Maximizing Landfill Capacity By Vertical Expansion – A Case Study For An Innovative Waste Management Solution

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ABSTRACT

It is forseeable that a landfill can prematurely run out of its design capacity for reasons such as unanticipated population growth, response to huge amount of debris waste from a natural disaster (e.g., hurricane), or because of an unexpected long permitting/approval process for a new landfill site. From the cost-benefit and timing standpoints, a vertical expansion of an existing landfill or a lateral expansion between two adjacent landfill cells provides an excellent and innovative waste management solution to solve the capacity problems. The vertical expansion, or the piggyback approach, is basically constructing a new landfill on top of one that is either closed or scheduled to be closed at an already-permitted site. By placing the expansion landfill on top of another landfill, it gains immediate airspace, increasing landfill lifespan, and fully maximizing utilization of the area that has already been disturbed for waste disposal.

The case study site is located in Frederick County, Maryland, USA. It is designated as "Site B" and has about 23 hectares (58 acres) of footprint. Due to a huge population growth in late 90s, the owner had to look into other options to accommodate the increasing waste volume and the resulting depletion of landfill capacity. Because of the time required for permitting a new landfill site, it became obvious that vertical expansion of the existing Site B made the most sense from economical and permitting points of view. As part of the vertical expansion, the final grading plan of Site B was modified from 1(V):4(H) to a 1(V):3(H) sideslope. The maximum waste height was raised by about 33 m or 107 feet.

The vertical expansion results in an airspace gain of about 1.8 million m^3 (2.4 million cubic yards), which extends the landfill lifespan by about 4.6 years, (based on an average of 1,375 tons per day, a 6-day per week operation, and a waste density of 959 kg/m^3 (1,620 pcy)). In this paper, it is shown that the vertical expansion of a landfill is a unique way of solving a waste airspace shortfall problem. Its feasibility is site-specific and depending on the existing waste types, slopes, liners, leachate and gas collection systems, and stormwater management system.

INTRODUCTION

Prior to discussing various techniques that aim to maximize or gain landfill airspace within the same horizontal limits, or "footprint", it should be pointed out that there are basic requirements which are fundamental in managing landfill airspace. These requirements include the ability of a landfill owner and designer to maximize airspace that begins long before the first load of trash is compacted and covered with alternative daily cover (ADC). It starts during the design process, reflects through the conceptual phasing, and gets restated every time the fill sequence plans are updated. No technologies would maximize or extend a landfill's life if the landfill operator neglects the fundamental practices. These practices include maximizing compaction efforts and controlling the materials coming into a facility.

Effective compaction on each thin lift of waste placed will reduce waste volume to the smallest practical size and hence minimize the airspace consumed. Maximizing compaction effort requires having the appropriately sized compactor, effective wheels and cleats on the compactor, minimizing working face areas, and a consistent maintenance program to ensure that the equipment is utilized effectively. Regular maintenance is required to ensure effective compactor performance. A maintenance checklist should be prepared that covers all of the compactor's critical systems. Wheels and cleats should be monitored and replaced at the wear level recommended by the manufacturer, as excessive wear will impede a unit's function and prevent an operator from achieving the necessary compaction to ensure that uniform waste compaction is taking place.

Many airspace maximizing techniques are available and practiced throughout the world and selection may be based on benefit-cost analysis alone. There is always an economic incentive to delay liner construction until other areas of the landfill have been filled. However, when it comes to obtaining permit approval for an expansion, stalling may not be advisable, since political tides do change and an opportunity to permit a landfill expansion may not be available if not seriously considered. Most waste regulations would allow a new solid waste unit or cell, or expansion, that is properly designed, permitted, constructed and operated over the side slopes or top areas of an existing solid waste landfill unit so long as it is operated in an environmentally protective and stable manner.

In addition, no new infrastructure, facilities, and monitoring systems are needed for a vertical landfill expansion within the original footprint. Some of the important technical considerations that need to be addressed are: slope stability, foundation support, waste settlement, integrity of the bottom liner and leachate header pipe systems, and stormwater management. In order to amend the existing permit to allow a vertical expansion landfill atop of the existing landfill, technical considerations as listed above would need to be addressed and submitted for the agency's approval.

AIRSPACE MANAGEMENT

Landfill airspace is defined as the volume of space on a landfill site which is permitted for the disposal of municipal solid waste (MSW). In the provision of solid waste disposal services, landfill airspace is depleted by being filled up with waste. From the point of view of public-sector landfill managers, landfill airspace represents a community resource to be wisely and economically used; private-sector landfill managers are in the business of selling landfill airspace. Therefore, in either case, proper airspace management becomes essential when one considers that everything that happens at a landfill can be translated into a benefit-cost evaluation.

Landfill managers and operators can use a variety of techniques and technologies to maximize the life spans of their sites. Since airspace is the primary asset of any landfill owner, he or she needs to consider all of the factors that impact the value of that airspace. There is price of the land property along with the costs of permitting, grading, liner installation, leachate collection system installation, road construction, stormwater sediment pond construction, and a host of other infrastructure expenses. There are the operational costs associated with that airspace, such as leachate collection/transport and treatment costs, equipment purchases/repair and maintenance costs, labor costs, host fees, and utilities/power expenses. And finally there are the closure and post-closure costs that need to be factored into the value of this commodity. It is also important to note that properly managing airspace begins with an efficient site design. The most efficient design is a rectangular shape, as is evident in the shapes of most landfills except due to boundaries or buffer zone setback constraints. The site owner must work closely with the design engineer to make sure that the design and permit allow for the maximum volume of airspace per acre of lined footprint.

MAXIMIZING AIRSPACE TECHNIQUES

There are many techniques and design solutions that can be utilized to maximize or expand the available airspace or waste holding capacity within a defined footprint of an existing landfill. These include:

- Perimeter retaining walls. In areas where land space is limited and especially where the population is dense, it is common to install a perimeter retaining wall around a landfill to gain additional airspace by 15 to 20 percent. When expanding a landfill vertically with retaining walls, a permit modification is typically required. Usually the permit changes are relatively easy to obtain because the expansion does not involve a lateral or horizontal expansion of the landfill. An advantage of a perimeter retaining wall is that it uses conventional geotechnical methods that can be designed with a low-maintenance concrete facing or segmental blocks. Disadvantages include challenges with managing surface storm water and the potential concerns about geotechnical stability or the long-term performance of the retaining wall materials. In China and in Taiwan, many of the early landfills were constructed with up to 3 – 6 m (10 – 20 feet) high retaining walls at the waste limits.

- Mechanically stabilized earth (MSE) perimeter berm. This technique is extremely valuable for facilities with no lateral room for expansion. Strong and durable geosynthetic reinforcement materials such as geogrid can be used to construct very steep perimeter berms that confine waste within the permitted waste limits. The slope can be very steep, with an outer slope near vertical. In the US, the walls have been successfully applied at several large solid waste landfills in the past 10 years, including a recent landfill expansion project on Cherry Island Landfill in Wilmington, Delaware. The technique of using MSE walls is to stack waste materials higher over the same permitted landfill footprint. Advantages of the MSE wall method include minimal disturbance areas around the existing landfill footprint and no need to permit a lateral expansion area. Disadvantages include hidden costs from long-term monitoring and maintenance, and the unknown performance rate and longevity of some geosynthetic materials used in MSE walls over a 30-year or more post-closure period.

- Dynamic compaction of waste. Densification of an existing waste mound or landfill can be done by dynamic compaction, so long as there is no impact to the liner or leachate collection system below. This method is most feasible if the landfill is located on a natural thick clay stratum and when the waste depth is at least over 20 m (>65 feet), depending on the weight of the compacting block used. Advantages include low lost to operate. Disadvantages include potential damage to the existing collection system(s).

- Aerobic bioreactor technology. The bioreactor technology can be used to accelerate waste decomposition and hence gaining available airspace, especially if the landfill has a liner and leachate collection system. Another similar variation is leachate recirculation, which is a practice that has been around since the 1970s and offers significant benefits related to extending landfill life. The moisture added to the waste can greatly enhance the compaction operation. Waste densities of more than 1200 kg/m^3 (2,000 pcy) can be attained when moisture is added to the waste prior to compaction. And with waste decomposition process, the final in-place densities can be up to 1540 kg/m^3 (2,600 pcy), making significantly more airspace available for new waste placement. Advantages include quick airspace gain by rapid decomposition of waste within 2 to 3 years. Disadvantages include operation and monitoring costs during operation and potential odour issue when the gas collection system is down.

- Landfill mining is another technique that can be used to empty a landfill and reuse its airspace. This method of waste management method is quite feasible especially for an old, unlined or unpermitted landfill site. Advantages include material recovery and reuse. Disadvantages include waste handling costs and potential odour problem during waste sieving and sorting.

To solve immediate airspace shortfall, an innovative approach selected may vary and it would depend on whether the landfill is new or old, lined or unlined, and if lateral expansion can be incorporated with a vertical expansion. Greater waste compaction effort and use of alternative daily covers during landfill operation can also increase waste airspace. In this paper, the focus is strictly considering a vertical-only expansion of the landfill by steepening the existing sideslope within the landfill footprint and maximizing the waste height. Certain design criteria and analyses that need to be verified include: slope stability, landfill base settlement, integrity of the bottom liner system and leachate header pipe, final cover system veneer stability, leachate and landfill gas collection and management systems, erosion and sediment controls, and stormwater management.

VERTICAL EXPANSION CASE STUDY

The case study site is located in Frederick County, Maryland. It is designated as "Site B" and has about 23 hectares of footprint. Due to a huge population growth in late 90s, the owner had to look into other options to accommodate the increasing waste volume and the resulting depletion of landfill capacity. Because of the time required for permitting a new landfill site, it became obvious that vertical expansion of the existing Site B made the most sense from economical and permitting points of view. A decision was then made by the owner to include a vertical expansion landfill at Site B. In order to modify the existing permit to allow a vertical expansion landfill atop of the existing landfill, technical considerations as listed below would need to be addressed in a permit modification application and submitted to the Maryland Department of the Environment (MDE) for approval.

Permit modifications include an alternative final grading plan that will increase the top elevation from +568 to +675 feet, or a waste height increased by 33 m (107 feet), and modify the permitted side slopes from 4(H): 1(V) to 3(H): 1(V). An alternative final cover system is considered which also provides additional airspace. The proposed vertical expansion will not increase the footprint of the existing landfill; therefore, in accordance with the Code of Maryland Regulation (COMAR) Solid Waste Management Regulations, the permit modification application is limited to an evaluation of current hydrologic conditions, the global stability evaluation, and foundation analysis of the subsurface materials to determine whether they can support the increased load of the proposed vertical expansion. The existing landfill design needs to be thoroughly investigated, engineered, and operated as a new facility if on compressible ground.

TECHNICAL CONSIDERATIONS AND EVALUATIONS

In order to evaluate the possibility of implementing a vertical landfill expansion, some of the important technical considerations that need to be addressed are: global slope stability under both static and seismic loading (if present) conditions, landfill base settlement, integrity of the bottom liner system and leachate piping, and stormwater management. As part of the modification to the existing permit allowing a vertical expansion landfill atop of the existing landfill, technical considerations as listed above would need to be addressed and submitted for the agency's approval. Each of these technical considerations was evaluated and presented below.

Global Slope Stability

The slope stability was evaluated using the computer program PCSTABL5M. This program uses two-dimensional limit equilibrium methods to calculate a factor of safety (FS) against shear failure for vertical expansion slope sections analyzed. This program is able to use an automatic search routine to generate multiple shear failure surfaces for both circular and block failure modes until the surface with the lowest FS-value is found. The analytical methods used for the circular and sliding block failure modes in the slope stability analysis is the Modified Bishop and Modified Janbu methods, respectively. Based on industry practice, acceptable factors of safety are 1.5 for static slope stability analysis and 1.3 for pseudo-static (seismic) analysis, using peak shear strength values.

The results of the global slope stability analysis for the various scenarios are summarized in Table 1. Based on the location of the sections and the assumptions made, the computed safety factors meet the requirements for long-term global slope stability.

Table 1. Results of Global Slope Stability Analysis

Section	Analysis	Failure Mode	Factor of Safety
Section AA'	Static	Circular	2.05
	Static	Block	1.82
Section BB'	Static	Circular	2.08
	Static	Block	1.81
Section CC'	Static	Circular	1.72
	Static	Block	1.71
	Seismic (0.05g)	Circular	1.46
	Seismic (0.05g)	Block	1.45

Based on the results presented, a minimum FS of 1.5 for static slope stability analysis and 1.3 for the pseudo-static (seismic) slope stability analysis can be obtained for the revised 1(V):3(H) final side slopes and at the new maximum waste height of 61 m (200 feet). These FS values depend on the critical shear strength parameters used in the analysis for both liner interfaces and the waste mass.

Landfill Base Settlement

Every landfill that contains organic material is at some stage of the decomposition process. As subsequent lifts of trash and soil are placed on top of a landfill, the underlying layers will be pressed down or consolidated. Over time as the waste decomposes, it releases moisture and heat and the landfill will settle further. The settlement process could be further enhanced by stockpiling soil, green waste, compost, rubble, or other material on top of the underlying waste.

The settlement of the landfill foundation soil layers was calculated using the new final waste height of approximately 61 m (200 feet) established for the vertical expansion of the landfill with 1(V):3(H) side slopes. The anticipated settlement was calculated along selected representative sections. The estimated settlement of the foundation soils under the weight of waste ranges from zero to six inches. The differential settlement was calculated by taking the difference in settlement at two graded break points along the sections at the base of the landfill. The differential settlement calculated was approximately 12.7 cm or 5 inches. This results in a change in the landfill base slope ranges from 0.07 to 0.12%. Despite settlement and with vertical expansion, a minimum 2% landfill base slope is maintained.

Geomembrane Compression

The maximum proposed height of the solid waste above the secondary geomembrane is approximately 61 m (200 feet). Assuming a compacted waste density of 959 kg/m3 (1,620 pcy) and the compressive stress on the geomembrane is 0.6 kPa (83 psi). The estimated compression of the geomembrane is 0.03 mm (0.0011 inches), which results in a strain of approximately 2 percent for the 60-mil HDPE geomembrane. Since compressive failure is defined as compression greater than ten percent of the geomembrane thickness, the compressive strength of the geomembrane is adequate.

Pipe Strength

The HDPE pipe was reevaluated for adequate strength against failure due to excessive deflection, crushing, and buckling for the increased expected loadings within the disposal area. The pipe strength analysis was performed for the 152 mm (6-inch), 203 mm (8-inch) and 305 mm (12-inch) diameter pipes under the new maximum expected load of the waste fill. Based on this analysis, it was determined that these HDPE pipes with a Standard Dimension Ratio (SDR) of 9 are adequate to withstand the maximum expected loadings.

Stormwater Management

During landfill modifications, existing sediment controls (Ponds A, B, C and D) will continue to provide storage for sediment control, in accordance with local and MDE requirements. Surface water runoff from the landfill will be collected by a drainage system of diversion berms, pipe gutters, and pipe downchutes that will drain to the perimeter channel. The drainage system will be installed over the life of the landfill. The diversion berms and pipe gutters can be installed on intermediate cover slopes as needed, and re-installed for final grade slopes. Energy dissipaters will be installed at the outlet of each pipe downchute, prior to entering the perimeter channel. The perimeter channel surrounding the landfill is designed to convey surface runoff to four culverts, each of which drains to one of the Sediment Control ponds. The four ponds were evaluated to determine their adequacy under current County and MDE guidelines for stormwater management, for final conditions of the landfill. Current stormwater management requirements call for quantitative control of the surface runoff rate, and qualitative control to reduce pollutants and sediment that might otherwise be present in surface runoff.

The vertical landfill expansion requires reevaluation of the stormwater management at the site due to the revised grading, and because stormwater management requirements have changed since the site was originally permitted. The storm water is directed to one of four ponds through a series of diversion berms, storm drains, channels and culverts. In the final cap design, pipe gutters and/or diversion berms, which feed into downchutes, have been placed every 12 m or 40 feet to accommodate the stormwater flows and minimize erosion of the final cap system.

Based on the pre-development and post development hydrology calculations, the storm water peak discharges from post development are less than from predevelopment for both the 2-year and 10-year, 24-hour storms. A summary of the stormwater peak management for the four basins is provided below in Table 2.

Table 2. Basin Stormwater Peak Management Summary

BASIN	CN		BASIN AREA		2-YEAR, 24-HOUR STORM			10-YEAR, 24-HOUR STORM		
	PRE	POST	PRE HA (AC)	POST HA (AC)	PRE CMS (CFS)	POST CMS (CFS)	CHANGE (%)	PRE CMS (CFS)	POST CMS (CFS)	CHANGE (%)
A	69	69	11.8 (29.6)	12.6 (31.6)	0.57 (20.0)	0.06 (2.2)	-89.0	1.72 (60.7)	0.43 (15.1)	-75.1
B	65	65	15.4 (38.5)	15.9 (39.8)	0.60 (21.3)	0.07 (2.5)	-88.2	2.24 (79.0)	0.91 (32.1)	-59.4
C	68	66	14.5 (36.2)	13.4 (33.4)	0.67 (23.6)	0.66 (23.3)	-1.2	2.17 (76.6)	2.06 (72.8)	-5.0
D	67	64	15.8 (39.4)	14.4 (36.0)	0.82 (28.9)	0.53 (18.8)	-34.9	2.51 (88.6)	1.86 (65.6)	-26.0

CN = Runoff Curve Number
CFS = flow rate in cubic feet per second
HA = hectares AC = acres

As discussed previously, based on the predevelopment and post development hydrology calculations, the storm water peak discharges from post development are less than from predevelopment for both the 2-year and 10-year, 24-hour storms. Because the ponds manage the 10-year storm, the overbank flood protection requirements of the current regulations are fulfilled.

RESULTS AND FINDINGS

As the results of the landfill vertical expansion, the final grading plan of Site B needs to be modified from 1(V):4(H) to a 1(V):3(H) sideslope (Figure 1). The vertical expansion results in an airspace gain of about 1.8 million m^3 (2.4 million yd^3), which extends the landfill lifespan by about 4 - 5 years, based on a 1,200 - 1,500 tons per day of waste placed in the landfill, a 6-day of operations per week, and assuming a compacted waste density of 959 kg/m^3 (1,620 pcy) placed. A typical section profile of the landfill is shown in Figure 2 and a panoramic view of before and after vertical landfill expansion is illustrated in Figure 3.

Evaluation of Useful Life of the Facility

Estimated useful facility life range for an expanded Site B Landfill was projected based on varying the waste flow rate, and in-place effective waste density (pounds of waste in-place per cubic yard of landfill volume used). Assuming that waste flow rates will increase nominally by 2% per year over the life of the facility, and assuming an in-place density ranging from 710 kg/m^3 to 948 kg/m^3 (1200 to 1600 pcy), the estimated lifespan will be 3 – 4 years. The corresponding useful life estimates are depicted graphically in Figure 4. If 90 percent of the waste flow is transferred to a transfer station, then the landfill airspace gain would be extended by at least 50 years.

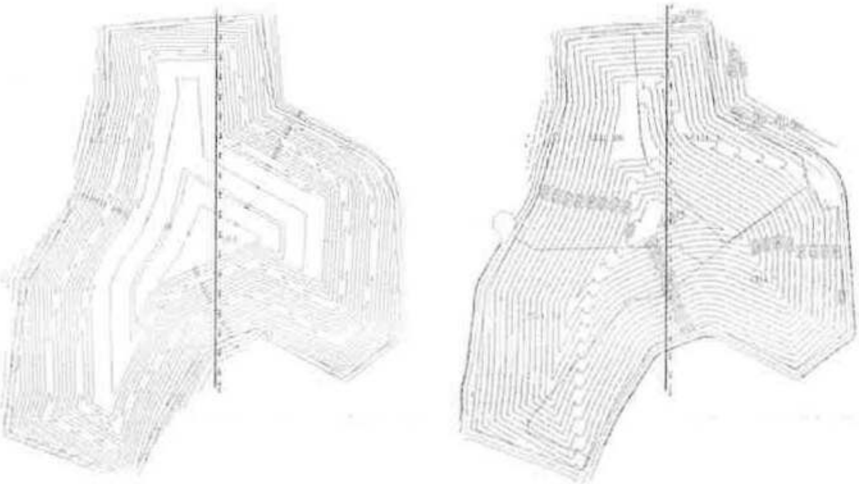

Figure 1. Landfill Plan View - Before and After Vertical Expansion

Figure 2. Section Profile Before and After Vertical Expansion

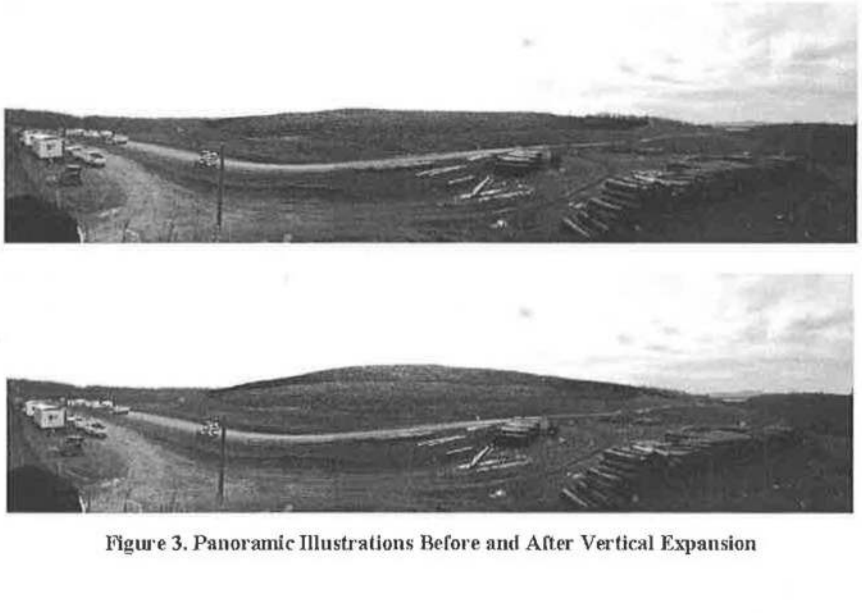

Figure 3. Panoramic Illustrations Before and After Vertical Expansion

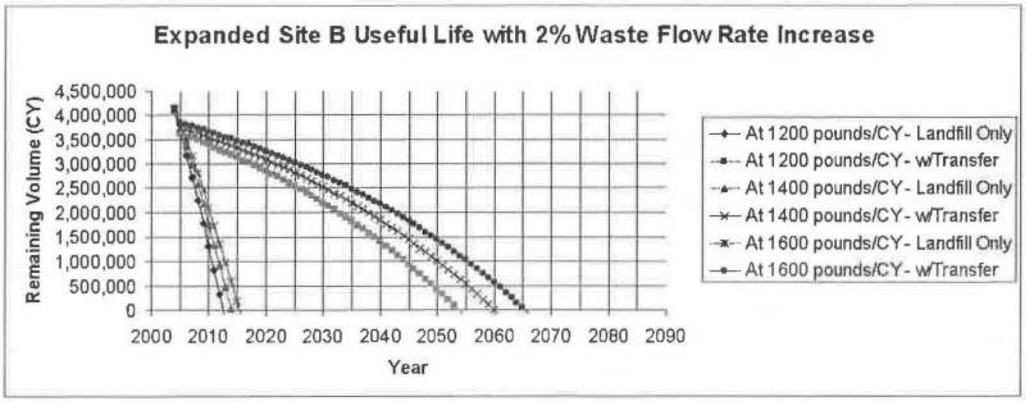

Figure 4. Useful Facility Life Estimates

CONCLUSION

A landfill operation permit modification application is usually required for proposing a vertical expansion that lies on top of the previously permitted landfill area. Some regulatory requirements, but not in this case study site, may even require a liner and leachate collection system between the old and new waste. In this case study, engineering evaluation and analyses needed to address the current hydrologic conditions, global slope stability, veneer slope stability, landfill base settlement, geomembrane compression, pipe strength, useful life of the facility, storm drainage, and alternative final cover system.

As a result of the vertical expansion, the final grading plan of Site B was modified from 1(V):4(H) to a 1(V):3(H) sideslope. The maximum waste height was raised by about 33 m or 107 feet. The vertical expansion results in an airspace gain of about 1.8 million m^3 (2.4 million cubic yards), which extends the landfill lifespan by about 4 to 5 years, based on a 1,200 - 1,500 tons per day of waste placed in the landfill, a 6-day of operations per week, and assuming a compacted waste density of 959 kg/m^3 (1,620 pcy) placed. From this case study, it shows that the vertical expansion of a landfill is a unique way of solving waste airspace management problem. Its feasibility is site-specific and depending on the existing waste types, slopes, liners, leachate and gas collection systems, and stormwater management system. In addition, the landfill design needs to be thoroughly investigated, engineered, and operated.

The global final slope stability, the veneer slope stability of an alternative final cover system, and landfill base settlement analyses have concluded that a vertical expansion from 1(V):4(H) to 1(V):3(H) sideslopes at the subject landfill will not increase the risk to human health or the environment over the current permit conditions. In addition, the geomembrane compression, pipe strength, stormwater management analyses demonstrate that the original design can accommodate a steeper side slope and an increased waste height. This vertical expansion provides the landfill owner with an opportunity to increase the landfill volume and provide the residents with the maximum service life within the existing footprint of the permitted Landfill. This maximization of available resources does not expand the environmental footprint of the site and provides better environmental protection and at the same time creates a sustainable landfill site.

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