EXTREME LANDFILL ENGINEERING: DEVELOPING AND MANAGING SOUTH AFRICA’S BUSIEST AND LARGEST LANDFILL FACILITIES

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ABSTRACT

The City of Durban owns and operates landfill sites that are arguably the busiest in South Africa with daily waste tonnages to one site reaching 5,200 tons. The sustainable development of the eThekwini Municipality does demand that funds are appropriately directed elsewhere, and that DSW succeed as a business unit within the City’s structure. The Bisasar Road Landfill is the present old facility which presents an extreme challenge being situated within the heart of a residential area, whilst the Buffelsdraai Landfill is eThekwini’s newly developed regional landfill that is situated some 35km to the north of Durban. Extreme challenges foster extreme measures. Indeed, odour management and mitigation is of the most important of measures. This paper illustrates the extreme engineering measures that the DSW engineers have adopted to ensure that Durban’s Landfills are well managed within residential areas, and new landfills appropriately engineered and managed as new generation waste treatment facilities.

It is now apparent that the economics of solid waste management are navigating a course for extreme landfill engineering measures. This paper addresses the economical and operational rationale for ongoing landfill rehabilitation, which could be an intrinsic part of the daily landfill operation and overall landfill design. This paper argues that no rehabilitation stage need exist with landfill developments.

The paper presents new techniques and innovation to landfill management. Extreme engineering applied to landfills will certainly increase the life-spans of many existing old landfill sites. However, the authors present a firm argument as to why landfilling of waste in a large regional landfill facility, which offers the “catch-net” to solid waste management for a metro, will remain as the most appropriate technology far into the foreseeable future.

KEYWORDS

Appropriate engineering; rehabilitation; odour mitigation; closed loop landfill; leachate treatment.
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 predicative 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(a) 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 NH₄-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).

Figure 1(b) presents the results of the sampling analyses for Cell 1 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. As is shown in this Figure, the leachate from this cell exhibits 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 leachate 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.
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 worldwide.

The Mariannhill Landfill Site currently has six gas extraction wells linked to a 500 Nm$^3$/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 m$^3$ 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 2 presents an aerial view of the Mariannhill Landfill Site showing the various aspects of the ‘closed loop design’.

**THE BUFFELSDRAAI LANDFILL FACILITY**

The new Buffelsdraai landfill was recently opened on 1st June 2006 with the closure of the La Mercy Landfill that had reached its full design capacity. The Buffelsdraai landfill is South Africa’s newest large-type regional landfill for General Waste and is the eThekwini Municipality’s flagship site offering a “disposal catch-net” of available landfill airspace volume for the foreseeable future for the greater municipal area of eThekwini and north coast resorts. The potential daily waste stream to Buffelsdraai, upon closure of the current Bisasar Road Landfill, will be some 6,000 tons/day. Indeed, it is hoped that the anticipated “Zero Waste” objectives of eThekwini would reduce such a waste volume considerably. The Buffelsdraai Landfill is situated on the 900 hectare Buffelsdraai farm, approximately 8 kms west of the town of Verulam in the north-western reaches of the eThekwini Municipal area. The footprint of the refuse disposal area will cover 100 Ha whilst the remaining area is to serve as a peripheral **buffer zone**. The total air space of Buffelsdraai is some 50 million cubic meters and is expected to serve the City for the next century. The site is a permitted GLB+ landfill in terms of the Minimum Requirements for landfill (DWAF; 1994, 1998, 2005) which allows the disposal of general type wastes. The Buffelsdraai Landfill is remotely located at a great distance from residential properties and in particular to note – municipal sewer
The landfill, it is anticipated, will produce up to 200 000 litres per day of leachate. The site is one of very few large landfill facilities located in a high rainfall region wherefrom potentially extreme volumes of contaminated water could arise. Extreme engineering concepts applied in eThekwini have also demanded that the site be developed along the guidelines as a national conservancy and discharge waters to the nearby stream are of a high quality standard. The water management design for the site has, therefore, demanded that the risks of contamination of surface waters are minimized. Additionally, that the recycling or reuse or waters within the site, whether they be rainfall or leachate derived, be maximized.

The initial phase of the construction of the site has allowed for containment only of the leachate wastewaters of some 340m$^3$. High flow storm waters that could be described as potentially contaminated are designed to discharge to a pollution settlement pond of some 10 500m$^3$ capacity. A shortcoming of any landfill waste water management system could be from the method of operations or the design of discharge and treatment systems provided on site. Firstly, the landfill cell must provide for the effective separation of clean storm waters and contaminated leachate waters during a rainfall event during the filling of the landfill cell – in particular the early days when the vast area of the leachate drainage layer is exposed. The landfill operation must be extremely neat in these early days to ensure that wastes are confined with specific drainage sub-cells (so to speak). Landfilling from the ‘top-down’ or ‘bottom-to-the-top’ approach must be strongly considered so to avoid the risk of a little leachate contaminating a large volume of clean water – as opposed to some dilution of some already high strength leachate. This is particularly crucial in a valley type landfilling operation where stability concerns are equally paramount to water quality management. Secondly, the adoption of ‘plug-flow’ systems should be avoided whereby, for example, the overflowing of leachate containment tanks could cause the release of the highest strength leachate to the pollution dam. Because of the extremely high strength of leachate likely to be generated over extended periods at Buffelsdraai, particularly from ammoniacal-nitrogen at levels of 1000~2000 mg/l, and because very low levels of contaminants can have significant impact on water quality for example 5-10 mg/l of ammoniacal-nitrogen can kill fish life, and when water is chlorinated for drinking, 2 mg of ammoniacal-nitrogen can have a severe impact on taste, then very low volumes of leachate entering into the stormwater containment dam will require that this water must be removed or treated. The volume of the Buffelsdraai dam could therefore be rendered contaminated should as little as 20~30 m$^3$ of high strength leachate discharge into it. Such a treatment cost would certainly be extreme. Hence, the extreme engineering applied at Buffelsdraai ensures that the strongest leachates are discharged to containment tanks that are dosed to the leachate treatment plant; the weak or highly diluted leachate is discharged to alternative containment and the lowest contaminant or clean storm waters are discharged to the containment dam. Since the site is managed as a conservancy comprising much indigenous vegetation, the reuse of the weak leachate and contained dam water is through irrigation systems or stand points for discharge to the site water tanker.

In June 2006, similar to the already established Mariannhill Leachate Treatment Plant (LTP), the Enviros (UK)-eThekwini team again collaborated to jointly design the leachate treatment plant for the new Buffelsdraai Landfill Site. This effective method of collaboration not only ensures upon the creation of an effective technical skills transfer to the eThekwini’s in-house technical team, but project costs are less (savings on design fees) and there are extreme benefits to the future operating of the plant with regards to in-house skills capacity.
Figure 2 (Top): Aerial view of the Mariannhill Landfill Conservancy;

Figure 3 (Left): Success of the Odour Management System (OMS);

Figure 4 (Right): eThekwini-DSW embarks on a landfill gas to electricity CDM project;

Figure 5 (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


