New Jersey Department of Environmental Protection

Site Remediation Program

TECHNICAL GUIDANCE ON THE CAPPING OF SITES UNDERGOING REMEDIATION

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1 Introduction

1.1 Intended Use of the Guidance Document

This guidance is designed to help the person responsible for conducting remediation to comply with the New Jersey Department of Environmental Protection (Department or NJDEP) requirements established by the Technical Requirements for Site Remediation (Technical Rules), N.J.A.C. 7:26E. Landfills regulated under the Solid Waste Management Act should continue to comply with the Solid Waste regulations at N.J.A.C. 7:26-2A. This guidance will be used by many different people involved in the remediation of a contaminated site, including Licensed Site Remediation Professionals (LSRP), non-LSRP environmental consultants, and other environmental professionals. Therefore, the generic term "investigator" will be used to refer to any person who uses this guidance to remediate a contaminated site on behalf of a remediating party, including the remediating party itself.

The procedures for a person to vary from the technical requirements in the regulation are outlined in the Technical Rules at N.J.A.C. 7:26E-1.7. Variances from a technical requirement or departure from guidance must be documented and adequately supported with data or other information. In applying technical guidance, the Department recognizes that professional judgment may result in a range of interpretations on the application of this guidance to site conditions.

This guidance supersedes previous Department guidance issued on this topic. Technical guidance may be used immediately upon issuance. However, the Department recognizes the challenge of using newly issued technical guidance when a remediation affected by the guidance may have already been conducted or is currently in progress. To provide for the reasonable implementation of new technical guidance, the Department will allow a 6-month "phase-in" period between the date the technical guidance is issued final (or the revision date) and the time it should be used.

This guidance was prepared with stakeholder input. The following people were on the committee who prepared this document:

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Please note that this technical guidance typically represents the consensus of the committee. There may have been a range of viewpoints on any given topic, but what is presented represents the majority view to the greatest extent possible. Ultimately, the guidance is the responsibility of the Department, which reserves the right to assert its position on the guidance.

Any reference to a product or proprietary name should not be construed to be an endorsement or recommendation by the Department. Such references are intended to be examples and their use does not imply that they should be used exclusively.

Citations and URL links will be current as of the date of this guidance document. The reader is advised that URL links are subject to change; however, both citations and URLs are provided to facilitate further investigation by those who use this guidance.

1.2 Purpose or Objective of the Guidance Document

This technical guidance will define what a cap is, describe various types of caps, and discuss the factors and limitations to be considered in selecting a particular cap. The goal is to provide information that investigators can use to determine which caps are best for the remedial issues facing them.

This technical guidance is not intended to determine whether capping should or should not be the remedial action; the guidance is intended to explain how to evaluate various capping options. This guidance assumes that the remedial investigation process (preliminary assessment, site investigation, remedial investigation, and receptor evaluation) has been completed pursuant to the Technical Rules; that a decision to install a cap as part of the site remediation process has been made; and that the reader is looking for guidance with respect to implementing a capping remedy, given the site conditions.

Containment is a practice that may be used in conjunction with capping but is not the principle focus of this document. Containment, which primarily refers to installing physical barriers to control the lateral movement of contamination, can be a critical element of a remediation strategy.

Capping, on the other hand, primarily precludes direct contact by acting as a barrier between a receptor and the contaminated media below, and prevents vertical contaminant movement. However, a cap may also serve additional functions besides simple physical isolation, which are discussed later in this guidance. This document assumes containment is present or is not needed. A more complete discussion of containment is provided in Appendix A.

Any capping remedy must comply with N.J.A.C. 7:26E-5.1 (e), which requires that "the person responsible for conducting the remediation shall treat or remove free product and residual product to the extent practicable, or contain free product and residual product when treatment or removal is not practicable."

Site-specific information will be needed to determine which cap to select and will be presumed to be available and accurate. If such information is not available, it will need to be procured, or a determination made that remediation will proceed based on certain assumptions. The investigator assumes the inherent risk in proceeding since such assumptions may prove to be wrong or the available information incorrect.

The investigator is advised to develop a conceptual site model (see Conceptual Site Model Guidance http://www.nj.gov/dep/srp/guidance/#csm) to make examination of critical aspects of the remediation easier. The conceptual site model will aid in identifying potential receptors and related migration pathways. The receptors and pathways to be addressed by specific types of engineered caps should be evaluated before construction takes place to make sure the goal of eliminating exposure pathways is achieved. Comparing the strengths and weaknesses of various caps against expected conditions in a conceptual site model will help in evaluating the viability of each capping option. An investigator must clearly understand the nature of contaminants to be remediated and the current and projected future conditions at the site. Without a conceptual site model, selecting an appropriate cap is much more difficult and does not allow for tailoring the remedial action to site-specific conditions.

This technical guidance will facilitate the cap selection process and provide a measure of assurance that the investigator is proceeding appropriately. Ultimately, the investigator bears responsibility for implementing a remedy that is protective of human health and the environment.

1.3 Document Overview and Structure

This technical guidance will consist of the following primary sections:

- Introduction
- Factors to Consider

- Cap Types
- Literature Cited
- Appendices

The Introduction (Section 1) includes statements on the purpose and use of this guidance document, as well as on organization. Also included are some of the initial concepts or definitions used by the committee.

The Factors to Consider Section (Section 2) provides information on elements that apply to all or a large majority of the caps described. Rather than repeat this general information when discussing each cap type, this information is provided in advance. These factors to consider have been organized in three subgroups that reflect their nature or relevance. These subgroups are Technical Factors, Regulatory Factors, and Responsible Party Factors.

Section 3, Classes of Cap Types, offers a selection of cap choices and is the core of the technical guidance. The three general classes of cap types are Low Permeability, Permeable, and Sediment. Within these three classes are specific types of caps.

The descriptions of the cap types include pertinent factors that have been useful, based on experience, in determining the applicability of a given system. To the extent possible, the discussion of each cap type follows the same structure. When necessary, more-detailed explanation of a relevant factor is provided. This information, such as materials used, should not be interpreted as requirements and is provided for illustrative purposes only. The described cap types are not the only capping choices available, so each investigator will likely need to tailor the choices provided to fit the requirements of each unique application. Alternatively, the investigator may need to develop a new approach.

Section 4, References, lists documents that are either cited or that have value as additional sources of information. References will be subdivided and listed alphabetically according to the sections in which they were referenced. However, to avoid confusion, all citations in Section 4 with the same author and year will be distinguished by consecutive alphabetic characters to make each citation unique.

The Appendices address the topic of containment (Appendix A), provide examples of caps that have been built (Appendix B), make available more detailed cost information (Appendices C through F), and list acronyms and definitions used in this document (Appendices G and H).

1.4 Definition of a Cap

The simplest definition of a cap is a barrier located over contaminated media that mitigates exposure to potential receptors. As with any selected remedial action, the capping remedy must be protective of human health and the environment. Typically such protection is provided by interrupting an exposure pathway or by exerting control of contaminant movement.

1.5 Compliance with Regulatory Requirements

The Technical Rules specify at N.J.A.C. 7:26E-1.1 (b) 2 that remediation performed pursuant to this chapter does not relieve any person from obtaining all permits required by federal, state, or local statute or regulation, except as expressly provided herein.

With regard to selecting a cap (engineering control) as a remedy, the investigator should be aware that a Soil Remediation Permit must be obtained pursuant to ARRCS (see Section 1.6 below). Also, under certain site-specific conditions, additional permits may need to be obtained. The intent of this section is to simply inform the investigator of this Technical Rule requirement and provide general guidance as to when permits may be necessary for a capping remedy. Because the need for permits depends on site-specific conditions, the information presented in this section should not be considered all-inclusive; rather, it is intended to provide general information about what types of permits may be needed, given the various types of habitats and contaminants present. Ultimately, the investigator is responsible for ensuring compliance with N.J.A.C. 7:26E-1.1(b) 2.

Please be aware that the Site Remediation Program (SRP) Office of Dredging and Sediment Technology issues land use permits for cases under SRP oversight as well as Acceptable Use Determinations for dredged material used for capping purposes.

The following permits, or adherence to rules, may be required when a capping remedy is implemented:

Federal

- Compliance with TSCA Rules may be required when polychlorinated biphenyls (PCB) are present pursuant to the Mega Rule (40 CFR Parts 750 and 761 Disposal of Polychlorinated Biphenyls (PCB)); Final Rule.

- United States Army Corps of Engineers – a Nationwide Permit or Individual Permit may be required if the cap footprint extends beyond the 100-year flood plain/riparian zone. Section 10 or Section 404 permits may be required for work in waters connected to tidal waters. A Section 404 permit is required in certain freshwater wetlands and inland water bodies.

State

- Flood Hazard Zone Permits, N.J.A.C. 7:13

- Freshwater Wetlands Permits (General or Individual), N.J.A.C. 7:7AWaterfront Development Permits (General or Individual), N.J.A.C .7:7, N.J.A.C. 7:7E
- CAFRA (Coastal Area Facility Review Act Permits (General or Individual), N.J.A.C. 7:7, N.J.A.C. 7:7E
- Clean Water Act Section 401 Water Quality Certificate
- Tidelands License, N.J.S.A. 12:3
- Federal Consistency Determinations for federal actions (15CFR Part 390) and Permit Equivalencies for Superfund and CERCLA, 42USC 9601 et seq
- New Jersey Pollution Discharge Elimination System (NJPDES) Storm Water Permits- quality of cap storm water runoff
- Landfill disruption and landfill closure permits
- Highlands Water Protection and Planning Act approval, N.J.A.C. 7:38
- Additional land use regulation permits and others

Local

- County Soil Conservation Service (soil erosion and sediment control)
- Township permits (i.e. tree removal)
- Construction permits
- Local soil import and export ordinances

1.6 Administrative Requirements

Caps are components of engineering controls used for remedial actions, and must comply with certain administrative requirements. Engineering controls for soil are always associated with institutional controls (i.e., deed notices). Deed notices are required whenever soil left in place exceeds the unrestricted-use standards. The regulatory requirements for a deed notice are provided in N.J.A.C. 7:26C-7 Administrative Requirements for the Remediation of Contaminated Sites. The deed notice includes as-built plans and details of the engineering controls (if used), including the cap, as well as monitoring and maintenance requirements.

Once a deed notice is recorded with the County Clerk, the responsible party is required to apply for a soil remedial action permit from the Department. Please see the document Remedial Action Permits for Soils Guidance (NJDEP 2010) at http://www.nj.gov/dep/srp/guidance/srra/draft_rem_action_permit_guidance_soils.pdf

The permit application would include, but is not limited to, a copy of the recorded deed notice, financial assurance mechanism (required for engineering controls), a description of the engineering controls (including the cap), a list of contaminants required in the deed notice, and a receptor evaluation summary. An application fee and annual fees are associated with the soil remedial action permit. Any modifications to the deed notice or engineering controls would require modification of the soil remedial action permit.

Institutional and engineering controls require a protectiveness, which is typically done biennially from the date the deed notice is recorded with the County Clerk. The purpose of the protectiveness certification is to ensure that the remedial action, which includes the institutional and engineering controls, remains protective of human health, safety, and the environment. The certification requires, but is not limited to, an evaluation of changes to relevant rules and regulations, evaluations of site use, and periodic inspections to determine disturbances to the engineering controls.

Administrative requirement for sediments are discussed in Section 3.3.5.

1.7 Presumptive Remedies

Pursuant to N.J.S.A. 58:10B-12(g), the Department is required to establish presumptive remedies for any remediation initiated after May 7, 2010, at a site or area of concern (AOC) where new construction is proposed for residential purposes; for use as a licensed child care center or as a public school, private school, or charter school; or where there will be a change in the use of the site to residential, child care, or public school, private school, or charter school purposes. It is necessary that a remedial action conducted at these facilities is an unrestricted use remedy, presumptive remedy, or an alternative remedy that is pre-approved by the Department prior to implementation.

To address this requirement, the Department issued a guidance document titled Presumptive and Alternative Remedy Technical Guidance (NJDEP 2013a) http://www.state.nj.us/dep/srp/guidance/srra/presumptive_remedy_guidance.pdf, providing specifications on the use of engineering controls to mitigate exposure to contamination for the receptor groups identified above.

The guidance contained in this document shall not be used to circumvent any of the presumptive remedies set forth in the Presumptive and Alternative Remedy Technical Guidance document. The intent of this document is to provide guidance on the selection and use of caps for receptor groups other than those covered in the Presumptive Remedy Guidance document.

2 Factors to Consider

Factors to Consider has three subdivisions: Technical Factors (Sections 2.1 through 2.3); Departmental or Regulatory Factors (Sections 2.4 through 2.7); Responsible Party or Investigator Factors (Sections 2.8 and 2.9).

2.1 Technical Factors

2.1.1 Contaminant Properties

The objective, extent, and components of a cap are based primarily on the types of contaminants present, their distribution, and the concentration of those contaminants. When evaluating the type of cap to be implemented, an investigator should consider the toxicity and mobility of the contaminants present, and should identify the primary migration and exposure routes. The combination of these factors will determine the viability of a given cap option and the associated set of design specifications.

For all contaminants, a fundamental purpose of a cap is to prevent direct exposure to contaminated media. However, the transport of chemicals to receptors of concern could also occur via (1) upward or downward movement of dissolved contaminant in soil moisture, and (2) volatile contaminant movement upward and downward in soil gas by vapor diffusion or bulk soil-gas flow. The cap may require features to control these modes of transport.

Most contaminants have some mobility in soil moisture (water present in the vadose zone), and this mobility should be assessed to determine whether the contamination poses a threat to groundwater quality through downward movement of soil moisture. If there is a risk, and the contaminants are inorganics or semi-volatile organic contaminants, the cap may contain a low hydraulic conductivity layer to prevent or reduce rainfall infiltration through the cap and percolation through the contaminated media. A low hydraulic conductivity layer will also prevent upward soil-moisture movement through the cap via capillary rise and potential accumulation of low-volatility contaminants on the surface of the cap. This movement is of particular concern for hexavalent chromium sites.

Volatile contaminants are mobile in both the soil moisture and the soil gas phase. When volatile contaminant concentrations in soil are relatively low, the upward movement of contaminant vapor and its dispersion into the overlying air may be a desirable natural attenuation process. A permeable cap may be useful in these situations, while the use of a low-permeability cap can be problematic because such a cap may increase lateral and downward movement of volatile contaminants. Increased impacts to groundwater or receptors may result. On the other hand, if volatile contaminant concentrations are sufficiently elevated, upward migration of contaminant vapor through the cap could pose an inhalation exposure risk in the air above the cap. In these cases, a low-permeability cap with a vapor barrier may be needed, and vapor movement under the cap may need to be controlled.

2.1.2 Media Properties

The media in which the contamination occurs should be assessed to determine its physical stability and potential to influence the mobility and degradability of the contaminants present. Some of the media-specific characteristics that control contaminant behavior are described below.

The rate of moisture-flow through the contaminated media affects the rate of contaminant-transport soil moisture. Volatile compounds, when present in the vapor phase, may also migrate in the contaminated media. Determination of the texture (i.e. particle-size distribution) of the contaminated media can assist in assessing the susceptibility of the media to contaminant migration in soil moisture and by vapor transport. More quantitative parameters may also be determined, such as unsaturated hydraulic conductivity, permeability and permeance (vapor-movement potential). These parameters will assist in determining the drainage characteristics of the media if a permeable cap is used.

For contaminants that may degrade under aerobic/oxidizing, anaerobic/reducing, acidic or alkaline conditions, assessment of the oxygen content (or lack thereof), carbon dioxide content, pE/Eh values, pH values, or other indicators, may help determine if conditions in the media will promote natural attenuation of the contaminants by degradation.

The organic content of the media may be correlated with the mobility of non-ionized organic compounds, and the pH of the media can provide information pertaining to the mobility of inorganic and some ionized organic contaminants.

Media characteristics unrelated to contaminant behavior should also be considered. Appropriate testing should be considered to determine the resistance of the media to compaction or settling because media instability could result in a cracked, damaged, or otherwise compromised cap. If plans call for installing physical features in the contaminated media (i.e. vents, sampling ports, other piping), the presence of obstacles (i.e. clay, large stones or boulders, etc.) that render the installation of these features difficult should be assessed. Additionally, the global stability and bearing capacity of media underlying the cap should be examined to ensure it can support the proposed cap. For caps placed on sloping ground, the resistance to sliding, or veneer stability, should also be examined.

2.1.3 Hydrology/Hydrogeology

Both site hydrology and geology should be considered in cap design. Depth to water, range of seasonal groundwater fluctuation, occurrence of shallow perched water and natural or man-made features that may control transient flows should be identified. The investigator should understand whether the potential exists for groundwater to rise up into the cap and should design the cap accordingly, based on the remedial objectives. Consideration should also be given to nearby features that have the potential to affect cap integrity (e.g. a pond that periodically floods or runoff from an upgradient impermeable area that may cause a soil cap to fail).

Conversely, the constructed cap may alter the site hydrology. For example, an impermeable cap can reduce infiltration and depress the water table, causing a change in groundwater flow. Moreover, such a cap could increase runoff to adjacent areas and result in increased flooding.

2.2 Regulatory Factors

2.2.1 Receptors

Beyond the site- and chemical-specific considerations discussed above, the proper design of a cap should include an assessment of potential exposure pathways and receptors. The Agency for Toxic Substances and Disease Registry (ATSDR) defines an exposure pathway as the link between environmental releases and local populations that might come into contact with or be exposed to environmental contaminants (ATSDR, 2005).

The cap should be designed to mitigate exposure to receptors. The potential exposure paths from contaminants are provided below, and a discussion of receptors including environmentally sensitive natural resources (ESNR) follows.

The potential exposure pathways for contaminated media are a function of the contamination and site setting. The primary exposure pathways are dermal contact, ingestion and inhalation. Not every site will have all of the exposure pathways listed below; however, the investigator should evaluate applicable potential exposure pathways to ensure the cap is sufficiently protective.

The location where a receptor can be exposed to contamination can be described as the exposure point. Exposure points can be identified and analyzed in soil, groundwater, surface water, sediment, air and the food chain (e.g. crops, fish and game). An assessment of the site conceptual model, updated to include the cap and future site use, should consider these exposure points. The cap design should include measures to mitigate contaminant exposure to receptors.

Table 1 below lists potential exposure points and exposure pathways that may arise from each exposure point type:

Table 1. Exposure points and exposure pathways

Exposure Point	Potential Exposure Pathway	
	Dermal Contact/Ingestion	Inhalation
Soil	X	X
Groundwater	X	X
Surface Water	X	
Sediment	X	
Air		X
Food Chain	X	

Receptors are defined in N.J.A.C. 7:26E – 1.8 as "a human or natural resource." Current and future receptors should be included in the exposure pathway evaluation while designing the cap. The potential for receptors to be impacted by contamination at a site depends on the site use (residential or nonresidential) and a complete exposure pathway. Exposure pathways should be evaluated for all media and potential receptors (human and ecological) at each capped area. The ATSDR document referenced above provides a detailed procedure for evaluating the completeness of each exposure pathway and point. Beyond chemical concerns, additional consideration should be given to hazards presented by physical hazards or components of the site. These physical hazards can include sharp changes in grade, large metallic debris (which could penetrate the cap after settlement), and groundwater upwelling, all of which can diminish the bearing capacity of the cap.

Environmentally Sensitive Natural Resources (ESNR): It is important to recognize that the presence of ESNRs on a site requires careful evaluation and may also require adherence to regulations outside the Site Remediation Program. ESNR means an area defined in N.J.A.C. 7:1E-1.8(a), or an area or resource protected or managed pursuant to the Pinelands Protection Act, N.J.S.A. 13:18A-1 et seq. and the Pinelands Comprehensive Management Plan (N.J.A.C. 7:50). Some examples of ESNRs include fresh- and saltwater wetlands, marshes, streams and rivers.

Contamination present in an ESNR must be evaluated pursuant to regulations set forth in N.J.A.C. 7:26E-1.16 and N.J.A.C. 7:26E-4.8, and as prescribed in the NJDEP Ecological Evaluation Technical Guidance (NJDEP 2012) http://www.nj.gov/dep/srp/guidance/srra/ecological_evaluation.pdf to determine whether a remedial action is necessary. If a remedial action is warranted, then all remedial alternatives (excavation, capping, in-situ treatment, etc.) must be evaluated on a site-specific basis.

A remedial action conducted in an ESNR, such as a wetland, stream, or flood plain, is considered a regulated activity and will require Land Use Regulation Permits (see Section 6.4.1 of the NJDEP Ecological Evaluation Technical Guidance). Remedial actions conducted in ESNRs may also be subject to Land Use Regulation Program (LURP) restoration and mitigation requirements.

Capping is a presumptive remedy for historic fill in upland areas. Where historic fill and associated contaminants are located within ESNRs, the presumptive remedy of capping does not apply. Alternative remedies should be considered if capping would result in adverse impacts to the ESNR (ref. Sections 6.4.9 of the NJDEP Ecological Evaluation Technical Guidance).

2.2.2 Current and Future Land Use

When selecting a cap as a remedial action, the investigator should be aware of the current and future land use, as well as the land-use categories within Site Remediation Reform Act (SRRA) and the remediation standards (N.J.A.C. 7:26D). For site remediation purposes within New Jersey, current and future land use is broken into two main categories: “Residential " and “Non-residential”.

From N.J.A.C. 7:26D-1.5 (Remediation Standards), “residential use” means a land-use scenario in which exposure to contaminated media lasts 24 hours a day, 350 days a year for 30 years for children and adults living on a site. Examples of residential land use include single-family dwellings, and multifamily dwellings (low, mid, and high-rise).

From N.J.A.C. 7:26D-1.5, "Non-residential use" means an exposure assumption based on exposure of adult outdoor workers to contaminated media during an eight-hour work day, 225 days a year for 25 years. Nonresidential land use can be broken down into commercial or industrial categories. Commercial land use examples include shopping malls, office complexes, restaurants, hotels, motels, grocery stores, automobile service stations, petroleum distribution operations, dry cleaning operations, etc. Industrial land use examples include manufacturing and assembling processes associated with factories, metal foundries, wood-treatment facilities, mines, refineries, and chemical plants.

However, other exposure scenarios exist and include both recreational and trespass exposure scenarios. These scenarios assume fewer days of direct contact than either the residential or non-residential exposure scenarios and may be used as part of a request for an alternative remediation standard.

The investigator will also need to be aware of restrictions on land use that derive from the Technical Rules. For example, construction of a single-family residence, school, or child care center is prohibited by N.J.A.C 7:26E-5.3 on a landfill that undergoes capping, if engineering controls are required for the management of landfill gas or leachate.

The investigator is cautioned that a change in use triggers a reassessment of the cap's ability to be protective of the future exposure scenario.

2.2.3 Compatibility with Ongoing or Potential Remedial Work or Existing Remedy

Remedial investigations and remedial actions are often carried out in phases. Future or additional remedial investigations or actions that may occur in the area being capped should be considered. To the extent possible, the engineering and regulatory requirements of any remaining investigation or remediation should be accounted for when designing the cap.

In some cases, performing a remedial action may be necessary before completing the remedial investigation of all media for an AOC. Installation of a cap at an AOC does not negate the requirement to complete the site or remedial investigation at that AOC, such as installing monitoring wells.

As an example, assume that a low-permeability cap was installed in an AOC near the entrance to a site. Future remedial action anticipates the excavation of 100,000 cubic yards of impacted materials that will be transported off site by truck. The cap should be designed to withstand the anticipated heavy loads and intense wear, so that it can continue to function as required. The potential impact of a cap constructed during early phases of a remedial action on areas that have not yet been remediated should be considered. Increased runoff to adjacent areas or depression of the water table resulting in changes of the direction of groundwater flow should be anticipated and incorporated into the Remedial Action Work Plan (RAWP) prepared subsequent to installing the cap.

2.3 Responsible Party Factors

2.3.1 Green Remediation & Sustainability Considerations

The capping technology should be evaluated in light of N.J.A.C. 7:26E-1.9, "Green and Sustainable Practices," wherein "the Department encourages the use of green and sustainable practices during the remediation of contaminated sites." Guidance toward these ends is available in the USEPA Region 2 "Clean & Green" Policy http://www.epa.gov/region2/superfund/green_remediation/policy.html. The Policy objectives are as follows:

- Protect human health and the environment by achieving remedial action goals

- Support human and ecological use and reuse of remediated land
- Minimize impacts to water quality and water resources
- Reduce air emissions and greenhouse gas production
- Minimize material use and waste production
- Conserve natural resources and energy

USEPA Region 2 Clean and Green Policy established Touchstone Practices, which may be applicable to the capping project:

- Use of 100% of electricity from renewable sources
  http://apps3.eere.energy.gov/greenpower/buying/buying_power.shtml
- Clean diesel fuels and technologies
  http://www.epa.gov/otaq/diesel/index.htm
- Methane capture at landfill sites
  http://www.epa.gov/region2/superfund/green_remediation/policy.html
- Industrial materials reuse or recycling within regulatory requirements
- Concrete made with Coal Combustion Products (CCP)
  http://www.epa.gov/wastes/conserve/imr/ccps/index.htm
- Construction and Demolition materials
- Recycle and reuse of organic materials generated on-site

  http://www.epa.gov/compost/pubs/index.htm

In addition, Executive Order No. 54, signed by Governor Corzine on February 13, 2007, requires a statewide stabilization of greenhouse gas emissions at 1990 levels by 2020, and a reduction in emissions to 80% of 2006 levels by 2050. Landfills are significant emitters of carbon dioxide and methane, both of which are greenhouse gases that can be mitigated by certain capping technologies

2.3.2 Cost

Cost to Construct the Cap: The cost would reflect not only the materials, labor, and engineering designs needed for constructing the engineering control (i.e. cap), but also for the elements necessary for the application for a “remedial action permit,” deed notice, etc.(See N.J.A.C. 7:26C- 5.3 & 7.5)

Cost estimates should be prepared by an experienced engineer or estimator knowledgeable in the construction of this type of cap. The cost estimate may be compiled either using a commercial software package (i.e. Cost-Pro™) or in-house procedures. Assumptions and sources should be documented. Costs should also include anticipated operation and maintenance (O&M) activities and repairs.

Relative cost information for various caps may be found in Appendix F. Do not rely on this information for final decision making, because actual incurred costs are subject to many variables and not all costs are included in the presented examples.

Cost for Long-term Operation and Maintenance of the Cap: The extent of the maintenance needed for the cap depends directly upon what type of cap is being used. Maintenance costs can be annual or periodic depending on the cap construction and use. Costs for O&M fall into four broad categories: inspection costs, usage costs, repair costs, and one-time events. Costs should reflect the material, labor, and professional services needed for the physical maintenance of the cap. Details on these categories can be found in the individual cap-type sections.

Costs should reflect any reporting obligations, including biennial certifications (protectiveness evaluations), and permit requirements to ensure that the cap remains protective. Additional future costs would apply to operate, maintain and inspect all engineering controls. See N.J.A.C. 7:26C-7.5(b)5-6. Additional details on biennial certifications and permit fees can be found in Appendix D.

Remediation Funding Source (RFS) and Financial Assurance (FA) requirements: The cost to construct and maintain a cap includes the two financing guarantees required by the Department. The Remediation Funding Source reflects the cost to implement the RAWP, while FA reflects the cost to operate and maintain the cap for 30 years. Refer to Appendix E for more information about RFS and FA.

2.3.3 Community Acceptance/Aesthetics

When a capping remedy is selected, community acceptance should be an important factor to take into consideration, especially when the cap will extend to areas proximal to residential neighborhoods, parks, or other areas (walkways, trails, etc.) where public use is anticipated. Involving community stakeholders (e.g. residential communities, homeowners associations, local environmental groups, townships, etc.) early on in the process may facilitate the selection of a remedy that addresses protectiveness and community concerns. The investigator needs to be aware of the notification requirements in ARRCS (N.J.A.C. 7:26C-1).

Under certain scenarios, several capping types or combinations of caps may be protective, and community stakeholders may have preference for one type over another. For example, consider a cap designed primarily to address direct contact that will border several residential backyards. Although an asphalt cap that covers the entire area might be protective, a combination of an asphalt cap and vegetated soil cap installed near the residential boundary might also be protective. Addressing community interests is not new and is frequently incorporated into many construction and development-related projects. The purpose of this section is to make the reader aware of community involvement. Ultimately, the capping type selected must be protective of human health and the environment.

3 Classes of Cap Types

For the purposes of this document, caps are classified as low permeability, permeable and sediment, based on certain commonalities in performance and construction characteristics. The following subsections provide a description, discussion of main components, design considerations and data needs, operation and maintenance, and cost considerations for each type of cap.

3.1 Low-Permeability Cap Types

- **Description**

A low-permeability cap is one that minimizes the transmission of water or vapor, and thus contaminants, through its structure. The two processes by which contaminants can pass through a cap include advection (bulk flow of water or soil gas through the cap) and by diffusion of contaminants caused by contaminant concentration differences between the two sides of the cap. When a cap's purpose is to resist water transmission, a low-permeability cap typically has a saturated hydraulic conductivity or coefficient of permeability of10^{-5} cm/sec or less, depending on the site conditions, nature of contamination, classification of the underlying aquifer, and design objectives for the cap. For caps addressing vapor migration, permeability is reported in units of perm or permeance. American Society for Testing and Materials (ASTM) provides a performance criterion of 0.1 perms for water-vapor retarders (ASTM 2011) that can also be used to retard movement of organic contaminant vapors (see ASTM 2013 for radon mitigation systems). As of the date of this guidance, the Department had no quantitative criteria for permeance of vapor-migration caps. However, in conjunction with other protective measures, the cap may be required to reduce contaminant concentrations in the air to safe levels.

A low-permeability cap is suitable to a wide range of contaminants and land uses. Examples of low-permeability caps include hazardous waste landfill caps, concrete building foundations, and vapor barriers. Typical materials used in the construction of low-permeability caps for the purpose of reducing water infiltration include, but are not limited to, geomembranes, clay barriers, geosynthetic clay liners, Portland concrete, and bituminous concrete (asphalt). Typical materials used in the construction of vapors barriers include plastic membranes made of polyethylene or propylene, and semisolid barriers that are applied by spraying or pumping.

- **Components**

The components of a low-permeability cap will vary depending on the type of cap constructed. The reader is also referred to the various sections within this document that describe specific low-permeability caps.

A typical low-permeability cap is constructed with a low-permeability layer underlying a soil cover. This layer could be constructed of a geomembrane, plastic liners, clay, or a geosynthetic clay liner. In many cases, a granular soil or drainage geocomposite is needed above the low-permeability liner to remove excess water. Geotextiles may be necessary beneath or above a low-permeability liner to provide protection or separation of the liner from underlying soil or overlying components. The soil cover overlying the low-permeability layer is typically up to 2 feet thick and may include the drainage layer. Thinner or thicker soil covers may be appropriate depending on site-specific conditions. The upper 6 inches of the soil cover is typically comprised of topsoil and vegetated or may be gravel or a crushed stone surface. This surface cover should be designed to prevent erosion and deterioration, and should be compatible with the intended use. In all cases, the imported soil cover material should meet the Department requirements for clean fill contained in the NDEP's Alternative and Clean Fill Guidance for SRP Sites (Section 3.6).

http://www.state.nj.us/dep/srp/guidance/srra/fill_protocol.pdfAnother type of low-permeability cap is a pavement system, which, typically, is constructed of bituminous concrete (asphalt) or Portland cement. Pavement systems may be used to prevent direct contact exposure to contaminated soils. Unlike the low-permeability caps described above, pavement caps have the low-permeability layer as the upper layer. Beneath the asphalt or cement is a suitable sub base, which will be composed of materials such as aggregate, depending on the structural needs of the pavement system. Contaminated soil particles can work their way to pavement surfaces where pavement settlement, cracking, freeze and thaw cycles, weathering and deterioration are not adequately addressed in the design, construction and maintenance of the cover. Sites where settlement and shifting are a potential problem may not be candidates for pavement direct-contact covers. Bituminous concrete (asphalt) pavement can generally tolerate more differential settlement without cracking than can Portland concrete pavement.

Note: An existing pavement cover may not have been designed and constructed to meet all the design concepts above. However, an existing pavement cover could be an acceptable direct contact remedy at many sites.

Changing the runoff characteristics of a site by paving may require the capture and detention or infiltration of stormwater. Porous pavement (a permeable cap) may be an acceptable cap if levels of contamination in the soil or waste do not exceed NJDEP impact to ground water guidance concentrations.

Exposed Geomembranes – Polymer (plastic) sheets, such as polyethylene or polypropylene, have been used to prevent direct contact with contaminated materials, such as solid waste. These not only provide a barrier to direct contact with the underlying contaminated media, but also are a barrier to water infiltration and vapor exfiltration. Some advantages of using geomembranes are:

a) In the event of large settlements, exposed geomembranes can be removed and the underlying material reshaped. This ability to remove the geomembrane may reduce maintenance costs as compared to other types of caps.

b) An exposed geomembrane may be removed to allow placement of additional contaminated material.

c) Geomembranes are available with photovoltaic cells installed.

d) The cost to place cover material over the geomembrane and to establish and maintain vegetation are saved.

Geomembranes are available that can be installed without cover material, and have a useful life of more than 30 years, where failure is defined as a loss of 50% of the elongation and strength properties (Koerner, 2010).

Processed Dredge Material has also been utilized in the construction of low permeability caps. Additional information on the use of this material can be found here:

http://cait.rutgers.edu/files/193-RU2763_1.pdf

- **Design Considerations and Data Needs**

The cover should be designed and constructed to provide the design thickness of materials over all areas that have contaminant concentrations greater than the direct-contact soil standards for the site.

Cover system designs should take into account site-specific factors, including, but not limited to:

a) Effectiveness in meeting the general design goals in Section 1

b) Compatibility with current and future site uses

Note: Potential future activities that could result in creating an exposure pathway to the contaminated media should be accounted for through the use of measures such as notification signs at the site, sending of periodic notification letters, deed notices, and engineering controls such as fencing.

c) Surrounding land use. Sites near residential areas may need a more protective cover

d) The nature of the contaminants (concentrations, mobility, toxicity)

e) The duration contaminant concentrations will remain above remedial goals

f) Other measures to be used to prevent access (such as fencing, guards, etc.)

g) The quality of the cover system construction and the monitoring and maintenance program for the site required by the Investigator, soil remedial action permit, or other permits

h) The reliability of the assurances that access restrictions, monitoring, and maintenance will be accomplished for as long as the contaminant concentrations remain above remedial goals

i) Stormwater management of runoff and infiltrated water

The slope for soil covers should preferably be no steeper than 3:1 (horizontal to vertical). Steeper slopes may be considered on a case by case basis if it can be shown that erosion will be adequately controlled through additional engineering controls. Steeper slopes may require slope reinforcement to provide long-term slope stability.

Pavement material should have appropriate subgrade soil preparation (grading, compaction, and drainage, as appropriate), to minimize freeze and thaw problems and settlement, which can cause the development of cracks. Designs that minimize long-term maintenance needs should be evaluated. A crushed-stone base course may be separated from the contaminated subsoils with a geotextile to prevent the migration of contaminated soil into the base course. Any imported soil should be verified to be clean.

The intended use of the area to be covered by pavement should be accounted for in the design. Areas with traffic loads will need to meet appropriate structural strength requirements. Areas with lower traffic loads, such as storage areas and parking lots should meet appropriate low to medium volume design requirements.

For all pavement designs, consideration should be given in the design to the crushed stone base course that can act as a preferential flow path for upgradient infiltrating surface water or groundwater. The infiltrating water may carry contamination and could discharge at a lower point that may not be paved.

- **Operations and Maintenance**

O&M for low-permeability caps will likely consist of inspections to ensure that the cap has not been impaired in any way, including, but not limited to erosion, scouring and cracks. Because a low-permeability cap may alter the elevations of the ground at the site, and its stormwater runoff characteristics, monitoring of the surrounding areas for adverse impacts, such as erosion or flooding, should not be neglected.

Biennial Certifications will be required in accordance with any NJDEP Soil Remedial Action Permit requirements.

Some conditions that may develop post-construction and that may compromise the effectiveness of a low-permeability cap include:

a) Incompatible human activities such as digging, gardening, heavy loading, and construction

b) Burrowing animals

c) Vegetative growth with roots that penetrate the low-permeability liner

d) Excessive settlement of the underlying media and potential ponding of water.

e) Erosion from stormwater, surface water, wind, and human or animal activities

f) Desiccation, cracking, or permeability changes caused by physical or chemical processes including drying-wetting cycles, freeze-thaw cycles, gas pressure, cation exchange in bentonite clay caps, and oxidative/UV light degradation for exposed geomembrane caps

g) Migration of ground or pore water into the cap by flow or capillary action

h) Diffusion of contaminants through the cap

i) Vandalism

j) Excessive or trapped underlying gas

The frequency of inspection and maintenance associated with low-permeability caps largely depends on the materials utilized to construct the cap as well as the end use of the cap area. Caps constructed using materials such as asphalt or concrete that are resistant to weathering/erosion, may cost more upfront, but are also associated with a lower frequency of monitoring and related cost savings. Conversely, caps constructed with natural materials (i.e. a low-permeability soil liner with a vegetated cover) that are more prone to erosion, may cost less upfront, but may require a higher frequency of monitoring and maintenance (repair); and thus are associated with higher, post-installation costs. The balance between cap construction and long-term maintenance and monitoring costs is site-specific and should be made during the remedy selection process. Regardless of the cap type selected, specific events such as vandalism or significant storms that may cause a breach in cap integrity should trigger an immediate inspection.

Monitoring methods will be site and cap specific ranging from walkover inspections to quantitative measurements of leakage through the cap. Procedures for monitoring may include:

a) Visual inspection with note-taking, checklists, and photos referenced to known landmarks.

b) Surveying for comparison with as-built conditions.

c) Test excavations for inspection and testing where excessive distress may have occurred.

d) Monitoring of soil moisture under the cap by means of drainage pipes, lysimeters, soil moisture sensors, or other appropriately designed methods.

e) Sampling of air above the cap with analysis in an NJDEP-accredited laboratory.

3.1.1 Landfill Closure Caps (RCRA, TSCA, Solid Waste)

- **Description**

Federal Resource Conservation and Recovery Act (RCRA) Subtitle C, Federal Toxic Substances and Control Act (TSCA), and NJDEP Hazardous Waste Regulations (N.J.A.C. 7:26G) concern, in part, the requirements for landfill disposal of hazardous waste. Caps for these landfills have a low permeability and are generally constructed with a geomembrane liner having a thickness of greater than 20 mils or a clay liner having a hydraulic permeability coefficient of less than or equal to 10^{-7} cm/sec. In addition, layers of soil or geosynthetic for drainage, gas venting, and vegetation are provided. TSCA landfill closure regulations require capping in accordance with RCRA Subtitle C.

RCRA Subtitle D and NJDEP Solid Waste Regulations (N.J.A.C. 7:26) concern in part the management of nonhazardous solid waste. The hydraulic permeability coefficient of these caps must be less than or equal to 10^{-5} cm/sec. In addition, the permeability should be less than or equal to that of the bottom liner under the waste to prevent leachate buildup within the capped material. These caps generally contain a geomembrane liner or low permeability soil layer, in addition to drainage, gas venting, and vegetative layers, and have a minimum thickness of 18 inches.

Depending on the year that a landfill closed or ceased taking waste, or the type of waste requiring closure, a soil-only cap can be proposed to the Department in a closure plan. The soil-only cap (permeable cap) will eliminate direct contact or exposure to the waste and can reduce infiltration depending on how stormwater is managed. Before proposing a soil-only cap, an evaluation of groundwater, surface water, soils and methane should be completed.

Landfills must be capped and remediated in accordance with N.J.A.C. 7:26, Solid Waste Management Regulations. However, landfills that meet the following exemptions must be addressed in accordance with N.J.A.C. 7:26C, Administrative Requirements for the Remediation of Contaminated Sites. The exemptions include sanitary landfills where:

a) The sanitary landfill or any portion thereof is slated for redevelopment that includes structures intended for human occupancy;

b) When sanitary landfill remediation activities are funded, in whole or part, by the Hazardous Discharge Site Remediation Fund pursuant to the Brownfield and Contaminated Site Remediation Act at N.J.S.A. 58:10B-4 through 9, a Brownfield redevelopment agreement pursuant to the Brownfield and Contaminated Site Remediation Act at N.J.S.A. 58:10B-27 through 31, or the Municipal Landfill Closure and Remediation Reimbursement Program pursuant to the Solid Waste Management Act at N.J.S.A. 13:1E-116.1 through 116.7; or

c) The person conducting the remediation wants a final remediation document.

Regardless of the applicability of legislative requirements, it is prudent to construct and operate RCRA, TSCA, and New Jersey Solid or and Hazardous Waste caps in accordance with the latest regulations and current technologies and methods. All caps must be protective of human health and the environment.

- **Design Considerations and Data Needs**

Solid and hazardous waste caps are generally designed to minimize leachate generation, control gas emissions, and prevent direct contact with waste. Design guidance documents are available on the Internet from several states, the U.S. Army Corps of Engineers, and manufacturers of capping components. Typically, a design progresses from predesign studies in the field and laboratory, to engineering studies and design leading to preparation of plans and specifications for bidding.

Predesign studies may include:

a) Surveying, including mapping of existing conditions, topography, property boundaries and easements, and utilities.

b) The following work should be completed by following the procedures outlined in N.J.A.C. 7:26E-3.11 SI-landfills, and the Landfills Investigation Guidance found at http://www.nj.gov/dep/srp/guidance/srra/landfill_guidance.pdf : Site investigations, sample collection, and testing to define parameters such as extent of waste to be capped; landfill and soil characteristics; concentrations and composition of landfill gas; leachate and groundwater levels; chemical analyses of soil, waste, groundwater, leachate and gas; and field and laboratory testing for engineering design parameters

Depending on site conditions, factors that may influence design include:

a) HELP (Hydrologic Evaluation of Landfill Performance) Model (Schroeder et al, 1994) studies to determine whether the cap will be sufficiently impermeable to reduce leachate generation to acceptable levels.

b) Thickness and composition of the cover layer required for protection of the low permeability layer.

c) . Thickness, permeability, and composition of a drainage layer, on top of the low permeability layer, to remove surface water that infiltrates the cap, and to maintain cap stability. Sufficient outlets for the drainage layer with erosion protection must be provided." Note that the Guidance is not intended to cover all possible design issues, as this is the responsibility of the engineer on a case-by-case basis.

d) Selection of a low-permeability layer; typically a geomembrane or clayey soil.

e) Design of a cushion layer under the low-permeability layer to protect it from damage caused by contact with waste materials.

f) Stability analyses to design against a sliding failure along the capping-material interfaces.

g) Global slope stability analyses to ensure the site remains stable under the weight of the cap.

h) Design of retaining walls where access is limited.

i) Sizing and spacing of drainage pipes and channels to remove water from the cap.

j) Design of a management system to remove, treat, and vent gas from under the low-permeability layer. This can be either a passive system or an active system with vacuum blowers to extract the gas.

k) Settlement analyses if the cap or structures will be adversely affected. If unacceptable settlements are expected, a minimum slope angle for the cap and structures, such as piping, should be required so the cap and structures will remain functional.

l) Controls for penetrations through the low-permeability liner to minimize leaks.

m) Design of stormwater management systems to handle any increased runoff.

n) Controls to prevent unauthorized access to the site and signage to restrict heavy equipment on-site from riding on the cap.

o) Roadways to allow O&M of the cap.

p) Special protective measures for environmentally sensitive receptors or habitats.

q) Other ancillary structures, as required by site-specific conditions.

- **Construction**

Solid or hazardous waste caps are required by regulation on all landfills, depending on the nature of the material being capped. The regulations are highly prescriptive concerning construction and O&M. If landfilling operations ceased prior to 1982, the solid waste capping regulations developed subsequently do not have the mandate of law. If a landfill closed after 1982, owners are required to (1) Submit closure and post-closure plans and establish escrow accounts for closure in accordance with N.J.A.C. 7:26-2A.9, and (2) install NJPDES groundwater monitoring systems in accordance with N.J.A.C. 7:14A-1.

Construction will be governed by the approved engineering plans and specifications and permits. The specifications should include requirements for additional plans to control the work, some of which may be developed by the contractor:

a) Health and Safety Plan.

b) Construction Quality Control and Quality Assurance (QA/QC) Plans to verify that materials brought to the site and the work meets specifications.

c) Site Operations Plan describing the sequencing of work and project schedule.

d) Environmental Pollution Control, including measures to control dust and odors.

e) Storm Water Pollution Prevention Plan to manage stormwater runoff that becomes contaminated by contact with waste material.

f) Security Plan to prevent unauthorized site access during construction.

g) Traffic Control Plan to manage truck traffic into and out of the site.

h) Community Relations Plan.

i) Construction Water Management Plan to manage the collection and disposal of water and leachate pumped from the site, and decontamination water.

j) Hazardous Substance Container Removal, Staging, Sampling, and Disposal Plan

k) Construction Erosion and Sediment Control Plan

- **Operations and Maintenance**

O&M requirements for RCRA and New Jersey Solid Waste Caps are prescribed by federal and state regulations. These requirements will also be referenced in the Landfill Closure Plan Approval issued by the Department for the site.

If a waste site is not a designated hazardous or solid waste landfill, but is being remediated with a RCRA or Solid Waste Cap, following the construction and O&M requirements in the regulations is recommended. Biennial certifications will be required in accordance with any NJDEP Soil Remedial Action Permit or Institutional Control (i.e. Deed Notice) requirements. Further requirements can be found in the introduction to Section 3.1.

- **Cost**

Capping costs will be less for a Solid Waste Cap with a single, low-permeability liner and greater for a RCRA Hazardous Waste or TSCA Cap with two liners.

A low-permeability liner will consist of a geomembrane or clay layer. The geomembrane cost will vary with the price of oil and the labor for installation. Installation of a geomembrane requires welding the sheets together. This welding process can be difficult and time-consuming particularly in cold weather. The cost of a clay liner will vary with the transportation distance from the borrow source, and its construction will also be negatively affected by cold or wet weather.

Clay bound in a geotextile, termed a geosynthetic clay liner (GCL), has been used as a cap liner. Installation is greatly simplified because sheets need only to be overlapped on each other. GCLs should be covered as soon as possible after placement, because a storm can cause them to hydrate and become unworkable.

3.1.2 Structure Caps for Low-Permeability Section

- **Definition**

Structure caps are comprised of general building and site development components. Generally, the site development can provide the engineering control requirements of structure caps without the need for additional types of caps. Structure caps that are used as low-permeability caps can include, but are not limited to, building slabs, asphalt, large concrete areas such as pads for equipment and dumpsters, sidewalks, and curbing.

- **Components**

The components of a structure cap vary depending on the specific item as indicated herein. The structure cap components are oftentimes dictated by the requirements of the site development as long as they meet the required protectiveness. The investigator is referred to the NJDEP's for residential, school, child care, or other sensitive uses. The structure cap may be comprised of one or more of these various types.

a) Building Slab – Typically the only component of a building slab cap is the concrete floor slab. In some cases, the subgrade beneath the concrete slab and a demarcation liner may be incorporated into the cap. The thicknesses of the concrete slab and subgrade (if used as part of the cap) can vary and are usually determined based on the requirements of the site development. The building subgrade may be used as a component of the building slab. The building subgrade cap may consist of the aggregate used to support the building slab and other building features, elevator pits, grade beams, pile caps, etc. Although the subgrade is physically permeable, it is typically used in conjunction with the overlying building slab to form an overall low-permeability cap.

b) Asphalt – The components of an asphalt cap typically consist of, from top to bottom, a top course, base course, and subgrade aggregate. Thicknesses of these layers will depend on the end use of the asphalt (i.e., parking areas, roadways, driveways, loading areas). This asphalt cap is suitable as a low-permeability cap. Specialized asphalt pavement mixes exist that have been shown to minimize infiltration to a much greater extent than standard pavement materials and may be considered a significant infiltration prevention cover system. If a specialized asphalt layer is selected as a hydraulic barrier, specialty inspectors and contractors will be needed to ensure that proper materials and construction techniques are used.

c) Concrete Pads and Other Large Concrete Areas – Concrete pads, along with concrete walkways, driveways, and patios, can be considered part of a low-permeability cap. Typically, the only component of a concrete pad cap is the concrete itself. However, the underlying aggregate subgrade can also be used within this type of cap. The thickness of the concrete will depend on the end use (i.e., slab under dumpsters, compactors, or recycling containers, transformer pads, patio, walkway, etc.).

d) Concrete Curbing – Concrete curbing that is placed adjacent to asphalt, concrete pads, or other concrete areas can be considered part of the low-permeability cap. The components of concrete curbing typically include the concrete overlying an aggregate subgrade. Thicknesses of these layers will depend on the purpose of the curbing.

- **Design Considerations and Data Needs**

Structure caps are appropriate to most sites where development is proposed. They are appropriate to a wide range of contaminants, although if volatile organic compounds (VOC) are present, vapor mitigation measures may need to be added to a building slab. Refer to the Vapor Intrusion Technical Guidance (NJDEP 2013b). In addition, the contaminants of concern should be evaluated to ensure that the proposed building materials will not be affected by the contaminant reactivity or toxicity. If necessary, chemical-compatible liners may need to be incorporated into the design to mitigate for potential damage to the concrete or other building material.

It is critical for the design engineer to understand the local hydrostratigraphic conditions at the site. Depth to water, seasonal groundwater fluctuation, and tidal conditions may affect the design. In addition, construction of a low-permeability cap can alter the water table, cause groundwater mounding or depressions, and change groundwater flow patterns.

The construction methods for these structures may differ from normal standards to serve as a low-permeability cap. The sealing of joints and gaps may be required.

It is critical for the design engineer to understand the geotechnical properties of the soil used to support the cap. Because of the nature of site development, the soil underlying a structural cap typically requires geotechnical improvement so that it can accommodate the heavy loads the cap must withstand.

Site development typically affects the site's runoff characteristics. Runoff may be diverted around certain features, such as buildings, and directed to other features, such as catch basins or stormwater detention basins. The design engineer should ensure that no detrimental effects, such as erosion or flooding, result from the altered runoff patterns affecting neighboring properties. In addition, sheet flow from paved areas to adjacent unpaved areas may cause increases in rates of erosion that should be considered in the design.

Structure caps are generally acceptable to the community, except where parks or other recreational areas are desired. Typically, various utilities run through or beneath the structural cap. Consideration should be given to address future maintenance of these utilities, such as construction of utilities within clean corridors. Consideration in the design of structure caps should be taken for protection of environmentally sensitive natural resources (i.e., wetlands, surface water, etc.) to ensure that these resources are not impacted during or post-construction.

- **Construction**

Construction of a structural cap will typically follow the construction QA/QC requirements dictated by the architect, civil and structural engineers and other design professionals involved with the site development. Typically, a structural cap does not require hydraulic- conductivity testing or other tests to verify the permeability of the cap. QA/QC is typically implemented by visual observations by the site engineer to document that the cap was constructed in accordance with the design documents. The site engineer should note any deviations from the design documents to determine whether those deviations may affect the integrity of the structural cap or whether additional measures need to be implemented. If a geomembrane or other liner is constructed as part of the cap, that component typically requires integrity testing, which should be completed in accordance with the manufacturer guidelines.

- **Operation and Maintenance**

O&M activities for a structure cap will depend on a variety of factors, as well as on the type of structure cap employed at the site. Factors to consider in developing the O&M plan include the nature of the contamination present, potential for that contamination to impact potential receptors, and overall protectiveness of the cap design. A cap design may be less robust if the intent was to incorporate an extensive monitoring program.

For example, a cap in a residential or school setting will require more extensive O&M than a cap in an industrial park. The type or thickness of the cap may result in a more extensive monitoring program to minimize the potential for exposure. An asphalt parking lot 4 inches thick may require a more robust monitoring program than a 12-inch-thick parking area to ensure that the cap remains protective for its intended purpose.

Because a structure cap can be constructed over a variety of contaminants and in a variety of settings, the monitoring and maintenance programs vary for any particular site. Typically maintenance for structure caps would not amount to anything beyond normal maintenance of the other development improvements. O&M would generally consist of periodic inspections, at a frequency to be determined based on the potential for exposure of underlying contaminants and the potential receptors involved, to ensure that cap components are performing as designed, and that scouring and cracks have not occurred to a degree that could affect the cap's protectiveness. Concrete and asphalt would require repair or patching of cracks as necessary.

3.1.3 Capillary Break

- **Description**

A capillary break is a cap or component of a cap that is designed to prevent the upward migration of dissolved- phase contaminants through capillary action (i.e., capillary rise). These contaminants may be associated with groundwater or soil water in the unsaturated zone impacted by soluble contaminants. Its predominant relevance to the Department to date is as a barrier to the upward migration of hexavalent chromium through the unsaturated zone to the ground surface and building interiors. Installing a capillary break prevents direct human exposure to hexavalent chromium that may be deposited by the evaporation of water on porous surfaces (more commonly referred to as "blooms").

Capillary rise is the mechanism by which water is drawn out of the zone of water saturation (i.e. water table) by capillary tension into the overlying soil. Capillary rise can contribute to frost heave and can carry dissolved salts to the ground surface where the salts precipitate as the water evaporates, forming deposits in surface soils or structures.

Maximum capillary rise is the upper limit in which soil moisture is continuous and remains hydraulically connected to the water table. If the depth from the ground surface to the water table is less than the maximum capillary rise, then the soil water and associated dissolved salts can be delivered to the surface through capillary action, leaving the salts after the water has evaporated. A combination of the concentration of dissolved salts, evaporation rate, depth to the water table, and the grain-size distribution of the soil in the capillary fringe influence the potential for deposition of surface salts. Capillary rise is greatest in fine-grained soil. When the capillary fringe reaches the surface and evaporation occurs, salts dissolved in the soil water will precipitate and may create a direct contact issue. If the precipitated salts are exposed to sufficient rain, they could dissolve and be transported back into the soil column. At sites where capillary rise and the surface deposition of salts is a concern, the cap should be designed to provide a capillary break.

- **Design Considerations and Data Needs**

Both low-permeability caps and permeable caps can be designed to provide a capillary break. A capillary break is typically incorporated as a component in the design of a cap, serving multiple purposes relative to achieving the remedial objectives and supporting the current and anticipated future use of the site. If a geocomposite or synthetic material is used to construct the capillary break, then the capillary break may also serve to prevent infiltration and control vapor migration.

Capillary breaks should be installed above the upper limit of groundwater fluctuation. Before selecting and designing a cap, an understanding of the magnitude of water table fluctuations is needed. The further above the water table that the capillary break is situated, the more diminished the capillary forces and the more conservative the design.

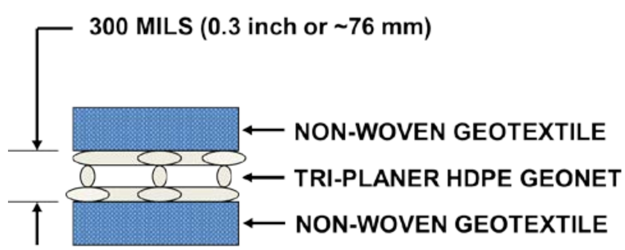
Permeable caps can be designed to provide a capillary break by using granular materials or geosynthetics to provide a "break" in the hydraulic connection between the water table and the unsaturated zone. A layer of relatively large-pore (i.e., clean coarse-grained (no fines)) material placed in a finer-pore soil can provide a capillary break and eliminate unsaturated flow upward caused by capillary rise. Because of the potential to promote capillary action, the use of clay or other fine-grained materials is not appropriate or recommended for use as a capillary break. Coarse-grained materials such as sand or gravel are commonly used for a capillary break. It is necessary that the thickness of the layer of appropriately graded coarse-grained material used as a capillary break exceed the height of maximum capillary rise in the selected material. Published values for anticipated maximum capillary rise in various soil types are available from various sources, including the NJDEP Vapor Intrusion Technical Guidance (VITG)

http://www.nj.gov/dep/srp/guidance/vaporintrusion/index.html.

Values range from several inches or less for clean crushed stone to several feet or more for very fine silts and clay (Bell 2007). Where coarse-grained materials are used to provide a capillary break, geotextiles are frequently placed above and below the layer to isolate the granular material and prevent the migration of fine-grained material into the pore space of the material, thus reducing its effectiveness as a capillary break.

Geocomposites or geomembranes can be an effective alternative to the use of granular material to provide a capillary break. Geosynthetics have several advantages over the use of granular capillary breaks in that they are typically made of hydrophobic (water repellant) materials, enhancing the effects that reduce both capillary rise and unsaturated water flow. Geosynthetics also add minimum thickness to the cap and may reduce the need for disturbance and disposal of impacted material. Geocomposites used as capillary breaks include materials that are commonly used as drainage layers in the design of landfill liners and caps. A variety of similar geocomposite materials are commercially available through a number of manufacturers. These materials are commonly used as drainage layers in landfill designs, road designs, athletic fields, and similar applications. These geocomposites typically include a "geonet" layer, which creates the void space or capillary break sandwiched between two geotextile layers, which prevent the migration of fine-grained particles into the geonet. A schematic of a common double-sided, triplaner geocomposite is below in Figure 1:

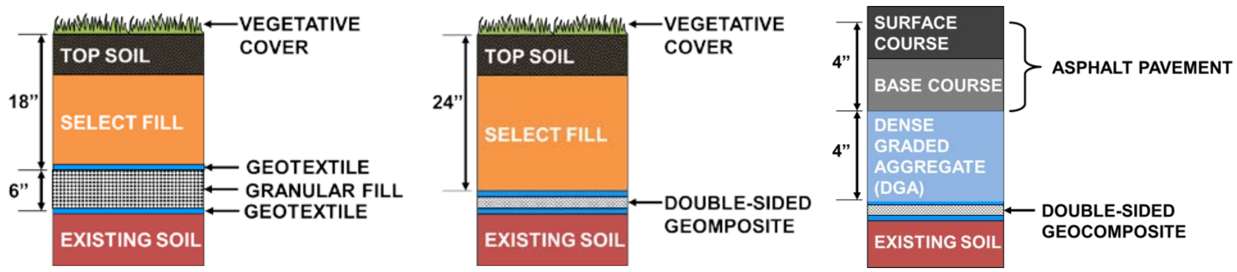
Figure 1. An example of a geocomposite capillary break



Because of their design thickness requirements, geocomposite capillary breaks are generally preferred over earthen materials in areas where there are height limitations. These limitations would include sites with a relatively shallow depth to groundwater or areas where increasing the final grade would conflict with existing structures and facilities. Capillary breaks of coarse-grained soil are generally more cost effective where additional fill or thickness of the cap is required or would be beneficial to support site drainage or anticipated future site use.

Several typical cap configurations that include a capillary break are shown below in Figure 2.

Figure 2. Various examples of capillary breaks



A wide range of materials and configurations may be equally protective, technically appropriate, and cost-effective at providing a cap and capillary break under various scenarios. The final design of a cap and capillary break should be developed and prepared under the responsible charge of a qualified professional engineer familiar with the remedial objectives, site-specific conditions, and anticipated future use of the site. Detailed design considerations relative to caps with capillary breaks are similar to those associated with traditional permeable or low-permeability caps including:

a) Overall remedial objectives

b) Surface drainage

c) Subsurface drainage (for low-permeability caps)

d) Depth to groundwater

e) Geotechnical conditions

f) Slope stability (considering saturation of soils along capillary break)

g) Cover thickness and loading on synthetic materials

h) Permitting issues including wetlands disturbance

i) Physical constraints including interface with existing permanent site features and structures

j) Underground utilities installation and maintenance (existing and proposed)

k) Current and anticipated site use.

- **Construction**

The construction requirements of caps that include capillary breaks are the same as those for other caps that include the use of geosynthetics and various distinct layers. Site preparation and the careful placement and preparation of the various layers of geosynthetics and various materials are critical. Construction documentation and quality assurance by qualified professionals should be implemented during the construction activities. A specific requirement for capillary breaks is to prevent mixing of the selected break material with the surrounding soils to maintain appropriate gradation. The horizontal and vertical limits of the cap should be surveyed by a licensed surveyor and provided on accurate record drawings documenting the construction configuration and details in the Remedial Action Report and Deed Notice.

- **Operation and Maintenance**

The specific operation and maintenance required is dependent on the design of the capillary break. If the distance between receptor and contamination is limited and if the break is minimal or subject to fracture, periodic inspection or relevant analytical testing is recommended. The presence of sensitive receptors or the future use of the site may also affect the recommended frequency of inspection or testing. Appropriate maintenance should be instituted to ensure the continued protectiveness of the cap.

- **Cost**

While labor and equipment to install the capillary break is a major cost, material costs are also significant, particularly with the geosynthetics. Costs will vary with the kind of composite or geosynthetic material, thickness of the composite or geosynthetic material, the site location, and time of year.

Operation and maintenance costs also need to be included because a capillary break is typically intended for long-term use. Monitoring costs can be prorated to reflect the expected durability of the specific capillary break. Irrespective of the material used to construct the capillary break, eventually repair or replacement may be needed, particularly if future construction requires that the capillary break be breached.

3.1.4 Vapor Barriers

- **Description**

A vapor barrier is a membrane or layer of material designed to prevent vapor-phase chemical migration through the barrier.

Vapor barriers are most often discussed in the construction industry where they are commonly used under building foundations to inhibit soil-moisture vapor from entering a structure. Another common use is for control of methane gas that is generated in landfills. Until relatively recently, discussion of vapor barriers in the literature has primarily focused on these two functions.

More recently, vapor barriers have become recognized for an additional function. They have been used in new construction (in conjunction with other passive or active design features) when vapor intrusion of subsurface VOCs into buildings is a concern. In this use, they help prevent the migration of vapors from the soil into the building structure. For guidance in the use of vapor barriers for mitigation of vapor intrusion, see the NJDEP Vapor Intrusion Technical Guidance (NJDEP 2013b):

http://www.nj.gov/dep/srp/guidance/vaporintrusion/index.html

When used to control vapor intrusion in indoor air, vapor barriers by themselves are often considered inadequate without the addition of passive or active venting systems, because of relatively low indoor air-exchange rates and the difficulty of making these barriers adequately leak proof.

The vapor-barrier discussion in this guidance document pertains to the use of vapor barriers in an external environment to prevent elevated VOC concentrations in outdoor air above or near capped contamination, when the contamination is not underneath a structure. In an outdoor setting, much higher air exchange rates over capped contamination will generally be present than in indoor settings, so small leaks in the barrier may not be of significant concern unless they are present above the most highly contaminated areas or at the most critical exposure points. Nonetheless, little information is available at this time regarding vapor-barrier effectiveness or their frequency of use in outdoor settings, except with regard to control of methane in landfills. Possible explanations for this dearth of information may include:

a) A lack of use of these barriers,

b) Remediation of contaminated soil before capping (e.g. to address acute or other exposure concerns) may be adequate to address outdoor inhalation concerns, or

c) A lack of awareness of the need to consider the chronic inhalation exposure pathway.

Therefore, the information presented in this section is largely drawn from information available pertaining to landfills, radon management, and vapor intrusion.

- **Design Considerations and Data Needs**

Concentrations of VOC in the contaminated soil will determine whether a vapor barrier may be necessary. The guidance document entitled Inhalation Standards Compliance, Development of Alternative Remediation Standards for the Inhalation (NJDEP 2008) should be followed, which contains suitable screening criteria and procedures for site-specific adjustments of these criteria. This guidance can be found on the following web page:

http://www.nj.gov/dep/srp/guidance/rs/compl_ars_inhalation.pdf

When describing the potential for a barrier to inhibit the transmission of chemical vapor, the term "permeance" is used. In the construction industry, this term is normally used to describe the rate at which water vapor may pass through a barrier or membrane under specific conditions. The quantitative unit for this term is the "perm," with U.S. units of grains of water per hour per square foot per inch of mercury pressure difference (water partial pressure difference) on the two sides of the barrier. While the permeance of a barrier to VOCs may differ to some extent from its permeance to water, water permeance has been used as a surrogate for estimating the permeance of a material to VOCs. Although water exhibits lower volatility than many VOCs, permeance through a vapor barrier is primarily controlled by diffusivity and molecular size. Once in the vapor phase, water's low molecular weight results in a higher diffusivity than many VOCs. Therefore, water will give a conservative estimate of permeance of a vapor barrier relative to volatile organic chemicals.

While all barriers transmit vapor to some extent, those that exhibit a water permeance below 0.1to 1.0 perm have been defined as vapor barriers, depending on the organization or standards agency. The more stringent standard of 0.1 perm has been used by the ASTM in its specification for water-vapor retarders (ASTM 2011), and this value has been used as the cutoff criteria for a vapor barrier in a widely cited and reproduced online article by Lstiburek (2006):

http://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

The value of 0.1 perm is also reported to be the lowest permeability class of vapor retarders in the International Residential Code(NAIMA):

http://www.naima.org/insulation-knowledge-base/residential-home-insulation/insulation-and-vapor-retarders.html

The use of a vapor barrier with this specification is, therefore, recommended.

While low-permeability caps such as concrete, asphalt, and clay substantially reduce vapor migration, these types of caps are used primarily to prevent direct contact with the contaminated media, or infiltration of water resulting from precipitation or surface runoff. Therefore, these caps may be inadequate for prevention of vapor migration to the atmosphere. A vapor barrier usually consists of a membrane specifically designed to prevent vapor migration through it. The two most commonly used barriers are plastic sheeting and fluid-applied rubberized asphalt emulsions that are poured or sprayed on the surface of concern and cured in place. A combination of these two types of barriers may also be used.

Plastic sheet barriers are usually composed of high-density polyethylene (HDPE), but may be composed of other plastics or rubber, providing they exhibit an adequate perm rating. The Insulation Contractors Association of America (ICAA) report perm ratings of various materials, drawn from the American Society of Heating, Refrigeration and Air-Conditioning Engineers Handbook (ICAA 2004). Polyethylene sheeting of 4 mils or greater is reported to exhibit a permeance of less than a value of 0.1 perm. However, for HDPE, a thickness of at least 40 mils is recommended to provide adequate puncture resistance and tensile strength during construction and use of the cap (USEPA 2008). This thickness is also recommended in NJDEP Vapor Intrusion Technical Guidance (NJDEP 2013b), and is in the range of the 30 to 60 mil HDPE thickness used for New Jersey landfills (N.J.A.C. 7:26-2A.7). Guidance for RCRA, TSCA, and solid waste caps recommend liner thicknesses greater than 20 mils, while the Interstate Technology Regulatory Council (ITRC) recommends liner thicknesses of 60 to 100 mils (ITRC 2007). Therefore, a 40-mil liner thickness seems to be a median recommended value. Standard perm ratings for pour-on or spray-on liquid barriers would depend on the product and the thickness of the layer, but manufacturer product data sheets indicate a perm rating of 0.1 or less can be achieved. For these rubberized asphalt barriers, a minimum thickness of ¼ inch is recommended (ITRC 2007).

The design of a vapor barrier should consider potential lateral and downward movement of VOCs.

- **Construction**

General recommendations on cap construction may be found in other sections of this document. This section discusses specific construction issues pertaining to vapor barriers.

Appropriate measures should be taken to adequately seal locations where utility lines or other items pass through the barrier, and where the edges of two plastic sheets overlap. Consult

Section 3.3.4 of the USEPA Vapor Intrusion Mitigation Approaches document for relevant references (USEPA 2008).

It is recommended that soil or other material be placed on each side of the membrane to provide cushioning and to reduce the potential for physical damage and deterioration via weathering. This protective material may be geotextiles, sand, or fine, rounded pea gravel (ITRC 2007). The barrier should not be directly exposed to the atmosphere because direct exposure of the cap material or membrane to sunlight will cause solar-induced damage. Other weathering damage caused by temperature fluctuations and other weather-related events will also be magnified.

Chemical resistance of the vapor barrier should be evaluated when used in areas where high levels of contaminants in the soil or groundwater are present. If the barrier is not chemically stable or is otherwise physically compromised when in contact with the contaminants of concern, it may deteriorate over time.

Because a vapor barrier will essentially prevent any transmission of water through it to the underlying soil, a mechanism for collecting and disposing of stormwater runoff will often be necessary.

Because a vapor barrier will restrict the upward migration of vapor-phase VOCs from the subsurface, vapor concentrations underneath the barrier will normally increase relative to those that would be observed in its absence. This increase will affect subsurface vapor concentration gradients, and will normally result in increased horizontal diffusion of these contaminants outward from the contaminated zone and increased downward vertical diffusion toward the groundwater. Thus, the groundwater and soil adjacent to the contaminated zone may become more vulnerable to contamination, or contaminated to a greater extent. This problem would be observed even in cases where a vapor barrier is not intentionally designed into the cap, such as when low-permeability caps are used to prevent water infiltration.

For further details on vapor barriers, including their use and installation, consult the various references cited in this section.

- **Operation and Maintenance**

Vapor barriers as described in this document are used to prevent VOC migration from the capped contaminated zone to the outdoor air. Failure of a vapor barrier could result in undesirable chemical exposure to receptors via the inhalation pathway. Adjacent uncontaminated soil is not necessarily considered a receptor but would represent a new source of contamination if allowed to become contaminated. Depending on contaminant concentrations, exposures could range from chronic to acute levels. For this reason, it is important to maintain the integrity of the barrier.

Plastic or rubberized vapor barriers, while potentially durable for many years, will ultimately be subject to natural deterioration from weathering and may need periodic replacement. Such liners would be expected to have a longer life when not exposed directly to sunlight (e.g. are covered). Additionally, potential chemical deterioration of the barriers can occur over time because of the presence of the contaminants of concern.

Natural events that may compromise a barrier also include burrowing animals and vegetative growth with roots that may penetrate the barrier.

There are also modes of failure of the barriers that could suddenly occur that are beyond the design parameters of the barrier. This includes accidental puncturing or tearing of the barrier by human activities, animal burrowing, or unexpected ground shifting. Floods could wash away these liners if they are not adequately secured or if the cover layer over the barrier is washed away. These events could result in unimpeded, rapid vapor migration to the outdoor air, so the occurrence of these events should trigger an immediate inspection of the barrier.

In the absence of such incidents, vapor barriers should be inspected periodically to ensure they have not been torn or punctured, do not exhibit cracks, or have not otherwise generally deteriorated. Seals should also be checked where utility conduits or other features protrude through the barrier, or where two sheets are joined together. Because the barrier may not be visually accessible if the barrier is not at the surface of the cap, this inspection may not be practical unless the covering layer is removed. If a visual inspection is not possible, air samples may be taken above the cap (on the clean side) to monitor for contaminant vapors of concern.

- **Costs**

When designing a vapor barrier cap, the long-term monitoring, maintenance, and replacement costs should be balanced against the cost of additional remediation. If long-term costs are higher than the cost of additional soil remediation, it may be preferable to simply remove the contamination of concern and avoid the need for a vapor barrier.

While monitoring frequencies and costs will likely be similar for all barriers, replacement frequencies of different types of barriers may vary. It may be preferable to install a more expensive vapor barrier initially if it will require less-frequent replacement.

At least two relatively recent cost estimates for vapor barriers have been reported. The USEPA estimates the installation of plastic membrane liners at $0.75 to $1.50 per square foot (USEPA 2008), while the ITRC gives a range of $0.50 to $5 per square foot (ITRC 2007). Liquid spray-on or pour-on rubberized asphalt emulsion barriers appear to be somewhat more expensive, but installation is easier for multiple penetrations through the liner. The USEPA estimates a cost of $5 to $7 per square foot, and ITRC gives an estimate of $2 to $3 per square foot. Neither barrier incurs routine maintenance costs other than inspection, although seals around protrusions or along seams where liner sheets are joined will likely require more frequent maintenance than the liner itself.

3.2 Permeable Cap Types

- **Description**

A permeable cap is an engineered cap that allows exchange of water and vapor between the subsurface and the environment above the cap. Such caps may be specified when venting of vapor, pressure equilibrium between surface and subsurface or availability of recharge to the subsurface is desirable.

Permeable caps can be used for protection of the direct contact pathway, when contaminant leaching and impact to groundwater are not concerns. Permeable caps are suited for sites where:

a) Contaminants present in the unsaturated zone are not likely to be mobilized by infiltrating precipitation and then impact the groundwater

b) Runoff management is required or where artificial changes in water table elevation should be minimized

c) A compressible substrate is present, because permeable caps are less subject to failure

d) Soil moisture is needed to sustain bioremediation or organic degradation

e) It is desirable or acceptable for vapors to diffuse to the atmosphere

Permeable caps may not be suitable for sites where:

a) Contaminants present in the unsaturated zone are likely to be mobilized by infiltrating precipitation and impact groundwater

b) Vapor capture is desirable (e.g. increased effort for methane collection)

c) Release of vapors to the atmosphere is not acceptable

A permeable cap mitigates potential impacts to wetlands and ecological habitat by allowing precipitation to percolate into the saturated zone and not greatly altering the water balance for the site. Porous concrete and asphalt are increasingly being used as part of green design in construction and a permeable cap would coordinate well with such features that may be used elsewhere on the site.

Vegetative caps, evaporation / transpiration (ET) caps and phytoremediation caps are examples of permeable caps that will be discussed in further detail.

From top to bottom, the permeable cap system generally consists of:

a) Optional cover layer

b) Permeable cap layer

c) Separation/Demarcation Layer

An optional cover layer may be installed over the permeable-cap layer. This cover layer may serve to protect the underlying cap from erosion (e.g. crushed stone over a sand cap) or provide appropriate seed base (e.g. top soil). The materials should be selected so the intended purpose of the cap is not affected. This optional cover layer may be used for establishing a vegetative cap that might also employ techniques such as evapotranspiration, as well as phytoremediation. These topics will be covered in more detail later.

The permeable-cap layer is typically constructed of a granular material (such as sand or gravel) but other materials may be used, including porous asphalt or concrete. The gradation is selected based on the required permeability. The thickness of the cap should be selected based on anticipated site use (e.g. parking lot or landscape area), the potential for erosion (i.e. surface slope and run-off from adjacent areas), anticipated service life of the cap and geotechnical properties of the subgrade (e.g. compressibility) and any other design considerations (e.g. ability to retain moisture). If the cap will be vegetated, the cap material and thickness, and the rooting requirements of the vegetation should be coordinated.

Appropriate construction methods (e.g. placement and compaction in lifts) and construction quality control methods (e.g. in-situ density measurements) should be used. Consideration should be given to the transition between the cap and the surrounding uncapped area. Excessive contrast in geotechnical properties (e.g. surface slope, gradation, and compaction) can lead to failure along the cap edge caused by preferential erosion.

The purpose of the separation/demarcation layer is to provide a visible indicator of the bottom of the cap, possibly provide structural support, and provide protection for the cap from upward migration of debris or cobbles from frost heave. The material for the separation layer will be selected based on the required permeability, the geotechnical characteristics of the subgrade and the profile of the cap. Consideration should be given to potential for subgrade settlement that could result in separation-layer failure. The separation-layer material should be selected to be compatible with anticipated subgrade contaminants and vapors. If the cap will be vegetated, the separation layer should be compatible with the root system of the vegetation.

- **Design Considerations and Data Needs**

It is assumed that the remedial investigation (RI) has delineated the types, horizontal and vertical distribution and concentrations of contaminants present. Since the RI is expected to provide the information necessary to select a remedy, it is expected that physical and chemical properties of the contaminants have been identified. Pertinent information includes contaminant aqueous solubility, contaminant affinity for the cap media, contaminant stability or reactivity with proposed cap materials, and decomposition products (if any).

The RI will have already identified the receptors present at the site. Any adverse effects (short term and long term) on those receptors from the construction of the cap should be considered.

Understanding local hydrostratigraphic conditions is necessary for successful design and function of the cap. Depth to water table and seasonal water table fluctuation can be used to predict the effects of any additional recharge through the permeable cap that may affect ground water flow direction, plume behavior, contaminant degradation and geotechnical properties.

Generally, the design engineer will define the geotechnical requirements (i.e. soils engineering properties) based on the characteristics of the cap and any additional requirements, such as the ability of the cap to accommodate loads. Consideration should be given to changes of the soil engineering properties as a result of the cap function, for example, groundwater mounding.

The design should consider potential impacts from changes to the site hydrologic regime. Construction of a permeable cap may alter the site's runoff characteristics. It is possible that runoff from the site may decrease. The effects of runoff received from adjacent areas also need to be considered. The design should consider measures to minimize cap erosion, especially when construction of a permeable cap changes the nature of site cover. Also, erosion of fines from adjacent areas and deposition onto the capped area should be considered. The design should consider whether the area to be capped is prone to flooding, because permeable caps are susceptible to damage.

As discussed above, construction of a permeable cap can affect the hydrologic and sediment budget. The effect of decreased runoff and increased recharge on adjacent properties should be assessed. Some examples of such effects include groundwater mounding affecting utilities and subsurface structures, changes in sheet-flow across formerly paved areas affecting the function of stormwater management systems. If the capping area was already permeable, some of these concerns would be minimized.

To the extent practical, cap design should consider future site use and activities. For example, if there are utilities located under the cap, how will they be accessed for repair and maintenance? The proper engineering solution will be devised on a site-by-site basis, and may include options such as clean utility corridors, maintenance-crew training manuals, etc.

Permeable caps may require special maintenance and inspection procedures to maintain their function as designed. Such requirements will need to be memorialized in the site control documents (e.g. institutional controls). Because permeable caps affect physical processes at the site, any changes to site use and associated features (e.g. paving or construction of below-grade structures) should be evaluated for potential impacts on the permeable-cap system.

- **Construction**

General construction QA/QC methods and guidelines can be used during construction of a permeable cap. Key components of the construction inspection and verification program should include conformance to the work plan of the following:

a) Area coverage
b) Thickness and consistent placement of the various layers
c) Permeability and drainage

Some deviation from the design dimensions is to be expected. In most cases, the design will specify tolerances for constructed layers. If the design does not specify acceptance criteria, the remediating party should consider factors such as layer design thickness and hydraulic design parameters in selecting acceptance criteria. Generally, if a deviation is observed, the effects on the cap performance should be evaluated by the investigator, before accepting the cap.

The construction details should be memorialized in a set of as-built drawings that document the extent and features of the cap and provide as many cross sections and details as necessary to document the profile and the construction details of specific features. Such drawings should be compiled using common engineering practices.

Appropriate safety plans, that consider both the hazards of construction, and exposure to site contaminants should be developed and implemented during construction. If construction will expose contaminated media to the environment, measures should be taken to mitigate concerns relative to short-term exposure for both the construction workers and the off-site public.

- **Operation and Maintenance**

Monitoring consisting of periodic inspections by appropriately skilled staff is necessary. The monitoring program should be based on known or anticipated site conditions and cap construction details:

a) timed to coincide with times of heavy traffic or,
b) at the end of the wet season or,
c) timed to coincide with periods of intense site use.

The expected exposure scenario should also be considered in designing a monitoring program (e.g. commercial site maintenance or residential planting and landscaping activities). Inspections should be spaced so that, if any damage or failures occur, it will not go unnoticed for a prolonged period. The frequency of inspections can depend on the likelihood that damage or failure may occur, the anticipated mode of failure and the contaminant concentrations, construction details (e.g. surface slope, use of vegetation, profile thickness), site use (e.g. traffic conditions) and site conditions (e.g. surface water run-on). The monitoring plan should identify potential events beyond the design capabilities of the cap that could result in excessive wear or catastrophic failure and provide for appropriate inspection triggers.

Monitoring should verify that the structural integrity of the cap is maintained. The thickness of the cap should be verified, preferably with nondestructive methods, such as elevation surveys. Signs of failure, such as slumping, fissuring, scouring, rutting, excessive settlement, animal burrowing and uncontrolled penetrations should be looked for during inspections.

The use of checklists and photo documentation of inspections should be considered. Maintenance should be expected to consist of periodic addition of fill. If the cap is vegetated, periodic replacement of dead or damaged vegetation should be anticipated. Any repairs should be documented using photographs, and, if appropriate, surveying. Certifications will be required in accordance with any NJDEP Soil Remedial Action Permit to document inspection result and repairs (if any).

3.2.1 Vegetative / Landscape Caps

- **Description**

A vegetative cap is a long-term, self-sustaining cover of plants growing in or over materials that pose environmental risk; the vegetative cap reduces that risk to an acceptable level. Vegetative caps have a vegetative layer as the uppermost layer of the cap design (Optional Cover Layer mentioned in Section 3.2 under Definition). Vegetative caps are generally 2 feet thick but can vary based on site specific conditions. Vegetative caps will also tend to have a more stringent inspection and maintenance program than low-permeability caps.

Caps can incorporate multiple layers to prevent direct contact. A vegetative cap typically incorporates the following three layers:

a) Vegetated Topsoil
b) Clean Soil Layer
c) Separation/Demarcation Layer

- **Components**

The vegetated top soil layer assists in the prevention of erosion of the soils of the cap from wind and rain. The vegetated top soil layer is typically 6 inches thick but should be thick enough to support the vegetation. If deeper rooted vegetation (trees and shrubs) is planned, the topsoil thickness may increase, or even be built up above the surrounding grade. It should be spread evenly and not overly compacted.

The clean fill layer is usually 12 to 18 inches thick. If this layer will also serve for drainage, filter fabric is normally installed to prevent the vegetated top soil layer from clogging the drainage pores.

The separation/demarcation layer is a visible barrier (such as snow fence, geotextile, distinctly colored soil) that is intended to provide a clear separation between the cap and the underlying impacted material, prevent mixing, and possibly provide structural support.

- **Design Considerations and Data Needs**

The design considerations and data needs are consistent with the permeable-cap considerations from Section 3.2 under Design Considerations and Data Needs, as well as Construction. These components are often dictated by the requirements of the site development, as long as they meet the required protectiveness. The investigator is also referred to the NJDEP Presumptive and Alternative Remedy Technical Guidance (NJDEP 2013a) for residential, school, child care, or other sensitive uses.

http://www.nj.gov/dep/srp/guidance/#presumptive_alt_remedy

This presumptive remedy guidance also provides guidelines for other types of permeable caps that are typically associated with the sensitive uses.

A vegetative cap can provide for a park-type setting and provide excellent aesthetics to a remediation project in a neighborhood or city. In some cases, a vegetative cap may provide a natural visual block to benefit an industry, while providing for enhanced visual appeal to fulfill the city management's aesthetic requirements. It also allows the investigator the potential to recapture habitat for native plants and animals while providing visual appeal.

In a vegetative cap, the investigator should use a cover layer that consists of sufficient soil to allow for root support and moisture storage to sustain a vegetative layer of growth that will stabilize the soil and provide erosion-control of the soil. Consideration should be given to deeper rooted shrubs and trees; if they are incorporated into the cap design, increased inspections and maintenance may be required for the longevity of the cap. Proper selection of plant species should be compatible with the design profile of the cap.

The type of vegetative species will have an impact on O&M, as well as on overall cap construction cost. Landscaping using native vegetation, which is naturally adapted to site-specific conditions, results in long-lasting, stress-tolerant, and low-maintenance plants, which may lower O&M costs. The selection of vegetation may affect the presence of burrowing animals that could negatively affect the performance of a cap. The investigator may want to consider alternative plantings including grasslands, mixed meadows, scrub and shrub habitats, and woodlands to promote ecological habitats. Appropriate selection of vegetative species may result in lower costs. If trees are incorporated into the cap, additional maintenance may be required to address breaches in the cap caused by fallen or uprooted trees.

The investigator will need to consider that contaminant toxicity to specific plant species may prevent proper plant establishment. For example, copper and zinc at elevated concentrations can be phytotoxic. The potential for uptake and bioaccumulation of contaminants into the plant species should also be considered. In addition, the investigator will need to determine timing to establish an effective vegetative cap as most of these caps will take a few years to be effectively established. Once constructed, a vegetated cap will mitigate against direct contact. However, routine inspections should be conducted and erosion control maintained until such time as plant establishment has occurred. In addition to precipitation, irrigation may be required to promote the establishment of vegetative cover.

When using vegetative or landscape caps as part of site development, the investigator should consider the effects of the site's runoff characteristics. Runoff may be diverted around certain features, such as buildings, and directed to permeable features, such as stormwater detention basins, which may be part of the permeable structural cap. The design engineer should ensure that no detrimental impacts from the altered runoff patterns affect neighboring properties. In addition, sheet flow from adjacent paved areas onto the cap may increase rates of erosion and should be considered in the design.

- **Construction**

Construction and permit considerations for vegetative caps are covered in Section 3.2. In addition to the considerations discussed above, the selection of certain plant species may be restricted in select regions (e.g. The Pinelands). It is the responsibility of the remediating party to identify and obtain all permits, based on the specific conditions of each project.

Construction of a vegetative cap will typically follow the construction QA/QC requirements dictated by the architect, civil and environmental engineers, and other design professionals involved with site development. Construction QA/QC requirements should include items such as grade check, layer thickness verification, and photo documentation. Upon completion, as-built drawings and a topographic survey should be compiled. These measures are undertaken to ensure that the specified design criteria have been met.

The site engineer should note any deviations from the design documents to determine whether those deviations may affect the integrity of the cap or whether additional measures need to be implemented.

- **Operation and Maintenance**

O&M activities for a vegetative cap will depend upon a variety of factors, as well as the site conditions and land use. Factors to consider in developing the O&M plan include the nature of the contamination present, the likelihood for that contamination to impact potential receptors, and the overall protectiveness of the cap design.

A cap design may be less robust if there is an extensive monitoring program. The type or thickness of the cap may result in a more extensive monitoring program to minimize the potential for exposure. For example, a landscaped area in a park with a 1-foot layer of clean fill and a demarcation barrier will likely warrant a more robust monitoring program than a similarly constructed landscaped area in a commercial shopping center.

Because a vegetative cap can be constructed to address numerous contaminants in a variety of settings, the operations and maintenance programs vary. O&M would generally consist of periodic inspections, at a frequency to be determined based on the potential for exposure of underlying contaminants and the potential receptors involved, to ensure that cap components are performing as designed.

Routine inspection of the vegetative cap should occur on a schedule to ensure that integrity of the vegetative cap has not been compromised. This inspection process may include review of slope stability, cracks, burrow holes, seepage, ponding, erosion, uprooted trees, and excessive settlement. In addition, water drainage systems should be checked to ensure that they are free of damage or obstructions and provide adequate runoff. The inspector may review the actual vegetation to identify whether vegetation is stressed or missing.

After inspection, the inspector will summarize findings and include appropriate corrective actions as part of the O&M requirements. Typical maintenance of a vegetative cap includes removal of burrowing animals; backfilling holes created by the burrowing animals or uprooted trees; regrading; and revegetation and mulching of eroded or stressed areas. In addition, periodic mowing may be a necessary component of the O&M plan depending upon plant species. Also, a special vegetative cap inspection should be conducted in cases where unplanned events such as a flood, major storm, or fire have taken place, so that cap integrity is documented and maintained.

3.2.2 Evaporation/Transpiration Cap

- **Description:**

An evapotranspiration (ET) cap is also known as a water-balance cap or cover. The evapotranspiration cap is composed of soil and plants that maximize the evaporation and transpiration process. These ET caps are also known as alternative earthen final covers, soil-plant covers, and store-and–release covers. The ET cap employs hydraulic control via soil and vegetation selection and relies mainly on leachate control. Water that infiltrates through the surface is held in the soil layer by capillary forces until the plant cover or evaporation removes the water. The soil provides a water reservoir to temporarily store water, and the plants empty the reservoir by their natural "pumping" action. ET caps are increasingly being used at waste disposal sites and landfills when equivalent performance to conventional caps is demonstrated as lowering costs and applying a greener remediation solution. The ultimate goal is to prevent leachate generation.

ET caps use one or more soil layers. A monolithic ET cap uses a single soil layer with fine-grained soils such as clayey silts and silts that have high water-storage capacity to establish native vegetation with high evapotranspiration rates above the contaminated media. A capillary ET cap uses the same fine-grained soils above a coarser-grained material such as sand. In the case of the capillary ET cap, the fine-grained layer has the same function as the monolithic ET cap, while the coarser material acts as a capillary break so that the fine-grained layer is able to retain more water than in a monolithic ET cap. This coarse layer also may eliminate concerns about burrowing and gas-collection systems.

- **Design Considerations and Data Needs**

RCRA subtitle D (40 CFR 258.60) and N.J.A.C 7:26 set the minimum design requirements for caps on municipal solid waste landfills. In addition, RCRA Subtitle C (40 CFR 264 and 265) provides USEPA guidance for capping of hazardous waste landfills. Under RCRA, an ET cap can be proposed by an investigator in lieu of a conventional low-permeability cap as long as it can be demonstrated that the ET cap will provide equivalent performance with respect to percolation reduction, erosion resistance, and gas control (USEPA 2011a). For a detailed review of case studies and equivalent performance on alternative landfill covers, the (ITRC 2003a) Technology Overview Using Case Studies of Alternative Landfill Technologies and Associate Regulatory Topics should be used.

http://www.itrcweb.org/Guidance/GetDocument?documentID=1

In addition, the USEPA (USEPA 2011b) provides a searchable online database that provides project profiles that include site background, project information, cover information, performance and cost information.

http://cluin.org/products/altcovers

The following parameters should be considered by the investigator when designing an ET cap. Each of these parameters (ITRC, 2003b) affects the water-storage capacity, as well as the evapotranspiration rates, which will ultimately control the water percolation into the underlying waste.

Climate: Precipitation is a major design consideration. Not only does the total precipitation need to be accounted for, but also the actual form (snow, ice, or rain) and overall distribution and variation month to month needs to be accounted for as well. In addition, overall temperature, atmospheric pressure, and relative humidity need to be considered for their impact when vegetation becomes dormant during particular times (seasons) and yields less evapotranspiration.

Soil: Soil types and thickness, as well as use of monolithic versus stratified designs, are considerations. The soil gradation and bulk density will affect the storage capacity of soil. Compaction of soil during construction may have an effect on the thickness of soil layers needed and on root growth. The design specification for soil thickness may be impacted significantly by the climate to accommodate extreme storms, as well as seasonal behavior of vegetation. The investigator may consider control layers in ET designs to minimize biointrusion, promote drainage, and control landfill gas. Finally, nutrient and salinity characteristics of the soil should be considered, because these are extremely important to vegetation growth. For ET caps, the topsoil layer is usually a minimum of 6 inches.

Vegetation: Grasses (wheatgrass and clover), shrubs (rabbit brush and sagebrush) and trees (willow and hybrid poplar) have been used extensively on ET covers. A mixture of native vegetation for warm- and cold-season species is usually employed because it is tolerant of disease and weather conditions. In addition, use of native vegetation is important so as not to disturb the natural ecosystem and to provide for water uptake throughout the growing season.

In considering these factors, it is necessary that the investigator ensure that the ET cap meets the following four technical specifications:

a) Soil with adequate plant-available water-holding capacity for all seasons

b) Adequate soil thickness to store water derived from a "critical-event" storm

c) Low soil density to permit adequate root growth (less than 94 pounds/ft3 [ITRC, 2003a])

d) Robust, healthy plant cover.

Most ET caps to date have been used in the western United States with climates that are considered arid or semiarid. The use of stormwater control enhancements, such as increased frequency of drainage channels, or similar measures could change the water budget, making the use of ET caps more viable in less arid climates such as New Jersey. Because these are relatively new caps (past 10 to 20 years), there are limited data and past performance statistics to show ET's long-term effectiveness for minimizing percolation, minimizing erosion, and resisting biointrusion, especially in the mid-Atlantic and Northeast.

Selection of a conceptual design for an ET cap should include some indication of expected performance. These data may be obtained through published literature from agricultural studies on movement of water in nearby soils. Additional performance information from test sections using lysimeter studies would provide better information and replication of these results would depend on proximity of the field test, as well as on similarities of soil, plants and climatic factors. Finally, the extrapolation of data from nearby facilities with ET caps may save significant time and money for determining design constraints and potential for an ET cap. In all cases, a thorough site investigation should be performed, and any further predictive modeling should be performed using site-specific data to incorporate climate, soil, and vegetative factors.

The investigator should evaluate the need for modeling. Three model types should be considered:

a) The simplified water balance;

b) The enhanced water balance (i.e. the USEPA HELP Model Schroeder et al 1994); and

c) The Richards equation-based models (i.e. UNSAT-H Model Fayer 2000) .

- **Construction**

Design drawings and specifications are required to define the geometric configuration, physical requirements, components, and proper placement of materials during construction of the ET cap. Project plans should be used to cover health and safety issues during construction, as well as long-term operations and maintenance. These plans should also include a construction quality assurance plan that provides the controls and assurance that the ET cap is constructed in compliance with the drawings and specifications.

Construction QA/QC inspections should verify consistency with the design. Slopes, thicknesses, elevations, and geotechnical parameters should be part of the construction QA/QC program. In addition, verification and location of moisture monitoring equipment should be included as part of the QA/QC design criteria with visual checks and photo documentation, as well. Any fencing and signage requirements should be verified for construction purposes. Vegetative cover should be verified versus design specifications and moisture readings should be checked.

The design criteria of an ET cap are based on the cover's effectiveness as a barrier to infiltration, precipitation run-on and runoff, differential settlement, and maintenance. The cover depth, planting of vegetation, and monitoring instrumentation will substantiate the performance against the design parameters of infiltration, run-on and runoff, and settlement. The periodic inspection and maintenance, as well as the moisture readings at the base of the cap, will ensure the performance and integrity of the cover for QA/QC purposes.

The federal regulation governing closure of municipal solid waste landfills, 40 CFR Part 258, Subpart F (Closure and Post-Closure Care), Section 6 (h) and federal regulations governing closure of hazardous waste landfills, 40 CFR Part 264, Subpart G (Closure and Post Closure Care) require notification and proper verification of these closure processes by certified independent personnel that the landfill cap was completed and implemented properly.

- **Operations and Maintenance**

Cover integrity—as well as leachate, groundwater, percolation, and landfill gas monitoring—are the keys to ET cap O&M (USEPA 2011a). Therefore, regularly scheduled walking inspections (every six months) are recommended to ensure that the cap has not been impaired in any way. Signs of holes from burrowing animals or human activities such as digging, gardening, vandalism, heavy loading or construction will need to be reported and corrected. In addition, erosion, excessive settlement and cracking or permeability changes from physical or chemical processes will need to be noted and repaired.

Monitoring methods will be site- and cap-specific varying from walkover inspections to quantitative measurements of leakage through the cap. Procedures for monitoring ET caps may include visual inspection with notes, checklists, and photos referenced to known landmarks, monitoring groundwater levels in response to precipitation events, as well as surveying for comparison with as-built conditions. Finally, monitoring of soil moisture under the cap by means of drainage pipes, lysimeters, soil-moisture sensors, or other appropriately designed methods may also be employed.

Post-closure care activities provided for under RCRA Subtitle D include leachate monitoring and management as necessary, groundwater monitoring, inspection and maintenance of the final cover. These activities normally continue for 30 years unless extended or shortened by the regulatory agency. In addition, groundwater monitoring will continue to take place to ensure the protection of human health. Landfill gas sampling and monitoring may also need to be addressed in the post-closure plans.

- **Cost**

Generally, construction costs may be higher than other cap types, based on geometry and location; however, O&M costs may be lower over the lifespan of the cap.

The ET design may also eliminate the need for a separate biointrusion layer or gas-collection layer as the secondary coarser-grained layer may provide for both when using a capillary ET cap design. O&M costs may vary based on site-specific conditions such as irrigation, nutrient addition, erosion, and biointrusion.

3.2.3 Phytoremediation

- **Description**

Phytoremediation takes vegetative caps to the next level and uses the capabilities of particular plant species to remove contaminants from the environment. By selecting appropriate species and by designing vegetative caps properly, the investigator is able to use the natural capabilities of plants to remediate toxic soils, groundwater, surface water, and sediments. With proper plant selection, organic compounds and metals can be remediated.

The various phytoremediation technologies provide a low-cost alternative to traditional remedial alternatives. From the regulatory perspective, cleanup goals can be the achievement of applicable remediation standards and mitigation of direct contact. Table 2 below lists the various phytoremediation technologies and provides examples of media, plant selection, contamination levels, and application status for reference (USEPA, 2000).

Table 2. Phytoremediation Overview

Mechanism	Process Goal	Media	Contaminants	Pla	Status
Phytoextraction	Contaminant extraction and capture	Soil, sediment, sludges	Metals:Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn; Radionuclides: ^{90}Sr,^{137}Cs,^{239}Pu,$^{238,234}U$	Indian mustard, pennycress, alyssum sunflowers, hybrid poplars	Laboratory, pilot, and field applications
Rhizofiltration	Contaminant extraction and capture	Ground water, surface water	Metals, radionuclides	Sunflowers, Indian mustard, water hyacinth	Laboratory and pilot- scale
Phytostabilization	Contaminant containment	Soil, sediment, sludges	As, Cd, Cr, Cu, Hs, Pb, Zn	Indian mustard, hybrid poplars, grasses	Field application
Rhizodegradation	Contaminant destruction	Soil, sediment, sludges, ground water	Organic compounds (TPH,PAHs, pesticides chlorinated solvents, PCBs)	Red mulberry, grasses, hybrid poplar, cattail, rice	Field application
Phytodegradation	Contaminant destruction	Soil, sediment, sludges, ground water, surface water	Organic compounds, chlorinated solvents, phenols, herbicides, munitions	Algae, stonewort, hybrid poplar, black willow, bald cypress	Field demonstration
Phytovolatilization	Contaminant extraction from media and release to air	Ground water, soil, sediment, sludges	Chlorinated solvents, some inorganics (Se, Hg, and As)	Poplars, alfalfa black locust, Indian mustard	Laboratory and field application
Hydraulic control (plume control)	Contaminant degradation or containment	Ground water, surface water	Water-soluble organics and inorganics	Hybrid poplar, cottonwood, willow	Field demonstration
Vegetative cover (ET cover)	Contaminant containment, erosion control	Soil, sludge, sediments	Organic and inorganic compounds	Poplars, grasses	Field application
Riparian corridors (non-point source control)	Contaminant destruction	Surface water, ground water	Water-soluble organics and inorganics	Poplars	Field application

The goal of this section was to expose the investigator to the potential to use a vegetative cap as a valid remediation process. Extensive information is available on the ITRC website for this type of cap, which includes decision trees for the application of the various phytoremediation technologies associated with the cleanup of the various media. The investigator who wants further information should become familiar with the ITRC Phytotechnology Technical and Regulatory Guide (ITRC, 2009).

3.3 Sediment Cap Types

3.3.1 Introduction

The remediation of contaminated sediments, to mitigate human and ecological exposure to contamination, is increasingly managed with technologies such as capping. The use of sediment caps has increased as the understanding of the sediment environment, construction techniques, and construction materials has evolved. However, the evaluation of appropriate remedies requires a complete and thorough site investigation because of the dynamic nature of the aquatic environments. Additionally, unlike a remedy solely implemented to mitigate human health risks, a sediment remedy may need to reduce risks to multiple trophic level receptors (i.e. macroinvertebrate community, fish, piscivorous birds and mammals, and humans). Because of these complexities, it is critical that the sediment remedy be carefully evaluated to ensure achievement of the remedial-action objectives, and that the remedy is designed to be protective for as long as the contaminants they address remain at levels of concern.

The following sections provide insight into some of the key components of sediment-cap selection and design. The information contained in this section should not be considered inclusive, but rather it is an overview of technical considerations for selecting a cap for contaminated sediments. Many of the concepts and components addressed in the sections are discussed broadly, and the reader is advised to refer to additional technical guidance documents and other resources to determine how their site-specific characteristics may affect the feasibility of a sediment cap. Some useful references for sediment capping are provided below:

> USEPA Office of Solid Waste and Emergency Response. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012, OSWER 9355.0-85, December 2005. Available online: http://www.epa.gov/superfund/health/conmedia/sediment/pdfs/guidance.pdf
>
> Palermo, M., S. Maynord, J. Miller, and D. Reible. 1998. Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. USEPA, EPA-905-B96-004, Great Lakes National Program Office, Chicago, Illinois. Available online: http://www.epa.gov/glnpo/sediment/iscmain/
>
> Palermo, M. R. 1991a. Design Requirements for Capping, Dredging Research Technical Note DRP-5-03, US Army Engineer Waterways Experiment Station,Vicksburg, MS.

Palermo, M. R. 1991b. Site Selection Considerations for Capping. Dredging Research Technical Note DRP-5-04, US Army Engineer Waterways Experiment Station, Vicksburg, MS

This guidance shall not be used as a means to bypass the assessment of ecological risk pursuant to N.J.A.C. 7:26E 1.16 and 4.8. The need for any sediment remedial action (dredging, capping, etc.) can only be determined pursuant to N.J.A.C. 7:26E 1.16 and 4.8, as well the NJDEP Ecological Evaluation Technical Guidance (NJDEP 2012)

http://www.nj.gov/dep/srp/guidance/#eco_eval.

The guidance contained herein only addresses sediment capping.

3.3.2 Description and Components

Sediments are unconsolidated materials that settle to the bottom of a surface water body or wetland. The sources of sediment can be terrigenous (sand, silts), biogenous (sea shells, plant debris), and anthropogenic (soot, cinders). For the purposes of this section, sediments are considered to be submerged. Contaminated sediments are those containing toxic or hazardous materials that may cause adverse impacts to human health or the environment.

Sources of sediment contamination vary. Once contaminated, the contamination behavior varies depending on the composition of the sediment and contaminant. Contamination in sediment may be directly adsorbed (typically to the finer or more organic portion of the sediment), otherwise bound to sediment particles (e.g. as ligand complexes in the case of metallic contaminants), integral in the sediment matrix, or present as non-aqueous phase liquid (NAPL).The contaminants in the sediment may also partition into the pore water, providing transport pathways through surface or groundwater flow. Contamination can also volatilize or otherwise interact with gas bubbles trapped in sediments. Evidence of sediment contamination can potentially be encountered in all media surrounding the sediments. This could include surface water, pore water, underlying groundwater, entrapped pore gases, underlying native soil and bedrock, the sediment matrix itself, and biota (through biouptake and biomagnification processes).

A sediment cap is used to provide a barrier between impacted sediments and the overlying surface water and benthic environment (conventional cap). In addition, a cap may be designed to provide treatment and/or increased sequestration of contaminants (amended cap). Caps can be constructed using a combination of materials, including sand, soil, rock aggregate, and engineered materials placed over the contaminated sediment. Caps can be constructed of one or more layers, depending on site-specific requirements. A sediment cap represents an engineering control. As such, it can be a stand-alone remedy or can be used in conjunction with other sediment remedies (i.e. monitored natural recovery (MNR), dredging, etc.). Institutional controls and post-remedial monitoring are required to ensure the long-term effectiveness of any remedy (see Section 3.3.5).

Depending on the potential exposure pathways and identified risks at the site, the purposes of a sediment cap may include the following:

- Prevent migration of contaminants to the surface water through
  a) Advective groundwater flow,
  b) Diffusion, or
  c) Ebullition;

- Prevent contact between the contaminants and humans or benthic organisms;

- Prevent future transport of impacted sediment within the water body through re-suspension;

- Reduce flux of dissolved contaminants into the water column (diffusion);

- Stabilize the impacted sediments; and

- Potentially remediate contaminated sediments below the cap using reactive media.

Selection of a cap as part of a sediment remedy should consider all impacted media and phases, the transport processes, and site conditions or future use.

The placement of a cap will most likely result in some sediment suspension. As such, care should be taken to reduce sediment migration during placement of cap materials. The use of silt-curtains may be warranted, as well as the sequencing of material placement. USEPA (USEPA 1994) and ERDC (ERDC 2005) consider silt curtains ineffective at depths greater than 20 feet and at current velocities greater than 50 centimeters second. Under these conditions, silt curtains can be reinforced to some extent with sheet piling at the corners or additional anchoring measures, but the effectiveness of any additional measures should be verified in the field.

3.3.3 Design Considerations and Data Needs

When a sediment cap is being considered as a remedial alternative, it is critical that adequate data exists to effectively design and construct a subaqueous cap. Sediment caps may be applied to freshwater and marine environments, all of which may exhibit unique, site-specific characteristics that need to be accounted for. Site conditions, more than any other consideration, will dictate the feasibility of capping. Site characteristics affect all aspects of a capping project, including design, construction equipment, and monitoring.

The following data needs (USEPA 2005) should be considered when a sediment cap is being contemplated. A brief explanation is provided as to why these parameters are important to consider; however, the reader is referred to the literature for a full understanding of how these factors may influence sediment capping at a particular site.

Physical factors include:

- Hydrodynamics/Erosion: The cap must be resilient to erosive pressures from the overlying water body for it to remain integral and protective. Common benchmarks include a 100-year storm or a watershed design flood, or for water bodies where navigation is present, the erosive forces associated with normal operation of the largest and most powerful vessels that might traverse the area. The potential effects of ice scour should also be considered. The effects of extreme weather events should also be taken into consideration.

- Deposition Rate: Many areas that require remediation are depositional by nature. If sources are adequately controlled, the continued deposition of sediments leads to natural capping of those sediments. The assessment of deposition rate and the quality of those deposited sediments relative to the contaminants of concern are a critical aspect of cap design. Measureable net deposition (e.g. few mm/yr or more) will provide improved performance of any cap.

- Water Depth: Maintenance of water depth may be important for a particular ecological receptor, to preserve navigability, or to protect flood capacity. Placement of a cap may reduce the water depth and limit the ability to meet these design criteria. Appropriate water depths should be assessed during design and modified to meet those requirements.

- Slope Stability: Placement of a cap and its subsequent integrity requires that the underlying sediment will not collapse because of cap placement. Excessive loading of a slope may result in failure of that slope and exposure of the contaminant to ecological receptors.

- Sediment Bearing Capacity: Bearing capacity is the ability of the native sediment to support the load of a cap. Low bearing capacity of the underlying sediment will require placement of a cap in thin lifts that will result in sediment consolidation and strengthening before the full cap thickness is placed.

- Advective Ground Water Flux: The movement of ground water through a cap often controls the ability of a cap to effectively retard contaminants. Measurement of ground water flux and the contaminant concentration in that ground water (pore water), is required to evaluate the contaminant flux that a cap must control. Pre-remediation pore water concentrations provide baseline data to compare to post-remedy pore water concentrations. This type of comparison is critical when assessing remedy effectiveness; especially where capping amendments are added to treat a specific contaminant.

Strong groundwater upwelling potential can add additional forces to a cap and induce contaminant flow through the cap. Groundwater flow-potential should be assessed in uplands and within the sediment, if possible, and should be considered in cap design. If groundwater upwelling is very strong (i.e. in a gaining stream or river), the use of a sediment cap may not be effective in preventing contaminant migration.

- Ebullition, or the transport of contaminants through gas generation and migration, can play a role in contaminant transport for NAPLs and moderate to high-volatility contaminants. This process may lead to breaches in cap integrity. Specific cap design alternatives can be included to minimize the impacts of ebullition.

- Geochemistry: The ability of a cap to contain particular contaminants is directly related to sediment geochemistry. This is particularly important for inorganic contaminants. Strongly reducing sulfidic sediments have the ability to reduce mobility of divalent metal contaminants such as Pb, Ni, Cd, Zn, and Cu because these species will form metal sulfides and precipitate. For organic contaminants, sediment geochemistry will primarily influence microbial degradation and transformation rates. Hydrocarbons and PAHs will tend to exhibit slow or minimal degradation under reduced conditions.

Sediment factors include:

- Physical Properties: The primary concerns for the sediment on which a cap is to be placed is its strength (load-bearing capacity) and consolidation characteristics. Sediments consolidated by the placement of a cap will express contaminated pore water. The zone that may be impacted will likely be minimal in situations where contaminants will sorb to cap material, but for nonsorbing cap materials, this may be an important transport mechanism that needs to be addressed.

- Bioturbation: Deposit feeding organisms move sediment and contaminants associated with that sediment as a result of burrowing and feeding activities. The depth and intensity of the mixing processes thus control contaminant migration and fate. In general, the thickness of a cap must be greater than the effective mixing depth of benthic organisms for it to be effective. The cap design should consider the known behaviors and depth distributions of the organisms expected to recolonize the cap. Clarke et al. (2001) discuss the bioturbation component of a cap in some detail.

Waterway use factors include:

- Background Sources: the effectiveness of capping can be completely offset by continued deposition of contaminated sediments to the cap surface. Assessment of the significance of continued sources should always be conducted before implementation of a sediment remedy such as capping. Complete control of ongoing sources may not be possible but the long-term implications of any continuing source need to be assessed. Association of State and Territorial Solid Waste Management Officials (ASTSWMO) has recently published a paper on sediment remedy effectiveness and background contamination (ASTSWMO 2013). Capping requires appropriate access to the waterway for staging and processing of cap materials. Access requires the ability to accumulate the cap material and transfer it to delivery equipment that can access the area being remediated.

- Existing and future conditions and infrastructure at the site (navigation channels, recreation uses, utility pipelines, outfalls, etc.) that could affect the integrity and functionality of the cap must be considered in its design

Contaminant data needs include:

- Horizontal and Vertical Extent: As with any remedy, it is critical that the contaminants of concern be accurately delineated as required by N.J.A.C. 7:26E 4.1 (a) 2 so the area requiring remediation is accurately defined. The vertical extent of the contamination must also be delineated because this factor may play a role in in calculating cap thickness, particularly if the cap is designed to be sorptive in nature.

- Contaminant Type: It is necessary to address the type of contamination present and its relative mobility. The presence of separate phase liquids (NAPLs) will increase the transport potential for contaminants in sediment, and potentially through a cap. Ebullition, or the transport of contaminants through gas generation and migration, can play a role in contaminant transport for NAPLs and moderate to high-volatility contaminants. Specific cap design alternatives can be included to minimize the impacts of ebullition.

3.3.4 Sediment Caps

A sediment cap may reduce risk through three primary functions (USEPA 2005). The design of a sediment cap includes a balance between these main functions:

- Physical isolation of the contaminated sediment sufficient to reduce exposure caused by direct contact and to reduce the ability of burrowing organisms to move contaminants to the surface

- Stabilization of contaminated sediment and erosion protection of sediment and cap sufficient to reduce resuspension and transport to other sites

- Chemical isolation of contaminated sediments sufficient to reduce exposure from dissolved and colloidally bound contaminants transported into the water column

Many variations in sediment caps exist, and alterations in cap design can be used to achieve increased performance for each of the criteria above. In general, sediment caps can be classified into two categories: conventional caps and amended caps. A description of these cap types is provided below, along with a discussion of the typical performance against the above criteria.

3.3.4.1 Conventional Caps

Conventional caps can be used to physically isolate sediments from the water column and prevent suspension and sediment transport, while also isolating the impacted sediments from local biota. These caps have been used at many sites and are typically constructed of sand, gravel, or other aggregate. Other natural materials can be used in creating a conventional cap, including sediments dredged from other areas. The incorporation of fine-grained materials into the cap design can limit the permeability of the capping material and groundwater upwelling through the cap. Organic content in the capping material can also retard chemical transport of contaminants through the cap by providing additional adsorption capacity for organic contaminants.

Grain size and other physical/geotechnical analyses of the cap material will be necessary to evaluate the physical suitability and potential long-term stability of the cap when subjected to the current and other erosive forces in the project area. This includes currents and waves generated by storms, flood conditions, and boat traffic (i.e. prop wash). In addition to grain size distribution, physical and geotechnical properties of interest include *in situ* density, compressibility, and shear strength. The grain size and other physical/geotechnical data will also be used to ensure that the in-place contaminated sediments are not dispersed as a result of the capping operation. In addition, this information will be considered as part of the evaluation of the potential recolonization of the cap by benthic organisms.

Material proposed to be used to cap contaminated sediment as part of the remediation activities at a contaminated site must be tested and evaluated consistent with the NJDEP (2011) document “Alternative and Clean Fill Guidance for SRP Sites” (Version 2.0, dated December 29, 2011), and any subsequent revisions thereto. At a minimum, such material must be free of contaminants and otherwise suitable for placement in surface waters.

These caps can include the installation of boundary and armoring layers in addition to the isolation layer. Boundary layers can include geotextile or geomembranes/plastic liners to prevent mixing of the clean capping material and underlying impacted sediments. A geomembrane liner can be incorporated to control ebullition. The geotextile layer can also assist in reducing differential settlement of the capping material and the underlying sediment. An armoring layer can also be incorporated to prevent scouring of the isolation layer in higher-energy situations, such as heavy rainfall or large wave situations.

The installation of conventional caps has been well documented and many placement techniques exist. The thickness of the capping layer will be dependent on anticipated transport time through the cap, required thickness to re-establish the benthic environment, and the anticipated extent of bioturbation. Armoring considerations would have to be incorporated in addition to these thicknesses when necessary, because armor layers will offer minimal effectiveness to prevent contaminant transport and are typically not suitable for benthic environments.

Conventional caps are typically designed to perform well for physical isolation and stabilization. Chemical isolation is often not a primary design parameter either because of limited contaminant transport potential or the adequacy of the isolation layers at preventing transport, however, it may play a role in determining cap thickness and selection of cap materials.

3.3.4.2 Amended Caps

Amended sediment caps generally include additional layers incorporated into the capping design to overcome limitations of a conventional isolation cap. These limitations arise when the physical isolation of the underlying contaminated sediment is insufficient to prevent contaminant migration. These types of caps are also referred to as reactive or active caps. Highly mobile contaminants, trapped NAPLs, ebullition or high rates of groundwater upwelling are factors that may result in use of an amended cap. They can also be used to treat contaminants in the underlying sediments before they are transported into the overlying water body. Amended caps may not be suitable for sites where the source area has not been remediated or where the groundwater or contaminant flux rates are high enough to exhaust the reactive media over a short time. Additionally, amended caps can be used to increase the performance of a cap with respect to physical isolation and durability. The incorporation of engineered materials such as liners or geotechnical structures can increase the durability of the capping layer while minimizing the thickness of an armoring layer. The inclusion of clay minerals such as bentonite can also increase the physical isolation of the contained sediments by providing a thin low-permeability layer. Bentonite materials like AquaBloK ® can be placed as an aggregate along the surface of impacted sediment, and then the clay coating will swell to form a low permeability surface.

Chemical isolation of contaminants can be enhanced by the inclusion of reactive or adsorptive media into the capping matrix. Reactive media such as zero valent iron can be used to reductively dechlorinate compounds before transfer through the cap matrix. Adsorption of organic contaminants can be achieved through the inclusion of granular activated carbon (GAC) in the matrix. The GAC acts like any organic portion of an aggregate cap in that it adsorbs and binds organic contaminants, retarding their flow through the cap. Unlike natural organics, GAC has been "activated" to provide an increased surface area, resulting in much greater adsorption potentials. Recently, some newer methods of delivering the activated carbon to the sediment have become available and have been successful at the pilot-scale level. AquaGate+PAC (a powder-activated carbon delivery system that uses the AquaBlok® technology) and Sedimite™ are two such technologies.

A similar technology, reactive core mats (CETCO®), involves the placement of reactive materials (apatite, activated carbon, organoclay) between geotextile fabrics, which are then applied atop the sediment. Regardless of the type of reactive media, bench-scale studies are usually required to determine the amount of reactive media required, the proportion of the reactive media to other cap components (i.e. sand), and to provide an estimate of anticipated life span of the reactive media. Models have been developed to help provide estimates for some these parameters (e.g. Reible and Lampert, University of Texas –

http://www.ce.utexas.edu/reiblegroup/downloads.html).

New technologies are evolving to control the transport of NAPLs and metals through a cap. Organoclays have been used in water-treatment technologies to adsorb NAPL and may be useful in the future as additional layers of a sediment cap. Removal or adsorption of metals may be accomplished by the addition of reactive media to the cap layers.

Capping schemes can include areas with reduced permeability specially arranged with areas of reactive media to provide specific zones where upwelling or ebullition is encouraged. The inclusion of reactive zones in the cap can reduce the volume of reactive media needed to treat contaminant flux and can allow for the placement of treatment zones away from areas with high scour potential and thick armoring layers.

USEPA has recently published a guidance document titled *Use of Amendments for In Situ Remediation at Superfund Sediment Sites* (USEPA 2013), which discussed several of the amendments noted above.

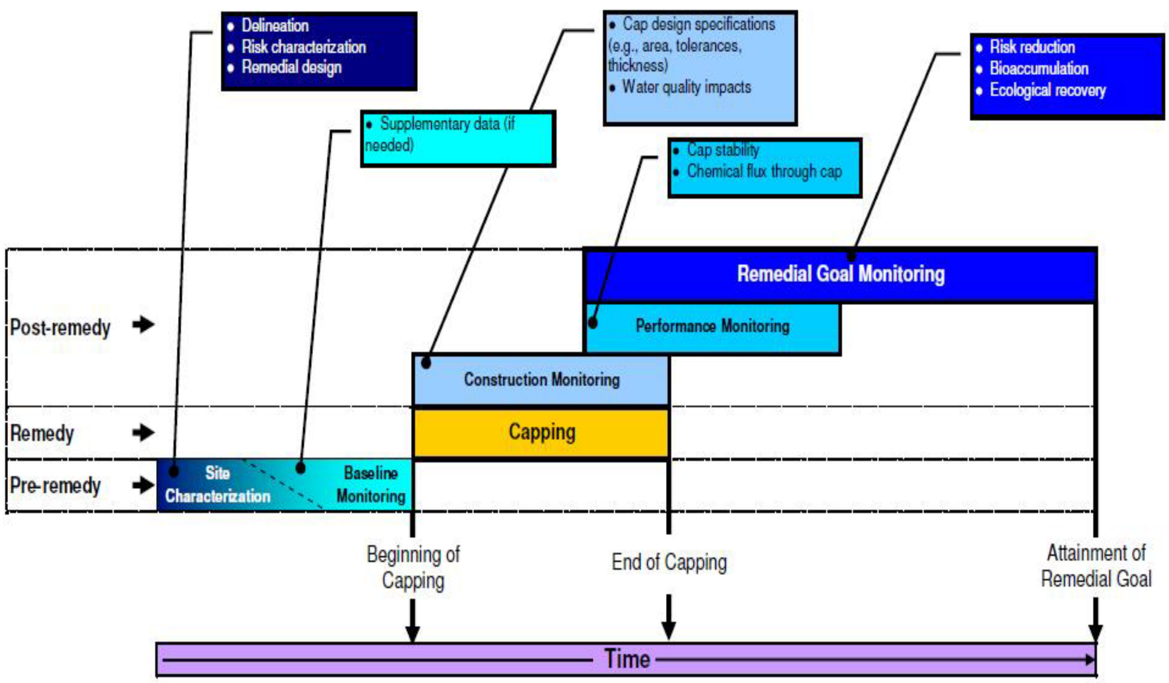
http://www.epa.gov/superfund/health/conmedia/sediment/pdfs/In_situ_AmendmentReportandAppendix_FinalApril2013.pdf

3.3.5 Monitoring

USEPA (USEPA 2005) states that a "monitoring program should be required as a part of any capping project design. The main objectives of monitoring for sediment cap is to ensure that the cap is placed as intended and that the cap is performing the basic functions (physical isolation, sediment stabilization and chemical isolation) as required to meet the remedial objectives. Specific items or processes that may be monitored include cap integrity, thickness, and consolidation, the need for cap replenishment, benthic recolonization, and chemical migration potential."

Sediment caps are located in dynamic environments, and are subject to forces that have the potential to undermine their integrity to a higher degree than do upland soil caps. A review of the literature has revealed that several types of monitoring are associated with sediment caps, namely construction, performance, and remedial goal monitoring. As with any remedial action, it is necessary to establish an appropriate baseline against which to measure the effectiveness of the remedy. The following figure illustrates a timeline of monitoring phases (construction, performance, remedial goal) relative to capping and pre-remediation activities, followed by a description of each monitoring phase (SPARWAR, Environ 2010).

Figure 3. Time line of monitoring phases



SPARWAR and Environ 2010 states: "Construction monitoring includes assessment of construction and operations activities, potential adverse conditions associated with remediation, and attainment of design criteria (i.e., in accordance with design specifications). ***Construction***

monitoring data are used to answer the question: Is the remedy constructed as designed? Construction monitoring occurs during active remediation, such as dredging or placement of a cap (Figure 3). Construction monitoring usually ends following completion of dredging or cap placement, culminating in the verification that design criteria were met." Monitoring of suspended sediment levels in the water column during cap placement may also be conducted or required to ensure compliance with State or Federal programs.

Example: Sediment bathymetry or sediment coring can be used to measure cap thickness during and after cap placement to ensure that the desired cap thickness (as identified in the design document) has been achieved.

SPARWAR and Environ 2010 states: "Performance monitoring addresses the remedy mechanism itself, such as sediment isolation (capping) and natural recovery processes (MNR). Performance monitoring is absent from dredging, as there is no ongoing remedy mechanism for risk reduction once construction activities are complete. ***Performance monitoring data are used to answer the question: Is the remedy mechanism performing as designed?*** Performance monitoring generally occurs after construction is complete. However, as the construction process slowly advances across the spatial extent of a site, performance monitoring can begin in areas where construction is complete while other areas remain under construction (Figure 3). Capping and natural recovery performance should be monitored over a broad range of physical, hydrological, and geochemical conditions over time in order to ensure that the cap continues to isolate sediments or that natural recovery processes continue to function (e.g., freshly-deposited sediments remain in place). A key focus is ensuring the physical, chemical, and ecological integrity of the remedy mechanism at the site. This is especially important following high energy disturbances at the site, such as storm events, in which the mechanism of the remedy can be damaged. For example, storm events can expose contaminated sediments that were capped or previously isolated via natural sedimentation."

Example: A capping design may include armoring to address potential erosion associated with storm events or ice flows. The integrity of the armoring could be evaluated (visually/grab samples) to ensure it remains at specifications (location, thickness) as specified in the design).

SPARWAR and Environ 2010 states: "Often referred to as "long-term monitoring", remedial goal monitoring provides an assessment of the extent to which the sediment remedy achieves RAOs that are the ultimate goals of sediment management—namely, the reduction of human health and ecological risks (USEPA 2005). ***Remedial goal monitoring data is used to answer the question: Is the remedy achieving risk reduction?*** Monitoring components may include direct measurements of risk reduction (e.g., biological chemical concentrations or biological effects) or indirect measurements of risk reduction (e.g., sediment, pore water, or surface water concentration reductions) with time."

Example: A sediment remedy may be implemented to meet the remedial action objective of reducing fish tissue levels suitable for consumption or returning water bodies to "swimmable" conditions. Monitoring associated with these remedial action objectives could include fish tissue sampling and surface water sampling, respectively.

In addition to the above monitoring phases, a monitoring plan should also take into account several considerations. The monitoring requirements should be clearly identified in the applicable documents (Remedial Investigation report (RIR) or Remedial Action report (RAR)). The monitoring program should be scheduled to coincide with times when the potential for damage is the greatest (e.g. highest and lowest water levels, major storms). Inspections should be spaced so if any damage or failure occurs it will not remain unnoticed for a prolonged period. Depending on construction details (e.g. profile thickness, nature of substrate, characteristics of armoring layer, site use (e.g. potential for boat traffic wake and, anchor damage) and site conditions (e.g. water velocity, wave base, sedimentation rate) inspections could be monthly, quarterly, semiannually or annually, depending on the likelihood that damage or failure may occur and the anticipated mode of failure. The monitoring plan will need to identify potential events (beyond the design capabilities of the cap) that could result in excessive wear or catastrophic failure and provide for appropriate inspection triggers.

Monitoring should verify that the thickness of the cap is maintained. Signs of failure such as slumping, scouring and channeling, anchor damage, excess bioturbation, excess deposition, and excess bed load movement—should be evaluated for during inspections. Periodic surveying of benchmarks should be used to verify cap integrity. Pore-water samples should be collected periodically to verify that treatment efficacy is maintained when an amended cap is used. As the treatment capacity of the reactive media is exhausted, an evaluation should be made as to whether and how the cap should be replaced or augmented.

Inspections may require the use of divers or specialized equipment. The development and use of checklists, as well as photographic and bathymetric documentation of conditions at the time of inspection, should be considered.

Maintenance should be expected to consist of repairs after periods of heavy scouring. Any repairs should be documented using photographs, and, if appropriate, surveying.

The findings of the periodic inspections (e.g. surveys, sampling) and any repair activities will be documented in the periodic reports required under the remediation permit.

Some useful references on sediment-cap monitoring are provided below:

Palermo, M.R., T. Fredette, and R.E. Randall. 1992. Monitoring Considerations for Capping. Technical Note DRP-5-07. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., June 1992. Available online: http://el.erdc.usace.army.mil/elpubs/pdf/drp5-07.pdf

SPARWAR - Space and Naval Warfare Systems Center Pacific, and Environ International Corporation. 2010. Long-Term Monitoring Strategies For Contaminated Sediment Management. Final Guidance Document, February 2010. Available online: http://israp.org/pdf/Navy_LTM_Guidance_FINAL_021110.pdf

USEPA Office of Solid Waste and Emergency Response. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012, OSWER 9355.0-85, December 2005. Available online: http://www.epa.gov/superfund/health/conmedia/sediment/pdfs/guidance.pdf

3.3.6 Institutional Controls and Permitting:

A sediment cap is similar to any other type of engineering control in that in order for it to remain protective, it must remain intact. Many of the contaminants (PCBs, metals, pesticides, dioxin, PAHs, etc.) that drive a sediment remedy are long-lived and degrade very slowly, if at all. The cap must be maintained for as long as the contaminants remain at levels of concern, and this can only be accomplished through monitoring.

The Department requires that upland caps (asphalt, concrete, soil, etc.) be addressed with a Soil Remedial Action Permit, and that a site-specific monitoring plan is developed as a condition of the permit. Additionally, the extent of the contamination and associated engineering control is recorded in a Deed Notice. The Soil Remedial Action Permit and Deed Notice are the administrative tools the Department uses to ensure that the engineering control (cap) is appropriately monitored and that the area is not disturbed in the future.

Given the dynamic nature of the aquatic environment, the need for monitoring (to ensure the cap remains protective) and a Deed Notice (to ensure these areas are not disturbed) is clearly evident. The intent is to mirror the requirements for an upland application. When the sediment contamination proposed to be capped is located within the property boundaries of a site (i.e. riparian rights establish lot and block parcels in a water body that are owned by an entity), then a Deed Notice may be established via N.J.A.C. 7:26C-7.2 (b) 1.

Additionally, if the contamination extends off-site onto the property owned by another entity that has established riparian rights, then a Deed Notice may also be established pursuant to N.J.A.C. 7:26C-7.2 (b) 1 *provided that the off-site property owner is willing to accept the Deed Notice*.

In many instances where sediment contamination is widespread, it is often located in off-site areas of streams and rivers that are owned by New Jersey and no deed for the property exists. In this scenario, documents shall be prepared in lieu of a Deed Notice pursuant to N.J.A.C. 7:26C-7.2 (b)2iii. In this scenario, the State of New Jersey must be willing to accept the equivalent of a Deed Notice.

When a sediment cap (engineering control) is being selected as a remedy to address the protection of ecological receptors, a Soil Remedial Action Permit must be obtained. The essential elements of the Soil Remedial Action Permit (monitoring and reporting schedule, financial assurance, permit obligations, etc.) apply for a sediment cap. Specific information on this issue can be found in the NJDEP's *Remedial Action Permits for Soils Guidance* document (NJDEP 2010)
http://www.nj.gov/dep/srp/guidance/srra/draft_rem_action_permit_guidance_soils.pdf

4 References

- **Introduction**

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NJDEP. 2013a. “Presumptive and Alternative Remedy Technical Guidance”, August 2013. Available online: http://www.state.nj.us/dep/srp/guidance/srra/presumptive_remedy_guidance.pdf

- **Factors to Consider**

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- **Class of Cap Types – Low-Permeability Cap**

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USEPA. 2013. "Use of Amendments for In Situ Remediation at Superfund Sediment Sites." OSWER Directive 9200.2-128FS. Available online: http://www.epa.gov/superfund/health/conmedia/sediment/pdfs/In_situ_AmendmentReportandAppendix_FinalApril2013.pdf

5 APPENDIX A: Containment

In remedial actions, the isolation of receptors from the effects of contaminants potentially occurs in all three dimensions. Capping primarily addresses the vertical migration of contamination. Integral to the success of a remediation is the prevention of horizontal contaminant migration. This technical guidance will presume that the horizontal pathway has been appropriately addressed. A brief discussion of methods to accomplish this is provided for investigator benefit and consideration.

Passive horizontal containment may be achieved by establishing a barrier in a direction down-gradient of an area of concern (AOC) or more typically by surrounding an AOC. The goal is to contain or redirect the movement of contaminated groundwater (concurrently isolating the contaminated material itself) in a lateral direction. These vertical cutoff walls usually extend from the surface into a low-permeability confining layer. An exception to this are hanging walls employed when the presence of contamination is limited to that floating on the water table as in the case of light non-aqueous phase liquids (LNAPL). Another passive variant is the placement of a vertical barrier only on the upgradient side of an AOC to prevent groundwater flow from reaching the AOC; however, this is a lesser-used strategy.

The most common passive horizontal containment systems are slurry walls, compacted clay barriers, grout curtains, and sheet-pile systems. While not impervious, the goal is to obtain a hydraulic conductivity of less than 10^{-6} centimeters per sec (cm/s).

Slurry walls (or trenches) generally start as a 2- to 4-foot-wide trench filled with a bentonite and water mixture and extends to a confining layer (usually no more than 50 to 100 feet deep). The bentonite mixture inhibits groundwater movement and maintains the trench configuration. The slurry also produces a low-permeability zone by filling the voids and walls of the trench. A soil and bentonite mixture is then prepared and poured carefully into the trench in a manner that does not mix with the slurry. This displaces the water-bentonite mixture and forms the slurry wall. Cement can be used as an additive to enhance the strength and load-bearing capacity. Grout-curtain systems are installed by injection or augering of particulate grouts (like bentonite slurries) or chemical grouts that involve a chemical base (e.g. sodium silicates), a catalyst, and water or another solvent. Augering usually employs a pattern of overlapping rows to create the final barrier.

Sheet-pile systems are constructed by driving interlocking steel sheets into a confining layer. Where increased impermeability is needed, the joints of the sheet piles can be sealed.

Active horizontal containment can be achieved through groundwater control. Groundwater extraction wells are the most common method of control and are frequently used in combination with a passive type barrier. The disadvantage is that remediation usually takes an extended period. Injection wells can be used in combination with extraction wells if the hydraulic conditions are not favorable and flow needs to be induced.

Downward containment can also be achieved with a barrier. In certain instances, an existing confining layer accomplishes this task. If contaminated material is to be placed in an area, geomembranes or other low-permeability material can be laid down to perform this function. Grouting techniques such as permeation grouting and jet grouting can also be used to create a confining layer below contaminated material that is already present. These techniques present installation challenges and are more favored where the soils are coarse-grained.

6 APPENDIX B: Examples

<u>Low-Permeability Cap – Solid Waste/RCRA Subtitle D Cap</u>

The Ottilio Landfill is located in the city of Newark. Surface and subsurface soils within the landfilled area were identified as the primary contaminant sources. These soils were found to be contaminated with volatile and semi-volatile organic, pesticide, metal, and petroleum compounds. The primary contaminant migration pathways were groundwater, surface water runoff, and erosion. Airborne particulates and vapors were also found to be sources.

Based on a remedial investigation and examination of cleanup alternatives, the Department instituted the following measures in 2003:

- Capping of the site with a low-permeability, geomembrane cap.
- Dredging of sediments from an adjacent ditch with placement under the cap.
- Fencing of the site.
- Long-term groundwater monitoring.
- Classification Exception Area and Well Restriction Area for groundwater.
- Passive landfill gas collection with venting to the atmosphere.

The low-permeability cap at the site consisted of the following layers (from top to bottom):

- Upper-cap layers to protect the geomembrane, minimize erosion, and manage stormwater.
- 6-inch vegetated topsoil or concrete revetment matting
- 12-inch soil (NJDOT Type I-13) with no particles greater than 3/8 of an inch in diameter to protect the geomembrane.
- Composite geonet consisting of a polyethylene net with geotextile facing to drain infiltrating water off the top of the geomembrane.

Low permeability layer to isolate waste from the environment

- 40-mil Linear Low Density Polyethylene (LLDPE) geomembrane.
- Cushion and gas-collection layer to keep waste from contacting the geomembrane and collect gas for passive venting to the air through carbon filters.

- 6-inches of soil (NJDOT Type I-13) with no particles greater than 3/8 of an inch in diameter.

The figure below shows the cap cross section.

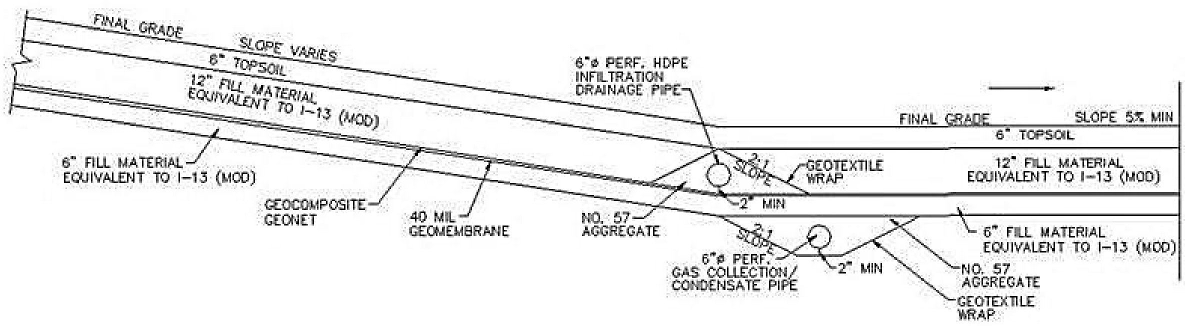


Figure 1. Typical section of landfill cap (Handex, 2005)

References:

NJDEP. 1996. Final Decision Document, Ottilio Landfill Site. Bureau of Site Management, Trenton, N.J.

Handex. 2005. As-Built Drawings for Ottilio Landfill Cap Remedial Construction. NJDEP Central File No. 1963 BIDC-07. Trenton, N.J.

Low-Permeability Cap –RCRA Subtitle C/Hazardous Waste Cap

The GEMS Landfill is located in the Gloucester Township. Groundwater, surface water, soils and sediments at the site are contaminated with organic compounds, heavy metals, and pesticides. Airborne particulates and vapors were a concern.

Based on a remedial investigation and feasibility study, a federal Record of Decision was signed in 1985 prescribing the following measures:

- Capping of the site with a low-permeability cap.
- Dredging of sediments with placement under the cap.
- Installing an active gas collection and flaring system.
- Construction of a groundwater, /leachate, and surface water treatment system.
- Connection of potentially affected homes to the public water supply system.
- Fencing of the site.
- Long-term groundwater monitoring.
- Classification Exception Area and Well Restriction Area for groundwater.

The profile of the cap varied depending on whether it was on the top of the landfill or on the steep side slopes. To provide stability against the cap sliding, geomembrane and soil bedding layers were not included on the side slopes. Cap layers from top to bottom were:

- 6 inches of vegetated topsoil
- 18 inches of on-site soil
- geotextile filter fabric
- 12 inches of high-permeability soil for drainage
- 40-mil High Density Polyethylene (HDPE) geomembrane – not used on side slopes
- 24 inches of low-permeability clay
- 6 inches of on-site soil bedding layer – not used on side slopes

The figures below shows the two types of cap cross sections.

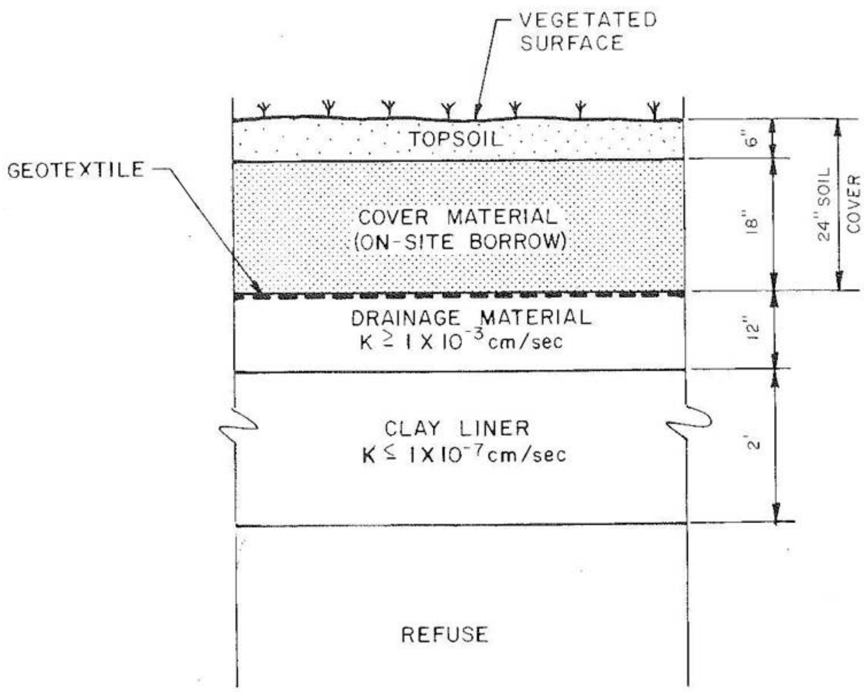


Figure 1a – Typical Section of Cap on Side Slopes (Cannonie, 1993)

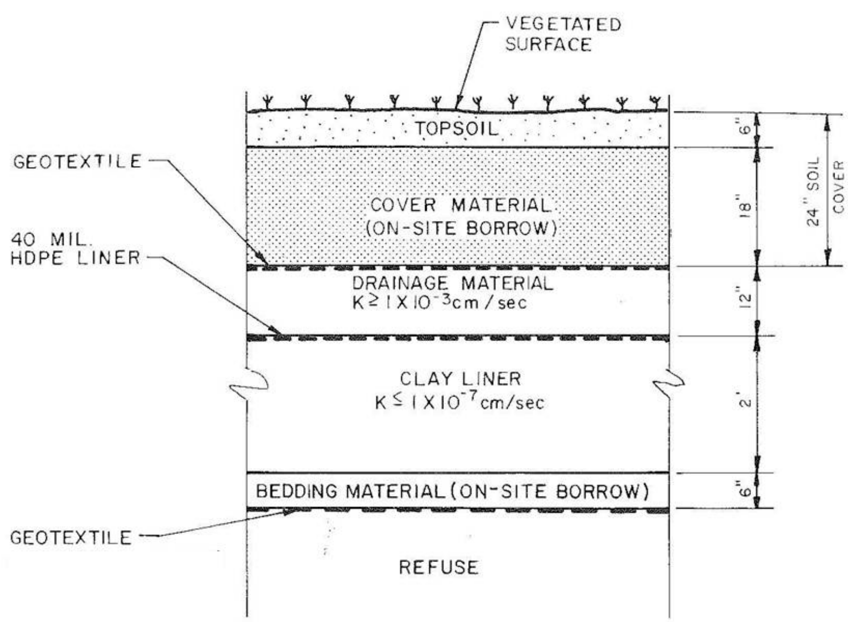


Figure 1b – Typical Section of Cap on Top of Landfill (Cannonie, 1993)

References:

USEPA. 2012. NPL Fact Sheet, Gems Landfill, New Jersey, EPA ID#: NJD980529192. http://www.epa.gov/region02/superfund/npl/0200627c.htm

Cannonie Environmental Services. 1993. GEMS Landfill Construction Record Drawings. NJDEP Central File Record No. D1-0103-10. Trenton, N.J.

Permeable Cap - Dunka Mine, Minnesota

The Dunka Mine is a large, open-pit taconite mine in northern Minnesota. Sulfide-containing waste material from the mine was stockpiled along the eastern edge of the mine and adjacent to wetlands. Based on the availability of borrow material and the characteristics of the spoils for capping, a soil permeable cap was selected for portions of the landfill. Subsequently, leachate generated from the landfill exceeded water quality standards. A treatment wetland was constructed to address the contaminated leachate.

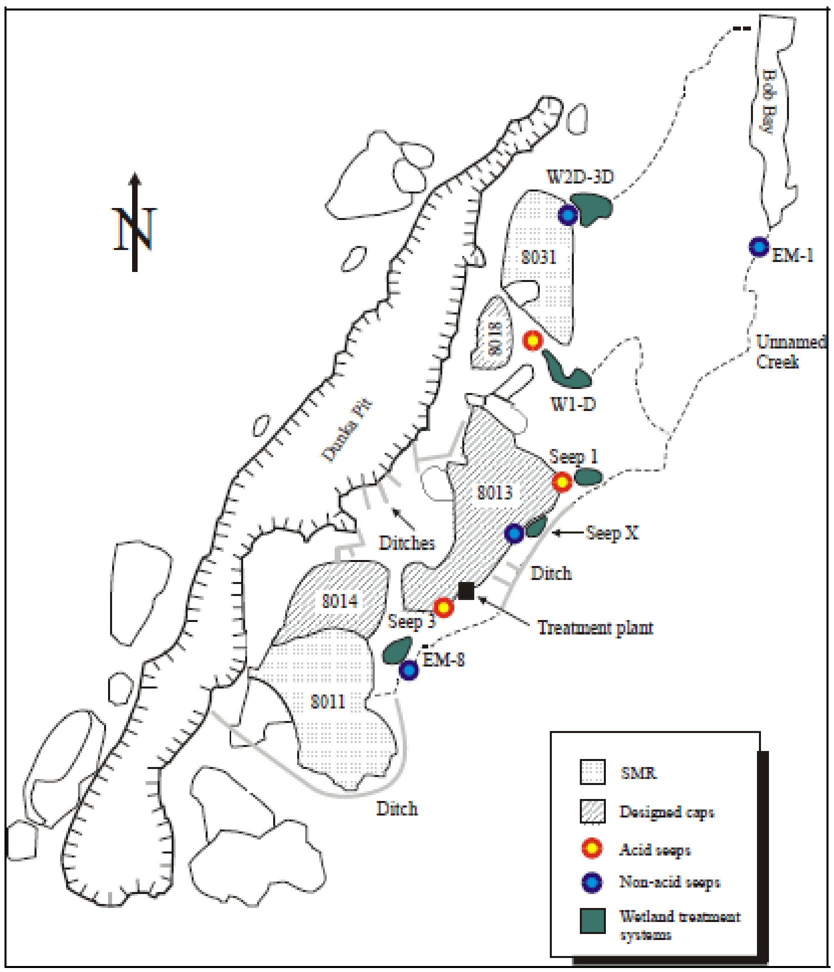


Figure 7. Area map of the Dunka Mine, near Babbitt, MN.

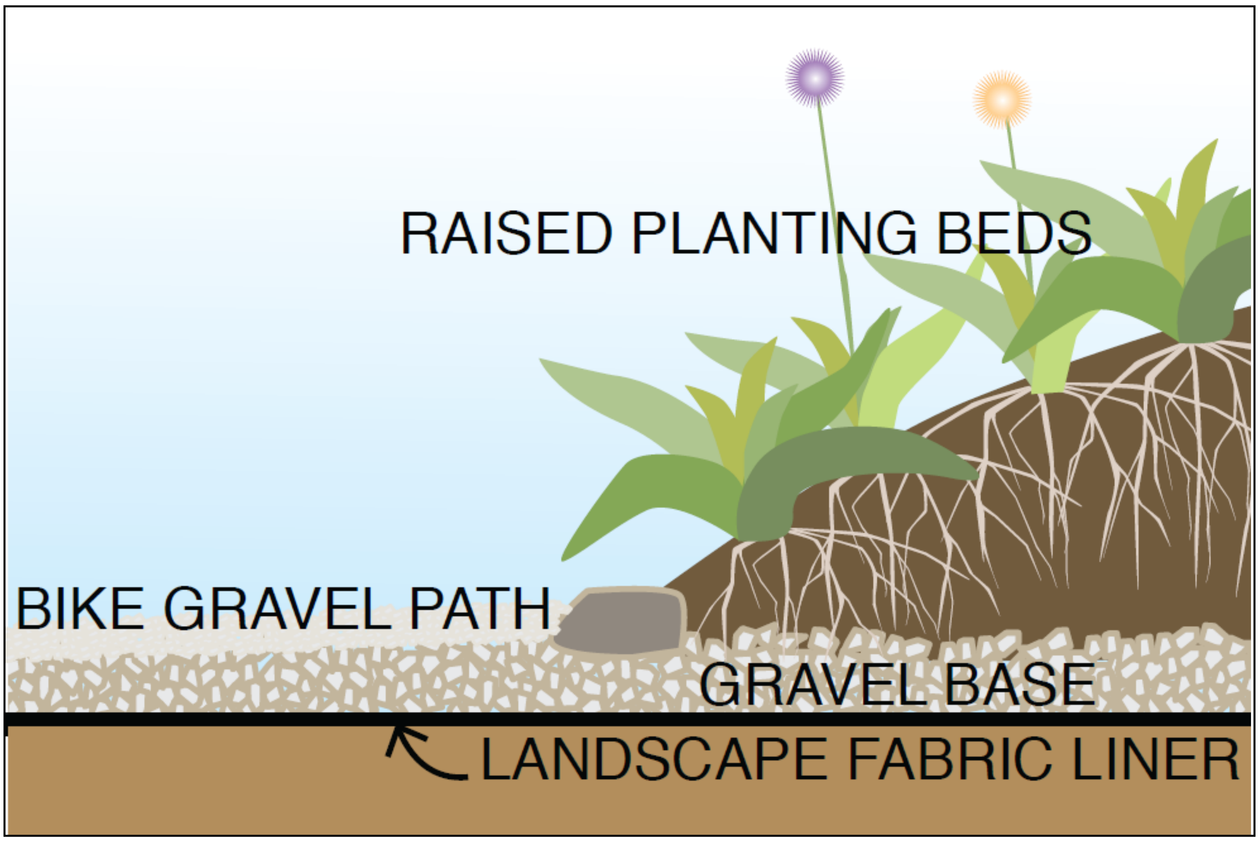
This case demonstrates the types of conditions that should be considered during design, and the ramifications of making certain assumptions. This case study also demonstrates how a particular design can be combined with other remedy components to achieve compliance with the applicable standards.

References

http://www.itrcweb.org/miningwaste-guidance/cs_dunka_mine.htm

Permeable Cap – Community Garden, Chicago, Illinois

The Field Museum of Chicago created the Chicago Community Climate Action Toolkit to develop and carry out local-climate action projects. One of the projects involved the creation of an urban garden in the Pilsen neighborhood of the city. The toolkit discusses options and selection considerations based on site setting and proposed land use. The selected approach was the construction of a permeable cap over the contaminated soils, separated by permeable fabric. This configuration protects the public from direct contact with the underlying contaminated soils, while at the same time it allows the development of a native garden where children can play and families can learn about climate change.



This example illustrates green and sustainable applications of the permeable-cap technology and how concerns such as community needs and community acceptance factor into cap design.

References:

http://climatechicago.fieldmuseum.org/sites/default/files/contaminated%20soil.pdf

Harrison Avenue Landfill – Permeable Capping Example

The Harrison Avenue Landfill is an 85-acre site located within the city of Camden, N.J., near the confluence of the Cooper and Delaware rivers (Figure 1). The site acted as a municipal solid waste (MSW) landfill from approximately 1952 to 1971. Impacts at the site are primarily related to the imported MSW (leachate, methane and landfill gas, uncapped MSW); however, some groundwater contamination related to the dumping of industrial waste was identified during the site remedial investigation. Site remediation and landfill closure are currently underway at part of the site, which is being redeveloped as a community center. Plans are being developed to remediate and close the remainder of the site to allow for public use.

Figure 1. Aerial Photograph of the Site Before Remediation

A permeable cap was selected as part of the remedy during the remedial alternative screening and was included in the Remedial Action Work Plan (RAWP). The permeable cap was selected to allow for continued natural remediation and biodegradation of shallow groundwater and leachate by allowing fresh oxygenated water to percolate through the site. The permeable cap was also selected to allow for natural passive venting of landfill gas to prevent the off-site migration of methane (after cessation of active filling). A geogrid layer was incorporated into the cap to improve the geotechnical stability of the cap, and a geotextile layer was incorporated as a demarcation layer and to prevent migration of the capping material into the municipal solid waste. A schematic of the cap is provided below in Figure 2.

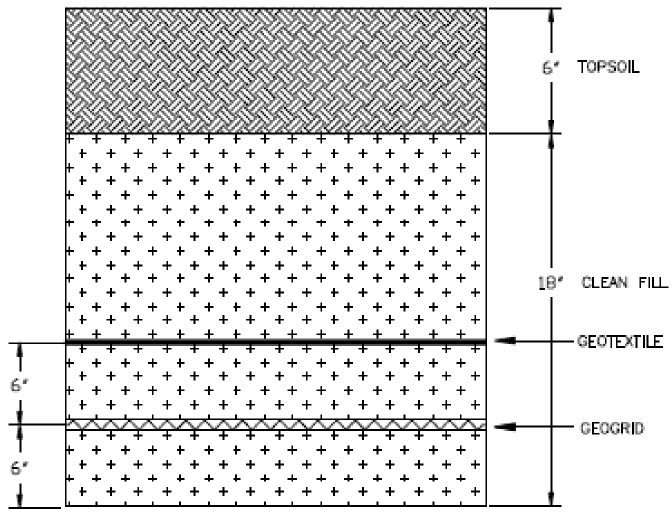


Figure 2. Schematic of Cap Design

Capping materials were mined from the Palmyra Confined Disposal Facility (CDF) in Palmyra, N.J. The CDF was used to store material dredged from the Delaware River as part of routine navigational dredging conducted by the US Army Corps of Engineers. A Department-approved sampling program was conducted at the CDF to determine the suitability of using this material to construct the cap. Chemical and geotechnical samples collected from the dredge material indicated that the soils could be used at the site. A beneficial-use determination was approved, and a licensing agreement was approved by the Bureau of Tidelands. The use of the dredge material greatly reduced the cost of importing clean fill and opened capacity of the CDF to receive additional dredge material in the future.

Sediment Capping Case Studies:

Case studies provide useful insight into the practical application, design, implementation, and performance of sediment-capping remedies. Provided below are links and other references to several documents that contain case studies where a sediment cap was selected as a remedial action.

1)**Use of Amendments for In Situ Remediation at Superfund Sediment Sites** OSWER Directive 9200.2-128FS, April 2013

http://www.epa.gov/superfund/health/conmedia/sediment/pdfs/In_situ_AmendmentReportandAppendix_FinalApril2013.pdf

Chapter 7 of this document includes two case studies where amended caps were used:

Spokane River, Upriver Dam PCBs Sediment Site, Spokane, Washington

An amended cap using coal as the carbonaceous amendment was constructed to address 3.5 acres of PCB-contaminated sediments. The sediment-capping remedy was implemented to address the consumption of PCB-contaminated fish. The cap design consisted of 4 inches of coal covering the contaminated sediments, followed by 6 inches of sand and 3 inches of gravel. Approximately 200 tons of coal was used. It was determined that a long-reach excavator releasing the coal above the water surface yielded the most uniform distribution. Piston core sampling and bathymetric surveys were conducted to ensure that the cap design specifications were achieved. Post-construction monitoring included bathymetric surveys, collection of sediment cores and surficial sediment samples, and visual observations. Post-remedy results indicate a 72 to 94% reduction in PCB concentrations in benthic worms 1 year after construction and a 63 to 99% reduction after three years.

Sediment Site Characteristics (USEPA, 2013)

- COC: PCBs
- Amendment: Coal
- Placement Method: A long reach excavator released the cap amendments above the water surface and allowed them to settle through the water column.
- Design: 4 inches of coal covering the contaminated sediments, 6 inches of sand over the coal, and 3 inches of gravel over the sand.
- Construction Complete: Fall 2006
- Cost: $1,578,000 (estimated in the draft Clean-up Action Plan for the entire remedy)
- Results: By the fall of 2008, consolidation and sediment deposition had occurred. Total PCBs were below detection limits in the sand and coal layers of the cap, indicating that the contaminated sediments were effectively isolated by the cap.

McCormick & Baxter Former Creosoting Company Superfund Site, Portland, Oregon

This site is located on the Willamette River adjacent to a facility where wood treatment operations were conducted between 1944 and 1991. The primary contaminants of concern included PAHs, creosote, diesel, pentachlorophenol, and heavy metals. Direct contact and ingestion of contaminated media are the main drivers of risk at the site.

Sediment Site Characteristics (USEPA, 2013):

- COC: PAHs, creosote, and NAPL
- Amendment: Organoclay Reactive Core Mat along the beach head and bulk Organoclay over the NAPL hotspots.
- Placement Method: The reactive core mat was deployed using a barge and crane, while the bulk Organoclay was placed from shore using a backhoe.
- Design: 1 foot of sand above the contaminated sediments, 1 foot of Organoclay over the sand, 4 inches of gravel over the Organoclay, and 10 inches of rock armor over the gravel.
- Construction Complete: Bulk placement – 2004, reactive core mat placement – 2005.
- Cost: The total cost is not available. The reactive core mat cost was $2 per square foot.
- Results: Monitoring in 2006 indicated that the Organoclay had similar sorptive capacity as fresh Organoclay. No significant signs of NAPL migration and no decrease in permeability were observed. Bubble migration was observed but no NAPL was associated with the gas bubbles.

The sediment remedy at this site consists of (1) 23 acres of a 2- to 5-foot-thick sand cap with armoring, including 600 tons of bulk granular Organoclay™ placed over the active creosote seep areas, and (2) 25,000 square feet (0.6 acre) of Organoclay™ reactive core mat placed over near-shore areas with ebullition-induced creosote sheens. The bulk Organoclay™ was placed in 2004, covering 20,000 square feet (0.5 acre), and the Organoclay™ mats were deployed in 2005 to cover three areas of the sediment cap where ebullition-induced sheen was observed.

The above case studies, as well as links to more detailed information, can be found at the following website:

http://www.clu-in.net/download/contaminantfocus/sediments/In_situ_AmendmentReportandAppendix_FinalApril2013.pdf

2) Steel Creek Savannah River Site, Aiken, South Carolina

A selected set of active capping treatment technologies (apatite and sand, biopolymer and sand, organoclay and sand) were used as a field demonstration at the Savannah River Site, Aiken, S.C (Knox et al undated). This demonstration has provided useful information on the effects of sequestering agents on metal immobilization, bioavailability, toxicity, and resistance to mechanical disturbance.

There were eight plots with four treatments:

- two controls consisting of uncapped sediments
- two caps composed of apatite and sand
- two caps composed of a layer of biopolymer/sand slurry over a layer of apatite and sand
- two caps composed of a top layer of biopolymer/sand slurry, a middle layer of apatite and sand, and a bottom layer of organoclay and sand.

Post-construction monitoring conducted one year after placement was designed to evaluate contaminant immobilization, amendment impact on the benthic organisms, and cap resistance to erosion. Additionally, pore-water samples were collected from untreated sediment outside of each cap and from sediment located beneath each cap at 12 months to evaluate the efficiency of amendment sequestrations.

Additional information on this study can be found here:

Knox et al, undated. In Situ Remediation of Contaminated Sediments – Active Capping Technology. Savannah River Nuclear Solutions, LLC

http://www.clu-in.net/download/contaminantfocus/sediments/Sed-SRNL-MS-2010-00171.pdf

3) Anacostia River Innovative Capping Demonstration Project:

The following abstract summarizes the features of this capping project (Reible, 2006):
An active capping demonstration project in Washington, D.C., is testing the ability to place sequestering agents on contaminated sediments using conventional equipment and evaluating their subsequent effectiveness relative to conventional passive sand sediment caps. Selected active capping materials include:

- AquaBlokTM, a clay material for permeability control;
- apatite, a phosphate mineral for metals control;
- coke, an organic sequestration agent; and
- sand for a control cap. All of the materials, except coke, were placed in 8,000-foot test plots by a conventional clamshell method during March and April 2004. Coke was placed as a 1.25-centimeter layer in a laminated mat because of concerns related to settling of the material. Post-cap sampling and analysis were conducted during the first, sixth, and 18 months after placement. Although post-cap sampling is expected to continue for at least an additional 24 months, this article summarizes the results of the demonstration project and postcap sampling efforts up to 18 months. Conventional clamshell placement was found to be effective for placing relatively thin (6-inch) layers of active material. The viability of placing high-value or difficult-to-place material in a controlled manner was successfully demonstrated with the laminated mat. Post-cap monitoring indicates that all cap materials effectively isolated contaminants, but it is not yet possible to differentiate between conventional sand and active-cap layer performance. Monitoring of the permeability control layer indicated effective reductions in groundwater seepage rates through the cap but also showed the potential for gas accumulation and irregular release. All of the cap materials show deposition of new contaminated sediment onto the surface of the caps, illustrating the importance of source control in maintaining sediment quality.

Reible, D., D. Lampert, D. Constant, R.D. Mutch Jr., and Y. Zhu. "Active capping demonstration in the Anacostia River, Washington, DC" Remediation Journal 17(1):39-53(2006)

Additional information on the Anacostia Capping demonstration project can be found at the links provided below:

- **Anacostia Active Capping Demonstration Status**
  Reible, D. 31 slides, NATO CCMS-Ljubljana, Slovenia , June 19, 2007
  http://www.clu-in.net/slovenia/download/Sediment_Remediation/Reible.pdf

- **Active Capping Demonstration in the Anacostia River, Washington, D.C.**
  Reible, D., D. Lampert, D. Constant, R.D. Mutch Jr., and Y. Zhu.
  Remediation Journal 17(1):39-53(2006)
  http://onlinelibrary.wiley.com/doi/10.1002/rem.20111/abstract

- **<u>Development and Placement of a Sorbent-amended Thin Layer Sediment Cap in the Anacostia River</u>**
  McDonough, Kathleen M., Paul Murphy, Jim Olsta, Yuewei Zhu, Danny Reible, and Gregory V. Lowry
  International Journal of Soil and Sediment Contamination, 24 pp, 2006
  http://www.clu-in.net/download/contaminantfocus/sediments/Sed-Cap-Place_inpress.pdf

- **<u>Demonstration of the Aquablok® Sediment Capping Technology: Innovative Technology Evaluation Report</u>**
  EPA 540-R-07-008, 145 pp, 2007
  http://www.epa.gov/nrmrl/lrpcd/site/reports/540r07008.html

7 APPENDIX C: Cost and Discount Rate

Discount Rate

Remediation projects using an engineering control as part of the remedy require the establishment of a Financial Assurance (FA), to ensure that funding is in place to cover the project throughout its life span. The FA should account for Operation and Maintenance (O&M) costs, periodic costs and one-time costs the project is anticipated to encounter through its life span. In developing these costs, the Present Value of the project should be considered to determine the amount of money required today to account for all of the anticipated project expenditures in the future. The present value of a project is based on a detailed cost estimate of anticipated project costs, and several other assumptions including the assumed life span and a discount factor.

The effect of a discount factor on a present value analysis can be significant for projects with a long duration, resulting in a decrease in the amount of money required today to fulfill future obligations. The present value concept accounts for the time value of money, in that an invested dollar today will have more buying power in the future. The process assumes that money invested today will grow at a pace greater than inflation, and the interest earned on the investment can be used to offset a portion of the future costs. **Thus, the present value can be defined as the amount of money invested in year zero to cover all of the anticipated project costs, with an assumed growth equal to the discount factor.** The attached example table below provides an example of a present value calculation for a project. The unadjusted project costs for 30years - add up to nearly $578,000, while the present value is equal to nearly $359,000. Using the present value in this example decreases the amount needed in the FA by $219,000, or approximately 38%, accounting for a 3% discount factor.

The EPA document: A Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA 2000), provides a detailed and comprehensive explanation of the present value analysis, and presents an outline for determining a project's present value. The steps described in the EPA document are as follows:

- Determine the Period of Analysis
- Determine the Annual Cash Flows
- Select a Discount Rate
- Calculate the Present Value

Most remediation projects assume a life span of 30 years to conduct the present-value analysis. Sites that use an engineering control as part of the remedial action must maintain financial assurance for the period that the engineering control remains in place; in most situations, this will go beyond a 30-year period. The Department uses a 30-year planning horizon for the calculation of the FA. Past EPA guidance had recommended the use of 30 years for all projects; however, this period may not always be appropriate. If a project is anticipated to continue for more than

30 years (cap inspections and maintenance to continue for longer), a longer duration may be warranted. Because a longer duration may be warranted, a calculation of FA for a timeframe longer than 30 years is an option.

The annual cash flows should include routine O&M costs, such as inspections and annual repairs and reporting, periodic repairs that may occur at a lower frequency, and any anticipated one-time expenditures. Periodic costs could consist of items such as replacing an area of a cap, repaving an area of an asphalt cap, replanting on a vegetated cap, or pest-control costs to deter burrowing animals. One-time costs may include extensive repaving events of an asphalt cap. These costs should be tabulated for each year in sequential order.

An appropriate discount rate should be selected to determine the potential growth of an investment today. The EPA required the use of a 7% discount rate for a Superfund project not located at federal facilities.

The present value can be calculated after the cash flow has been finalized and a discount rate has been selected. The present value is calculated for each year of the project duration and the individual annual costs are added together to determine the project's present value. The formula for calculating the present value for any year is presented below (EPA 2000):

$$PV = \frac{1}{(1+i)^t} \; x_t$$

Where:

PV – Present Value
i – Discount Factor
t – Year
x_t – Annual Cash Flow for year t

Simplified methods are available when the cash flow is constant for each year (e.g. the same amount of money is spent each year). The following table provides an example of a present value calculation using a Microsoft Excel spreadsheet.

It is recommended that the LSRP document the factors and process used to arrive at the selected discount rate and project duration.

NET PRESENT VALUE TEMPLATE
NJDEP CAPPING GUIDANCE DOCUMENT

NOTE: Example is provided for reference, and many not be complete for every site. Inspection, permitting and reporting fees and cap reapir costs should be determined by the LSRP. Additional columns can be added to include further cost items.

YEAR	CAPITAL COST	OM&M COSTS (W/CONTINGENCY)				Total Annual Cost (Not Adjusted for Inflation)	PRESENT VALUE
		Annual OM&M		Biennial Costs	Periodic OM&M		
		Annual cap Inspection	Annual Permit Fee	Biennial Report	Cap Repairs		
0		$ -	$ -	$	-		$ -
1		$ 500	$ 660			$ 1,160	$1,126
2		$ 500	$ 660	$ 4,200		$ 5,360	$5,052
3		$ 500	$ 660			$ 1,160	$1,062
4		$ 500	$ 660	$ 4,200		$ 5,360	$4,762
5		$ 500	$ 660		$ 80,000	$ 81,160	$70,009
6		$ 500	$ 660	$ [illegible]		$ 5,360	$4,489
7		$ 500	$ 660			$ 1,160	$943
8		$ 500	$ 660	$ 4,200		5,360	$4,231
9		$ 500	$ 660			1,160	$889
10		$ 500	$ 660	$ 4,200	$ [illegible]	85,360	$63,516
11		$ 500	$ 660			1,160	$838
12		$ 500	$ 660	$ 4,200		5,360	$3,759
13		$ 500	$ 660			$ 1,160	$790
14		$ 500	$ 660	$ 4,200		[illegible],360	$3,544
15		$ 500	$ 660		$ [illegible]	[illegible],160	$52,094
16		$ 500	$ 660	$ 4,200		[illegible],360	$3,340
17		$ 500	$ 660			[illegible],160	$702
18		$ 500	$ 660	$ 4,200		$ 5,360	$3,148
19		$ 500	$ 660			$ [illegible]	$662
20		$ 500	$ 660	$ 4,200	$ 80,000	$ [illegible]	$47,262
21		$ 500	$ 660			$ [illegible]	$624
22		$ 500	$ 660	$ 4,200		$ [illegible]	$2,797
23		$ 500	$ 660			$ [illegible]	$588
24		$ 500	$ 660	$ [illegible]		$ [illegible]	$2,637
25		$ 500	$ 660		80,000	$ [illegible]	$38,762
26		$ 500	$ 660	$ [illegible]		$ [illegible]	$2,485
27		$ 500	$ 660			$ 1,160	$522
28		$ 500	$ 660	$ 4,200		$ 5,360	$2,343
29		$ 500	$ 660			$ 1,160	$492
30		$ 500	$ 660	$ 4,200	$ 80,000	$ 85,360	$35,167
					Total Annual Costs:	$ 577,800	
					Total Discounted O&M Costs:		$358,636

3.0% Discount Factor

Discount Factor: Cell C45

Formula:
=sum(c13:f13)

Formula:
=sum(c14:f14)

Formula:
=PV($C$45,A13,0,-G13)
or:
=1/((1+$C$45)^A13)*G13

Formula:
=PV($C$45,A15,0,-G15)
or:
=1/((1+$C$45)^A15)*G15

Sum of unadjusted costs above. Represents payments made every year to cover costs.

Sum of adjusted costs above. Accounts for the growth of money, and represents the principal investment required in Year 0 to cover all costs with a growth equal to the discount factor in cell C45.

References:

USEPA. 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002

8 APPENDIX D: Biennial Certifications and Permit Fees

Costs for Biennial Certification: Pursuant to N.J.A.C. 7:26C-7.7, the Person Responsible for Conducting the Remediation (i.e. Remedial Action Permittee) must submit to the Department a biennial certification of the continued protectiveness of a remedial action that includes an engineering control. (See Remedial Action Protectiveness / Biennial Certification Form - Soil: http://www.nj.gov/dep/srp/srra/forms/rem_action_prot_cert_soil.pdf)

If there is more than one remedial action permit for a site, then a separate biennial certification form must be submitted for each remedial action permit. The "Instructions" document for the above Form indicates: "Biennial Certification submittals are covered by the Annual Permit Fee, permittees are mailed invoices annually on the anniversary date when the permit became effective." (See "Fees" section):

http://www.nj.gov/dep/srp/srra/forms/rem_action_prot_cert_soil.pdf

9 APPENDIX E: Remediation Funding Source and Financial Assurance

Parties obligated to post a Remediation Funding Source (RFS) or Financial Assurance (FA) must comply with the requirements detailed in subchapter N.J.A.C. 7:26C-5. The establishment of a RFS is required with submission of a remediation certification, signing of an administrative consent order, as directed in an Order or Court Order or upon the approval of a remedial action work plan for facilities subject to Industrial Site Remediation Act (ISRA). The amount of the RFS must reflect the estimated cost of the remediation, including the Department's fees and oversight costs, plus a FA equal to the estimated cost to operate, maintain and inspect engineering controls as part of a remedial action permit as provided in N.J.A.C. 7:26C-7.5. When applicable, parties must pay a surcharge on the amount of RFS posted. Upon issuance of the final Remedial Action Outcome (RAO), and after the remedial action permit application is submitted to the Department with evidence that the FA has been established for such costs, the amount of the RFS may be reduced to the amount of the FA. The amount of the FA must reflect the estimated cost to operate, maintain and inspect engineering controls as part of a remedial action permit as provided in N.J.A.C. 7:26C- 5.3 & 7.10.

The method to calculate the amount of the FA is the Net Present Value calculation. To calculate the amount of the assurance that needs to be posted, the annual outgoing flows of cash must be scheduled. Additional guidance on Net Present Value (NPV) and its calculation are in Appendix C.

10 APPENDIX F: Cap Cost Information and Design Specification Examples

Cost Estimates for Various Cap Types

Cap Type	Layer	Thickness (in)	Unit	Cost	Cost ($/acre)
Soil	Seed/Fertilize/Mulch	-	$1.60	syd [1]	$7,744
	Topsoil	6	$30.00	cyd [1]	$24,200
	Common Fill (I-13)	18	$26.00	cyd [1]	$62,919
				Total	$94,863
Clay	Seed/Fertilize/Mulch	-	$1.60	syd [1]	$7,744
	Topsoil	6	$30.00	cyd [1]	$24,200
	Common Fill (I-13)	18	$26.00	cyd [1]	$62,919
	Drainage Net	Varies	$10.00	syd [2]	$48,400
	Clay	12	$52.00	cyd [3]	$83,893
	Sand Cushion	6	$26.00	cyd [1]	$20,973
				Total	$248,129
Geomembrane	Seed/Fertilize/Mulch	-	$1.60	syd [1]	$7,744
	Topsoil	6	$30.00	cyd [1]	$24,200
	Common Fill (I-13)	12	$26.00	cyd [1]	$41,946
	Geocomposite Drainage Net	Varies	$10.00	syd [2]	$48,400
	Geomembrane	40 mil	$7.50	syd [2]	$36,300
	Sand Cushion	6	$26.00	cyd [1]	$20,973
				Total	$179,563
Hazardous Waste	Seed/Fertilize/Mulch	-	$1.60	cyd [1]	$7,744
	Topsoil	6	$30.00	cyd [1]	$24,200
	Common Fill (I-13)	18	$26.00	cyd [1]	$62,919
	Drainage Net	Varies	$10.40	syd [2]	$50,336
	Geomembrane	40 mil	$7.50	syd [2]	$36,300
	Clay	24	$52.00	cyd [3]	$167,785
	Sand Cushion	6	$26.00	cyd [1]	$20,973
				Total	$370,257
Asphalt Pavement	Hot Mix Asphalt Surface Course	2	$9.30	syd [4]	$45,012
	Hot Mix Asphalt Base Course	4	$7.80	syd [4]	$37,752
	Prime Coat	-	$8.00	syd [4]	$38,720
	Dense Graded Aggregate Base	4	$22.00	cyd [5]	$11,831
	Sand Subbase	12	$26.00	cyd [1]	$41,946
				Total	$175,260
Evapotranspirative	Seed/Fertilize/Mulch	-	$1.60	cyd [1]	$7,744
	Topsoil	6	$30.00	cyd [1]	$24,200
	Common Fill - Water Storage Layer	54	$26.00	cyd [1]	$188,758
				Total	$220,702

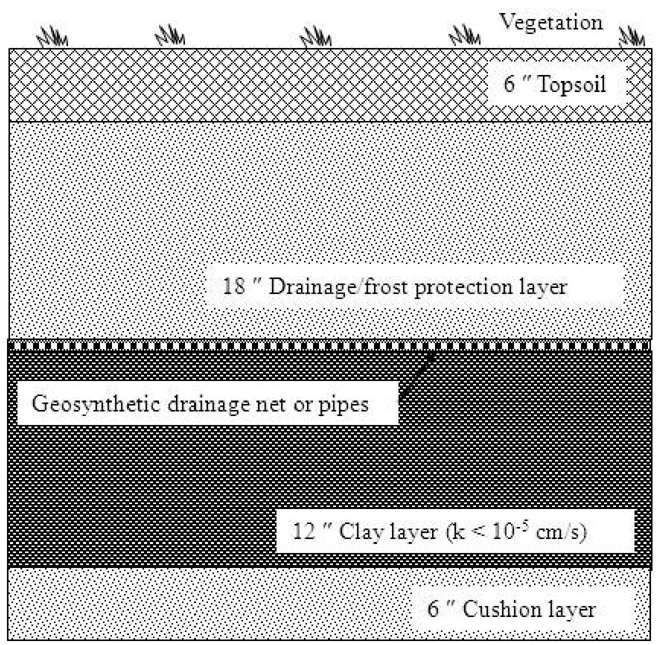
Notes:
- Costs do not include gas- or leachate-control systems.
- Costs for soil layer assume material is purchased from an off-site supplier.
- Costs for stormwater and soil-erosion controls not included.
- Unit costs include transportation, placement, and testing.

References:

[1] NJDEP. 2009. MSLA 1D Landfill Site Improvements Project Bid Prices. IFB No. 10-X-20957. Bureau of Site Management, Trenton, N.J.
[2] NJDEP. 2013. Engineer's Cost Estimate, MSLA 1D Landfill Capping Project. Bureau of Site Management, Trenton, NJ. and Duffy, D. P. 2005. “Landfill Economics Part III: Closing Up Shop”. MSW Management Mag. Sept–Oct. 5 pgs.
[3] Maxey, R. 2007. “Cost Estimating for Landfill Design”. ASTSWMO Meeting. Portland. http://www.astswmo.org/Files/Meetings/2007/2007-Solid_Waste_Conference/BobMaxey.pdf
$32.90/cyd delivered; balance of cost is placement and testing.
[4] NJDOT. 2012. Bid Price Report 2012. http://www.state.nj.us/transportation/business/trnsport/estimation.shtm
[5] Kearny Municipal Utilities Authority. 2008. Contract 2006-2 Bergen Avenue Pump Station and Harrison Avenue Force Main Project, Canvass of Bids. Available from NJDEP, Bureau of Site Management, Trenton, N.J.

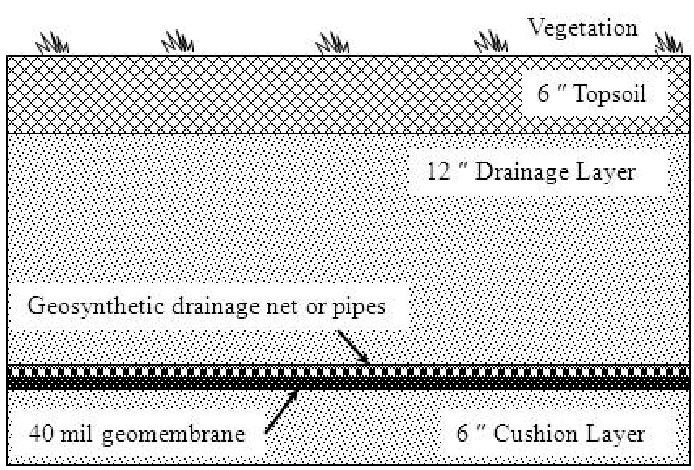
Typical Sections – Low Permeability Caps

Clay Cap



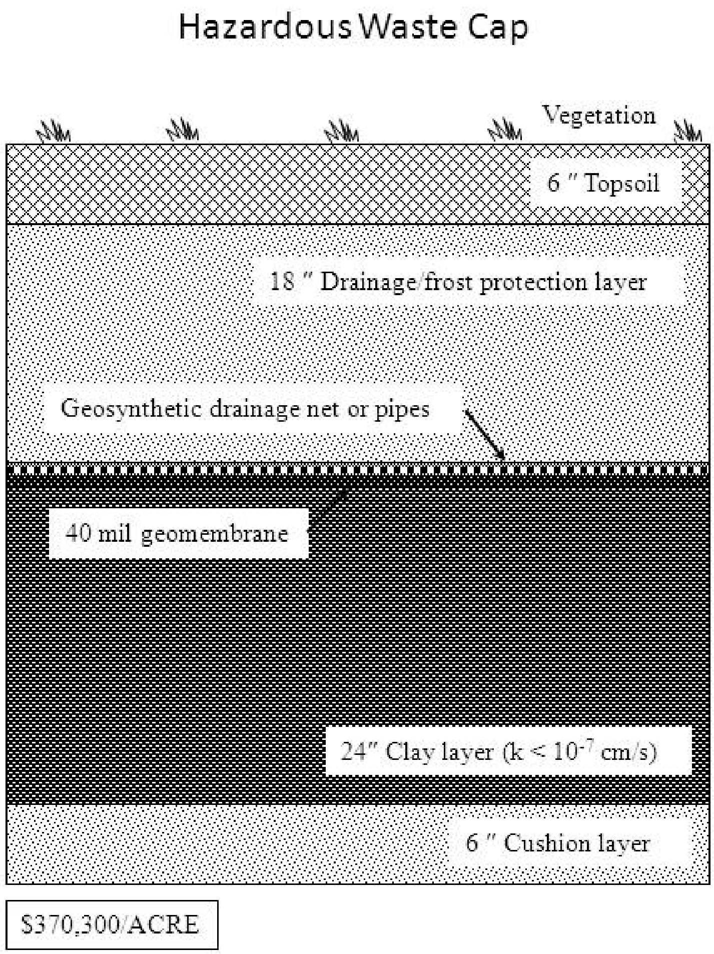
$248,100/ACRE

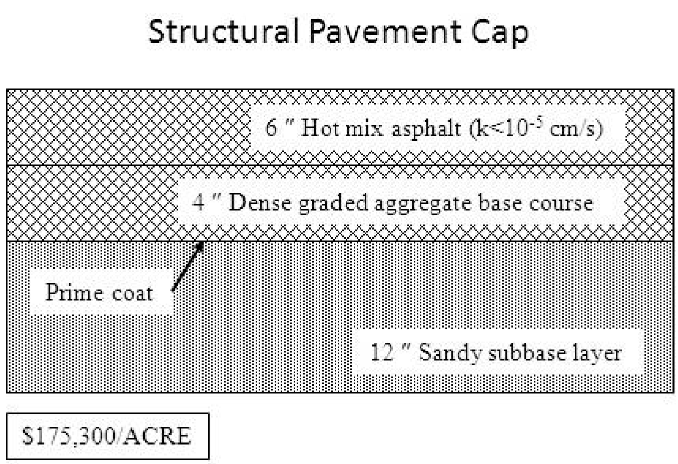
Geomembrane Cap



COST: $ 179,600/ACRE

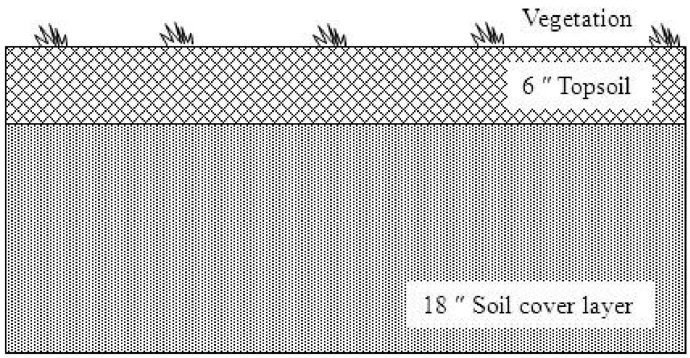
Typical Sections – Low Permeability Caps (continued)





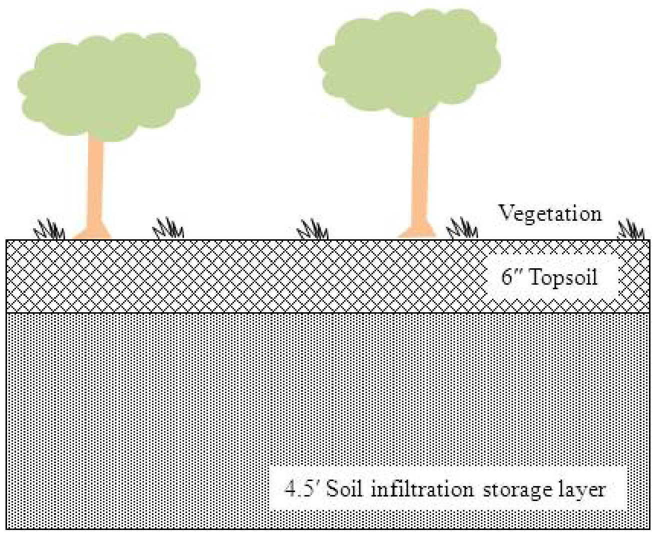
Typical Sections - Permeable Caps

Soil Cap



$94,900/ACRE

Evapotranspirative Cap



$220,700/ACRE

11 APPENDIX G: Glossary

Department = the New Jersey Department of Environmental Protection or NJDEP

Investigator = Any person that uses this guidance to remediate a contaminated site on behalf of a remediating party, including the remediating party itself

Technical Guidance = Documents inclusive of those produced by the New Jersey Department of Environmental Protection that can be found on the Department's website at www.nj.gov/dep/srp/srra/guidance that have the purpose of informing how the current Technical Requirements for Site Remediation are to be correctly implemented

Technical Rules = Technical Requirements for Site Remediation or N.J.A.C. 7:26E

The reader is referred to N.J.A.C. 7:26E-1.8 for the definitions of common remediation related terms.

12 APPENDIX H Acronyms and Abbreviations

AOC = Area of concern

ASTM = American Society for Testing and Materials

ATSDR = Agency for Toxic Substances and Disease Registry

ASTSWMO = Association of State and Territorial Solid Waste Management Officials

CFR = Code of Federal Regulations

CSM = Conceptual site model

Eh = Oxidation reduction potential

ESNR = Environmentally sensitive natural resources

ET = Evapotranspiration

FA = Financial assurance

GAC = Granular activated carbon

GCL = Geosynthetic clay liner

HDPE = High-density polyethylene

ICAA = Insulation Contractors Association of America

ITRC = Interstate Technology and Regulatory Council

LNAPL = Light nonaqueous phase liquid

LSRP = Licensed Site Remediation Professional

LURP = Land Use Regulatory Program

mil = One thousandth of an inch

MNR = Monitored natural attenuation

MSW = Municipal solid waste

NAPL = Nonaqueous phase liquid

N.J.A.C. = New Jersey Administrative Code

N.J.A.C. 7:26 = NJDEP Solid Waste Management Regulations

N.J.A.C. 7:26C = NJDEP Administrative Requirements for the Remediation of Contaminated Sites

N.J.A.C. 7:26D = NJDEP Remediation Standards

N.J.A.C. 7:26E = NJDEP Technical Requirements for Site Remediation

N.J.A.C. 7:26G = NJDEP Hazardous Waste Regulations

NJDEP = New Jersey Department of Environmental Protection or Department

NJPDES = New Jersey Pollution Discharge Elimination System

N.J.S.A. = New Jersey Statutes Annotated

N.J.S.A. 58:10B = Brownfield and Contaminated Site Remediation Act

NPV = New present value

O&M = Operation and maintenance

PAH = Polycyclic aromatic hydrocarbons or Polyaromatic hydrocarbons or Polynuclear aromatic hydrocarbons

PCB = Polychlorinated biphenyl

pE = Oxidation reduction potential

perm = U.S. units of grains of water per hour per square foot per inch of mercury pressure difference (water partial pressure difference) on the two sides of the barrier

pH = Measure of the acidity or basicity of an aqueous solution

PV = Present value

QA/QC = Quality assurance and quality control

RAO = Remedial action outcome

RAR= Remedial action report

RAWP = Remedial action work plan

RCRA = Resource Conservation and Recovery Act

RFS = Remediation funding source

RIR= Remedial investigation report

Rt = Cash flow

sec = Second

SRP= Site Remediation Program

SRRA= Site Remediation and Reform Act

t = Periods

TSCA =Toxic Substances Control Act

USEPA = United States Environmental Protection Agency or the Environmental Protection Agency

VITG = Vapor Intrusion Technical Guidance

VOC = Volatile organic compound