United States
Environmental Protection
Agency

Office of Emergency and
Remedial Response
Washington, D.C. 20460

EPA 540-K-01-008
OSWER 9230.0-100
February, 2002

EPA

Reusing Superfund Sites:

Commercial Use Where Waste is Left on Site

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Office of Emergency and Remedial Response
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington DC 20460

EPA Contract 68-W6-0046, Work Assignment 4

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Preface

As of February 2001, more than 190 cleaned up Superfund sites have been returned to productive use. Half are being used for commercial or industrial purposes. Other sites are restored for use as recreational or ecological areas, such as wildlife habitats. Many more Superfund sites, and some non-time-critical removal sites, may have potential for similar uses after they are cleaned up. Recognizing this, the Environmental Protection Agency (EPA), through the Superfund Redevelopment Initiative, encourages and supports the productive reuse of Superfund sites. EPA's overriding objective for any site is to ensure it is safe. With forethought and effective planning, communities can return sites to productive use without jeopardizing the effectiveness of the remedy put into place to protect human health and the environment.

This report provides industry and government officials with technical information useful in planning, designing, and implementing safe commercial reuse of sites where the remedy calls for on-site containment of contaminated material. This information may be useful when considering commercial reuse options during EPA's process of selecting, designing, and implementing a cleanup plan for a Superfund site or non-time-critical removal action. The report draws from experiences at completed and current redevelopment projects, EPA technical guidance, and other sources to describe remedy approaches and commercial facility design features that have been used to accommodate commercial and industrial uses at Superfund sites where waste has been left on site.

This document is intended for information only, and should not be considered agency policy or guidance. It is one of a series of planning reports being developed under EPA's Superfund Redevelopment Initiative to inform interested parties at hazardous waste sites about how EPA may take intended and potential reuse into account during the process of selecting, designing, and implementing remedies. Other reports in this series provide technical information on the reuse of Superfund waste containment areas for outdoor recreational areas, golf courses, and ecological resources.

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1. Introduction

Former landfills, abandoned dumps, and other contaminated sites throughout the United States, once thought to be of limited or no value, are being transformed into viable commercial and industrial developments, parks and other recreational areas, and wildlife areas. Half of the over 190 Superfund sites that have been redeveloped over the past 20 years are being used for commercial or industrial purposes. Cleaned up Superfund sites are being used for high-rise office buildings, retail centers, intermodal transportation facilities, port cargo handling facilities, airports, restaurants, and indoor recreational buildings. These commercial developments provide positive economic impacts and social and environmental benefits to their communities.

At many successfully redeveloped sites, waste has been left on the property in containment systems that protect people and the environment from exposure and prevent contaminant migration. This report provides techniques for ensuring that these containment systems can accommodate the broadest possible range of potential commercial uses, while ensuring that reuse activities do not reduce the effectiveness of the remedy. If the remedy allows for a broad range of uses, communities will not be left with containment systems that preclude the most efficient use of their land. The successful and safe use of a remediated site for commercial purposes requires careful planning, the involvement of the community and other interested parties, and appropriate design, construction, and post-construction operation and maintenance practices.

Purpose

This report was developed to provide federal and state Superfund site managers, property owners and developers, potentially responsible parties, local planning officials, and remediation contractors with information useful for planning, designing and implementing site cleanups that will safely support commercial and industrial uses. The information could also be applied at certain non-time-critical removal sites. The report describes how redevelopment and remediation design can be coordinated to ensure successful commercial projects at sites where some or all of the hazardous wastes will be, or have been, left on site. It focuses on the planning-level issues, not detailed design information. This document does not address how communities and property owners plan for the reuse of these cleaned up sites. It is generally their responsibility to decide how they will use these properties, although the remedy may limit some future uses.

The information in this document is based on the combined experiences of successful Superfund remediation and reuse projects, previous EPA technical guidance, and other sources. It includes considerations for determining the types of uses possible; remedy design, construction, and maintenance issues important for a site; and references to completed projects. This information may be useful in supporting remedy selection, design, construction, long-term monitoring and maintenance, and general reuse and community planning. It is also useful to planners designing remedies when no clear redevelopment plan is available. This information can help a site manager determine the remedy design features that would be compatible with a number of different future reuses. This approach may afford communities more flexibility in planning future development.

Superfund Redevelopment Initiative

EPA prepared this report as part of the agency's Superfund Redevelopment Initiative. This initiative reflects EPA's commitment to consider reasonably anticipated future land uses when making remedy decisions at Superfund sites, and to ensure that the cleanup of Superfund sites allows for safe reuse for commercial, recreational, ecological, or other purposes.

Through this initiative and other efforts, the agency works with communities to determine remedial action objectives that will allow for reasonably anticipated future land uses, wherever possible. The determination of how to reuse a site is the responsibility of the community, and EPA's primary responsibility is to ensure that the remedy is effective in protecting human health and the environment. Land use is a local matter, and EPA does not favor one type of reuse over another.

The safe and appropriate redevelopment of sites can provide significant benefits to communities and help ensure that remedies will be maintained. These potential benefits include:

- New employment opportunities, increased property values, and catalysts for additional redevelopment;
- New recreational areas in communities where land available for such activities is scarce;
- Better day-to-day property management, which can result in improved maintenance of the remedy and continued protection of human health and the environment; and
- Improved aesthetic quality of the area through the creation of well-maintained commercial facilities and discouragement of illegal waste disposal and similar unwanted activities.

For more information on the Superfund Redevelopment Initiative, including information about current developments, pilot programs, tools and resources, and site-specific case studies, visit the Superfund Redevelopment Initiative web site at **www.epa.gov/superfund/programs/recycle**, or contact the following numbers:

Outside the Washington, DC area: 800-424-9346;
TDD for the hearing impaired outside the Washington, D.C. area: 800-533-7672;
In the Washington, D.C. local area: 703-412-9810; or
TDD for the hearing impaired In the Washington, D.C. local area: 800-412-3323.
Hours: 9:00 AM to 5:00 PM Eastern Standard Time, Monday through Friday.
Closed on federal holidays.

Integrating Reuse Plans With Cleanup Remedies

The future use of a Superfund site can affect all aspects of the removal and cleanup processes, from the remedial investigation/feasibility study (RI/FS), through remedy selection, to remedy design and implementation. Thus, it is important to carefully consider the roles of anticipated future land uses, EPA's process and timing for considering the anticipated future use, and the scope of EPA's authority to accommodate the remedy throughout the remedial process. For some sites it may also be possible to begin development while remediation is still occurring on other parts of the site.

Consideration of Future Land Uses

The anticipated future use of land is an important factor that EPA uses to determine the appropriate remedy. The process for identifying the reasonably anticipated future use of land begins during the Remedial Investigation/Feasibility Study (RI/FS) stage of the Superfund cleanup. A useful way to accomplish this is to conduct a reuse assessment.

The reuse assessment typically identifies broad categories of potential reuse (*e.g.*, recreational, commercial). This assessment may also initiate the reuse planning process and lay the groundwork to integrating reuse into the cleanup plan. In some cases, property owners, PRPs, and communities may have initiated a reuse planning process. Information from a reuse plan may serve as useful input to the reuse assessment. As part of the reuse assessment process, EPA holds discussions with local land-use planning authorities, local officials, property owners, PRPs, and the public to understand the reasonably anticipated future uses of the land on which the Superfund site is located. Based on these discussions, EPA develops remedial action objectives and identifies remedial alternatives that are consistent with the anticipated future land use. If there is substantial agreement on the future use of a site (*e.g.*, commercial, residential), EPA may be able to select a remedy that supports that use and take measures to accommodate that use when designing the remedy.

However, EPA must balance this preference for future land use with other technical and legal provisions in the Superfund law and its implementing regulations.[1] For example, the Agency's decisions must conform with preferences for using one or more of a number of approaches, such as treating principal-threat wastes, engineering controls such as containment for low-level threats, institutional controls to supplement engineering controls, and innovative technologies. In addition, EPA must comply with other laws when they are "applicable or relevant and appropriate" (ARAR).

After considering these factors, EPA selects a remedy. Two general land-use situations could result from EPA's remedy selection decision:

- If the remedy achieves cleanup levels that allow the site to be available for the reasonably anticipated future land use, EPA will work within its legal authorities to support that reuse; or
- If the remedy achieves cleanup levels that require a more restricted land use than the

1 See section 300.430(a)(1)(iii) of the National Contingency Plan at 40 CFR Part 300.

reasonably anticipated future land use, the site will probably not support the community's reuse preferences and the interested parties will have to discuss other reuse alternatives.

For detailed information on how EPA considers land use in the remedy selection process, see EPA's *Land Use in the CERCLA Remedy Selection Process*, EPA OSWER Directive No. 9355.7-04 (http://www.epa.gov/swerosps/bf/ascii/land_use.txt); and *Reuse Assessments: A Tool to Implement the Superfund Land Use Directive*, OSWER Directive No. 9355.7-06P (http://www.epa.gov/superfund/programs/recycle/pdf/reusefinal.pdf).

Timing

To allow for evaluations of a variety of remediation and reuse options, reuse planning should be initiated as early in the cleanup process as possible. The longer reuse planning is delayed, the greater the possibility that some reuse options will be foreclosed by decisions already made.

There are two major components to the reuse planning process: making reuse assessments and creating reuse plans. A reuse assessment, which typically identifies broad categories of potential reuse (*e.g.*, recreational, industrial), should be developed at the RI/FS stage. This assessment initiates the reuse planning process and lays the groundwork for additional planning. Because the land-use categories used in making the reuse assessment are broad, they may not provide sufficient detail to ensure that the remedy being considered will allow for a specific use or to guide the detailed design or implementation of the remedy. When communities need more detailed land-use proposals, they may initiate the second component of the reuse planning process—the creation of reuse plans.

Reuse plans may be developed by communities to provide more specific and detailed proposals for the redevelopment of a property. These plans are often developed after the RI/FS and may not be available until later stages of the site management process, such as during remedy design or construction. When the EPA receives the reuse plans prior to remedy selection, the site manager should evaluate them in the course of developing the remediation alternatives. When reuse information is received after the remedy is selected, the site manager evaluates it to determine whether the response action is consistent with the proposed reuse and whether design modification might be easily made to accommodate it.

Development of the reuse project can sometimes begin on parts of a site before construction of a remedy is completed. This can be done by segmenting the site into different operable units (OUs) which proceed on different schedules according to the nature of the cleanup approaches, location, and expected completion time; deleting portions of the site from the NPL while cleanup continues elsewhere; and sequencing the cleanup work to coordinate with development needs. For example, at the Ohio River Superfund site in Neville Island, Pennsylvania, remedial investigation and remediation activities were interrupted when EPA agreed to make part of the sight available for replacing the old, unusable Coraopolis Bridge, which was important to the community.

Although many cleaned up Superfund sites currently do not support any type of reuse activity, EPA expects that a number of these sites may eventually be returned to productive use. Where hazardous substances, pollutants, or contaminants remain on site above levels that would allow for unlimited use and unrestricted exposure, EPA conducts reviews at least every five years to ensure that the remedy remains protective. Should land use change, it will be necessary to evaluate the implications of that change for the protectiveness of the selected remedy.

In many cases, a completed remedy may not be able to accommodate the planned use without modification because of technical, legal, or other factors. If, in the future, landowners or others decide to change the land uses in such a way that makes further cleanup necessary, EPA does not prohibit them from conducting such a cleanup, so long as protectiveness of the remedy is not compromised. Retrofitting an existing remedy to support reuse requires careful planning, design, coordination with, and approval by, EPA and other regulatory agencies. As discussed below, EPA is prohibited from funding, nor can it require PRPs or others to fund, activities that are considered “enhancements” to the remedy.

Accommodating Future Use in the Remedy

The consistency of the chosen remedy with the future use of a site contributes to its long-term protectiveness. Protecting human health and the environment over the long term is the key objective of remedial action. EPAs Land Use Directive identifies anticipated future use of land as an important factor that EPA considers when it selects a remedy. Thus, understanding and accommodating future use in selecting and implementing remedies is an integral part of EPA’s cleanup responsibility, and not a separate discretionary goal.

Because the effectiveness of a remedy can be compromised if it is not consistent with the eventual use of a redeveloped site, EPA chooses remedies that are consistent with anticipated use, and implements them, insofar as possible, in ways that accommodate that use. The Agency will not for example, leave a site with no means, short of modifying the remedy, to support structures that will be required for the anticipated use. The remedy will allow reasonable areas for them. As a part of the remedy, EPA may provide clean corridors for future utility access when anticipated use makes it likely that they will be needed. EPA may also, for example, move wastes to a location other than the one that might otherwise have been chosen, in order to avoid blocking an access to the site that will be needed for its anticipated future use. In another example, EPA may take future use into account in deciding on the placement of monitoring or extraction wells, air-stripping towers, or other treatment units, so that they do not interfere with placement of structures needed for the redevelopment of a site. EPA may fund, or require a potentially responsible party (PRP) to fund such actions as are necessary to ensure that the site is capable of accommodating the reasonably anticipated future land uses, so that the remedy will remain protective over the long term.

Activities like those in the examples above, which are necessary to accommodate the remedy to the anticipated future use, are remedial activities because they contribute to the long-term protectiveness of the remedy. They are not “enhancements” or “betterments.” An enhancement is not a remedial feature or activity. It is not necessary for the effectiveness of the remedy, even though it may make some contribution to its effectiveness. Enhancements include such things as building roads, foundations or parking lots. Providing additional compaction of a site beyond what is needed to keep the protective cap from settling under anticipate future use would be an enhancement, as would providing extra clean fill above a containment system cover beyond that required to make it protective under the anticipated future use. EPA is not authorized to pay for enhancements, nor to require PRPs to construct them. EPA determines case-by-case whether an activity or feature constitutes an enhancement.

Organization of Report

The remainder of this document describes the key technical considerations that should be addressed when developing and operating commercial facilities on properties where hazardous waste has been left on site. It includes the following:

Section 2 This Section describes the most common site configurations and remedy design features that affect the suitability of a site for reuse when removal or on-site destructive treatment are not viable options. It addresses the most frequently used remedy design components, such as containment system covers and groundwater extraction and treatment systems. It also provides references to relevant EPA guidance documents.

Section 3 This Section outlines remedy and commercial facility design issues that may have to be considered to ensure that the facility is compatible with the remedy. The key design features include techniques for the safe placement of utilities, footings, foundations, and containment cells; methods for managing gases; and provisions for utilities, site access, and short-term and long-term stewardship of the effectiveness of the remedy.

Section 4 This Section describes seven previous projects where successful redevelopment has occurred on remediated waste sites that have contaminated material left on site or where waste treatment is to continue for a number of years. The discussion for each site includes the site configuration and contamination problems encountered, key factors considered during remediation that were important to the commercial redevelopment, and the redevelopment plan. These case studies demonstrate how remediation and redevelopment efforts may complement each other.

Section 5 This Section provides references on remedy and redevelopment design features, such as EPA guidance manuals, text books, and journal articles.

Appendix A This appendix describes some of the key monitoring and maintenance needs that EPA, developers and property owners should address after construction of the remedy is completed.

Appendix B This appendix includes brief descriptions of 15 completed projects where various types of commercial and industrial development occurred on sites with a range of containment systems.

2. Site Configurations and Remediation Approaches for Commercial Reuse

Remediation and redevelopment approaches differ according to whether the contaminated materials are closed in place, as in the case of an old landfill or large impoundment; placed in a new containment system created as part of the remedial action; or treated over time with special structures or equipment that remain on site after the initial remedy construction is completed. Each of these potential situations presents a different set of remediation and redevelopment considerations, such as how to design and build containment systems, prevent or reduce groundwater contamination, and ensure long-term stewardship.

This Section describes key factors considered during remediation that will influence the commercial redevelopment of a property that has contaminated material or operating waste treatment systems left on site. By examining the potential impact of the remediation process on the ultimate uses for the site, site managers may contribute to positive outcomes for the community.

Closed-in-Place Sites

Sites that are closed in place primarily include municipal or industrial/commercial waste depositories, some large surface impoundments, and mine tailings. Site managers and developers for many of these sites have to deal with existing conditions such, as the potential for substantial subsidence, gas production, and very hazardous materials remaining on site. These types of facilities frequently lack bottom liners and, if covered prior to becoming a Superfund site, the covers may be poorly designed. The primary redevelopment issues include general subsidence, differential settlement, cover integrity, and, in many cases, the presence of gases. There are generally few remedial options for old landfills and other existing waste depositories that are to be closed in place. The presumptive remedy for these sites is to install a protective cover and, where necessary, treat or control groundwater.

New Containment Systems

New containment systems are those that are created as part of the site remediation. These systems range from simple covers over contaminated materials that are left in place to highly engineered depositories into which waste from the site or other sites are consolidated. A new containment system may also include material that has been solidified or stabilized *ex situ*. High-hazard wastes are generally not placed into new containment systems, as these would either be treated or sent to an off-site commercial disposal facility.

Engineered containment systems generally do not have serious differential or general subsidence, or gas production. As part of good construction practice, the materials would be compacted as they are placed into this type of containment system. A minimum amount of compaction may be necessary to minimize settling of the cover. If there is commercial interest in redeveloping the site from the beginning, and the planned redevelopment requires additional compaction, it should be arranged for early in the remediation process. This approach was followed at the Raymark Superfund site in Stratford, Connecticut, where a prospective developer, anticipating that a building would later be placed on the site, paid for dynamic compaction and the installation of pilings during the construction of the containment system.

EPA site managers have more flexibility in deciding which materials will remain on site and in designing and locating new containment systems, than in existing waste depositories. This flexibility allows for a greater range of development options. The site manager typically considers factors such as the types of contaminants, their stability, the media through which they travel (*i.e.*, air, soil, groundwater), and the type of future commercial facilities anticipated. For example, instead of building one large containment cell, smaller separate cells with channels of clean soil between them could be designed to allow for utility access. Also, the containment areas could be located where buildings are not likely to be placed. Utility corridors and shallow foundations can often be located in uncontaminated materials by placing sufficient clean fill above the containment system cap. When this is done, a good safety measure is to place visible barriers, such as colored soil or brightly colored synthetic geotextile material between the contaminated material and the clean fill to act as permanent markers for future workers. Some of these approaches were used at the Denver Radium site in Denver, Colorado. A large retail store and parking lot was built on a site where insoluble metals-contaminated soil was consolidated into four containment cells with unlined bottoms. The spaces between the cells were used for utility corridors, and the asphaltic covers also serve as a parking lot.

The asphalt parking lot at the Home Depot site in Denver, Colorado also serves as a protective cover for insoluble metals-contaminated soils. The contaminated soils were consolidated into four containment cells.

A simple cover may be used at some sites with widespread surficial contamination where the main health threat is through direct contact with the soil or inhalation of wind-borne particulates. In this situation, the material may be covered in place. If the solubility of the contaminants is low, the cover can be constructed of materials such as native soils or asphalt. Such areas are generally good candidates for parking lots and commercial buildings. At the Mid-Atlantic Wood Preservers site in Harmans, Maryland, surficial contamination over a three-acre area was covered with asphalt, which is being used as a parking and storage facility by a trucking company. Building over these types of containment systems is often no more difficult than building on an uncontaminated area, as long as the construction crew is properly trained and any contaminated material excavated is properly managed.

On-site Waste Treatment Facilities

The selected remedy often includes treatment or containment equipment that will remain on site for a number of years after the initial remedy construction at the site is completed. This equipment can include groundwater extraction and treatment systems, monitoring wells, reactive walls, and diversion walls. When development is to occur on a site, provision should be made to allow access for maintenance and repair, and to prevent the public from having ready access to the equipment. Also, with the exception of *in situ* stabilization, the EPA site manager has some flexibility in determining the location of the systems and can use this flexibility to avoid diminishing the usefulness of the site. For example, the site manager has some discretion in determining the location of extraction wells, on-site treatment facilities, and underground piping.

Piping for groundwater treatment at the Peterson/Puritan Superfund site in Cumberland and Lincoln, Rhode Island.

Common Containment Methods and Features

At many Superfund sites, the remedial action leaves contaminated material on site. A number of technologies can be used to ensure that the waste is safely contained. This section addresses the most common approaches, including the use of cover systems, gas collection and treatment systems, groundwater collection and treatment systems, diversion walls, solidification and stabilization, and permeable reactive barrier walls.

Cover Systems

Cover systems at containment sites are used to minimize the infiltration of water into the contaminated material and to serve as protective barriers to isolate contaminants from the public and the environment. Regulations under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA) require that cover systems at Superfund sites attain, at a minimum, applicable or relevant and appropriate requirements (ARARs). Resource Conservation and Recovery Act (RCRA) Subtitle C and Subtitle D and state regulations are the most common ARARs for containment systems at Superfund sites. RCRA regulates wastes that are the same as or similar to those found at CERCLA sites. Although cover systems at Superfund sites are not necessarily based on RCRA closure regulations, these requirements are the prevalent basis for cover system design. RCRA and state regulations usually require that the cover be built to:

- minimize the migration of liquids through the system over the long term,
- function with minimum maintenance,
- promote drainage and minimize erosion, and
- accommodate settling and subsidence.

EPA encourages flexibility in the design of covers for all waste sites. Covers can range from a simple soil or asphalt layer to protect people from contact with the contaminants, to multi-layered composite caps recommended for more demanding situations. General design requirements are based on federal or state criteria.[2] Cover systems can use one or more of the following types of barriers:

Hydraulic barriers, the most common of the three types, use low-permeability material to impede the downward migration of water. They are usually multi-layered cover systems that typically incorporate geomembranes, geosynthetic clay liners, compacted clay liners, or a combination of these as the hydraulic barrier or barriers. These systems may also include features such as a gas venting layer, biota layer to prevent burrowing animals or plant roots from damaging the cover systems, drainage layer, and soil and vegetative or other top layer. However, in some cases, asphalt or other materials may also be used as a barrier. Currently, multi-layered hydraulic barriers are the most common type of cover systems, and are typically used at RCRA "Subtitle C" and "Subtitle D" facilities that require covers.

Capillary barriers are intended for use in arid to semi-arid climates where unsaturated soil conditions prevail. This type of cover exploits the differences in pore water pressure potential between fine and coarse grained soils to limit the downward movement of water. A simple configuration of this type of cover system consists of a fine-grained soil (clay) located over a coarser-grained soil (sand). Under unsaturated conditions the fine-grained clay holds water, preventing its movement to the lower coarse-grained sand. However, when the entire fine-grained layer becomes saturated, it will release water to the lower coarse layer.

Evapotranspiration barriers are also used predominantly in arid and semi-arid environments. This type of cover typically consists of a thick layer of relatively fine-grained soils, which is capable of supporting vegetation. The soil layer inhibits downward water movement and serves as a storage reservoir that holds water until it is removed by evapotranspiration. It is built to have a greater storage capacity than that needed for the maximum anticipated rainfall.

Depending on site-specific conditions, cover systems may be composed of multiple layers of natural and/or synthetic materials, each designed for one or more specific purposes, such as gas control, internal drainage, and vegetative support. Section 5 (Bibliography) lists a number of

2 For example, the Resource Conservation and Recovery Act (RCRA) Subtitle C closure requirements for hazardous waste management facilities (40CFR 264.310). EPA anticipates that it will issue new technical guidance for RCRA/CERCLA final covers in 2001.

EPA guidance documents that address cover system function and design (EPA 1983, 1985a, 1985b, 1987a, 1987b, 1989b, 1991c, and 1994).

Gas Collection and Treatment Systems

Gas management systems used in containment areas can be grouped into two types: passive and active venting. Passive venting allows gases building up in a containment area to exit through a vent that has an air pressure equal to that of the outside air. As gas pressures build up inside a containment area, the gas migrates towards the vent and out of the containment area. Active venting produces a negative pressure by pumping air out of the vents. Vents, discharge points, and treatment systems should be located so as not to interfere with the future use of the property. Structures placed over an area that has a gas problem, should be designed with their own gas management system. Some of these are discussed in Section 3.

Groundwater Extraction and Treatment Systems

Groundwater extraction and treatment systems are used to remove contaminated groundwater to an above-ground facility for subsequent treatment. These systems typically consist of extraction wells or french drains (collection drains). Extraction wells can be deployed in most hydrogeologic situations, while french drains are generally limited to shallow, low hydraulic conductivity aquifers. A typical groundwater extraction and treatment system can also be combined with techniques that treat or remove contaminants from the subsurface without extracting the soil or groundwater. Some of these techniques are dual phase extraction, soil vapor extraction, and air sparging.

Whatever the specific groundwater treatment system and media, all collection and treatment systems require piping, utilities, and on-site or off-site treatment systems, in addition to wells and drains. Since access for operation and maintenance must be available throughout the life of the systems, which can be many years, the placement of the components will have an impact on redevelopment activities. To the extent that there is flexibility in placing this equipment, the site manager should consider potential development scenarios or land-use plans, if any are available. Careful consideration of the location of groundwater treatment wells and equipment can maximize the potential for commercial or other reuse of the site.

Diversion Walls

A diversion wall is a below-grade vertical structure designed to divert groundwater flow away from contaminated material or to divert or channel contaminated groundwater. Diversion walls can be grouped into three types: sheet pile, grout, and slurry.

Construction of a slurry wall at the Ohio River Park Superfund site in Neville Island, Pennsylvania.

Of the three types, slurry walls are the most common. They are less costly and have lower permeability than grouted barriers. They are often used in combination with hydraulic controls or extraction and treatment technologies to channel groundwater into a particular area or to enhance containment measures. These structures are also used in conjunction with covers to fully confine a waste area and to prevent clean water from leaching through the wastes. A slurry wall is built by excavating a narrow trench, filling it with a bentonite-water slurry or other mixtures, which solidify to form the wall. Sheet pile walls are built by driving strips of steel or other material into the soil to form a subsurface barrier. Grout walls, also called grout curtains, are built by injecting fluid under pressure into soil or rock, where it permeates voids and gels or sets in place.

Groundwater wells, which are used to monitor the continued effectiveness of the remedy, are usually used in conjunction with all types of diversion walls. Since there may be a need to repair a failing wall or well, access to them should not be blocked. Thus, the EPA project manager should consider the potential impact of the location of these walls on future development. For example, barrier walls can be placed near the property line, outside of any building footprint, and under open areas.

Solidification/Stabilization

Solidification and stabilization (S/S) involve modifying the physical or chemical properties of the waste to improve its engineering or leaching characteristics, or to decrease its toxicity. Solidification encapsulates contaminants into a solid material of high structural integrity. Stabilization converts waste contaminants into a less soluble, mobile, or toxic form. S/S can be done either *in situ* or *ex situ*. *Ex situ* processing involves (1) excavation to remove the contaminated waste from the subsurface, (2) sorting to remove large pieces of debris, (3) mixing with an S/S agent, and (4) delivering the treated wastes to molds or trenches, or for subsurface injection. *In situ* processing entails only mixing the waste with an S/S agent. Some types of waste require solidification or stabilization prior to being placed into a landfill or covered by an engineered cover system.

Vitrification, a special type of S/S, is the application of high temperature treatment aimed primarily at reducing the mobility of metals by incorporating them into a vitreous mass. The temperatures required to vitrify soils will also result in the pyrolysis and combustion of organic contaminants. As with most S/S operations, vitrification can be performed both *ex situ* and *in situ*. If *ex situ* S/S is used, the RPM has the choice of returning the treated material to the original excavation or placing it in another excavation at a different part of the site. The location of this material may significantly affect the type and amount of development that can occur on the site.

Permeable Reactive Barrier Walls

Permeable reactive barrier (PRBs) walls are both a containment and treatment system for contaminated groundwater. Reactive material is placed in the subsurface in the path of a plume to intercept it. As the groundwater flows through the media, contaminants are "trapped" or destroyed by the reactive material and treated water flows out the other side of the barrier. When properly designed and implemented, PRBs are capable of remediating a number of contaminants to regulatory concentration goals.

The PRBs generally have monitoring wells behind them to monitor their compliance with the cleanup goals. They may also have performance monitoring wells placed within them to evaluate changes in physical and chemical characteristics over time. Because of both sampling activities and the potential need to replace or repair the reactive materials, access to the wall is required until the cleanup is complete.

3. Remedial Design Considerations for Commercial Facilities

Federal and state law requires that containment systems be designed to comply with federal, and state standards, whether the property is to be reused or not. At most sites, remedies and commercial facilities can be structured to safely accommodate each other and still meet all the regulatory requirements. However, some remedy design considerations that are not critical to sites that are not being reused can, if not accounted for in the remedial design, have a detrimental impact on the reuse activities. For example, general subsidence can seriously damage a building or parking lot, but may have little impact on the cover's effectiveness at an unused site.

This Section describes key planning and design issues that must be addressed when a waste containment area is expected to have commercial reuse in the future. These issues include settlement and subsidence; the design of foundations and platforms; the provision for utilities and managing gas; access for people and goods; and methods for ensuring the short-term and long-term effectiveness of the remedy and the health and safety of site users and communities. The information is based on EPA's experience at Superfund and other waste sites and is not intended to serve as policy or guidance.

The community will have the greatest flexibility if redevelopment and remediation plans are coordinated prior to remediation. Nonetheless, redevelopment can still occur if it is not conceived until after the remedy is in place. In this situation, it is especially important that the developer coordinate with regulatory authorities concerning the development plans and obtain accurate, current, as-built drawings of the remedy construction rather than base the plans on designs prepared prior to construction of the remedy.

Key Commercial Facility Design Issues

- Settlement and subsidence
- Foundations
- Gas management
- Utilities
- Site access for people and goods
- Other design considerations
- Ensuring the near-term and long-term effectiveness of the remedy

Settlement and Subsidence

General subsidence and differential settlement may cause damage to containment systems, buildings, parking lots, and other site features. It is primarily an issue at closed-in-place sites, such as old landfills and impoundments. Most old landfills experience general subsidence over time. Studies show that most municipal landfill sites settle from 5 to 20 percent of the landfill depth over a 15 to 30 year period, and some have been known to settle as much as 30 percent. Subsidence and differential settlement are primarily caused by the compression of the contaminated material under its own weight and the weight of the cover system and any overlying materials or structures and chemical and biological degradation of subsurface material.

The magnitude, distribution, and rate of settlement are governed by a number of factors including material age, density, thickness, and manner of placement, loadings, and the amount of moisture.

Differential settlement results when the disposal history and practices of the landfill were not uniform or portions of the disposed material decay more quickly than others. This situation is more likely to result in a "sinkhole" effect, than widespread uniform settlement. Settlement of somewhat wider areas often results from some landfill operators' practice of segregating wastes by type, such as construction debris in one area, appliances in another, and municipal refuse in yet another. As a result of this practice, some large areas of a landfill may settle faster than others. Differential settlement can result in high maintenance costs to prevent or repair damage to covers, and pose special problems for structures built on footer or slab foundations. A number of EPA guidance documents address settlement and cover subsidence of hazardous waste landfills (U.S. EPA 1985b, 1987b, and 1991c).

Types of Sites Likely to be Affected

Current operating practices at RCRA Subtitle C facilities (*e.g.*, banning of liquids and partially filled drums of liquids) are expected to minimize major settlement of newer landfills after they close. However, most Superfund abandoned dumps, industrial waste, and landfill sites were created using older disposal practices. Because these practices allowed liquids, drums, and other containers, there is potential for significant general subsidence and differential settlement of containment systems built on such sites. For current Subtitle D facilities and older co-disposal sites (municipal and industrial), the normal decomposition of the waste will invariably result in settlement and subsidence.

Evaluating Settlement and Subsidence

While many cover systems can be designed to accommodate settlement, many structures do not have the same flexibility. The first step in addressing settlement is to estimate its magnitude, distribution, and rate. These values are determined by a number of factors, such as material age, type, density, thickness, loadings, and moisture conditions. In addition, it is necessary to evaluate the potential for localized settlement from the collapse of buried drums and other subsurface processes. The estimation should be undertaken as early in the remedial investigation process as possible. These estimates can help determine if any special design features are needed for the cover and the feasibility of commercial redevelopment. The rate and magnitude of general and differential settlement will profoundly affect the foundation design and maintenance procedures.

> Because it is difficult and time-consuming to estimate the magnitude and rate of subsidence, measurement should begin early in the site management process.

It can be difficult to accurately estimate the magnitude and rate of waste consolidation and the corresponding settlement of cover systems and other structures, particularly at sites where there is a variety of subsurface materials or where little is known about the waste types and distribution. In some cases, survey instruments or settlement gauges may be used to monitor the settlement rate of the surface of the waste prior to and during design, in order to improve the accuracy of the settlement estimates. Because this approach usually requires an extended period of time, it should begin as early in the Superfund process as possible (*e.g.*, remedial investigation). Field or laboratory load tests may also be used to estimate potential subsidence. CERCLA guidance recommends that the remedial design include estimates of the rate of subsidence (U.S. EPA 1995c).

Cover Integrity

After the potential for settlement and subsidence is evaluated, it should be accounted for in the final cover design. Usually, general subsidence does not result in excessive strains on the cover and may improve its stability. Differential settlement, on the other hand, can produce excessive strains that can result in damage to the cover. The cover design process should consider the stability of all the waste layers and their intermediate soil covers (if known), the soil and foundation materials beneath the landfill, leachate and gas collection systems, and all final cover components. To ensure cap integrity in the future, after construction of the remedy is completed, regular inspections need to be scheduled and any apparent problems, such as the appearance of low spots, should be repaired.

Considering Subsidence and Differential Settlement in Planning Facilities

Several methods are available to reduce the potential for damage due to settlement and subsidence. When severe general or differential settlement is expected, it is sometimes best to delay redevelopment until settlement has largely ceased. One approach is to install an interim cover that protects human health and the environment. Then, when settlement and subsidence is essentially complete, the interim cover could be replaced or incorporated into the final cover. Another approach is to phase in redevelopment by first developing already stable areas and delaying development on the parts of the site still settling. In the interim, some settling areas may be suitable for temporary uses for low-impact or moderate-impact activities, such as a park or parking lot.

One or more construction techniques may also be used to avoid potential damages to future facilities and the cover systems. Options to improve foundation conditions include accelerating the consolidation of the subsurface materials and grade modifications. Subsurface materials can be consolidated by preloading, dynamic compaction, and vibrocompaction. However, these approaches will not affect settlement caused by chemical and biological degradation.

Preloading involves piling soil or other heavy material and allowing it to stand over a period of time. A rule of thumb is that the longer and heavier the preloading, the less likely it is that settlement due to poor compaction and voids will pose a problem. The decision of how much preload to use and for how long is related directly to the types of materials disposed of in the landfill, the age of the landfill, and the trade-offs between the costs of the preloading, delay in site use, and building construction costs. More preloading may entail additional labor and materials and delay the site's productive use. Less preloading may necessitate additional building design and construction cost to accommodate a greater potential for post-development settlement.

Dynamic compaction involves compressing the materials by dropping a heavy weight from a crane. This method was used at the Raymark Industries Superfund site in Stratford, Connecticut, to prepare the site for a retail development (see the case study in Section 4). Dynamic compaction may not be possible for some sites where unknown wastes may present worker safety concerns.

Grade modification may also be used to accommodate settling. This technique is primarily used for open areas such as lawns, athletic fields, and common areas. In order to meet minimum regulatory grade requirements for proper drainage (typically three to five percent), cover systems are commonly built with steeper angles than required, with the expectation that the site will flatten over time as the underlying material consolidates. As the cover system settles, additional fill can be placed on the surface to maintain the desired slope without impacting the performance of the underlying cover system.

Foundations

Foundations support the walls, floors, and roof of a structure. The two most important issues in placing a building foundation in a waste containment area are the protection of the final cover system and, where relevant, the prevention of damage to the building or creation of unsafe conditions that may result from subsidence or differential settlement. Although the foundation systems that can be used at sites containing contaminated waste are similar to those used in general construction, their use may entail special considerations.

Deep Foundations

Deep foundations are generally used when the ground immediately below the surface is not strong enough to support the proposed structure, and it would be too costly to increase its strength. Deep foundations are pilings that are driven or drilled into the subsurface to reach a geologic material capable of supporting the proposed structure. Pilings may be made of steel I-beams, precast reinforced concrete, poured in place concrete, and caissons (metal casings set at the appropriate depth and subsequently filled with concrete).

Because many closed-in-place containment areas are expected to undergo settlement, deep foundations are an effective way of protecting structures placed on them. Pilings may be driven or drilled into a containment system that has an unlined bottom. However, pilings may not be appropriate in situations where the waste contains materials that can damage them, such as construction debris or corrosive chemicals, nor where the geologic conditions indicate that a piling may provide a conduit for contaminants to reach an uncontaminated aquifer. Also it may be unsafe to drill into a containment area where the contents are not known.

Piling Foundations are Useful in the Following Situations:

- The site has the potential for extensive settlement, which makes a shallow foundation inappropriate
- The containment system has an unlined bottom
- The waste material can be driven or drilled through
- There is no potential of reaching an uncontaminated aquifer

If piling type foundations are to be used at a containment area, they will have to be engineered into the cover system. This process involves the installation of engineered seals (sometimes called boots) where the pilings penetrate the cover. The boots need to be attached to both the cover and the piling and be built to prevent water from infiltrating around the piling. At the Raymark Industries, Inc. Superfund site in Stratford, Connecticut, a developer and EPA worked together to arrange for soil compaction on parts of the site and the installation of pilings during construction of the containment system.

If a structure built on pilings settles less than the surrounding ground, gaps can occur between roads, parking lots, or lawns and the structure, which can result in damage to utilities and building entrances. The future building owners would find it necessary to periodically renovate the building entrances and regrade the area around the building. At the Columbia Point Landfill in Boston, Massachusetts, over 100 pilings were driven into the bedrock to provide foundations for the University of Massachusetts' Boston campus buildings. Following completion of the structures, general settlement of the ground adjacent to the buildings was noticed and regular maintenance was required to keep the grounds level and to landscape or fill the gap between the base of the buildings and the receding ground.

Shallow Foundations

Shallow foundations can be divided into two broad categories–footing and slab. A footing foundation is one designed to support the outside walls or vertical support columns of a building. They are placed in the ground directly beneath the structure to be supported. While they can be placed directly into some contaminated materials, this practice is generally avoided because of concerns for the health and safety of the construction crew and future maintenance workers. More commonly, footing foundations are placed in clean fill above the cover of the containment system. When differential settlement is a concern, one design alternative for one and two story buildings is the use of tilt-up wall construction. In this type of construction both the wall and the footing are broken up into discrete sections that allow for some differential settlement without putting stresses across the entire building. Control and leveling joints are used to offset the settlement of specific wall sections.

Built Up Grades Can Provide the Following:

- An uncontaminated space for foundations, utility corridors, and piping for gas ventilation systems
- Protection of the cover and utilities from freeze/thaw cycles
- Protection of the cover and commercial facilities from floods
- Additional compaction of waste materials

Slab foundations are usually reinforced concrete placed directly on the ground. One approach to using slabs on a site that has potential for differential settlement is to build the slab in separate sections and install cable linkages between them and precast ports for pressure grouting. This arrangement allows for differential settlement of each slab, and provides the building owner the capability to separately level each section by pressure grouting into the areas that have settled. Slab foundations can also be "stiffened" by incorporating beams into their construction. This approach allows the slabs to bear differential settling to a greater degree than regular slabs. Slab foundations can be engineered to accommodate a variety of situations, depending upon the type of waste containment system and budget.

Although buildings with slab foundations are usually relatively low and carry light to moderate loads, these foundations can be engineered for heavy loads. For example, concrete slabs at a cargo container handling facility built on the Ascon Landfill in Los Angeles, California, are designed to carry very heavy loads, such as cargo containers, and heavy-duty forklifts (with 68,000 pounds of load per single axle), and a building.

Managing Gases

Depending on their composition, containment sites have the potential to generate gas, which, if not properly controlled, could damage the cover system, infiltrate buildings, provide fuel for fire or explosion, stress vegetation, and pose other health or safety hazards. Although gas control is important for all sites, added emphasis and caution are required at sites containing structures with enclosed spaces that will be used by the public.

The quantity, rate, and type of gas that a landfill or other containment site will generate are primarily dependent on the composition, age, and volume of the waste, and moisture conditions. Gases from municipal landfills generally contain approximately 50 percent methane, 40 percent carbon monoxide, and 10 percent other substances, including nitrogen and sulfur compounds (U.S. EPA, 1991c). Gases from mixed waste municipal landfills and industrial landfills may also contain other volatile organic compounds.

Sites that are expected to produce significant amounts of gas may not be good candidates for commercial uses, unless the gas is well controlled. There are two aspects to gas control: a gas collection system that is usually built into the containment system, and gas protection incorporated into the commercial facilities developed on or near the containment system. Section 2 discusses gas management for waste containment areas. Gas collection systems can include subsurface piping, and wells and vents that extend through the cover system and discharge gases to the atmosphere or to a treatment system. When designing a gas collection system in an area that will be used by the public, particular attention should be given to the types and concentration levels of the gases and their potential health and safety impacts on site users, site aesthetics, and access to future commercial facilities. Vents, collection wells, piping, discharge points, and treatment systems can be placed in areas that will not interfere with planned or prospective uses, where they minimize noise, odors, or other disamenities, and where they are less likely to be accessible to potential trespassers and vandals.

> Structures placed over a landfill or other containment area that has a gas problem, should be designed with gas protection and not depend solely on the cover's gas management system.

If structures are to be placed over a landfill or other containment area that has a gas problem, they should be designed with gas protection and not depend solely on the cover's gas management system. The following are examples of gas protection techniques for buildings:

- Construct floor slabs with convex bottoms to prevent methane from pooling below the structure.
- Place an impermeable (gas resistant) geomembrane or other hydraulic/gas barrier under the structure or within the building's floors. This is especially important for sites likely to experience settlement that may disrupt the cover.
- Engineer an air space below a structure to allow for gas detection and venting, as well as to facilitate inspection and maintenance of the cover.
- Place gas detectors in closed structures to warn of potential gas buildup.
- Install vent fans to remove methane buildup from the structure.
- Ensure that the design of utilities does not allow for gas migration along utility conduits. One approach is to attach utility service entrances to the outside wall of the structure so they do not penetrate the floor slab, which may create a pathway for gas entry.

If they carefully consider both the needs of the development project and the remediation system, site managers and developers could coordinate to determine the least invasive ways to place the venting system.

Utilities

Almost all commercial facilities will require utilities, such as sanitary sewers, potable water, natural gas, electricity, and telecommunications. Although most utilities are installed underground, some, such as electricity and telecommunications lines, can be above ground. Utilities can impact the effectiveness of the containment system in the following ways:

- If the utility is located within or below the cover system, liquids leaked from a sewer or water supply line can increase the quantity of leachate being generated and accelerate biodegradation of wastes in specific areas within the containment system.
- Leakages from a sanitary sewer located above a cover system's barrier layer might be captured by the cover's internal drainage system and cause excessive bio-fouling of drainage media.
- A utility line can become a conduit for gas, which can migrate along a pipe or wire.
- A utility line can hamper the normal flow of water off the site or into the drainage layers of the protective cover.
- A utility structure that penetrates the cover system can serve as a conduit for surface water to infiltrate the cover.
- If water does not drain properly around a utility, it can pool, thereby aggravating any settlement.
- If the utility is located within or below the cover system, repair or upgrade work would also require excavation into the cover and contaminated material.
- If a utility is located in an area where significant differential settlement occurs, the above conditions may be aggravated.

A number of engineering approaches are available to ensure that these potential occurrences do not hinder the effectiveness of the containment system. Some of the approaches that site managers and developers can use to locate and configure the containment systems and utilities.

When the containment system is newly built on the site, the EPA site manager may have a great deal of discretion in how containment systems are built and where they are placed on the site. For example, clean "utility corridors" can be created by placing the piping and other components into oversized trenches, which are then backfilled with uncontaminated, or "clean" soils. The additional width and depth of the trenches limits the possibility that waste will be encountered or the cover system will be damaged during future excavations. This method was used to install electrical conduit trenches to accommodate development of athletic facilities at the Chisman Creek Site in Virginia. A variant of this approach was used at the Denver Radium site in Denver, Colorado. Instead of building one large containment cell, four smaller ones were built with spaces between them. These spaces contain sufficient volumes of uncontaminated native soils to allow the utilities to be laid in clean material between the cells. Also, the containment areas were located where buildings were not likely to be placed, such as areas designated as parking lots or lawns.

Utility corridors can often be placed in uncontaminated materials by adding sufficient clean fill above the contaminated material. When this technique is used, a good safety measure is to place visible barriers, such as colored soil or brightly colored synthetic geotextile material between the contaminated material and the clean fill to act as permanent markers for future workers. However, with proper precautions, such as the use of a contractor who is certified to work with hazardous waste, the utilities can be installed directly in the contaminated area. A contractor or property owner who intends to excavate into material classified as a RCRA hazardous waste is required to obtain authorization from EPA to excavate into the materials, as well as obtain EPA approval of the plan for the proper management of any contaminated material. The requirement for EPA approval may be specified in the remedy, whether or not the material is a RCRA hazardous waste.

Approaches for Installing Utilities on Remediated Sites:

- Put service entrances for gas, water, sewers, electricity, and communications on the wall of the building, so they do not penetrate the floor slab, which could create a potential for gas entry.
- Place active or passive gas control and warning systems in all closed structures.
- Place clean fill on either side and below the utility conduit, where it is built below the protective cover.
- Place utilities in clean areas constructed between containment "cells."
- Place the utilities in built up areas of clean fill above the protective cover. (Some building codes mandate that utilities be below the frost line).Where settlement is likely, design piping and other components to accommodate some movement.
- Incorporate monitoring systems to detect leakage or breakage of utilities.

When used in areas that will experience differential settlement, piping should be designed to accommodate some movement by using features such as ductile materials and flexible connections. For pressurized water and gas systems, automatic monitoring devices and shut-offs could be used to prevent large uncontrolled releases. Gravity sewers and other non-pressurized systems should also be designed for easy monitoring. For example, double-walled piping equipped with an integrated leak detection system could be used. Another example of a monitoring system consists of lining the utility trench with a geomembrane prior to installing the piping and backfilling, and sloping the trench to direct the flow to monitoring sumps. The sumps could be periodically checked for liquids. The need for and type of monitoring system would be decided based on cost, implementability, performance, maintenance, and perceived risk of leaks.

Site Access

Efficient ingress and egress for people and freight is crucial to the success of a commercial facility. Poorly designed entrances and exits may cause site occupants, vendors, and customers to lose valuable time waiting for traffic or negotiating difficult turns. Local governments and state highway jurisdictions determine the general requirements of site access. Their primary concerns are to minimize disruption to traffic flow on streets and highways and to ensure the safety of neighborhoods and highways. State and local planning agencies may restrict access on certain roads within a specified distance from an intersection. Thus, one of the first actions of a site planner should be to contact the local planning agencies.

To avoid dangerous traffic jams on public streets and highways, properties are often designed to favor incoming traffic. Incoming traffic can be expedited by providing a reservoir of space inside the property's entrances. If necessary, this may be done at the cost of a more complicated exit, since exiting traffic moves more slowly than incoming traffic and can more easily negotiate complicated turns. After considering the requirements of local planning authorities, the RPM and other stakeholders should consider the potential impact of the following important factors on containment systems:

- the loads and stresses from heavy or outsized trucks that are expected to enter the site; and
- the future maintenance and repair requirements for remedy components, such as monitoring wells or diversion walls.

If some remedy components are placed near or under an entrance or exit, future maintenance activities could disrupt access to the property.

Other Design Considerations

Paved Surfaces

Most commercial sites have paved surfaces for parking lots, sidewalks, roads, and common areas. Paved surfaces can be an integral part of the cover system, placed above a complete cover system, or located outside the contaminated area. Paved surfaces that serve commercial functions and are an integral part of the remedies are in place at the Mid-Atlantic Wood Preservers Superfund site in Harmans, Maryland, the Peterson/Puritan Superfund Site in Cumberland and Lincoln, Rhode Island, and the Ascon Landfill site in Los Angeles, California, among others.

Paved surfaces are generally made of asphalt, concrete, or crushed rock. The factors to consider when choosing among these are: their permeability, load-bearing capacity, durability, long-term maintenance needs, susceptibility to damage from settlement, ease of repair of settlement damage, the amount of subsidence and settlement anticipated, and the nature of the contaminated material. Also, the needs of the commercial activities need to be considered.

Asphalt has been the most frequently used material for paved surfaces over containment areas. Because it is somewhat flexible, it can deform somewhat without failing. Settled or damaged areas can be quickly filled in. Most asphalt surfaces, by themselves, are too permeable for some types of contaminants. However, they may be used at sites where the underlying contaminated material is insoluble, or where the principle purpose of the cover is to prevent human contact with the waste. Where the situation warrants the expense, special asphalt mixtures and engineering techniques are available. For example, at the Ascon Landfill, a special double-sealed asphalt design was used. It included 12 inches of asphalt aggregate and 2-3 inches of asphalt-macadam as a wearing surface. Although the slope was only one percent, the state accepted the design because it met permeability requirements. The asphalt cover over the Mid-Atlantic site's containment area is used by a trucking company as a parking lot. Because the contaminated soil under the cover is only slightly soluble, there is little risk of contaminants leaching into the groundwater. Nevertheless, the site owner has agreed to monitor groundwater as a precaution.


Part of the Enterprise Avenue site at the Philadelphia International Airport is covered with a concrete runway capable of landing large aircraft.

Although concrete surfaces may be used to cover many containment systems, it is not used as often as asphalt. At the Enterprise Avenue Superfund site, a concrete runway was placed over part of a containment system. Concrete can be damaged by settling, and is expensive and time-consuming to repair.

Crushed rock or gravel surfaces are often used for access roads, support areas, and parking lots that experience limited traffic volume. Because surfaces made with these materials can be quickly repaired, they are useful for temporary surfaces where development is being delayed pending the cessation of settlement. Although crushed rock or gravel are generally not useful as the primary cover material, they may be useful as a component of a cover system. For example, a gravel surface can protect a soil cover from damage caused by heavy truck traffic.

Surface Vegetation

Most landscaping at commercial developments is included in the overall site design to enhance common areas, walkways, roads, and buildings. The landscape features and vegetation can also limit erosion of the underlying soil and promote evapotranspiration. The type of vegetation used at a site depends on the climate in the region, type of containment system, the planned future use, and the availability of irrigation. Grasses are often used because they have shallow root systems, minimize erosion, and often require little irrigation or fertilization. Deep-rooted plants, such as trees and shrubs, typically have not been used because of the potential that roots would damage the cover systems or grow into the contaminated material. However, if properly accounted for in the design, a Superfund site can support a wide variety of vegetation. Specially designed "planting zones," "islands," terraces, or above-ground planters may be located within the limits of the cover system. Such features may require thicker layers of supporting soils, biota barriers, enhanced drainage, and other modifications to ensure the integrity of the cover system.

Surface Water Management

Surface water can erode the surface layer of a cover system as well as percolate into the cap. Examples of techniques used to manage surface water on cover systems include grading the cap to establish an effective slope (usually 3-5 percent), and building drainage channels and swales. However, many commercial uses require a flatter slope. To accommodate such needs while maintaining the integrity of the cover, the surface layer may be minimally sloped to support the reuse activity, while the underlying drainage or other layers can be more steeply sloped. Flat areas should be periodically inspected to avoid pooling of water.

Ensuring the Effectiveness of the Remedy

While considering the need for reuse, all remediations should include measures to ensure that future activities at the site do not reduce the effectiveness of the remedy. These measures include the consideration of future stewardship in the planning, design, and implementation of the remedy and redevelopment projects, techniques for ensuring the integrity of the protective cover, operations and maintenance (O&M) on a continuing or periodic basis, and institutional controls.

Planning and Design

Preparation for safeguarding the effectiveness of the remedy should begin as early in the remedy planning and design process as possible. It is important that the remedy maintenance be practicable, to minimize disruption to the site's future uses and to foster implementation and oversight. Although a state or PRP is generally responsible for O&M, many maintenance tasks can be implemented by the site operator or owner. For example, at the Denver Radium site in Denver, Colorado, the owner's maintenance of the parking lot also serves to maintain the protective cover. Overly complex O&M requirements are less likely to be fully implemented. It is important that regulatory authorities, developers, and other stakeholders know, in as much detail as possible, the implications of institutional controls, so they can plan their operations accordingly. The O&M plan and institutional controls should be considered early, along with reuse information, although it may not be possible to specify the details until later in the remedy design stage. By considering the long-term stewardship requirements early in the Superfund process, site managers and communities can help select remedies that are practical and that can be implemented.

Ensuring Containment System Integrity

Maintaining the integrity of the cover system involves controlling whether and how facilities on the surface penetrate the cover system, and preventing accidental intrusion into the cover system. Foundations and supports for fences, light poles, signs, and other features could penetrate the cover system and possibly extend into waste if standard construction techniques are used.

Because items that penetrate the cover can provide a conduit for gas and water movement, special construction techniques, such as engineered seals to prevent the migration of gas or water or built up clean soil above a cover system to allow foundations and utilities to be placed in uncontaminated material, must be used. These techniques were addressed earlier in this Section.

Accidental intrusion into the containment system can result from unauthorized digging for repairs or improvements, wear and tear of surface layers due to traffic or animals, and other activity. The use of warning or barrier layers, therefore, should be considered to minimize damage to critical cover system components and encroachment into waste. Visible barriers, such as colored geotextiles or other synthetic layers, can be placed in the upper portion of the cover system to serve as a warning to workers that additional digging can result in damage to underlying layers and exposure of contaminated material. A visible layer can also be used under high-activity areas to provide early warning that the soil has eroded to a point where repair is necessary.

Intrusion into the containment system can also be caused by digging activity by animals and people. A biota-barrier may be used to prevent such activities. Depending on the situation and anticipated intruder (*e.g.*, children or animals) an appropriate barrier layer might range from a geogrid or other geosynthetic to gravel or cobbles**.** The barrier will be most effective if it is separated from the critical components of the cap or is thick enough to withstand a limited degree of intrusion. For example, at the Cohen Property Superfund site in Taunton, Massachusetts, a salt storage area was constructed over lead contaminated soils. High visibility orange fencing was placed over the contamination to mark the beginning of contaminated soil and to serve as a warning against encroachment.

Another method for preventing damage to containment systems is to register the site with the county or state "one call system," which all states have to prevent excavators from inadvertently damaging subsurface utilities. The site could be registered with the one-call system, and markers could be placed on the site to help workers locate the containment areas before digging. Although EPA does not know of any such application at a Superfund site, there in no reason why such an arrangement could not be negotiated with a one call system.

Operating and Maintaining Remedy Components

After construction of the major portions of the remedy is completed, the site may require monitoring and periodic maintenance of fixed and operating components to ensure that the remedy functions properly and protects human health and the environment. O&M can include a wide range of activities, such as operating gas and groundwater collection and treatment systems, caring for surface vegetation and paved areas, conducting annual and special inspections, monitoring air, water, and soil quality, and making any necessary repairs and upgrades to remedy components. Appendix A describes some common monitoring and maintenance needs. O&M is especially important at reuse sites since, in addition to normal operations of the remedy, the site is subject to continued wear and tear by people and vehicles. Moreover, the site may be used in ways that were not anticipated when the remedy was designed, or in ways that were not specified in the reuse plans existing at the time of the site remediation.

Monitoring and maintenance are usually arranged for by the PRP or state and may be conducted by the site owner or occupant, or a state or local government agency. At some redeveloped sites, the responsibility for implementing and paying for O&M may be split among various parties. Generally, an agreement is reached between the regulatory authority, developer, and PRP to establish monitoring procedures, acceptance criteria, and remediation methods for the critical maintenance needs. It is important that the roles and responsibilities are clearly delineated in enforceable agreements and specified in an O&M plan. For more details on operation and maintenance of Superfund sites, see *Operation and Maintenance in the Superfund Program*, OSWER 9200.1-37FS, EPA 540-F-01-004, May 2001.

At certain sites, normal maintenance of buildings and surface features may also address concerns about maintaining the integrity of the containment systems. At the Ohio River Park, Pennsylvania, Ascon Landfill, Los Angeles, and Denver Radium, Colorado sites, the property owners are responsible for normal maintenance of the asphalt and other surfaces, which also serves to protect the containment systems. If such areas are properly maintained, the need for maintenance by PRPs or the state would be minimal.

EPA regulations require that an O&M plan be developed for fund-financed sites to aid in the transition from EPA to the state for O&M. O&M plans may also be useful for PRP-financed sites. The plan should delineate the responsibilities of the various parties, and such items as the nature and frequency of maintenance activities, sampling, and inspections. It should also address limitations on the reuse activity; for example, if vehicles above a certain weight are to be prohibited from the property. The plan should also include requirements for documenting and reporting maintenance and related activities at the site. This information typically would be included in an annual report distributed to interested parties and regulatory agencies. In addition to the requirements for annual and special inspections, EPA conducts an in-depth review of the remedy at least every five years, for any Superfund site where the remedial action resulted in hazardous substances, pollutants, or contaminants remaining on site above levels that would allow for unlimited use and unrestricted exposure. The five-year review generally results in two products: a determination of whether the remedy is still protective of human health and the environment, and a list of recommendations of activities that need to be performed to ensure continued protectiveness, including an identification of the parties responsible for those activities. The results of these reviews can be used to modify operating plans and site-use plans as needed.

Institutional Controls

Remedies often incorporate institutional controls to prohibit certain activities and land uses that are incompatible with the remedy. Because of their importance in restricting future land uses and in defining long-term compliance needs, the need for institutional controls should be identified as early in the remedy selection process as possible. Stakeholders are required to be informed whenever institutional controls are added or modified if ti constitutes a substantial change in the remedy documented in the ROD.

Institutional controls include measures such as prohibiting drilling wells, excavating below a specified depth, and placing buildings on the site. Public access to certain parts of the site, such as areas containing gas vents, may also be restricted to authorized personnel. These controls are implemented through land-use regulations imposed by local governments; property law devices such as easements and covenants that restrict future land or resource use; and informational devices such as deed notices that inform prospective purchasers of residual on-site contamination.

Several of the above mentioned controls were used at the Bunker Hill Superfund site in Kellogg, Idaho. The site encompasses both the smelter facilities and a surrounding 21-square mile area that includes five towns. The ROD specifies that surface soils in the towns be excavated, a plastic barrier be placed in the shallow (1-2 feet) excavations, and clean soil and sod be placed over the barrier. Institutional controls were imposed on digging in the re-sodded areas. During remedy selection and design a PRP can address how to accommodate a potential future need to excavate into contaminated materials and how to ensure that institutional controls are maintained well into the future, especially when properties change hands. The following are some considerations for designing effective institutional controls.

- **Excavating into Contaminated Materials**. A site owner who intends to excavate into a containment system must obtain prior written approval from the EPA Region and use a contractor certified to handle hazardous materials if the materials are classified as a RCRA hazardous waste, or if the requirement is specified in the remedy. This requirement could mean costly delays for the developer. The process can be simplified by including excavation procedures in the institutional controls and other site agreements. This approach could preclude the need for special approvals, as long as the contractor follows the established procedures and notifies EPA or a state regulatory authority. Another useful approach to ensure that future excavations at a site do not disturb the containment system is to require the PRP or property owner to file a survey plot recording the type, location, and quantity of contained waste, and as-built drawings with the clerk of the local court and with the local recorder's office.

- **Long-Term Compliance with Institutional Controls**. Institutional controls are often incorporated into consent decrees and other enforcement documents. One potential pitfall of this approach is that enforcement documents may only be binding on the signatories and do not "run with the land." Thus, a property transfer can occur without informing the future owner of the requirements. Although the responsible parties are still ultimately responsible for compliance with the institutional controls, future owners of the property may not be bound to the terms of the consent decree. It may be possible to avoid this pitfall by requiring signatories of an enforcement document to implement more long-term institutional controls, such as information devices or proprietary controls, and to record all relevant information about the site with the clerk of the local or district court.

In developing remedial alternatives that include institutional controls, EPA may also consider the capability and resolve of local authorities or private sector interests to implement the institutional control program. At the Bunker Hill site, a system of flexible institutional controls is operated by existing local administrative structures and programs that are consistent across all jurisdictions affected by the site. Using this strategy, the Environmental Health Code in the Idaho Legislature was amended to include specific containment management regulations and performance standards. With the state legislature's approval, the local jurisdictions were given the authority to

At the Bunker Hill Superfund site in Kellogg, Idaho, a system of flexible institutional controls is operated by existing local administrative authorities.

govern all excavation, building, development, grading, and renovation at the site. Furthermore, the local jurisdiction was made responsible for educating the community about the redevelopment program.

At the Fairchild Semiconductor Superfund site in Mountain View, California, the PRP signed an indemnity agreement to protect the developers, lenders, tenants, and successors in title as the redevelopment process proceeded. In these circumstances, the agreement holds the buyer harmless for actions, liability, loss, or damage arising from claims made for further remediation, third party damages, and the like.

4. Redevelopment Case Studies

This Section describes seven projects where successful redevelopment has occurred on remediated waste sites where contaminated material or waste treatment systems remain on site. Although these projects represent a wide range of sites, pollution problems, and commercial uses, they are not exhaustive of all circumstances that occur at Superfund sites. Nevertheless, they demonstrate how remediation and redevelopment efforts may complement each other. The discussion for each site includes a brief description of the site and contamination, key factors considered during remediation that were important to the redevelopment, and the redevelopment plan. Appendix B contains one-paragraph summaries of these seven sites plus eight other sites where redevelopment has occurred on containment systems. The seven detailed cases are listed below.

- **Denver Radium, Denver, CO:** A large retail store and parking lot was built on a site where insoluble metals-contaminated soil was consolidated into four containment cells with unlined bottoms and asphaltic covers. The covers also serve as the store's parking lot.

- **Raymark Industries, Stratford, CT:** A 300,000 square foot retail center is planned for this 33-acre site. The site was compacted to accommodate planned structures and fill dirt was added above the protective cover. Piles were driven into the ground on part of the site to provide for future buildings. The piles extend through the cap, and are fitted with seals to prevent water infiltration.

- **Mid-Atlantic Wood Preservers, Harmans, MD:** A 3.2 acre site with shallow contaminated soil was covered with asphalt and is being used as a parking lot for a trucking business.

- **Ascon Landfill, Los Angeles, CA:** A port facility was built on a municipal landfill with a deep water table. Although not an NPL site, this landfill was compacted and covered with a uniquely engineered surface that would meet most requirements for a RCRA type C cover.

- **Ohio River Park, Neville Island, PA:** A sports center that includes several acres of indoor facilities, outdoor sports fields, and parking areas was built on a 32-acre site that contained a number of contaminated areas. The project involved installing protective covers, a slurry wall, groundwater monitoring system, and gas collection system; adding clean fill above the covers; compacting parts of the site; and foundation designs that accommodate the remedy.

- **Rentokil, Inc., Henrico County, VA:** Light industrial and commercial buildings are planned for this 10-acre site. Building foundations are to be incorporated into the cover, using special structures that Rentokil calls "divider walls."

- **Peterson/Puritan, RI:** This 980-acre site contains six businesses, an industrial condominium complex, a little league park, a dog pound, and a riverside park and bike path. Cleanup of the site, including operation of in place waste treatment systems, was accomplished without shutting down existing businesses.

Denver Radium

Site History: Operable unit (OU) 9 of the Denver Radium Superfund site in Denver, Colorado is a 17-acre property that includes a former brick plant, a parking lot, and a large area of exposed soil. Land use in the vicinity of the site is predominantly commercial and industrial, with a residential area located several blocks to the east. Industrial activities began at the site in 1886 with the construction of the Bailey Smelter. In 1890, the Gold and Silver Extraction Company began a cyanide leaching operation. By 1903, a zinc milling operation had been added. From 1914 to 1917 the U.S. Bureau of Mines operated a radium ore processing facility on site. Other industrial operations have included minerals recovery, manufacturing and servicing of storage batteries, and oil reclamation. The last industrial use, from 1940 to 1980, was for brick manufacturing.

Remedy: The remedial investigation (RI) found that the site was contaminated at various depths with radioactive materials, heavy metals (primarily zinc and lead), and arsenic. All radioactive materials found at the site were excavated and shipped to an offsite-licensed disposal facility. Approximately 16,500 cubic yards of metals-contaminated soil remained on site. The selected remedy called for the consolidation of the remaining contaminated soil into four separate on-site cells with asphaltic caps. The contaminated material presents an ingestion or, if windblown, inhalation risk. A highly impermeable cap was not required, because the material is only slightly soluble and water infiltration is not likely to cause it to migrate. Nevertheless, long-term groundwater monitoring (to monitor existing groundwater contamination) and maintenance of the cap are required to ensure that the remedy is working. Deed restrictions prohibit the placement of drinking water wells on the site because of the existing groundwater contamination.

Redevelopment Plan: Before the remedial action was implemented, Home Depot Inc. expressed an interest in purchasing the property to build a retail store. The remedy included consolidation of the metals-contaminated soils into four cells. To allow utility corridors to be placed in uncontaminated material the cells were separated by clean fill. Future utility maintenance contractors do not need to encounter hazardous materials. Geotextile materials were placed at the edges of cells to provide markers for the contaminated soils, and these were covered with clean fill. As a condition of the agreements between EPA and other interested parties, the developer was required to build and maintain an asphaltic cover, which limits access to the materials below and serves as the store's parking lot. The groundwater monitoring wells were completed at the grade level of the parking lot to prevent obstructions to the redevelopment.

At Denver Radium

- Contaminated soil was compacted as it was placed into the excavation.
- The original ROD, which called for a multi-barrier cap, was changed to allow a less restrictive cap, because the solubility of the contaminated material is low.
- The containment system was redesigned to include four containment cells, instead of one, to allow for areas of clean soil for utility corridors.

Lessons:

- If the contaminated material is not soluble, water infiltration will not cause migration of hazardous materials, and a highly impermeable cover is not required. Thus, the cover may be constructed of available materials with moderately low permeability, such as clean soil and asphaltic materials.
- If the contaminated material is somewhat soluble, the cover could be of a single barrier design.
- The bearing strength of the consolidated material should be enough to support the cover without subsidence and should be checked to ensure that it will support the planned or anticipated redevelopment.
- The potential for future disruption of the waste can be minimized by strategically locating the consolidated materials where they are least likely to be disturbed.

A Home Depot store has been built on a portion of the Denver Radium Superfund site in Denver, Colorado.

Raymark Industries

Site History: The Raymark Industries, Inc. Superfund site encompasses 33 acres in Stratford, Connecticut. Raymark produced automotive parts and products at the site from 1919 until 1989. During that time, manufacturing waste was disposed of on the plant site, 46 residential properties, and numerous commercial and municipal properties in Stratford. Contaminants include polychlorinated biphenyls (PCBs), dioxin, semi-volatile and volatile organic compounds (SVOCs and VOCs), asbestos, and metals.

Remedy: The Raymark remedial action began in September 1995 with the demolition of 15 acres of buildings and the placement of an impermeable cover over the demolished buildings and the remaining 20 acres of the property. Underneath the cover, a pump-and-treat system is removing solvents from groundwater, and a gas collection system is operating. Two buildings on the property house equipment for collecting solvents pumped out of the groundwater and treating gases collected from beneath the cover.

At Raymark, close cooperation between EPA and the developer led to effective strategies

- Special efforts were made to compact the ground to accommodate development.
- The grade level above the containment system can be raised enough to allow foundations and utilities to be placed in clean fill.
- Pilings were installed through the cap and the cover is properly sealed; the containment area does not have a bottom liner, and there is no potential for damage to any underlying aquifer.
- Groundwater extraction and treatment systems were designed to be inconspicuous and allow for site reuse.

Construction of the protective cover involved the following:

- A gas collection system was built using four miles of perforated piping laid within an 8-12 inch thick bed of sand.
- Over 36 acres of cover materials, including a plastic liner, a clay liner, and other synthetic materials were placed over the waste.
- Between three and ten feet of clean fill were placed over these liners.
- Two miles of storm water piping were installed in the clean fill layer to collect rainwater and carry it off-site. Over 100 catch basins, manholes, and water quality units connect to this storm drainage system. On-site pavement directs rainwater into the catch basins and protects the underlying soil from erosion.
- Fifty-three wells were installed beneath the cover to monitor groundwater quality. Twelve vapor extraction wells pump solvent contaminated air out of the soil beneath the cover into a treatment building. Five extraction wells pump solvent located in pockets in the groundwater into a holding tank on the western edge of the property.
- Two buildings were built at opposite ends of the property to treat collected gases.

Redevelopment Plan: The protective cover was designed to allow for the redevelopment of the property for retail and other commercial uses, without compromising its performance. Prior to the cover's construction, soil and wastes on the site were stabilized to support development. This effort involved the following activities:

10,000 truck loads of waste excavated from contaminated off-site locations were stabilized with cement.
Six piles of soil up to four stories high covering areas as large as two acres were placed on the ground to compress the underlying soils by as much as 5.4 feet.
A 15-ton weight was dropped 70,000 times from a height of 60 feet to stabilize the soil in certain areas of the property.
9,545 wick drains were installed to help compress underlying peat deposits.
277 fourteen-inch steel piles were driven 100 feet into the ground to support a one-half acre platform designed to support the weight of planned commercial buildings.

Lessons:

- Various construction methods, such as those discussed in Section 3, can be used to build on a RCRA type C or other containment system. If the containment system does not have a bottom liner it may be feasible to drive pilings through it, so long as the cover is properly sealed and the pilings do not affect an underlying aquifer.
- It often helps to coordinate remediation plans with potential developers.
- There may be some flexibility in locating the consolidation area on the site.
- There is little difference in cost between the typical method of completing groundwater monitoring wells (with a 2-3 foot standpipe with locking cover, a concrete pad, and protective barrier) and completing the wells at the grade level, which generally improves the appearance of the property.
- There are a number of effective strategies for groundwater treatment, such as extraction wells and reactive barriers, as described in Section 2.

A conceptual drawing of the future shopping center at the Raymark Industries, Inc. Superfund site.

Mid-Atlantic Wood Preservers

Site History: The 3.2 acre Mid-Atlantic Wood Preservers facility in Harmans, Maryland is located in a mixed industrial, commercial, and residential area. The site is adjacent to a major international airport and the closest residence is within 200 feet. The facility treated lumber from 1974 through 1993. The operation employed a two-part process to preserve the wood with chromated copper arsenate (CCA). First, the lumber was pressure treated with a CCA solution in a housed processing plant; then the wood was allowed to drip and dry in the open. A spill of CCA solution in 1978 resulted in the contamination of nearby drinking water wells.

Remedy: In 1980, the owners removed 26 cubic yards of highly contaminated soil and shipped it to an off-site disposal facility. However, large portions of the facility's surface soil remained contaminated with chromium and arsenic. In 1990, the facility was ordered to move 90 cubic yards of contaminated soils from off-site areas and consolidate them on site. Following the consolidation, the whole area was covered. Groundwater testing revealed no health hazards.

Redevelopment Plan: An adjacent trucking business expressed an interest in the property. After the company entered into a prospective purchaser agreement with EPA, the land was covered with asphalt and converted to a parking lot. The new owner agreed to perform long-term monitoring and maintenance to ensure the asphalt was preventing the leaching of chromium and arsenic into the underlying groundwater. Monitoring wells were placed at grade.

At Mid-Atlantic Wood Preservers

- A moderately permeable asphalt cover was allowed because the solubility of the contaminants was not high.
- After removing highly contaminated materials, the remaining soils were consolidated with soils from off-site areas.
- Monitoring wells were installed downgradient at grade.
- The new property owner has agreed to perform long-term monitoring and maintenance to ensure that the asphalt is preventing metals from leaching into underlying groundwater.

Lessons:

- On-site consolidation and burial is not always an option, such as when the contaminants are soluble and the water table is shallow. If the solubility of the contaminants is not too great, a moderately permeable cover, such as asphalt, may suffice.
- Monitoring wells may also be placed downgradient to ensure that the contaminants are not leaching into the groundwater.
- When a simple cover, such as an asphaltic material slab is used, the institutional controls should detail how activities that require excavation into the cover should be conducted.
- If utilities or other facilities are to be placed in contaminated material, it is best done before the cover is installed. It may also be done after the fact, as long as the developer follows the procedures outlined in Section 3.

Ascon Landfill

Site History: The State of California required the formal closure of an abandoned 38-acre landfill located near Los Angeles Harbor. Although not listed on the NPL, this site provides valuable lessons for any type of waste depository. The site was originally used in the 1940s and 1950s as a source of soil for other construction projects. Prior to excavation and landfilling, the site contained silty fine sand and alluvial deposits. When groundwater was encountered, excavation of materials from the pit ceased. From 1964 to 1981, the open excavation was turned into a landfill. It was initially filled with construction debris and old tires. At a later date, these materials were covered with municipal waste. The total depth of the fill is about 95 feet with the upper 50 feet consisting of trash. After the landfill was full (1981), it was closed. A 1.5-foot soil cover was placed over the waste, and a passive gas extraction system was installed. From 1981 to 1986, large piles of coke (up to 40 feet high) were stored on the site. This process served to partially compact the waste.

The site is in an area that has saltwater intrusion, and the groundwater is not potable. Beginning in 1965, government authorities have operated a wastewater injection system just south of the site to prevent saltwater from further intruding inland. This system raised the water table about 20 feet and will keep the groundwater at this artificially high level for as long as it operates. Although a large portion of the construction debris is now inundated with groundwater, there is no evidence of groundwater contamination.

Remedy and Redevelopment: Because this site is near Los Angeles Harbor, it was ideal for locating a cargo-container handling, storage, and maintenance facility. The developer, prospective user, and State of California cooperated to develop a landfill cover that will also serve as the foundation for the new facility. The developer paved the top of the fill for work surfaces that can be adjusted to account for differential settlement and built a 7,500 square foot, five story warehouse and a small one-story office building.

Pavement Construction. Since the pavement was also to function as the final cover for the fill, its design required a permanent cover material that would be impermeable to both runoff water on the surface and to methane landfill gas from below. The design would also have to account for subsidence of the underlying material, which had recently been measured at 3.5 inches per year. The planned commercial use required that the pavement be capable of supporting the operations of a container forklift vehicle with a 68,000-pound single axle load on the front wheels and a 38,000-pound steering axle load on the rear wheels. These loads are similar to those of commercial aircraft and three to four times those used in the design of highways that carry commercial trucks. In addition, the slope of the pavement would have to be nearly flat to prevent tipping of the forklifts. The state closure law requires at least a three percent slope, which is too steep for the vehicles. A special double seal asphalt design and a one percent slope was accepted by the state in lieu of the requirement.

Before construction of the pavement began, the top of the fill was regraded by importing about 230,000 cubic yards of silty fine sand that provided a level, minimum 2-feet thick layer of soil above the existing soil cover. The total thickness of the fill over the rubbish ranged from three to ten feet, with an average of four feet. This fill was compacted to 90 percent of maximum density, per ASTM D1557, using a sheepsfoot compactor and a heavy rubber-tired loader. The compacted surface was covered by 12 inches of asphalt aggregate and two to three inches of asphalt macadam as a wearing surface. The resulting pavement has a vertical permeability of less than 10^{-6} cm/sec and a rigidity slightly less than that of road grade pavement. This level of permeability meets requirements for closures of RCRA Subtitle D facilities.

The fill side slopes were 20 feet high with a 4:1 slope. These were completed by placing two feet of compacted sand over them followed by 12 inches of compacted clay. A compacted clay cutoff wall was placed at the interface of the fill material, natural soil, and clay barrier. The clay layer was covered with fill to achieve a final slope of 2:1. The fill soil was landscaped to prevent erosion.

Building Construction. Like the pavement design, the building design had to take into consideration subsidence, differential settlement, and methane gas. Because the lower 45 feet of the fill consists of construction rubble and tires that would prevent the driving of piles, a deep foundation was ruled out. Instead, the buildings were placed on reinforced concrete mat foundations. The mat sections were approximately 50 feet by 50 feet by 18-inches thick. They were connected by post tension cables to allow for movement between segments. Regularly placed permanent pipe sleeves were fitted in the segments to enable them to be re-leveled with cement grout. The building is designed with leveling pads at the column connections to allow movement, and to tolerate up to six inches of differential settlement.

Both buildings have methane gas collection systems. These systems consist of (from bottom to top) waste covered by five feet of compacted soil, 12 inches of pea gravel, and an 80 mil HDPE membrane. The extraction piping is embedded in the gravel.

Other Observations:

- The seal, as installed, can probably be employed only in a dry climate because the asphalt mix is very moisture sensitive and cannot be placed or cured (30-60 days) during rainy weather.
- To obtain the low permeability rating, the asphalt cover required extremely close quality control measures with respect to asphalt and moisture content.
- The maintenance cost of the surface over a landfill is approximately twice the maintenance cost of a parking lot. Maintenance for this cover is estimated to be two to three cents/square foot/year.
- The closure cost for the project was approximately 10 to 20 percent higher than the closure costs for normal landfills without a planned reuse.
- The coke stock piling that occurred earlier served to partially compact the site, thereby reducing subsequent settlement.

Lessons:

- Structures employing foundations placed over or in fill material may experience subsidence or differential settlement. In such cases, consideration should be given to the impact this may have on the integrity of the cover, and the stability of structures placed over it.

- Alternative approaches to managing runon and runoff may be used in place of the requirements for the finished grade of the cover (*e.g.*, 3-5 percent required for a RCRA type C cover). The developer must demonstrate that the reuse has an equivalent runoff removal efficiency or will prevent infiltration entirely.
- Creative engineering based on knowledge of an existing landfill and hydrogeology can lead to useful designs, especially unique ways to meet requirements for permeability of the cover.
- Depending upon the size of the landfill, its final closure configuration, and the demand for usable land in the area, this type of landfill may be redeveloped for a variety of commercial, industrial, or recreational uses.
- Landfill contents, such as construction debris, may preclude the use of pilings.

Ohio River Park

1999 Junior Olympics at the Island Sports Center Ice Rink, one of several facilities, at the Ohio River Park site.

Site History: The site consists of approximately 32 acres on the western end of Neville Island, roughly 10 miles downstream from the City of Pittsburgh. The Ohio River borders the site to the north and the river's back channel borders it to the south. The site is accessible from the mainland via the Coraopolis Bridge, linking the Town of Coraopolis with Neville Island. Land use on the island is primarily industrial/commercial, although there are some residential areas between the site and the eastern end of the island, which is occupied by petrochemical facilities, coal coking facilities, and abandoned steel facilities. The nearest residence is approximately 450 feet from the site. The site sits on a 20-30 foot high bluff overlooking the river. The bluff shows signs of erosional sloughing. A large part of the site is within the 100-year flood plain. The river has flood control dams that periodically cause the water table to rise above the level of areas filled with waste. Industrial waste disposal activities were conducted at the site from 1952 through the 1960s. Much of the industrial waste was disposed of in two ways: wet wastes were placed into trenches and dry wastes were piled on the surface. Construction debris was also deposited on the site.

Remedy: The Remedial Investigation determined that there were three primary areas of soil contamination: one approximately seven acres and the other two approximately one-half acre each. The principal contaminants were coal tars, pesticides, organic chemicals, and metals. The coal tars had been disposed of in an unknown number of trenches, and were slowly migrating. The investigation also found a groundwater plume consisting primarily of volatile hydrocarbons.

The remedy, which was installed in 1998 and 1999, involved covering the three concentrated waste areas with a Subtitle C type cover; covering areas without concentrated waste with an erosion protection cover; providing for runon and runoff control by directing the water flows into ditches or piping systems that discharge into the river or its back channel; and installing a passive gas collection system. The passive gas collection system, which was incorporated into the cover, consists of a series of trenches that were backfilled with gravel and perforated pipe. These were overlain with compacted soil and covered with an HDPE liner. The overall slope of the surface of the liner was kept at three percent. The liner was covered by a synthetic drainage layer and a thin layer of fill. Groundwater monitoring wells were placed through the cover. For non-concentrated waste areas, a 10-inch thick soil cover was placed to control erosion and prevent direct access. It was determined that the groundwater plume had stabilized and long-term monitoring of natural attenuation of the groundwater contaminants would be appropriate, unless otherwise indicated.

Before placing the RCRA cover, it was discovered that the coal tar had migrated to the edge of the bluff and could be observed along the upper wall. To prevent further migration and subsequent release down the slope, a 15-20 foot deep by 200 foot long cement slurry wall was placed along the edge of the slope. Although a cement slurry generally has a higher permeability than a bentonite one, cement was chosen because of its higher physical strength. Rip rap was placed along the slope to shore up the bluff during construction of the slurry wall and to prevent further erosion.

Redevelopment: The site's owner determined that the property's location and size made it ideal for a sports center that could include several acres of indoor and outdoor facilities. The construction to date has included a five-acre building housing two Olympic class indoor ice skating rinks, a golf training facility, a fitness center, and restaurant; an approximately 2-3 acre covered golf dome; an outdoor site appropriate for team sports such as soccer and baseball; and accompanying parking lots and sidewalks. Before construction could begin, the grade levels of several areas of the site were raised with clean fill to bring them above the 100-year flood plain elevation.

The approximately 250 by 300 foot covered golf dome was situated on the eastern section of the seven-acre covered landfill area. Prior to construction of the facility, settlement plates were placed on the fill and loaded with five or more feet of clean soil. Potential settlement was monitored for one to three months. The site was then re-graded to make it completely level. This involved placing from three to eight feet of clean fill (equivalent to an erosion layer) over the cover. By allowing at least three feet of clearance between the drainage layer of the cover and grade, it was possible to run utility and sewer lines to the structure in clean soil. The foundation for the dome is anchored by concrete footers 2.5 feet deep by 10-12 feet long. These types of footers, which are usually narrower and deeper, were made wider and shallower to keep them in clean soil. The parking area is asphalt, and the field is built with synthetic turf. The turf's design calls for sand to be worked into the artificial fibers to give a true turf "feel." The design allows the surface to be used both with and without a cover. The playing field includes a drainage layer to accommodate the potential for precipitation when the cover is down. This drainage layer directs water to collection pipes and then to the sewer system. It is not associated with the RCRA cover drainage system.

The ice rink and restaurant are placed in an area of the site where the Record of Decision (ROD) calls for at least a ten-inch erosion protection cover of clean soil. Since this area was below the 100 year flood plain, an average of eight feet of fill was placed there, to raise the elevation above the flood plain. This fill serves as the erosion cover and provides more than sufficient clearance of clean soil to allow for utility construction.

Lessons:

- When the waste materials are deposited in an area that is too large and diverse to excavate and treat or remove, a combination of techniques may be used to remediate and redevelop the site.
- A Subtitle C type cover over the landfill is useful to prevent further leaching of materials from the unsaturated zone to the groundwater and to collect gas.
- The use of clean fill and effective grading of the site can promote a safer remediation as well as flexibility in redevelopment.
- A groundwater monitoring system is a useful precaution, especially when there is incomplete knowledge about the types of materials that have been placed in the landfill.
- Deed restrictions to prevent people from disturbing the cover or installing drinking water wells are crucial to the long term viability of the remedy.

Protective cover installation, slurry wall construction, and the completed Island Sports Center.

Rentokil, Inc.

Construction of "divider wall" at the Rentokil site. All development must occur within the walls to prevent cover disruption.

Site History: The 10-acre Rentokil, Inc. site in Henrico County, Virginia is the location of a former wood treating plant that operated between 1957 and 1990. Although the manufacturing processes that were used at this site are similar to those used by Mid-Atlantic Wood Preservers, the remediation and redevelopment options were quite different.

Between 1982 and 1990, Rentokil used only the chromated copper arsenate process to treat wood. Prior to 1982, it also used several other compounds, including chromated zinc arsenate, creosote, xylene, pentachlorophenol, and fire retardants in a solution of ammonium phosphates and sulfates. These processes used mineral spirits and fuel oil in the preserving mixtures. From 1957 to 1963, waste processing liquids were discharged into an open earthen pit. In 1963, this pit was cleared, cleaned, and replaced with a concrete holding pond. In 1976 or 1977, approximately 1,100 to 1,400 pounds of chromated copper arsenate (CCA) were disposed of in an on-site pit. The EPA site investigation determined that the groundwater, soil, and surface water are contaminated with pentachlorophenol, creosote derivatives, copper, chromium, arsenic, and dioxin.

Remedy: All wood treating equipment was removed from the site and sediment control structures were built to reduce further migration of sediment containing arsenic, chromium, copper, and zinc to a tributary of North Run. The remaining structures were demolished, material contaminated with unusable CCA and pond sediments were excavated and disposed of or incinerated off site, and a RCRA Subtitle C type cover was built. In addition, a slurry wall and dewatering system (horizontal wells) were installed, and three wetland areas were restored.

Redevelopment Plan: A 1996 ROD amendment included a provision allowing Virginia Properties, Inc. to redevelop the site after completion of the remedy. The company plans to construct light industrial and commercial buildings on the site. The building foundations are to be incorporated into the cover, a concept Rentokil terms "divider walls." All structures must be placed within the area enclosed by these subsurface barriers. The divider walls extend below the cover and enclose approximately 50,000 square-feet. A concrete pad was placed on top of the divider walls to further prevent disturbance of the materials below the cover. To prevent slurry wall damage, heavy vehicle crossings were built where parking lots will cross the slurry wall. These crossings are designed to distribute vehicle mass over a larger area, minimizing the possibility of damage to the underlying slurry wall. Construction was completed in August 1999.

Lessons: When barrier walls are used, some planners recommend not building structures over them, to avoid potential damage from heavy loads or vibrations, and to allow for future repairs. However, with proper engineering design to spread the load over a larger area, some structures, parking lots, or roads may be built on them.

Peterson/Puritan, Inc. Superfund Site

Gracious Living industrial condominiums in an old textile mill near the waste treatment shed

Site History: The site is approximately two-miles long and extends about 2,000 feet to the east and west of the main river channel of the Blackstone River. It is located in a mixed industrial and residential area within the towns of Cumberland and Lincoln in north-central Rhode Island. The concentrated industrial area of the site (OU1) was used for the manufacture of general industrial and specialty chemicals, and packaging of aerosol products, soaps, and detergents. In 1974, a railcar accident resulted in the release of an estimated 6,000 gallons of solvents on the site. Groundwater is contaminated with chlorinated solvents, volatile organic compounds (VOCs), and heavy metals. Surface water is contaminated with low concentrations of VOCs. Prior to the cleanup, people in the area faced risks from contact with, or ingestion of, contaminated groundwater, surface water, sediment, or soil. Other environmental concerns at the site relate to a closed industrial landfill (OU2), which is still being investigated.

Remedy: The remedial action addressed identified two primary sources of contamination in OU1, which were identified in the Remedial Investigation. At the first property, known as CCL, some of the contaminated soil was excavated from two catch basins and a manhole located at the property's tank farm, and a subsurface soil vapor extraction system was installed to treat the rest of the soils in the area. Contaminated groundwater at this part of the site is being extracted and treated by air stripping and granular carbon filtration. At the second property, known as PAC, soils contaminated with VOCs and arsenic were excavated and an in-place oxidation treatment system was installed to immobilize the arsenic in the soil and reduce its concentration in the groundwater. At this part of the site, natural attenuation of groundwater contaminants is being monitored, and institutional controls have been implemented to restrict activities on the site. The remedy for the closed landfill on the property has not yet been determined.

Redevelopment Plan: Since the site contains a number of operating commercial and light industrial businesses, as well as an outdoor athletic facility, a remediation plan was developed that allows for continued use of these facilities. A concrete cover was placed in the tank farm area to allow for vehicle and cart access. An asphalt pad was placed in the PAC area to increase the size of the parking and truck facility, and a bituminous concrete cover was placed over the soil vapor extraction system. These covers protect people from exposure to the contaminated soils, prevent infiltration of rainwater into the subsurface contaminated materials, and allow parking and other commercial activities to be conducted in the areas over the subsurface treatment systems and the contaminated soils. Thus, commercial and recreational activities continue while the soil and groundwater are being treated.

Lessons:

- It is possible to install and operate *in situ* treatment technologies, such as soil vapor extraction and oxidation, without removing existing buildings or hampering the operations of their tenants.
- In a commercial area, contaminated areas that are unpaved can be covered with asphalt or concrete to eliminate direct contact exposure and protect and enhance the *in situ* treatment systems.
- The above ground portion of the groundwater pumping and treatment systems can be placed in a small building in an inconspicuous location on the site.

The CCL Custom Manufacturing facility on Martin Street is one of a number of businesses on the site.

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Appendix A
Key Monitoring and Maintenance Needs at Containment Systems

Agreements between the EPA, PRP, developer, and other interested parties should address the following monitoring and maintenance needs:

1. ***Groundwater quality.*** For containment systems that do not have an active treatment component, monitoring generally requires periodically drawing samples from monitoring wells to ensure that the water quality is stable and that the potentiometric surface remains within an allowable range. The former indicates that the containment system is effective and the latter that the direction of groundwater flow has not changed nor has the water level risen above the level of the waste. The monitoring frequency may range from monthly to annually, depending on the type of containment and historical data available. If there is an active treatment system on site, then provision should be made for regular inspections to verify that the equipment is working and process stream testing to verify effectiveness. Redevelopment activities will have to allow for access to this equipment.

2. ***Leachate monitoring.*** Containment systems that have an engineered bottom liner with a leachate collection system will generally require monitoring of these systems to ascertain if the quantity and chemical makeup of the leachate is consistent over time. For many Superfund sites where there is no engineered bottom to the containment area, the groundwater monitoring system is analogous to leachate monitoring.

3. ***Gas release concentrations.*** When it is anticipated that a containment system will generate gas, the remedy designer can specify passive or active gas collection and venting. Both types of systems require monitoring and maintenance. Passive systems require regular monitoring to ensure that the system is not violating air quality standards and is behaving in a predictable fashion. When it is determined that gas production has ceased, the vents should be removed, as they represent a weak point in the cover system. The critical component in active systems is the equipment used to handle, treat, or recover gas. This equipment requires regular maintenance. A gas meter in a building will indicate if the gas control system needs repair.

4. ***Subsidence monitoring.*** When subsidence and settlement are expected, EPA recommends that the entire area be monitored, not just the vicinity of building structures. Monitoring can include routine re-surveying of pre-placed markers and regular walkovers of the property, especially after heavy rain. Subsidence in the basement of a structure may also provide warning of potential damage to any subsurface cover. Puddling of water indicates settling, which represents a potential danger to the integrity of the cover, and should be repaired.

5. ***Surface erosion.*** Unless the cover system is a rock armor or hardened surface (*e.g.*, asphaltic concrete), there will generally be some erosion. Routine inspections of the runon/runoff control systems should be conducted to ensure they are functioning. All above-grade slopes should be examined for signs of erosion, such as rills, and repaired as necessary.

Appendix B
Waste Sites With Commercial Use Over Containment Systems

Below are brief descriptions of 15 completed projects where various types of commercial and industrial development occurred on sites with a range of containment systems.

Abandoned Municipal Landfills, Coquitlam, British Columbia, Canada: The closed landfills, which contained municipal waste, construction debris, and wood waste, were redeveloped to accommodate light industry and commercial structures. The construction techniques used for the redevelopment included preloading, pile foundations, and load compensating foundation designs constructed with lightweight cellular concrete.

Ascon Landfill, Los Angeles, CA: This former 95-foot deep landfill near Los Angeles Harbor was ideal for locating a ship-container handling, storage, and maintenance facility. The developer, prospective user, and State of California cooperated to develop a landfill closure design that would also serve as the foundation for the new facility. The design included unique paving approaches on top of the fill to create work surfaces that can be adjusted to account for differential settlement, and construction of a 7,500 square-foot, five story warehouse and a small one-story office building. Although the slope of the top surface is lower than usually required for a containment system cover, the use of a special asphaltic concrete mixture provided a permeability low enough to meet the RCRA Subtitle D requirements. Both buildings have methane gas collection systems.

Bangor Gas Works, Bangor, ME: This four-acre site is a former gasification plant with coal tar contamination in the subsurface. The contaminated soils were covered in place by a parking lot, and a supermarket now thrives on the site.

Brickyard Shopping Center, Chicago, IL: This fifty-acre site was once a clay pit that had been mined to a depth of 70 feet. After mining operations ended, the pit was filled with refuse. To accommodate a two-building structure that houses 110 retail stores, the ground was dynamically compacted, and spread footer foundations were used to support the buildings.

Denver Radium Operable Unit (OU) 9, Denver, CO: The area of concern is a 17-acre parcel that was contaminated with radionuclides and heavy metals. The radionuclides were excavated and disposed of at a permitted off-site facility. The metals-contaminated soils were consolidated into an on-site excavation and covered. To remediate the site and allow for retail development, the metals were placed into four separate excavations. These excavations were placed with sufficient separation between them tp allow for utility corridors to be placed in clean fill between them. The excavations were completed at the surrounding grade, and covered with an asphalt parking lot. Downgradient groundwater monitoring wells were also completed at grade.

H. Brown Company, Grand Rapids, MI: This site contained heavy metals as a result of former battery recycling operations. The remedy involved placing three-feet of clean soil on top of the contaminated soil and covering the clean soil with buildings and asphalt parking lots. The clean soil layer allowed for placement of utilities without intrusion into the underlying contaminated soils. The buildings and parking lot act as covers. The developer has assumed responsibility for long-term groundwater monitoring and the maintenance of the buildings and asphalted areas.

John F. Kennedy Library, Boston, MA: Built over part of the Columbus Point landfill, the Point was created by 50 years of dumping of refuse. It was closed in the 1950s. Before building could begin, underground fires had to be extinguished. The building itself is constructed on piles driven into the bedrock.

Lorentz Barrel & Drum Company, San Jose, CA: The 6.7-acre drum recycling site was contaminated by releases of VOCs, heavy metals, PCBs, and other materials. The principal chemicals of concern were the VOCs in the soil and groundwater. The remedy was to install a pump-and-treat system for the groundwater, remove and dispose of debris and PCB-contaminated soils off site, construct an SVE system, and install an asphalt concrete cover. The SVE and pump-and-treat systems are expected to operate for some time. San Jose State University and EPA are discussing the purchase of the covered property for use as a parking lot for nearby sports facilities.

Mid-Atlantic Wood Preservers, Harman, MD: A 3.2-acre property was contaminated with chromated copper arsenate. Highly contaminated soil was removed. However, elevated levels of chromium and arsenic are still present. The remedy involved covering the entire site with asphalt, for use as a parking lot by an adjacent trucking company. The company has assumed responsibility for the long-term groundwater monitoring program, and for maintaining the asphalt in good condition.

North Albany Demolition Landfill, Albany, NY: The approximately 45-acre North Albany Landfill was used primarily for disposal of demolition debris and excess soils, but municipal solid waste was also disposed there. Little sorting and compaction was performed on the material placed in the fill, which is estimated to be between 4.6 and 9.2 meters thick. Groundwater occurs at approximately the original grade. The planned development is a public works garage/office building and a maintenance building. The site investigation suggested the use of dynamic compaction where buildings would be placed.

Ohio River Park, Neville Island, PA: The Ohio River Park site consists of approximately 32 acres on the western end of Neville Island, roughly 10 miles downstream of the City of Pittsburgh. The Remedial Investigation (RI) determined that there were three areas of primary soil contamination. One is approximately seven acres and the other two are approximately one-half acre each. The principal contaminants were coal tars, pesticides, organic chemicals, and metals.

The remedy, which was installed in 1998 and 1999, involved covering the three concentrated waste areas with a Subtitle C type cover, covering areas not including concentrated waste with an erosion protection cover, providing for runon and runoff control, and installing a passive gas collection system. In addition, groundwater monitoring wells were placed through the cover. The owner covered a large portion of the covered area with up to eight feet of clean fill and built a golf driving range with a removable dome roof. In addition, a sports complex containing indoor ice rinks and a restaurant, and parking lots and sidewalks were built.

Peterson/Puritan site, Lincoln and Cumberland, RI: This site covers approximately 980 acres along the Blackstone River in a mixed industrial and residential area. It consists of two operable units (OUs), the first includes the industrial park and the second a closed industrial landfill. The primary chemicals of concern at OU1 are chlorinated solvents, VOCs and arsenic. In addition to excavation, the remedy has included the following on-site treatment: groundwater extraction involving air stripping and granular activated carbon filtering, soil vapor extraction (SVE), *in situ* oxidation to immobilize arsenic in the soil and reduce groundwater contamination, and a program of natural attenuation of groundwater. A concrete pad was placed in the tank farm area to allow access for vehicles and carts. An asphalt bed was placed in a treatment area, increasing the size of the parking and truck facility. A bituminous concrete cover covers the area containing the SVE system, thereby protecting it while allowing for additional parking and access for servicing the treatment system. This remedy allowed the industrial park to remain in operation during and after the remediation. The landfill (OU2) has been fenced and is still under investigation. The city has used a small portion of the site that lies along the river opposite OU2 for a bicycle path.

Raymark Industries, Inc., Stratford, CT: This 34-acre site was found to contain organic compounds, asbestos, and heavy metals contamination. The site also has product floating on the groundwater. The remedy was to consolidate hot spots and contaminated soil on site and to partially stabilize the material using cement. The landfilled material was compacted using both soil preloading and dynamic compaction. The contractor drove 277 steel pilings up to 100 feet deep, to provide a foundation platform for future development. The pilings include special fittings at the points where they extend through the cover. The remedy also includes groundwater source extraction wells, a soil vapor collection system, and monitoring wells. Many of the monitoring wells were placed within the covered area, and access was provided to service them.

Rosen Brothers Scrap Yard Dump, Cortland, NY: Prior to 1970, this 20-acre site was used to manufacture small metal items. From 1971 to 1985, it was used as a scrap metal processing and disposal facility. The soil is contaminated with VOCs and heavy metals, and the site contains a former three-acre lagoon that has been partially filled with construction debris and municipal and industrial wastes. The remedy is to consolidate material from hot spots into the lagoon area, cover it, and install a soil cover over the rest of the site to prevent contact with residual contamination. The city has installed an asphalt cover, underlain with a geomembrane, over five-acres of the site. This area is for a planned rail spur to contain a rail to truck transport facility. The location of the remainder of the site is amenable to commercial and other types of redevelopment. However, the balance of the remedy has not yet been completed.

Sears Roebuck Freight Terminal, Chicago, IL: This 61-acre former landfill and railway loading dock was created from refuse and river dredge material. Dynamic compaction was used to prepare the site for construction. The loading dock structure was demolished and fed through a rock crusher to provide an 18-inch crushed rock layer over the compacted material. The developers built a 461,291 square foot warehouse and a 45,000 square foot office building on this material.