INTRODUCTION

The limited availability of suitable land for landfills in the eThekwini Metropolitan Area, which incorporates the City of Durban on the east coast of South Africa, has resulted in landfills being sited in close proximity to residential areas. The establishment of landfills in these areas has also ensured that the cost of waste disposal is not excessive, as the disposal facility is located in close proximity to waste generators, which is vital in the context of a developing economy. The development of such landfill sites has, however, necessitated a shift in the engineering philosophy, which now combines environmentally sound landfill operations, active community participation and leading technology. This has resulted in landfills that can be considered assets to the environment and local communities and even be potential tourist attractions!

A landfill life-cycle typically involves definitive stages, these being the planning and permitting, design, operation, closure and rehabilitation, and aftercare. In the past, these stages have generally been considered independently, particularly that of closure and rehabilitation. This paper describes engineering practices that incorporate all facets of a landfill life-cycle and presents an integrated approach to the management of landfill sites.

A shift in landfill operations from the ‘open dump’ to ‘sanitary landfill’ in line with Best Practice and government legislation has necessitated the involvement of Engineers. In addition to ensure adequate stormwater control and leachate drainage systems for the site as a whole, the daily placement of waste is essentially a bulk earthworks operation, with the requisite intermediary stability requirements and stormwater control being intrinsic in the operation. In addition to this, the management of odours during the operation of a landfill and the long term management of odourous and potentially explosive landfill gas (LFG) and the management of leachate are pertinent to the operation of a sustainable landfill.

The Department of Cleansing and Solid Waste (DSW) have to date developed “extreme engineering” solutions to the traditional problems associated with landfills including:
• Understanding of odour plume movement through the study of wind and terrain effects using atmospheric dispersion modeling thus allowing for appropriate mitigation strategies to be implemented

• Introduction of a ‘closed loop design’ philosophy to landfills - This involves the completion of landfill cells to final design levels to allow for continuous rehabilitation and re-instatement to the original environment during the operational life of the landfill. Further to this, it also includes the management and treatment of landfill emissions (LFG and leachate) to standards where they can effectively be returned to the receiving environment.

ODOUR MITIGATION AND LANDFILLING IN URBAN AREAS

Arguably the biggest obstacle to the operation of landfills in residential areas and contributor to the NIMBY (Not In My Back Yard) attitude is odour. Some one decade ago, ‘open dumps’ were common place in South Africa and quite understandably lead to the stigma associated with ‘dumps’. The introduction and enforcement of the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1994; 1998) has ensured graded standards for landfills and that communities surrounding landfills have a voice through public participatory processes.

In 1999, DSW embarked on a research project in conjunction with the University of Kwa-Zulu Natal (then University of Natal) aimed at understanding the development and movement of odour from a landfill site and to develop possible mitigation strategies (Laister et al, 2002; Stretch et al, 2001). The research was conducted at the Bisasar Road Landfill Site in Durban, KwaZulu-Natal - one of busiest landfill sites in South Africa, receiving an average of 3 000 tons/day of MSW (Municipal Solid Waste). The landfill is located in the heart of a residential area, making odour mitigation strategies vital in the sustained operational development of the landfill.

The initial part of the research was aimed at the development of a real-time model that could predict the movement of an odour plume from an odour source (e.g the landfill working face). The results of the modeling would enable DSW to proactively mitigate the odour. The key technological component was the numerical dispersion modeling with the capability to predict the off-site migration of odour and to track the source of odour problems (Laister et al, 2000). Evaluation of the complaints log for a period of three years indicated that the residential areas surrounding the site (predominantly located to the south west of the landfill) were significantly affected by the predominant north-easterly wind direction. Various numerical atmospheric dispersion models were evaluated, with the ADMS™ model being chosen as the most appropriate and is regarded as the one of the most advanced modern dispersion models.

An Odour Management System (OMS) was born out of this initial research, with a real-time visual prediction of the odour plume from the landfill. The OMS receives information from the on-site weather station, various static parameters and the odour source (generally the filling location) to generate the visual display on an on-site computer every 10 minutes, which is readily accessible to the landfill operator. This allows DSW to accurately determine where odour is expected to be
problematic, and therefore time to introduce mitigation strategies. Typical strategies include the automatic activation of an odour neutralizing spray system located on the boundary of the site, early closure and covering of the working face and application of larger quantities of cover material. In addition, the predication modeling can be used to determine the most appropriate filling locations in relation to the prevailing climatic conditions so as to minimise the impact of odour on the surrounding community. Figure 5 shows a press article demonstrating success of the OMS.

The research project was validated by the involvement of the community in form of questionnaires. In this way, the theoretical modeling could be compared to the actual odours being detected by the community, which had the additional benefit of having the community being part of the mitigation strategy. An odour-nose electronic device was also utilized as an additional checking tool.

A further outcome of the OMS is the effect of complex terrain in the movement of air (and hence odour). It was found that the influence of the topography could effectively channel odour in a vastly different direction to the prevailing wind direction, and hence the construction of the landfill can influence the location of where odour is detected. This is indeed a vital finding, and could ensure the successful operating of landfills in or close to residential areas as landfill design incorporates the sensitive receiving locations into the operational plan to ensure that odour is channeled to less sensitive locations. Figure 7 presents a typical OMS plot, showing the movement and intensity of the odour plume and the possible location of complaints.

CHARACTERISATION OF LANDFILL EMISSIONS UNDER A SUB-TROPICAL CLIMATE

A further research project undertaken by DSW in conjunction with the University of KwaZulu-Natal focused on the characterisation and management of landfill emissions under a sub-tropical climate as experienced in the eThekwini Municipality region (Bowers, 2002; Bowers et al 2002; Trois et al 2001). The aim of the research was to determine the effects of the high rainfall and warm, humid climate on the duration and concentration of landfill emissions. In addition, the benefits of a 'cellular' landfill operation were investigated. The sites chosen for the study were the Bisasar Road Landfill site in Durban, and the Mariannhill Landfill Site in the Pinetown region.

Leachate Characterisation

Two landfill cells at the Mariannhill Landfill Site and the newly lined “Randles Cell” at the Bisasar Road Landfill Site were studied in the research project, with leachate samples being collected over a period of three years. These ‘new generation’ landfill cells presented the ideal case study as they were constructed to modern text-book standards, particularly with regards to the leachate management with each cell having a separate leachate collection system. This enabled accurate sampling and characterisation of the individual leachates.
Leachate samples were collected from the leachate discharge pipes on a weekly basis. A sample analysis suite was chosen based on the typical parameters used to determine the level of biodegradation of leachates (and hence of the waste body), and included the COD (Chemical Oxygen Demand), pH, Ammoniacal-Nitrogen, Alkalinity, Chloride and Solids.

Figure 1 shows the leachate sampling results for the Randles Cell. As can be seen from the Figure, the pH range consistently remained between 7 and 8, with only the first sample analysed showing signs of an acetogenic leachate. Within three months after the start of disposal operations, the leachate showed characteristics of a stable methanogenic leachate (relatively low COD, neutral pH, raised NH$_4$-N). This is in contrast to typical time frames reported in the literature that suggest a period of 2-3 years is required before stable methanogenisis is reached (Robinson, 1993).

Figures 2 and 3 present the results of the sampling analyses for Cells 1 and 2 at the Mariannhill Landfill Site. The sampling of Cell 1 began some 3 years after the opening of the cell, and some 16 months after the closure of the cell. The sampling of Cell 2 began approximately 14 months after the opening of the cell, with the closure of the cell occurring during the course of the sampling period.

As is shown in Figures 1 and 2, the leachates from both Cells exhibit typical *stable* methanogenic characteristics, with relatively low COD concentrations, neutral pH and Ammoniacal-Nitrogen concentrations in the 400-700 mg/l range. This suggests that the leachates had already reached the typical methanogenisis stage prior to sampling and further indicates that the onset of methanogenisis occurs at an accelerated rate in the Durban region.

![Figure 1](image-url)  
**Figure 1** Variation of the COD, Ammoniacal-Nitrogen and pH with time for the Randles cell leachate (Bowers et al, 2002)
Biogas Characterisation

In addition to the leachate characterisation, biogas sampling and characterisation was also undertaken. The biogas was sampled by means of shallow probes driven into landfilled waste of varying age to a depth of two metres. Various areas of the Bisasar Road and Mariannhill Landfill Sites were used in the research.

The composition of the sampled biogas over time presents an insight into the biodegradation characteristics of the waste body, and in particular the concentration of methane provides conclusive evidence of the presence of methanogens and hence the stage of biodegradation. Table 1 presents a summary of the results of the research, showing the approximate time at which methanogenic conditions were reached in the waste body. The results indicated that methanogenic conditions (considered to be 40% methane (vol/vol)) are reached between six and
nine months under the Durban climatic conditions. The full results of the biogas characterisation are presented in Bowers (2002).

**Table 1** Summary of the time required for establishment of methanogenic conditions for each set of 2m deep shallow probes at the Bisasar Road and Mariannhill Landfill Sites.

<table>
<thead>
<tr>
<th>SET OF SAMPLING PROBES</th>
<th>TIME OVER WHICH PROBES WERE SAMPLED</th>
<th>AGE OF METHANOGENIC WASTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisasar Road Plateau Area</td>
<td>4 months</td>
<td>&lt; 1 year</td>
</tr>
<tr>
<td>Bisasar Road - Randles Cell</td>
<td>2 months</td>
<td>&lt; 9 months</td>
</tr>
<tr>
<td>Mariannhill Cell 1</td>
<td>1 year</td>
<td>&lt; 1 year</td>
</tr>
<tr>
<td>Mariannhill Cell 3</td>
<td>3 months</td>
<td>4 – 6 months</td>
</tr>
</tbody>
</table>

THE CLOSED LOOP LANDFILL

The Mariannhill Landfill Site presents a landfill development where landfill engineering methods have successfully combined to realize South Africa’s first landfill conservancy. The Mariannhill Landfill Site, opened in July 1997, was located to leading world standards being well hidden from the public view by the natural topography and well established vegetation (Strachan et al, 2002). The landfill currently receives some 550~700 tons/day of MSW (Municipal Solid Waste).

The traditional civil engineering item ‘clear and grub’ is indicative of environmental engineering ignorance (Strachan et al, 2002). The value of the original soil profile at the Mariannhill Landfill was identified from the onset of a Conservancy creation plan, as a vital component to the environmental equation that must be rescued for effective rehabilitation to be realized.

**PRUNIT (Plant Rescue Unit) Nursery**

Further to the process of soil recovery, it was evident that vast tracts of indigenous vegetation exist both within the buffer zone and the waste footprint of the landfill property. A holding nursery was therefore created to store rescued indigenous vegetation from within the landfill footprint prior to lining works and consequent landfilling operations. The PRUNIT concept has proven to be both environmentally and economically successful. PRUNIT has provided indigenous vegetation to the peripheral buffer zone areas of the site, as well as to rehabilitated areas of the Bisasar Road Landfill. In fact, PRUNIT has realised the low cost remediation of several old, defunct ‘dump’ sites within the eThekwini Municipal Area (EMA).
The Landfill Conservancy

The Mariannhill Landfill Site is an excellent example of an ecosystem restoration project, which is becoming increasingly important in biodiversity conservation. The loss of natural ecosystems as a result of rapid urbanization is occurring to a larger degree, and restoration projects have become a vital tool in preserving and improving existing ecosystems. Benefits include the minimisation of biodiversity losses and increasing connectivity in nature reserve networks. Some of the results realized through the Mariannhill Landfill Conservancy include (Strachan et al, 2002):

- Mariannhill was the first landfill site, possibly worldwide to be incorporated into an ecosystem restoration site and be a registered National Conservancy Site
- The maintenance of the indigenous ecosystem minimises biodiversity loss in the area
- The landfill site serves as an important natural corridor for species migration
- The conservancy is open to the general public and boasts more than 80 different species of birds
- Numerous job opportunities and skills development
- Education of learners, students and the general public is effective and ongoing.

Cellular Landfilling

Intrinsic to the Mariannhill Landfill Conservancy is the continuous restoration of areas of the landfill and re-instatement to the original environment. As described earlier, waste degradability under the sub-tropical climate of KwaZulu-Natal results in stable methanogenic conditions being established in the waste body relatively soon after the waste is placed. The high biodegradation rate of the waste and the natural flushing of the pollutants to low levels allows for the management of the landfill in a series of containment cells. These completed cells can then be rehabilitated and introduced back to the natural environment during the operational life of the site, with the associated return of flora and fauna to the site.

Removal and Re-use of Landfill Gas

The cellular landfilling management approach further allows for the capture of landfill gas almost immediately after the closure of a landfill cell due to the rapid biodegradation sequence and the arrangement of the rehabilitated cells presenting tracts of undulating to flat land suitable for the insertion of gas wells. The recent availability of carbon finance, since South Africa’s recent signing of the Host Country agreement, has created the possibility that landfill gas-to-electricity generation can be financially viable (Strachan et al, 2003). The viability has been presented through the Kyoto protocol’s derived Clean Development Mechanism (CDM).

The eThekwini Municipality has a proposed project (currently in the EIA process) that will combat climate change and will find a financially viable use for the power potential of landfill gas. The project is made possible through “Carbon Finance” which is channeled through the World Bank’s Prototype Carbon Fund (PCF) – a Public-Private partnership with several participants world wide.
The Mariannhill Landfill Site currently has six gas extraction wells linked to a 500 Nm³/Hr flare unit, which has been in operation for some four and a half years. This gas collection system could prove an adequate starting point as a pre-injection treatment system for the engine generators, albeit that these wells form the current “baseline condition” for the proposed CDM project. As is typical to most landfill gas extraction systems world wide, landfill gas will be drawn from wells through pipe work systems by extraction equipment and fed to spark-ignition type electrical generation units, with any surplus gas, or “spill-over” gas being flared. Figure 6 shows the cover of a DSW publication as an attempt to inform the general public on this landfill gas CDM project.

Treatment and Re-use of Leachate Emissions

DSW began leachate treatability trials in 1998 in collaboration with Enviros UK. The trials demonstrated that the Mariannhill Landfill leachate could be treated to high standards, within the limits of the discharge standards required by the Department of Water Affairs and Forestry for discharge of waste water by irrigation. The findings of the research allowed DSW to design a full-scale leachate treatment plant for the Mariannhill Landfill.

The overall philosophy of the treatment process is the use of ‘natural, low cost and robust’ treatment processes. This plant, therefore, adopts aerobic biological primary treatment processes and secondary ‘polishing’ treatment by vegetated wetlands. The aim of the treatment process is to remove the ammoniacal-nitrogen from the leachate as this is one of the most consistent contaminants in leachate and is not removed biologically during degradation processes in the landfill. In addition, the aerobic treatment process is aimed at the removal of readily biodegradable COD (chemical oxygen demand).

The treatment plant, commissioned in February 2004, comprises a Sequencing Batch Reactor (SBR) unit, constructed of reinforced concrete 10 metres in diameter and 6 metres deep. The capacity allows for the treatment of up to 50 m³ of high strength leachate daily. The plant also consists of a lined reedbed which provides secondary ‘polishing’ treatment for the removal of residual BOD (Biochemical Oxygen Demand), COD and solids. All treated effluent from the SBR is fed to a balance tank, which is level controlled to supply a portion to a standpoint for use by the site water tanker for dust suppression and a portion to the reedbed. The effluent from the reedbed is then used for irrigation of the landfill conservancy areas. All processes within the treatment plant are controlled by a program logic controller (PLC), which has a visual interface on a computer.

Results to date indicate that there is 100% removal of ammonical-nitrogen, and a decrease in COD of some 75%. The remaining COD is considered to be refractory, and is therefore not harmful when returned to the environment.

Figure 4 presents an aerial view of the Mariannhill Landfill Site showing the various aspects of the ‘closed loop design’
Figure 4 (Top): Aerial view of the Mariannhill Landfill Conservancy;

Figure 5 (Left): Success of the Odour Management System (OMS);

Figure 6 (Right): eThekwini-DWS embarks on a landfill gas to electricity CDM project;

Figure 7 (Bottom): Screen display of OMS predictions
CONCLUSION

The various engineering strategies applied to DSW landfills, as described in this paper, have shown that landfills can be operated within or very close to residential areas, to high standards with minimal impact on the receiving environment. The continuous closure and rehabilitation of small landfill cells and introduction of indigenous vegetation through DSW’s ‘PRUNIT’ method helps foster acceptance of landfills by the community, as they are seen to add value rather than to detract from the surrounding environment. The development of the Mariannhill landfill is an example of what can be achieved when traditional engineering principles combine with sound environmental methodologies.

REFERENCES


