ENVIRONMENTAL RESTORATION

Sustainable Long-Term Management of Landfills under the Navy's Environmental Restoration Program

Introduction

Landfill owners are increasingly interested in adopting sustainable long-term management (SLM) strategies. These strategies help to minimize the lifecycle depletion of energy, material resources, and financial resources without compromising environmental protection or passing the burden of cost for post-closure care (PCC) onto future generations. This fact sheet describes SLM strategies that may be suitable for implementing at Navy landfill facilities, including historic landfills managed under the Environmental Restoration (ER) and Base Realignment and Closure (BRAC) programs. In this context, the ultimate goal of SLM of closed landfills is termination of active PCC based on demonstration of *functional stability* and transition to passive controls for off-gas and leachate management.

Functional stability is defined in this fact sheet as a landfill site that demonstrates no unacceptable risk to human health or the environment (HHE) at the relevant point of exposure (POE) in the absence of active care. Therefore, functional stability is the foundation for demonstrating how and when PCC can end in the context of Federal and State regulations. In addition, several examples of passive controls are presented. Other issues addressed to support SLM strategies include optimized landfill cap design and maintenance, optimized long-term monitoring (LTM), beneficial site reuse, clean closure considerations, and shoreline erosion protection issues. A case study from a Department of the Navy (DON) installation is included and key references are identified for more detailed information.

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Regulatory Framework and Guidance on Landfill Post-Closure Care

Post-closure at hazardous and non-hazardous landfills is regulated under Resource Conservation and Recovery Act (RCRA) Subtitle C (i.e., 40 Code of Federal Regulations [CFR] §264.117 for permitted facilities and §265.117 for interim status facilities) and Subtitle D, Subpart F (i.e., 40 CFR §258.61), respectively. Landfills covered by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) program must comply with applicable or relevant and appropriate requirements (ARARs). Overall, it is reasonable to assume that care and monitoring activities at CERCLA sites will generally reflect ARARs under RCRA (NAVFAC, 2014). In addition, closed non-hazardous landfills pre-dating promulgation of Subtitle D are typically regulated directly by the States, which generally impose applicable PCC conditions in line with RCRA requirements.

Authority for determining what PCC period is sufficient has been delegated to the States. For its part, the United States Environmental Protection Agency (USEPA) simply stipulates that the owner/operator of a closed landfill is responsible for its maintenance, monitoring, and condition for 30 years, or for an alternative period as necessary to protect HHE. Protection of HHE is demonstrated when potential threats posed by a closed landfill are minimized to acceptable levels at the relevant POE, which is typically identified as the closest property boundary location at which a receptor could be exposed to contaminants and receive a dose via a completed exposure pathway (USEPA, 1993). As defined above, the term *functional stability* is used for a landfill site that demonstrates no unacceptable risk to HHE at the POE in the absence of active care and forms the foundation for demonstrating how and when PCC can end.

At the Federal level, official guidance from USEPA on demonstrating the end of PCC at Subtitle D landfills is not yet available. However, USEPA has supported development of *Technical and Regulatory Guidance for Evaluating, Optimizing, or Ending Post-closure Care at MSW landfills based on Site-Specific Data Evaluation* by the Interstate Technology and Regulatory Council (ITRC, 2006). In addition, USEPA recently issued draft *Guidelines for Evaluating and Adjusting the Post-Closure Care Period for Hazardous Waste Disposal Facilities under Subtitle C of RCRA* for public comment (USEPA, 2015).

Several States have developed regulations and guidance to assist in decision-making on the completion of PCC at landfills. According to a survey by the Association of State and Territorial Solid Waste Managers and Officers (ASTSWMO, 2013), 10 States have promulgated regulations or guidance to extend or reduce the PCC period, with plans underway to develop such guidance in additional States. Recent notable examples include California, which issued regulations requiring a landfill owner to demonstrate financial assurance (FA) for a minimum of 30 times the annualized PCC costs, but allow a step-down approach to be used to reduce FA starting five years after landfill closure if this is supported by performance data (CalRecycle, 2010). The State of Washington issued revised PCC rules requiring a landfill owner to provide an estimate of the time for a landfill to reach functional stability after closure (Washington Department of Ecology, 2012) and total PCC funding requirements based on this estimate. The owner must also file a covenant, which is intended to specify the activity or use limitations on the property once the site is functionally stable (after which the solid waste permit is no longer applicable).

The Florida Department of Environmental Protection (FDEP) recently issued guidance on using a performance-based approach to demonstrate completion or extension of long-term care (LTC) at older landfills and construction/demolition debris disposal facilities (FDEP, 2016). LTC primarily addresses maintaining the final cover, water quality monitoring, and to the extent that they apply, gas and leachate management.

Optimization and completion of PCC through demonstration of functional stability is consistent with the long-term management (LTMgt) phase of the ER Program. This phase involves LTM to confirm that a remedy remains protective at closed sites where contaminants of concern remain above levels that would allow for unrestricted access and reuse of the property. LTMgt is required at landfills with long-term remedies, LTM, land use controls (LUCs), and five-year reviews. Although the adequacy of PCC funding is of more concern for privately-owned landfills, the magnitude of LTMgt costs projected over a 30-year time period for landfill sites is also a factor to consider for cost-to-complete of the ER program.

Reporting and Documentation

Reporting and documentation requirements for CERCLA and RCRA landfills vary. However, in all cases, a PCC or Long-Term Care Plan is required to describe the organization of inspection, monitoring, and operation and maintenance (O&M) activities to be performed, as well as the planned uses of the property. The plan should also provide details regarding recordkeeping, data evaluation procedures, decision-making for potential corrective actions, communication, and reporting requirements. Based on the plan, an estimate of the total cost of PCC should be provided. It is generally recommended that the plan and cost estimate be updated on a regular basis (i.e., every 5-10 years) as additional monitoring data (e.g., leachate, groundwater, landfill gas, settlement, etc.) are available (International Solid Waste Association, 2013). For CERCLA landfill sites that are closed in place, a five-year review is completed to evaluate the continued protection of HHE.

Key SLM Consideration

Regulatory PCC typically commences once closure construction is certified. Typical landfill PCC activities can be divided into six broad categories:

- Cap inspection and maintenance (e.g., annual mowing, localized repair and soil placement, fertilizing and reseeding/replanting, tree removal, remediation of leachate seeps or breakouts) to verify the cap is stable against erosion, instability, subsidence, or washout;
- Inspection and repair of stormwater management system features (e.g., dredging or excavation to remove sediment

from ditches and ponds, unclogging of toe drains, regrading drainage swales to promote drainage);

- O&M of the leachate management system, which may include leachate monitoring, treatment, and discharge/disposal;
- O&M of the gas management system, which may include flaring and methane utilization;
- Groundwater, surface water, and gas monitoring, data analysis, and reporting, including periodic maintenance and replacement of groundwater monitoring wells and gas monitoring probes; and
- Site security maintenance (e.g., fence repair and replacement, sign replacement).

Realizing objectives for SLM requires a proactive reduction of the landfill's potential environmental and financial liabilities in order to achieve functional stability. This can be achieved through interrelated optimization of closure design and post-closure O&M, monitoring, and property management.

Completion of PCC Obligations and Transition to Passive Controls

Regulations generally stipulate that PCC can only be completed once the landfill does not pose a threat to HHE. A number of approaches have been proposed to provide guidance on how to assess potential threats to HHE posed by landfills, and how to make decisions regarding optimization and completion of PCC (Laner et al., 2012). There is general agreement that a progressive approach to reducing care activities and monitoring efforts is sensible. This can be achieved in a technically and economically appropriate way by adopting a performance-based approach (Morris and Barlaz, 2011) in which reductions in care are based on periodic assessment of potential threats posed by uncontrolled leachate releases (Gibbons et al., 2014) or gas emissions (Morris et al., 2012).

The overall aim is to shift from active controls (e.g., leachate pumping, landfill gas flaring) to more passive measures that reduce energy consumption and costs (Zeiss, 2007). The ultimate goal is responsible cessation of active leachate and gas management through demonstration of functional stability, with residual treatment of *de minimis* emissions provided by natural analog systems (e.g., constructed wetlands for leachate, all-soil biocovers for gas) that are fully passive or require only low levels of unspecialized maintenance (e.g., windmill pumps for leachate, "whirlybird" vents for gas). Examples of passive systems for off-gas and leachate management are shown in Figures 1 and 2, respectively.

(Courtesy of Geosyntec)

Figure 1. Examples of passive control options for sustainable gas management: solar spark "tiki-torch" (left), "whirlybird" vent (center), or biofilter (right)

(Courtesy of Zirkon Research, Inc. [left]; Geosyntec [center]; Aqua Treatment Technologies [right])

Figure 2. Examples of passive control options for sustainable leachate management, featuring windwill pumps (left), and gravity-flow constructed wetlands (center and right)

In some cases, it may be demonstrated that monitoring alone is appropriate, which has significant parallels to USEPA's approval of monitored natural attenuation (MNA) for remediation of groundwater at CERCLA and RCRA sites. Protecting against disturbance of buffer zones or passive barriers (mainly the cap), while facilitating beneficial reuse of the property will require establishment of institutional controls such as deed restrictions and covenants. The extent of landfill buffer zones is not specifically regulated under RCRA or CERCLA and thus varies significantly between sites as a result of land use patterns, topography, and other factors.

Landfill Cap Design and Maintenance

Landfill caps are designed to promote runoff, minimize erosion, prevent direct exposure to waste, improve gas collection efficiency, control fugitive gas emissions and odors, and provide an aesthetically pleasing final appearance for the landfill. Most post-closure maintenance is expended on the cap because this is the main component of the landfill exposed to physical and climatic stresses; however, long-term cap performance is not necessarily linked to high levels of post-closure maintenance. Key issues for addressing landfill cap design and O&M focus on:

- Tailoring cap construction specifications to reuse or to utilize local materials or recycle existing building materials and wastes;
- Assessment of material use on the basis of life-cycle analysis (LCA);
- Integrating landfill cap designs with site reuse for generating renewable energy from landfill gas, solar, or wind resources or for other beneficial use;
- Development of alternative cap systems and passive leachate/gas treatment technologies that are compatible with or integrated into the cap;
- Maintaining and monitoring a cap through streamlined O&M activities and automated equipment; and
- Performance of climate variability assessments and incorporating sustainability considerations to develop alternative design criteria.

There is increasing evidence that the required functions of a final cap can be achieved with alternative designs in which geosynthetics are eliminated in favor of monolithic all-soil evapotranspirative (ET) caps, capillary-break ET caps, and phyto-caps (USEPA, 2011; ITRC, 2003). These performance-based cap designs are often implemented as part of sustainable landfill designs, providing increased longevity, stability, and protection of HHE and satisfying long-term performance criteria for infiltration control, while remaining compatible with the local ecosystem. Benefits include enhanced methane oxidation, reduced greenhouse gas (GHG) emissions, and a wider range of beneficial reuse options for the property. USEPA (2011) provides more information on best management practices (BMPs) for designing and installing a landfill cap using alternative caps and/or conducting a lifecycle assessment of material options for conventional covers.

Optimization of Landfill Monitoring

Monitoring at landfill sites will only be effective if the monitoring data are continually compared to decision criteria and evaluated to ensure progress is being made toward remedial objectives. The most common pitfall associated with landfill monitoring is a lack of understanding of site conditions caused by the failure to update the conceptual site model (CSM) through routine review of monitoring data. Critical elements to consider while designing and optimizing a monitoring program at landfill sites are summarized in Chapter 12 of the *Guidance for Planning and Optimizing Monitoring Strategies* (DON, 2010). The NAVFAC

Management and Monitoring Approach (MMA) is also a useful resource for LTMgt tools and strategies (NAVFAC, 2012). The optimization process should focus on collecting relevant data of the appropriate quality to achieve overall program goals. Optimized LTM can be accomplished by:

- Optimizing the number and location of monitoring points;
- Minimizing the frequency and/or duration of monitoring;
- Reducing the analyte list, simplifying the analytical protocols, and enhancing quality assurance/quality control (QA/QC) measures;
- Ensuring efficient field sampling procedures and techniques, with focus on passive sampling techniques as an opportunity to implement green and sustainable remediation (GSR) practices; and/or
- Streamlining data evaluation, management, and reporting procedures.

An exit strategy should also be developed for the monitoring program in collaboration with the stakeholder team. This will consist of the decision criteria that direct the decision to discontinue monitoring at a single monitoring point and/or for an entire monitoring program. An agreed to exit strategy will enable the frequency and duration of monitoring to be more readily optimized throughout the monitoring program. Additional guidance on proactive data collection for landfills is provided by ITRC (2006). Another resource is the ASTM Standard D7045-04, *Standard Guide for Optimization of Groundwater Monitoring Constituents for Detection Monitoring Programs for RCRA Waste Disposal Facilities* (ASTM, 2004). An update to procedures for modifying and eliminating gas controls is provided by Morris et al. (2012).

Beneficial Site Reuse

A key consideration for SLM is beneficial reuse of the landfill property. Performance-based assessments of PCC can define long-term care needs and help to identify suitable beneficial reuse options that will enable the site to safely return to useful service. Closed landfills provide opportunities to create facilities for walking, running, cycling, mountain biking, horse riding, golf, and many more activities (International Solid Waste Association, 2013). In addition to methane utilization projects, closed landfills may offer opportunities to host renewable energy developments such as solar arrays or wind farms (National Renewable Energy Laboratory, 2013). Such renewable energy developments may provide an economically viable reuse for sites that may have significant cleanup costs or low real estate development demand. However, it is important to understand that several site-specific geotechnical, hydrogeologic, ecological, and other considerations may limit the extent of reuse options available at a landfill. Settlement may continue for several decades after closure depending on the types of waste landfilled, decomposition, leachate and gas production. It is important, therefore, that any proposed reuse of a site is compatible with maintaining the necessary long-term integrity and performance of landfill component systems, particularly the cap. Figure 3 is an example of mixed use redevelopment for a landfill site featuring a recreational park, wildlife refuge, and renewable energy facility.

Figure 3. Proposed mixed use redevelopment of Fresh Kills Landfill in New York City

HRSC Landfill Mining and Clean Closure

CERCLA and RCRA define two general types of closure: "clean closure" and "closure with waste in place." In clean closure, waste is removed for off-site treatment or disposal in another waste management facility, and there are no PCC requirements or related issues with long-term methane emissions, local pollution concerns, settling/subsidence, or limitations on site redevelopment. Landfill mining has been suggested as a strategy to achieve clean closure, which in principle means the excavation, processing, treatment and/or recycling of disposed materials. However, Krook et al. (2012) reviewed 39 research studies published between 1988 and 2008 and concluded that landfill mining has primarily been seen as a way to resolve traditional landfill issues related to lack of disposal space and local pollution concerns. Although most mining initiatives have involved some recovery of disposed resources, mainly cover soil and waste fuel for incineration, recycling and recovery efforts have largely been secondary considerations. A decision-making procedure that allows landfill owners to examine the feasibility of a landfill mining project based primarily on the risks and costs of landfill mining versus retaining the landfill in PCC is described by Hermann et al. (2015).

Climate Change and Shoreline Erosion Protection

The consideration of shoreline erosion protection as a component of SLM is rather unique, but reflects the fact that some of the Navy's landfills are located near coastal properties. The USEPA recently released a *Climate Change Adaptation Technical Fact Sheet: Landfills and Containment as an Element of Site Remediation* (USEPA, 2014). The fact sheet provides a brief overview of potential climate change vulnerabilities and possible adaptation measures that may be considered to increase a landfill's resilience to climate change impacts. Adaptation strategies should include: monitoring of implemented measures, periodic re-evaluation of the system's vulnerability, and incorporating any needed changes. An increased vulnerability to shoreline erosion may be one impact from sea level rise associated with climate change. Many traditional methods for shoreline stabilization have resulted in the hard armoring of the ocean-land interface with concrete revetments, rip-rap, or seawalls (e.g., U.S. Army Corps of Engineers, 1985). However, strategies must be devised that balance competing demands for coastal resources now and in the future as sea levels rise due to climate change. Decision makers must consider how numerous factors will influence coastal habitats, water resources, and infrastructure.

Moving or abandoning shoreline infrastructure may not be feasible for shorelines already constrained by coastal armoring, especially where that armoring protects a landfill. In these cases, engineers will need to develop strategies and methods to control shoreline erosion in a dynamic and constantly evolving environment. Soil bioengineering offers a sustainable approach by combining non-living structural components with plants to create a mutually reinforcing and complementary stabilization system. Traditional underlying materials or structural methods can be combined with some form of vegetation to create a soft-armor system. Examples include:

- Rip-rap underlain with sand or gravel rather than an impervious geomembrane can be backfilled with soil and seeded or planted with appropriate woody vegetation;
- Wire-mesh gabions can be alternately filled with rock, soil, and living plant material;
- Geogrids or other geosynthetic products such as "geo-web" can be infilled with sand or stone and seeded or planted to form a biotechnical system, which combines permanent structure with plant material to create a flexible, wave-resistant matrix; and
- Wattle fences, which are short retaining walls built of live cuttings, can provide live bank protection through creation of a woody buffer against erosion.

Bioengineering measures should be proactively considered as a sustainable alternative to any new hard armoring project, or prior to making repairs or extending existing hard armoring. Transitioning from hard armoring to bioengineered shoreline protection has many similarities to alternative cover systems in lieu of geomembrane caps as described previously. A properly designed bioengineering system can have lower overall costs, improve water regimes, ameliorate soil loss, and integrate erosion control structures into the landscape. Additional references on soil bioengineering for the protection of coastal and riparian zones can be found in Gray and Leiser (1982) and United States Department of Agriculture (2007).

Case Study

Optimized Shoreline Protection Design for Site 10 North End Landfill, Naval Magazine Indian Island, Port Hadlock, Washington

Site 10 served as a landfill for residential and industrial waste between the 1940s and 1970s. USEPA added the entire 2,700 island site to the National Priorities List (NPL) in 1994, and DON began remedial activities in 1996, which allowed the site to be delisted in 2005. The selected remedy for Site 10 included multiple components to protect HHE, including:

- Placing a geosynthetic cap over approximately 3.7 acres;
- Removing eroded landfill debris that was located in the intertidal area;
- Excavating landfill waste from the water's edge; and

- Preparing the shoreline for the construction of erosion protection measures, which comprise vegetated geogrids (VGs) and shoreline protection system (SPS) along approximately 900 linear feet of the landfill perimeter.

In addition, institutional controls are relied on to protect HHE. DON performs regular maintenance and inspection of the landfill cap and SPS, particularly after storm events, and conducts five-year reviews of the site. The SPS was originally divided into three sections according to its erosion potential:

- Low Energy (LE) SPS, which consisted of large anchored logs
- High Energy (HE) SPS, which consisted of large stones
- Very Low Energy (VLE) SPS, which consisted of quarry spalls (riprap)

Since the installation of the SPS, signs of erosion, particularly along the eastern portion of the LE section where it meets the HE section, have been observed and additional armor rock was placed there in 2004, thus effectively extending the HE section. In 2012, evidence of additional erosion at the 2004 LE/HE boundary led to further extension of the HE section (Figure 4).

In 2013, NAVFAC commissioned a remedial design (RD) to provide shoreline protection for at least 50 years. As detailed in the *Fourth Five Year Review* (DON, 2015), the RD recommended improvements to the SPS. However, subsequent reviews noted that the measures recommended in the RD were overly conservative as there has been no threat of waste being released to the environment even when erosion has been noted. In 2014, additional maintenance of the armor rock was conducted at the LE/HE boundary, which consisted of relocating some existing armor rock and placing additional material to further strengthen the rock revetment.

The VGs and SPS, as modified following repairs in 2004, 2012, and 2014, are functioning as intended and have significantly reduced the potential for erosion issues. Therefore, it was concluded that the current approach of placing additional armoring rock on an as-needed basis is more cost-effective and sustainable, and ultimately more favorable to stakeholders that have an interest in shellfish harvesting. As long as shoreline inspections are conducted and additional armoring stone is placed as needed, the current remedy was found to be protective.

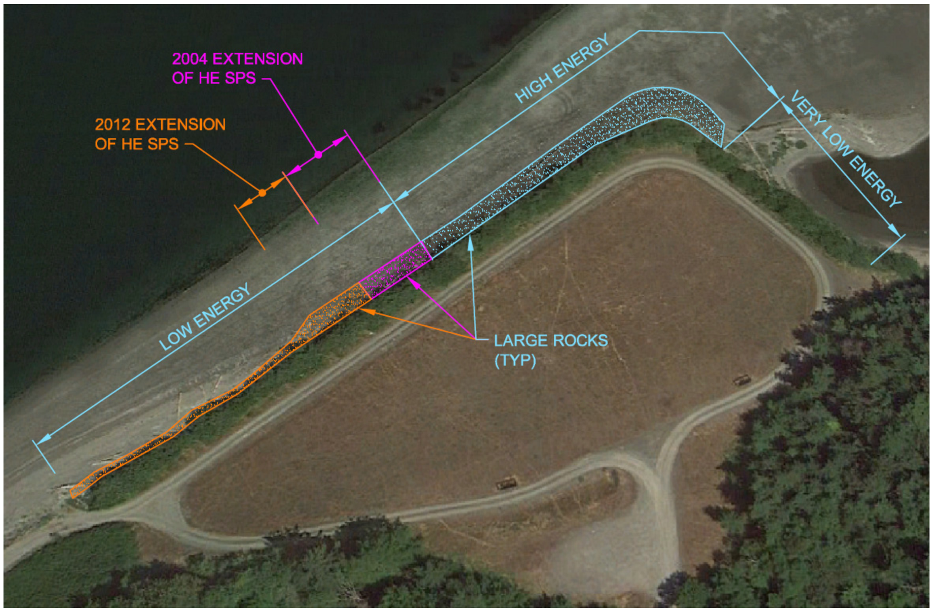

Figure 4. Recent improvements to shoreline protection system at Site 10

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