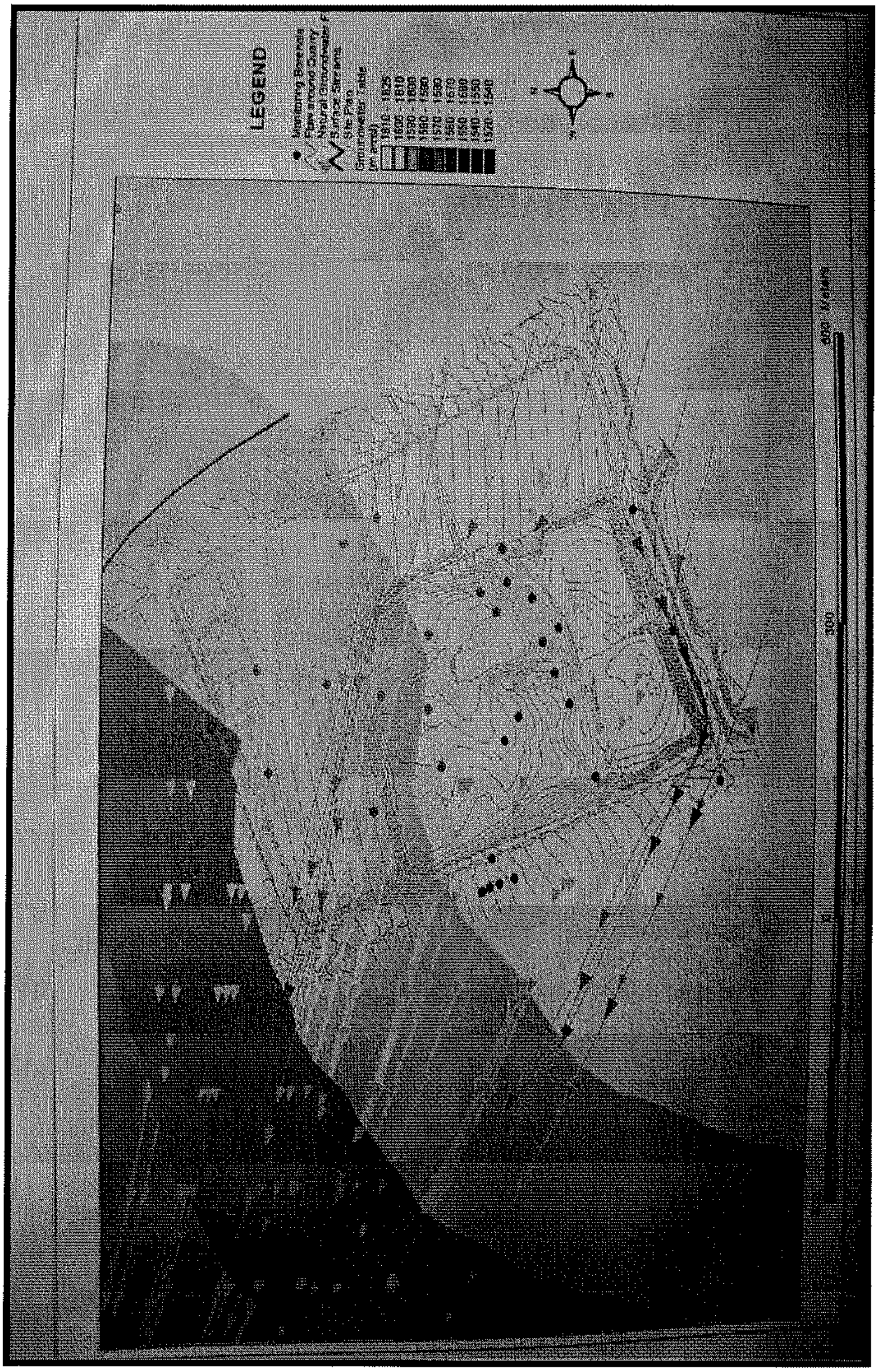


Figure 7.7 – **Deviation in Groundwater Flow due to Landfill Lining**



7.5 Conclusion

The Landfill X case study shows the work that goes into developing and implementing a water quality monitoring plan. Because of costs, the monitoring procedure is carried out quarterly and a detailed analysis done once a year. Any water pollution issues are summarised and remedial action is recommended.

The author also feels that the geohydrological assessment should have been done after a risk assessment was undertaken to determine the risk level of the landfill. This should then have been used together with other factors relating to the site to determine the groundwater monitoring layout and monitoring frequency. The risk assessment would have considered the different geological settings and how they relate to the groundwater flow in both the weathered and fractured aquifer. This would have led to an insightful risk management strategy and implementation plan.

The case study also highlights the importance of considering the geology pattern of a site when designing the water quality monitoring system. The existing monitoring network wouldn't distinguish between the weathered and fractured aquifer underlying the site for both the granite and dolerite hence boreholes had to be sealed and others had to be reconstructed. If this case study is inferred to other existing landfills, then one can safely assume that a number of landfills in South Africa are currently not being monitored effectively.

8. ENVIRONMENTAL LIABILITY PARAMETERS

8.1 Introduction

The case study has shown that it is important to factor in the geology of a landfill site as well as undertake a risk assessment to set up an effective groundwater monitoring system. Even if the geology and risk assessment are undertaken, the liability aspect of the South African legislation discussed in chapter 3 needs to be strengthened by looking at introducing an environmental liability approach as a penalty if pollution standards are exceeded. Assigning monetary values to each of the analytical variables at the landfill will assist the government in having a structured methodology of recovering any costs with respect to any form of obligation as discussed in chapter 4.

The author feels that the BATNEEC is a good approach but not all costs are considered by landfill operators when drawing up their projected balance sheets in terms of liabilities and potential liabilities. Introducing liability parameters and assigning charges to them will help the landfill manager in better evaluating options during the beginning and during the life of the landfill and in deciding what maximum costs to incur in terms of investing in technology.

8.2 Current DWAF Parameters for Monitoring

The DWAF-MR (1998) suggests that the same water quality parameters be used for surface and groundwater monitoring for consistency and comparative purposes. In addition, other parameters should be added by the responsible person, should they be relevant at a specific site.

The impact of the landfill on water quality is assessed by making a comparison between the pre-disposal, upgradient or ambient background and the downgradient concentrations monitored. This will indicate whether there is a pollution problem due to contaminated surface water or leachate leaving the site and seeping into the ground water (DWAF, 1998).

The current parameters that are suggested for detection monitoring are split into annual and bi-annual sampling as shown below. This exercise is carried out three times a year for Chloorkop landfill.

Bi-Annually	Annually
Alkalinity (Total Alkalinity)	Calcium (Ca)
Ammonia (NH_3-N)	Fluoride (F)
Chemical Oxygen Demand (COD)	Magnesium (Mg)
Chlorides (Cl)	Sodium (Na)
Electrical Conductivity (EC)	Sulphate (SO_4)
Nitrate (NO_3-N)	
pH	
Pottasium (K)	
Total Dissolved Solids (TDS)	

Table 8.1: Current DWAF Parameters for Detection Monitoring

Source: DWAF-MR (1998)

Ammonia (NH_3 as N)	Electrical Conductivity (EC)
Alkalinity (Total Alkalinity)	Free and Saline Ammonia as N (NH_4-N)
Lead (Pb)	Magnesium (Mg)
Boron (B)	Mercury (Hg)
Cadmium (Cd)	Nitrate (as N) (NO_3-N)
Calcium (Ca)	pH
Chemical Oxygen Demand (COD)	Phenolic Compounds (Phen)
Chloride (Cl)	Pottasium (K)
Chromium (Hexavalent)(Cr^{6+})	Sodium (Na)
Chromium (Total)(Cr)	Sulphate (SO_4)
Cyanide (CN)	Total Dissolved Solids (TDS)

Table 8.2: Current DWAF Parameters for Background and Investigative Monitoring

Source: DWAF-MR (1998)

8.3 Monitored Parameters in Case Study

The DWAF list of suggested parameters seems to be quite extensive and can be used in the background analysis to establish which parameters are relevant to that particular landfill site, which then becomes the environmental liability parameters. The environmental parameter list must be reviewed from time to time to keep it up to date. This can be seen when looking at the parameters being analysed in the case study. The detection monitoring parameters are the same as those listed in table 8.1.

Ammonia (NH_3 as N)	Electrical Conductivity (EC)
Alkalinity (Total Alkalinity)	Free and Saline Ammonia as N (NH_4-N)
Lead (Pb)	Magnesium (Mg)
Boron (B)	Mercury (Hg)
Cadmium (Cd)	Nitrate (as N) (NO_3-N)
Calcium (Ca)	pH
Chemical Oxygen Demand (COD)	Phenolic Compounds (Phen)
Chloride (Cl)	Pottasium (K)
Chromium (Hexavalent)(Cr^{6+})	Sodium (Na)
Chromium (Total)(Cr)	Sulphate (SO_4)
Cyanide (CN)	Total Dissolved Solids (TDS)

Table 8.3: Inorganic Parameters Monitored

Source: Engineers Report (2004)

The case study then further splits the organic parameters into volatile and semi volatile. It should be noted that this list of organic parameters were determined from the investigative monitoring done over the years at the site. It is important to also note that this list of organic parameters may not be generalised to all landfills when monitoring for groundwater quality.

Volatile Environmental Liability Parameters	
Dichlorodifluoromethane	Tetrachloroethene
Vinyl Chloride	Dibromochloromethane
Trichlorofluoromethane	1,2-Dibromoethane
1,1 - Dichloroethene	Chlorobenzene
Dichloromethane	1,1,1,2-Tetrachloroethane
trans-1,2-Dichloroethene	Ethylbenzene
1,1-Dichloroethane	m,p-Xylene
cis-1,2-Dichloroethene	o-Xylene
2,2-Dichloropropane	Styrene
Bromochloromethane	Bromoform
Chloroform	Isopropylbenzene
1,1,1-Trichloroethane	1,1,2,2-Tetrachloroethane
1,1-Dichloropropene	1,2,3-Trichloropropane
Carbon Tetrachloride	Bromobenzene
1,2-Dichloroethane	n-Propylbenzene
Benzene	2-Chlorotoluene
Trichloroethene	1,3,5-Trimethylbenzene
1,2-Dichloropropane	4-Chlorotoluene
Dibromomethane	tert-Butylbenzene
Bromodichloromethane	1,2,4-Trimethylbenzene

Toluene	sec-Butylbenzene
1,1,2-Trichloroethane	4-Isopropyltoluene
1,3-Dichloropropane	1,3-Dichlorobenzene
	1,4-Dichlorobenzene
	n-Butylbenzene
	1,2-Dichlorobenzene
	1,2-Dibromo-3-chloropropane
	1,2,4-Trichlorobenzene
	Hexachlorobutadiene
	Naphthalene
	1,2,3-Trichlorobenzene

Table 8.4: Volatile Organic Parameters Monitored

Source: Engineers Report (2005)

Semi Volatile Environmental Liability Parameters	
bis(2-Chloroethyl)ether	4-Bromophenyl-phenylether
Phenol	Hexachlorobenzene
2-Chlorophenol	Pentachlorophenol
1,3-Dichlorobenzene	Phenanthrene
1,4-Dichlorobenzene	Anthracene
1,2-Dichlorobenzene	Carbazole
Bis(2-chloroisopropyl)ether	Di-n-butylphthalate
2-Methylphenol	Fluoranthene
Hexachloroethane	Pyrene
N-Nitroso-di-n-Propylamine	Butylbenzylphthalate
4-Methylphenol	Benzo[a]anthracene
Nitrobenzene	Chrysene
Isophorone	bis(2-Ethylhexyl)phthalate
2-Nitrophenol	Di-n-octylphthalate
2,4-Dimethylphenol	Benzo[b]+[k]fluoranthene
bis(2-Chloroethoxy)methane	Benzo[a]pyrene
2,4-Dichlorophenol	Indeno[1,2,3-cd]pyrene
1,2,4-Trichlorobenzene	Dibenz[a,h]anthracene
Naphthalene	Benzo[g,h,i]perylene
4-Chloroaniline	Dibenz[a,h]anthracene
Hexachlorobutadiene	Benzo[g,h,i]perylene
4-Chloro-3-methylphenol	
2-Methylnaphthalene	
Hexachlorocyclopentadiene	
2,4,6-Trichlorophenol	
2,4,5-Trichlorophenol	
2-Chloronaphthalene	
2-Nitroaniline	
Acenaphthylene	
Dimethylphthalate	

2,6-Dinitrotoluene
4-Nitrophenol
Fluorene
4-Chlorophenyl-phenylether
Diethylphthalate
4-Nitroaniline
4,6-Dinitro-2-methylphenol
Azobenzene

Table 8.5: Semi Volatile Organic Parameters Monitored
Source: Engineers Report (2005)

8.4 Liability Parameters

The author feels that because each landfill should be treated uniquely proposed environmental liability parameters may not be relevant to all landfills but will depend on the background analysis. Once the comprehensive analysis is conducted, an initial list of liability parameters applicable to that particular landfill can be determined. After this is done, indicator analysis exercises will then be carried out regularly until undesirable trends are uncovered. This will keep analytical costs to a minimum, but still provide enough information upon which further action can be initiated (DWAF, 1998). Government will have to conduct a study to compile a comprehensive list of all organic and inorganic variables applicable to a landfill. A cost value will then need to be assigned to each of the analytical variables depending on the level of impact each of the variables pose to the environment.

8.5 Conclusion

The author feels that the current DWAF –MR procedure for determining analytical variables to be monitored is quite comprehensive. A list of liability parameters can therefore be determined using the same procedure. The case study has also shown that a landfill can have a long list of parameters to be monitored and they cannot be generalised or inferred to another landfill. The initial step is for government to compile a list of all the possible analytical parameters applicable to a landfill and assign penalty values to be paid by polluters. The rest of the steps are included in the proposed risk management approach in chapter 9.

9. PROPOSED RISK MANAGEMENT APPROACH

9.1 Introduction

An approach that involves the use of environmental liability and risk assessment is proposed in this section. This proposed methodology builds up from the existing DWAF-MR and only differs in the way monitoring and compliance is managed.

The author proposes two phases in the environmental liability and risk management approach. The methodology is split into these phases, the first phase involves the initial investigations undertaken as per the DWAF-MR (1998) and the second phase covers the operational phase of the landfill.

9.2 Initial Investigation Phase

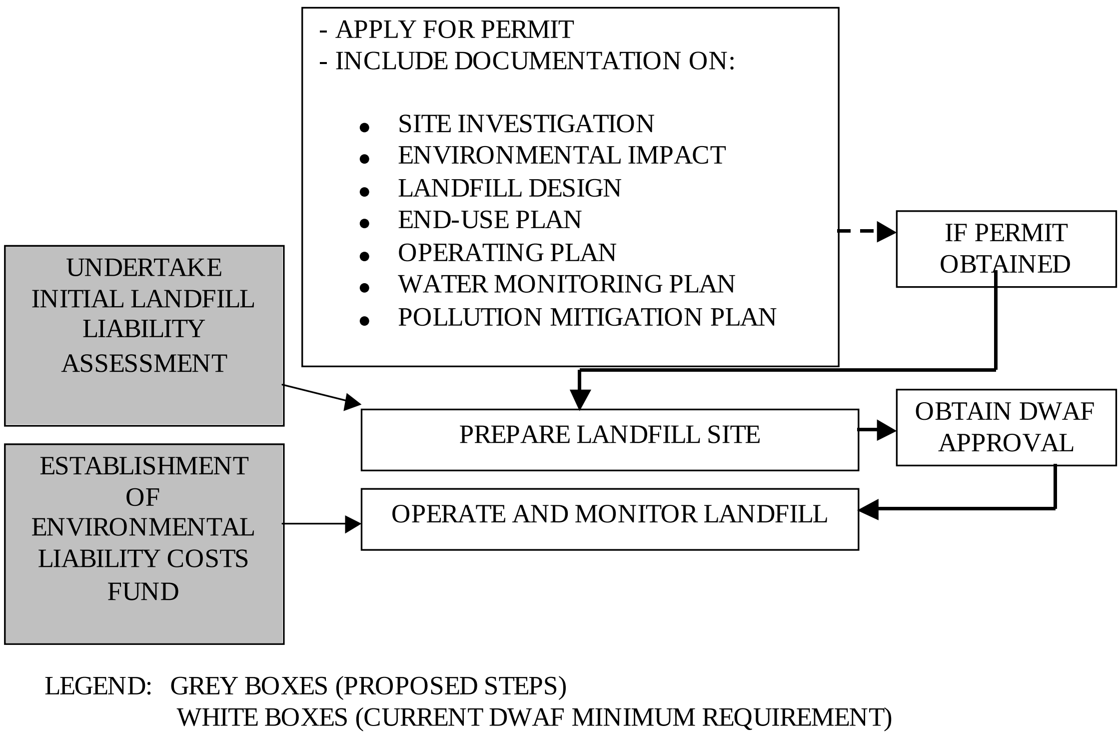


Figure 9.1: Initial Investigation Phase of Proposed Methodology

9.2.1 Landfill Operation Permit

At the beginning the operator will have to apply for Landfill Operation Permit from DWAF as per DWAF-MR (1998). Once the ideal site is identified, a permit application report is then drawn up, which documents:

- Site Investigation
- Environmental Impact Assessment
- Landfill Design
- End-use plan
- Operating plan
- Water Monitoring plan

9.2.2 Landfill Environmental Liability Assessment

If permit is approved, this step will be to undertake an initial landfill environmental liability assessment. Here, the operator will investigate the list of proposed environmental liability parameters and determine which ones apply to that landfill

This environmental liability assessment will be performed to determine whether environmental contamination is likely to be present at the landfill area, which may result in future environmental liability and also compile a list of liability parameters for that landfill to be approved by DWAF. Most of the information necessary to carry out this exercise is part of the sequential steps for the design of a water quality monitoring system. Once a list of environmental parameters are compiled in this stage, the landfill operator together with the relevant government department will assign penalty values for each of the parameters.

The penalty accorded to each parameter will depend on the risk level posed by it. There are a lot of ways to conduct a risk assessment as discussed in chapter two. For this section the author uses a fuzzy logic based approach to determine the risk rating of the liability parameters. Rating occurs when contaminant sources are given a quantitative or qualitative measure of the potential hazard they pose to groundwater. Prioritisation methods focus on aspects such as contaminant loading, mobility, persistence and risk. A risk analysis estimates the probability and consequences of a contaminant event and usually considers both the properties of the contamination source and the hydro-geological environment (WRC, 2004).

According to the WRC (2004) , using a fuzzy logic based approach when conducting the risk assessments takes the following factors into account. The main objective is to quantify aquifer vulnerability, the parameters needed for describing vulnerability are:

- Depth to groundwater
- Urban recharge
- Aquifer media (see chapter 5)
- Soil media
- Topography
- Impact of the vadose zone
- Health effects of contaminant.
- Source type
- Physio-chemical aspects of contaminant (exposure and dose-response assessment, see chapter 2)

Once this exercise is completed, a list of environmental liability parameters applicable to that landfill together with the relevant risk ratings will be forwarded to DWAF. The penalty fees will then be agreed by DWAF and the operator depending on extent of deviation from the acceptable standard of that parameter.

9.2.3 Site Preparation and Construction

Once approved, the landfill operator will start preparing the site. This involves the design and construction of the relevant infrastructure. This will include the design of the landfill liner system including leakage detection monitors according to DWAF-MR (1998) specifications.

9.2.4 Environmental Liability Costs Fund

The author proposes that an Environmental Liability Costs Fund be established, which will be under the custodianship of DWAF or an independent approved financial institution. A monthly fee will be charged to each landfill and will accumulate in the landfills unique account under that fund, and statements will be sent to the landfill quarterly. The monthly fee charged to each landfill will depend on the size of the landfill (*see table 6.1*) and the type of landfill (*see chpt 6.2.1*). An example of this monthly fee structure is shown below:

Table 9.2: Monthly Costs Fund Fee Structure - Example

		Type of waste		
		General	Hazardous	
Size of Landfill	Small			
	Medium	R25	R75	H:h
	Large	R50	R150	H:H

The author suggests that small sized landfills be exempted from this fee because they are normally non-money generating. The fee paid by general waste is less than hazardous because of the impact of the pollutants in the landfill, should there be any leakage into the underlying groundwater. The money collected will accumulate in the landfill operators account under the liability costs fund although a certain percentage of the accumulated funds may be given back to the landfill operator if they haven't claimed from the fund within a certain period. This is further discussed in the incentives program section later in this chapter.

9.2.5 Groundwater Quality Monitoring System

This step is the final part of this phase and leads into the second phase, which covers the operational and monitoring part. This step mainly includes how the groundwater quality monitoring system will be set up as the list of environmental liability parameters have already been determined. The DWAF-MR (1998) recommends that a water quality monitoring system be set up to ensure that the water quality in the vicinity of a disposal site is regularly monitored and reported throughout its life to enable a quick response where necessary. The ten sequential steps that entail the designing of the monitoring system have already been covered (see fig 6.8).

9.3 Operational Phase (Pollution Not Detected)

This phase covers detection monitoring and discusses the different steps that are covered depending on whether pollution is detected or not during the detection monitoring exercise. During this phase, detection monitoring is undertaken where a few environmental liability parameters are used in the groundwater quality testing. This is done because of the huge costs that come with testing for a lot of water quality parameters frequently

9.3.1 Monitoring Report

If no pollution is detected during the detection monitoring exercise, the groundwater quality monitoring report is compiled with the detection monitoring results and submitted to the relevant government department quarterly.

9.3.2 Quarterly Transactions Statement

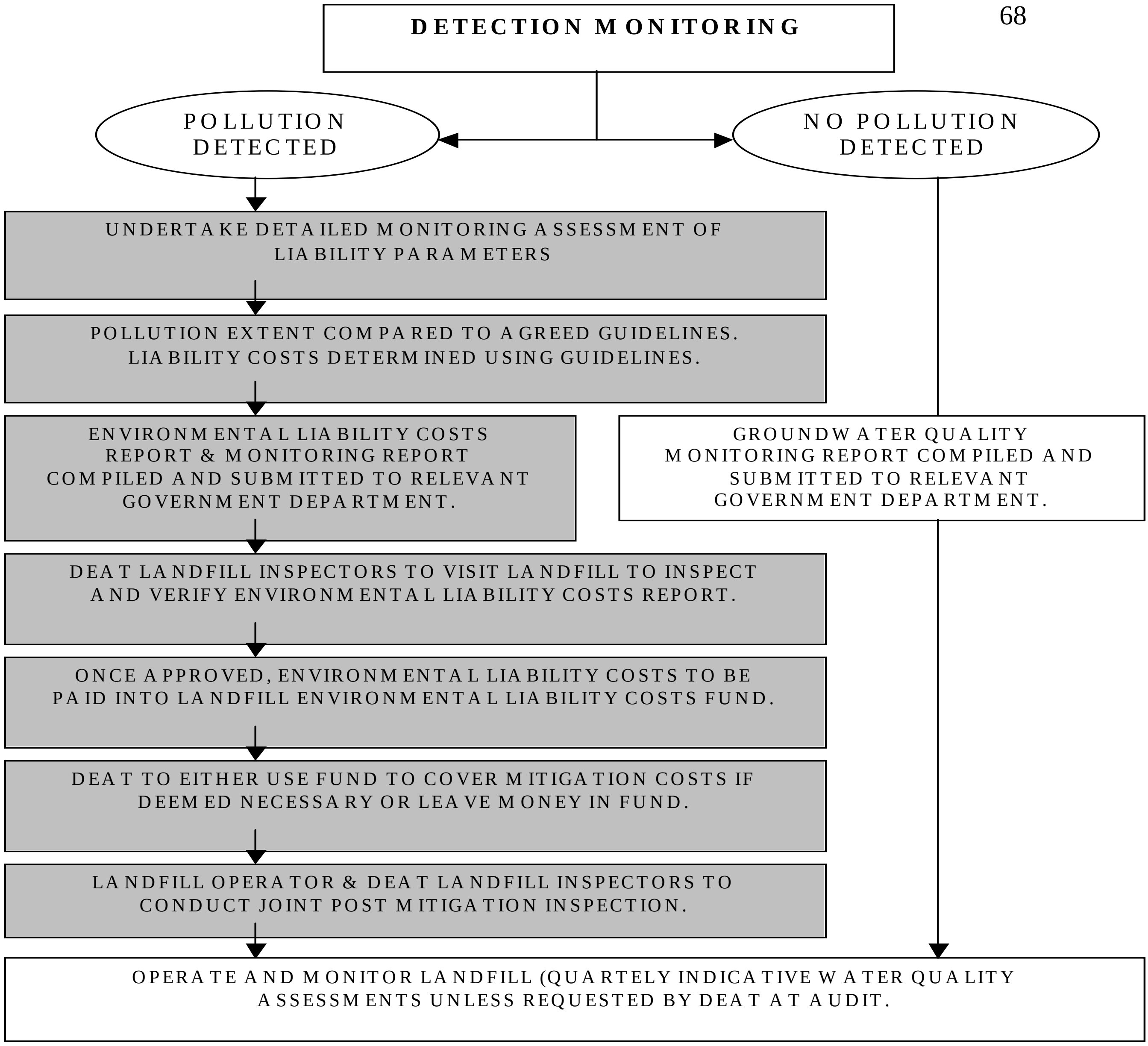
Receipt of monitoring report will be acknowledged by relevant government department and the quarterly account statement of the landfill will be sent to the landfill operator to show any financial movements in the environmental liability costs fund.

9.4 Operational Phase (Pollution Detected)

As discussed in the previous section that the aim of this phase is to detect any pollution parameter. . If detection monitoring indicates some liability parameters are above the stipulated standards, then a full groundwater quality investigation will be undertaken.

9.4.1 Detailed Investigation

If pollution is detected during the detection monitoring exercise, then a detailed investigative monitoring exercise must be undertaken.



LEGEND: GREY BOXES (PROPOSED STEPS)
WHITE BOXES (CURRENT DWAF MINIMUM REQUIREMENT)

Figure 9.2: Operational Phase of Proposed Methodology

9.4.2 Environmental Liability Penalty

The investigative monitoring results will then be compared to the agreed guidelines on the landfill operations permit. Any parameters above the standards will be deemed as liable to an environmental liability penalty. All the liability parameters above the stipulated standards will then be used to determine the total environmental liability cost to be charged to that landfill by the relevant government department.

9.4.3 Rehabilitation Cost Report

An environmental rehabilitation costs report will be submitted to the government department in addition to the normal monitoring report submitted quarterly. This report will explain in detail all the steps that are to be taken to rehabilitate the polluted environment and the costs that will be incurred during this exercise. These costs will be charged directly from the polluters account in the superfund and if there is still an amount outstanding, that amount will be charged directly to the polluter. These are classified as either compulsory or remediation obligations as discussed in chapter 3 and are also included in section 19 of the National Water Act as well as section 2 of NEMA (1998).

9.4.4 Initial Assessment Audit

The inspectors from the relevant government department will then conduct a high level audit of the landfill to verify the contents of the environmental liability costs report.

9.4.5 Payment of Costs

Once the costs report is confirmed by the inspectors the relevant government department can access the account on the liability costs fund and use the costs reflected on the report for remediation where necessary and demand any additional costs.

9.4.6 Final Assessment Audit

The inspectors from the relevant government department will conduct a high level audit of the landfill to ensure that all the work listed in the remediation report has been carried out to completion and the case is closed.

9.5 Incentives Programme

If a number of years pass and the landfill has been operating without any pollution incidents and their operations plan shows that they are investing towards avoiding pollution using best available practices, then that landfill may apply to get a certain percentage of the money in their account paid back to them tax free.

The author is therefore proposing a system that will be run like a pollution-risk insurance with incentives for landfills operators who adopt best practices in the running of their landfills by incorporating risk management The concept of environmental liability is also introduced with penalty fees assigned to each of these parameters. If the landfill exceeds any of these liability parameters during monitoring, then the landfill will be liable to pay the charges calculated using the penalty fees. The money will be paid into a unique account in the environmental liability costs fund. The fund is to either be under the custodianship of the relevant government department or an approved financial institution. The landfills are to be charged monthly and that money accumulated into the fund. If the landfill pollutes and the penalty charge against the landfill exceeds what is in the landfill’s account then they have to pay the difference. If there is any pollution, then the money in the account is debited and used for mitigating the effects of the pollution. All the points stated will be discussed further (Deltas, 2004; Schmitt, 2005).

10. CONCLUSION

The aim of this research was to highlight the importance of undertaking risk assessment and propose an environmental liability and risk management approach when dealing with groundwater quality monitoring, which leads to a more proactive way of risk management by landfill operators.

This report gives a general overview of the concept of risk assessment in landfills and explains how a risk assessment approach is used to protect the environment. From the DWAF-MR (1998), one is therefore made to believe that risk assessment for landfill sites is done for the sake of minimising the chances of leachate leaking through the liners and reaching groundwater. On that note, we might have to consider the risk estimation models, which take into account variability and uncertainties of leachate in the ground which eventually reaches the groundwater, e.g. Aquamod which is also briefly discussed. This confirms that there is a risk posed by a landfill, no matter how well engineered it could be and the risk assessment is for the sake of decreasing the chances for this risk taking place.

Taking a look at South African legislation, it is clear that the concept of environmental liability is entrenched in the legal system and so the document merely proposes to alter the approach currently used by the country. The author proposes a more proactive approach when using the environmental liability concept, which will result in a more harmonized risk management approach owned by both government and the landfill operators. This can therefore significantly reduce the need for monitoring and enforcement by government.

The DWAF-MR (1998) requires a Water Quality Monitoring Plan as part of its permitting requirements. The Water Quality Monitoring Plan ensures that the water quality in the vicinity of the landfill is regularly monitored and reported throughout its life, so that, where necessary, remedial action can be taken. Landfill X was used as a case study to showcase the practical implementation of the monitoring plan. The proposed environmental liability and risk management approach will therefore build up from this monitoring approach whilst introducing the aspect of environmental liability and integrating it into the water quality monitoring plan.

The author feels that the current DWAF-MR (1998) list of suggested parameters is sufficient and should therefore be used as the liability parameters. This list of parameters seems to be quite extensive and can be used in the background analysis to establish which parameters are relevant to that particular landfill site, which then becomes the proposed environmental liability parameters. As in the DWAF- MR document (1998), the parameters are grouped into inorganic and organic (volatile and semi-volatile) chemical parameters.

Each environmental liability parameter will be assigned a penalty charge and weight depending on a number of factors including:

- Location of the landfill i.e. distance to acquifer and GW level
- Geology of area
- Type of aquifer
- Type of landfill i.e. General of Hazardous
- Risk level of that parameter to human health i.e. Health Risk Assessment

The author proposes the introduction of an environmental liability costs fund with a compulsory monthly fee, which will be set up by both the landfill operator and the relevant government department. The water quality monitoring protocol will not differ much from the present structure. If pollution is shown during detection monitoring and a further detailed investigation indicates that exposure is higher than allowable limits, then a combined environmental liability penalty will be evaluated and the monetary value will be charged into the landfill operator’s account in the liability costs fund, although the landfill operator and DEAT can decide to use another method to determine the environmental liability e.g. liability insurance assessors. If the penalty required exceeds what has been accumulated in the liability fund account, then the difference will be demanded directly from the landfill operator. If the quarterly monitoring reports compiled by the operators show no mitigation claims into the liability find then the money accumulates in their account and a certain percentage will be paid back to the landfill operator as an incentive.

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APPENDIX

APPENDIX A – LIST OF VOC's MEASURED AT LANDFILL X

Volatile Organic Constituents	
Dichlorodifluoromethane	Tetrachloroethene
Vinyl Chloride	Dibromochloromethane
Trichlorofluoromethane	1,2-Dibromoethane
1,1 - Dichloroethene	Chlorobenzene
Dichloromethane	1,1,1,2-Tetrachloroethane
trans-1,2-Dichloroethene	Ethylbenzene
1,1-Dichloroethane	m,p-Xylene
cis-1,2-Dichloroethene	o-Xylene
2,2-Dichloropropane	Styrene
Bromochloromethane	Bromoform
Chloroform	Isopropylbenzene
1,1,1-Trichloroethane	1,1,2,2-Tetrachloroethane
1,1-Dichloropropene	1,2,3-Trichloropropane
Carbon Tetrachloride	Bromobenzene
1,2-Dichloroethane	n-Propylbenzene
Benzene	2-Chlorotoluene
Trichloroethene	1,3,5-Trimethylbenzene
1,2-Dichloropropane	4-Chlorotoluene
Dibromomethane	tert-Butylbenzene
Bromodichloromethane	1,2,4-Trimethylbenzene
Toluene	sec-Butylbenzene
1,1,2-Trichloroethane	4-Isopropyltoluene
1,3-Dichloropropane	1,3-Dichlorobenzene
	1,4-Dichlorobenzene
	n-Butylbenzene
	1,2-Dichlorobenzene
	1,2-Dibromo-3-chloropropane
	1,2,4-Trichlorobenzene
	Hexachlorobutadiene
	Naphthalene
	1,2,3-Trichlorobenzene

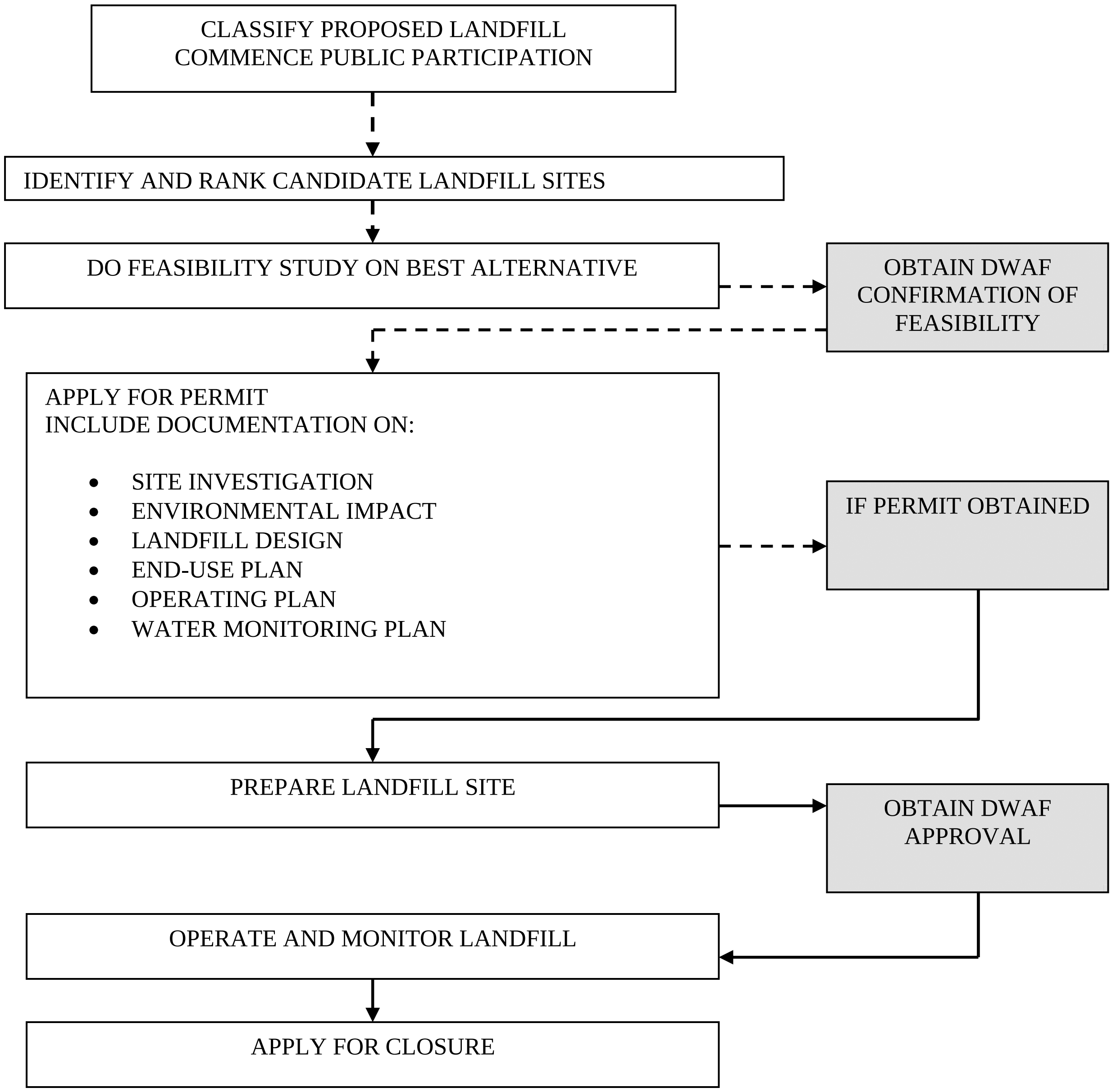
Source: Engineers Report, 2005.

APPENDIX B – LIST OF SVOC's MEASURED AT LANDFILL X

Semi Volatile Organic Constituents	
bis(2-Chloroethyl)ether	4-Bromophenyl-phenylether
Phenol	Hexachlorobenzene
2-Chlorophenol	Pentachlorophenol
1,3-Dichlorobenzene	Phenanthrene
1,4-Dichlorobenzene	Anthracene
1,2-Dichlorobenzene	Carbazole
bis(2-chloroisopropyl)ether	Di-n-butylphthalate
2-Methylphenol	Fluoranthene
Hexachloroethane	Pyrene
N-Nitroso-di-n-Propylamine	Butylbenzylphthalate
4-Methylphenol	Benzo[a]anthracene
Nitrobenzene	Chrysene
Isophorone	bis(2-Ethylhexyl)phthalate
2-Nitrophenol	Di-n-octylphthalate
2,4-Dimethylphenol	Benzo[b]+[k]fluoranthene
bis(2-Chloroethoxy)methane	Benzo[a]pyrene
2,4-Dichlorophenol	Indeno[1,2,3-cd]pyrene
1,2,4-Trichlorobenzene	Dibenz[a,h]anthracene
Naphthalene	Benzo[g,h,i]perylene
4-Chloroaniline	Dibenz[a,h]anthracene
Hexachlorobutadiene	Benzo[g,h,i]perylene
4-Chloro-3-methylphenol	
2-Methylnaphthalene	
Hexachlorocyclopentadiene	
2,4,6-Trichlorophenol	
2,4,5-Trichlorophenol	
2-Chloronaphthalene	
2-Nitroaniline	
Acenaphthylene	
Dimethylphthalate	
2,6-Dinitrotoluene	
4-Nitrophenol	
Fluorene	
4-Chlorophenyl-phenylether	
Diethylphthalate	
4-Nitroaniline	
4,6-Dinitro-2-methylphenol	
Azobenzene	

Source: Engineers Report, 2005.

APPENDIX C – CURRENT PROCESS OF OBTAINING LANDFILL OPERATING PERMIT



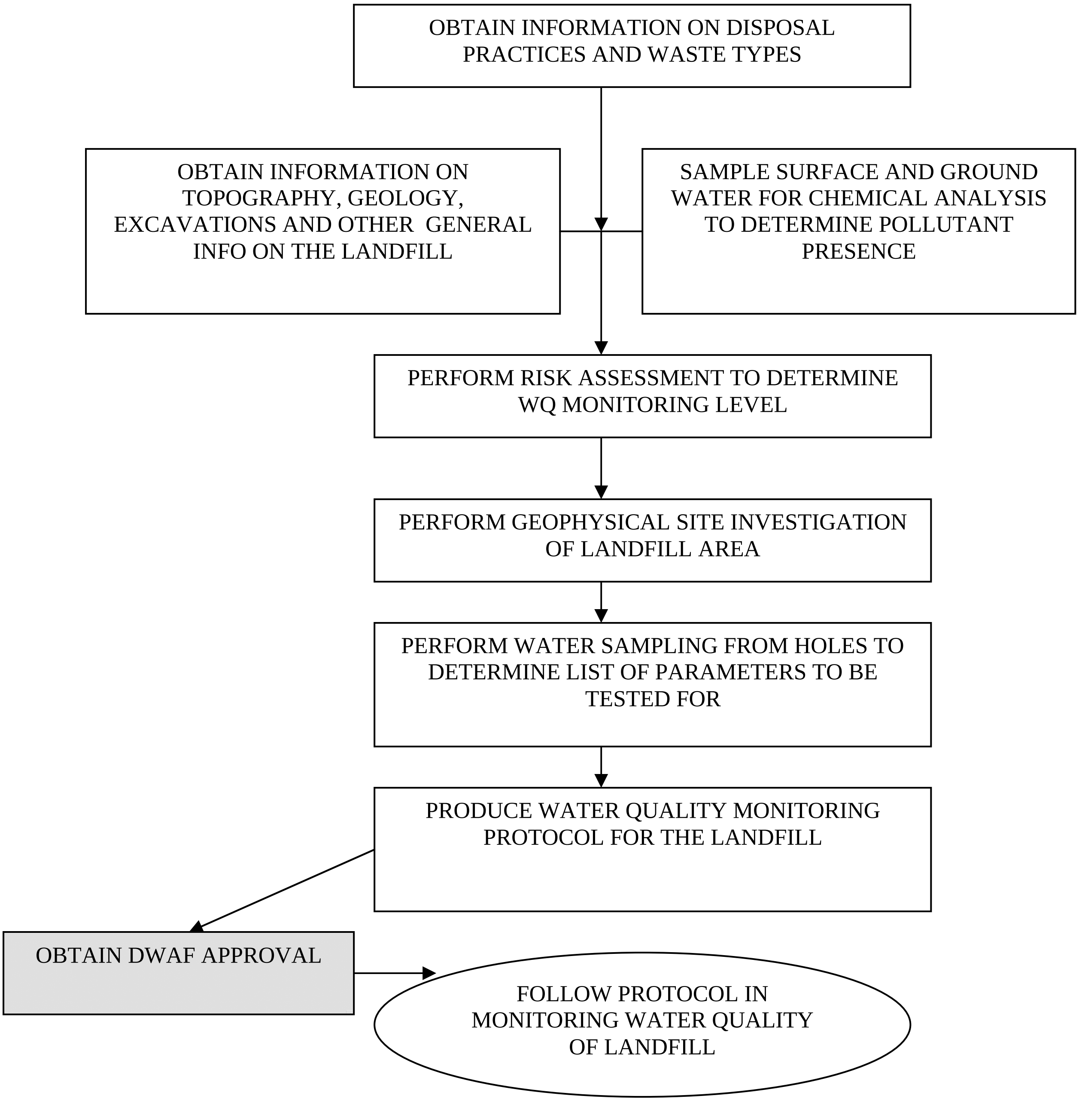
LEGEND:

Landfill sites without permits - - - - - →

Landfill sites with permits ———→

Source: DWAF- MR, 1998.

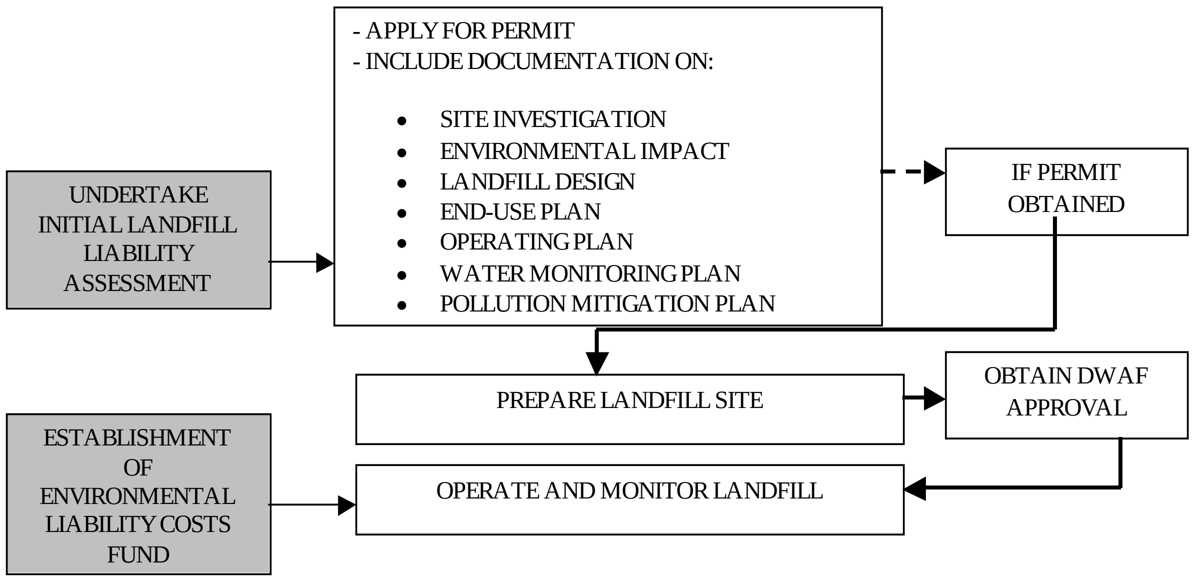
APPENDIX D – SEQUENTIAL STEPS FOR THE DESIGN OF A WATER QUALITY MONITORING SYSTEM



Source: DWAF-MR, 1998.

APPENDIX E – PROPOSED NEW ENVIRONMENTAL LIABILITY & RISK MANAGEMENT METHODOLOGY FOR INITIAL PHASE

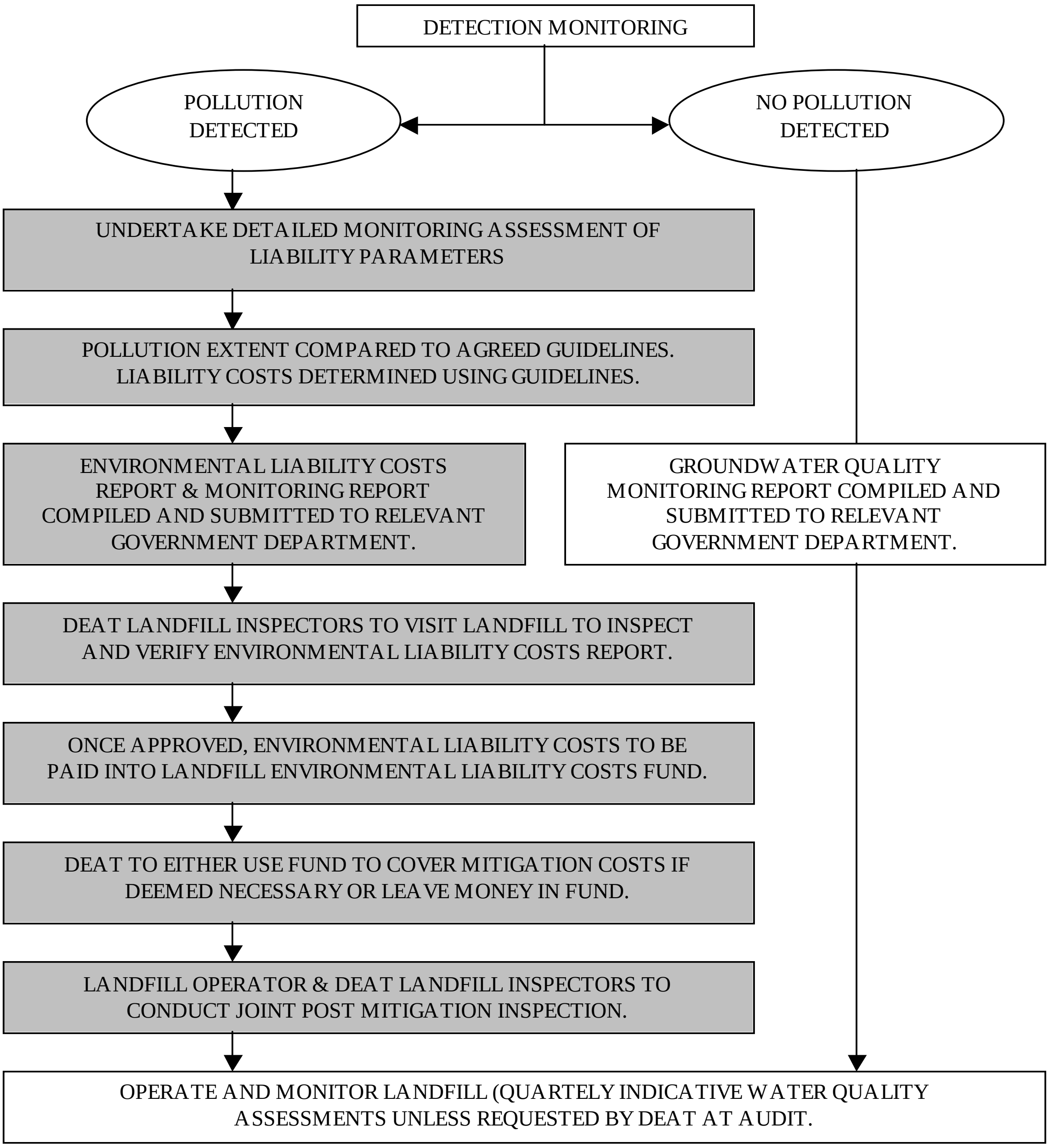
INITIAL INVESTIGATION PHASE



LEGEND: GREY BOXES (PROPOSED STEPS)
WHITE BOXES (CURRENT DWAF MINIMUM REQUIREMENT)

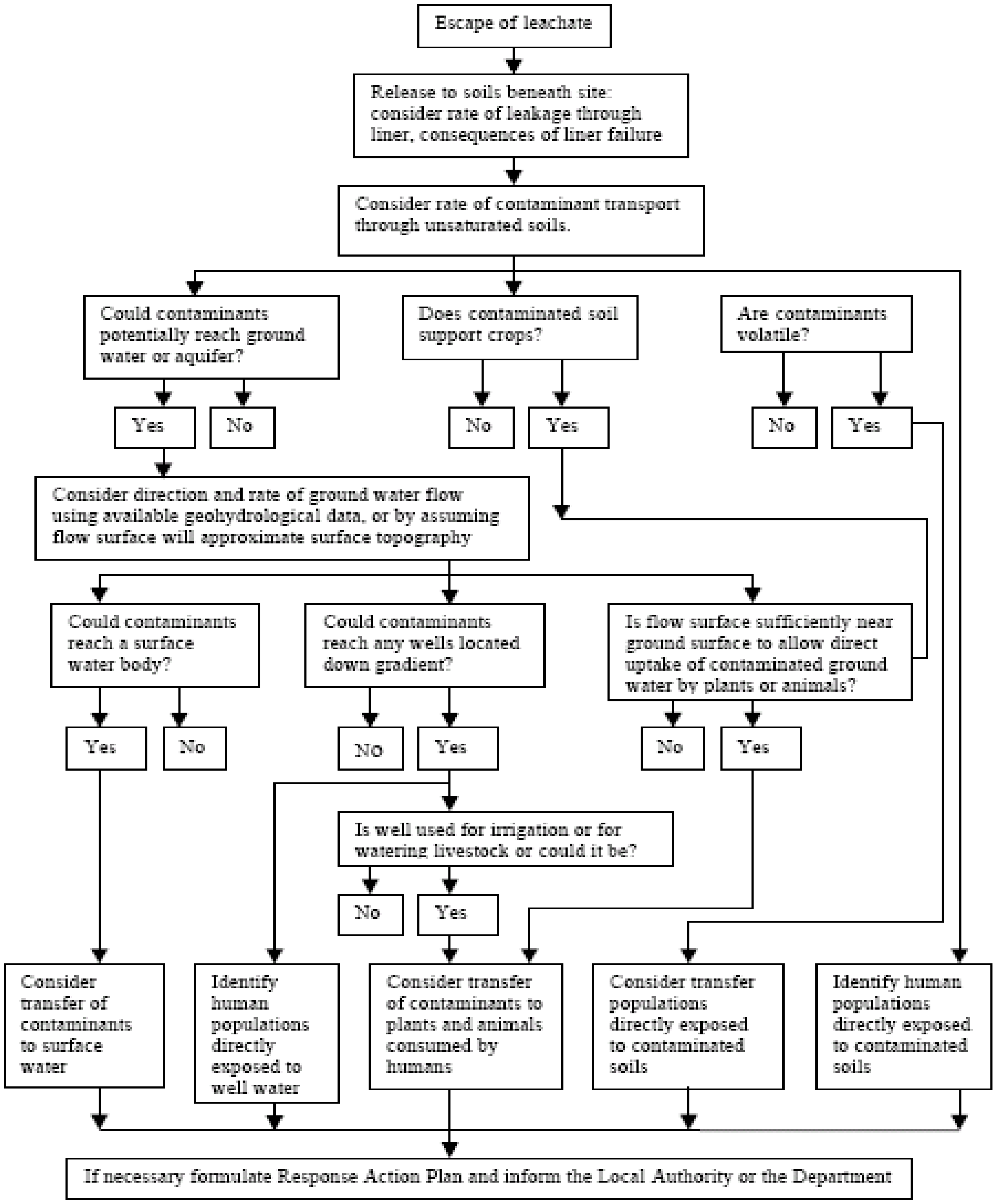
APPENDIX F – PROPOSED NEW ENVIRONMENTAL LIABILITY & RISK MANAGEMENT METHODOLOGY FOR OPERATIONAL PHASE

OPERATIONAL PHASE



LEGEND: GREY BOXES (PROPOSED STEPS)
WHITE BOXES (CURRENT DWAF MINIMUM REQUIREMENT)

APPENDIX G : ENVIRONMENTAL CONSEQUENCES OF LINER FAILURE TO GROUNDWATER (RESPONSE ACTION PLAN



Source: DWAF- MR (2005).

APPENDIX H: MINIMUM REQUIREMENTS FOR LANDFILL OPERATION MONITORING

LEGEND

B^- = No significant leachate produced
B^+ = Significant leachate produced
R = Requirement
N = Not a requirement
F = Flag: special consideration to be given by expert or representative(s) of the Competent Authority and/or the Department

LEGEND	CLASSIFICATION SYSTEM									
	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4
MINIMUM REQUIREMENTS	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+		
Responsible Person	R	R	R	R	R	R	R	R	R	R
Landfill Monitoring Committee	N	N	F	F	F	F	R	R	R	R
Conduct Audits	N	N	R	R	R	R	R	R	R	R
Conduct external Audit twice per annum	N	N	N	N	N	N	R	R	R	R
Appropriate records and data collection	R	R	R	R	R	R	R	R	R	R
Record deposition rate	N	N	R	R	R	R	R	R	R	R
Waste stream records, including cover	F	F	F	R	R	R	R	R	R	R
Height and slope surveys	F	F	F	F	R	R	R	R	R	R
Volume survey	F	F	F	R	R	R	R	R	R	R
Collect climatic statistics	N	N	N	F	N	R	N	R	R	R
Water quality monitoring	F	F	F	R	R	R	R	R	R	R
Gas management system	F	F	F	F	F	F	F	F	F	F
Gas monitoring system	F	F	F	R	R	R	R	R	R	R
Air Quality Management and Monitoring Plan	N	N	F	F	F	F	F	F	R	R
Stability monitoring	N	N	N	N	F	F	F	R	R	R
Monitoring of progressively remediated areas	F	F	R	R	R	R	R	R	R	R
Ongoing maintenance	R	R	R	R	R	R	R	R	R	R

Source: DWAF-MR (2005).

APPENDIX I: MINIMUM REQUIREMENTS FOR WATER QUALITY MONITORING AT A LANDFILL

LEGEND

- B^- = No significant leachate produced
- B^+ = Significant leachate produced
- R = Requirement
- N = Not a requirement
- F = Flag: special consideration to be given by expert or representative(s) of the Competent Authority and/or the Department

	CLASSIFICATION SYSTEM									
	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4
MINIMUM REQUIREMENTS	B^-	B^+	B^-	B^+	B^-	B^+	B^-	B^+		
Designate a Responsible Person	F	F	F	R	R	R	R	R	R	
Pre-operation Monitoring Surface water monitoring	F	F	F	R	R	R	R	R	R	R
Ground water monitoring	N	N	F	R	F	R	R	R	R	R
Background results reported in Permit Application Report	F	F	F	R	R	R	R	R	R	R
Water analysed in accordance with parameters in *Table 13.1*	F	F	F	R	R	R	R	R	R	R
Sample analysis in accord with SABS methodology or equivalent	F	F	F	R	R	R	R	R	R	R
Operation Monitoring Surface water monitoring	F	F	F	R	R	R	R	R	R	R
Ground water monitoring	N	F	R	F	R	R	R	R	R	R
Leachate treatment effluent/sludge/concentrate monitoring	N	F	N	R	N	R	N	R	R	R
Report sporadic leachate	F	F	F	R	R	R	R	R	R	R
Post-Closure Monitoring Post-closure surface water monitoring	N	F	N	R	F	R	R	R	R	R

Source: DWAF- MR (2005).

APPENDIX J: AQUIFER YIELD AND SIGNIFICANCE TABLE

Yield and significance classification highlights importance and sensitivity to pollution.

Yield	**Low**	**Medium**	**High***	**Very high**
Range	<1l/sec	1-5l/sec	5-20l/sec	>20l/sec
Potential usage	Stock, garden, domestic	Limited development potential	Small community	Large-scale water supply

Sole source aquifer	An aquifer that is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major aquifer	High-yielding aquifer of acceptable quality water.
Minor aquifer	Moderately yielding aquifer of acceptable quality or high yielding aquifer of poor quality water.
Non-aquifer	Insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special aquifer	An aquifer designated as such by the Minister of Water Affairs after due process.

Source: DWAF- MR (2005).

APPENDIX K: LANDFILL LINER DESIGN LAYERS

S layer: A waste separation layer consisting of a woven geotextile placed directly on top of the leachate collection layer (A layer) to protect the drainage media from possible biochemical clogging and/or blinding with fine waste particles. The installation of this layer depends on the nature and composition of the waste in the landfill.

O layer: A desiccation protection layer consisting of 150 mm of soil, gravel, rubble or other similar material that completely covers the B layer for $G:M:B^-$ and $G:L:B^-$ landfills and protects it from desiccation and cracking until it is covered by waste. Under certain circumstances, the thickness of the O layer may need to be increased.

A layer: A leachate collection layer comprising a 150 mm thick layer of single-sized gravel or crushed stone having a size of between 38 mm and 50 mm, and a system of perforated pipe drains located within the stone layer.

B layer: A 150 mm thick compacted clay liner layer. This must be compacted to a minimum density of 95% Standard Proctor* maximum dry density at a water content of Proctor optimum to optimum +2%. Permeabilities must be such that the outflow rates stated in Section 8.4.3 are not exceeded. Interfaces between B layers must be lightly scarified to assist in bonding the layers together.

The surface of every clay liner layer must be graded towards the leachate collection drain or sumps (see section 8.4.4) at a minimum gradient of 2% for general waste disposal sites and 5% for hazardous waste disposal sites. At the discretion of the Competent Authority, up to 4 x B layers may be replaced by a GCL of at least equivalent performance, (in terms of permeability, toughness and chemical resistance) supported on a 100 mm thick silt/sand layer.

C layer: This is a layer of high modulus geotextile laid on top of any D layer to protect it from contamination by fine material from above.

Source: DWAF-MR (2005).

APPENDIX K: LANDFILL LINER DESIGN LAYERS (CONT'D)

D layer: A leakage detection and collection layer. This is always below a C layer and above a B layer in B^+ and hazardous waste landfills. In lagoons it is underlain by an E layer which protects the second FML or geomembrane. It has a minimum thickness of 150 mm and will consist of single-sized gravel or crushed stone having a size of between 38 mm and 50 mm. At the discretion of the Department (formal communication should take place through the Competent Authority), this layer may be replaced a geosynthetic drainage of at least equivalent drainage performance.

E layer: This is a cushion of 100 mm of fine to medium sand or similar suitable material which is placed immediately above any F layer to protect it from mechanical damage.

F layer: A geomembrane or flexible membrane liner (FML) which must be laid in direct contact with the upper surface of a compacted clay B layer. A geomembrane is a Minimum Requirement for all hazardous waste landfills and lagoons. In the case of an **H:h** landfill, it is a 1,5 mm thick geomembrane underlain by four B layers. In the case of an H:H landfill, it is a 2,0 mm thick geomembrane underlain by four B layers. In the case of a hazardous waste lagoon, there are two geomembranes. The first is 2,0 mm thick underlain by four B layers and the second is 1,0 mm thick underlain by two B layers[34].

The geomembrane thickness specified shall be minimum nominal thickness, as measured in accordance with the SANS 1526:2003.

G layer: This is a base preparation layer consisting of a compacted layer of reworked in-situ soil with a minimum thickness of 150 mm and constructed to the same compaction standards as a B layer. Where the permeability of a G layer can be proven to be of the same standard as a B layer, it may replace the lowest B layer.

The surface of every G layer must be graded towards a leachate collection drain or sump in the case of B^+ landfill or to a central channel on the down gradient side of a B^- landfill, from which sporadic leachate can be collected if it occurs. The central channel must contain a prism of A layer material with a perforated pipe drain so as to act as an efficient leachate collector or finger drain. The minimum gradient must be 2% for **G** sites and 5% for **H** sites.

Source: DWAF-MR (2005).