ENVIRONMENTAL PROTECTION AT THE MANAGED SOLID WASTE LANDFILL

EXECUTIVE SUMMARY
ACKNOWLEDGEMENTS AND DISCLAIMER

This document is the executive summary of a detailed technical report prepared by Geosyntec Consultants and funded by Waste Management, the largest waste management company in North America. Geosyntec Consultants would like to acknowledge the assistance of Waste Management in providing access to their databases, landfill information, and technical personnel.

Geosyntec comprehensively reviewed the technical and peer-reviewed literature in order to provide an up to date evaluation of the regulatory oversight, engineering design, active management, routine maintenance, and long-term monitoring requirements associated with the modern managed solid waste landfill. The findings and conclusions of the technical report characterize the state-of-practice in terms of the systems and controls routinely implemented by the solid waste industry to protect the environment. However, the report is not intended as a substitute for thorough engineering and technical research with respect to any specific site and may not be relied upon for that purpose.
EXECUTIVE SUMMARY

Geosyntec Consultants, an independent consulting firm, prepared a detailed technical report discussing the protectiveness of modern managed landfills, specifically landfills that receive non-hazardous municipal solid waste (MSW). This executive summary is an overview of the detailed technical report. Although the discussion herein highlights the main elements of the seven chapters comprising the detailed technical report, it is not intended to be a replacement for the references and detailed information contained in the technical report.

What is The Purpose of the Detailed Technical Report?
The detailed technical report is intended as an independent treatise on solid waste landfills that describes liner and cover performance, landfill gas generation and collection efficiency, and long-term protection of groundwater and other environmental media in a single document. It includes supporting references to more than 200 peer-reviewed technical papers addressing how a modern managed MSW landfill is protective of human health and the environment.

What is The Main Message?
The report concludes that no one single element is relied on to maintain long-term environmental protection; rather, it is the overlapping function of the landfill containment systems, operations, and maintenance procedures, combined with independent regulatory oversight and on-going system performance monitoring, that protect human health and the environment for the very long term.

Who is the Intended Audience?
The report provides a compendium of information regarding the protective features, processes, and regulatory and community oversight of modern landfills that should be useful to both technical professionals and the general public.

What Principal Questions Does it Seek to Answer?
The report answers many typical questions asked about landfills such as, “Are landfills safe?”, “How are landfills protective of groundwater, surface water, soil, and air?”, “Are landfills still protective after a natural disaster?”, and “Are landfill failures common?”

The conclusions presented herein are supported by peer-reviewed research and practical field studies on landfill performance and their ability to provide long-term protection of human health and the environment. Technical references are provided at the end of the detailed technical
report. Each chapter of the technical report is intended to be self-contained for readers interested in particular elements of a landfill; as a result, there is a necessary level of repetition of key points. Symbols are used to simplify for the reader where to find information on a specific topic. As illustrated below, the most commonly used symbols relate to the key elements of modern managed landfills – containment, treatment (biodegradation), operation, maintenance, and monitoring.

**KEY ELEMENTS OF MODERN MANAGED LANDFILLS**

![Symbols for Containment, Treatment (Biodegradation), Operation, Maintenance, Monitoring]

**Introduction**

The modern, managed municipal solid waste (MSW) landfill consists of a combination of regulatory, design, operational, maintenance, and monitoring features. The permitting, design, construction, and regulation of MSW landfills are intended to protect human health and the environment both during their active operating phase and after they stop receiving waste and are closed. MSW landfills are engineered to provide overlapping measures for environmental, health, and safety protection. These measures include monitors and back-up systems that help protect the integrity of landfills in the event of emergencies or natural disasters.

In preparing the technical report, Geosyntec Consultants conducted a comprehensive study to summarize the state-of-the-practice of the modern managed landfill. Primary findings include:

- **Landfill Design and Operation is Highly Regulated**: Location and site characterization requirements combined with professional design standards and prescriptive best management operating standards for waste acceptance and operations serve to uphold the physical integrity of MSW landfills.

- **Containment Systems are Scientifically Engineered**: Scientific research and testing shows that engineered and natural liners and cover systems can likely provide effective containment in excess of 1,000 years.

- **Landfills are Actively Maintained**: Active management through the operating, closure, and post-closure stages helps to prevent system breakdowns, enabling engineered containment systems to operate as designed.
• **Generation of Waste Byproducts Decreases Over Time** ➔ Predictable and decreasing trends in the generation and concentration of non-hazardous waste liquids generated in the landfill (termed “leachate”) and biologically generated landfill gas mean that, over time, the landfill unit can progress to a relatively inert state that does not require active management.

• **Landfills are Actively Monitored** ➔ Monitoring systems are designed to detect signs of system malfunction or a potential release of solid waste or byproducts from the landfill, and allow for a timely response prior to potential off-site impact.

Lastly, with effective end-use planning, the managed landfill can also provide beneficial land use options to support renewable energy projects, sustain wildlife habitats and parks, or offer “green space solutions” (such as golf courses or walking trails).

Each of these findings is addressed in more depth in the following sections, and is detailed in the technical report.

**Regulatory Requirements for Landfill Design and Operation**

Modern MSW landfills are designed and operated pursuant to strictly enforced regulatory standards established by the U.S. Environmental Protection Agency (USEPA) and implemented by State environmental regulatory agencies. Under the provisions of Subtitle D of the Resource Conservation and Recovery Act (RCRA), owner/operators of MSW landfills are required, by permit, to characterize site geology and develop plans for operation, maintenance, and monitoring prior to constructing a landfill unit that will accept waste. In addition, landfills must operate in compliance with regulations governing waste screening and inspection, daily waste disposal and cover operations, odor control, and storm water control and monitoring. State and local laws also govern the safety of landfill operations and stipulate a list of wastes prohibited from being disposed of in an MSW facility.

The regulatory requirements imposed at the modern MSW landfill to assure protection of human health and the environment are summarized below.

• **Permitting** ➔ Advanced planning and regulatory approvals, including:
  - Siting Considerations such as surface and subsurface characterization to avoid siting landfills in unsuitable locations such as floodplains, wetlands, or locally unstable areas; and
  - Planning and Design, including engineer-certified calculations and plans regarding geotechnical stability, proper management of waste by-products (gas and leachate), effective control of stormwater runoff, and prevention of environmental and community impact and nuisance.
• **Construction** ➔ Implementation of engineered plans for containment and monitoring, including independent certification by Construction Quality Control (CQA) technicians and engineers that the landfill is built as designed.

• **Operation and Maintenance (O&M)** ➔ Performance of disposal, prevention, compliance, and response actions, including system maintenance by trained professionals to avoid breakdown or failure of containment features as well as planning to protect worker and public safety.

• **Environmental Monitoring** ➔ Establishment of scientifically-developed monitoring plans implemented to measure system performance and provide early warning of operational upsets (such as a leachate spill or other release) prior to potential off site impact.

• **Closure and Post-Closure Care Maintenance and Monitoring** ➔ Planning and implementation of long-term managed care, including:
  - **Closure** in accordance with approved engineered plans for the landfill to remain in compliance with state and federal regulations; and
  - **Post-Closure Care**, a regulatory-required period of maintenance and monitoring with the objective of demonstrating that landfill containment systems are performing as designed after active landfill operations cease.

From the above, it is clear that there are many regulatory compliance requirements that must be achieved during design, construction, operation, and maintenance of a MSW landfill. Furthermore, the scientifically engineered systems and components of the modern managed MSW landfill also meet long-term performance criteria as described below.

**Performance of Scientifically Engineered Landfill Containment Systems**

A cornerstone of the modern managed landfill is containment of waste and waste by-products. The materials and construction methods used in Subtitle D landfill containment systems are well known and have been comprehensively tested, and their performance has been documented through more than three decades of research and field observation.

The modern managed MSW landfill is comprised of **engineered systems and components** functioning together with natural geologic conditions to optimize overall landfill environmental performance. These systems and components must meet strict design standards and receive approval from the governing regulatory authority prior to construction. Once approved for construction, component systems are designed to meet long-term performance goals. Component systems include:

• **Liner system** ➔ An engineered barrier system designed to contain the byproducts of MSW stored in landfills. In particular, liner systems are designed to prevent leachate (liquids present in the disposed waste) from migrating into subsoil, groundwater, and surface water.
**Long-Term Liner System Performance**

Scientific studies and testing have shown that the service life of typical synthetic materials used in liner construction (most commonly, high-density polyethylene membranes) is estimated to exceed a thousand years. Composite liner systems consisting of a synthetic membrane liner overlying a compacted clay layer, similar to those used at Subtitle D landfills, have been designed for radioactive waste depositories requiring the highest standards of containment for tens of thousands of years.

**Leachate management system ➔** A system of drains, pumps, pipes and hoses designed and operated to remove leachate from above the liner and convey it away for treatment and/or disposal. The leachate collection and removal system controls leachate build-up on the liner, working in conjunction with the liner’s barrier systems to minimize the potential for seepage to groundwater and other environmental media.

**Cover system ➔** An engineered system used to control moisture and percolation from entering the landfill, promote surface water runoff, minimize erosion, prevent direct exposure to waste, control animal or plant intrusion, control gas emissions, control odors, and meet aesthetic and other end use purposes.

**Long-Term Cover System Performance**

Regulatory compliant cover system types are designed to have service lives in excess of a thousand years. The service life can be further maximized by ensuring a diverse native plant community is established on the cover, which will be more resilient to natural and man-induced catastrophes and the anticipated unpredictable changes in environmental conditions (such as overgrazing or fires) and climatic fluctuations that can occur over time.

**Landfill gas management system ➔** An engineered system of wells, surface and subsurface pipes, gas extraction pumps (termed “blowers”), and flares. Use of gas management systems adds to the control of gas migration from the landfill as emission to the atmosphere or laterally into the unsaturated soil (or vadose zone) and groundwater. At many modern managed MSW facilities, landfill gas is used to generate green energy.
• **Stormwater management system** ➔ An engineered system designed to divert rainwater and snowmelt away from the landfill to control potential contact of surface water with waste. Stormwater runoff is monitored in accordance with the Clean Water Act standards and compliance is overseen by the applicable Federal or State agency.

Although each of the systems described above provides an element of environmental protection, it is the overlapping integration of all systems that provides for comprehensive protection of human health and the environment over the long term.

**Landfills Are Actively Maintained**

Active and responsible operation provides for regulatory compliance and environmental protection at the managed landfill. Key elements of responsible landfill operation include:

- Incoming waste screening, documentation, and waste load inspections (to prevent disposal of hazardous or unacceptable waste);
- Safe operations at the working face (to protect site workers and waste haulers);
- Daily covering of the waste (to avoid litter and access by rodents, birds, or other vectors);
- Odor and nuisance control;
- Leachate and landfill gas management (to control potential environmental impacts); and
- Routine inspection, repair, and replacement of equipment, structures, and systems.

Maintenance and monitoring activities continue after landfill closure, when the landfill no longer accepts waste. Post-closure care activities include regular inspections, maintenance, and optimization of principal post-closure care elements, including the leachate management system, final cover system, landfill gas management system, and environmental monitoring programs.

Like any complex engineered system, operation and maintenance of a modern managed MSW landfill requires a skilled workforce trained in system operation, safety, and environmental regulatory compliance. A key responsibility of the site operations team is waste screening. All trucks entering an MSW landfill must check in with the gatehouse attendant. Waste loads are visually inspected to prevent acceptance of non-compliant wastes at the landfill. Site operators are trained in visual recognition of potentially unacceptable wastes when placed at the working face and follow strict procedures to return unacceptable waste to its originator for proper handling and disposal.

**Generation of Waste Byproducts Decreases over Time**

The chemistry of leachate from MSW landfills is well documented, understood, largely predictable, and has been shown to improve with time after capping. Similarly, LFG
generation is predictable over time and is based primarily upon waste type and moisture. LFG
generation has also been documented to decrease with time after capping. Because leachate
and landfill gas have predictable and decreasing trends in their generation and concentration
over time, potential emissions of leachate and landfill gas from a landfill unit can progress to a
relatively inert state that ultimately does not require active management.

A large number of scientific studies have been conducted on closed landfills. The results of these
studies support the following broad conclusions:

- MSW landfill leachate is a non-hazardous liquid that predictably decreases in volume
  and concentration after landfill closure;
- As waste material in a landfill degrades, the bottom-most layers decompose fastest and
  can act as an effective biological filter that reduces the concentration of leachate as it
  passes from upper waste layers to the leachate collection system;
- Landfill gas generation declines in a predictable manner after closure; and
- Future quantities and concentrations of landfill gas and leachate can be estimated based
  on current and historic measurements.

**Active Landfill Monitoring**

Environmental monitoring systems are used to monitor landfill system performance and
environmental compliance. Because a comprehensive environmental monitoring
program (EMP) is implemented to confirm that containment and control systems are
performing as designed to protect groundwater, surface water, land, and air, an EMP serves as
an early warning system for potential environmental impacts.

The principal EMP components include:

- **Groundwater** monitoring for a potential release from the landfill to the uppermost
  aquifer;
- Monitoring of **surface water** quality onsite and in the local vicinity of the landfill where
  rainwater or snowmelt may have potentially come in contact with waste;
- Monitoring the **vadose zone** (unsaturated shallow subsurface above groundwater) for
  potential landfill gas migration;
- Cover system monitoring to detect and quantify low-level **landfill gas** emissions and
  potentially indicate the need to restore an area of the cover system to optimize its
  integrity and ability to control landfill gas emissions; and
- Performance monitoring of permit compliance conditions such as confirming no build-up of
  **leachate** on the engineered liner.
Effective environmental monitoring can readily detect potential upsets to control systems and/or releases of leachate or gas, allowing necessary response actions to be implemented expeditiously before long-term damage or potential offsite migration occurs. Monitoring data can also help predict future landfill performance based on trends in past and current data.

**Control of Greenhouse Gas Emissions at Landfills**

Landfill gas, which is comprised mostly of methane and carbon dioxide, is generated from the decomposition of organic constituents in the waste mass. If released into the atmosphere, methane is considered a greenhouse gas (GHG). Managed MSW landfills are designed and operated to control emissions of landfill gas.

Three primary mechanisms combine to directly control the emission of landfill gas from a landfill:

- The efficiency of landfill gas collection;
- Natural oxidation, a process by which specialized bacteria living in landfill cover soils consume methane in the presence of air; and
- Permanent storage of non-decomposed organic constituents within the landfill itself (termed “carbon sequestration” in the context of controlling greenhouse gas emissions).

Landfill gas collection efficiency is the percentage of the total amount of landfill gas generated that a collection system is effective in collecting. According to the USEPA’s “Compilation of Air Pollutant Emission Factors” (commonly referred to in the industry as the “AP-42 document”), estimated efficiencies of landfill gas collection systems typically range from 60 to 85 percent. A default value of 75 percent is often assumed, although the USEPA notes that well-operated systems may achieve collection efficiencies in excess of 90 percent. Other researchers and practitioners have observed that collection efficiencies at well-designed and operated landfills can be even higher. For example, at landfills that contain a final soil and/or geomembrane cover system, gas collection efficiencies are reported to range from 90 to 99 percent. Climatic conditions also play a role in gas generation rates and collection efficiencies achieved. In arid regions such as southern California, for example, gas collection systems are reportedly capable of close to 100 percent control efficiencies.

A portion of the landfill gas that is not captured by the gas collection system can migrate into the landfill cover soils. A fraction of the methane in that gas is converted (oxidized) into carbon dioxide by bacteria within the cover soil. This transformation further reduces the amount of methane that can potentially escape into the atmosphere. Based on a review of recently published literature, the percent of methane oxidized in landfill cover soils ranges from 22 to 55 percent of the gas not collected, with a reported average of 35 percent. The percent of methane controlled via active gas collection or oxidation in cover soils is dependent on the type of cover system in place. Gas collection efficiencies at landfills with low-permeability covers have been reported to range from 90 to 99 percent, leaving little uncollected methane available for oxidation. On the other hand, the gas collection efficiency is generally less where thicker all-soil
cover systems using more permeable, organic material is in place. This is because these covers allow more air to come in contact with methane within the cover, which in turn facilitates greater methane oxidation. Landfill engineers are able to take advantage of the dual benefits provided by gas collection systems and final cover designs to maximize the level of landfill gas control.

Research has shown that MSW landfills permanently store a significant amount of carbon. This storage, or “sequestration,” is important because it permanently removes carbon from the natural carbon cycle. The USEPA, the United Nation’s Intergovernmental Panel on Climate Change (IPCC), the Oregon Climate Trust, and the California Air Resources Board (CARB) all recognize that when organic wastes are deposited in landfills and do not completely decompose, the carbon that remains is effectively removed from the global carbon cycle. In other words, although landfills produce methane, they also play an important role in sequestering carbon that would otherwise contribute to the accumulation of GHGs in the atmosphere. Taken together, responsible landfill design and operation, active gas collection systems, oxidation of methane in cover systems, and the permanent storage of carbon in landfills all combine to produce low net methane (GHG) emissions.

**Long Term Landfill Integrity – How Safe are Landfills?**

Modern landfill designs are very safe and significant failures at managed landfills are extremely rare. A large number of scientific studies have been conducted on closed landfills to predict long-term environmental protection at modern landfill sites. The results of these studies support the following conclusions:

- The containment features of the modern landfill are designed, constructed, and maintained as necessary to protect human health and the environment throughout the operational and post-operational life of the facility; and
- Where natural catastrophic events have occurred at modern landfills (even after closure), the facility’s environmentally protective features have not been found to be significantly compromised.

In addition to design, construction, operation and monitoring objectives, the physical integrity of the landfill is a key focus for engineers before and after closure. Factors that can affect the integrity of the landfill before closure or during post closure care are well understood and can be accounted for during the design of modern landfills. There is nothing in the literature identifying major structural failures at closed, modern landfills, and no significant impacts have been caused by catastrophic events (e.g., hurricanes, earthquakes, or wildfires). The few significant problems that have occurred at operating landfills are well documented and, following investigation, have been found to be the result of a specific operational failure or poor construction practice. Forensic studies on the performance of landfills during catastrophic events have found that landfills are highly resistant to damage from such events and that environmental protection systems remain intact. Of the studied events, only surface features (e.g., vegetation and landfill gas vents) showed signs of significant damage.
**Integrated Systems for Overlapping Protection:** Managed MSW landfills may have differences in designs and in operational methods to reflect local climate, geology, and adjacent land use. However, effective landfill designs consider these site-specific differences and appropriately incorporate the systems necessary to optimize landfill performance and provide integrated waste containment, leachate management, and landfill gas control. In this way, no single element is relied upon to protect human health and the environment. It is the combination of multiple systems and active management (including monitoring) that provides a comprehensive level of protection.

Empirical studies of liner quality and impacts to groundwater downstream of Subtitle D-lined landfills using site-specific data indicate that properly installed liner systems and effectively maintained leachate collection systems can prevent leachate impacts to groundwater. For example, a recent study that included more than 60,000 data records collected from some 740 monitoring wells installed at over 100 landfills showed no evidence of leachate impacts to groundwater from Subtitle D-lined cells. These results are consistent with earlier USEPA studies on the effectiveness of engineered liners to contain MSW leachate.

**Planning for Care After Closure:** There is considerable empirical evidence that the modern managed MSW landfill is a safe and responsible long-term waste management solution. Tools exist to evaluate appropriate levels of care after closure, and monitoring can confirm that any changes made are protective of human health and the environment. Because leachate and landfill gas concentrations and volumes decrease during the post closure period, a performance-based evaluation of threat after closure can represent not only current conditions but future conditions as well. Regulations stipulate that post closure care be provided for a period of 30 years, unless it is demonstrated to the regulatory agency that any change would not harm human health and the environment. As summarized in the post-closure care guidance document published by the Interstate Technology and Regulatory Council (ITRC) in 2006, enhanced landfill management has the potential to end regulated post-closure care activities earlier than the traditional 30 years. ITRC is a coalition of state environmental regulators working with the USEPA and other federal partners, industry, and stakeholders to advance innovative environmental decision making (see [www.itrcweb.org](http://www.itrcweb.org) for more information regarding the work of ITRC).

Planning for Care after Closure

Quote from the Interstate Technology and Regulatory Council (ITRC) Technical Regulatory Guidance document on Post-Closure Care (September 2006):

“Ongoing evaluation of MSW leachate quality and landfill gas production indicates that leachate quality improves and landfill gas production decreases from the time of closure in a manner that makes the 30-year prescriptive post-closure care term reasonable for financial planning purposes.”
Beyond Waste Containment – Landfills as a Resource

The science of waste containment, degradation, and treatment continues to evolve in response to industry and socio-economic needs. Three areas of study and advanced use of MSW landfills as a resource beyond providing a responsible means of waste disposal include the following.

- **Landfill gas-to-energy (LFGE),** in which the methane contained in landfill gas is utilized to provide renewable **green energy** and further optimize greenhouse gas emission reductions through replacement of fossil-fuel derived energy.

- Enhanced waste treatment through wet landfill operation (that is, where the landfill is operated as a waste treatment vessel rather than a storage unit and generally cited in industry references as “bioreactor operation”). Enhanced waste treatment landfills are engineered to degrade the waste faster, speeding up landfill gas production, and facilitating more efficient energy use (thus decreasing the time for which that active landfill gas management is needed).

- **Carbon sequestration,** in which carbon is permanently stored in the landfill and removed from the global carbon cycle, leading to more accurate inventories of greenhouse gas emissions from solid waste management activities.

With **effective end-use planning,** the managed landfill can also provide beneficial use of the land to sustain wildlife habitats and parks and offer “green space solutions” (such as golf courses or walking trails).

In summary, the technical, regulatory, and operations sectors of the solid waste management industry continue to study the science of landfill systems and waste degradation in order to improve landfill efficiency, environmental compliance, and responsiveness to public needs. Peer-reviewed studies have concluded that actively managed modern MSW landfills are effective in containing and treating solid waste, and preventing impact to the environment. Moreover, they can be used as a source of renewable green energy for local communities and industries.