

Coal Combustion Residuals Pond Closure

Guidance for Construction Over Closed or Closing Ponds



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Ponds

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ABSTRACT

In June 2010, the Environmental Protection Agency proposed national regulations for disposal of coal combustion residuals (CCRs) and sought comment on several alternative regulatory approaches. Regardless of the alternative selected, the rule is expected to lead to a significant number of wet-to-dry conversions and closure of many CCR ponds.

The purpose of this guidance document is to provide power companies with comprehensive guidance and information related to the engineering issues associated with construction of landfills and other structures over closed or closing CCR ponds. A significant amount of information on the behavior of impounded materials, especially fly ash, has been developed over the past 10 years. This report provides state-of-the practice information on static and seismic liquefaction, field and laboratory testing of impounded materials, and design analyses for closure cap construction and landfilling on ponds. It provides guidance on feasibility-level evaluations, hydrogeologic investigations, construction and operation, and post-closure care.

A companion document, *Coal Combustion Residuals Pond Closure: Guidance for Dewatering and Capping* (EPRI report 3002001117), provides the same type of information for dewatering and closure of CCR ponds.

Keywords

Fly ash

FGD (Flue gas desulfurization)

Ponds

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Overfills

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LIST OF ACRONYMS

ACAA	American Coal Ash Association
ASTM	American Society for Testing and Materials
C&D	construction and demolition
CCR	coal combustion residual
CD	consolidated-drained test
CFR	code of federal regulations
CGI	combustible gas indicator
CPT	cone penetration test
CPTu	cone penetration test with pore pressure measurements
CRR	cyclic resistance ratio
CQA	construction quality assurance
CSM	conceptual site model
CSP	concentrating solar power
CSR	cyclic stress ratio
CU	consolidated-undrained triaxial test
CWA	Clean Water Act
DPT	direct push technology
EDPM	ethylene-propylene-diene-monomer
EGC	exposed geomembrane cover
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FGD	flue gas desulfurization
FOG	fats, oil, and grease
FS	feasibility study or factor of safety
GCL	geosynthetic clay layer

GWMP	groundwater monitoring plan
HDPE	high density polyethylene
LLDPE	linear low density polyethylene
LMS	leachate management system
MSE	mechanically stabilized earth
MSW	municipal solid waste
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PCC	post-closure care
PMF	probable maximum flood
PMFA	potential failure mode analysis
POTW	publicly owned treatment works
PP	polypropylene
PV	photovoltaic
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
SESC	soil erosion and sedimentation control
SPT	Standard Penetration Test
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey

1

INTRODUCTION

1.1 Background

In June 2010, the Environmental Protection Agency (EPA) proposed national regulations for disposal of coal combustion residuals (CCR) [1]. One proposed alternative was to regulate CCR as a special waste under 40 Code of Federal Regulations (CFR) parts 261, 264, 265, 271, and 302 through 40 CFR Part 264, which implements Subtitle C (hazardous waste) provisions of the Resource Conservation and Recovery Act (RCRA). Subtitle C regulates waste under a federal EPA program. Regulation under Subtitle C would essentially result in complete conversion from wet handling of CCR to dry handling and closure of all active CCR ponds. A second proposed alternative was to regulate CCR as a solid waste under 40 CFR Part 257, which implements the Subtitle D (nonhazardous waste) provisions of RCRA. Subtitle D regulates solid waste under programs administered by the states. While Subtitle D regulation would offer more opportunity to continue some wet handling practices, such as for bottom ash, it would still lead to a significant number of wet to dry conversions and closure of many CCR ponds. EPA also recently proposed Effluent Limitations Guidelines (ELGs) for steam electric plants, which will provide additional incentive to close CCR ponds [2].

The consequence of the regulatory changes is that power plants will likely be closing a large number of ash and flue gas desulfurization (FGD) solids settling ponds under an aggressive timeline over the next 10 years. The EPA began a survey of existing CCR disposal ponds in 2010 and as of June 2013 has provided final reports for 516 ponds [3]. Closing or retrofitting these ponds will require significant cost and design and construction resources over the next two decades.

A companion EPRI report [4] provides guidance on dewatering and closing of CCR ponds. The present report specifically provides guidance on the construction of landfills over closed or closing ponds. Some of the material is repeated in order to create two stand-alone documents. The reuse of closed pond properties as a site for landfills was successfully initiated in the mid-2000s at several power plant sites, demonstrating that the technology is available and cost effective. This approach is being examined and implemented at more facilities every year, and there are a number of common engineering challenges that must be addressed. Sections 2 through 10 of this EPRI guidance document provide information that has been used to address the engineering challenges associated with construction of a new landfill over a closed or closing pond. Section 11 discusses construction of other facilities over a closed pond.

1.2 Purpose

The purpose of this guidance document is to provide power companies with detailed guidance and information related to the engineering issues associated with the design and construction of a landfill or other structures over an open or closed CCR pond.

1.3 Coal Combustion Residuals

CCRs – fly ash, bottom ash, and FGD solids – have been described by EPRI in several previous publications (for example see [5], [6], [7], [8], [9], and [10]), and are briefly summarized below.

1.3.1 Fly Ash

Fly ash refers to the lightweight particles that travel with the flue gas as it exits the furnace and moves away from the high-temperature combustion zone. Power plants are equipped with particulate collection devices, either electrostatic precipitators (ESPs) or baghouses, designed to remove nearly all of the fly ash from the flue gas prior to reaching the stack to prevent it from being emitted to the atmosphere. Dry fly ash collected in the ESP or baghouse is then either pneumatically conveyed to a hopper or storage silo (i.e., dry management) or mixed with water and sluiced through a series of pipes to an on-site pond (i.e., wet management).

Fly ash particles are composed mainly of amorphous or glassy aluminosilicates. However, the particles also contain some crystalline compounds that either pass through the combustion zone unchanged or are formed at high temperatures. Elements such as arsenic and selenium that become volatile at high temperatures preferentially condense on the surface of the ash particles as the flue gas cools.

Fly ash particles are typically spherical in shape, either solid or with vesicles (see Figure 1-1). A small percentage of particles are thin-walled hollow particles called cenospheres. The particles are fine-grained, typically silt-sized, ranging from 0.001 to 0.1 mm in diameter, with median particle diameter of 0.02 to 0.025 mm. Fly ash is usually tan to dark gray in color.

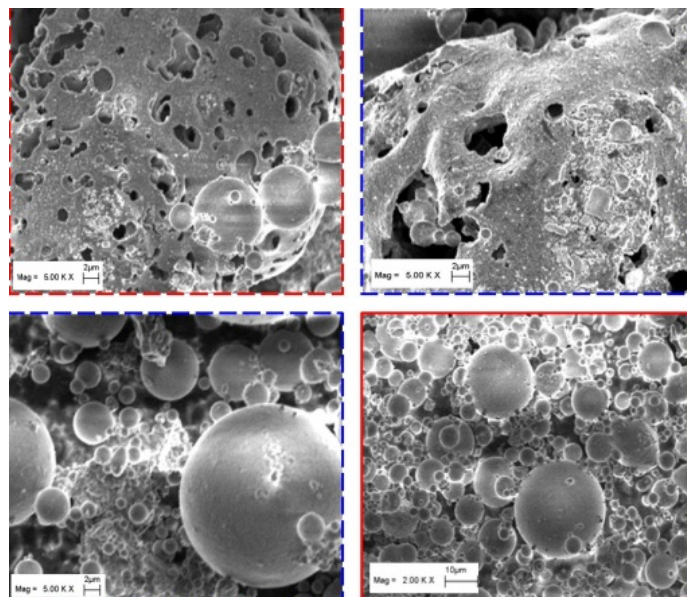


Figure 1-1
Fly ash morphology [7]

1.3.2 Bottom Ash

Bottom ash consists of heavier particles that fall to the bottom of the furnace. Bottom ash is also composed primarily of amorphous or glassy aluminosilicate materials derived from the melted mineral phases. Most bottom ash is produced in dry-bottom boilers where the ash cools in a dry state. Boiler slag is a type of bottom ash collected in wet-bottom boilers where the molten particles are cooled in a water quench.

Whether collected from dry-bottom or wet-bottom boilers, bottom ash is usually mixed with water and conveyed away from the furnace in a sluice pipe. It is transported either to a dewatering bin or to an on-site pond.

Bottom ash is coarser than fly ash, with a sandy texture and particles ranging from about 0.1 mm to 50 mm in diameter. Bottom ash from dry-bottom boilers is generally dull black and porous in appearance. It typically has the consistency of coarse sand to gravel and higher carbon content than fly ash. Boiler slag is black and angular, and has a smooth, glassy appearance [8].

1.3.3 FGD Residuals

FGD residuals are produced by the removal of SO_2 from the flue gas. Because there are many different types of FGD processes available, different types of FGD residuals are produced, varying from wet sludges to dry powders. FGD systems are generally categorized as “wet” or “dry”. Wet FGD systems contact the flue gas with an aqueous slurry or solution in an absorber vessel. The solid produced is collected in the bottom of the absorber in the form of slurry (a few percent solids) that must be dewatered.

Dry and semi-dry FGD systems produce a dry product that does not require dewatering [6] and is generally managed in a landfill. This document focuses only on wet residuals disposal.

Most wet scrubbers use slaked lime or limestone (CaCO_3) as the alkaline reagent. Some limestone-based FGD systems use lime with a high magnesia (MgO) content; the high magnesia content leads to increased liquid-phase alkalinity in the scrubber, and can enhance SO_2 removal [6].

Wet FGD residuals from calcium-based systems are primarily composed of either calcium sulfite hemihydrate ($\text{CaSO}_3 \cdot 1/2\text{H}_2\text{O}$, “calcium sulfite”), calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, “calcium sulfate” or “gypsum”), or a mixture of the two. The design and operation of the wet FGD system determines which type of residual is formed. Calcium sulfite is the initial reaction product formed, and is the predominant solid from inhibited oxidation systems. In forced oxidation systems, the calcium sulfite is converted to calcium sulfate. In natural oxidation systems, a mixture of calcium sulfite and calcium sulfate is formed, depending on the absorber conditions. If the oxidation is less than 15%, all of the sulfate gets incorporated into the calcium sulfite crystal lattice. So even though the solids might contain up to 15% sulfite, they look and behave as 100% calcium sulfite hemihydrate. As the oxidation exceeds 15%, gypsum begins to form as a separate solid phase [6].

Forced oxidation systems are the most common type of FGD system currently in use. The CCR produced by this system is FGD gypsum. The FGD gypsum has a fine-grained consistency and although it is produced with a water slurry from the scrubber, it can be dried and used in

wallboard or placed in a landfill. In some cases, FGD gypsum is managed in rim ditch ponds and gravity drained prior to use or placement in a landfill.

Following initial dewatering, calcium sulfite still has high water content (as much as 200 percent) and is described as having a consistency similar to oat meal. It is weak and difficult to dewater and handle. Calcium sulfite FGD solids are sometimes managed in ponds. In other cases, fly ash and lime may be added to improve handling and increase the material's strength and suitability for placement in a landfill.

1.3.4 Wastewater Streams

Wastewater streams include bottom ash (see Figure 1-2) and fly ash (see Figure 1-3) sluice water, FGD blowdown and dewatering effluent, leachate, and rainfall runoff that has contacted the CCRs. All of these wastewaters contain constituents derived from the source CCRs, and can vary widely in elemental concentrations. One or more of these wastewater streams may be managed in CCR ponds [10]; as such, they must be considered during the pond closure process.

If other byproduct materials are managed within the ponds, consideration must be given to how they will continue to be managed during and after closure of the pond.



Figure 1-2
Fly ash sluice lines [11]



Figure 1-3
Bottom ash sluice lines [11]

1.4 Description of Coal Combustion Residuals Ponds

1.4.1 Pond Types

CCR ponds are typically primary treatment facilities. The CCRs are retained within the pond for sufficient time to permit settling to meet discharge criteria. A CCR pond may also be a treatment pond where chemicals are added to treat the sluiced water to meet discharge criteria and may be followed by a secondary or polishing pond to allow for mixing, normalization, flocculation, and/or settling.

CCR ponds are created using four primary methods.

- *Retention Dam.* This type of pond is created by construction of a retention dam with an overflow spillway in an existing stream valley to contain sluiced CCRs (see Figure 1-4). The sluiced CCRs are piped from the plant to the pond and the CCRs are allowed to settle prior to

overflow of the supernatant through the spillway under a National Pollution Discharge Elimination System (NPDES) point source discharge permit. The sluice lines are moved to different locations to more uniformly fill in the valley. The spillway is often constructed using stop logs to control the elevation of the ponded water and may be raised or lowered to increase or decrease the holding time of the water. This type of CCR pond is normally designed to manage a specific design rainfall such as a 25-year, 24-hour storm and is permitted under a separate state dam safety program. An emergency spillway is often required to prevent overtopping during the maximum design rainfall. The maximum design rainfall is often the Probable Maximum Flood (PMF) as defined by the U.S. Army Corps of Engineers. Periodically the retention dam may be raised to allow for additional disposal capacity and/or flood control. The settled CCRs may be periodically removed and placed in a landfill but are typically closed in place as a landfill. Smaller operations may be closed by removal of the CCRs.

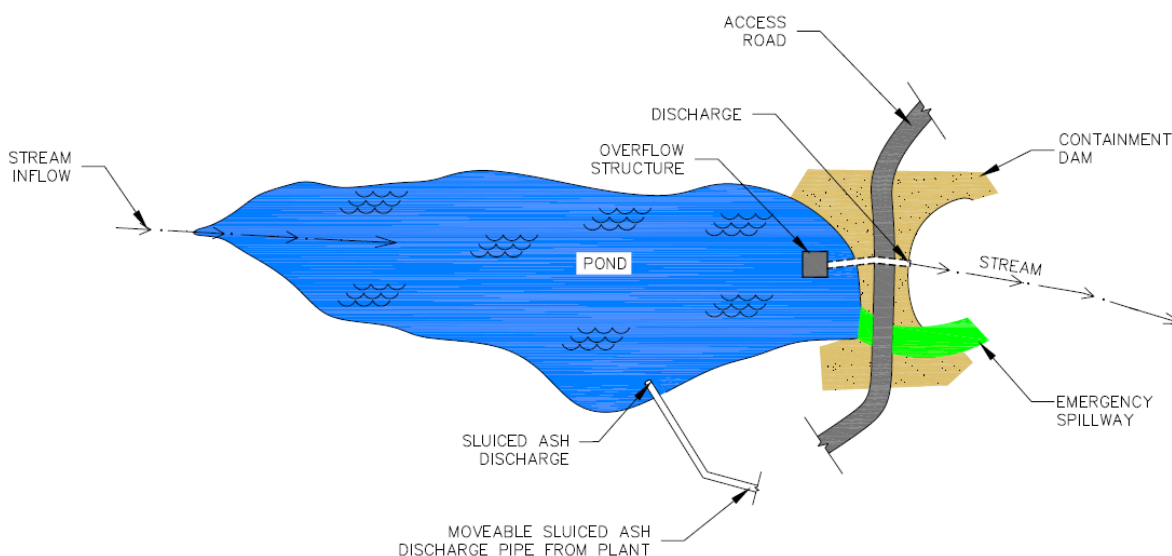


Figure 1-4
Fly ash pond constructed in stream valley fill

- Perimeter Embankment.** This type of pond is created by construction of a perimeter embankment with an overflow spillway to contain sluiced CCRs (see Figure 1-5). This type of pond may have the embankment around the entire perimeter (i.e., 360 degrees) if located on relatively flat land or around a portion (i.e., 270 degrees) on the side of a hill. The embankment is constructed by excavation of native soil within the footprint of the pond and placement of native soil in the embankment. The depth of the excavation is dependent upon the site geology and hydrogeology and could be several feet deep to several tens of feet deep. The height of the embankment can be adjusted/raised to meet ongoing disposal requirements. The sluiced CCRs are piped from the plant to the pond and the CCRs are allowed to settle prior to overflow of the supernatant through the spillway under a NPDES point source discharge permit. The sluice lines are moved to different locations to more uniformly fill in the pond. The spillway is often constructed using stop logs to control the elevation of the

ponded water and may be raised or lowered to increase or decrease the holding time of the water. This type of pond only receives sluiced water containing CCRs, other wastewaters, or direct rainfall and does not receive runoff from outside of the embankment from a stream. As for a retention dam, the disposed CCRs may be periodically removed and placed in a landfill but are often closed in place as a landfill in the pond. Smaller operations may be closed by removal of the CCRs.

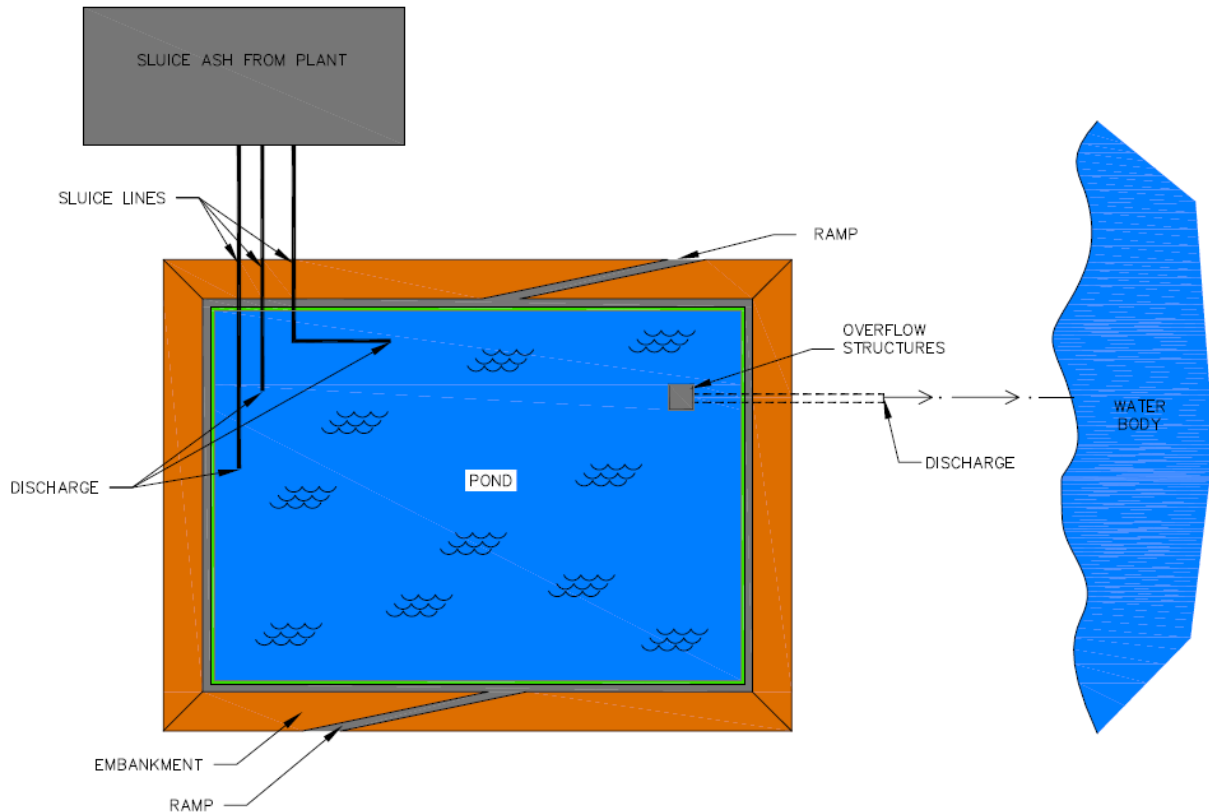


Figure 1-5
Fly ash pond constructed using perimeter berms

- Rim Ditch.* This type of “quasi” pond is created using either a retention dam or perimeter embankment (see Figure 1-6). CCRs are sluiced to the inside of the containment structure where they are allowed to settle. The CCRs are excavated to create a drainage channel directing sluice water flow within the containment structure in a recirculation loop. As the sluiced CCRs flow through the ditch, the CCRs are allowed to settle to provide clear decant water by the end of the rim ditch which can then flow back to the plant for reuse or to a discharge spillway for discharge under an NPDES permit. The settled CCRs are then excavated and placed adjacent to the drainage ditch and allowed to further drain. The drained CCRs are periodically removed and placed within the containment structure as a landfill operation. The drainage channel or ditch operation is called a “rim ditch” because the ditch is often located around the edge or rim of the containment structure. Periodically, the containment structure (i.e., dam or perimeter embankment) may be raised to allow for additional disposal capacity. The disposed CCRs may be periodically removed and placed in

a landfill but are typically closed in place as a landfill. Smaller operations may be closed by removal of the CCRs.

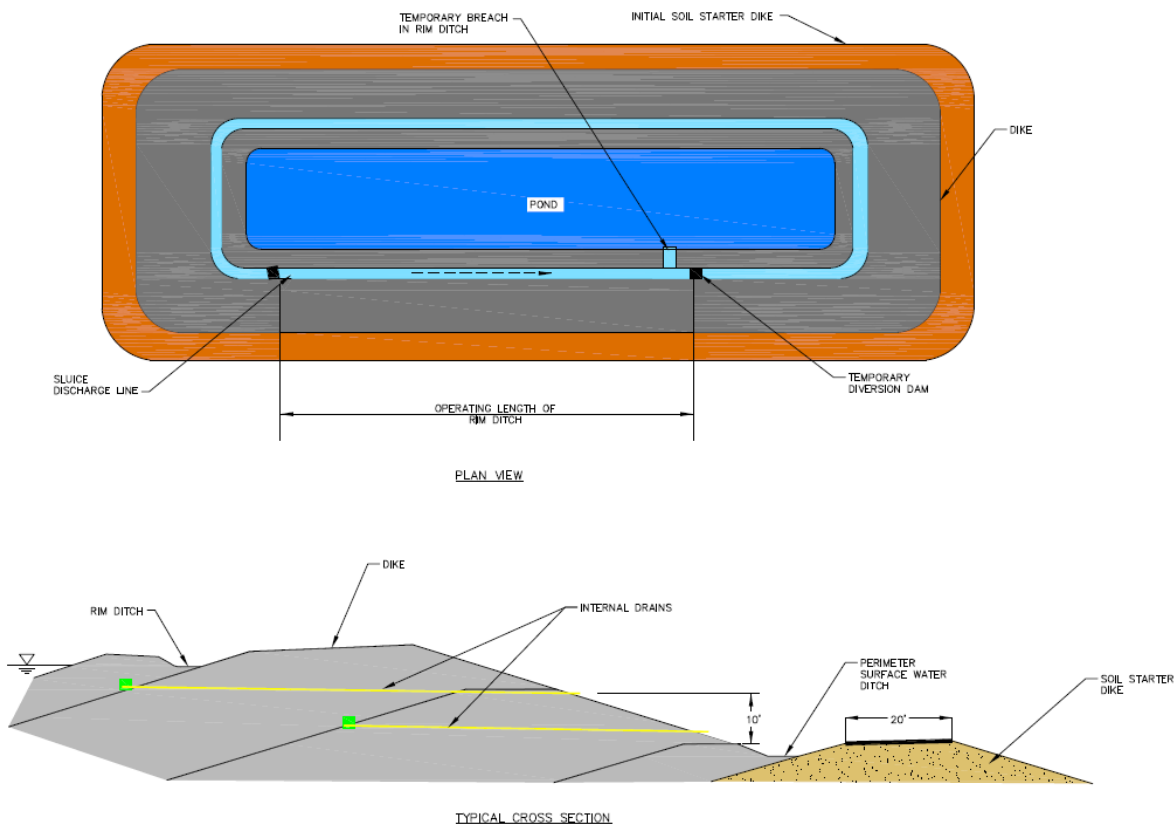


Figure 1-6
Fly ash pond constructed using rim ditch method

- *Incised Pond.* This type of pond is created by excavation into existing ground to create the storage volume required for adequate treatment through settling. Stormwater run-on is often prevented by use of perimeter berms. The pond is operated similarly to a perimeter embankment or retention dam.

1.4.2 Components of CCR Ponds

Components of CCR ponds vary by necessity and may include one or more of the following:

- *Containment structure.* The containment structure includes a perimeter embankment or retention dam (see Figure 1-7). The structures are typically constructed of low permeability soil but are often a composite dam structure containing a low permeability soil layer with more permeable soil layers that could include bottom ash, general fill, aggregate, or large stone/rip rap.



Figure 1-7
Containment structure (courtesy of AEP)

- *Bottom liner.* The bottom liner serves to contain waste material to protect the underlying groundwater and adjacent surface water. The bottom liner typically consists of a low permeability material that may include either a native soil layer or a barrier constructed of compacted clay soil, a geomembrane, or a geosynthetic clay layer.
- *Underdrain.* Underdrain systems are used to collect the upwelling of groundwater that could cause uplift pressures under the bottom liner when the pond is being constructed or when it is drained while the CCRs are being removed. Underdrain systems are comprised of a granular/permeable soil or a geocomposite drainage material. The underdrain typically includes a drainage piping system to convey collected groundwater to a discharge point (see Figure 1-8).



Figure 1-8
Groundwater underdrain (courtesy FirstEnergy)

- *Spillway.* Common forms for a spillway include:
 - Vertical drop-down overflow structure (“decant structure”) with a lateral discharge pipe to convey overflow through the containment structure to a stream (see Figure 1-9).



Figure 1-9
Decant structure [12]

- Stop logs are utilized with the drop-down structure to enable raising and lowering of the pond water level (see Figure 1-10).



Figure 1-10
Stop logs (courtesy DTE Energy)

- Overflow weir with stop logs to regulate the elevation and flow of treated pond water. The overflow weir may convey water into discharge piping or over a reinforced concrete or armored spillway to convey the design flow and minimize erosion.
- A discharge channel is used to convey water away from the downstream toe of the containment dam without channel erosion.
- An emergency spillway may be constructed to convey flow from extreme rainfall events that cannot be safely conveyed using the normal overflow structure.
- *Aerator.* An aerator may be used to infuse oxygen into the discharge water to meet discharge criteria (see Figure 1-11). The aerator is typically a structure that causes turbulence of the water prior to entering the discharge receiving stream.



Figure 1-11
Aerator at discharge (courtesy DTE Energy)

- *Energy dissipater.* An energy dissipater is used to reduce the energy from the overflow prior to discharge into the receiving stream to reduce erosion potential. The energy dissipater could include large rip rap or engineered concrete flumes to reduce the velocity of the discharge overflow (see Figure 1-12).



Figure 1-12
Energy dissipater [12]

- *Interior containment berms.* Interior containment berms are used to separate disposal or treatment areas to optimize disposal practices. They may be used as an initial treatment step to remove bottom ash which will settle out before the fly ash; an interior containment berm would be used to contain the bottom ash and allow the sluiced water containing fly ash to overflow into a large pond that has a longer retention time to settle the finer fly ash. The interior containment berms may also be used to convey flow across previously placed CCRs in an engineered channel.

- *Monitoring instrumentation.* Instrumentation is used to monitor the conditions of the disposal facility to identify any early signs of distress that could lead to slope movements or other instability. Common monitoring instruments can be described as follows:
 - Slope indicators are used to measure the lateral displacement of soils and are used to detect potential slope movements in perimeter containment berms.
 - Pore pressure probes (i.e., piezometers) are used to measure pore water pressures in the containment structure and subsurface materials around the containment structure to identify potential leakage from the pond.
 - Staff gauges are used to make direct measurements of the water levels in ponds to aid in controlling the sluicing operations to avoid potential overtopping or operating at water levels outside of the design parameters (see Figure 1-13).

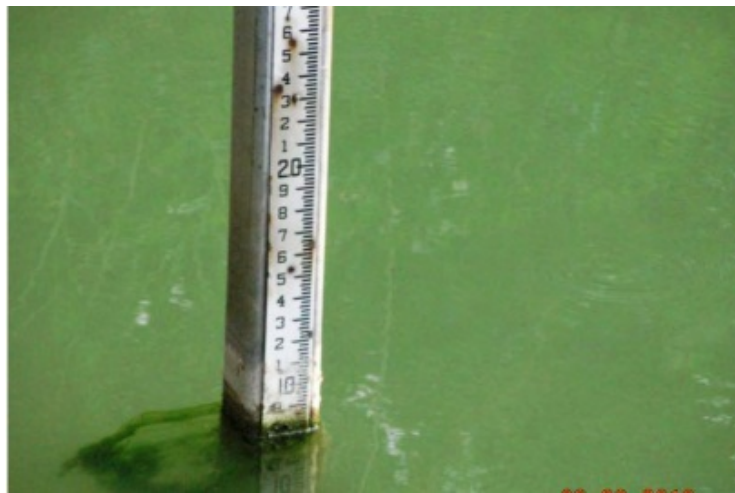


Figure 1-13
Staff gauge [11]

- Settlement monuments are used to measure settlements of the structures at various locations to provide data to assess whether the settlement is within design parameters and identify unusual deformations.
- Groundwater monitoring wells are placed around the pond to assess water quality and water levels and allow a comparison against background (i.e., normal) conditions to assess whether the pond is impacting groundwater.
- Gallery drains or blanket drains are constructed inside of the containment structure to control leakage through the structure and avoid internal “erosion” (i.e., soil loss) that could lead to slope instability. Gallery drains are not common in CCR ponds but may be used in geologic areas where the containment structure abuts fractured bedrock. In that case, the gallery drain is used to convey water from the abutment through engineered piping instead of through soil.
- Flow measurement devices include V-notch weirs and Parshall flumes (see Figures 1-14 and 1-15, respectively). They allow measurement of flow rate by measuring the depth of water above the measurement point.



Figure 1-14
Parshall flume [12]



Figure 1-15
V-notch weir [12]

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2

PROCESS OVERVIEW

2.1 Introduction

Construction of a new CCR landfill over an existing closed pond can be a complicated undertaking from regulatory, technical, economic, legal, and public perspectives. The new CCR landfill will be regulated under a combination of state and federal criteria and could be considered a part of the closure of the underlying treatment pond and require consideration of NPDES wastewater treatment pond closure criteria.

The premise used in this document is that construction of a new CCR landfill over an existing closed or closing pond can be completed by integrating the bottom liner system of the new landfill into the cover system of the existing closed or closing pond using the equivalent of solid waste disposal (Subtitle D) criteria. Therefore, there are significant cost savings by combining these two systems at a brownfield facility and avoiding the cost to site and design a new greenfield landfill facility.

Closure of wastewater treatment ponds is most commonly completed by excavation and removal of the wastes to achieve a “clean” closure in accordance with state regulations. However, the closure of CCR ponds is not normally achieved through the removal process because of their large size. Therefore, they can be closed as a quasi-landfill using a combination of the most appropriate state regulations and engineering judgment applied through a state permitting process.

This section provides an overview of the process of constructing over CCR ponds. Details of each of these processes are contained in subsequent sections. The primary elements to be considered include:

- Initial Planning
- Feasibility Study
- Permitting and Regulatory Considerations
- Concept Design
- Geotechnical Evaluation
- Hydrologic Evaluation
- Hydrogeologic Evaluation
- Wastewater Infrastructure Needs
- Landfill Location and Design Criteria
- Construction and Operational Considerations

- Long-Term Care
- Considerations for Construction of Other Structures

Sections 2.2 through 2.12 of this section provide information on the process of constructing CCR landfills over existing closed ponds. Section 2.13 provides information for construction of other structures over existing closed ponds.

2.2 Initial Planning

Initial planning is conducted to understand the general requirements for the project to develop an understanding of the time and cost to complete the project along with any legal or regulatory requirements that could affect the outcome.

Initial planning is typically conducted at a high level within the corporation, with input from various departments such as environmental, real estate, engineering, procurement/supply chain, regulatory, operations, construction, and legal.¹ The general outcome of the initial planning is the agreement that the project should be pursued and to define the process to reach a conclusion of the viability of the project. Determining the viability of the project requires a series of evaluations that are outlined in this section. Further, the initial planning team outlines the scope of work for the evaluations, determines the assignment of the project to an “owning” department, and develops a planning schedule and planning budget to complete the construction of a landfill or structure over a CCR pond.

2.3 Feasibility Study

The primary objective of the feasibility study (FS) is to document that appropriate construction alternatives are identified; these alternatives are presented to the project team so that the viability of the project can be assessed. The FS is oftentimes broad and general because certain site-specific information may not be available. The FS commonly addresses the following:

- Definition of the Project Objectives
- Summary of Existing Site Conditions and History
- Regulatory Requirements
- Site Characterization (which often includes a preliminary field investigation)
- General Design Criteria
- Development of the Construction Alternatives
- Assessment of Each of the Alternatives (including implementability, effectiveness, and cost)
- Ranking of the Alternatives
- Recommendation of One or Two Alternatives
- Recommendations for Follow-up Work to Complete the Project

¹ The names of the departments within the many utility company/pond owners vary. The names used herein are based upon the general function of the department and are not intended to exclude appropriate departments.

When a new landfill over a pond is to be integrated into the closure of a pond, the FS can include considerations of remediation such as covering/capping and control of groundwater and/or surface water contamination.

Detailed information on the feasibility evaluation is provided in Section 3 of this document.

2.4 Permitting and Regulatory Considerations

Once the FS is completed and the landfill alternative is selected, the final permitting and regulatory requirements are defined. These requirements typically address state and/or federal regulatory requirements for:

- National Pollutant Discharge Elimination System (NPDES) CCR wastewater treatment pond closure criteria and discharges
- Solid waste disposal facilities
- Soil erosion and sedimentation control under non-point source NPDES rules
- NPDES CCR leachate (generated from the underlying landfill) treatment and discharge permitting
- Air pollution controls, primarily for dusting of the CCRs, associated with the plant Clean Air Act Title V permit
- Corrective action (remediation) for solid waste disposal facilities Occupational Safety and Health Administration (OSHA) health and safety for environmental contamination projects
- OSHA general construction
- Clean Water Act: U.S. Army Corps of Engineers for work in waters of the United States (e.g., wetlands, floodplains, etc.)
- Local rules such as those associated with mining (for borrow soils), zoning, transportation, soil erosion control, noise, etc.

Overfills are not specifically regulated at the federal or most state levels. Herein, typical solid waste disposal design criteria are considered where appropriate and when they reflect sound engineering judgment. For example, the bottom liner of a new landfill, which is the cover for the underlying pond, doesn't require an underdrain system. However, when adding the loading of a new landfill, an underdrain may be required to dissipate pore pressures to provide foundation stability, promote/accelerate settlements, and allow filling (loading) of the landfill sooner.

General permitting is discussed in Section 4.

2.5 Concept Design

The concept design refines the FS and may include an evaluation of different landfill configurations that meet the existing site/pond footprint, disposal capacity, criterion for maximum elevation/height above surrounding land, and siting (location) criteria. Usually the siting criteria are acceptable if there is no lateral expansion that results in a landfill footprint larger than the existing pond footprint. This assumes that the regulatory agency has concluded

the existing pond location is acceptable and current environmental conditions (i.e., primarily groundwater and surface water impacts) are acceptable.

The concept design first establishes conceptual design criteria. The design criteria must consider all regulatory requirements, plant restrictions, and public considerations and is done with the owner and the engineer. Once the concept design criteria are established, a “fatal flaw” analysis is completed to identify conditions that would preclude development of the new landfill.

The controlling factors of construction of new landfills over existing ponds are predominantly the stability of the new landfill and the cost of grading required to achieve an acceptable subgrade. The stability is related to the saturation and strength of the CCRs in the pond and the ability to dewater the CCRs adequately to construct a stable foundation for the overlying landfill. The cost to achieve a stable foundation may make it uneconomical compared to development of a greenfield facility wherein the foundation soils would normally be more stable than a CCR foundation. However, this document has been prepared assuming the facility has been examined and it has been determined to be in an acceptable location.

A site reconnaissance is essential and frequently done during the feasibility study phase (see Section 3). An initial site investigation is often completed during the FS or conceptual design to understand the existing conditions, especially the characteristics of the CCRs in the existing pond, other subsurface features such as the presence of karst geology or underground mines, and groundwater contamination.

Typically a concept design is completed using conservative engineering criteria because detailed analyses are not conducted. These “conservative” criteria include maximum bottom liner and cover slopes of four horizontal to one vertical (4H: 1V) to avoid interface instability, leachate collection lines sloped at greater than two percent to account for settlement, and foundation stabilization to avoid seismic liquefaction or static slope instability. This conservative analysis will normally result in smaller disposal capacity but will provide a reasonable understanding of whether the overall concepts will work. The concept design also includes an assessment of the availability and cost of construction materials, especially general fill and low permeability bottom liner soils, often requiring an assessment of nearby potential borrow sources. It is recognized that these “conservative” criteria will be modified to be less conservative after the concept design is completed and additional information/field investigation data are obtained.

2.6 Geotechnical Evaluation

The primary geotechnical evaluation is conducted after completion of the concept design. Typically the geotechnical evaluation includes:

- preliminary investigation to obtain information to characterize the subsurface; and
- supplemental investigations as the design progresses and further data gaps are identified.

During the design process, it is normal that additional field data will be required as the design progresses. This information is often related to the need to obtain additional samples for laboratory testing or to obtain data for an area that was not originally intended to be a part of the landfill footprint.

Detailed information on the geotechnical evaluation is provided in Section 5 of this document.

2.7 Hydrologic Evaluation

The hydrologic evaluation focuses on surface water conveyance across and off of the site. If the CCR pond has already been closed, that hydrologic evaluation phase of the project will have been completed. The new landfill hydrologic evaluation will address the increased flows off of the new landfill caused by the increase in slopes of the new landfill final cover system. If the CCR pond has not been closed, the hydrologic evaluation will address management of surface water during pond closure and for the new landfill final cover.

CCR ponds often have been constructed in a pre-existing drainage valley by construction of a dam to impound and settle CCRs. When the CCR pond is closed and a new landfill is constructed in a valley fill, the downstream and upstream hydraulics of the discharge should be examined to assess the potential for impacting drainage culverts and roads, and the potential for stream bank overflow/flooding. Note that it is considered standard practice to demonstrate that impacts (defined as increases or decreases of water levels) upstream and downstream of the site are minimized. Consequently, the hydrologic evaluation should consider both downstream and upstream impacts that could raise or lower the water levels.

Information on the hydrologic evaluation for the closed pond and a new landfill is described in Section 8.2.3 of this document and is also addressed in the companion EPRI document [1].

2.8 Hydrogeologic Evaluation

The goal of the hydrogeologic evaluation is to develop the necessary data base and groundwater monitoring program for a new overfill landfill to obtain construction and operating licenses. The site hydrogeologic evaluation for the new overfill landfill should be integrated into the existing hydrogeologic evaluation for the underlying pond. However, the extent of historical information available for the pond may vary considerably from site to site. Therefore, a review of the extent of available hydrogeologic data should be made at the outset of the project and a work plan should be developed to supplement the hydrogeologic information as necessary.

Detailed information on the hydrogeologic evaluation is provided in Section 6 of this report.

2.9 Wastewater Infrastructure Needs

Wastewater infrastructure needs are primarily: (i) collection of pore water from the underlying CCRs in the closed pond during and after the closure process; (ii) collection of leachate from the overlying landfill leachate collection system; (iii) stormwater management; and (iv) treatment associated with any NPDES permits.

The design can account for the wastewater infrastructure needs by assessing the potential for generation of CCR leachate from the underlying closed pond CCRs, and leachate and contact water runoff from within the new landfill, and providing for leachate collection and conveyance systems and treatment facilities. Therefore, when designing the individual cells of the new landfill it is important to allow for construction of an appropriately sized treatment facility. In some instances there may be an existing NPDES discharge permit that can be utilized.

Other infrastructure needs would include electricity and access roads that support semi-truck trailer loads to the treatment facility and emergency vehicles. Wastewater infrastructure is discussed in Section 7.

2.10 Landfill Location and Design Criteria

Landfill location and design criteria currently vary considerably from state to state from very prescriptive to very general for different CCRs. Some significant criteria that need to be considered include:

- distance to nearest drinking water well
- location of karst or mine voids
- location relative to a fault active in the Holocene period
- seismic design
- distance to nearest surface water body

In most instances the existing CCR pond may not meet some of the above criteria. However, the CCR pond likely existed before the criteria were in effect (before there was a rule). Therefore simple examination of siting and design criteria should not rule out a site without approaching the regulatory agency because the site location may be “grandfathered” and the criteria may be waived.

The criteria for each facility need to be evaluated and compared to the needs of the project.

2.11 Construction and Operational Considerations

Construction concerns for vertical landfill expansions (overfills) include quantity of fill needed to achieve bottom liner grades, compaction of soils over a soft subgrade (i.e., the closed CCR pond), control of run-on, management of stormwater, control of erosion, proximity of soil borrow materials, and construction phasing.

Operational considerations are similar to current CCR landfills and include maintenance of leachate collection piping, management and minimization of contact water, control of dusting, compaction of CCRs, and control of run-on and leachate treatment.

Information on construction and operational considerations for landfills over ponds is described in Section 9 of this document.

2.12 Long-Term Care

Long-term care is conducted through the post-closure care period, and requirements currently vary state by state. RCRA Subtitle C (hazardous waste) facilities and RCRA Subtitle D (MSW/solid waste) facilities include a 30-year post-closure care period. However, the required post-closure care period can be shortened or extended by the director of an approved state program as necessary to ensure protection of human health and the environment.

Long-term care considerations for the landfill built over a pond are similar to conventional CCR landfills and include maintenance of the integrity of the cover, groundwater and surface water monitoring, and leachate collection and treatment. For landfills over closed ponds, however, the potential for differential settlement continues in the post-closure period.

When establishing a long-term/post-closure care plan, it is suggested that sufficient inspection, monitoring and maintenance data are collected to track the conditions of the facility through

post-closure. These data may be used to demonstrate that the requirements of post-closure care period may be reduced. Long-term care is discussed in detail in Section 10.

2.13 Considerations for Construction of Other Structures

Closed CCR pond properties may also be utilized for other purposes and structures, such as:

- lined wastewater ponds;
- recreational facilities (e.g., park, archery, sledding, hiking/exercise, hunting, etc.);
- wetlands;
- vehicle parking area;
- maintenance buildings;
- transmission towers;
- solar/photovoltaic panels; and
- warehousing.

The considerations for all of the above other uses include safety of the users, maintenance of the integrity of the containment and monitoring systems, and maintaining the ability to conduct adequate inspections (i.e., keep the surface clear to allow visual inspection). Most of the above uses do not require additional permitting or additional groundwater monitoring. However, all of the uses are expected to require regulatory agency approval because of the potential to impact the cover/containment system of the CCR in the underlying closed pond.

A closed CCR pond is more amenable for future use than MSW facilities because the CCR is non-biodegradable and therefore does not reduce in volume and cause settling, and does not generate methane gas. However, some FGD wastes have been known to generate hydrogen sulfide gas.² Where gas generation is not expected, there is no need for gas vents or well risers, making the surface amenable for other uses.

Information on construction of other structures on top of a closed pond is provided in Section 11 of this document.

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² In 1998, a fatality occurred due to accumulation of hydrogen sulfide gas in a catch basin that was a part of a French drain to collect seepage from a CCR slurry pond containing FGD [2].

3

FEASIBILITY EVALUATION

3.1 Introduction

This section provides a framework to consider when evaluating the feasibility of constructing over closed or closing CCR ponds. The purpose of the feasibility evaluation is to assist decision-makers in evaluating the viability of options for constructing over CCR ponds by providing sufficient information upon which to base a decision. The feasibility evaluation framework documented in this section includes the following:

- examples of potential development options for closed or closing CCR ponds;
- types and sources of existing information that are often available to conduct an initial site conditions assessment; and
- a systematic approach to document the feasibility evaluation, including data compilation, data gap evaluation, “fatal flaw” analysis, and the comparison of development options.

The feasibility evaluation forms the foundation for the next phase of project planning including conceptual design, refining permitting and regulatory requirements, and refining the project costs and schedule. The information gathered during the feasibility evaluation is also the basis for developing a site-specific subsurface exploration program.

3.2 Development Options

Development over a CCR pond is challenging from both a technical and regulatory perspective. However, these sites present a number of advantages over “greenfield” and other brownfield sites. Examples of some development options which are considered potentially applicable to these sites include landfills, athletic fields and parks, constructed wetlands, solar power systems, and storage and other industrial facilities. An overview of these potential development options is provided in Section 11. However, it should be noted that there may be other equally applicable development options that could be considered, depending on the particular location and character of the CCR pond being evaluated.

For any development alternative, technical, regulatory, constructability, and public considerations should be part of the FS, including:

- settlement potential and its impact on the structural integrity of designed systems and structures;
- stormwater management and the possible need for integration into existing structures;
- monitoring systems for potential gas leakage and groundwater contamination;
- regulatory rules at the federal and state level;

- public perception and potential for project opposition;
- site accessibility for during and post construction;
- availability of borrow sources of material; and
- site safety and security.

3.3 Site Conditions Assessment Using Existing Information

Existing information is often available to conduct an initial assessment of site conditions to evaluate the feasibility of constructing over CCR ponds. This information typically includes access and topography, pond construction and filling history, geotechnical, geohazard, hydrological, hydrogeological, and other site conditions information. This information is highlighted in the following sections along with the typical sources that are often available to obtain the information.

An example site conditions information checklist is provided as Appendix A. It is important to note that the types of information highlighted in the following sections and in Appendix A should be considered a guide and that there may be other conditions that are specific to a particular site that are equally relevant to the feasibility evaluation.

3.3.1 Access, Topography, and Site Limitations

The feasibility of the site with regard to access and topography can be evaluated by reviewing property-specific as-built and current survey and mapping information, on-line county geographical information system (GIS) mapping information, USGS topographic maps, and state department of transportation (DOT) mapping information. Recent aerial photographs are also a valuable tool for evaluating access and topography.

Typically, the locations of utilities (sewer, gas, water, electricity, fiber optic lines, etc.), oil and gas wells, archeological sites, etc. would not be critical considerations because these would have been addressed for the original pond construction permit or for the pond closure design. However, if not completed already, these features should be investigated. Sources of information are buried utility location companies, utilities, county databases, and the state department of natural resources.

3.3.2 Site Reconnaissance

A site reconnaissance should be conducted by an engineer or geologist to assess subsurface and topographic conditions at a pond site before a subsurface exploration program is implemented. The site reconnaissance should be conducted after a review of available information such as permit applications, previous investigations and studies, and information available in the public domain. Reconnaissance personnel should meet with appropriate plant personnel to understand specific access restraints and safety hazards. For a typical pond and the areas adjacent to it, it is suggested that the following information be obtained during the site reconnaissance:

- apparent wetlands
- underground mine features (subsidence, openings, etc.)

- surface water features and structures
- topographic features
- unconsolidated materials
- rock outcrops
- groundwater seeps
- surface mining features
- oil, gas, and water wells
- possible geophysical survey locations
- possible subsurface exploration locations (borings, CPT, test pits, wells)
- potential borrow sources
- evidence of landslides
- bedrock type, bedding orientation

All features identified should be photographed and their locations recorded with a hand-held GPS unit.

For typical pond sites, access to proposed exploratory locations may be limited. For example, locations outside of the pond may be difficult to access unless roads are built and/or improved. Also, access to locations over the pond may require roads to be built or, if the exploration location is underwater, the use of barge-mounted equipment. These issues could also require permits (e.g., soil erosion and sedimentation control) and represent significant extra cost and schedule for the detailed subsurface exploration program and should be considered.

3.3.3 Pond Construction and Filling History

A critical component to evaluating the feasibility of constructing over CCR ponds is to identify how the pond was constructed and the nature and filling history of the ponded materials. This information, together with the geotechnical conditions information (see Section 3.3.4), is used to evaluate settlement and stability issues for the planned development.

The following is a summary of the types of CCR pond construction and filling history information that should be identified and reviewed during the feasibility evaluation:

- pond configuration including containment structures (e.g., perimeter embankment or retention dam, bottom liner, underdrain, and any interior containment berms);
- pond base grades and range of thickness of the ponded materials;
- types, character, extents, and periods of filling for various ponded materials;
- processes used to place ponded materials;
- current and past pond water levels; and
- identifying if the containment structure was periodically raised to allow for additional disposal capacity and how this raising was designed and constructed.

These and potentially other relevant CCR pond construction and filling history information can be obtained from a number of sources, including the following:

- Pre-pond construction topographic maps;
- Pond and containment structure design reports, plans, and drawings;

- Regulatory permitting documents;
- Construction drawings and specifications;
- Facility operations, monitoring, and inspection records;
- As-built and current topographic maps; and
- Historical aerial photographs.

3.3.4 Geotechnical Conditions

The geotechnical conditions at the site are critical to evaluating the feasibility of constructing over CCR ponds. Existing information on the geotechnical conditions of the ponded materials, the native soils and rock below the ponded materials, and the pond containment structures should be reviewed during the feasibility evaluation.

The following is a summary of types of existing information on geotechnical conditions that may be available and should be reviewed during the feasibility evaluation:

- soil and rock boring logs and cone penetration testing (CPT) data;
- monitoring well and piezometer static water level data;
- geological/hydrogeological cross-sections;
- laboratory and field testing data for CCRs;
- laboratory and field testing data for native soils and rock under CCRs;
- design analyses and calculations for settlement, static and seismic stability and liquefaction, and seepage;
- construction specifications for containment structure soils; and
- pond instrumentation monitoring data including surface elevation monitoring (survey) points, slope indicators, settlement plates, and piezometers.

These and potentially other relevant geotechnical conditions information can be obtained from a number of sources, including the following:

- geotechnical investigation reports;
- pond and containment structure design reports, plans, and drawings;
- regulatory permitting documents;
- construction drawings and specifications;
- permit applications; and
- annual inspection reports.

3.3.5 Geohazards

Geologic hazards or “geohazards” are geologic conditions, either manmade or natural, that could impact the feasibility of constructing over CCR ponds. Geohazards may include karst (e.g., caves and sinkholes), mine subsidence, earthquakes, landslides, and shore erosion. These geologic conditions may limit the amount of stresses that can be applied by constructing over CCR ponds or require costly mitigation prior to construction.

Existing information is typically available for the locations of the following geohazards:

- karst features and other fissured or porous rock strata/formations;
- fault lines or significantly fractured geologic structures and information on recent fault activity;
- seismic impact zones;
- abandoned and underground mines;
- landslide prone areas; and
- shore erosion prone areas.

These and potentially other relevant geohazards information can be obtained from a number of sources, including the following:

- geotechnical investigation reports;
- geophysical survey reports;
- regulatory permitting documents;
- state department of natural resources or geological survey reports and mapping information;
- U.S. Geological Survey reports and mapping information;
- state DOT geohazards inventory and mapping information;
- county GIS databases; and
- aerial photographs.

The siting criteria for landfills relative to the allowable proximity or setback distances to geohazards typically vary between states. For example, some states prohibit landfills within the angle of draw of underground mines, which includes all areas near the mine where subsidence could occur.

3.3.6 Hydrologic Conditions

Site and vicinity hydrologic conditions have the potential to affect the feasibility of constructing over CCR ponds. The following is a summary of the types of existing pond information on hydrologic conditions that should be identified and reviewed during the feasibility evaluation:

- flood plains and wetlands;
- perennial streams and navigable waterways;

- existing pond topography, including low points, slopes, drainage patterns, diversion, culverts, and channels;
- stormwater inflows from other than precipitation; and
- stormwater management structures such as dam spillways and dam seepage gallery discharge.

These and potentially other relevant hydrologic conditions information can be obtained from a number of existing sources, including the following:

- pond and containment structure design reports, plans, and drawings;
- regulatory permitting documents;
- construction drawings and specifications;
- as-built topographic maps;
- stormwater management plans;
- property-specific survey and mapping information;
- flood plain and wetland mapping information;
- on-line county GIS interactive mapping information;
- USGS topographic maps;
- U.S. Fish & Wildlife Service National Wetlands Inventory; and
- current aerial photographs.

3.3.7 Hydrogeologic Conditions

Hydrogeologic conditions are important to evaluating the feasibility of constructing over CCR ponds. The characteristics of site groundwater are particularly pertinent for the proper siting, construction, operation, and monitoring of a landfill constructed over a CCR pond.

The following is a summary of the types of hydrogeologic conditions information that may be available from the CCR pond records and should be reviewed during the feasibility evaluation:

- critical groundwater resources such as drinking water source protection areas for public water systems, sole source aquifers, and high-yield unconsolidated aquifers;
- private or public drinking, irrigation, or livestock water supply wells;
- springs and sand and gravel pits and limestone or sandstone quarries connected to groundwater resources;
- geological cross-sections;
- site-specific hydrogeologic conditions including:
 - uppermost aquifer system and other significant zones of saturation;
 - interconnection of zones of saturation;

- hydraulic conductivity;
- flow direction and rate;
- potential perched zones within CCR pond;
- groundwater level elevations, including temporal (seasonal) fluctuations; and
- elevation of the base of the CCR pond;
- regional and site-specific groundwater quality;
- regional and local groundwater recharge and drainage areas; and
- migration and exposure pathway and risk evaluation information.

These and potentially other relevant hydrogeologic conditions information can be obtained from a number of sources, including the following:

- state department of natural resources or geological survey reports and mapping information;
- U.S. Geological Survey reports and mapping information;
- regulatory permitting documents;
- hydrogeological investigation reports;
- baseline groundwater quality reports;
- risk assessment reports; and
- groundwater monitoring reports.

The siting criteria for landfills relative to the allowable proximity or lateral setbacks to drinking water supply wells vary between states. In addition, some states prohibit the location of landfills within certain time-of-travel for groundwater flow to a public water supply well or designated drinking water source protection area. However, if the CCR pond does not meet a location criterion, it is possible that the CCR pond existed before the criterion became a requirement and it may be acceptable.

3.3.8 Other Relevant Conditions

Examples of other types of relevant conditions that have the potential to affect the feasibility of constructing over CCR ponds may include the following:

- proximity to designated natural and wildlife areas, residential development, utility corridors, transportation routes, and archaeological sites and historic districts; and
- proximity to borrow sources for landfill construction materials (e.g., liner, drainage, and cover materials).

This information can be obtained from a number of sources, including the following:

- regulatory permitting documents;
- construction drawings and specifications;

- property-specific survey and mapping information;
- state department of natural resources or geological survey reports and mapping information;
- county soil surveys;
- on-line County GIS interactive mapping information;
- USGS topographic maps; and
- current aerial photographs.

As indicated previously, the types of information highlighted in the preceding sections and in Appendix A should be considered a guide. There may be other conditions that are specific to a particular site that are equally relevant to the feasibility evaluation.

3.4 Decision Making

This section outlines an approach for documenting the feasibility evaluation in a manner that advances the decision making process and allows the project to move forward to the next step of project planning. This approach typically includes defining the development options, the compilation and analysis of the site conditions information, and the qualitative or quantitative comparison of the development options.

3.4.1 Development Options

The feasibility evaluation may involve evaluating: (i) options associated with the development of a closed or closing CCR pond site versus a greenfield or another brownfield site for a particular use; or (ii) or a range of development options for a particular closed or closing CCR pond site.

3.4.2 Site Conditions Information Compilation and Analysis

The first step in documenting the feasibility evaluation is to compile the site conditions information in a functional and comprehensive manner such as a table, spreadsheet, or database. The following information should be identified and highlighted during data compilation:

- the most salient site conditions information for the subject site and the development options being considered; and
- significant data gaps and limitations.

If substantial data gaps are identified during data compilation, consideration should be given to filling those gaps prior to the next phase of evaluation (i.e., fatal flaw analysis or comparison of development options). This may involve preliminary field activities such as site and vicinity reconnaissance, surveying, and/or focused subsurface exploration.

Following data compilation and data gap analysis, any potential “fatal flaws” or site conditions should be identified that would likely prevent the implementation of any of the development options being considered. It is suggested that identified fatal flaws be vetted with decision makers and potentially with applicable regulators before development options are eliminated from further consideration.

3.4.3 Comparison of Options

For development options determined to be viable, a systematic comparison is often conducted to assist in the decision making process. The comparison of options typically includes the following:

- *Compositing the salient site conditions information into key comparative criteria for the evaluation of the viable development options.* In addition to the site conditions information, economic criteria are often incorporated into the feasibility evaluation. The economic criteria are typically conceptual (e.g., -30 to +50 percent) and often include capital construction costs and operation, maintenance, and monitoring costs.

Other comparative criteria that may be applicable to the feasibility evaluation include the following:

- *Sustainability or “green” development.* This would include considering the environmental and community effects or “footprints” of development implementation. Environmental and community effects can include fossil fuel consumption, emission of greenhouse gas and air pollutants, disruption to water cycle balances, and soil erosion. An evaluation of a project’s degree of sustainability is becoming increasingly common [1].
- *Federal or state corrective action program feasibility study criteria.* Groundwater impacts are sometimes present at CCR ponds. Monitoring programs are used to assess changes in the nature and extent of impacts determine the need for corrective action. When the development over a CCR pond is integrated into the closure of a pond, the action may be considered a corrective action (e.g., capping and control of groundwater and/or surface water contamination). In this case, the feasibility evaluation criteria may need to include or be framed by those criteria specified by applicable U.S. EPA [2] or state remediation program regulations and guidance.
- *Conducting a comparative evaluation of the viable development options using the established criteria in a matrix.* The comparative evaluation of options can be based upon a qualitative system that utilizes relative ratings or on a numerical rating scale of each option’s degree of performance with respect to the evaluation criteria. A weighting factor can also be assigned to each of the criteria based on the relative importance of the criteria for a particular site or development approach. An example matrix framework is included in Appendix B.

It should be noted that it is not uncommon for the feasibility evaluation to be an iterative process as development options are modified or as data gaps identified during the study are addressed. It is not uncommon to go back into the field to collect additional data before proceeding with the feasibility evaluation. The feasibility evaluation may also be integrated with the conceptual design phase of the project.

3.4.4 Feasibility Evaluation Report

The scope, procedures, and results of the feasibility evaluation should be documented in a comprehensive written report to the project decision makers. If the report is likely to be submitted to the regulators as part of a permit application, the report format may need to be consistent with particular state or federal regulations and guidance.

The feasibility evaluation report will form the foundation for the next phase of project planning including conceptual design, refining permitting and regulatory requirements, and refining the project costs and schedule. The information gathered during the feasibility evaluation also is the basis for developing the site-specific subsurface exploration program.

3.5 Cost and Schedule

The feasibility evaluation is typically contracted to an engineering firm. The cost to complete the feasibility evaluation is typically on the order of \$50,000 to \$75,000 but could be as much as several hundred thousand dollars if significant site investigation work is required. The feasibility evaluation can typically be completed in two to three months if the existing information is reasonably available. These estimates assume that the feasibility evaluation relies entirely on existing information (i.e., does not include any field data collection).

References

1. U.S. Environmental Protection Agency, (2010) Superfund Green Remediation Strategy. OSWER, Office of Superfund Remediation and Technology Innovation, <http://www.epa.gov/superfund/greenremediation>.
2. U.S. Environmental Protection Agency, Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final. EPA 540/G-89/004, OSWER 9355.3-01, 2010.

4

PERMITTING AND REGULATORY CONSIDERATIONS

4.1 Current Permit Requirements

4.1.1 Landfill

The current permit requirements for landfills are state-specific, permit-specific, and owner-specific. For this report, it is assumed that permitting requirements for landfills over ponds are similar to those for conventional solid waste landfills.

Landfill permits are typically divided into construction permits and operating permits. The construction permit is also often called a “permit to install” (PTI). The level of information/detail in the PTI application ranges considerably from state to state and may be in the form of a letter report or a multi-binder submittal of many documents.

The PTI application to the state includes required information such as:

- owner and operator information;
- facility information;
- legal information;
- waste characterization;
- site characterization (geology, hydrogeology, geotechnical, hydrology, etc.)
- location restrictions;
- design report and construction specifications;
- operating procedures;
- closure and post-closure plans; and
- cost estimate and financial assurance.

The landfill PTI application is typically completed without all of the details that are desirable for a construction project. Therefore, the PTI drawings and specifications are supplemented with additional details, drawings, and specifications in a contract document package to provide sufficient control of the construction contractor.

Additional permits that may accompany the landfill PTI include:

- A wastewater/NPDES permit for a treatment pond for landfill leachate.

- A USACE permit for dredge/fill in waters of the U.S. (aka “wetlands” permit). The wetlands permit jurisdiction is CWA Section 404. It is common for an individual state to have a wetland permitting program that is coordinated with the federal USACE permit process.
- CWA Water Quality Certification under Section 401. Once the wetland/404 permit is obtained, a water quality certification is required under Section 401 of the CWA.
- The plant Clean Air Act permit may require modification to address the change in operations that could affect air quality, which should be submitted in adequate time prior to construction.
- A General Construction NPDES permit application for soil erosion and sediment control under the state program.
- Local permits should be evaluated on a site by site basis. For example, a local permit could include a county mining permit for a soil borrow pit.

After the PTI/construction and other permits are received, the landfill can be constructed. The operating permit application is then submitted with as-constructed information necessary to confirm the landfill facility was constructed in accordance with the construction permit. Following receipt of the operating permit, the facility may begin management/disposal of CCRs.

4.1.2 Closed CCR Pond

In the case of a landfill over a closed pond, the CCR pond will require an NPDES permit modification to close the pond as discussed in the companion report to this document [1]. Further, there could be an ongoing facility discharge such as any water that is expressed from the pores of saturated CCR caused by constructing the overlying landfill (see Section 8), and may be regulated under the existing NPDES permit. There would likely be two divisions of state agencies involved in approving a permit for a landfill over a CCR pond: (i) the surface water division for the underlying pond, which would likely be in a post-closure monitoring period and would require approval to build on or disturb the closed pond; and (ii) the solid waste division for the landfill.

In the case where the CCR pond containment structure is regulated as a dam, there will be a third agency (such as a department of natural resources or a dam safety division of another agency) responsible for any changes in the dam. For example, if the dam is to be lowered or the spillway redesigned, a permit application with the design change should be submitted to the state agency for approval.

The current operating permit requirements for ponds are state-specific, permit-specific, and owner-specific. The state operating wastewater permit requirements typically follow an NPDES industrial discharge permit and are often minimal. The NPDES requirements are normally performance based (e.g., meet specified discharge limits) and normally are not procedural. Additional requirements could come from state dam safety permit programs that require inspections and reporting if the embankment is high enough.

Since the release at the TVA Kingston Plant, many pond owners have undergone internal evaluations of operations and have made constructive changes to avoid decreasing the stability of the pond containment structure(s). These changes include consolidating the O&M documents

and clearly stating the design and operating criteria and the maintenance to be implemented if the design or operating criteria are violated.

A number of owners have undergone a voluntary potential failure mode analysis (PFMA) of their CCR pond containment structures that is analogous to the process followed by the Federal Energy Regulatory Commission (FERC) for hydropower dams. This process is used to identify design or operating conditions that could lead to reduction of the safety of the facility. It is helpful to undergo the PFMA to identify conditions that could limit the usability of a closed pond as the subgrade for an overlying structure, especially a landfill.

Further, owners have put more controls on changes that could reduce the stability of the pond containment structure. For example, when a structure is proposed to be located near the crest of an embankment or where soil is to be excavated from the toe of an embankment, the person or team of people that are responsible for the safety of the pond must be consulted and the change appropriately analyzed and approved.

4.2 Schedule Impacts

The schedule for implementing a landfill over a closed or closing pond is affected by the plant operations and when new CCR disposal is needed. First, the time to close the existing CCR pond has to be taken under consideration. This time period could take many years. The time to prepare a landfill PTI (procure consultants, obtain information, prepare the design, etc.), build a landfill, and receive an operation permit can also range over many years. The time to obtain the necessary approvals depends upon the size and complexity of the CCR pond and new overfill facility, the condition of any existing infrastructure in place, the state regulatory requirements, and thoroughness of the PTI application and operating permit application.

Therefore, thorough planning is required when the need for a landfill is identified.

References

1. Electric Power Research Institute, *Coal Combustion Residuals Pond Closure: Guidance for Dewatering and Capping*. EPRI, Palo Alto, CA: 2014. 3002001117.

5

GEOTECHNICAL EVALUATION

5.1 Introduction

The design and construction of a pond closure or the construction of, for example, a landfill over a pond includes significant earthwork comprising cuts and fills on or within the ponded material. This earthwork not only affects the stability of the ponded CCRs but may also affect the stability of dikes and dams which may surround the pond. The closure of the CCR pond is addressed in an EPRI companion report [1]. To facilitate use of the present report, much of the information in [1] is repeated herein.

Herein, information on the scope of a geotechnical site investigation and laboratory testing program for the characterization of ponded materials is described. It is helpful to consider the ponded material to be the foundation for either: (i) a soil or geosynthetic cover system and grading fill for a pond closure; or (ii) the subgrade below a landfill. The purpose of the subsurface exploration and laboratory testing of CCRs is to obtain information used to evaluate static and seismic liquefaction, slope stability, settlement, and appropriate loading rates for construction.

This section also provides information on engineering analyses, design, and constructability considerations related to the geotechnical characteristics of ponded CCRs.

5.2 Preliminary Evaluation

5.2.1 Overview

A preliminary evaluation is conducted to understand data necessary for the geotechnical analysis. As a part of the preliminary evaluation, a site reconnaissance should be conducted by an engineer or geologist to assess subsurface and topographic conditions at a pond site before a detailed subsurface exploration program is implemented (see Section 3.3.2). The preliminary evaluation also examines pond foundation conditions, pond dike and dam conditions, and the condition of ponded materials as detailed below.

5.2.2 Pond Foundation Conditions

The surface area of a pond is typically large, and structures that will be built over a pond are usually as large (e.g., landfills, closure cover systems, etc.). For this reason, loads from new structures are expected to stress the foundation (i.e., the ponded materials) to great depths, including beyond the bottom of the pond and into the native soil and rock below the pond.

For design, it will be necessary to evaluate the strength and compressibility of the CCRs and the native soils and rock below the ponded CCRs. While it may be obvious that the compressibility of the CCRs (e.g., saturated fly ash which may be tens of feet thick) is relatively high, the

compressibility of native soils below the pond (particularly if clayey) may be similar and therefore such strata must also be considered for design.

The engineer should review original (i.e., pre-pond construction) topographic maps and compare these to as-built topography of the original pond. This exercise will allow areas where cuts and fills were originally constructed to be identified. Due to the resolution of USGS topographic maps, the accuracy of this estimate may be limited; however, this exercise should provide a sense for the range of soil thickness below the ponded materials. The thickness and characterization of the soils below a pond will be investigated via borings and sampling and/or cone penetration test (CPT) soundings. If access to sounding locations is difficult or impractical, the effect of the thickness, strength, and compressibility of the native soils should be addressed parametrically, i.e., ranges of parameters will need to be assumed.

5.2.3 Pond Dike and Dam Conditions

Dikes and dams surrounding CCR ponds at a power plant are usually monitored and inspected in accordance with specific state regulations consistent with the hazard rating of the dike or dam; a discussion on dam and dike inspection is not provided in this report. However, the closure of a pond and/or construction of a structure on top of the pond will likely result in: (i) changes to static and seismic design loads on the dike or dam; (ii) changes to short-term and long-term water levels behind the dike or dam; and (iii) possible modifications and/or decommissioning of existing spillway structures.

Original dike and dam design and/or as-built drawings should be reviewed, as subsurface material parameters (e.g., material thickness and shear strength) will be required for design analyses. Slope stability analysis can be conducted using original dike or dam parameters and the current water pressure condition within the dike or dam, considering additional loading from the proposed design to evaluate whether the stability of the proposed design is sufficient. The engineer should review the shear strength parameters used for the original dam design and consider whether additional boring, sampling, and laboratory strength testing is required. For example, clayey layers that were not fully consolidated at the time of original dam construction may be significantly stronger and therefore verification of the current shear strength through laboratory testing may be beneficial.

If a pond closure includes the lowering of an existing dam, dam materials to be excavated should be considered for specific fills for the closure. For example, soil drainage layers which may be removed may be reusable for drainage layers or construction ramps required for the pond closure and/or landfill construction; the same logic would apply to the reuse of low permeability materials from the dam for a low permeability layer for a closure cover system or landfill bottom liner system.

5.2.4 Ponded Materials Conditions

The construction of a closure cover system or other structure over a pond represents a challenging soft ground engineering project. The characterization of the ponded materials will be critical to selecting specific options necessary to construct the structure. The preliminary evaluation of the condition of the ponded materials should endeavor to:

- estimate the range of thickness of the ponded materials;

- understand the various CCRs placed within the pond and, if possible, an assessment of the lateral and vertical extent of these CCRs;
- understand the processes used to place CCRs in the pond;
- review current water levels in the pond and, if areas of the pond are not under water, how long these areas have been without ponded water;
- assess the stability of the CCRs relative to the ability to safely operate equipment on the surface; and
- locate areas of the pond with roads, cross dikes (either buried or exposed), and CCR (or soil) stockpiles.

The engineer should review available boring and laboratory data for the ponded materials. This data will be useful in developing a cost-effective subsurface exploration and laboratory testing program.

5.3 Subsurface Exploration and Laboratory Testing

5.3.1 Overview

This section provides information on the various investigative tools typically used to assess subsurface conditions at CCR ponds. In some cases, structures to be constructed may not lie completely within the pond footprint, but could be affected by ground conditions adjacent to the pond which should also be evaluated.

Typical subsurface exploration tools used to investigate ponds include: (i) geotechnical borings and sampling; (ii) CPT; (iii) geophysical survey methods; and (iv) laboratory testing of disturbed and undisturbed samples. Key issues associated with the use of these tools for investigating the subsurface conditions at CCR ponds are summarized herein. Detailed information is found in various textbooks and manuals (e.g., [2]).

Information needs and geotechnical testing requirements for a CCR pond closure and/or the construction of a landfill over a CCR pond are summarized in Table 5-1. Additional information on these data needs is described throughout the remainder of this section.

Table 5-1
Summary of information needs and testing considerations for CCR ponds

Engineering Evaluations	Required Information (for Design Analyses)	Field Testing	Laboratory Testing
- Settlement (magnitude and rate) - Bearing capacity - Slope stability - Borrow source availability - Decanting and dewatering - Bridging layer construction - Drainage layer design	- Subsurface profiles including groundwater elevation - Compressibility parameters - Shear strength parameters - Unit weights - Time-rate consolidation parameters - Piezometric levels - Degradation properties of soil and rock fill - Hydraulic conductivity of ponded materials, low permeability layers, and drainage layers - Low strain shear modulus (for seismic analyses)	- SPT borings and sampling - CPT (with dissipation tests and shear wave velocity) - Test fills - Geophysics	- Grain size distribution and hydrometer - Atterberg limits - Specific gravity - Moisture-density relationships for compacted fills - Fixed/flexible wall permeability - Triaxial/direct shear strength testing - Cyclic shear strength (for seismic analysis) 1-D oedometer - In-tube density

5.3.2 Access and Safety for Subsurface Explorations

A site investigation work plan should be prepared with input and review of appropriate site personnel prior to mobilizing to the site to implement the subsurface exploration program. This work plan should include:

- required plant safety training prior to start of field activities and logs for documenting when such training is completed;
- a Health and Safety Plan;
- procedures and information to be included in Daily Safety Tailgate Meetings such as: (i) scope of the day's field activities; (ii) applicable health and safety procedures; (iii) special safety concerns based on work activities, location, or weather conditions; and (iv) completion of the drill rig checklist, if drilling is planned; and
- a work hour log for all consultant and subcontractor personnel (signed at the beginning and end of each workday with plant security) which identifies on-site personnel by their name, their employer, and their daily arrival and departure time.

Specific access and safety issues that are typical for geotechnical investigations associated with CCR ponds at power plant facilities include:

- Be alert of falling hazard associated with working over or near a water body.

- Be alert of the potential for a broken hydraulic line or other environmental release.
- A small crane may be required to load equipment.
- Repeated trafficking over the surface of a pond (with subsurface exploration equipment) may result in degradation of the pond surface and ultimately bearing capacity failure.
- Roads (paved or gravel) are required for access of semi- and low-boy trailers.
- The buddy system should be employed for work performed in remote areas or areas that are not frequented by other onsite personnel.
- A reliable means of communication with others on shore is required. Cell phone signals are not always available and, if allowed, two way radios should be used.
- A transport boat should be available to ferry people and supplies to and from a barge. Barges and so-called “marsh buggies” do not move quickly in the water. Also, a means to monitor weather conditions is required; thunderstorms can come up quickly and if it takes 30 minutes or longer to get off of the water, lightning could be a safety concern.
- Access to emergency showers and eye wash stations may be needed if someone falls in a pond where impounded waters do not have a neutral pH.
- Barges and marsh buggies should be equipped with railings along the sides to mitigate the potential for falling overboard. Workers should wear personal floatation devices, and a throw-able personal flotation device should also be on board.
- For barges, multiple means of anchoring (e.g., spuds, anchors, tie lines, etc.) should be available and these options should be discussed and limitations understood prior to mobilization to the field. For example, if the submerged fly ash is very soft and thick, spuds or other anchors will likely not stabilize the rig sufficiently to prevent unacceptable movement and inhibit sampling.
- A GPS unit should be used to locate investigation points.
- Consider the weight or buoyancy of the barge or marsh buggy and how it may affect the downhole pressure during CPTs or other drilling techniques.
- There is a potential for hazardous hydrogen sulfide (H_2S) gases in and around FGD ponds. A combustible gas indicator (CGI) should be maintained onsite to test for H_2S . Confined spaces such as excavations, pipes, and conduits should be accessed very carefully, and only after gas readings are obtained to verify safe access conditions. Appropriate personal protective equipment such as respirators may be needed for confined space entry near FGD ponds.
- Driving around perimeter dike roads should be coordinated. These dikes often have space only for one lane traffic. When geotechnical exploration is being carried out using multiple vehicles such as CPT trucks, drill rigs, grouting trucks, and other small trucks to carry field personnel, traffic flow should be coordinated to avoid the need to reverse vehicles over long distances to facilitate passing of vehicles. A clockwise or counter-clockwise travel direction can be established to avoid this hazard.

5.3.3 Borings and Sampling

The purpose of conducting boring and sampling for a CCR closure project is to: (i) estimate in situ CCRs and soil stiffness and strength (e.g., Standard Penetration Test [SPT]); (ii) obtain undisturbed and disturbed samples of CCRs and soil for laboratory testing (e.g., grain size distribution); and (iii) obtain subsurface profile information including thickness of soil and CCRs, depth to bedrock, and piezometric level. Typical geotechnical boring and sampling techniques can be used for soil sampling through dikes and areas adjacent to the pond (see Figure 5-1).

Although the properties for fly ash are relatively well understood from test data available in the literature, there is considerably less geotechnical data available on bottom ash, gypsum, FGD residuals, and other types of CCRs. Considering that the physical and chemical compositions of soil and CCRs are quite different, designers are cautioned against using empirical correlations and estimation based on past experience on soils to derive closure design parameters for CCRs. EPRI-sponsored research [7] provides recommended correlations for estimating fly ash parameters.

Boring and sampling of CCRs within the pond, however, require specific tools and techniques, as discussed below.



Figure 5-1
Tracked drill rig being used at a fly ash pond

- CCRs in a pond are typically loose, saturated, and, on average, non-plastic. Drilling below the water level in a pond using hollow stem augers (HSA) will typically cause “blow in” of the CCRs into the voided space inside the HSA, making sampling difficult. Therefore sampling will require the use of drilling fluids (or muds) to keep the borehole open and to minimize disturbance of the bottom of the borehole (where a CCR sample may be taken using a Shelby tube). The rotary wash boring method is suggested (see Section 3.1 of [2]).

- SPT measurements (i.e., obtaining blow counts and calculating “N” values) can be used as an index of material compactness but should not be used as the sole measurement to estimate engineering parameters such as shear strength or compressibility for design analyses.
- For laboratory testing, relatively undisturbed CCR samples can be collected using a thin-wall (i.e., Shelby) tube deployed with a piston sampler (e.g., Osterberg sampler, Gregory sampler). Experience suggests that recovery can be maximized through the use of a piston sampler, although poor recovery should be anticipated from time to time.
- Recovered tube samples of CCRs should be weighed in the field prior to transport to the laboratory. The length of the sample and height of any free water in the tube should be recorded. The density (or unit weight) of CCRs is important for the assessment of liquefaction potential. Density measurements must be made on samples received at the laboratory.
- Drill holes which penetrate into soil or rock layers below the pond should be abandoned with grout from the bottom of the borehole to several feet above the CCR/soil (or rock) interface. In general, individual states will have guidelines for abandoning boreholes. In cases where the pond may be lined with an engineered soil or geosynthetic liner, care should be exercised to make sure that the liner is not penetrated.
- Drilling and sampling in a CCR pond is more difficult than typical on-land drilling and therefore slower productivity and increased costs should be expected. Unless there is a regulatory requirement for minimum number of borings or a boring frequency based on the size (i.e., plan area) of the pond, the number and location of borings should be selected based on the following:
 - Available information that has been compiled concerning the CCR materials placed in the pond and whether specific changes in deposition methods were ever implemented at the pond. Efforts should be taken to characterize portions of the pond where coarser materials may have been deposited and portions of the pond where finer materials are located. Ultimately, strength and compressibility testing on these ranges of materials will be required.
 - A sufficient number of borings should be advanced to allow for the assessment of the pond bottom geometry (i.e., elevation of bottom of CCRs) at multiple cross sections. The engineer should review original pond bottom design or as-built drawings to develop an understanding of the potential variability in CCR material thickness. Borings should be advanced, however, below the bottom of the CCRs to obtain samples and thickness of native soil materials below the pond, provided there is no bottom liner that could be breached by a boring.
 - Borings should be located where there is a potential for a “hard spot,” such as where bedrock is at an unusually higher elevation than surrounding softer materials within the pond or areas where other stiffer and/or stronger fill materials were placed in the pond.
 - Borings should be advanced in areas which have been underwater for extended periods of time and not covered with any soil fill or “bridging layer”. It is likely that CCRs at these locations will be the weakest within the pond. Access to such areas may require ramps to be constructed.

As with all geotechnical investigations, the number of boring locations required to obtain sufficient information for design is site-specific. For CCR ponds which may be several hundred acres, significant cost savings can be realized by augmenting the site investigation to include cone penetration testing.

5.3.4 Cone Penetration Testing

The cone penetration test (CPT) (ASTM D-5778) is quickly becoming the most popular type of in-situ test because it is fast, economical, and provides continuous profiling of stratigraphy. The penetrometer is deployed from a rig which may be equipped for overland work (see Figure 5-2) or for work overwater (see Figure 5-3).

For soils, the CPT also allows for continuous profiling of soil parameters (e.g., drained friction angle in sands, undrained shear strength in clays). Intuitively, this should be possible for CCRs. EPRI [7] includes some basic correlations between CPT-based parameters and fly ash performance parameters (e.g., drained friction angle) that may be used for preliminary design; however, correlations between laboratory measured CCR parameters (other than fly ash) and profiles from CPTs in ponded CCRs are not yet sufficiently developed at this time.



Figure 5-2
Tracked CPT rig (photo courtesy of Conetec)



Figure 5-3
Overwater rig for CPT deployment (courtesy AEP)

The primary advantages of the CPT are that a continuous vertical profile of stress, pore pressures, and other measurements can be obtained without a borehole, cuttings, or spoils. Since a soil sample is not obtained using a CPT, it is suggested that CPTs be conducted as a complement to boring and sampling, for example at 10 to 25% of the boring locations, depending upon subsurface variability.

Piezocones are cone penetrometers with added transducers to measure penetration pore water pressures during the advancement of the probe. In some CCRs, the measured penetration pore pressures (u) are nearly equal to the static water pressure in the ground because the permeability of the CCRs permits immediate pore pressure dissipation. In some CCRs, the penetration pore pressure is above hydrostatic because of a lower permeability. If the advancement of the penetrometer is arrested, the decay of pore pressure can be monitored with time and used to estimate the rate of CCRs consolidation and the permeability.

Unlike the field (visual) or laboratory classification of a soil sample, the CPT uses parameters such as tip resistance (q_t) and friction ratio (R_f), to characterize the material using a “soil behavior type” (SBT) chart [4]. The friction ratio (R_f) is defined as the ratio of sleeve friction (f_s) to tip resistance (i.e., $R_f = f_s/q_t \times 100\%$). For example, clean sands are generally evidenced by tip resistance $q_t > 50$ tsf, while soft to stiff clays and silts have $q_t < 20$ tsf. In soft to stiff clays, penetration pore pressures are several times hydrostatic, whereas fissured overconsolidated materials exhibit noticeably negative penetration pore pressures.

Figures 5-4 and 5-5 show a CPT profile in two different fly ash ponds. The ponds are located on power plant sites along the Ohio River which are approximately 200 miles apart.

- The CPT in Figure 5-4 indicates about 72 ft of fly ash overlying stiff clays to a refusal³ depth of about 90 ft. The tip resistance in fly ash can be quite low (q_t less than 5 tsf). The penetration pore water pressure (u) indicates zones of relatively high hydraulic conductivity (where the pore water pressure is very close to hydrostatic [shown as a dashed line]). Also, the negative pore water pressures measured in the clayey soils below a depth of 72 ft are an indication that these materials are stiff and overconsolidated.
- The CPT in Figure 5-5 indicates about 12 ft of sandy material at the surface. Fly ash is evident from about 12 ft below the ground surface to a depth of 62 ft. From 62 ft to a refusal depth of 68 ft is a stiff, overconsolidated clay soil, as indicated by the negative pore pressure readings. The CPT signature in Figure 5-5 was obtained using a cone with a tip area of 10 cm², whereas the signature in Figure 5-4 was obtained with a 15 cm² cone; better resolution in the low tip resistance fly ash is therefore noted in Figure 5-5.

³ Refusal for a CPT is not the same as “auger refusal” for a drilling operation. Refusal will be determined by the CPT operator.

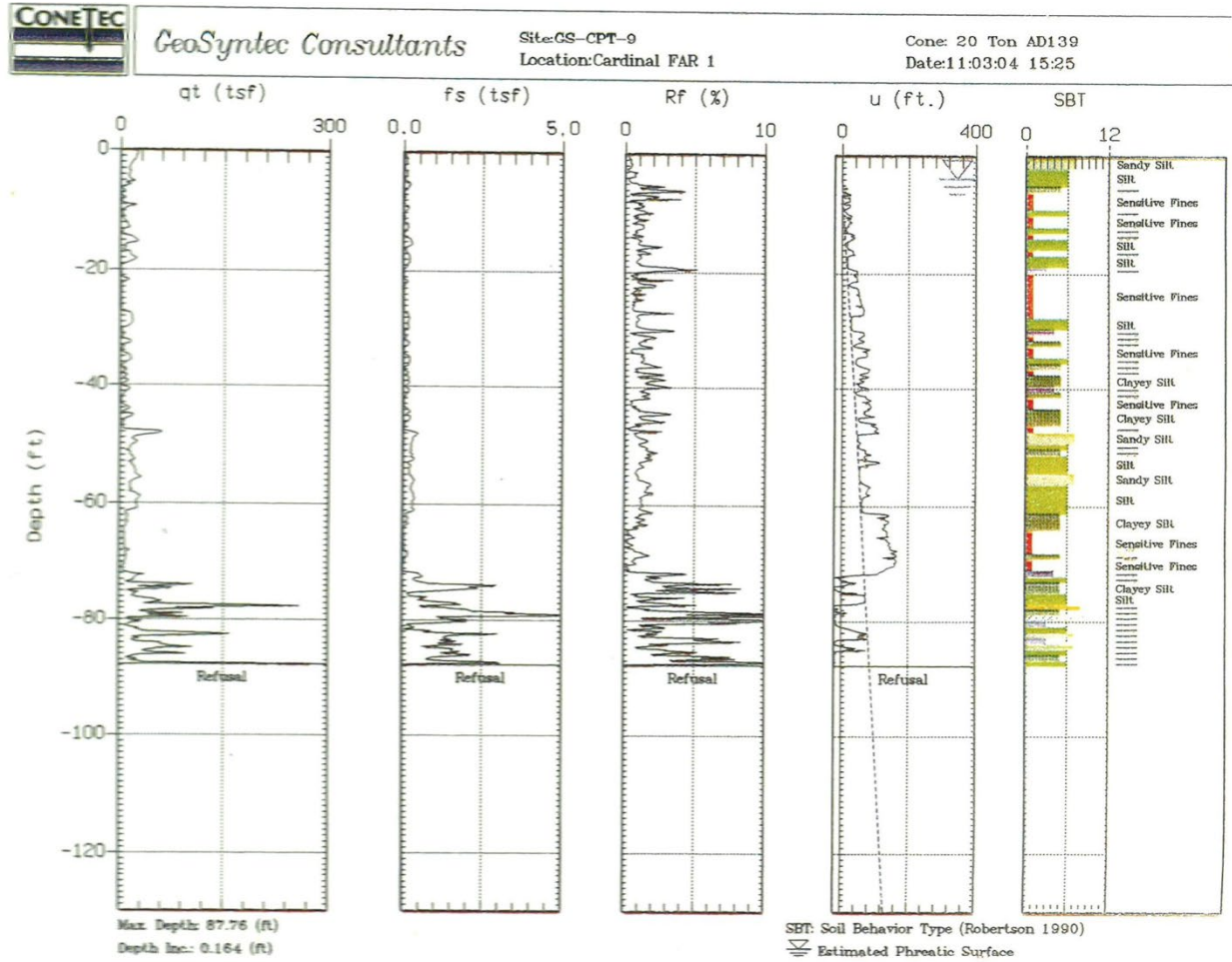


Figure 5-4

CPT profile for a fly ash pond – Site A (courtesy of AEP). Plots include tip resistance (q_t), side friction (f_s), friction ratio (R_f), and the Robertson Soil Behavior Type (SBT) [2]

Figures 5-4 and 5-5 show the interpreted soil behavior type based on the Robertson Soil Behavior Type (SBT) approach where tip resistance and friction ratio are normalized by the vertical effective stress in the ground [4]. It is noted that CPT contractors will oftentimes provide data reports with the normalized cone tip resistance, Q_t , and the normalized friction ratio, F_r , already computed.

Normalized cone resistance,

$$Q_t = \frac{q_t - \sigma_{vo}}{\sigma'_{vo}} \quad (\text{Eq. 5-1})$$

Where q_t = tip resistance, σ_{vo} = total vertical stress and σ'_{vo} = effective vertical stress.

Normalized friction ratio,

$$F_r = \frac{f_s - \sigma_{vo}}{\sigma'_{vo}} \quad (\text{Eq. 5-2})$$

Where f_s = side friction

The user of the data should recompute the total vertical and effective vertical stress values recognizing the variability in unit weight of fly ash and soil materials. Typically, fly ash has a significantly lower unit weight than soils, and the standard computations using soil unit weights would yield incorrect results.

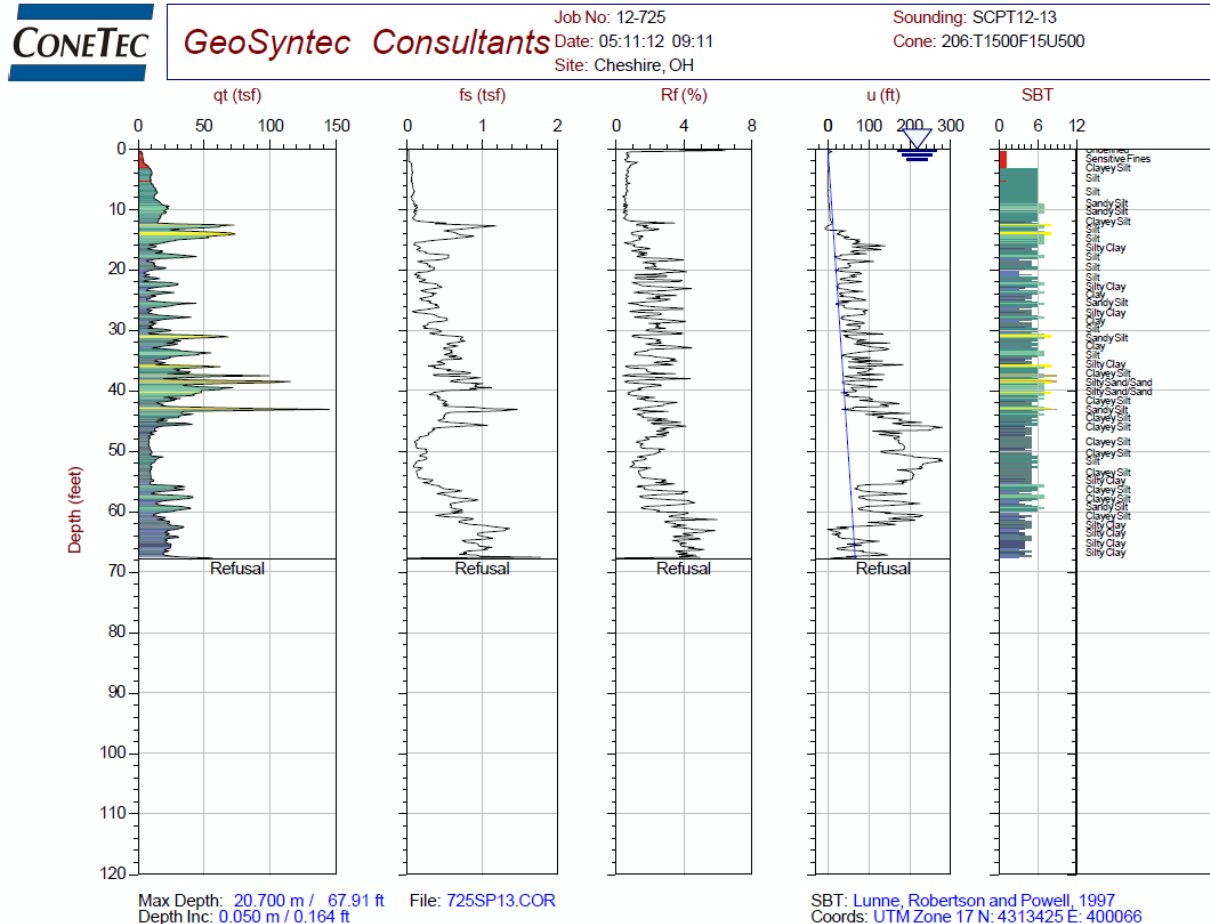
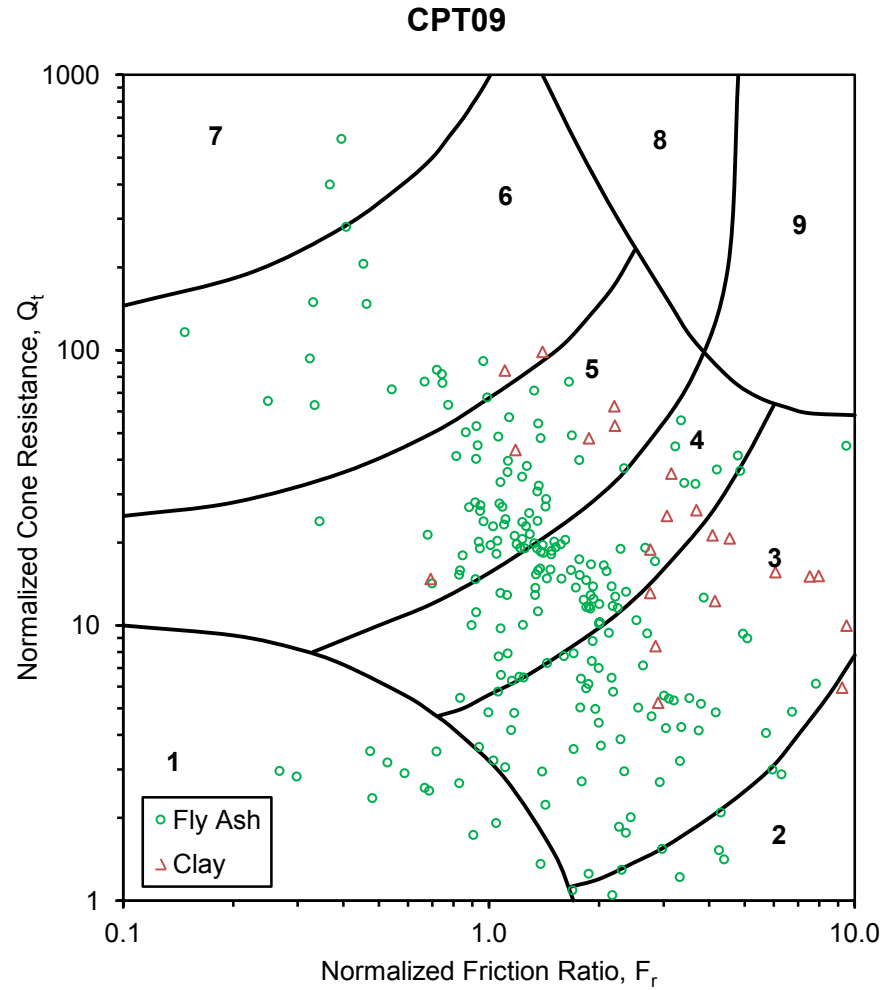


Figure 5-5
CPT profile for a fly ash pond – Site B (courtesy of AEP). Plots include tip resistance (q_t), side friction (f_s), friction ratio (R_f), and the Robertson Soil Behavior Type (SBT) [2]

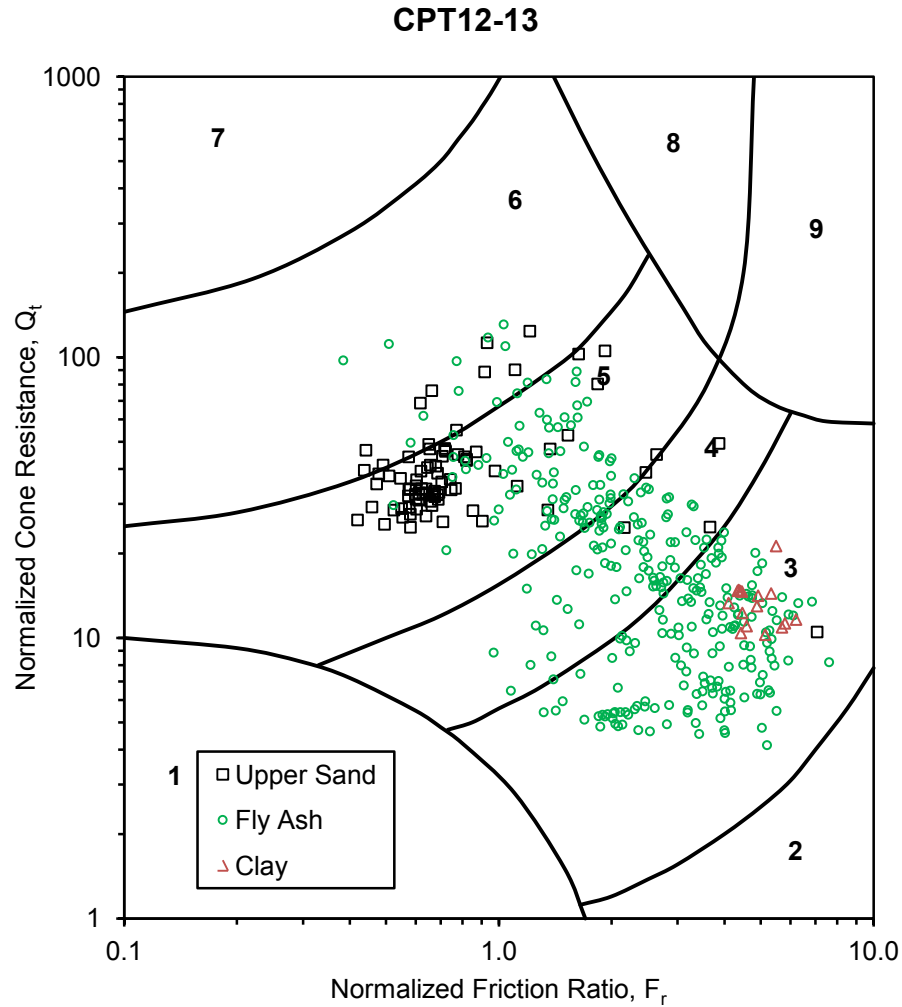
Information provided in Figures 5-6 and 5-7 indicates that because of the low tip resistance in fly ash, a soil behavior type of clay (i.e., Soil Behavior Type 3) may be computed. This is contradicted by the fact that penetration pore water pressures dissipate quite rapidly in fly ash. For example, the plot shown in Figure 5-8 indicates that pore water pressures reduce to near hydrostatic pressures in about 30 seconds. The user should therefore not rely solely on a soil behavior type plot to characterize the behavior of ponded CCRs. Such plots, while useful, have not been developed specifically for CCRs in ponds.



Soil Behavior Type

- | | |
|--|-------------------------------------|
| 1. Sensitive, fine grained | 6. Sands - clean sand to silty sand |
| 2. Organic soils - peats | 7. Gravely sand to dense sand |
| 3. Clays - silty clay to clay | 8. Very stiff sand to clayey sand |
| 4. Silt mixtures - clayey silt to silty clay | 9. Very stiff, fine grained |
| 5. Sand mixtures - silty sand to sandy silt | |

Figure 5-6
Soil behavior type for Site A

**Soil Behavior Type**

- | | |
|--|-------------------------------------|
| 1. Sensitive, fine grained | 6. Sands - clean sand to silty sand |
| 2. Organic soils - peats | 7. Gravelly sand to dense sand |
| 3. Clays - silty clay to clay | 8. Very stiff sand to clayey sand |
| 4. Silt mixtures - clayey silt to silty clay | 9. Very stiff, fine grained |
| 5. Sand mixtures - silty sand to sandy silt | |

Figure 5-7
Soil behavior type for Site B

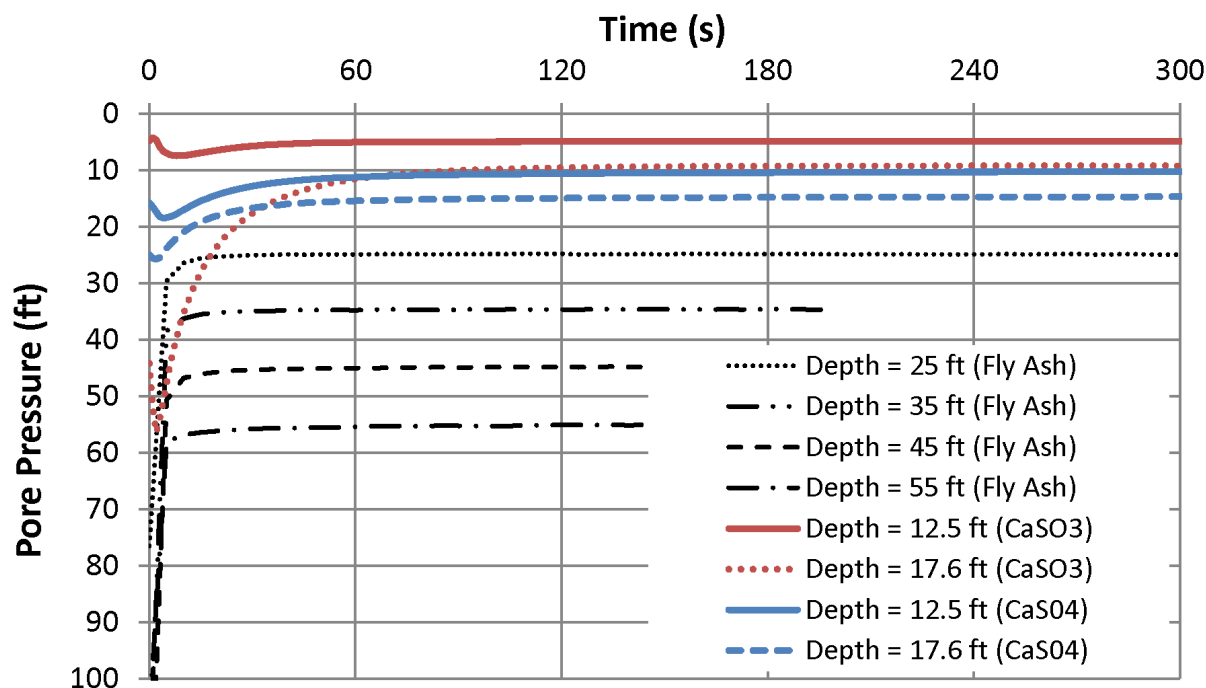


Figure 5-8
Pore water dissipation tests from fly ash and FGD ponds (fly ash data from AEP and FGD data from a confidential utility)

A CPT can also be fitted with a geophone and can be used to measure shear wave velocity at multiple depths within a pond. Shear wave velocity measurements are quite useful for establishing parameters for seismic analyses. Also, shear wave velocity can be used to assess the potential for aging (also referred to as “diagenetic cementation”) of a pond deposit (see Section 5.4.6 for specific information on aging).

5.3.5 Laboratory Testing

The suite of laboratory testing included in Table 5-1 to be conducted on ponded materials is very similar to that conducted for any soil which acts as a subgrade and/or foundation for an embankment (e.g., landfill) or area fill (e.g., cover system as part of a closure). The reader is referred to an EPRI-sponsored research report [5] for a detailed review of fly ash parameters. Herein, basic information on CCR material parameters which may influence laboratory testing is described.

CCRs in a pond, in particular fly ash, are unique from a geotechnical characterization point of view. Table 5-2 provides a comparison of fly ash in a pond to more conventional “textbook” soils such as sand, silt, and clay. As can be noted, fly ash may behave similarly to a wide range of soil types, depending on the specific material parameter being considered.

Table 5-2
Comparison of fly ash material parameters to conventional soil types

Characteristic	Fly ash behaves like ...
Grain size distribution	Well-graded silt
Specific surface	Silt comprised of spherical particles
Plasticity	Low plasticity silt
Specific gravity	No typical soil – but typically low
Porosity	Very loose granular material (with internal pores like a volcanic rock)
Permeability	Coarse grained (not consistent with particle size; depositional-induced anisotropy)
Shear strength	Granular material
Compressibility	Sand to low plasticity clays
Shear wave velocity	Soft clays/loose sands to dense sands/medium stiff clays

A summary of relevant information concerning laboratory testing of ponded materials is provided below.

- *Grain size distribution:* Fly ash is typically characterized as a well-graded silt under the Unified Soil Classification System (ASTM D-2487). Oftentimes, the gradation curves for fly ash samples from within the same pond can vary both vertically and horizontally. For a given project, this may be the result of sampling very near or far away from the ash sluice line discharge. Grain size distribution testing sieve analyses (ASTM D 421) and hydrometer tests (ASTM D422) should be conducted on multiple samples with the objective of discerning “coarser” (or “finer”) zones and/or the presence of potentially different materials (e.g., bottom ash). It is suggested that shear strength testing be conducted on samples which have the most fines.
- *Density (unit weight):* Recovered tube samples should be weighed immediately in the field following extraction from the sampler, and the height of the sample and the height of free water in the tube should also be measured prior to sealing and shipment to the laboratory. A procedure to compute the density of the sample in the field and once received in the laboratory is provided in EPRI [5]. Once received in the laboratory, the in-situ density (unit weight) can be measured. Of particular importance is to measure the amount of compression of the sample during shipment and to observe whether there is free water at the top of the sample or whether the compression appears to just be densification. If free water or densification is noted, this is an indication that the original in-situ sample was a “loose” sample. A loose sample has a greater potential for undrained failure (e.g., resulting from rapid placement of fills in the field). Also, compression which may have occurred during transport is an indication of sample disturbance.
- *Specific gravity:* The conventional approaches to evaluating the potential for static liquefaction are highly dependent on an accurate assessment of the void ratio of the material,

which requires an accurate laboratory assessment of specific gravity. Fly ash has intraparticle voids as well as the interparticle voids present in most conventional soils. Intraparticle voids are those within individual particles (e.g., plerospheres and cenospheres) [5]. Because of this, measured specific gravities may be much smaller than for typical soils and hence result in higher calculated void ratios. While higher void ratios may be calculated, typical settlement behavior (i.e., compression) of fly ash is more consistent with a lower void ratio material. Specific gravity, however, should still be measured because this parameter (coupled with in-situ density) is required to understand the variability of the density of the material within a pond, which is important for design. Testing of specific gravity can be done using methods commonly used for soil (ASTM D854).

- *Hydraulic conductivity:* Ponded CCRs such as fly ash experience segregation during sluicing into a pond. For fly ash, for example, this results in layers of finer and coarser fly ash. A laboratory hydraulic conductivity test (ASTM D5084) will measure the vertical hydraulic conductivity of the specimen and will be controlled by the hydraulic conductivity of the finer material in the sample. For this reason, a laboratory measured hydraulic conductivity likely represents a lower bound estimate of the ponded material hydraulic conductivity.

Figure 5-9 correlates measured penetration pore pressures to a laboratory measured hydraulic conductivity. For the two tests conducted on FA12-01 GUS-2, the laboratory reported that the sample from the Shelby tube was dissimilar in that the lower specimen had 56.3 percent fines and the upper specimen had 96.2 percent fines. As can be seen, however, the difference in hydraulic conductivity is relatively small. Of more importance, however, is that a review of the piezocone data indicates that at a depth interval of 50 to 57 ft, the penetration pore pressure (u) response is nearly hydrostatic and more free-draining than fly ash materials above and below this depth. This may imply that a reasonable upper bound vertical hydraulic conductivity value for the fly ash (for this project site) is around 1 to 2×10^{-4} cm/s. It is suggested that the horizontal hydraulic conductivity be estimated using piezocone dissipation tests (ASTM D5778) [7]. The ability of the fly ash to drain during construction and/or erode will be controlled by the horizontal hydraulic conductivity.

Referring to Figure 5-8, approximately 50 percent pore pressure dissipation was achieved in 5 to 10 seconds in fly ash. For FGD residuals comprising either calcium sulfite (CaSO_3) or calcium sulfate (CaSO_4), it is expected that 50 percent pore pressure dissipation would occur in 20 seconds to about 1 minute. The hydraulic conductivity of FGD residuals comprising calcium sulfite is on the order of 1×10^{-5} to 1×10^{-6} cm/s.

- *Consolidation:* Conventional one-dimensional consolidation tests (ASTM D2435) on fly ash are appropriate for obtaining compression parameters for design analyses. Figure 5-10 shows consolidation test results for fly ash samples from the same CCR pond. Additional discussion on interpreting laboratory one-dimensional consolidation test data is provided in Section 5.4.3.

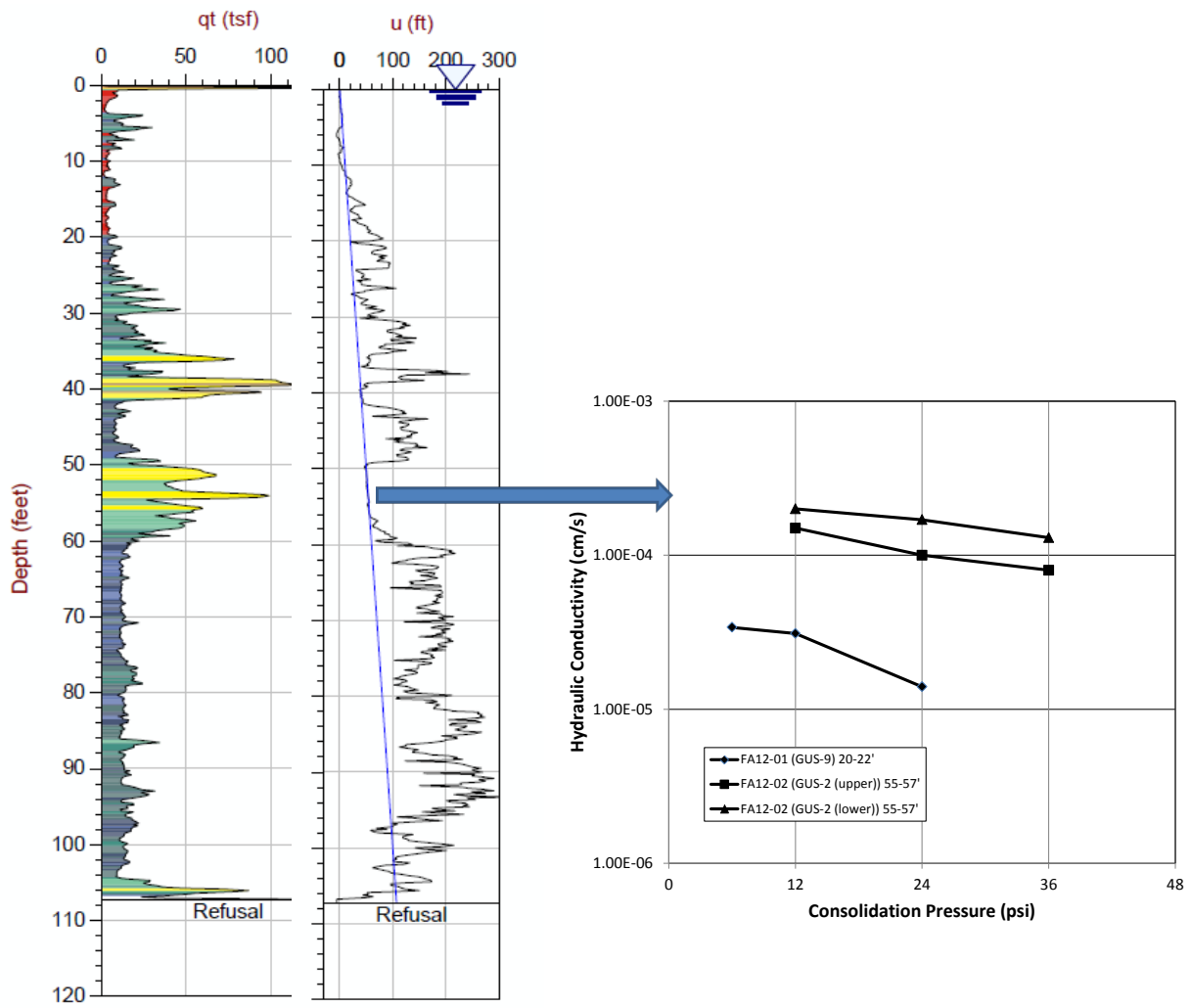


Figure 5-9
Hydraulic conductivity of fly ash (courtesy of AEP)

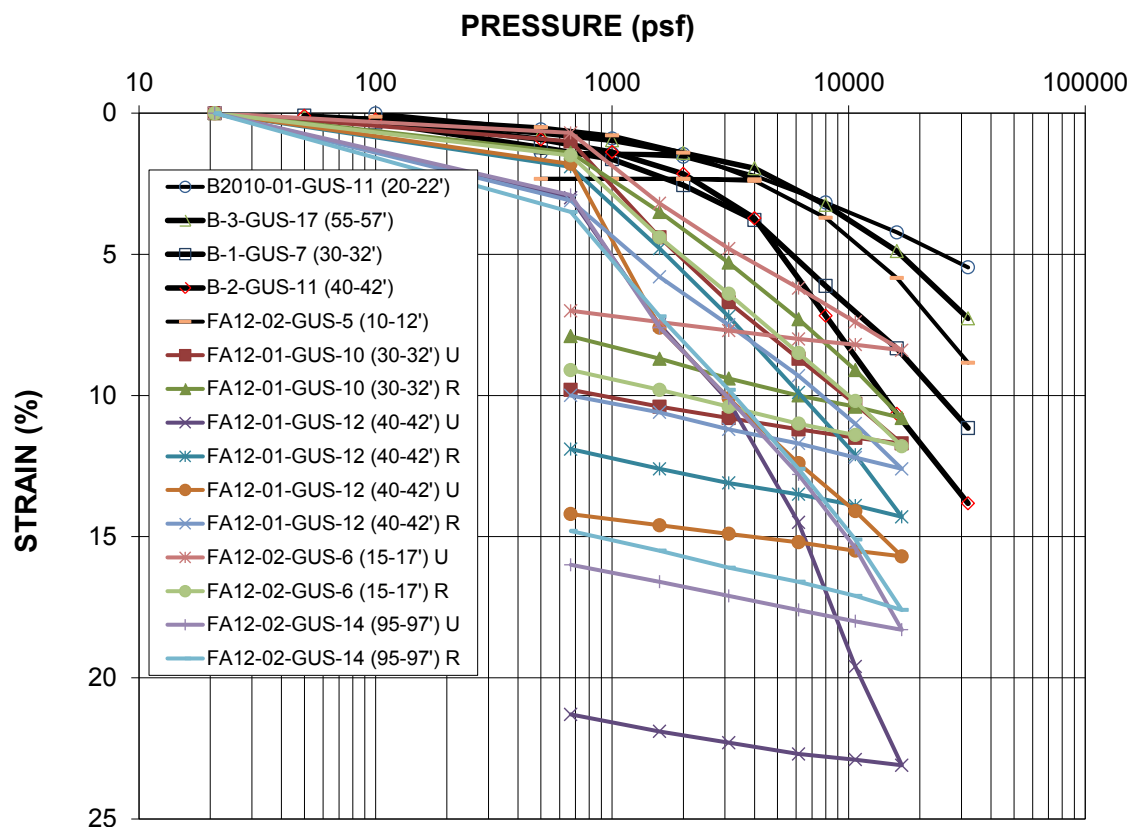


Figure 5-10
Laboratory one-dimensional consolidation testing on fly ash specimens from a single pond (courtesy of AEP)

- *Shear strength:* Fly ash in a pond has different properties in the vertical and horizontal directions, as previously described with respect to hydraulic conductivity. For this reason, it is possible that the shear strength of a fly ash sample is weaker if sheared along a finer layer as opposed to being sheared along a coarser layer. A mitigating factor is that given the deposition process in CCR pond, it is unlikely that these layers are continuous over distances that are relevant for a design stability analysis; however, at this time, this argument is still speculative. It is suggested that samples be taken from portions of the pond which are known (or believed) to comprise finer materials, such as at locations far from the location of ash sluice line discharge, and that conventional undrained triaxial tests (ASTM D4761) be conducted. This approach should result in a conservative assessment of ponded material shear strength.

Results in EPRI [5] indicate that, for relatively loose samples at confining pressures no higher than that for a 90-ft deep pond, the shear strength of fly ash under drained conditions can be represented by a friction angle ranging from 29 to 36 degrees.

5.3.6 Costs for Subsurface Investigation and Laboratory Testing

A design subsurface investigation in support of a closure design comprising drilling, sampling, and CPTs will likely range from tens of thousands of dollars for a small pond (e.g., less than 20

acres without overwater work) to several hundred thousand dollars for a large pond (e.g., more than 100 acres with overwater work). This would include all investigations conducted during the design phase and excludes any initial investigation conducted during the FS or concept design. Wherever possible, CPT soundings should be substituted for drilling and sampling; it is advantageous to conduct CPTs before drilling and sampling so that locations for drilling and sampling depths can be selected based on data from the CPTs. For fly ash ponds, shear wave velocity measurements and pore pressure dissipation testing using the CPT are relatively inexpensive and provide useful data for design. Nominally undisturbed fly ash samples from piston samplers may cost approximately \$300 per attempt.

Conventional laboratory geotechnical testing costs may be on the order of \$10,000 to \$20,000 with additional costs of \$10,000 to \$20,000 associated with conducting specialized laboratory testing to obtain parameters for seismic analysis.

5.3.7 Test Fills

The use of subsurface exploration and laboratory testing represents a sound and practical approach for assessing information required for the design of CCR pond closures. Until recently, the comprehensive evaluation of CCR parameters for such designs has been limited. For this reason, some owners have used large test fills constructed over CCR ponds to evaluate the performance of CCRs. It is noted that while instrumented test fills have previously been constructed over fly ash ponds and information is available in the literature [6], it may be beneficial to consider test fills for projects involving construction over FGD ponds, for which there is little experience and less availability of geotechnical data.

Test fills that are instrumented with settlement and pore pressure measuring devices can be used to evaluate the response of CCRs in ponds to typical loadings which may be introduced by the construction of a closure or a landfill over a CCR pond. An instrumented test fill of reasonable size can cost on the order of \$200,000 to \$500,000 or more.

A case history of a 300 ft by 800 ft, by 30-ft high instrumented test fill built over a fly ash pond is found in [6]. The results of that test fill indicated the measured settlement from the test fill, coupled with previous design calculations based on laboratory testing data, reasonably estimated settlements. Also, pore-water pressure dissipated quickly, approximately one week after completion of an incremental lift of fill. This result was significant because laboratory consolidation data (which provides an estimate of vertical drainage characteristics) indicated that it might take on the order of several months for significant pore pressure dissipation.

Figure 5-11 provides a timeline of measured excess pore pressures and the sequence of filling (i.e., height of fill as a function of time) for the case history in [6]. As no slope instability was noted, it can be concluded that the rate of loading used was slow enough to preclude the generation of pore pressures which could result in failure. Section 5.4.8 provides information on selecting a safe filling rate for construction over a pond.

5.3.8 Other Test Methods

Other field and laboratory testing methods have been used in recent EPRI studies to evaluate fly ash parameters and response to loadings that may be associated with a CCR pond closure; these test methods are significantly less expensive than full scale test fills. EPRI [7] reported the

results of an instrumented plate load test built on top of saturated coal ash. Vertical deformation, lateral deformation, and pore pressures in the subsurface were measured as part of the plate load test. The main purpose of this test was to evaluate the response of ponded fly ash to the loading, in particular, the excess pore water pressure induced by the load at or near failure conditions. As discussed in [7], this test demonstrated that review of excess pore pressures during field loadings can be used to control load levels to mitigate the potential for instability.

As another example of an alternate test, EPRI [8] conducted a centrifuge test including a sand embankment constructed over saturated fly ash. For centrifuge modeling, a reduced scale model is constructed in the laboratory and then loaded onto the end of the centrifuge. As the centrifuge spins, the centrifugal acceleration simulates an increase in gravity forces on the model, allowing the field loading condition to be simulated.

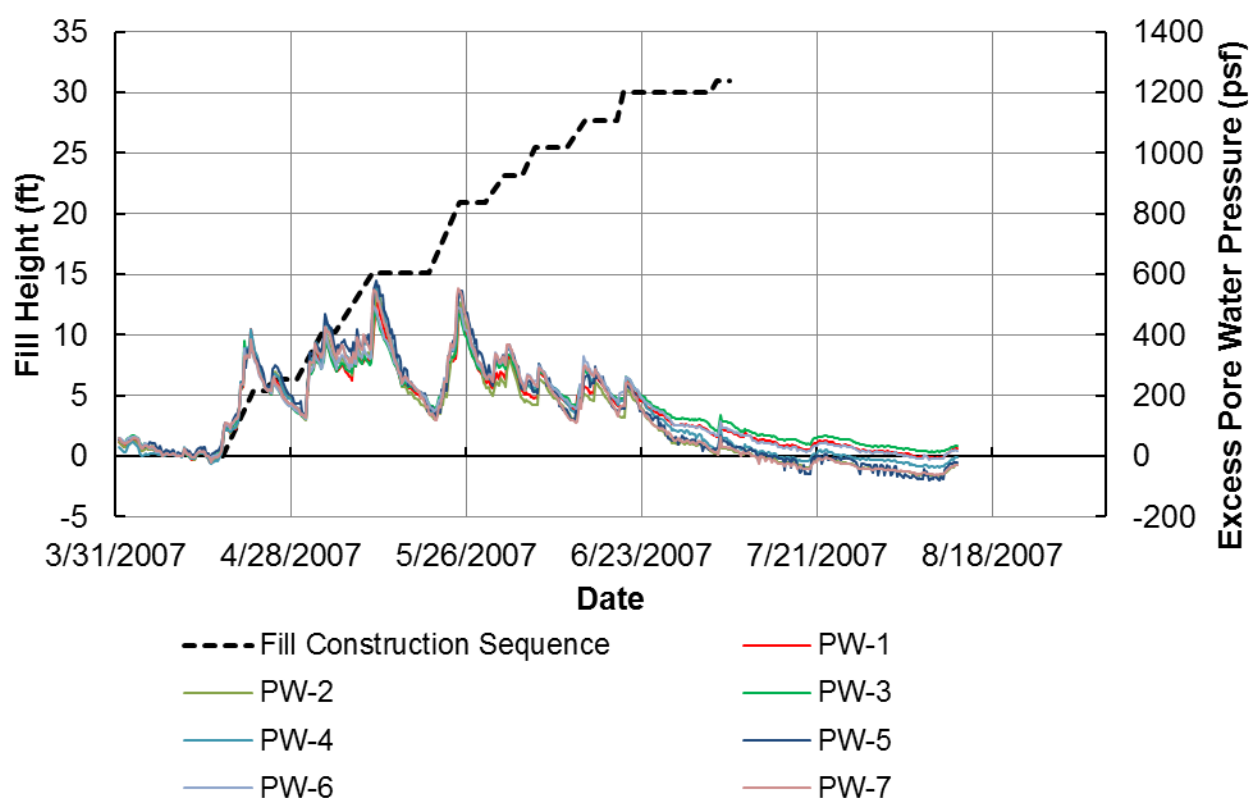


Figure 5-11
Measured pore pressures in fly ash pond resulting from test fill loading [6]

5.4 Geotechnical Analyses and Considerations

5.4.1 Overview

The purpose of this section is to provide guidance on specific geotechnical design assessments that are typically relevant for a CCR pond project.

5.4.2 Seismic Liquefaction

Liquefaction potential of soils subject to seismic loads is commonly evaluated using the so-called “Simplified Procedure” originally developed by Seed and Idriss ([9], [10]). That procedure compares the Cyclic Resistance Ratio (CRR) (i.e., the cyclic stress ratio required to induce liquefaction for a cohesionless soil stratum at a given depth) with the earthquake-induced Cyclic Stress Ratio (CSR) at that depth from a specified design earthquake (defined by a peak ground surface acceleration and an associated earthquake magnitude).

CCRs in a pond are typically loose, saturated, non-plastic, and silt-sized. From a preliminary screening perspective, it is likely that a significant thickness of such material in a pond would be deemed by the design engineer as “potentially liquefiable” and therefore requiring additional liquefaction analysis. For example, oftentimes blow count data from an SPT boring indicate extensive very soft zones demonstrated by weight of rod or weight of hammer material (i.e., indicative of a liquefiable material).

Since the Simplified Procedure was not developed for fly ash or other CCRs, the use of this procedure as the sole method to evaluate liquefaction potential for fly ash or other CCRs is not appropriate. Laboratory studies on fly ash liquefaction have been conducted to estimate the CRR for fly ash materials (see [11]).

A procedure to evaluate liquefaction potential of ponded materials includes:

- Conduct seismic piezocone tests to develop an estimate of the shear wave velocity with depth profile in the pond. Other geophysical methods can be used to measure shear wave velocity, however the seismic piezocone is relatively inexpensive; consider the cost to be about \$30 per shear wave velocity measurement once the equipment is in the field and set up and operating to conduct testing.
- Conduct laboratory cyclic triaxial (CTX) or cyclic direct simple shear (CDS) tests on ponded materials. Details of a cyclic triaxial test program can be found in ASTM D-5311⁴. The objective of the laboratory testing is to develop an understanding of the CRR for the ponded materials. In the laboratory, liquefaction would typically be defined as occurring when shear induced pore pressures are equal (or very near equal) to the initial effective confining pressure (i.e., this corresponds to a pore pressure ratio, $r_u = 100\%$); alternative definitions based on a maximum strain may also be used.
- From these laboratory data, a relationship between the number of cycles (N) to cause liquefaction and CRR is developed; an example of this for a specific laboratory testing program on fly ash is shown in Figure 5-12. The laboratory curve should then be adjusted to represent field conditions (e.g., corrections should be applied for differing stress conditions between triaxial and simple shear, the effect of multi-directional shaking, etc.; see [12] and [13] for information on these adjustment factors); see Figure 5-13.

⁴ The reader is referred to ASTM D-5311, “Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil”. It is noted that the results of cyclic testing will be significantly affected by the method of specimen preparation and achieved specimen density. EPRI [5] provides specific information on specimen preparation for reconstituting samples from a fly ash pond.

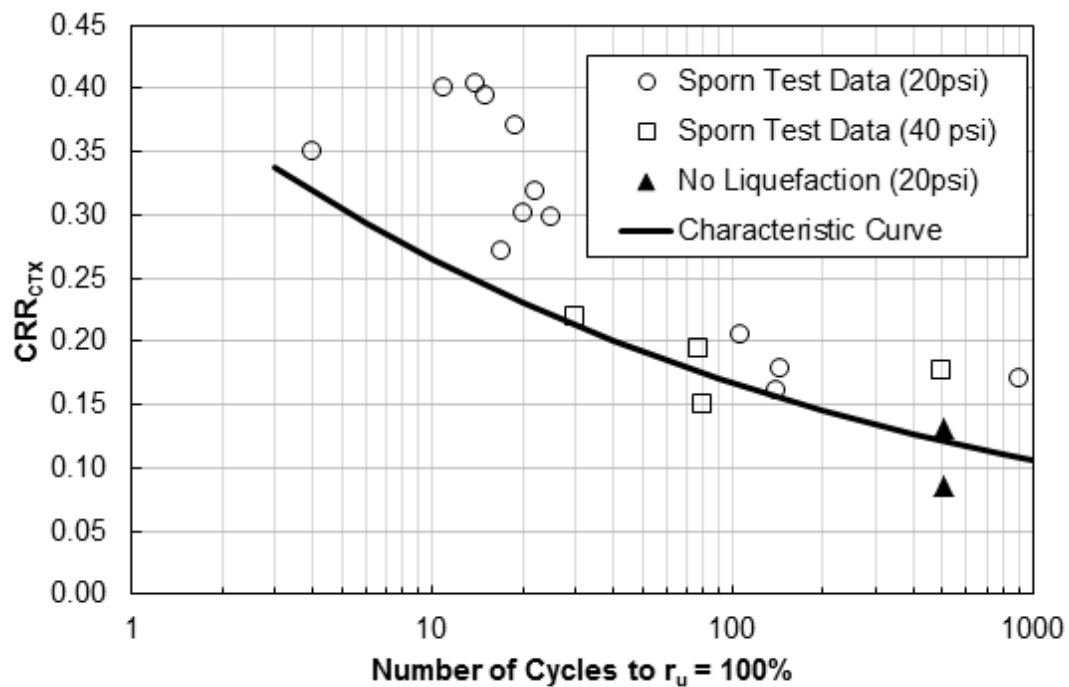


Figure 5-12
Plot of Cyclic Resistance Ratio (CRR_{CTX}) vs. number of cycles to reach Pore Pressure Ratio (r_u) = 100% (courtesy of AEP)

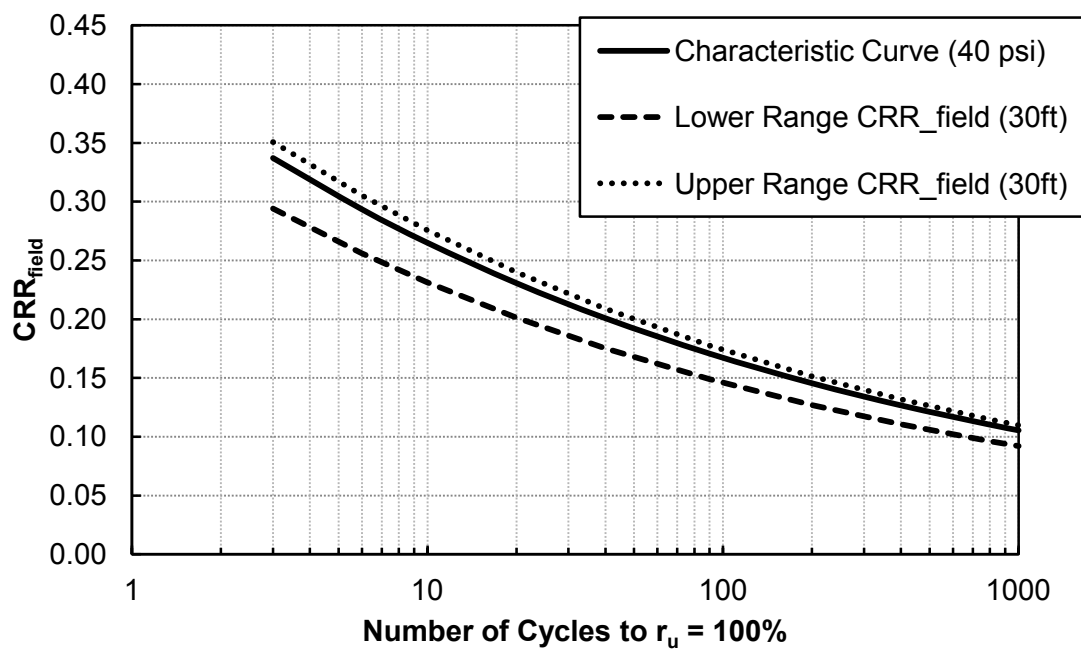


Figure 5-13
Plot of Cyclic Resistance Ratio (CRR_{field}) vs. number of cycles to reach Pore Pressure Ratio (r_u) = 100%

- The CSR is a measure of the earthquake-induced stresses on the soil and is calculated as:

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = \frac{0.65 \times PGA \times \sigma_{vo} \times r_d}{\sigma'_{vo}} \quad (\text{Eq. 5-3})$$

where PGA is the peak ground acceleration at the top of the soil column, r_d is a shear mass participation factor, τ_{av} is the average horizontal shear stress during seismic loading, and σ_{vo} and σ'_{vo} are the geostatic vertical total and effective stresses, respectively. The PGA can be estimated using information from the U.S. Geological Survey Geohazards Internet Web Site (<http://eqhazmaps.usgs.gov/>) or from a site-specific seismic hazard evaluation. The website provides peak rock acceleration based on site latitude and longitude or zip code. This rock acceleration must be adjusted to estimate the PGA in consideration of the specific soil type(s) including the material in the pond⁵. A summary of seismic site response analyses for several ash pond sites in the Midwest is provided in [14]. The cost for a relatively simple site response analysis using, for example, SHAKE2000 [15], is on the order of \$10,000⁶.

- A relationship provided in [16] can be used to calculate the number of uniform stress cycles (N) that are developed by the design earthquake occurring at a specific distance from the site.
- The magnitude of CSR together with the number of equivalent uniform stress cycles (N) is plotted in Figure 5-14 for comparison with the laboratory-derived cyclic resistance curves. For this example, the median value of N is calculated to be 23 cycles. The data on the plot indicates that the seismically induced stresses (i.e., seismic demand) are insufficient to develop a condition of $r_u = 100\%$ in the fly ash located at a depth of approximately 30 ft (i.e., factor of safety against liquefaction is greater than 1.0). The analysis should be repeated for multiple depths in the pond.

If zones within the CCR pond are deemed to be liquefiable (i.e., the factor of safety against liquefaction is less than 1.0), more sophisticated analyses can be conducted or liquefaction mitigation measures can be implemented. Mitigation measures may include: (i) use of toe berms to increase confining stresses within the liquefiable zones; (ii) dewatering to lower the water levels within the pond; or (iii) various measures to increase the shear strength of the liquefiable zones including deep soil mixing. Section 8 of [17] provides detailed information on liquefaction mitigation measures. CCR pond sites which are located in areas corresponding to ground accelerations on the order of 0.05 g or higher should be evaluated at the feasibility stage for liquefaction potential, as liquefaction mitigation strategies can be very costly.

Seismic liquefaction will also induce post-liquefaction settlements as excess pore pressures dissipate. This should be considered in the design of landfills and covers over the ponded materials. Laboratory cyclic triaxial tests can also be used to measure the volumetric strains by allowing the undrained samples to drain after the cyclic test is concluded.

⁵ A seismic site response analysis (e.g., SHAKE2000 analysis) can be conducted with one or more representative earthquake acceleration-time histories to estimate τ_{av} in Equation 5-3.

⁶ This cost is only for engineering effort; costs for obtaining site-specific data for shear wave velocity and unit weight are included in the site investigation cost.

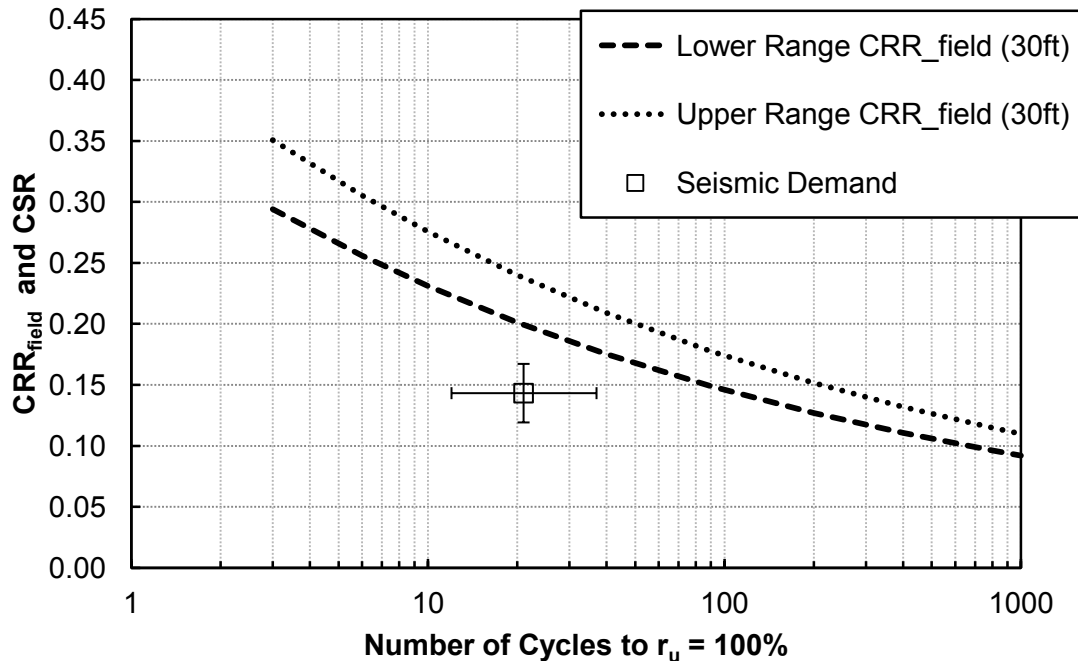


Figure 5-14
Comparison of Cyclic Resistance Ratio (CRR_{field}) with Cyclic Stress Ratio (CSR) for
depth = 30 ft

5.4.3 Settlement

Loads imposed by a landfill or closure cover system will result in time-dependent compression (or settlement) of CCRs. Depending on the magnitude of the loads (e.g., compare a closure which may include just several feet of soil cover to a landfill which may comprise a 200-ft thick waste loading) and compression properties of the CCR foundation, settlements of up to several feet (or more) can be expected. While embankments are very flexible structures and can easily withstand relatively large settlements, internal systems such as plastic liners, leachate piping, and drainage layers can be affected by such settlements.

Design analyses in consideration of CCRs settlements typically include the following evaluations:

- Calculate the post-settlement grade of the landfill liner system and cover system to demonstrate that these features still maintain positive drainage (i.e., no calculated grade reversals) for the post-settlement (or long-term) condition.
- Verify that settlement of piping near connections is relatively small and/or flexible connections are included in the design to withstand calculated settlements.
- Using calculated settlements, estimate the tensile strain that may occur (for the post-settlement condition) in landfill liner components that could be adversely affected, such as geomembranes. Guidance on allowable strains in geomembranes is provided in [18]. The allowable tensile strain of a compacted clay component (which provides a hydraulic containment function) may also be evaluated. Most of the available literature on tensile

strains in compacted clays would only be applicable for cover systems (where stresses are very low). The extrapolation of such data to evaluate allowable tensile strains for clays in a liner system (where stresses are much higher) is conservative.

Methods used to estimate settlements for geotechnical designs are well-developed and discussed in numerous textbooks and guidance documents (e.g., [19]). Settlements of ponded materials are typically computed using standard one-dimensional consolidation theory, according to the following equations:

$$S_p = \frac{C_r}{1 + e_o} H_o \log \left(\frac{\sigma'_{vo} + \Delta \sigma_v}{\sigma'_{vo}} \right) \quad (\text{Eq. 5-4})$$

$$S_p = \frac{C_r}{1 + e_o} H_o \log \left(\frac{\sigma'_p}{\sigma'_{vo}} \right) + \frac{C_c}{1 + e_o} H_o \log \left(\frac{\sigma'_{vo} + \Delta \sigma_v}{\sigma'_p} \right) \quad (\text{Eq. 5-5})$$

where:

S_p = primary consolidation settlement;

C_c = compression index;

C_r = recompression index;

e_o = initial void ratio;

H_o = initial thickness of compressible layer;

σ'_{vo} = initial vertical effective stress in the ground before additional loading;

σ'_p = preconsolidation stress; and

$\Delta \sigma_v$ = increase in vertical stress.

Alternatively, these equations can be written as:

$$S_p = RR H_o \log \left(\frac{\sigma'_{vo} + \Delta \sigma_v}{\sigma'_{vo}} \right) \quad (\text{Eq. 5-6})$$

$$S_p = RR H_o \log \left(\frac{\sigma'_p}{\sigma'_{vo}} \right) + CR H_o \log \left(\frac{\sigma'_{vo} + \Delta \sigma_v}{\sigma'_p} \right) \quad (\text{Eq. 5-7})$$

where: $RR = C_r/(1+e_o)$ and $CR = C_c/(1+e_o)$.

Computer programs, such as WIN-SAF-I [20] or SETTLE3D [21], or settlement calculation spreadsheets can be used. Using the data in Figure 5-10 as an example, it is evident that the selection of a single value of CR is difficult, as: (i) it varies depending on the specimen; and (ii) it varies based on the stress level of interest. Table 5-3 provides a summary of the interpreted values for RR and CR for the Figure 5-10 data for a stress range (for CR interpretation) of

between approximately 3,000 psf and 10,000 psf (i.e., stress range of interest for a particular closure design). Using this data, a reasonable average value for design for CR is 0.11 and RR = 0.02.

An alternative method could be used to compute settlements wherein the difference in strain is computed based on the initial effective stress in the ground and the final effective stress in the ground after closure construction (resulting from weight of fill soils). With this approach, the engineer would need to select a single laboratory test result or develop some average curve (with appropriate conservatism); this approach avoids the difficulties in computing (or selecting) a preconsolidation stress, σ'_p . For this evaluation, replot the lab data in terms of strain vs. pressure on an arithmetic scale (see Figure 5-15).

Laboratory one-dimensional consolidation test data for four fly ash ponds owned by a single Midwest utility is provided in [14]. The data indicate that the average amount of strain (expressed as total strain to reach 32,000 psf) may range from 5 percent to more than 20 percent. It is therefore necessary to conduct site-specific consolidation testing for design.

Table 5-3
Summary of consolidation test parameters for tests shown in Figure 5-10 (courtesy of AEP)

Location	Sample No.	Depth (ft)	e_o	CR	RR
B-1	GUS-7	30-32	0.93	0.084	0.013
B-2	GUS-11	40-42	0.86	0.110	0.020
B-3	GUS-17	55-57	0.60	0.067	0.007
B2010-01	GUS-11	20-22	0.56	0.038	0.008
FA12-02	GUS-5	10-12	0.84	0.085	0.000
FA12-01	GUS-10 (U)	30-32	0.93	0.067	0.014
FA12-01	GUS-10 (R)	30-32	0.91	0.071	0.021
FA12-01	GUS-12 (U)	40-42	1.14	0.176	0.013
FA12-01	GUS-12 (R)	40-42	1.08	0.092	0.017
FA12-01	GUS-12 (U)	40-42	0.82	0.075	0.011
FA12-01	GUS-12 (R)	40-42	0.88	0.065	0.019
FA12-02	GUS-6 (U)	15-17	0.90	0.049	0.010
FA12-02	GUS-6 (R)	15-17	0.86	0.071	0.019
FA12-02	GUS-14 (U)	95-97	1.14	0.099	0.016
FA12-02	GUS-14 (R)	95-97	1.28	0.099	0.020

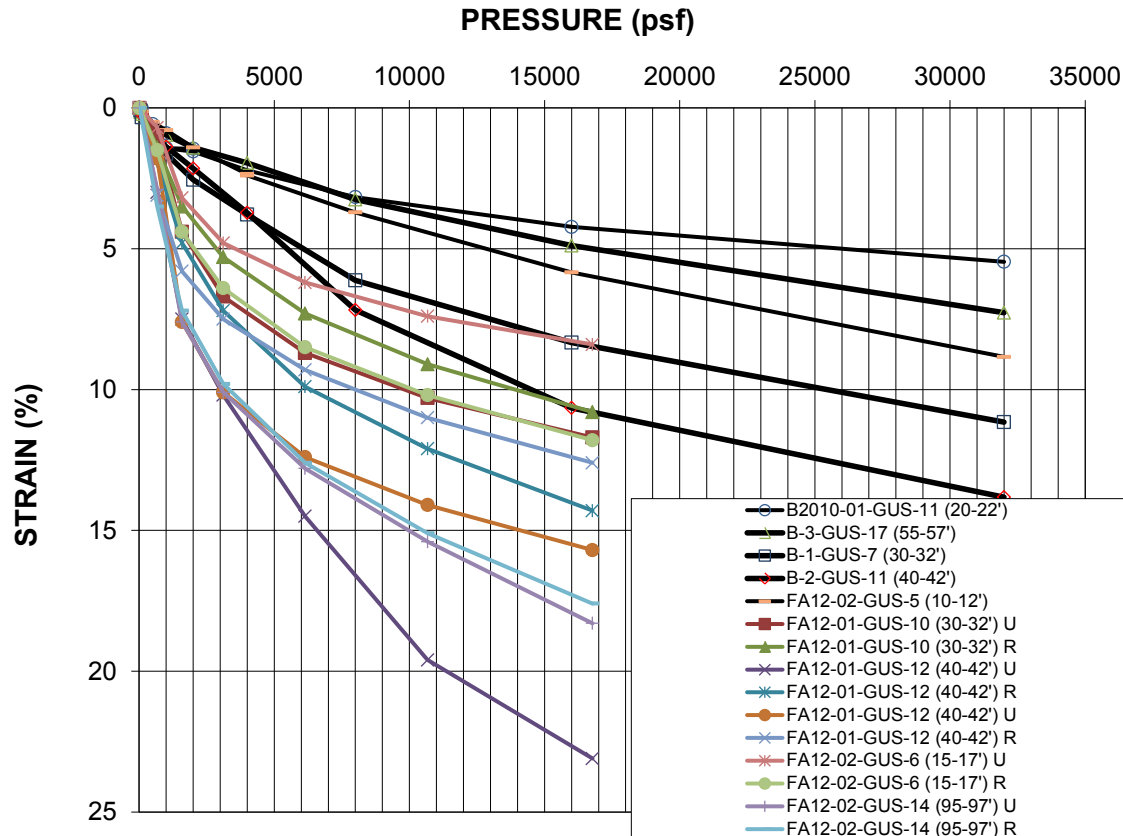


Figure 5-15
Laboratory one-dimensional consolidation testing plotted with pressure on arithmetic scale (courtesy of AEP)

For closures and landfills over CCRs, the following issues should be addressed with respect to assessing the effect of settlements:

- Typically, the plan area of the pond to be loaded is many times the thickness of the CCRs in the pond which will be loaded, thus a one-dimensional loading can be considered wherein all load is assumed to reach the very bottom of the CCR pond.
- For valley-fill CCR ponds, the original bottom of the pond is irregular in elevation and shape, unlike constructed ponds. Therefore it is critical to develop an understanding of the original (i.e., pre-pond filling) topography. In a valley-fill, the thickness of the ponded CCRs will vary across the pond, thus creating the potential for differential settlements. Also, this effect can be compounded by variations in material types. For example, Figure 5-16 depicts a valley-fill pond where a new landfill would traverse not only ponded fly ash, but also a large portion of the site which had been previously filled with mine spoil. The variation in compressibility of these materials required that the temporary and permanent leachate collection system pipes be designed with compound grades to maintain positive post-settlement grades.
- If possible, settlements associated with the weight of contouring fills required to achieve a cover system grade (for a closure) or a landfill subgrade should be completed before the cover system or liner is constructed. That is, it is advantageous to allow for near-complete to

complete dissipation of pore pressures from contour fills before the engineered cover or liner is constructed.

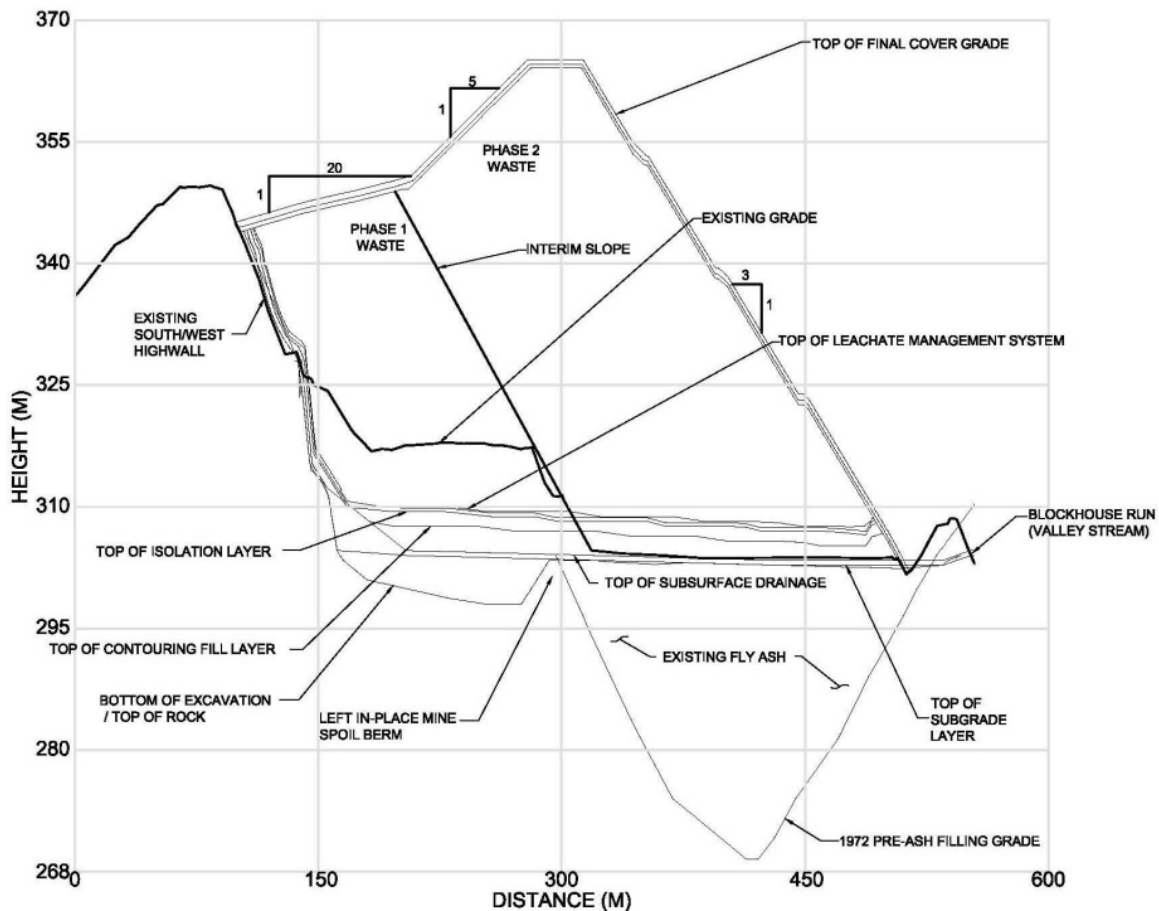


Figure 5-16
Cross section of an FGD landfill over a fly ash pond

5.4.4 Static Slope Stability

5.4.4.1 Overview

A detailed slope stability evaluation is typically required for the design of any slope. Slopes for a closure may be as steep as 10 percent, whereas slopes for a landfill may be as much as 33 percent (i.e., 3 Horizontal: 1 Vertical) or more. A slope stability analysis requires a careful evaluation of:

- surface and subsurface geometry of all soil, rock, and geosynthetic layers;
- water levels and/or pore pressures in affected materials;
- appropriate shear strength values for critical material layers and interfaces;
- magnitude and position of any surcharge or equipment loadings; and

- reasonableness of the extent and location of the critical failure surface (i.e., the computed slip surface with the lowest calculated factor of safety (FS)).

5.4.4.2 Pond Closures

In general, final constructed fill slopes associated with a pond closure will be relatively shallow and therefore the stability of these slopes should be adequate; however, as a matter of standard practice, stability analyses still are conducted. Specific stability conditions that should be verified are described herein.

- The steepest final closure slope should be identified and a deep-seated slope stability analysis (i.e., through the cover system soils and into the CCRs comprising the foundation) should be conducted. A stability analysis considering sliding along soil/geosynthetic and geosynthetic/geosynthetic interfaces within the cover system should also be conducted. For these analyses, estimates of the degree of saturation of soils should be evaluated for long-term (i.e., post-closure conditions) with due consideration for the beneficial effects of any drainage systems.
- As part of a closure, it may be beneficial to relocate ponded materials to achieve specific design grades and/or promote a cut/fill balance for a phase of the project. This is considered a temporary, construction condition. For this, consideration should be given to safe excavated (i.e., “cut”) slopes of ponded materials. This condition is difficult to analyze and will likely be controlled by the saturation of the slope at the time of excavation. Experience indicates that excavations in materials such as fly ash will become less stable with time. For this reason, analyses to evaluate safe slopes should be based on drained shear strength parameters, as materials such as fly ash (which can appear stable due to capillary action and hence negative pore pressures) can drain rapidly.

5.4.4.3 Landfills

Slope stability analyses considering landfills that are constructed over CCR ponds are conducted using typical procedures and methods for soil slopes. The reader is referred to “Geotechnical and Stability Analyses for Ohio Waste Containment Facilities” ([22]) for a detailed discussion of slope stability analyses for waste slopes. While this guidance was developed specifically for landfills in Ohio, the information provided is quite comprehensive. The reader is also referred to [17] for additional information on static stability analyses.

The measurement (or estimate) and selection of appropriate shear strength parameters for a slope stability analysis is important. Shear strength testing can be performed on nominally undisturbed samples or reconstituted samples. For reconstituted samples of ponded materials, multiple methods of sample preparation have been used, including wet pluviation, slurry-deposition, and moist tamping. Procedures for each of these methods are provided in [5]. For shear strength testing, water pluviation is suggested to create samples to model depositional conditions in a typical pond.

Laboratory test results and results from test fills indicate that excess pore pressures in fly ash ponds typically dissipate much faster than periods of time required for construction. Therefore, consolidated-undrained triaxial (i.e., CU) tests or consolidated-drained (CD) tests can be used to estimate the drained friction angle of the material for stability analysis. It is noted, however, that

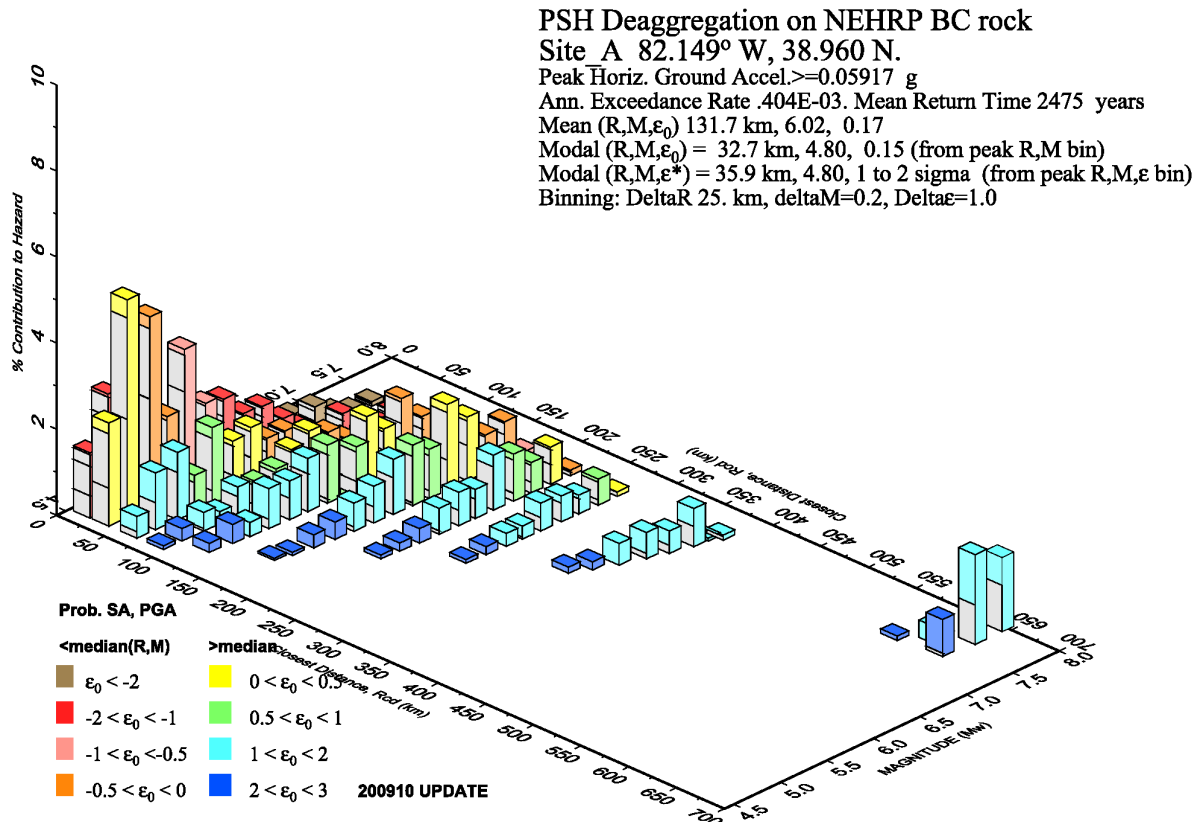
ponded materials may have “locked-in” high porosity due to post-depositional diagenesis (light cementation), which may collapse on loading and result in a rapid settlement during field/temporary loading (see Section 5.4.6). It is therefore prudent to measure pore pressures during field loading using a suite of piezometers and verify actual rates of pore pressure dissipation for expected rates of construction.

5.4.5 Seismic Slope Stability

Seismic slope stability analyses should be conducted for any engineered slope as part of a pond closure or landfill slope construction over a CCR pond. Common practice is to utilize a pseudo-static representation of seismic demand in which a destabilizing horizontal coefficient (k) is used in a conventional slope stability calculation. The seismic coefficient represents the fraction of the weight of the sliding mass that is applied as an equivalent horizontal force acting through the centroid of the sliding mass.

The seismic coefficient is also related to a reference acceleration which is typically taken as the acceleration in bedrock below the slope. The value to be used for the seismic coefficient has been based on precedence. In [23], a procedure is provided to estimate the seismic coefficient based on a project-specific evaluation of allowable permanent deformation. The seismic response characteristics of the slope being analyzed are represented by the fundamental period of the sliding mass (which is computed based on the height of the sliding mass and the average shear wave velocity of the material comprising the sliding mass).

Many electric utilities with CCR ponds are located in the eastern half of the United States, where extensive data from previous earthquakes does not exist. For sites with less information, accelerations can be established using the U.S. Geological Survey Geohazards Internet Web Site (<http://eqhazmaps.usgs.gov/>) or from a site-specific seismic hazard analysis. An example output from the USGS site is provided in Figure 5-17, where the peak rock acceleration associated with a Magnitude 6.02 earthquake (with a return period of 2,475 years (i.e., a 10% chance of exceedance in 250 years) is 0.059g.



GMT 2014 Apr 9 12:38:28 Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on rock with average vs= 760. m/s top 30 m. USGS CGHT PSHA2008 UPDATE Bins with lt 0.05% contrib. omitted

Figure 5-17
Seismic hazard for a site in southeast Ohio

The target FS value for a seismic slope stability analysis using the method described is typically 1.0. If the FS value is less than the target value, this implies that the slope is subject to some amount of permanent deformation resulting from the design earthquake. These deformations can be computed using Newmark-type sliding block analyses [24]. Typical tolerable displacements are: (i) 12 in. for landfill covers; and (ii) 6 in. for landfill liners. The reader is referred to [25] for additional information on seismic stability analyses.

5.4.6 Static Liquefaction

After the December 2008 slope failure at the TVA Kingston Fossil Plant, the U.S. EPA and all electric utilities that used wet disposal techniques to manage CCRs raised concerns regarding geotechnical stability including the potential for static liquefaction of CCRs. Static liquefaction is a phenomenon in which the granular skeleton of a saturated, loose soil matrix collapses during an undrained shear loading resulting in a significant reduction in effective stress and flow of the soil mass.

A comprehensive evaluation of static liquefaction of fly ash is provided in [5]. A detailed literature review and a comprehensive suite of laboratory testing were conducted as part of that evaluation. The primary conclusions of the study (as they relate to the potential for static liquefaction in ponded fly ash) include:

- Fly ash contains occluded and intra-particle voids that result in low specific gravity which leads to difficulty in consistent determination of specific gravity of solids. Based on this, fundamental geotechnical parameters such as void ratio, porosity, and degree of saturation are difficult to accurately assess. Since void ratio is the key parameter used to assess the tendency of a soil to undergo a volume change during drained shear (i.e., contract or dilate) and degree of saturation determines whether excess pore pressures will be generated during undrained loading, alternative techniques are required to characterize ponded fly ash.
- An alternative technique to the use of void ratio is provided in [5] for assessing maximum and minimum “realizable densities” (or unit weights) for a specific fly ash. By comparing the actual in situ density to the maximum and minimum realizable densities, an estimate of the potential for static liquefaction should be achievable; it is noted that further research is necessary to identify an approach to measure the density below which static liquefaction may occur.
- Laboratory test results suggest significant segregation of the fly ash during sedimentation; the resulting layered structure will exhibit significant anisotropic properties such as higher permeability in the horizontal direction than in the vertical direction. Also, the presence of layered fine zones can lead to preferred weak planes.
- Early diagenesis (i.e., aging) during initial fly ash wetting and deposition was observed in most of the fly ash specimens, particularly for materials that tend to exhibit relatively high pH (see Figure 5-18). Early diagenetic cementation prior to self-weight consolidation “locks in” relatively high interparticle porosity during burial, and the ponded fly ash will have an increased contractive tendency (i.e., be more prone to static liquefaction). To evaluate the potential for diagenetic cementation, shear wave velocity should be measured in the field using, for example, a seismic piezocone. Compare these shear wave velocity measurements to laboratory-measured shear wave velocity on reconstituted specimens at the same vertical effective stress. If the field-measured values of shear wave velocity (corresponding to an undisturbed specimen) are higher than the shear wave velocity (and have lower density; see Section 5.3.5 for discussion on density determination in the laboratory) than for the laboratory specimens, diagenetic cementation can be expected.

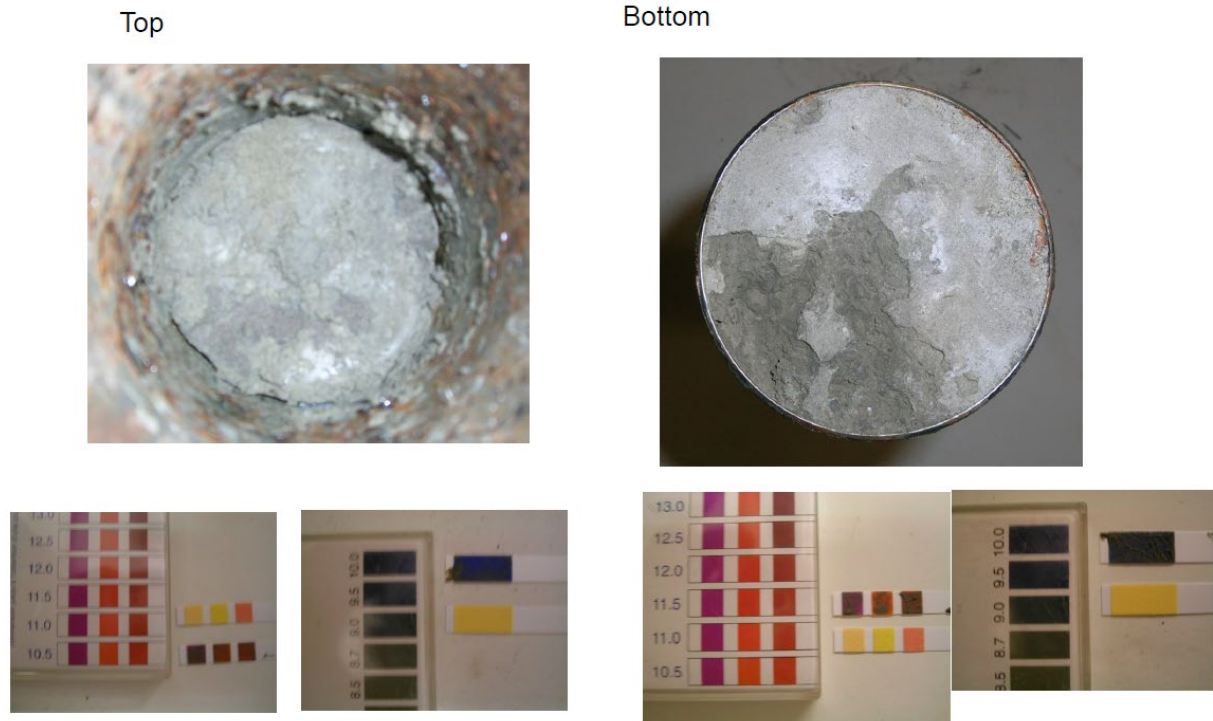


Figure 5-18
Fly ash specimen in Shelby tube with pH = 10.5 (top) and 11.5 (bottom) [5]

- In the absence of early diagenesis, the study authors [5] noted that none of the tested specimens indicated the strongly contractive response necessary for static liquefaction. It was noted that: (i) fly ash exhibits higher strain levels to reach peak and quasi-steady state conditions than for sands; (ii) there are pronounced difficulties in forming clearly contractive fly ash specimens for the nominal effective confinement of interest to ponded fly ash of approximately < 200 to 300 kPa; and (iii) fly ash exhibits high internally connected voids that are difficult to completely evacuate of air; these internal compressible air “pockets” in the fly ash will limit the generation of positive excess pore pressure during undrained loading.

The study authors conclude that the failure of a containment structure must precede the failure of the ponded fly ash [5]. If the containment fails (e.g., dike failure), water-saturated ponded fly ash with high locked-in porosity due to early diagenesis and the presence of free water in the pond can produce a post containment fly ash flow failure similar to that observed at the TVA Kingston Plant. If containment can be assured, then fly ash flow failure should be rare and unexpected.

If diagenesis is considered to be a possibility based on: (i) relatively high pH values; (ii) differences between laboratory and field measured shear wave velocity; and/or (iii) a one-dimensional consolidation curve which exhibits a marked transition between overconsolidated and normally consolidated behavior, it is prudent to exercise specific controls on filling rates for construction. For example, if the critical load (i.e., the transition between overconsolidated and normally consolidated behavior) can be estimated, it would be prudent to load the ponded

material to below this value and allow pore pressures to completely dissipate before increasing the load (via filling) to a value above the critical load (see [14]).

5.4.7 Preloading and Accelerated Construction Techniques

Preloading and other measures used to facilitate more rapid construction are required for situations wherein the rate of loading is so fast that excess pore pressures generated in foundation layers do not have time to dissipate. These excess pore pressures may lead to global (i.e., deep seated) or local instability (such as local failure of the leading edge of an advancing earthwork layer). CCRs are usually neither “free draining” or “low permeability”. That is, they behave in a partially drained manner for typical construction loadings. For this reason, the decision to use measures to reduce the time required for excess pore pressures in the CCRs to dissipate to a safe level (so that soil filling can occur) should be based on site-specific information including test excavations, test fills, and instrumentation monitoring. For example, experience indicates that excess pore pressures that may be generated in fly ash during construction of area fills will typically dissipate in a few weeks.

Information on the use of prefabricated vertical drains (i.e., “wick drains”) for pre-drainage of CCRs in a pond (including bottom ash, fly ash, and FGD by-products) is described in Section 8.3.

5.4.8 Rates of Filling

The deposition of wet fly ash into a fly ash pond setting results in significant segregation taking place during sedimentation. The resulting layered structure will exhibit anisotropic properties. This segregation-induced heterogeneity will impact permeability of the material as well as pore pressure dissipation.

The ability to load under undrained conditions in the field is related to the rate of load application compared to the rate of pore pressure dissipation. The rate of pore pressure dissipation is governed by the coefficient of consolidation, a function of hydraulic conductivity and matrix compressibility, and the rate of load application.

The time for pore pressure dissipation (t) can be estimated as $t = H^2/C_v$ and it depends on the coefficient of consolidation (C_v)⁷ for the particular fly ash material and the largest distance from the center of the compressible material to a drainage boundary (H), assuming that the areal extent of the load (L) is much greater than the distance H , a common situation for a closure in which the thickness of the ash is likely to be much less than the average length or width of the pond closure area. Therefore, the time for pore pressure dissipation is specific to the fly ash material, the degree of segregation that took place during sedimentation, the type of natural soils lining the boundaries of the pond, and the overall geometry of the reservoir. In one study [26], an average degree of consolidation of 82 percent was achieved in 60 days for a pond with a thickness of fly ash from 100 to 120 ft.

⁷ For laboratory samples, C_v can be estimated using one-dimensional consolidation test results on nominally undisturbed samples or samples reconstituted using water pluviation methods.

The rate of loading of the pond depends on the proposed closure sequence and the magnitude of the fill necessary to achieve desired grade elevations. Bozok and others [26] found that a rate of loading of 0.5 ft/day was concluded to be sufficiently slow to allow significant pore pressure dissipation in fly ash. Information provided in another study [14] indicates that average filling rates for four different ash closure projects is anticipated to be on the order of 0.1 ft/day with a maximum specified rate of 1 ft/day.

A conceptual approach to estimate a rate of loading (at the time of design) is to conduct slope stability analyses assuming an initial 2-ft thick lift of a bridging layer and appropriate surcharge load for the construction equipment used to build the lift. Then estimate the pore pressures in the pond materials required to just be at a FS value of say 1.3 to 1.5. Then, conduct successive analyses wherein 1-ft thick additional lifts are placed and compute the pore pressures required to just be at the target FS value. With this approach, a graph of layer thickness vs. pore pressure can be developed. In this case, it is convenient to report the pore pressure as a ratio of the total load imposed by the lift and construction equipment. Using measured pore pressures from piezometers (see requirements for a staged filling plan in Section 9.5), the filling progress can be controlled so as not to exceed pore pressures developed from the analysis. The objective is simply to allow enough pore pressure to dissipate before placing the next lift of fill.

EPRI [7] has conducted a specially designed field plate load test on a coal ash pond to induce near surface failure and measure the rate of loading and excess pore pressure induced by the load (see Section 5.3.8). Further, EPRI [8] conducted a centrifuge test to model an assessment of the rate of loading and the potential for failure (see Section 5.3.8).

5.4.9 Borrow Source Evaluation

The construction of a CCR pond closure and/or a landfill over a CCR pond will require the use of soil materials to meet specific design functions, as described below:

- Relatively low permeability soil for a recompacted soil liner and/or recompacted soil barrier for a soil cover system
- Relatively free-draining soil materials for: (i) subsurface drainage (or underdrain) layers; (ii) leachate collection layers; (iii) capillary break layers to minimize equipment induced “liquefaction” of saturated CCRs; and (iv) drainage aggregate layers around piping
- Embankment/structural fill soils must: (i) have sufficient strength to stand on proposed slopes; (ii) provide a stable working surface to permit construction of other fill soils and geosynthetics; and (iii) where permanently exposed, be resistant to erosion and be durable

Information previously provided for site reconnaissance and executing a site investigation also applies to a borrow source evaluation. Since borrow soils that are used for construction are reworked, placed, and compacted, only disturbed samples are required for laboratory testing. The laboratory testing is conducted to identify whether a performance metric (e.g., hydraulic conductivity of clay liner soil must be less than or equal to 1×10^{-7} cm/s) can be achieved.

Experience suggests that, for a large project, it may be best to execute the borrow source evaluation in multiple phases in which the first phase involves excavating test pits within specific areas identified on the site which are known to include the desired soil type, followed by a second phase in which further investigations (e.g., more test pits) are conducted in those areas

“ranked” highest. Borrow areas with a high ranking are near the project site (e.g., near the pond), have significant quantities of the required soil type, and are readily accessible (i.e., do not require roads or bridges to be constructed for access). Low ranking areas are far from the project site, may have depleted resources (possibly due to previous excavation and use), and are difficult to access.

5.4.10 Material Selection (Soils and Geosynthetics)

5.4.10.1 Overview

Material selection considerations for soils and geosynthetics are discussed in this section. Different soil materials may need to be selected for underdrain layers, low permeability soil liner/cover, drainage layer, protective soil layer, rock fill and structural fill, and aggregate around piping. In addition, geosynthetics such as geomembranes, geocomposites, geotextiles, and, in some cases, geogrids may be used.

5.4.10.2 Underdrain Layer

An underdrain layer may be constructed beneath the liner system of a CCR landfill built over a CCR pond to provide a path for pore water expelled from the CCRs to drain without causing uplift of the liner system. This layer can also be used as a pathway to safely vent any gas generated from FGD ponds. The design calculations to select the materials properties for this layer will include flow capacity and filter criteria. Gravel is the material of choice for most underdrain layers; however bottom ash may also be used. Graded filter design approaches will most likely be needed to satisfy the filter criteria and provide adequate separation from the ponded materials. Grain size (ASTM D422), hydraulic conductivity (ASTM D5084), and carbonate content (if acidic leachate is present) (ASTM D3042) are typical tests likely to be required.

5.4.10.3 Low Permeability Soil

In general, low permeability soil liners have a hydraulic conductivity less than or equal to 1×10^{-7} cm/s. If clay material is not available in sufficient quantities to meet this hydraulic conductivity requirement, combinations of geosynthetic clay liner (GCL) and geomembrane (GM) layers have been used as part of the liner system, to allow for the specified hydraulic conductivity of the low permeability soil liner to be increased from 1×10^{-7} cm/s to 1×10^{-5} cm/s.

Benson et al. ([27]) provide information on the influence of different clay properties on its hydraulic conductivity. According to their study, recommended minimum properties for liner materials are: (i) gravel content < 20 percent; (ii) fines content > 30 percent; (iii) clay content (2 μ m) > 15 percent; (iv) liquid limit > 20; (v) plasticity index > 10; and (vi) classification as CL, CH, SC, SC-CL, or SC-CH. While bentonite amendments have been used to achieve acceptable hydraulic conductivity values for low permeability soil layers, their use should be evaluated carefully for CCR landfills due to cation exchange potential, and may not be feasible.

Compacting a low permeability material on top of a compressible foundation to achieve the 1×10^{-7} cm/s hydraulic conductivity requirement can be challenging, especially if a thick bottom ash layer is not constructed as a bridging layer in the subgrade. However, a dry bottom ash layer may result in transport of some moisture from clay and result in increasing the hydraulic

conductivity of the clay. A test pad for the clay on top of the closed or closing CCR pond should be considered as part of material selection.

5.4.10.4 Soil Drainage Layers

Several of the requirements presented for material selection of underdrain layers are applicable for soil drainage layers and leachate collection layers. Drainage layers must be designed with adequate flow capacity to maintain heads at less than a one foot level for the design storm event. Analyses are performed using water balance models such as the HELP model [28] for operating and final conditions to demonstrate that the drainage layer will have adequate flow capacity.

Calculations are performed to verify that the filter criteria are met. As is the case for underdrain layers, soil drainage layers will most likely require the use of graded filters. Use of geotextile filters with CCRs is suggested only after project specific leaching tests are done to evaluate the potential for clogging. However, geotextiles may be used that are sandwiched between a fine sand filter layer and gravel drainage layer and can be designed using standard filter criteria for geotextiles (e.g., [29]). In this example, the geotextile is used to replace a coarse sand filter layer. As part of the filter calculations, CCRs and other material gradations should be measured in the laboratory.

It is noted that CCR gradation depends on coal type, plant processes, sluicing history, and many other factors. Therefore, it should be expected that CCR gradation may vary for different plants, ponds, or within different parts of a pond.

5.4.10.5 Aggregate

Aggregate is generally placed around perforated or slotted leachate collection pipes and sumps. The requirements discussed herein for soil drainage layers are also generally applicable for selecting aggregate materials for these applications. The aggregate to be placed in the sump will influence its storage capacity.

5.4.10.6 Protective Soil Layer

The main function of a protective soil layer is to provide adequate protection from physical damage to the liner system components, especially geosynthetic components. It is also used to provide vertical confining load over GCLs to avoid swelling prior to landfilling. Usually the thickness of this layer is selected to meet a regulatory requirement, and is on the order of two feet. If a graded soil filter is used above a soil drainage layer, it can also serve the dual function of a protective soil layer. A minimum hydraulic conductivity requirement (such as 1×10^{-3} cm/s) should be specified to promote unimpeded flow of liquids to the drainage layer. The soil filter should also be free of any organic material, and have less than five percent fines content. The use of fly ash has been accepted by at least one state (West Virginia) as the protective layer [30].

Protective soil layer requirements may vary from state to state. The filter criteria should be checked for the protective soil layer and the CCRs likely to be placed above. If a bottom ash layer is selected to be placed above the protective soil layer, the filter criteria for the bottom ash layer and fly ash to be placed on top of the bottom ash should be checked. Criteria applicable for

gap graded mixtures of materials such as CCRs (e.g., mix of fly ash and bottom ash) are provided in [29].

5.4.10.7 Structural Fill

Structural fill will be required as part of subgrade, cover, access roads, and general fill. Requirements for structural fills may vary based on the purpose and availability of material sources. Any soil material that can be compacted to meet specifications and is free of significant amounts of organics or other deleterious materials can be used as structural fill. Soils classifying as SC, SM, ML, CL, GM, GC, or GW according to the Unified Soil Classification System (ASTM D 2487) or combinations of these materials are generally acceptable as structural fill. CCRs can sometimes be used as structural fill for the grading layer, primarily for overfills.

A tighter specification may be needed based on the specific function of the structural fill and other site-specific conditions. Rock fill may be needed as part of construction for riprap channels, downchutes, large and steep berms, and other stormwater management structures. For landfills constructed over closed or closing CCR ponds, these structures may need to be designed to function as a system with the hydraulic structures of pond dams.

5.4.10.8 Geomembranes and GCLs

While high density polyethylene (HDPE) is the most widely used geosynthetic liner product and has gained wide regulatory acceptance, other liner types such as polyvinyl chloride (PVC), polypropylene (PP), linear low density polyethylene (LLDPE), and ethylene-propylene-diene-monomer (EPDM) are also available and may be more appropriate for landfill liner systems located on compressible foundations. EPRI [31] provides detailed guidance on the state of the practice for liners and caps. In general, HDPE has the best compatibility properties with different CCRs. PVC, LLDPE, and EPDM can tolerate larger tensile strains than HDPE. The liner system components should be selected to satisfy the design conditions, including higher tensile strains and differential settlements for landfills built over closed or closing CCR ponds.

There are some challenges in justifying the use of GCLs with CCRs at this time due to the potential for cation exchange and resulting increase in hydraulic conductivity values for certain stress ranges. Several manufacturers are working to develop enhanced GCL products targeted for use with CCRs. New and existing GCL products are being evaluated under an EPRI-sponsored laboratory testing program to assess changes in hydraulic conductivity under different stress conditions and leachate characteristics [32]. These new products will need to be tested independently on a project specific basis.

Shear strength is a key consideration for use of GCLs in liner systems. GCLs are available as needle punched and stitch bonded products to provide improved peak shear strengths. The large displacement shear strengths for these products can also show an improvement compared to unreinforced products when the shear strengths are measured at a displacement of a few inches such that the reinforcements still contribute to resisting shear stresses. If shearing is continued to reach truly residual conditions, both the unreinforced and reinforced GCLs will reach the shear strength of bentonite, which is represented by friction angles on the order of 4 to 8 degrees. Truly residual conditions cannot be reached by standard testing equipment, and are not needed for most projects. The engineer should evaluate the need for evaluating slope stability under large displacement versus truly residual conditions for a particular project.

Shear strength testing is suggested to be performed by testing the liner system components as a sandwich in the shear box such that the failure is initiated in the weakest internal or interface component, rather than testing each layer of the liner system separately. However, it is possible that some states may require that each individual liner interface be tested and that the weakest (i.e., lowest shear strength interface) at a given normal stress be used to develop a minimum shear strength envelope.

5.4.10.9 Geotextiles and Geocomposites

The potential for clogging of geotextiles and geocomposite drainage layers by fine grained CCRs such as fly ash and FGD should be considered in the design and material selection. Use of sand or gravel drainage layers in lieu of the more popular geocomposites in the landfill industry may be warranted in some cases. Calculations for filter design should be verified by specific laboratory tests to support the selection of geotextiles and geocomposites with CCRs.

Geocomposites can withstand large strains and differential settlements. In some cases, geogrids may be needed to support access for equipment, placement of bridging layers, and/or mitigate the impact of potentially large differential settlements for landfills constructed over closing CCR ponds. The Geosynthetic Institute's website [33] and several papers by Dr. J.P. Giroud [34 through 38] are useful sources for use of geosynthetics for different applications.

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6

HYDROGEOLOGIC EVALUATION

6.1 Overview

An evaluation of the hydrogeology is necessary prior to committing to designing a landfill over a closed CCR pond, both to understand the previous impacts of the CCR pond on the native hydrogeology and to estimate the future impacts of the overfill. This information will also be used for an assessment of the potential need for corrective action.⁸

There are two general subsurface hydraulic systems that are affected by construction of a landfill over a closed pond: (i) the pore water in the CCRs underlying the landfill; and (ii) the native hydrogeologic system outside of the CCR pond. The native hydrogeologic system has historically been affected by the CCR pond; it is expected that the water levels and pore water pressures in the native hydrogeologic system have increased because of the elevated pond water levels, resulting in groundwater mounding below the pond. Similarly, the pore water pressures in the CCRs have been elevated from sluicing operations and/or runoff contained behind valley fill dams. When a landfill is constructed over the pond, the pond waters will be removed, some amount of dewatering of the CCRs will take place to facilitate construction, and the overfill will reduce the availability of infiltration water into the CCRs. All of these conditions will again change the hydrogeologic system.

The hydrogeologic evaluation will be used to develop a hydrogeological conceptual site model (CSM), which in turn will be used to guide development of a groundwater monitoring program and the design of the landfill. There may be a pre-existing hydrogeologic evaluation and CSM developed for the pond. These documents should be reviewed to evaluate whether or not they provide sufficient information to characterize the site for landfill development. If not, either because the evaluation is out-dated or because it does not satisfy criteria for a landfill hydrogeologic evaluation, then the pre-existing information can be used to provide preliminary information to guide data collection for the hydrogeologic evaluation for overfill design.

6.2 Scoping Project Requirements

There are two approaches to the hydrogeologic investigation required for construction of a landfill over a closed or closing pond:

1. Augmenting existing data where a significant amount of hydrogeologic data have been obtained; and
2. Performing a comprehensive hydrogeologic investigation for facilities with limited pre-existing data to collect information necessary to obtain regulatory approval of the pond closure plan and overfill design.

⁸ Corrective action is not addressed in this report.

Some older pond facilities have not completed hydrogeologic investigations and do not have groundwater monitoring programs. Therefore, much of this section will address the second approach to provide comprehensive guidance, with specific discussions for overfills. This guidance provides a broad outline to the methods used in a hydrogeologic investigation; references are provided for more detailed explanations.

The hydrogeologic investigation should focus on the potential changes to CCR pore water and groundwater during and after construction of the overfill. Potential changes to CCR pore water include reduction of pore water levels and infiltration, and corresponding reduction in seepage out of the CCRs. Potential changes to groundwater include changes to groundwater elevation, flow, and quality. Once the groundwater flow regime and baseline water quality associated with the pond have been evaluated, data must be collected to evaluate the potential impacts to groundwater quality at the site. For example, construction of a landfill over a closed pond can potentially alter the geochemistry of the groundwater. Altering the geochemistry of the ponded CCR pore water-soil-groundwater system from an aerobic to an anaerobic system has the potential to either mobilize or immobilize CCR constituents, depending on the constituent and the geochemical change.

6.3 Geology and Hydrogeology

Knowledge of the regional and site-specific geology and hydrogeology is necessary to facilitate the overfill design and provide an understanding of the potential groundwater changes attributable to the overfill. The information required for development of the hydrogeologic CSM is summarized below.

- *CCR Pond Characteristics.* Identification of the pond water quality, geochemistry, depth, saturation conditions, and physical properties (specific gravity, density, porosity) of the CCRs in the underlying pond.
- *Physiography and Topography.* Identification of native geomorphologic zones based on surface geologic expressions, topography, and overall landform conditions.
- *Surface Drainage Basins and Surface Water Flow.* Determination of regional drainage patterns and basins including streams, rivers, ponds, and lakes.
- *Geology.* Identification of native surface and subsurface soils and bedrock (lithology), stratigraphic units, soil and rock properties (porosity, density, chemical characteristics), and geologic structures (karst, faults, folds, linear features).
- *Hydrogeology.* Identification of hydrostratigraphic units (aquifers and confining units), groundwater levels, groundwater flow patterns and velocities, interaction with surface water bodies, water quality (ambient and background), and aquifer characteristics (hydraulic conductivity, transmissivity, storativity, and inter-aquifer communication).

This evaluation is typically initiated with a review of regional geology and hydrogeology from publically available information such as U.S. Geological Survey reports and bulletins, State Geological Survey documents, and other technical resources. Site-specific geologic and hydrogeologic data may also be available from previous geotechnical and environmental studies performed at the site. A site-specific investigation is then designed to collect information not

available through regional publications and prior investigations, and to satisfy state regulatory requirements as needed.

6.4 Site Investigative Methods

Various site investigative methods are available for the collection and evaluation of geologic and hydrogeologic data. These methods are briefly summarized in Table 6-1 and in the descriptions that follow. More detailed information on groundwater investigations can be found in various texts and reports [e.g., 1, 2]. In addition, some states provide guidance documents for completing site-specific hydrogeologic investigations for landfill sites.

Table 6-1
Summary of in-situ investigative methods

Method	Media	Key Parameters
Test Pits	Shallow Soils/CCRs	Physical Characteristics/Extent of Shallow Soil/CCRs, Depth to Water
Soil Sampling/Borings	CCRs Vadose Zone Soil/ Saturated Soil/ Bedrock/Sediments	Physical, Chemical, Geochemical and Geotechnical Data, Depth to Water, Hydrologic Properties of Soil and Bedrock
Cone Penetrometer Testing	CCRs Soil/Bedrock	Geochemical and Geotechnical Data, Depth to Water, Hydrologic Properties of Soil and Bedrock, Shear Wave Velocity, Pore Pressure Dissipation Characteristics, Soil Type
Piezometers	Saturated CCRs Groundwater	Limited Water Quality, Water Level Elevation
Monitoring Wells	Saturated CCRs Groundwater	Water Quality, Water Level Elevation, Geochemical Data
In-Situ Groundwater Instruments	Groundwater and CCR Pore Water	Automated Collection of Long-Term Groundwater Elevation and Limited Water Quality Data
Aquifer Performance Testing	Groundwater	Aquifer Characteristic Data (Hydraulic Conductivity, Transmissivity, Storativity)
Geophysical Testing	Soil/Bedrock/ Groundwater	Physical and Geotechnical Data of Soil and Bedrock, Limited Water Quality Data
Lysimeters	CCR Pore Water	Measure quantity of flow through CCR layers or below liner systems

- *Test Pits.* Test pits dug with excavation equipment are useful for evaluating shallow subsurface conditions (i.e., soils and CCRs) above the water table.
- *Soil Borings and Rock Cores.* Soil borings and rock cores are used to determine depth and thickness of CCRs, evaluate site geology (i.e., lithology and stratigraphy), and collect CCR, soil, and rock samples for chemical and geotechnical analysis. Methods for sample collection include hand augers (for shallow sampling) and drilling equipment such as direct

push technology (DPT), air and mud rotary, hollow stem auger, and sonic drilling rigs for the collection of deeper samples. Drilling rigs are capable of collecting soil and rock samples via standard penetration tests (SPTs/“split spoons”), Shelby tubes, undisturbed sampling using coring techniques (Gregory Undisturbed Sampler, Osterberg Sampler, etc.), and rock coring techniques.

- *Cone Penetrometer Testing (CPT).* CPT can be conducted at sites with unconsolidated surficial soils and CCRs when a large quantity of geotechnical data is required. CPTs can obtain soil type and lithology, pore pressure/piezometric information, pore pressure dissipation rates, and shear wave velocity to assess stiffness (see Section 5.3.4).
- *Piezometers and Monitoring Wells.* Piezometers and monitoring wells are installed for the assessment of aquifer characteristics and saturated/ponded CCR characteristics such as water levels and hydraulic gradients, and for the collection of groundwater quality data. Installation methods include DPT for shallow and small diameter piezometers and monitoring wells (<1-inch), and hydraulic rotary, hollow stem auger, and sonic drilling rigs for larger diameter and deeper wells. Monitoring well construction is dependent on site-specific conditions and lithology, which will determine screen intervals, screen slot size, filter sand material, and development procedures. Monitoring wells should be screened in specific aquifer units, and should be designed to avoid potential for cross-communication between different hydrostratigraphic units. This is particularly true when working near unlined ash ponds if a release to groundwater is suspected. Monitoring wells and piezometers intended for collection of groundwater quality samples should not be screened beneath CCR unless specific precautions are taken to assure that CCR constituents are not introduced to the screened interval during drilling.
- *In Situ Sensors.* In addition to manual groundwater level measurements, groundwater monitoring sensors can be installed in monitoring wells and piezometers to collect groundwater levels and various water quality parameters over extended periods of time. Data loggers record the measurements. This data is useful in evaluating rapid groundwater level fluctuations over time due to changing river stage, tidal effects, and rainfall/drought events, and changes in water quality indicator parameters such as pH and specific conductance.
- *Groundwater Sampling.* Groundwater sampling is conducted to evaluate and quantify water quality. This includes field parameters (e.g., pH, conductivity, dissolved oxygen, oxidation-reduction potential, turbidity, and temperature) and laboratory parameters (e.g., major ions and trace constituents). Groundwater samples are typically filtered and preserved in the field, unless otherwise specified by the regulatory agency. If unfiltered samples are required, precautions should be taken to minimize turbidity, because elevated turbidity in groundwater samples can lead to false positives for constituents associated with CCRs. Low flow groundwater sampling techniques can be used to minimize disturbances in the well and produce a more representative sample while reducing the investigative derived waste (IDW) produced.
- *Aquifer Performance Testing.* Aquifer performance testing involves the use of various methods to evaluate the hydraulic properties of the aquifer, and potential for leakage across confining layers. Aquifer properties include hydraulic conductivity, transmissivity, and storativity. Methods to estimate the hydraulic properties of the aquifer include laboratory analysis of soil cores, single well tests (slug tests and packer tests), and multiple well aquifer

performance tests. Laboratory testing provides small-scale hydraulic conductivity results from the soil sample tested; single well tests provide horizontal hydraulic conductivity in the vicinity of the monitoring well; and aquifer performance tests evaluate average aquifer hydraulic conductivity and storativity across the site (i.e., between wells) in three dimensions (i.e., horizontal and vertical) [3].

- *Geophysical Testing.* Surface geophysical methods are used to investigate small-scale features (e.g., sinkholes, buried objects, underground utilities) and bulk groundwater quality in the shallow (< 100 ft) to deep subsurface (>100 ft) depending upon the method selected. Surface geophysical methods include seismic refraction and reflection, gravity, magnetic, electric, and electromagnetic methods. Borehole geophysical testing can be conducted to document well construction details and to identify the geologic/hydrogeologic nature of the materials adjacent to the casing and screened/open section of monitoring wells. This type of testing is primarily conducted in large diameter (>6 in.) wells constructed into underlying water producing zones [4].

6.5 Monitoring Network

6.5.1 Groundwater Monitoring Plans

The ideal monitoring network will provide horizontal and vertical delineation groundwater flow, background/upgradient groundwater quality, existing groundwater impacts quality, and suitable detection monitoring for the overfill. Groundwater monitoring plans (GWMPs) document the objectives and methods of the groundwater monitoring program. The GWMP should include location, construction, and development details for the monitoring wells, a groundwater sampling and chemical analysis protocol, a sampling schedule, and procedures for data evaluation. An important part of any GWMP is the sampling plan and adherence to the appropriate quality assurance/quality control protocol for sample collection and analysis.

An important component of the monitoring network for overfill sites is documentation of both background natural groundwater quality and existing groundwater quality around the pond. This information is used to determine whether any CCR constituents are already present in groundwater due to the pond operation, and for selection of appropriate constituents and criteria for evaluating site-specific data. The GWMP should indicate how a release from the overfill will be determined in the downgradient monitoring wells. EPRI [1] and US EPA [5] provide detailed guidance for the evaluation of groundwater monitoring data for statistically significant increases in constituent concentrations. Groundwater at the site may also be classified according to state and or other official (quality) designations.

Parameters analyzed in a groundwater monitoring program are selected based on state-specific requirements and the CCR monitored at the site. Inorganic parameters are appropriate for CCR facilities. Refer to EPRI (2012) [2] for guidance on selecting indicator parameters appropriate for different types of CCR. Collection and evaluation of leachate samples from the CCR porewater, analyzed for the same constituents as the downgradient wells, is suggested to facilitate data evaluation and subsequent determination of compliance. Ideally, groundwater monitoring is initiated for all constituents prior to construction of the landfill. This is particularly important for overfills because potentially impacted groundwater will be monitored for changes in existing quality, rather than changes relative to background.

Groundwater monitoring is initiated in the detection monitoring phase to detect and characterize any release of constituents. If a statistically significant increase in the levels of any of the monitored constituents is identified in downgradient wells, a more extensive phase of monitoring (i.e., assessment monitoring) is activated. Assessment monitoring typically involves a comparison of downgradient well data to a groundwater protection standard, which may be a limit derived from background or a fixed concentration limit (such as a maximum contaminant level (MCL), a risk-based limit, an alternate concentration limit, or a defined clean-up standard under corrective action). The suite of monitoring parameters is typically expanded as the program moves from detection to assessment monitoring.

6.5.2 Performance Monitoring at Overfills

Many older CCR ponds have natural bottoms (no liners), and operating ponds have a larger driving hydraulic head than drained ponds. These conditions suggest the potential for leakage to groundwater during active operation. One function of the overfill is to limit the potential for leakage from the closed pond by one or more of the following mechanisms:

- dewatering of the closed pond, which reduces the hydraulic gradient and thereby reduces the potential for vertical migration into the subsurface;
- for overfills with no liner, the low hydraulic conductivity of the CCRs in the overfill will impede vertical migration into the closed pond; and
- for overfills with a bottom liner, the liner serves as a cap for the closed pond.

These changes serve to reduce the mass flux of dissolved constituents released from the pond.

Performance monitoring of overfills presents unique challenges with respect to distinguishing between releases from the pond and from the overfill. The most appropriate monitoring approach depends on the overfill design and the CCRs placed in the facility.

6.5.2.1 Overfills containing the same CCR types as the closed pond

In this case, it may not be possible to chemically distinguish releases from the two units. A groundwater monitoring network located around the pond will serve to assess leakage of CCRs from the composite unit (pond and overfill).

A groundwater monitoring strategy for these types of overfills is to evaluate groundwater quality individually at each monitoring point for trend (intrawell analysis). Since the pond has been dewatered and then capped by the overfill, concentrations of affected constituents should decrease if the pond CCR is above the water table, and be stable or decreasing if the pond CCR is below the water table. Groundwater modeling (Section 6.7) may be used to predict the time frame over which concentrations will decrease, and the expected final concentrations. If groundwater monitoring results indicate a repeated pattern of deviation from these predictions, then additional investigation and assessment may be warranted to determine if the deviation is due to a release from the landfill or if it is due to another cause. One tool that may be useful in such an assessment is a geochemical model as described in Section 6.7.

Stable or decreasing trends may be analyzed using the Mann-Kendall test for Trend. With this approach, trend is calculated for each monitored constituent at each monitoring well beginning

with four or more samples collected prior to landfill construction and including samples collected after the landfill is constructed. Alternatively, a prediction interval or Shewart-CUSUM control chart may be used to determine whether or not concentrations of each constituent at each monitoring well are statistically higher than a baseline concentration, with baseline being defined as groundwater concentrations prior to construction of the landfill. At least four baseline groundwater quality samples are necessary for calculation of the prediction interval, and additional baseline samples provide greater statistical power.

When model predicted concentrations are used as groundwater compliance standards, evaluation of compliance may be achieved by comparing monitored results to model predictions. This comparison can be performed using tabular data, but is most effectively communicated by graphically comparing monitoring data to concentrations predicted by the model.

6.5.2.2 Overfills containing different CCR types than the closed pond

In this case, it may be possible to distinguish releases from the two units based on unique indicator constituents in the leachates. Leachate from the two units should be fully characterized, and the detection monitoring program should then be designed to include suites of constituents that can be used to uniquely identify the different sources. Intrawell statistical analyses such as prediction intervals and Shewart-CUSUM control charts could be used to statistically evaluate the constituents unique to the landfill leachate; although in this case the prediction interval does not have to be limited to baseline data as long as the data used to calculate the upper limit do not exhibit an increasing trend. The trend-based or model-based approaches described above can be used to evaluate compliance for constituents common to both leachates.

6.5.2.3 Unmonitorable units

If a facility is deemed unmonitorable under state or federal regulations due to the inability to distinguish releases from the pond and the overfill, a separate leak detection layer below the overfill bottom liner may be necessary. This leak detection layer includes an underlying low permeability liner and drainage layer to allow collection of leakage below the primary liner system. One disadvantage of a leak detection system with CCR located both above and below is that any liquid collected from such a system may result in a determination of non-compliance. It is therefore important that compliance based on a leak detection system include pre-determined assessments of allowable volume and concentration over time.

6.6 Hydrogeologic Conceptual Site Model

The hydrogeologic CSM will be developed using regional and site-specific hydrogeologic, geologic, and water quality and CCR pond information. The key components of the hydrogeologic CSM include the hydrogeologic/geologic framework of the site, including the objectives listed in Section 6.1. As mentioned, the CSM is refined as additional data are collected.

6.7 Groundwater Models

6.7.1 Overview

Groundwater flow and transport models, and geochemical models are used to simulate and predict groundwater movement and geochemical processes in subsurface media. These codes can be particularly useful for predicting fate and transport of dissolved constituents from CCRs. In addition, chemical analyses of the infiltrating water, taken at different points along a flow path, may be useful in assessing the source of the CCR constituents that are detected in monitoring wells. Model accuracy is highly dependent upon the quality of the input data. In the case of geochemical models, that includes access to an accurate and complete set of water quality and chemical analyses.

In the context of overfills, groundwater flow and transport models and geochemical models may be useful for predicting the:

- effect of pond dewatering and capping (via the landfill liner) on groundwater flow to evaluate where landfill monitoring wells are optimally located
- maximum possible extent of migration from a pond where a release has occurred to determine the locations where pond monitoring wells may be needed
- time period over which concentrations of key constituents will decrease after the pond is dewatered and the landfill constructed, assuming no release from the landfill
- concentrations over time at downgradient monitoring points to use as performance-based compliance criteria for landfill monitoring
- geochemical changes in the pond leachate resulting from dewatering and capping

Accuracy of both groundwater flow and geochemical models relies on an understanding of both vertical and horizontal flow components. Only when water chemistry and flow characteristics are well understood is the model capable of generating reasonable predictions. Data needed for a groundwater model are collected during the hydrogeologic evaluation described previously in this section, and during subsequent groundwater monitoring. Data needed for a geochemical model are mostly developed during groundwater monitoring and special investigations. In either case, supplemental data collection may be performed as needed once it is determined that a model can provide useful information.

Model output is typically generated using graphical post-processor software. Output from the groundwater models can be utilized to refine the CSM so that it more accurately represents site conditions. The model output will include visual representation of site geology, groundwater flow (hydrogeology), contaminant distribution, and predictive scenarios (such as pre- and post-landfill construction) of future site conditions.

6.7.2 Flow and Transport Models

Flow and transport models couple flow modeling with transport modeling to simulate changes in water chemistry as groundwater moves through the subsurface. Commercially available groundwater modeling software simulates groundwater flow and transport in two steps. First the groundwater flow model is calibrated to match observed groundwater elevations and flow

directions at the site. Then a transport model is used to calibrate the distribution of one or more dissolved constituents in groundwater, based on the results of the flow model, to match an observed concentration distribution. In practice, there are many combinations of flow parameters that will produce an acceptable match to an observed concentration distribution, but few that will produce an acceptable match to the concentration distribution. So the flow and transport calibration process is performed iteratively until an acceptable match to observed flow and concentration is achieved. Calibration is more powerful when performed under both steady-state and transient flow conditions (transport calibration is almost always transient). Steady-state calibration assumes no changes in the flow field, and in an overfill application may be appropriate to calibrate a model to an initial condition while the pond is active. Transient simulations involve changing hydraulic head as would be observed or predicted when a pond is dewatered and the landfill constructed to provide a cap for the pond.

Numerous groundwater flow modeling software programs are available; however, the industry standard is the U.S. Geological Survey's MODFLOW program [6], which is a finite-difference flow model capable of simulating two- and three-dimensional groundwater flow through porous media. MODFLOW was originally developed and released as a groundwater-flow simulation code in 1984. Today, MODFLOW consists of several related programs which include capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management.

There are several transport models that can be coupled with MODFLOW to simulate transport in groundwater. The USGS (<http://water.usgs.gov/ogw/modflow/>) has developed several transport packages. One of the more commonly used commercially available transport models is MT3DMS [7, 8]. MT3DMS includes all of the transport calculations normally used for inorganic constituents at CCR sites. It calculates concentration distribution for a single dissolved solute as a function of time and space using a three-dimensional, non-uniform, transient flow field. Solute mass may be input at discrete points (wells, drains, river nodes, constant head cells), or distributed (evenly or unevenly) over the land surface (recharge). MT3DMS accounts for advection, dispersion, diffusion, first-order decay, and sorption. Sorption can be calculated using Linear, Freundlich, or Langmuir isotherms. First-order decay terms may be specified separately for the adsorbed and dissolved phases.

The outputs from flow and transport model simulations are contaminant concentrations that are in equilibrium with the groundwater flow system and steady state conditions with respect to the geochemistry for the modeled area.

6.7.3 Geochemical Models

Geochemical models apply the principles of equilibrium thermodynamics to systems composed of water, minerals, and gas-phase species. Geochemical models are often used to interpret or predict groundwater system parameters based on measured, or sometimes assumed, chemical conditions. As would be expected, output quality generally improves as the number of validated chemical parameters increases.

The models can be grouped as forward and inverse models. In *forward* modeling, reaction progress is governed by thermodynamic equilibrium. In *inverse* modeling, probable reactions

are calculated based on the information supplied at initial and final points along a flow path, and as such, do not necessarily represent equilibrium conditions.

The quantity and quality of thermodynamic data for aqueous and mineral species is a consideration when selecting a geochemical modeling code. Another feature to consider is whether the model supports high-salinity waters that are beyond the range of application for Debye-Hückel theory. Modeling high ionic strength solutions, such as those produced by scrubber blowdown and dewatering FGD solids, often can be accomplished using a database containing Pitzer-derived parameters. In addition, databases utilizing two ion-association aqueous theory and Specific-ion Interaction Theory (SIT) are available. In general, all models have limitations, and the user should select a code that is appropriate for the problem at hand. In addition, most geochemical modeling software permits entry of user-specified data, which can be beneficial when modeling a system that is less common.

Several geochemical modeling codes are available commercially or can be found in the public domain. The following are brief descriptions of three geochemical codes that are frequently cited in recent literature.

- The Geochemist's Workbench® (ver. 10) (commercial) has the capability for modeling 1-D and 2-D reactive, bioreactive, and colloidal transport. In addition, the model can simulate reactive transport and integrate kinetic rate equations into the simulations. The Pro version accounts for equilibrium and kinetic reactions in heterogeneous, dual-porosity media, including simulation of microbial metabolism and growth. The Geochemist's Workbench® was developed by Bethke (2014) and is available from Aqueous Solutions LLC [9].
- PHREEQC is a public domain computer program that was developed by Parkhurst (1995) and is available from the U.S. Geological Survey [10]. It was designed to perform a wide variety of aqueous geochemical calculations, including: (i) speciation and saturation-index calculations; (ii) batch-reaction and one-dimensional (1-D) transport calculations with reversible and irreversible reactions; and (iii) inverse modeling.
- EQ3/EQ6 was originally developed at Northwestern University, and then brought to Lawrence Livermore National Laboratory [11] where it was enhanced and later became most known for use in modeling the disposal of high-level nuclear waste. EQ3 contains an extensive database, including trace metals. EQ6 is the reaction path modeling component of the software. It is able to simulate titration processes (including fluid mixing), irreversible reaction in closed systems, irreversible reaction in some types of open systems, and heating or cooling processes, as well as solve "single-point" thermodynamic equilibrium problems.

Geochemical models can be used to calculate the concentrations of dissolved metals and other inorganic species and determine degree of saturation with respect to mineral phases. They also can be used to calculate the effects of dilution from source locations to compliance points. Geochemical models are often used to interpret or predict groundwater system parameters based on chemical reactions and local hydrologic features to account for dilution and dispersion.

Dewatering and capping of a CCR pond or constructing an overfill would not only greatly reduce infiltration but could also affect the mobility of certain metals. Subtle changes in pH and redox potential can greatly influence the solubility of certain solid phases. For example, arsenic exists predominantly as arsenate [As(V)] under oxidizing environments and arsenite [As(III)] under mildly reducing environments (see Figure 6-1). Inhibition of oxygen diffusion into the

subsurface can lead to mildly reducing conditions. Under some circumstances the reducing environment can cause arsenic to become more soluble and therefore susceptible to being released to groundwater. Geochemical modeling offers insights into the mechanisms controlling leachability in the ponded CCR both before and after construction of the overfill.

6.8 Costs and Schedule

Costs and schedule associated with the hydrogeologic evaluation are highly dependent on the size and scope of the investigation, the geologic and hydrogeologic setting, the horizontal and vertical extent of groundwater impacts (if present), and state regulatory requirements. Table 6-2 presents conceptual costs associated with an example site with no special considerations. The example used for cost estimation is: 100 to 200 acre CCR pond, 500 to 1,000 acre area of investigation, adjacent to a surface water body (or cooling pond), and sand/silt aquifer underlain by a relatively impermeable confining unit. These costs are illustrative only, and can vary substantially based on site-specific hydrogeological conditions.

The approximate schedule required for the example site includes: (i) development of a work plan – 1 to 2 months; (ii) conducting site characterization field work – 2 to 4 months; (iii) groundwater and surface water sampling for 4 to 8 rounds of data (1 to 2 years depending on the number of rounds collected and the data collection frequency); and (iv) completing development of the CSM, modeling, and preparation of a hydrogeological assessment report – 6 to 12 months.

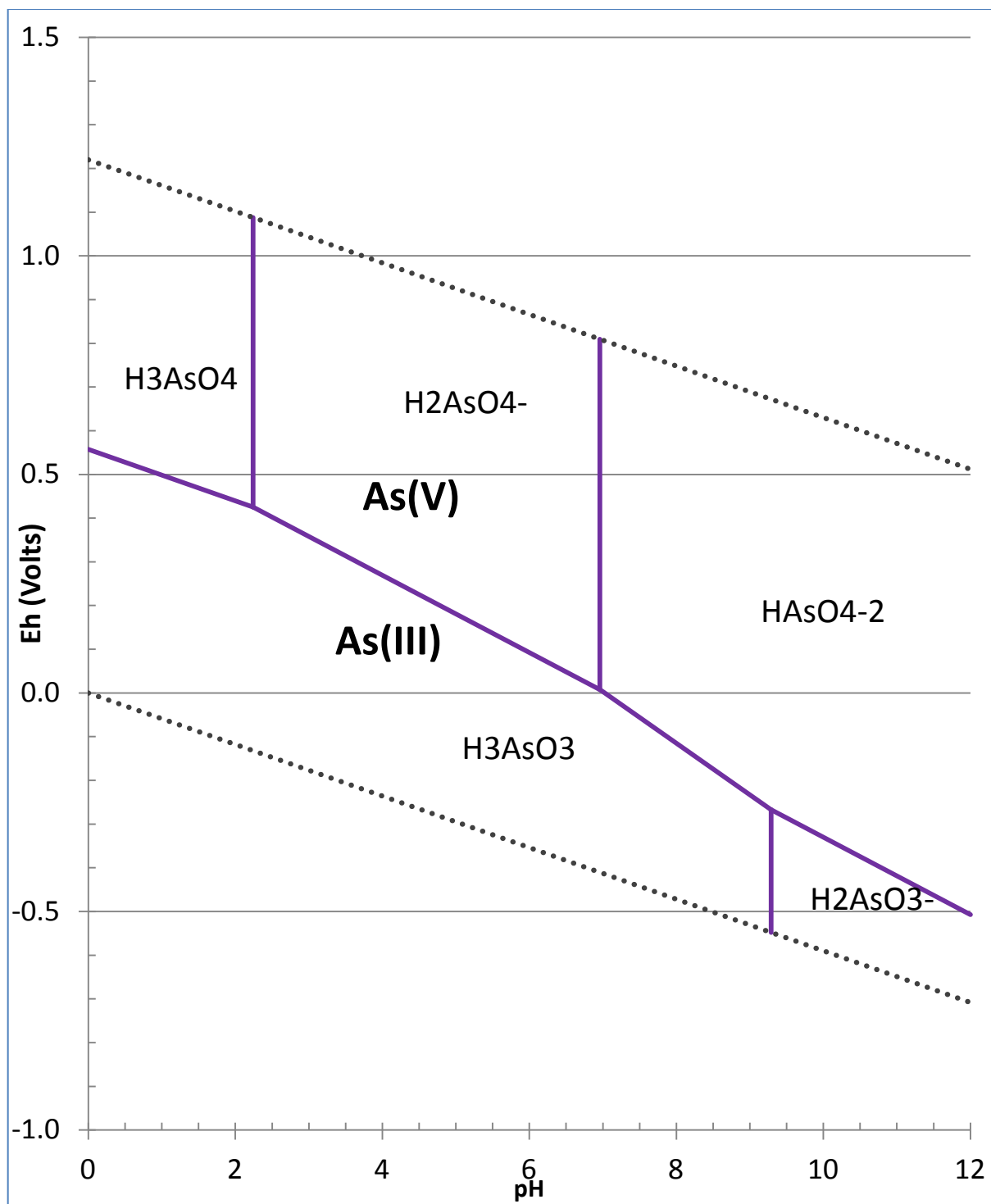


Figure 6-1
Eh-pH diagram showing predominant aqueous arsenic species

Table 6-2
Conceptual costs for various hydrogeologic evaluation scenarios

Activity	Major Assumptions ¹	Projected Cost ² – Variability ³
Work Plan Preparation	1. Knowledge of site operations is available from the client. 2. Some site-specific data (water quality, geotechnical, geologic) available.	\$30,000 – Low
Test Pits/Soil Borings/CPT/Soil Sampling	1. Installation of 10 test pits. 2. Installation of 20 CPT borings to 100-ft BLS. 3. Installation of 5 continuously sampled lithologic borings to 100- ft BLS and collection of 10 Shelby Tube samples. (Note: additional geologic characterization included in monitoring well borings, see below) 4. Analysis of 20 soil samples for various geotechnical parameters (i.e., grain size analysis, Atterberg limits). 5. Collection of soil samples for analysis of CCR constituents. 6. One week for a Project Geologist and Staff Scientist to complete all field work.	\$90,000 – Moderate to High
Piezometer and Monitoring Well Installation	1. Installation of 8, 1-inch diameter piezometers to a depth of 20-ft BLS. 2. Installation of 10, 2-inch diameter monitoring wells to a depth of 20-ft BLS (includes development and surface completion, and geologic characterization). 3. Installation of 10, 2-inch diameter monitoring wells to a depth of 50-ft BLS (includes development and surface completion, and geologic characterization). 4. Installation of 5, 2-inch diameter monitoring wells to a depth of 75-ft BLS (includes 50-ft of surface casing, development, and surface completion, and geologic characterization). 5. Collection of split spoon samples on 5-ft intervals at all well locations. 6. Two weeks for a Project Geologist and Staff Scientist to complete all field work. 7. Installed monitoring well network achieves groundwater plume delineation.	\$120,000 – Moderate to High
Groundwater and Surface Water Sampling/Monitoring	1. Sampling 25 wells per event, 4 times per year for 1 year. 2. Sampling 5 surface water points per event, 4 times per year for 1 year. 3. Monitoring water levels at 25 wells, 5 staff gauges for 4 times per year for 1 year.	\$55,000 – Moderate
Aquifer Performance Testing	1. Conducting slug tests in all monitoring wells. 2. Conducting a 48-hour pumping test at one location with one week of groundwater monitoring prior to and after testing.	\$35,000 – Moderate

Table 6-2 (continued)
Conceptual costs for various hydrogeologic evaluation scenarios

Activity	Major Assumptions ¹	Projected Cost ² – Variability ³
Geophysical Investigation	1. Surveying five 4,000-ft electrical resistivity imaging lines. 2. Surveying 5,000-ft of anomalies using ground penetration radar	\$54,000 – Low
Groundwater Flow Modeling	1. Develop groundwater flow model using MODFLOW.	\$40,000 – Low
Geochemical Modeling	1. Develop geochemical model using PHREEQC, Geochemist's Workbench®, or similar software.	\$20,000 – Low to Moderate
Hydrogeologic Characterization Report Preparation	1. Prepare draft report and address one set of comments from client. 2. Address one set of comments from the regulator.	\$70,000 – Low to Moderate
TOTAL	Variability up to 100% above total estimated cost	\$500,000 – \$1,000,000

Notes:

1. Example site based on 500–1,000 acre study area, with an adjacent water body (cooling pond or river) and assessment of one aquifer zone approximately 50-ft thick, with an underlying confining unit or bedrock.
2. Projected costs are based on “Major Assumptions” and include labor, expenses, and subcontractor fees. Costs can vary substantially based on size of site, horizontal and vertical extent of groundwater impacts, and complexity of geology and hydrogeology.
3. Variability is dependent on the actual activities required to complete the assessment, and can result in an increase of up to 100% of the estimated costs.

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7

WASTEWATER INFRASTRUCTURE NEEDS

7.1 Process Overview

The process of addressing wastewater infrastructure needs assumes a typical closed pond scenario where the pond water has been decanted and removed and the underlying CCRs are largely saturated. Wastewater that will require treatment in an NPDES permitted facility will normally be generated when a structure is built on top of such a closed CCR pond. The wastewater is generated from: (i) consolidation under the CCRs' own weight or consolidation from the additional vertical load by the new structure on the saturated CCRs, causing the pore water to be expressed from the CCRs and out of the containment facility; and (ii) the runoff and percolation from the landfill that is collected in the leachate collection system. These wastewaters will generally be discharged to a plant-operated treatment facility or to a publicly owned treatment works (POTW).

Wastewater will not always be expressed from the CCRs. For example, if the CCR is sufficiently dewatered prior to construction or the subgrade for the new structure is composed of sufficiently thick unsaturated backfill and the backfill is of sufficient permeability, the expressed water will migrate upward into unsaturated zones and will not leave the containment area.

7.2 Permitting

The wastewater discharge for the typical closed pond scenario will normally require an NPDES point source permit under 40 CFR 423 [1] if it is discharged to surface water, or a discharge authorization pretreatment permit if it is discharged to a POTW. If the wastewater characteristics, flow rate, and the location of the discharge considered under the existing NPDES permit for the CCR pond do not change, then the NPDES permit may not require modification. It is expected that the water expressed from CCRs will be considered an existing source, not a new source. However, the leachate from the new landfill may be considered a new source. The regulatory agency should be consulted when the pond is being closed or prior to construction of the structure to confirm general permit requirements.

The NPDES permit application will be a modification to the existing permit. The permit modification will require the following:

- a description of the change in the existing permit conditions;
- characterization of the wastewater chemistry;
- the flow rate of the wastewater;
- a schematic of the proposed treatment process; and
- facility information provided on NPDES permit application forms.

Individual states have added additional limits for metals based on monitoring data and specific state agency requirements. Discharge criteria are reviewed at each five year NPDES permit renewal cycle and established for the permit renewal.

7.3 Wastewater Characterization

It is necessary to understand and accommodate any wastewater that may result from the new construction. There are two potential approaches to obtaining a representative sample of the wastewater. The least expensive and most direct method is to use historical pond discharge data. However, the agency may require analysis of leachate samples from the CCRs. Representative leachate samples may be obtained through installation of temporary monitoring wells into the saturated ash and obtaining a number of samples. The samples may be analyzed individually and an upper confidence level can be calculated or the samples may be composited to obtain a spatial representation of the leachate characteristics. However, certain parameters (e.g., fats, oil, and grease [FOG], pH) are not allowed to be composited and must be analyzed for each measurement/monitoring location.

Because of the fine-grained particle size of CCRs, developing the monitoring wells to the degree necessary to meet pre-sample turbidity requirements is very difficult. It is suggested that samples be collected both filtered prior to analysis and unfiltered to assess the impact of turbidity. A filtered sample is expected to be more representative of the pore water expressed from the CCRs that would undergo self-filtering by the CCR particles prior to discharge.

The leachate sample analytes should be based on the CCRs and wastewaters historically put into the pond. The following CCRs and wastewaters have been historically placed in ponds:

- fly ash in sluice water;
- bottom ash in sluice water;
- rainfall runoff “contact water” impacted by the CCR constituents from adjacent facilities such as a CCR landfill operation;
- FGD by-products and processing water (e.g., dewatering FGD gypsum to make a wallboard grade product); and
- leachates from adjacent CCR landfills.

Typically CCRs contain inorganics such as boron, chloride, fluoride, sulfate, and sulfide and may be high in total dissolved solids and total suspended solids. Additional constituent metals include aluminum, iron, lead, manganese, mercury, molybdenum, selenium, and thallium. FGD has chemical distinctions from fly ash which should also be considered, such as sulfites and higher chlorides. Appendix III and Appendix IV to the proposed Part 257 rule specify analytes for groundwater that should be considered when developing the leachate analyte list.

The U.S. EPA conducted a survey of coal fueled power plants to develop new effluent guidelines [2]. The survey obtained information regarding the chemistry of CCR leachate. EPRI [3] has also characterized leachates at coal combustion product sites. Table 7-1 presents a summary of the metals data that may be helpful when selecting analytical parameters for characterization of the CCR landfill leachate.

Table 7-1
Average pollutant concentrations from untreated landfill leachate [2]

Analyte	Unit	Untreated Active Landfill Concentration	Untreated Inactive Landfill Concentration
Aluminum	ug/L	5,030	100
Antimony	ug/L	4.6	4.9
Arsenic	ug/L	46	10
Barium	ug/L	57	50
Beryllium	ug/L	1.9	0.47
Boron	ug/L	20,500	3,640
Cadmium	ug/L	2.7	1.9
Calcium	ug/L	481,000	386,000
Chromium	ug/L	4.9	1.6
Cobalt	ug/L	84	3.8
Copper	ug/L	10	1.7
Iron	ug/L	59,000	95
Lead	ug/L	1.4	0.47
Magnesium	ug/L	115,000	33,700
Manganese	ug/L	4,360	355
Mercury	ug/L	1.4	0.01
Molybdenum	ug/L	1,880	995
Nickel	ug/L	69	43
Selenium	ug/L	74	84
Silver	ug/L	0.68	0.42
Sodium	ug/L	327,000	16,700
Thallium	ug/L	1.3	0.96
Tin	ug/L	11	13
Titanium	ug/L	17	15
Vanadium	ug/L	3,240	6.2
Zinc	ug/L	154	58

For an NPDES permit, the regulatory agency will normally request a treatability test on the wastewater to confirm that the proposed treatment technology is effective. Because there are extensive data for the treatment effectiveness for CCR leachate, that data might be used to forego a treatability study. Therefore, the regulatory permitting agency should be contacted to identify whether a treatability study is necessary or whether existing data is adequate.

Whole Effluent Toxicity (WET) tests are designed to predict the impact and toxicity of effluent discharges from point sources into waters of the United States. WET limits developed by permitting authorities are included in NPDES permits to ensure that the state or tribal water quality criteria for aquatic life protection are met. WET monitoring requirements that are representative of the discharge effluent (40 CFR Part 122.44(d)(1)(ii)) are included in NPDES permits to generate WET data used to determine whether reasonable potential for WET has been demonstrated. If reasonable potential has been demonstrated, then a WET limit must be included in the permit (40 CFR Part 122.44(d)(1)(iv) and (v)) [4].

7.4 Treatment and Infrastructure

The U.S. EPA conducted a survey of the CCR leachate treatment technologies that have been historically utilized. They presented the findings in [2]. Figure 7-1 presents the historical use of treatment technologies.

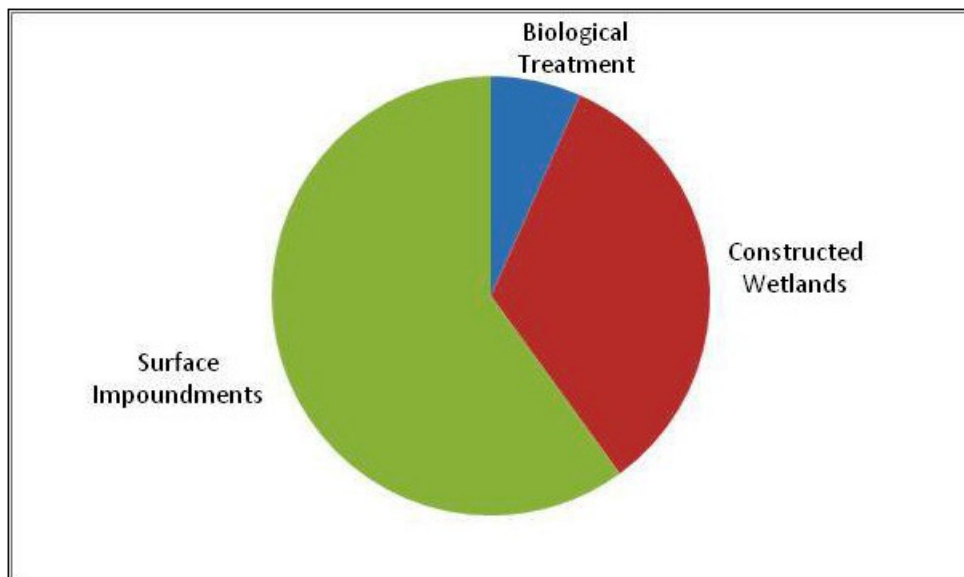


Figure 7-1
Distribution of treatment systems for leachate from landfills and impoundments containing combustion residuals [2]

Surface impoundments are used to provide time for total suspended solids (TSS) to settle and for pH control if necessary. The impoundments may also be used for metals precipitation by use of chemical reagents to promote the formation and settling of metal precipitate solids.

In June 2013, the U.S. EPA proposed new effluent limit guidelines (ELGs) for the steam electric power generating industry [1]. It is uncertain what requirements, if any, the final ELGs will have for CCR leachate.

7.5 Schedule Implications

The schedule will be dictated by when the discharge is expected to occur, the time to procure a design firm and design the wastewater treatment system, the time to obtain the permit from the regulatory agency, and the time to procure a contractor and construct the facility. It is suggested that 6 to 10 months be allocated to procure the design firm, obtain the CCR characterization data and complete the design, 6 to 10 months to obtain a permit, and 8 to 12 months to procure a contractor and construct the treatment facility. In summary, it will take from approximately 20 to 32 months from the time the treatment permit is identified to be ready to discharge under a new NPDES permit.

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8

LANDFILL SITING AND DESIGN

This section addresses siting and design of CCR landfills over CCR ponds. Siting and design of CCR landfills on natural ground itself has unique challenges such as slaking shale subgrades, karst conditions, underground mine voids, groundwater uplift and seismicity. This section, however, focuses on specific siting and design considerations associated with building CCR landfills over closed or closing CCR ponds.

8.1 Regulatory Considerations for Siting and Design

8.1.1 Regulatory Framework

The siting and design of solid waste (i.e., nonhazardous) disposal facilities are governed by EPA regulations established under RCRA Subtitle D. CCRs have been exempted from hazardous waste regulation under the Bevill Amendment since 1980, and therefore fall under solid waste regulations. Most states have their own solid waste regulations for CCRs that further define siting and design requirements and can be more restrictive than the federal requirements. EPA's regulations for landfills include specific requirements for siting (e.g., location standards) and design (e.g., liner, leachate collection, run-off controls, etc.). The current primary federal solid waste regulations are found in 40 CFR Part 257 and Part 258 of the Code of Federal Regulations and are discussed further in Section 4.

Federal regulations for CCR disposal are scheduled for publication in December 2014. This guidance document is written assuming minimum technology requirements typical for nonhazardous landfills under RCRA.

CCR landfills over CCR ponds are unique disposal facilities, and siting and design must be based on detailed review of the applicable state regulations and preferably an initial meeting with state regulators to confirm interpretations. This coordination with state regulators is essential, as many states are still formulating frameworks and regulations that are applicable for siting and designing landfills over CCR ponds. Dam safety regulations may be applicable if a CCR pond containment berm is being regulated as a dam even though there is no longer water retained behind the dam.

8.1.2 Siting Criteria and Restrictions

Current landfill siting criteria and location restrictions vary from state to state. The proposed EPA CCR location criteria are different for a new landfill and the lateral expansion of an existing landfill versus the vertical expansion (overfill) of an existing landfill facility. The location criteria for landfills constructed over ponds will depend on whether they are considered new or existing facilities.

8.2 Capacity and Footprint Selection Considerations

Capacity and footprint selection considerations include: (i) landfill life and capacity selection; (ii) geotechnical considerations; (iii) hydrologic considerations; (iv) hydrogeologic considerations; (v) preliminary phasing concepts; and (vi) infrastructure for dry landfilling and effect on CCR ponds. In addition, the location restrictions outlined in Section 8.1.2 will also play an important role in the footprint selection. This section focuses on specific considerations that are applicable for CCR landfills to be built over closed or closing CCR ponds.

8.2.1 Landfill Life and Capacity Selection

Landfill life and capacity should be developed based on the future volume of CCRs to be disposed from the plant for the required time period for any CCR landfill design. Options for comingling different CCR types versus disposal in separate cells should be evaluated at this stage. For example, an incentive for separate disposal of CCRs may be the potential for mining in the future for beneficial reuse of the segregated CCRs.

The selected design capacity will likely influence whether the CCR landfill will be located: (i) entirely within a CCR pond boundary; (ii) covering several adjacent CCR ponds, potentially consisting of different CCR types (e.g., ash pond, FGD pond); or (iii) partially over a CCR pond and partially over natural ground. Each of these siting options will present unique design challenges that should be addressed.

Simple preliminary grading concepts can be used to calculate available disposal capacities for different siting options. The need to excavate and relocate select CCR pond areas to address potential groundwater contamination from unlined areas, improve stability if needed, or enhance capacity should be considered at this stage.

Mechanically stabilized earth (MSE) berms or walls have been used to enhance capacity of CCR landfills. MSE berms are constructed with layers of geotextiles or geogrids that allow construction of slopes of 0.5H: 1V (or steeper), which is significantly steeper than common 3H to 4H: 1V slopes for perimeter berms. MSE walls can be built on the existing CCR pond berms or outside the berms to create more disposal capacity. The authors are not aware of projects wherein an MSE wall was built directly on top of ponded CCRs, but their use should be considered. Section 8.5.2 discusses the design of MSE berms.

8.2.2 Geotechnical Considerations

A number of geotechnical considerations will play a role in capacity and footprint selection. The geotechnical analyses were presented in Section 5.4. The applicability of these analyses and considerations for capacity and footprint selection are discussed below.

Settlement. Total and differential settlements can affect the integrity and functionality of a CCR landfill built on top of a closed or closing CCR pond⁹. Some of the conditions that have the potential to cause large differential settlements are locating a CCR landfill to:

- span over more than one CCR pond consisting of different CCR types;
- span over interior dikes of a CCR pond; and

⁹ Settlement analysis is addressed in Section 5.4.3.

- be partially founded on natural ground.

Designing the CCR landfill with several cells with inter-cell berms located strategically is a good way to avoid the liner system of the landfill spanning irregular subsurface conditions within the CCR ponds.

Static Slope Stability. Slope stability considerations can influence the capacity and footprint of a CCR landfill to be built on top of a closed or closing CCR pond¹⁰. The height and side slopes of the CCR landfill may be limited to achieve acceptable slope stability factor of safety values. Some states or local regulations may have limits for maximum elevation and side slopes. Slope stability considerations will likely influence the location of the perimeter berms of the CCR landfill. As presented in Figure 8-1, these options will include landfill perimeter berms located:

- on top of the perimeter berm of the CCR pond;
- fully or partially (i.e., downstream method) outside the perimeter berm of the CCR pond; and
- fully or partially (i.e., upstream method) inside the perimeter berm of the CCR pond.

From a slope stability point of view, the first two options are preferred to the third option as it minimizes the footprint area of the landfill perimeter berm that is over potentially weak ponded CCRs.

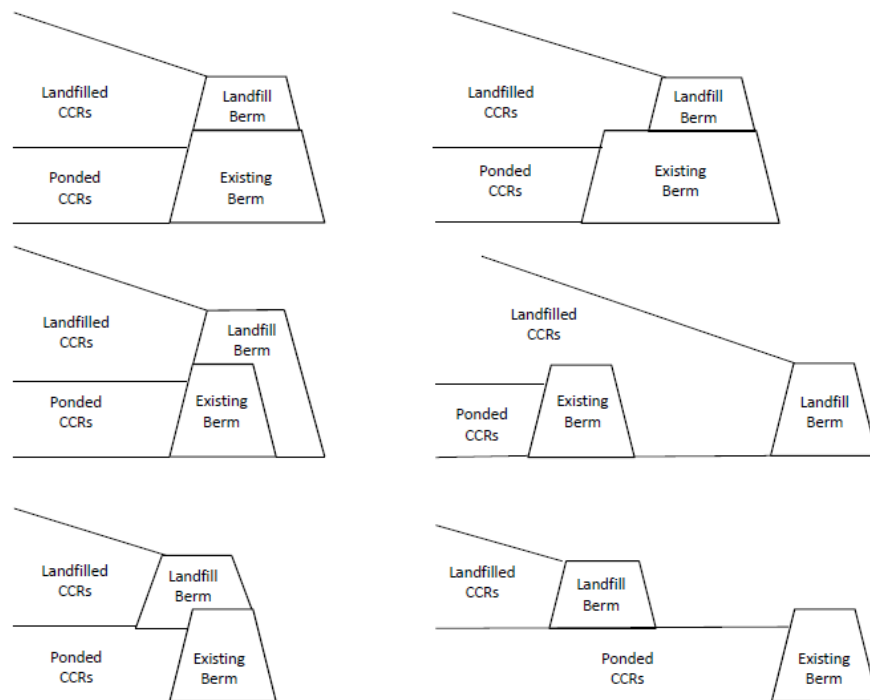


Figure 8-1
Possible configurations of landfill berms

¹⁰ Static slope stability analysis is addressed in Section 5.4.4.

Static Liquefaction. Static liquefaction assessment primarily considers loadings during construction and therefore will not likely affect decisions regarding footprint selection¹¹. Careful assessment of rate of loadings compared to ability of subsurface CCR materials to drain is required to address static liquefaction¹².

Seismic Slope Stability and Seismic Liquefaction. Results of analyses for seismic slope stability and seismically induced liquefaction of the ponded CCR foundation material may limit the landfill cell geometry, maximum height, slope, footprint, and capacity¹³.

8.2.3 Hydrologic Considerations

Specific hydrologic and related considerations¹⁴ with potential to affect the overfill capacity and footprint selection include:

- option for removing any CCR pond dams or perimeter embankments/dikes versus fully or partially retaining them, and impact to dam flow structures such as spillways;
- impact of increased flows due to the landfill on post-development discharges and capacity of the receiving streams to convey the increased flows;
- earthwork near an existing CCR pond dam or perimeter dike; and
- re-use of CCR pond dam materials for landfill construction.

While detailed hydrologic analyses and design will be performed based on the CCR landfill layout and grading at a later design stage, these hydrologic considerations should be a part of the capacity and footprint selection stage because they may reduce the available footprint and corresponding capacity.

8.2.4 Hydrogeologic Considerations

The design of an overfill and the monitoring network need to be coordinated. Section 6.5 addresses hydrogeologic monitoring.

The cutting off of surface recharge area by the installation of a low permeability landfill liner system will eventually lower the water levels within the CCR pond materials and lead to reduced potential for outward seepage. Figure 8-2 displays the pond water level during operations and the lowered levels necessary to construct the overfill bottom liner system.

¹¹ Static liquefaction analysis is addressed in Section 5.4.6.

¹² The rate of filling is addressed in Section 5.4.8.

¹³ Seismic slope stability is addressed in Section 5.4.5 and seismic liquefaction is addressed in Section 5.4.2.

¹⁴ Hydrologic and hydraulic analyses are addressed in [1].

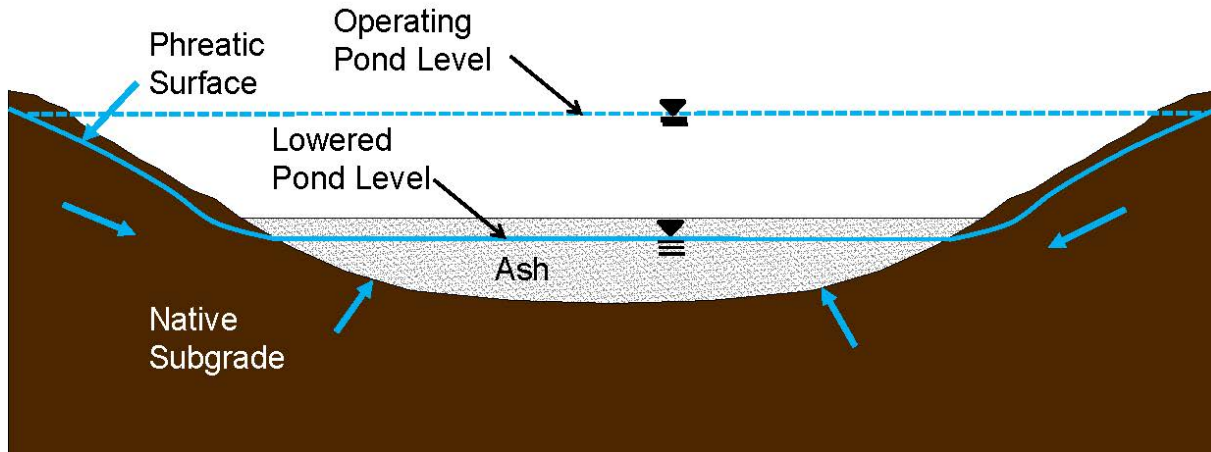


Figure 8-2
Operating pond level and lowered level to construct overfill bottom liner

However, if there is groundwater recharge from sidewalls for cross-valley, side-hill, or incised CCR pond configurations, the water levels within the CCR pond materials may increase over time because the pond water level was lowered below static levels and the groundwater will reestablish static levels. Figure 8-2 displays the return of static water levels after construction and how pore pressures can increase below the bottom liner, causing the potential for instability from uplift of the liner.

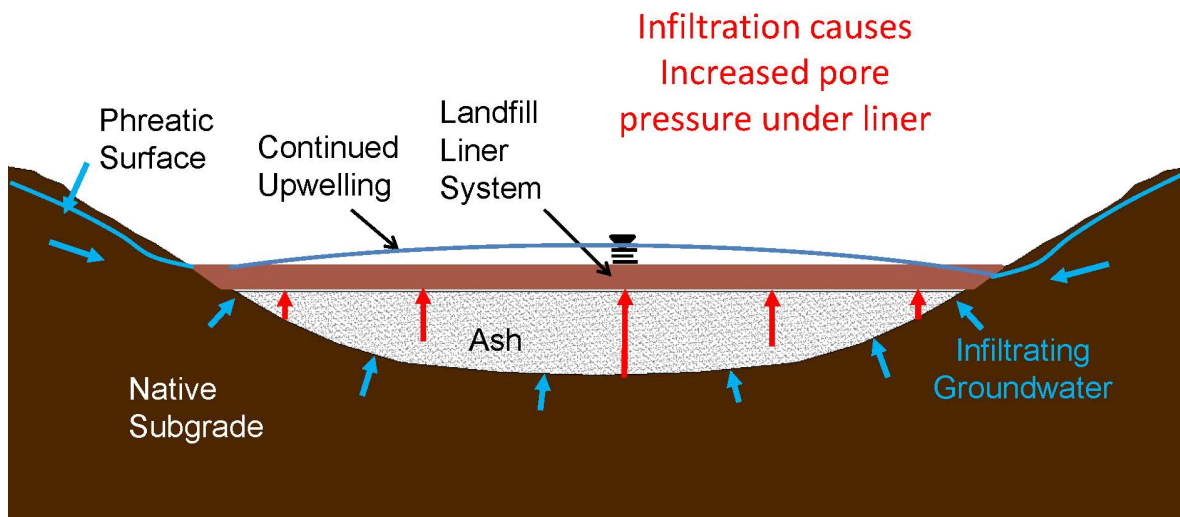


Figure 8-3
Infiltration and rising groundwater levels below overfill bottom liner

The CCR landfill design should be developed by considering the infiltration recharge and drainage potential of the native geology/subsoils. An example would be construction of an underdrainage system below the bottom liner to relieve pore pressures.

Existing groundwater contamination or potential for future contamination based on the hydrogeologic model in a specific area (e.g., sand lens connecting the CCR pond base to a water

body) may require special engineering considerations, such as removal of CCRs from part of a pond, lining part of the pond, and using the lined area of the pond as part of a CCR landfill liner system. It may be necessary to integrate pond remediation options such as cutoff walls, permeable reactive barriers, and pump and treat systems with the pond closure/landfill construction. The space requirement for these systems may affect the CCR landfill layout if the CCR landfill or its perimeter berm is to be located outside the CCR pond boundary.

8.2.5 Preliminary Phasing Concepts

Preliminary concepts of phased development of landfill cells should be incorporated in the capacity and footprint selection stage. An example phasing plan is presented in Figure 8-4.

Factors to be considered in developing preliminary landfill phasing and layout concepts include:

- allowing enough time to dissipate excess pore pressures and avoid rapid loading of soft, saturated subgrade CCRs in consideration of avoiding static liquefaction;
- stormwater management ponds/dikes during construction and post-construction;
- disturbance of the cover of the closed pond and obtaining necessary permitting agency approval, which may be a surface water division and/or a solid waste division;
- excavation or removal of ponded CCR material;
- need for continued use of CCR ponds for treatment of plant wastewater streams during the time needed for the plant to develop independent wastewater treatment systems;
- considerations for disposing different types of CCRs in separate cells;
- avoiding the high cost of initial site development to allow initial CCR placement while keeping the capital cost down; and
- need for preloading certain areas of the pond.

Areas with deeper CCRs have the potential to undergo more settlements than areas with shallower CCRs. Therefore, areas with deeper existing CCR subgrades are more likely to require preloading as part of the landfill development to remove settlement prior to construction. CCR relocation and consolidation in a smaller footprint within the same pond may be a phasing option for ponds that have remaining capacity in certain areas. CCR relocation can lead to the creation of improved foundation conditions in areas that will have CCR removed for development of a landfill. This cleared area can be used for siting new lined leachate, wastewater treatment, or stormwater ponds as well. Further discussion of the construction considerations is presented in Section 9.

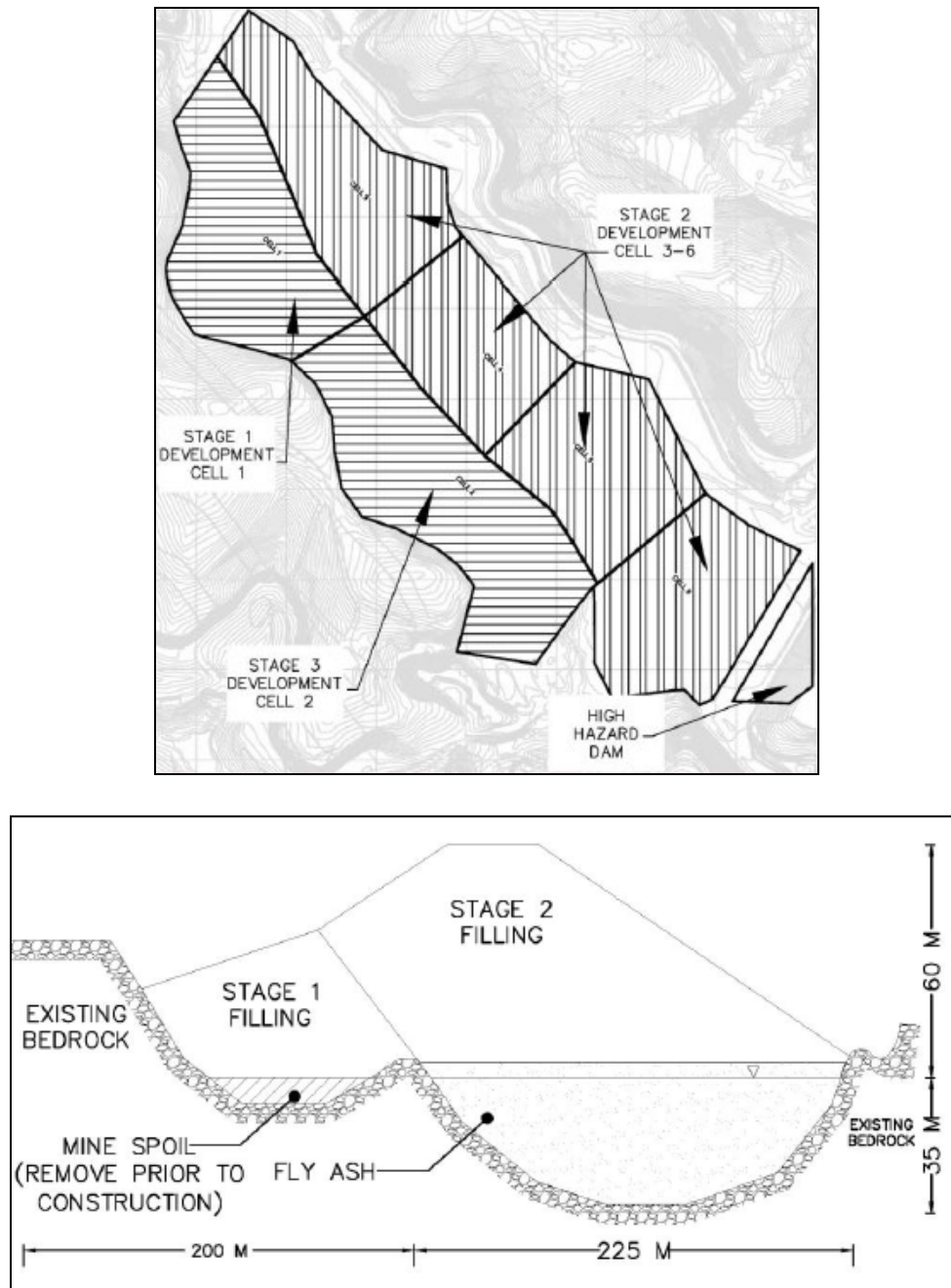


Figure 8-4
Example layout of CCP landfill cells over a CCP pond [1]

8.2.6 Infrastructure for Dry Landfilling and Effect on CCR Ponds

Switching to dry handling of CCR from wet handling will result in the need for infrastructure such as haul and access roads or mechanical conveyor systems, staging areas, and stormwater ponds. While these considerations are applicable for CCR landfills constructed on natural ground, there are some specific items related to the construction of CCR landfills over closed or closing CCR ponds. Haul and access roads, staging areas, and lined stormwater ponds may be located fully or partially on top of CCR ponds, posing special challenges for their design as well

as layout of the landfill. These infrastructure needs should be considered at the capacity and layout selection stage.

8.3 Subsurface Drainage Systems

Excess water pressures may build up within the pores (i.e., pore pressure) of the CCRs in CCR ponds during construction of an overlying contouring fill layer and as a result of landfilling. Excess pore pressures can lead to slope instability and localized bearing capacity failures near edges of fills. Timing of the overlying liner system settlement is linked to dissipation of excess pore pressures.

Subsurface drainage systems may be needed to relieve excess pore pressure buildup. Dewatering or decanting of ponded water from CCR ponds is different from promoting dissipation of excess pore pressures. Section 5 presents information on drainage properties of CCRs. In general, past case histories indicate that fly ash dissipates excess pore pressures relatively quickly. Stated differently, typical thick CCRs (e.g., fly ash) in ponds can dissipate pore pressures at a rate faster than the time required for typical earthwork construction and landfilling; this, however, should be verified for the specific materials and construction and filling rates on a project-specific basis. Use of prefabricated vertical drains (i.e., wick drains) and underdrains to promote dissipation of excess pore pressures is discussed later in this section.

Certain CCR streams, such as FGD (calcium sulfite) by-products, have the potential to generate hydrogen sulfide (H_2S) gas. The design of the subsurface drainage systems should consider this gas generation potential, and associated liner system uplift, stability, and health and safety issues. Gas testing can be completed during site investigations or a test patch can be constructed to assess gas buildup over time. A passive venting system may need to be provided at the edge of the “under-drain” layer to collect and vent the gas in a controlled manner.

8.3.1 Wick Drains

Wick drains are commonly used in combination with preload or surcharge application to accelerate consolidation of fine grained soils to expedite construction or reduce long-term settlements. Wick drains, or prefabricated vertical drains (PVDs), comprise a polypropylene core with a large water flow capacity in the longitudinal (typically vertical) direction. The core is wrapped in a geotextile filter fabric.

Design procedures are available to select the spacing of wick drains to limit long-term settlements and promote rapid dissipation of excess pore pressures [2, 3]. Three to five feet spacing is typical for application of wick drains to accelerate settlements in soils using preloads to support construction of buildings. An example wick drain system detail is provided in Figure 8-5.

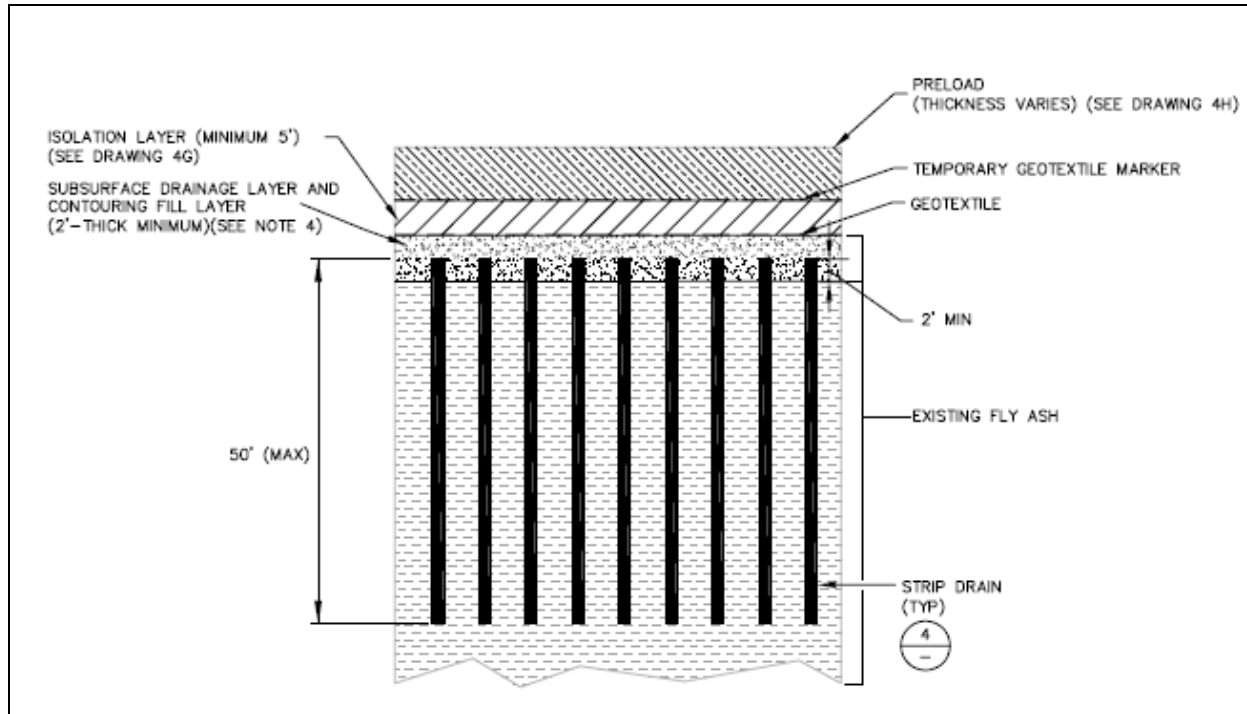


Figure 8-5
Example details of an underdrain or subsurface drain layer with optional preload and strip drains (courtesy of AEP)

Available test fill data on fly ash indicates that consolidation occurs relatively quickly (i.e., weeks to months) for typical CCR ponds [4, 5]. Because of the relatively fast consolidation compared to typical rates of loading, wick drains may not be needed for construction of CCR landfills over most fly ash ponds. In addition to the test fill data, the above observation is supported by several case histories of CCR landfills constructed over fly ash ponds without the use of wick drains [4, 5].

Bottom ash and boiler slag are expected to drain faster than fly ash, and hence the use of wick drains is not expected to be needed for these materials. The need for wick drains on other types of CCRs such as FGD streams is less well understood. Miller [6] stated that before disposal in ponds, FGD products of lime or limestone forced oxidation processes (gypsum, calcium sulfate) generally were observed to readily dewater to a moisture content of 7 to 12 percent by natural drainage without mechanical dewatering equipment. Unoxidized lime or limestone FGD products (calcium sulfite) are thixotropic sludges with the consistency of toothpaste and are difficult to dewater. Krizek [7] noted that the primary consolidation time for FGD gypsum was very short compared to that for most natural clays. Therefore, it appears that wick drains may not be needed for FGD gypsum from forced oxidation processes, while additional evaluation may be necessary for FGD products that did not go through forced oxidation systems and behave like thixotropic sludges.

Geotextile wick drains have the potential to be clogged by fly ash or gypsum size particles. In addition to the application of traditional filter criteria developed for geotextiles (e.g., [8]), laboratory testing can also be performed to evaluate the performance of geotextile filters when used with different types of CCRs. If a wick drain system is used in a CCR pond, the evaluation

depends on whether the purpose is to use the wick drains as part of a preloading program or for pore pressure dissipation during landfilling. If it is the latter objective, long-term performance of wick drains gains greater importance. An underdrain drainage layer is installed to connect the top of wick drains and provide a pathway for pore water expelled from the wick drains to travel laterally and be removed from underneath the CCR landfill.

In general, wick drains should not be needed for CCR ponds consisting of fly ash, bottom ash, boiler slag, or FGD gypsum (produced from forced oxidation systems) to support the construction of a landfill over the CCR pond. However, available consolidation test and CPT pore pressure dissipation test data and grain size data should be reviewed before making a final decision. Consolidation testing in the laboratory, CPT pore pressure dissipation test in the field, and additional instrumented field test fills may be needed to evaluate the need for wick drains for unoxidized lime or limestone FGD products that behave like thixotropic sludges.

8.3.2 Underdrain Drainage Layers for Consolidation Water Removal

An underdrain drainage layer may be necessary beneath the liner system of a CCR landfill to provide a path for expelled pore water from the CCR pond to dissipate without causing uplift of a low permeability liner system. Depending on the landfill perimeter location and detail, separate conveyance pipes may be required within the underdrain drainage layer to provide a pathway for the expelled pore water to leave the landfill footprint. Example details are presented in Figures 8-6 and 8-7. This pore water flow may need to be monitored during routine inspections of the landfill and the ponds and discharged under an NPDES permit.

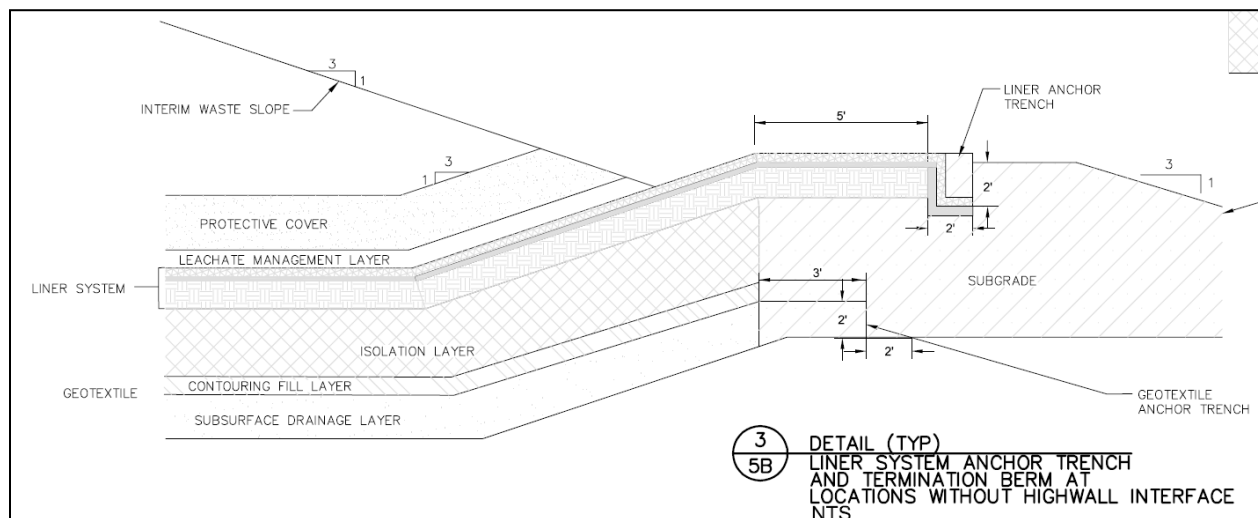


Figure 8-6
An example detail of a foundation and liner system for a CCR landfill constructed over a CCR pond (courtesy of AEP)

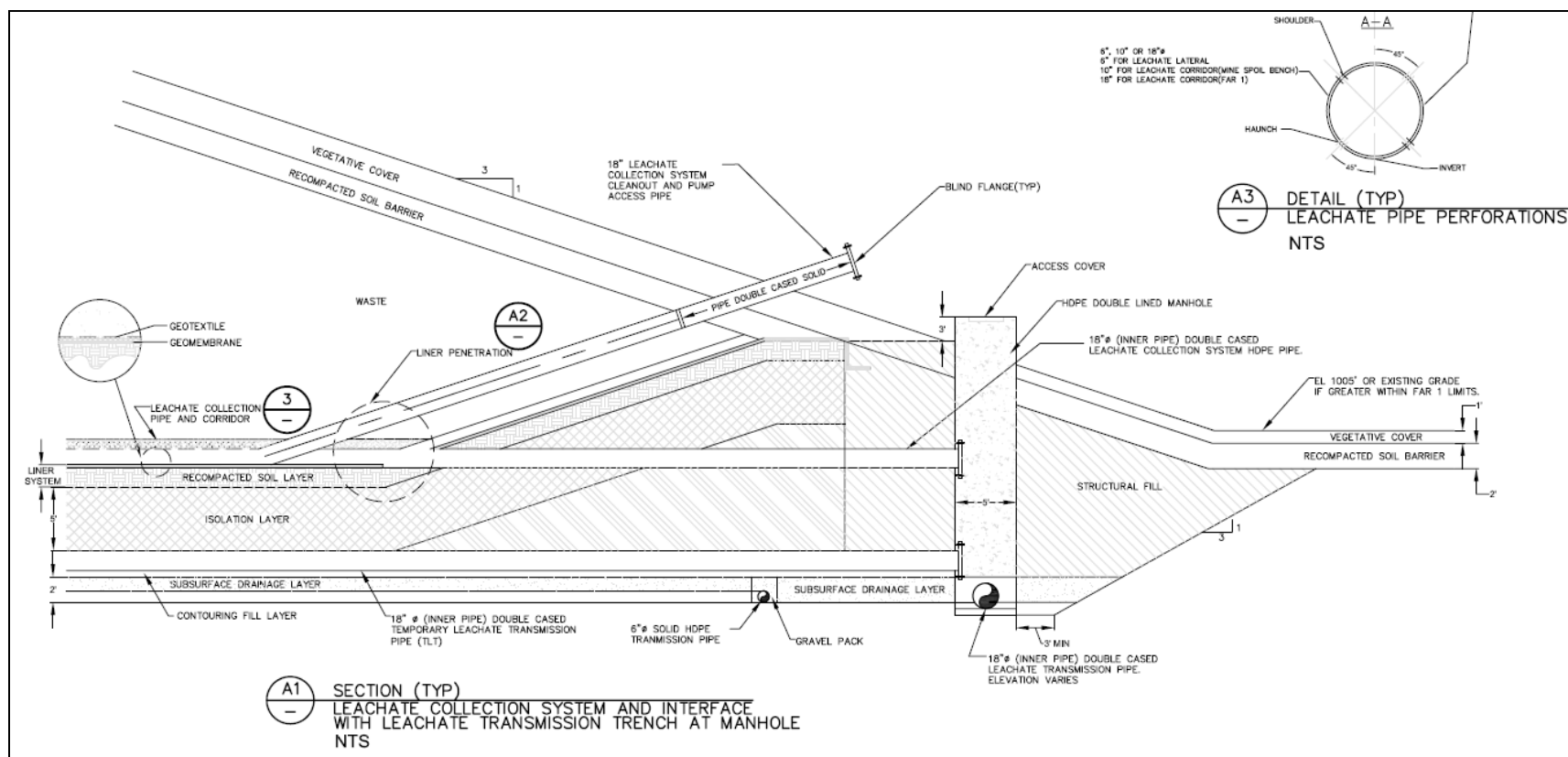


Figure 8-7
An example detail of a foundation and liner system at the piping location for a CCR landfill constructed over a CCR pond (courtesy of AEP)

The underdrain layer can be constructed using bottom ash, gravel, or sand. Use of a geocomposite drainage layer may pose some challenges due to clogging concerns. Bottom ash will be the most economical material if available on-site in sufficient quantities. However, the hydraulic conductivity of bottom ash may vary from site to site.

The underdrain layer should be designed in recognition of an achievable hydraulic conductivity throughout its design life and therefore any material to be used as an underdrain should be tested as part of the design (and later confirmed during construction). Filter criteria and flow capacity should be checked as part of the design of the underdrain layer.

The underdrain layer should be designed to provide adequate slope to promote flow in the long-term, and not be affected by grade reversal due to settlement under the loading from the landfill. The underdrain layer can also be used to collect and passively vent H₂S gas for FGD ponds.

8.4 Liner Subgrade Grading and Constructability

Subgrade grading should begin with a careful review of the existing topographic contours of the CCR pond material and the base grades of the CCR pond. Potential for settlements and reversal of liner system grades should be considered at the liner subgrade grading stage. For CCR ponds closing in a few years, constructability considerations should include using future CCR sluicing to shape the pond surface to approximate the desired landfill subgrade grading. Identification of low points and slopes for drainage, long-term settlement considerations, and cut and fill balancing and material source evaluation are discussed below.

8.4.1 Identification of Low Points and Slopes for Drainage

Existing topographic contours of the CCRs in the pond should be reviewed to identify low points, slopes, and drainage patterns. In general, CCR ponds have low points near the outlet discharge structures. However, some CCR ponds may have been out of service for a period or closed, and may have undergone some grading that changed the location of the low points. For active ponds it is not uncommon to have several low points, including in the upstream reaches of the drainage valley of the pond.

In general, for CCR ponds undergoing closure prior to landfill construction, the CCR surface within the pond can be: (i) concave with the low point near the middle; (ii) convex with the high point near the middle; (iii) approximately flat; or (iv) sloping from one end of the perimeter to another, with a high point near the inlet discharge location (i.e., within the ash disposal delta) and a low point near the outlet discharge structure location. The pond grades may also have remnant features from operational practices such as rim ditching or borrow pit excavations within the pond footprint.

A grading plan that incorporates the existing ponded CCR surface grading patterns into the landfill subgrade grading is generally more cost effective. It will also result in landfill liner system grades that are sustainable in the long-term.

Landfills are often developed into a number of distinct cells. Leachate collection sumps are located at the low points for each landfill cell. These sump locations must remain as low points in the long-term, as well as being accessible from the sides for installation of side slope risers and pumps. An example contouring subgrade fill grading plan is provided in Figure 8-8. If low points or sumps are located in the middle of a landfill, vertical risers may need to be provided for

access to sumps for leachate removal via pumps. Side slope risers are generally preferred to vertical risers in the landfill industry because vertical risers do not have a good performance record based on prior applications in MSW landfills where large settlements have been observed to cause damage to vertical risers.

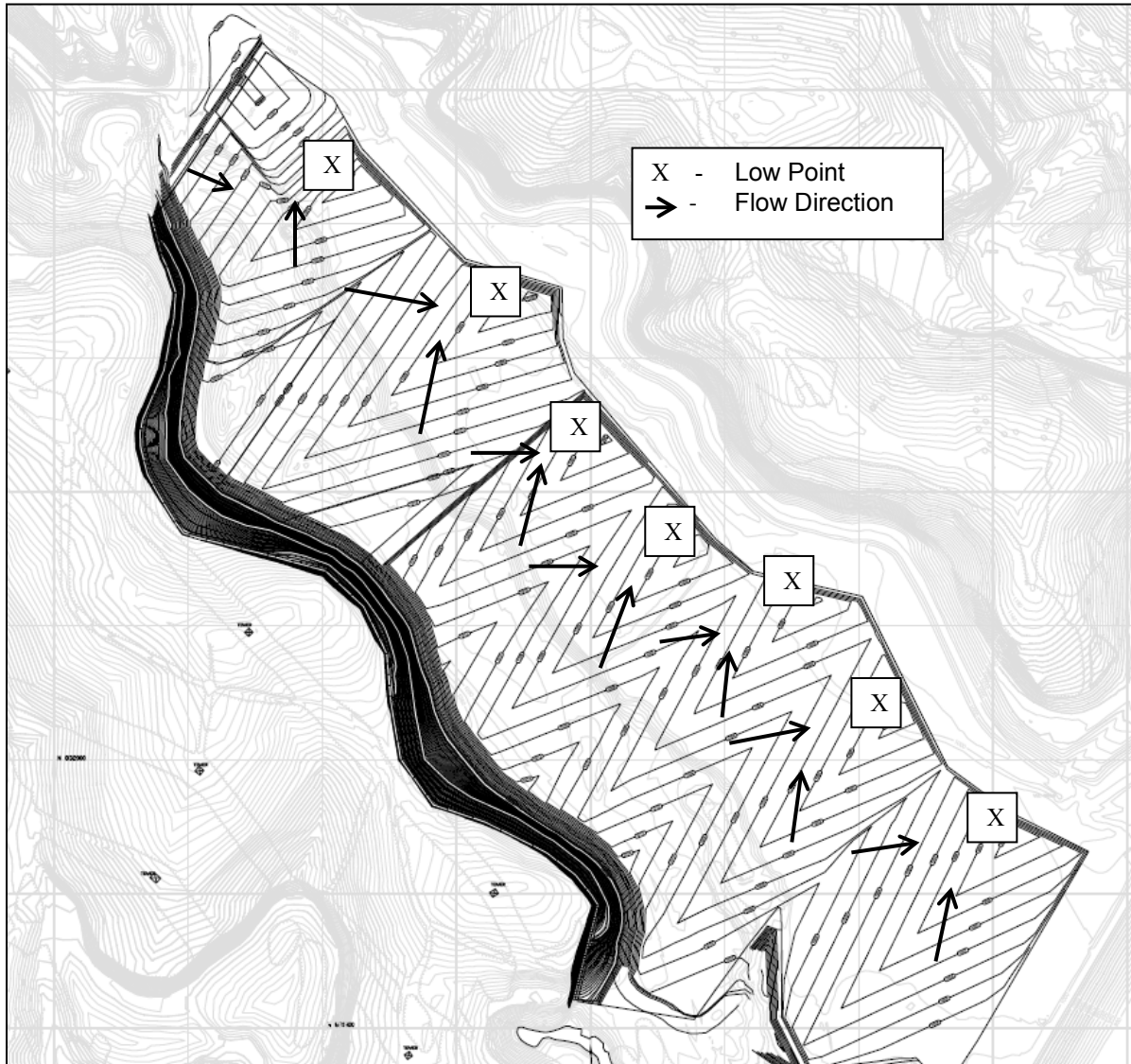


Figure 8-8
An example grading of contouring fill over an ash pond as part of designing a landfill

8.4.2 Long-Term Settlement Considerations

Long-term settlement considerations may result in the need for installation of a “settlement crown” (or high point), especially if the existing pond grades are concave and they should be modified to a convex shape for installation of the liner system and sumps with side slope risers. In general, the loading from the settlement crown and the landfill will be more in the middle than along the sides, thereby increasing the potential for more settlement in the middle than along the sides. The geometry of the settlement crown should be designed using settlement theory (see

Section 5.4.3) by considering the above challenges, and not result in grade reversal of the liner system.

An alternate grading approach is to use landform grading techniques to develop the subgrade grading that is likely to be sustainable in the long-term. Landform grading is a grading approach where the final grades are very similar to the existing grades. This approach minimizes cut or fill requirements and only results in limited modifications to the existing grades to develop the final grades. Depending on the location of low points, cutting and relocation of ponded CCRs or provision of vertical sump risers may be needed for the landform grading option.

8.4.3 Cut and Fill Balancing and Material Source Evaluation

The quantity of cut and fill will have a very strong impact on construction cost. Therefore, minimizing the cut and fill volumes and finding economical and suitable material sources are required for liner subgrade grading. The settlement crown option will likely include the need for significant fill material as part of grading.

For ponds still receiving CCRs, sluicing to shape the pond surface to be close to the desired landfill subgrade grading can be considered. For plants that have already converted to dry processing, dry CCRs can be used to achieve the target subgrade contours. Dry stacking on top of a wet pond could be performed after slope stability analyses are performed to confirm that adequate slope stability will be maintained.

If available in sufficient quantities, bottom ash is a suitable material to be used as a contouring fill due to its ease of placement and adequate drainage properties. Due to its particle sizes, bottom ash can function as a capillary break for the water in the CCR pond and provide a good working platform for construction of the landfill liner system. As discussed in Section 8.4.2, using landform grading concepts to develop the subgrade of CCR landfills will result in minimizing cut and fill volumes.

8.4.4 Evaluation of Need for Staged Filling

Staged filling should be considered if field and laboratory testing at a pond site indicates that the site has weak foundation soils, layers of very weak materials within the CCRs, or loose CCRs susceptible to static liquefaction as presented in Section 5.4. A field embankment load test¹⁵ may also be needed with the objective of better understanding the response of the ponded materials to staged landfilling (see [4] and [5]). The embankment load test program is structured to provide key design information and construction methodology for the full-scale staged filling. Target design parameters include:

- settlement of the CCRs in response to loading;
- horizontal (i.e., lateral displacement) in the CCRs and foundation;
- predicted and measured short-term and long-term strength projections;
- pore pressure development and dissipation characteristics;
- subsurface drainage mechanisms;

¹⁵ Field embankment load tests are addressed in Section 5.3.7.

- confirmation of design slope geometry; and
- acceptable fill placement rates based on measured pore water pressure ratios and limiting deformation ratios.

The embankment load test can be done either as a pre-design test, if the site investigation and preliminary investigation indicates it is necessary for design, or as a production fill that can be done after the design (but during initial filling) to confirm design parameters. It is the authors' opinion that for closures involving ponded fly ash materials only, this can be done as part of initial phases of construction. For example, if it was proposed to construct a landfill over a FGD sludge pond, it may be necessary to consider the load test program as part of design because currently there is no load test information available for FGD. This decision should be based on the complexities of the loading, height of the landfill, and uncertainties associated with the response of the ponded materials to application of vertical load.

The test fill must have sufficient height and breadth to create a pressure footprint that exerts pressures over the entire thickness of ponded materials and potential soft/compressible foundation soils. The goal should be to uniformly stress a zone of ponded materials by filling in lifts at rates up to or some percentage beyond the maximum practical production filling rate. Also, the test fill area would ideally be wide enough to create plane-strain conditions along the entire test embankment length and influence shear strains in the ponded materials down to the elevation of stable subsurface material. Typically, this requires a fill at least four to six times wider than the thickness of foundation ash fill and underlying foundation soils. In terms of fill length, it is desirable to be able to test different underdrain systems within the fill at the same time; for example, one section with a granular underdrain (aka "capillary break") and the adjacent section with no underdrain.

The test filling program will be conducted under a structured monitoring plan. Geotechnical instrumentation included in the test would generally consist of:

- one settlement plate at the base of the fill along each instrumented section at the test embankment crest to provide vertical consolidation data of the foundation with time in response to embankment loading (see Figure 8-9);
- one slope inclinometer terminating in stable ground along each instrumented section at the toe of the test embankment to characterize lateral movement of the embankment and foundation materials; and
- vibrating wire piezometers nested in a single grouted borehole (or multiple boreholes) located within the ponded materials and foundation soil layers under the crest and toe of fill along each instrumented section to monitor pore pressure response with time under embankment loading (see Figure 8-10); a line of piezometers may also be constructed as an option at mid-slope. This information may also be used to assess the degree of saturation of the embankment compared to predicted or calculated values used in slope stability design.

Seepage and stability analyses using effective stresses with pore water pressure assumptions and undrained shear strength analysis for the proposed staged fills should be conducted using seepage and slope stability computer programs (e.g., [9]). Global and local stability of the internal slopes of the staged fill should be evaluated under both drained and undrained loading conditions. Threshold analyses will be incorporated in the analysis to determine acceptable slope

grades, filling rates, and possible excess pore water pressures. The analysis will also incorporate the benefit of proposed foundation improvement, internal drainage blankets, or capillary breaks, as needed. Surcharge loads imposed by earthmoving equipment will also be taken into account.

Based on the results of geotechnical investigations, field performance testing (i.e., test fill, if used), and engineering analysis, recommendations could be provided that address:

- foundation preparation and/or improvement;
- internal drainage and/or capillary break at base of fill;
- target moisture/densities of fill materials;
- vertical lift thickness;
- compaction requirements;
- rate of placement (vertical rate in feet over a specified period);
- slope grading, smooth drum rolling, management of surface water and dust control;
- site plan lateral placement requirements and constraints;
- instrumentation protection and monitoring requirements and proposed performance threshold values and appropriate actions to take if these thresholds are exceeded, including acceptable fill placement rates based on measured pore pressure ratios and limiting deformation ratios;
- alternate ash placement locations if instrumentation action levels are experienced;
- other construction quality assurance testing equipment and test method requirements; and
- blending and/or separation requirements for possible CCR streams.



Figure 8-9
Settlement plate with PVC riser sleeve



Figure 8-10
Vibrating wire piezometer being lowered down drill hole

8.5 Landfill Perimeter Berms

The purpose of this section is to describe specific grading issues associated with various methods of perimeter berm construction for CCR landfills to be constructed over closed or closing CCR ponds.

8.5.1 Berm Sizing Considerations

Landfill berms should be located and sized by considering the impact of slope stability, run-off and run-on control, and capacity. While these factors must be considered for landfills sited on natural ground, there are some specific considerations for landfills sited on top of closing or closed CCR ponds.

In general, the shear strength of the perimeter berm area and the foundation underneath influences the slope stability of CCR landfills more than the shear strength of interior areas. For this reason, it is important to try to locate the landfill perimeter berms in relatively stronger areas such as on or near pond perimeter berms or interior divider berms. The side slopes and height of the landfill perimeter berm are selected by considering slope stability as one of the factors. In some cases, the width of the top deck of the perimeter berm is increased to create a “counterweight” berm or “buttress” for added stability.

Landfill perimeter berms should be designed to provide run-off and run-on control for CCR landfilling operations. Run-off control can be provided by designing appropriately sized ditches as part of the landfill perimeter berms to collect and convey stormwater run-off from the CCR landfill during operations and after closure. Run-on control should be based on overall surrounding topography and water flow patterns. Cross-valley, side-hill, and potentially, incised CCR pond configurations have the highest potential to pose run-on issues for landfills constructed over them. Diked CCR ponds generally do not have the potential for posing run-on issues for landfills constructed over them.

For a given landfill side slope, the higher the perimeter berm size, the larger is the disposal capacity of the landfill. A cost optimization can be performed to select the optimum berm height that meets the slope stability and storm water requirements for a landfill to be built over a closing or closed CCR pond. The required capacity for the specific plant should be addressed.

8.5.2 Mechanically Stabilized Earth Berms

Mechanically stabilized earth (MSE) berms have been used to increase capacity of landfills (see Section 8.2.1). MSE walls can be built on the existing CCR pond berms or outside of the berms. MSE berms require a smaller footprint compared to traditional earthen berms for a given berm height. This is particularly advantageous when space is limited for raising pond berms by expanding beyond the existing outside toe of the berm. Suitable CCRs can be used as MSE berm backfill if an appropriate containment liner system option is developed. An example detail is shown in Figure 8-11.

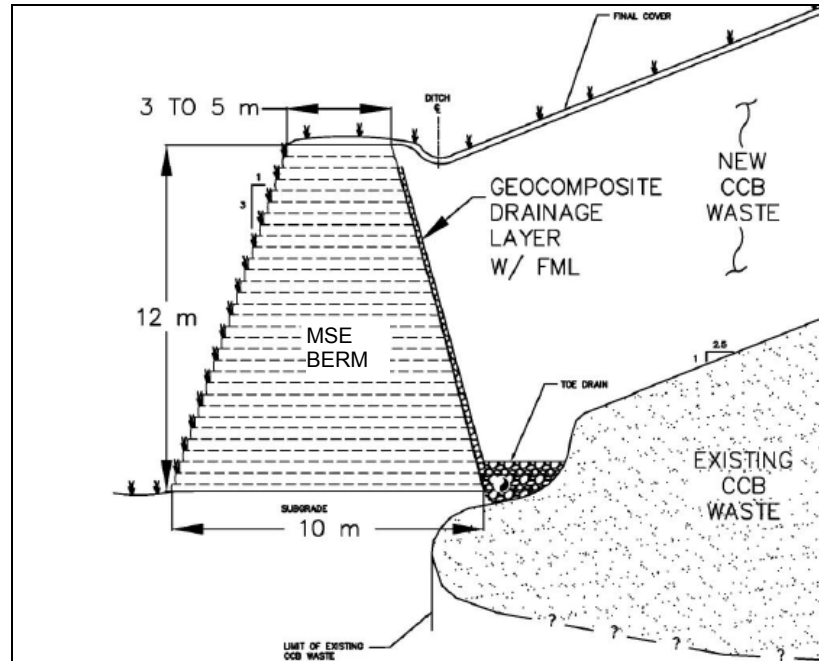


Figure 8-11
Use of MSE berms to support a CCR landfill over a CCR landfill [1]

8.5.3 Berms Over CCRs

Site conditions and landfill design configurations may necessitate locating perimeter or interior berms of landfills directly on top of ponded CCRs. Slope stability analyses should be performed to evaluate whether targeted ground improvement of the foundation CCRs may be needed for such cases. Ground improvement methods may include targeted dewatering, pre-loading, and deep soil mixing. Landfills can be designed such that the most critical cross sections for slope stability run through landfill berms located on pond perimeters or on natural ground, rather than through berms located on top of CCRs. Further, the edges of new cells for the landfill may coincide with existing berms to increase slope stability, primarily where the berms are separator berms constructed down to the native soil at the bottom of the pond.

8.6 Liner and Cover Grading Considerations

There are several considerations that are specific for developing liner and cover grading for landfills located over closing or closed CCR ponds. Most of the liner grading concepts are similar to the liner subgrade grading concepts discussed in Section 8.4. This section provides information on liner and cover grading considerations related to: (i) settlement and potential for grade reversal and liner damage; (ii) stormwater management; and (iii) interconnection of liner and cover systems to adjacent CCR pond covers.

8.6.1 Settlement and Potential for Grade Reversal and Liner Damage

In general, contour filling is used to develop the desired landfill base grades, and a liner system with a constant thickness is installed on top. Settlements should be calculated using a grid

pattern to cover the landfill base and along critical cross sections such as leachate collection corridors¹⁶.

In addition to evaluating the potential for grade reversal and ability to maintain the minimum required post-settlement slopes, tensile strains on the liner due to differential settlements should also be calculated. Settlement of the cover system should be evaluated to verify that minimum required slopes are maintained after settlement. The effect of differential settlement and tensile strains on the performance of the cover system components should also be evaluated.

8.6.2 Stormwater Management

Stormwater management considerations play a key role for developing landfill cover grading plans. Stormwater management design for ponds undergoing closure is addressed in [10]. For CCR landfills to be built over closing or closed CCR ponds, the role of stormwater management is even more complex. Several CCR ponds have dams and hydraulic structures that require careful consideration for integrating with a landfill built over.

Landfill covers are typically crowned in the middle and are required to meet the minimum cover slope requirements to effectively shed surface water and minimize ponding. A closed pond cover may or may not be crowned in the middle. Grading should be developed to merge the pond cover and landfill cover stormwater flow patterns. Based on the state regulatory requirements, the landfill cover and pond cover may fall under the permitting authority of different departments. This may in some cases lead to the potential for design using different criteria (e.g., storm event) for the landfill and pond cover.

Drainage benches/ditches, chimney drains, downchutes, perimeter drainage channels, culverts, and stormwater ponds typically form the stormwater management network for a landfill cover. For a landfill constructed over a closed CCR pond, the new landfill cover stormwater management structures should be connected to the CCR pond's hydraulic structures such as dam spillways and CCR pond cover drainage structures. Most stormwater conveyance structures are sensitive to grade reversal or reduction of their slopes caused by settlement. Landfill cover grading should be developed with consideration of the effects of settlement on the slopes of the cover and stormwater management systems.

There are a variety of approaches to analyze the hydrology of the watershed including the landfill and pond structures, with an even greater number of available tools to perform the analysis. The approach should include the ability to develop a hydrograph (i.e., flow rate versus time) for the watershed and sub-watersheds. The data requirements, limitations, and assumptions of each approach must be considered when selecting the hydrologic analysis approach. Several widely used and accepted public domain models are readily available. As an alternative, proprietary models that offer additional features or advanced interfaces are also available. Each model may have unique data requirements, which should be considered when selecting the approach. Several of the parameters and data requirements are common among all the models:

- *Rainfall conditions.* Precipitation frequency data can be obtained from the National Weather Service [11].

¹⁶ Settlement calculations are presented in Section 5.4.3.

- *Hydrologic drainage units (watershed).* Break down major watershed into appropriate sub-watersheds. Watersheds can be delineated with USGS quadrangle maps if local topographic data is not available [12].
- *Overland flow paths.* Determine the overland flow path for each sub-watershed and the major reaches between sub-watersheds. The flow paths can be delineated with USGS quadrangle maps if local topographic data is not available [12].
- *Land cover.* Categorize the hydrologic land cover parameter, such as the Runoff Curve Number (RCN) if using the SCS hydrologic analysis method. The land uses along with the soil type are inputs used to determine the RCN. Soil types can be obtained from the NRCS soil survey [13].
- *Land use.* Categorize the land use within the watershed for each of the analyzed conditions. Aerial photographs provide an efficient means to classify the land use at different time periods in the watershed.

There is also a variety of approaches to analyze the hydraulic features and structures located in the watershed. The hydraulic features can include the receiving stream, channels, culverts, spillway, and outfall structures. Hydraulic analysis tools can include simple spreadsheets or complex software models. A spreadsheet using the Manning's equation could be sufficient for many cases to analyze open channel flow, such as in spillways or channels. Simple spreadsheet tools can also be adequate to analyze the hydraulic properties of culverts and outfall structures that function as an orifice.

8.6.3 CCR Landfill Cover Systems and Adjacent CCR Pond Covers

If the CCR landfill perimeter berm is located interior to the CCR pond perimeter berm, the CCR landfill cover system may need to be tied to the cover system of the CCR pond to provide for effective containment of CCRs. For this case, the CCR pond cover system will likely wrap over the CCR landfill perimeter berm and terminate in the CCR landfill anchor trench with a tie-in to the CCR landfill cover.

8.7 Liner and Cover System Selection

There are several considerations for selection of liner and cover system soil and geosynthetic materials for CCR landfills, and these are also discussed in [14]. This section focuses on specific considerations for CCR landfills located over closing or closed CCR ponds, including: (i) soil and geosynthetic liners; (ii) soil and geosynthetic covers; and (iii) special considerations for use of geosynthetics with CCRs.

8.7.1 Soil and Geosynthetic Liners

Soil and geosynthetic components of CCR landfill liners include low permeability soil layers, geosynthetic clay liners (GCLs), and geomembrane liners. Material properties considered in design are discussed in Section 5.4.10. GCLs are available as needle punched and stitch bonded products to provide improved peak shear strengths. HDPE is the most widely used geosynthetic liner product and has gained wide regulatory acceptance but has been required to be 60-mil thick in Subtitle D. However, other liner types such as PVC, PP, LLDPE, and EPDM are also

available and may be thinner for cover systems and therefore may be more appropriate and less expensive for landfill liner systems located on compressible foundations.

8.7.2 Soil and Geosynthetic Landfill Covers

Soil and geosynthetic components of CCR landfill covers include low permeability soil layers, GCLs, geomembrane liners, protective soil layers, and vegetative soil layers. The considerations discussed in Section 8.7.1 for selecting soil and geosynthetic liners and material properties discussed in Section 5.4.10 are also applicable for selecting soil and geosynthetic covers. Additional settlement potential of the final cover system due to the compressible nature of the ponded CCRs in the CCR landfill foundation is a specific design consideration when compared to the design of CCR landfill covers for landfills located in natural ground.

8.7.3 Special Considerations for Use of Geosynthetics with CCRs

GCLs, geomembranes, geocomposite drainage layers, and geotextiles are some of the geosynthetics that are used in landfill liner and leachate collection systems. There are some special design considerations when these geosynthetics are to be used with CCRs, such as:

- CCRs such as fly ash and FGD have the potential to clog geotextiles and geocomposite drainage layers; and
- hydraulic conductivity of the sodium montmorillonite based GCL products may increase due to ion exchange with calcium rich CCRs such as FGD wastes (see [15]).

The above concerns are mostly the same for CCR landfills to be built on natural ground or over CCR ponds. Manufacturers have developed enhanced versions of these products targeted for the CCR market to address the above issues. Site-specific confirmation testing may need to be performed before use of such products. An alternative approach is to use traditional soil components such as low permeability soils and sand or gravel drainage layers in lieu of GCL and geocomposites (or geotextiles), respectively.

8.8 Leachate Management Systems

Leachate management systems (LMSs) include leachate collection layers, collection pipes, sumps, pumps, and riser pipes. There are challenges with designing these systems for CCR landfills located on natural ground due to the properties of the CCRs. For CCR overfill landfills founded on closed or closing CCR ponds, the potential for large differential settlements and associated strains on the LMS components is an additional concern that needs to be addressed in the design.

8.8.1 Soil and Geosynthetics Systems

The potential for clogging of geotextiles and geocomposite drainage layers and collection piping by fine grained CCRs such as fly ash and FGD wastes should be considered in the design. Use of sand or gravel drainage layers in lieu of geocomposites may be warranted in some cases. Figure 8-12 illustrates LMS piping clogged with FGD wastes from an FGD pond. The LMS was intended to function throughout wet sluicing and after pond water removal. However, the suspended FGD sediments were too fine and were not retained on the filter fabric. The ineffective LMS had to be removed and replaced with an aggregate drainage medium and

granular filter media. This demonstrates the importance of confirming the adequacy of the filter design using bench or pilot testing during the design phase.



Figure 8-12
Clogged FGD leachate collection piping [Courtesy of TVA]

Calculations for filter design can be verified by specific laboratory tests to support the selection of geotextiles and geocomposites with CCRs. Specifications of geocomposites that can withstand large strains and differential settlements are available. The geomembrane component of the liner system will have a lower tolerance for tensile strains and differential settlements than the LMS components, and consequently govern the design. However, it should be verified that leachate collection pipes can withstand the anticipated strains and differential settlements, and maintain the required minimum positive slopes to promote drainage.

It is noted that the gradation of CCRs varies from plant to plant and depends on the characteristics of the coal and the processes used in the plant.

8.8.2 Sump Design Considerations

Sumps are located in low points in the landfill base grades. As discussed in the previous sections, settlement analyses should be performed to demonstrate that sump locations will be maintained as low points in the long-term. Because sumps are by nature the low points of the liner system, they will also extend deeper into the underlying CCRs than the rest of the bottom liner. To be able to construct the sump, excavation into the CCRs could require additional dewatering, shoring, or strengthening.

A CCR filling plan should be developed by considering the need to maintain the sump locations as low points during operations. The need for pre-loading the sump location should be evaluated on a case by case basis. Sump construction will most likely involve excavation into ponded CCRs.

8.8.3 Considerations for Pipes and Pump Design

Pipes and pumps in sumps should be designed to withstand potentially high differential settlements and handling of high TSS liquids. Therefore the pipes will need to structurally withstand high strain induced by high loading. Perforations should be adequately protected against clogging by CCRs through use of designed filters. Pump design should consider potential impact of differential settlement to allow removal of pumps for maintenance after settlement. Deformation of the access riser pipes up the side slopes of the bottom liner should be expected. Therefore, all changes in direction of the access risers should be gradual (large radius bends). Further, the materials for the pump parts and discharge pipes exposed to high TSS need to be selected to withstand erosion and scour.

8.9 Cost and Schedule

A CCR landfill over pond design submittal will consist of a drawing set with about 20 to 60 drawings; the number mostly depends on the amount of detail required to convey landfill phasing and to meet regulatory requirements. Calculation packages presenting geotechnical, civil, surface water, and other supporting calculations, text plans and specifications, and an engineering report summarizing the design and various submittal components are also provided. Design submittals may be delivered and reviewed by the owner at 30% (conceptual), 60%, 90%, and 100% (final) stages with corresponding reviews typically focused on drawings (rather than supporting documents). Regulators may or may not review submittals at interim stages, but it is suggested that meetings be scheduled to discuss key design concepts during the design to expedite the final review. The typical design cost, excluding the costs of the field investigation, preplanning studies, and feasibility studies, which are discussed separately in other sections, is expected to vary from \$300,000 to more than \$500,000.

The overall design and permitting period may vary based on site-specific conditions, but are expected to be about three months of planning, three months of field investigation, nine months of design effort, and six months to a year of review period.

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9

CONSTRUCTION AND OPERATIONAL CONSIDERATIONS

9.1 Decommissioning and Demolishing CCR Pond Structures

9.1.1 *Dike or Dam Removal*

For ponds which were originally created with a retention dam, it is possible that, as part of the construction of a landfill on top of a pond, the retention dam should be modified (e.g., the dam crest lowered) or removed. Typically, retention dams are regulated and categorized based on height of the dam, size of the impounded area, and risks associated with dam failure (i.e., property damage, loss of life). Herein, it is assumed that a portion of the retention dam will remain, and therefore the discussion regarding construction involves best practices to effectively lower the dam to achieve closure requirements.

Issues related to constructability as part of a dam modification are described below.

- It is likely that a dike or dam will be lowered in multiple phases as it will be necessary to use water storage volume provided by the dam for temporary sediment control during closure construction. During closure, since the dam would still be impounding water, it may be necessary to still provide for sufficient storage to manage the design storm event (e.g., 25-year storm, 100-yr storm, probable maximum flood, etc.). As the area for impounding water gets smaller and as the closure construction approaches the last phase, it will likely be necessary to receive regulatory approval to manage a smaller storm event.
- Dam lowering will reduce available water storage volume. The potential for TSS exceedances during construction, therefore, increases as the dam is lowered.
- Dam lowering will likely reveal previously filled areas along the dam abutments. For many dam applications, a program of grouting would have occurred to minimize seepage from the abutments. The condition of the abutments should be inspected during construction, and measures may need to be implemented to assure stability of abutment sidewalls (e.g., grouting, drainage).
- As the dam is lowered, internal dam drainage systems may be uncovered. Design analyses should be conducted to verify if such drainage systems are required for the post-closure condition. For example, pore water within the CCRs may be released as a result of cover system loading. Therefore, the dam blanket drainage layer would still be necessary to collect and convey the pore water within the dam internal drainage system.
- The final grades of the lowered dam will likely need to “meet” grades of the final cover system over the closed pond to avoid long-term ponding of water behind the dam. It may be necessary to excavate below the final elevation of the lowered dam to facilitate spillway

construction; in that case, temporary support such as sheet piles may be required to retain CCRs.

9.1.2 Auxiliary Structures

A typical water level control structure in a pond comprises a drop inlet/decant structure (or vertical shaft) connected to a sloping conduit that traverses the dam cross section and eventually daylight at the downstream side of the retention dam. This structure would likely be abandoned in place; however, this structure would ideally remain operational for as long as possible to facilitate water removal during construction.

Penetrations through or under the dam that are no longer necessary need to be thoroughly abandoned/sealed to avoid degradation over time and collapse. The decommissioning of a drop inlet or penetration should include sealing off the downstream end, filling the conduit/penetration and vertical shaft with grout or flowable fill. If the length of the shaft and conduit is long, it may be necessary to construct one or more vertical “bulkheads” to facilitate grouting over controlled lengths. It is possible that the length of the conduit would make the above procedure impractical; in that case, vertical holes should be drilled through the dam to the top of the conduit, the conduit top should be breached, and then the conduit should be filled with grout or flowable fill. A specialty grouting contractor may be required for this service.

9.2 Dewatering, Excavation, and Pond Surface Preparation

The pond supernatant waters must be completely removed and the water level within the ponded CCRs must be reduced to allow for subgrade construction for a landfill. Following removal of ponded waters, dewatering and subgrade improvement need to be completed to provide a stable foundation for the overfill. Pond water removal, dewatering, excavation, and pond surface preparation of CCRs are addressed in [1].

This report stresses the importance of understanding the time to complete this process and incorporating it into the schedule for the overfill design and permitting and construction. Additional information regarding scheduling is provided in Section 9.4.

9.3 Wastewater Management

During dewatering and subgrade preparation, significant quantities of water are handled. Sources of this water include: (i) existing impounded waters; (ii) bound water within the ponded CCRs that may be released during excavation; and (iii) direct precipitation and run-on from adjacent properties. Such waters will usually be collected passively and will be progressively removed from the construction work area as construction continues and specific areas for subgrade are prepared and readied for soil placement. Management of this water is addressed in [1].

9.4 Construction Schedules

Specific items which will affect the duration of a construction project will include¹⁷:

- *Complexity of pond water removal.* For example, is the removal of water from the pond going to be conducted using existing pond discharge structures and therefore the duration of water removal will be controlled by the operational limitations of such structures, or is the dewatering going to be augmented by pumping? A cost and schedule risk for the contractor would relate to TSS levels in the water resulting from uncontrolled runoff from upstream areas that may resuspend particles and runoff rates that exceed the drawdown rates from the pond.
- *Amount of dewatering.* It is expected that all CCRs will require some amount of dewatering to achieve a stable grade. Dewatering has been addressed in the companion EPRI pond closure document [1] and historically in EPRI [2].
- *Amount of CCRs moving to achieve cover grades.* The amount of “earth” moving (i.e., CCRs, soil, rock) to reach the subgrade elevation for the landfill can be very large. This is a key schedule element where the surface of the CCRs is low in particular areas that require moving sometimes hundreds of thousands of yards of relocated materials.
- *Need for liquefaction mitigation.* Mitigation (e.g., strength improvement) to address potential liquefaction of the subgrade could require, as examples, construction of shear keys in the CCRs around the landfill perimeter, deep subgrade (CCR) improvement/densification, deep CCRs dewatering (using wick drains, for example), and preloading to increase density.
- *Size of the project.* It is prudent to phase the project so that specific areas of the project can achieve subgrade and liner system grades as soon as possible. Large open areas pose a significant risk for erosion of CCRs and non-compliance with stormwater discharge requirements.
- *Availability of soil materials.* As with any large earthwork project, the objective is to take materials from a borrow source immediately to its designated “as-built” location. Additional schedule may be required to: (i) test soil materials to assure compliance with performance requirements; (ii) temporarily stockpile materials for drying; and (iii) process materials to meet gradation requirements, and/or amend soils (e.g., add bentonite) to achieve permeability requirements for low permeability soil liner layers.
- *Construction, operation, and maintenance of haul roads.* Roads will need to be constructed over portions of the ponds to haul excavated CCRs and other soils to other portions of the site. For roads constructed over CCRs, repetitive loading will likely result in deterioration of the road during construction.

Project owners should anticipate delays associated with weather and difficulties with CCRs dewatering and stabilization. Also, there are serious safety concerns associated with operating construction equipment in and around pond materials that are near saturation (and close to open water), especially where equipment is operating directly over the CCRs as described in [1]. These conditions should be taken into account in the overall timeline.

¹⁷ Herein, it is assumed that a landfill subgrade and liner system is to be built over a former CCR pond which may have portions still under water.

9.5 Staged Fill Plan

The construction of a landfill over a CCR pond may require the development of a Staged Fill Plan (SFP) to allow for safe CCR filling where foundation materials (e.g., fly ash, soft clays) may be susceptible to instability resulting from undrained loadings (i.e., filling that occurs too fast). The SFP constructs the landfill in a number of stages (areas) to allow for subgrade improvement prior to construction. The SFP will be designed using information from the field embankment load test (see Section 8.4.4).

The SFP will consist of a narrative plan with stage-specific engineering drawings. The following activities are conducted to complete the SFP:

- Prepare a base map to facilitate rapid grading development, air space quantification, and comparison of alternate grading concepts.
- Identify existing site infrastructure in the vicinity of the staged filling operations so that it is considered and handled during the staged filling. Prepare a list of existing site infrastructure that may potentially be impacted by the proposed filling and closure activities. The list will be developed based on the site map, other site utility drawings provided by the utility, a field reconnaissance of landfill and perimeter areas, and interviews with plant personnel familiar with the area.
- Review/identify other current or planned site improvement projects that may need to be considered in designing the SFP.
- Review available documentation concerning the current and future CCR streams and their anticipated generation rates. The generation rates will be one of several significant factors in developing typical dimensions of active filling areas.
- Design road alignments, with typical cross-sections and maximum grades of site roads required for project implementation and operation. The road designs will consider: (i) alignment, elevation, as-built details (if known), and condition of existing roads; (ii) types of roads that will be necessary from site preparation and staged filling operations including site construction access roads, perimeter/maintenance access roads, and interior operation-phase haul roads; (iii) types of vehicles, vehicle load, and anticipated traffic frequency; (iv) alignment, profile, and cross-section necessary for all-weather access for drainage features; and (v) tie-in to existing or proposed project features and coordination with the staged fill sequence.
- Prepare drawings depicting transition from current operating conditions to the surface water management design required in the final closure plan.
- Update QA/QC requirements to incorporate the procedures applicable to the staged filling operations.
- Prepare a set of stage-specific plan view and detail drawing sheets for key stages in the preparation and operation of the filling program, progressing from existing conditions to the permitted final grades of CCRs. Key factors in developing the overall sequence and the stage-specific plan drawings will include:
 - remaining air space;

- permitted final grades of CCRs;
- CCR generation/delivery rate;
- anticipated CCR stream co-disposal method(s); and
- geotechnical-related construction and operation requirements including: (i) special considerations for variability of geotechnical properties of existing foundation material; (ii) ground improvement requirements (e.g., vertical drains, drainage blankets, etc.), if any; (iii) anticipated allowable loading rate; (iv) overall horizontal filling progression; and (v) allowable fill slopes;
- operational requirements (e.g., minimum necessary working area for equipment);
- operational efficiencies (e.g., minimizing expense associated with temporary cover);
- regulatory requirements of existing permit and applicable regulations; and
- operational contingencies in the event of instrumentation-related concerns (higher than anticipated pore pressures, excess settlement, etc.) or environmental conditions.

An SFP narrative should be prepared to accompany the stage-specific plan drawings. The SFP narrative will include the following elements:

- *Purpose for implementing staged-filling operation.* The staged-filling method is critical to safe and continuous operation of the landfill and should be stressed to operation personnel. It will explain the susceptibility of the existing foundation materials (CCRs and/or native soils) to load-induced pore pressures that can temporarily reduce foundation material shear strengths and the potential consequences (i.e., detrimental excessive settlements and/or instantaneous slope stability failure of the CCRs and underlying foundation).
- *Active monitoring program.* Successful implementation of an SFP requires specialized instrumentation and on-going monitoring that is not typically used in other solid CCR filling operations. This section will describe the types and purpose of the instrumentation that will be installed and periodically monitored. Specific instrumentation installation and monitoring requirements and operational contingencies and action levels (e.g., temporarily discontinuing fill placement in one area, reducing typical operating lift thickness, etc.) based on the results of on-going monitoring will be provided.
- *Stage-specific written operation plan.* This portion of the document will detail the operational procedures applicable to each stage of filling and will be subdivided into sections that are coordinated with the stage-specific plan view drawing sheets. Each of these drawing-coordinated written plans will describe:
 - precursor activities that must be completed prior to the stage of filling depicted in the drawing;
 - anticipated routine filling operations (e.g., placement areas, placement procedures, fill placement progression, CCR slope requirements, temporary cover, end-of-stage fill configuration, final cover areas (if applicable to that stage) to be followed during that stage of filling);

- CCR hauling operations (e.g., exterior and interior haul routes, modifications or improvements to exterior roads (if necessary), planned alignments and construction requirements for temporary or transitional interior haul roads, etc.);
- surface and stormwater management strategy for that stage of operation (i.e., bottom ash sluicing and pond location and management, CCR slope grading and flow directions, anticipated minimum drainage structure dimensions, etc.);
- other construction, infrastructure modifications, or external project coordination required during that stage of filling;
- reference to operation-related QA/QC requirements applicable to that stage of filling. It is anticipated that this component of the stage-specific written operation plan will only identify the type of QA/QC activities and, in some cases, the timing of certain QA/QC activities (e.g., stage-specific geotechnical instrumentation installation and/or abandonment timing);
- reference to operation-related construction and material specifications. As with the QA/QC requirements, this component of the stage-specific written operation plan will reference the separate Technical Specifications for the project; and
- operational contingencies (e.g., weather-related contingencies, instrumentation-related contingencies, etc.).

It may be necessary to prepare and present a training program (e.g., a one-day training at the site) to utility employees and utility-designated contractors that will cover implementation and management of significant construction elements and long-term operation of the staged filling. The training program will include presentation materials and a compilation of applicable construction and operation reference documents for each attendee. Additional training may be required upon initiation of staged-filling operations.

9.6 Geotechnical Instrumentation and Monitoring

Geotechnical monitoring may be required during the implementation of a pond closure or as part of the design of a landfill built over a CCR pond. As construction over a pond comprises so-called “soft ground construction”, items that will likely need to be measured during construction include: (i) excess pore pressures in the ponded CCRs; (ii) settlements resulting from the weight of fills; and (iii) lateral deformations of fill slopes. In general, excess pore pressures and lateral deformation measurements are used as a means to control potential instability resulting from exceeding the shear strength of the ground; settlement information can be used to verify settlement estimates used for design.

Results of instrumented test fills built over ponds (e.g., [3] and [4]) indicate that fly ash and bottom ash materials in ponds are relatively free-draining and that typical loading rates associated with closure or landfill construction are far slower than that required to result in a filling-induced foundation or slope instability (even though there is a tendency to impede lateral drainage as the pond closure progresses). Case histories indicate that the critical stability condition for these materials is during initial fill placement.

Because of the anticipated size (i.e., plan area) of a pond, it is not practical to instrument a site with the purpose of using instrumentation to control construction over the entire closed or

closing pond. If possible, it is suggested that portions of the pond that are most critical (e.g., in and around portions with thickest CCRs) be instrumented and that information from these areas be used for other areas of the site. Measured excess pore pressures should be compared to those computed during design (and which correspond to an acceptable stability condition) and, if used, lateral deformations measured via an inclinometer should be reviewed to identify if rates of lateral movement are increasing. It is important to note that an increasing rate of lateral movement is not necessarily an indication of incipient failure; for this reason, where rates of movement may be increasing, it is important to review pore pressure measurements and verify that excess pore pressures have significantly dissipated before placing the next lift of material.

The following summarizes some common instrumentation:

- Pore pressure piezometers.** Pore pressure piezometers are commonly used to measure water pressure in the pores of a saturated porous medium (e.g., soil, rock, CCRs). They are typically used for longer term applications (i.e., weeks to years) to measure conditions in or under earth structures during and after construction to assess stability. Vibrating wire pore pressure transducers are robust and can function at a wide range of pressures, temperatures, and chemical conditions and are also applicable to measure pore pressure in CCRs (see Figure 9-1). They contain a transducer that uses a vibrating wire element attached to a pressure sensitive diaphragm. As the diaphragm is depressed under pressure, the electrical signal changes across the vibrating wire and the output signal is calibrated to pressure. The assembly is enclosed in a metal casing with a saturated porous filter to allow exposure to the porous medium water pressure. The signal is transmitted through a cable to a measurement readout instrument/data logger. Information from the data logger can be downloaded in the field or uploaded via cell phone to the internet and transmitted to the user's location, thereby avoiding field personnel time to download data.



Figure 9-1
Various types of vibrating wire pore pressure transducers manufactured by Geokon, Lebanon, NH

- Inclinometers.** Inclinometers are used to measure lateral deformations over the depth profile to detect and track movements that could lead to slope instability. The inclinometer has a casing and a portable inclinometer measurement system that is comprised of a probe, a cable,

and readout box. The measurement system is shown in Figure 9-2. The casing is vertically grooved at each 90 degree quadrant and grouted into a borehole. The probe has roller guides/wheels that are orientated at 180 degrees. The probe is inserted into the casing with the wheels in two opposing grooves, and it is raised up from the bottom of the casing on the cable that leads to the readout box. Readings are taken at intervals, and the orientation of the casing is measured and transmitted to the readout box and the lateral deformation is calculated. The probe is then rotated 90 degrees and the orientation of the casing is measured [5]. There are other types of inclinometers which can be used for measuring both vertical and lateral deformation without the need for a probe (see SAA inclinometers, www.measurand.com).



Figure 9-2
Digitilt AT slope inclinometer system [5]

- *Sondex Settlement System.* The Sondex Settlement System is used to monitor settlement and heave in excavations, foundations, dams, and embankments. The Sondex system consists of a probe, signal cable, a cable reel with a built-in voltmeter, and a number of stainless steel sensing rings. A survey tape is typically connected to the probe. The sensing rings are fixed to a continuous length of corrugated plastic pipe which is installed coaxially with inclinometer casing or access pipe. The annulus between the corrugated pipe and the borehole wall is grouted. The corrugated pipe and its sensing rings settle with the surrounding ground. Figure 9-3 presents a schematic of the system [6].

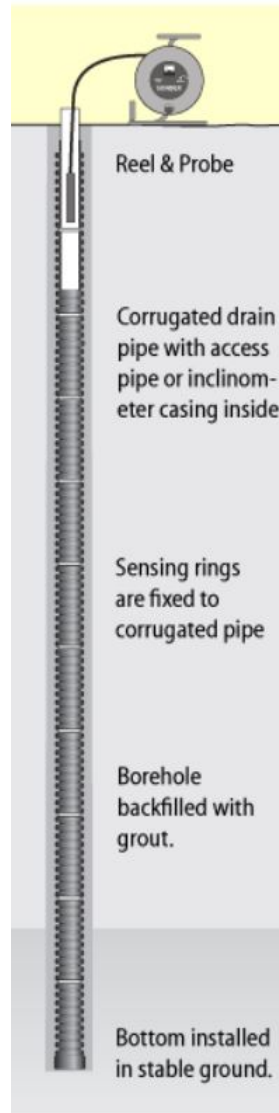


Figure 9-3
Sondex settlement system [6]

- **Settlement cells.** Settlement cells are used to measure settlement below earth fills. A settlement cell consists of a liquid reservoir, liquid-filled tubing, and the settlement cell, which contains a pressure transducer. Figure 9-4 presents a schematic of a settlement cell. One end of the tubing is connected to the settlement cell, which is embedded in fill or installed in a borehole. The other end of the tubing is connected to the reservoir, which is located away from the construction area. The transducer measures the pressure created by the column of liquid in the tubing. As the transducer settles with the surrounding ground, the height of the column is increased and the settlement cell measures higher pressure. Settlement is calculated by converting the change in pressure to millimeters or inches of liquid head [7].

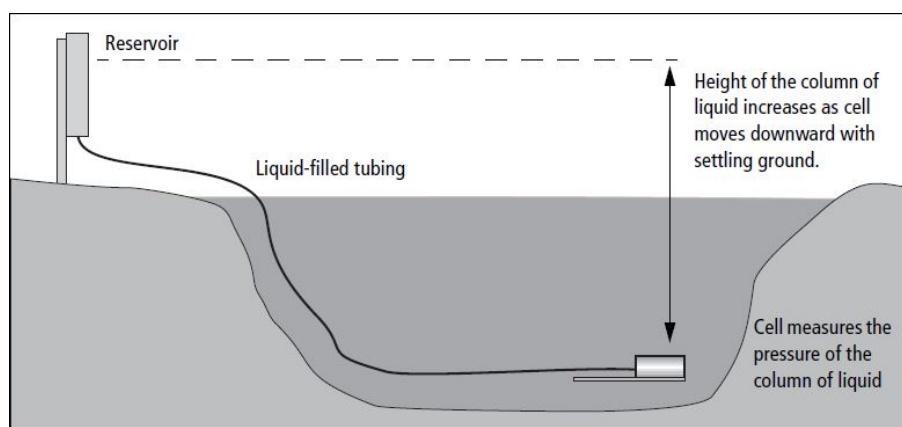


Figure 9-4
Settlement cell [7]

9.7 Hydrogeological Monitoring

Planning for groundwater monitoring must be conducted prior to construction and during operation of a disposal facility. Section 6 addresses how to develop a monitoring network and a groundwater monitoring plan (GWMP). A GWMP provides information to the owner, the regulatory agency, and the general public about what the facility does, or will do, to ensure compliance with applicable groundwater quality standards. The plan provides reasonable assurance that groundwater standards will be met at the edge of the facility's zone of discharge or point of compliance, as applicable. By developing a GWMP, the owner evaluates the facility's operations, discharges, and the actual and potential environmental risk posed by any discharges from the facility.

Monitoring of an overfill will require additional evaluation of groundwater conditions that may have been affected by the CCR pond and whether a leak detection layer is necessary below the overfill to distinguish whether the overfill is leaking. These issues are addressed in Section 6.

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7. Durham Geo Slope Indicator Company (2014):
<http://www.slopeindicator.com/instruments/settlementcell.html>

10

LONG-TERM CARE

Post-closure care (PCC) activities for a landfill built over a CCR pond will typically comprise monitoring (e.g., groundwater, surface water, and leachate) and maintenance (e.g., cover system, leachate and stormwater control systems, monitoring wells, and access controls).

10.1 Environmental Media Monitoring

10.1.1 Groundwater

When groundwater monitoring is implemented, the monitoring program should be documented in a GWMP or similar document. A GWMP provides information to the owner and, if applicable, regulatory agency and the general public about what the facility does, or will do, to ensure compliance with applicable groundwater quality standards. Hensel and Powell [1] provide guidance on developing and implementing groundwater monitoring programs at CCR containment sites.

Development of a GWMP specifically for landfills over closed ponds is addressed in Section 6.

10.1.2 Surface Water

Once the facility closed and capped with clean cover soil, runoff from the cover system should be allowed to discharge without NPDES monitoring. For post-closure stormwater flows that discharge through a previously permitted outfall, the change in effluent composition (i.e., from decant water to non-contact stormwater) should be documented in a NPDES permit modification. At the time of application, a decision whether to eliminate or maintain the outfall should be made. Maintaining the outfall may be beneficial if other future discharges are expected.

10.2 Geotechnical Monitoring

Because construction of a landfill over a CCR pond is a relatively new practice, it may be beneficial to implement a geotechnical monitoring program or continue an existing program after a pond is closed. For example, the geotechnical monitoring data collected during the post-closure period may be used to demonstrate the CCR pond is performing as designed or to support ending post-closure care.

Geotechnical monitoring during the post-closure period may include measurements to demonstrate aspects such as pore pressure dissipation in the CCRs or other performance criteria. Geotechnical instrumentation/practices used for these demonstrations may include measurement of pore pressure by use of standpipes or vibrating wire piezometers, measurement of fill settlements by settlement plates or sensors, and measurement of lateral deformation of fill or soil

slopes using inclinometers or a shape accelerator array (SAA) (see Section 9.6). Dunnicliff [2] provides detailed guidance on geotechnical instrumentation and monitoring.

10.3 Visual Inspection and Maintenance

The cover system should be regularly inspected and maintained during the post-closure period. Inspection procedures may be described in a Post-Closure Inspection Plan, and the plan may include inspection forms for field personnel. Any damage noted or corrective actions taken should also be documented on the inspection forms.

The cover system should be regularly inspected for vegetation condition (coverage and vitality), erosion, signs of burrowing animals, surface cracking and fissures, and surface depressions. Healthy vegetation should be maintained throughout the post-closure care period to control soil loss and enhance evapotranspiration. If visual inspections indicate poor vegetation on the cover, maintenance actions may include reseeded, applying fertilizer or other amendments, or other measures. If the cover system exhibits excessive erosion, the soil cover may be remediated by backfilling eroded areas with erosion-resistant soil, enhancing the surface layer to increase its resistance to erosion (e.g., installing erosion mats), modifying drainage patterns (e.g., with diversion berms), or other erosion control methods. Animal burrows, surface cracks and fissures, and depressions should be backfilled to promote runoff and control infiltration of surface water. Grassed cover systems are often mowed to promote good vegetation.

In inspecting the site for cracks and evidence of settlement, attention should be given to the perimeter areas of the cover system. At these locations where the less compressible perimeter berm material abuts the more compressible CCRs, the potential for differential settlement of the cover system is expected to be greatest. Differential settlement may create cracks that are visible at the surface and, potentially, cracks and tears in the underlying cover system components that are not readily apparent from the surface. If significant differential surface cracking is observed (e.g., on the order of 2 to 3 ft), it may be necessary to evaluate the competency of the hydraulic barrier component of the cover system. Figure 10-1 shows an example of a tear in a geomembrane component of a capping system that resulted from significant differential settlement along a containment system perimeter.



Figure 10-1
Example of a torn geomembrane cap caused by differential settlement

The stormwater management system for the cover system should also be inspected and maintained. Stormwater management features should be inspected for signs of excessive erosion, settlement, embankment failure, clogging, sediment buildup, and grade reversal. Routine maintenance of the stormwater management system may include removing excessive sediment, regrading to allow sufficient drainage, filling eroded areas, and repairing damaged structures.

10.4 Long-Term Care Costs

The cost of PCC for a landfill built over a closed CCR pond will vary based on the site size, climate, and regulations. Costs can generally be grouped into the following two categories:

- environmental media monitoring (e.g., groundwater and surface water monitoring programs); and
- cover system monitoring maintenance and reporting (e.g., periodic mowing of the cap, repair of erosion, and other miscellaneous construction activities).

Costs for groundwater monitoring are estimated to be \$8,000 per year per groundwater well assuming quarterly monitoring, and costs for NPDES surface water monitoring are estimated to be \$15,000 per year [3]. Costs for cover system maintenance and reporting are estimated to be \$300 per acre per year [3, 4].

10.5 Ending Post-Closure Care

Because of the characteristics of the CCRs comprising the foundation of the landfill and the landfilled material itself, there are several mitigating factors which may result in a shortened PCC period, as compared to, for example, MSW landfills, including:

- CCRs in a landfill are uniform and non-biodegradable and consequently are expected to have little post-closure settlement; therefore the cover system maintenance is reduced and the cover can be stabilized in a shorter time than an MSW facility.
- When a low permeability (i.e., $k = 1 \times 10^{-7}$ cm/sec) cover or an overfill is placed over the closed pond and considering the relatively low permeability CCRs (i.e., $k \sim 1 \times 10^{-5}$ cm/sec) compared to typical MSW (i.e., $k \sim 1 \times 10^{-3}$ cm/sec) [5], it is expected that there should be a relatively rapid reduction of leachate generation after closure; this could lead to elimination of leachate treatment operations in a relatively short time (e.g., less than 10 years) based on research conducted by the U.S. EPA, which found that much of the leachate generation for landfills with low permeability covers declined to *di minimus* after 7 years [6].
- CCR constituents have low leachability into leachate thereby resulting in a greatly reduced potential for groundwater impacts when placed in a lined disposal facility. This may justify elimination or significant reduction of required groundwater monitoring.

The above characteristics of CCRs can lead to a post-closure care period with reduced requirements if the inspection, monitoring, and maintenance data are collected to allow the demonstration. The shortened post-closure care period would result in elimination or significant reduction of groundwater and surface water monitoring, and reduction of the amount of financial assurance, but would not eliminate the need for periodic inspections and a commitment to maintain the integrity of the cover/containment system.

References

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2. J. Dunnicliff (1993). "Geotechnical Instrumentation for Monitoring Field Performance". John Wiley and Sons, New York.
3. Electric Power Research Institute, *Disposal Site Economic Model for Coal Combustion Residuals Under Proposed Federal Non Hazardous Waste Regulations*. EPRI, Palo Alto, CA: 2012. 1025378
4. Missouri Department of Natural Resources – Solid Waste Management Program (2006) "Closure and Post Closure Cost Worksheets (Forms MO 780-1879 11-10 and MO 780-1882)". Jefferson City, Missouri.
5. Schroeder, P.R., Lloyd, C.M., and Zappi, P.A. (1994) "The Hydrologic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3," U.S. Environmental Protection Agency, Office of Research and Development Washington, D.C., Report No. EPA/600/R094/168a.
6. Bonaparte, R., Daniel, D., and Koerner, R. (2002) "Assessment and Recommendations for Improving the Performance of Waste Containment Systems". EPA/600/R-02/09.

11

CONSIDERATIONS FOR CONSTRUCTION OF OTHER STRUCTURES

11.1 Introduction

Beneficial use of closed or closing CCR ponds to build athletic fields and parks, solar power generation systems, wastewater treatment components, industrial buildings, and storage and staging areas may be feasible based on site conditions. The most effective way to design these land use options is to design them at the time of the pond closure. Cover system components can be more easily integrated with the end use if the two are designed at the same stage, and activities such as grading can be more efficiently performed.

11.2 Athletic Fields and Parks

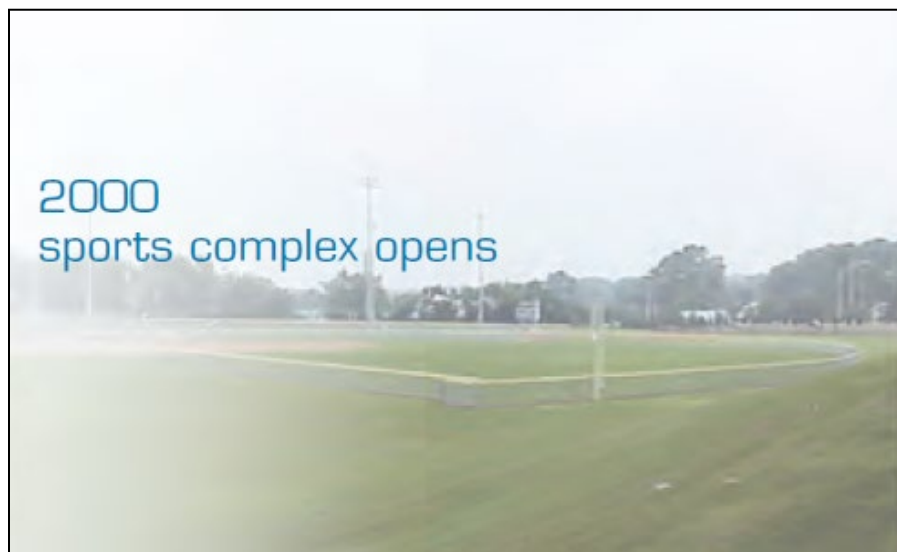
Development of athletic parks on closed CCR ponds offers a number of benefits. These parks offer beneficial reuse of land that is typically difficult to redevelop, and they provide local communities with valued green space. Because they are generally large flat spaces, closed CCR ponds can be redeveloped into a variety of athletic fields and parks, including sporting fields, playgrounds, trails, and other recreational facilities. Figure 11-1 shows before and after photographs from one such athletic field complex developed on a former CCR pond [1].

11.2.1 Settlement

Athletic parks must be designed and constructed with consideration for the additional loading they will place on the cover system and the interaction they will have with the cover system. Differential settlement is an important consideration for foundations and structures. Structures which are intolerant to settlement should not be placed on the cover system. The potential for settlement can be reduced by using dynamic compaction, geogrid/geotextile reinforcement, preloading, or redeveloping with a phased approach in which buildings or other structures are built on the oldest areas of the CCR pond first, where rates of settlement would have decreased with time.



Before



After

Figure 11-1
City of Akron, Ohio's Patterson Avenue Sports Complex, built on FirstEnergy's former CCR pond [1]

11.2.2 Surface Vegetation and Landscaping

Vegetation should be selected based on site topography and the intended use of the site, and should accommodate site infrastructure, such as irrigation and ventilation systems. Grasses are typically used as surface vegetation in athletic parks since they have shallow roots, grow with minimal upkeep, adapt to local environments, and are resilient to heavy foot traffic. Deep rooted vegetation can damage the cover system and should generally be avoided on the cover system, unless an evapotranspirative (ET) cover design utilizing specialized trees is chosen. The trees of an ET cover should not be put on side slopes of embankments because of the potential to compromise the containment embankment.

Artificial closure turf systems are available and incorporate some of the final cover components such as geomembranes, geonets, and artificial turf in one product. Table 11-1 presents surface vegetation options and resources.

Table 11-1
Comparison of cover system materials for construction of athletic fields and parks

Cover Type	Benefits	Resources
Natural Grasses	Allows vegetative cover to survive in a variety of conditions related to use, drought, temperature, and disease.	- National Turfgrass Evaluation Program [2] - Natural Resources Conservation Service [3]
Tree Cover	- Promotes evapotranspiration - A phyto cover design will need to be performed for closure	Ecolotree [4]
Synthetic Grass Closure Systems	- Can be integrated with impermeable layers and/or drainage features - Eliminates the need for a soil layer underlying the vegetation layer (potentially providing significant reduction in construction and long-term maintenance costs)	- Closure Turf™ [5] - LiteEarth [6]

If surface water features are included in the design, consideration should be made to minimize drainage from surface water features into the closed pond. Infiltration prevention may include additional impermeable and leak detection layers in the cover system. Athletic fields may require use of irrigation in excess of typical use in landfill and pond cover systems. If such excess use is anticipated, water balance and infiltration calculations should be performed by incorporating this additional irrigation water.

11.2.3 Grading and Stormwater Management

The stormwater management plan is developed in conjunction with the final cover system design to address erosion prevention and slope stability. Vegetated landfill covers are designed to absorb some stormwater runoff into the cover system layers. Water that is not absorbed into the cover is conveyed to stormwater ponds via surface stormwater collection systems which are installed to prevent channeling and erosion of the cover system.

While typical landfill final cover grades are about 3 to 5 percent to maintain effective drainage, CCR pond closures may consist of landform grading with 1 percent slopes. However, developers of recreational fields generally prefer slopes of 1 to 2 percent [7]. To accommodate both uses, a cover can utilize a surface grading appropriate for athletic fields while also utilizing a subsurface drainage layer to accommodate regulatory requirements. To avoid a situation where the cover has been installed at 3 to 5 percent slope and fill is needed to reduce the slope to 1 to 2 percent, grading of the athletic fields should be merged with the closure cover grading as much as

possible. A second grading event will require material to be added on top of the final cover to reduce the slope, which will increase the weight on the cover and may increase settlement.

Parking lot design will also affect the stormwater management plan. Paved parking lots will increase runoff compared with vegetated surfaces and will require larger retention ponds and supporting infrastructure, while unpaved parking (e.g., gravel) will increase infiltration. The weight of vehicle traffic on parking areas may also increase settlement within the pond. Siting these features away from the cover system will reduce loads on the cover system and decrease costs for stormwater infrastructure.

11.2.4 Maintaining Cover Integrity

Recreational use of a CCR pond cover as an athletic field or park requires special care to avoid surface exposure of the ponded CCRs. Maintaining final cover integrity involves both controlling designed penetrations into the system and preventing accidental intrusion into the system.

Foundations for infrastructure supporting athletic fields (i.e., lighting, fences, backstops, scoreboards, etc.) may require penetration into the cover system and/or ponded materials. Any penetrations required for these types of installations must be sealed so as to prevent the migration of water into the cover system or gases out of the cover system. Cover system geosynthetics should be properly connected using boots to allow for differential settlement of the cover system and the foundation components.

Site improvements or unauthorized digging could also expose the ponded CCRs. To minimize the potential for accidental exposure of the CCRs or damage to critical cover system components, warning or barrier layers can be installed to act as a warning to site workers. Warning layers can additionally be installed in areas where erosion may be a concern, alerting site personnel that repair is needed if the warning layer becomes exposed.

11.2.5 Utilities

Water, sewer, and electric utilities are often used to support field activities, bathrooms, concessions and lighting, and sprinkler irrigation systems at athletic parks. Installing utilities on cover systems can present many challenges, including:

- buried utilities can interfere with the cover system through the installation process, and above-ground utilities can interfere with the cover system through the construction of foundations; and
- leaking water or sewer lines can cause settlement or infiltration through the cover or foul the stormwater collection system; if not done properly, repairing these leaks could further damage the cover.

Overcoming these challenges requires special consideration for utility installation, including:

- locating utility lines in areas where significant settlement is not expected (i.e., pond berms);
- connecting utilities through building sidewalls instead of through floorings to minimize risk for possible vapor intrusion (information on management of gases is found in Section 11.2.7);

- using ductile piping materials and flexible connections to reduce pipe failure in the case of settlement; and
- monitoring pressurized systems to detect leaks.

11.2.6 Access

Roads and parking will be needed to allow access to athletic parks. Access infrastructure may be located off of the footprint of the cover system, but if space is limited and roads and parking must be located on the cover system, the following should be considered:

- during and potentially after construction, access roads will be required to allow construction and maintenance traffic to access the cover system; the need to accommodate construction loads (e.g., trucks, cranes, etc.) may affect the performance of the cover;
- paved surfaces can be incorporated into the cover system to act as a barrier layer;
- paved surfaces will increase runoff and must be incorporated into the stormwater management plan; and
- the materials used to construct parking areas and the location of driving and parking surfaces must be carefully integrated with the cover system; the additional loading on roads and parking lots from vehicle traffic may lead to differential settlement, so the facility design should address differential settlement.

11.2.7 Management of Gases

As discussed previously, gas control is usually not necessary for CCR sites, but should be considered, particularly when sites will be used by the public. Hydrogen sulfide can be a concern if FGD was disposed in the CCR pond. If hydrogen sulfide is a potential threat, gas management should be considered during the design of the CCR pond closure cover system. Surface emission monitoring using hydrogen sulfide monitors can be used for evaluation purposes. Gas management may include either passive or active systems.

An additional consideration is the potential for vapor intrusion into buildings. Vapor intrusion into structures on the closed CCR pond can be minimized by constructing floor slabs in convex forms, placing geomembranes/plastic vapor barriers between the ground surface and the floor of the structure, installing passive vent layer under the floor slab and venting to above the roof level, and connecting utilities outside of the structures to avoid penetrating the floor slabs [7]. Ventilation may be an important consideration as well. It may be necessary to monitor enclosed structures built on the closed CCR pond if there is potential for vapor intrusion.

11.2.8 Construction-Related Considerations

Construction of the athletic park may require grading, removal and replacement of vegetation or topsoil, excavation to accommodate foundations or footings, installation of roads and parking areas, installation of utilities, and the use of staging areas. Settlement from the rapid compression of buried CCRs can occur during construction or when heavy equipment is used on the cover system. Construction activities must safeguard against large localized settlements by

controlling construction traffic on the cover or using engineered controls such as construction mats, geogrids, or bridging lifts to spread weight more equitably across the cover system.

Other concerns to be considered during construction include:

- if the pond cover is already installed, grading of the cover must follow regulations and should be minimized to avoid compromising the integrity of the cover system, or the cover system will have to be repaired;
- erosion should be minimized during construction activities;
- additional stormwater permitting (General Stormwater Permit) for soil erosion and sedimentation control (SESC) may be required during grading or construction activities; and
- areas to be used for staging during construction should be considered during the design process to mitigate the risk of large localized settlements.

11.2.9 Operational Considerations

There are several operational considerations, including the following.

- Site security controls may be needed to reduce the risk of vandalism and to maintain safety of the users of the park. Site security most typically includes perimeter fences, security lighting, and/or cameras.
- Sprinkler irrigation schedules should be coordinated with weather patterns to avoid excessive watering that may cause excessive infiltration into the cover system.
- All repair activities that may affect the cover system should be coordinated with the design engineer and pond closure regulatory agency and properly documented.

11.2.10 Long-Term Care and Monitoring

Inspection of athletic park components will go hand-in-hand with cover system inspections and will include:

- maintenance and re-vegetation of cover system vegetation, including periodic mowing;
- inspection, maintenance, and repairs of the stormwater collection and treatment system;
- cover inspection and repairs; and
- inspection and repairs to monitoring systems.

11.3 Solar Applications

The installation of solar (photovoltaic [PV]) systems on closed CCR ponds offers a number of benefits. Using the closed CCR pond footprint is less expensive and creates less of an environmental impact than installing the same system on a greenfield. These systems also offer beneficial reuse of land that is typically difficult to redevelop, and they provide land owners with additional funding to offset the costs of system operations and maintenance. Since CCR ponds are typically located on or near sites where power is produced, the sites are easily interconnected with the power grid.

11.3.1 Solar Power Systems

Photovoltaic systems convert energy from solar radiation directly into electricity and are able to generate electricity from both direct and diffusive sunlight. PV systems can operate in cloudy conditions, which effectively extend their applicability to non-arid and rainy climates. Temperature is not a major determinant of efficiency, so the technology works in northern and southern climates. Maps of solar resources in the U.S. are available from the National Renewable Energy Laboratory [8].

Solar power can be converted to electricity using several systems, as presented in Figure 11-2 and discussed below:

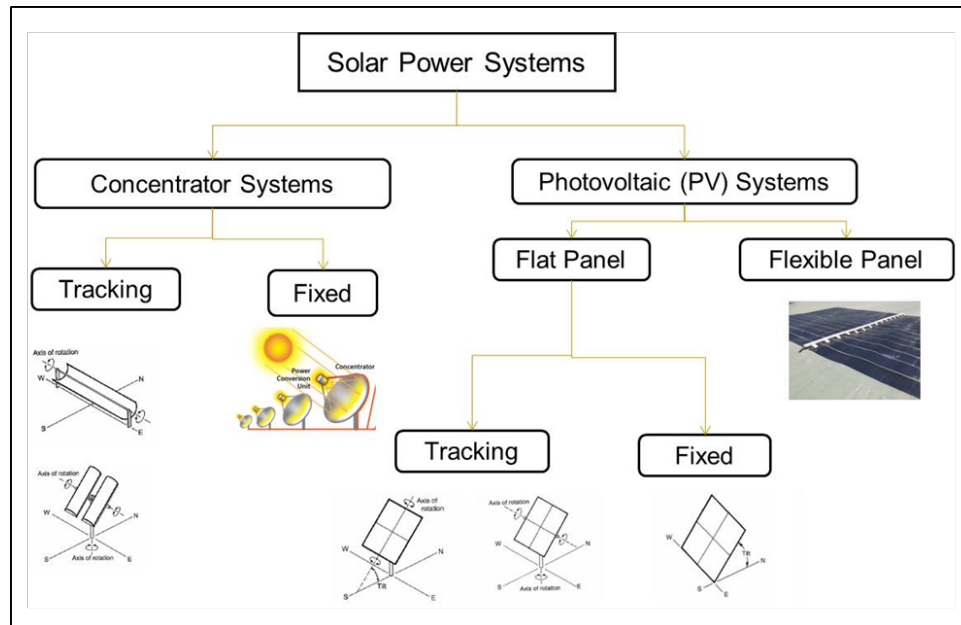
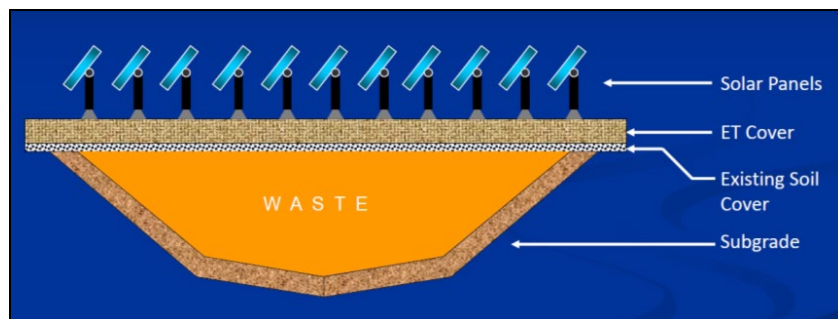


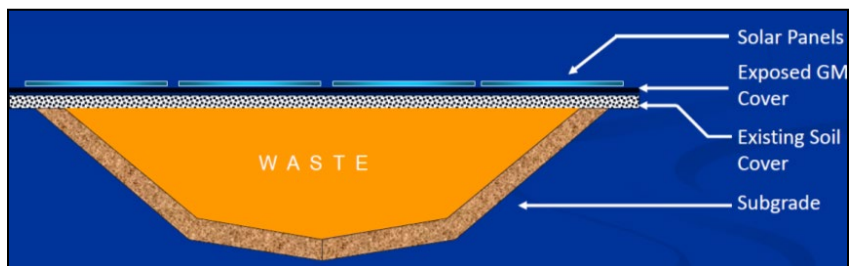
Figure 11-2
Different solar power generation systems

Concentrating Solar Power (CSP) Systems. CSP systems collect solar energy using mirrors and reflectors to concentrate heat or generate mechanical power for electricity generation. CSP technologies include linear concentrator systems, power tower systems, and dish or engine systems. CSP installations perform best on flat grades, so their application on closed CCR ponds is feasible, although significant land is required for linear concentrator and tower power systems. Dish or engine systems are better suited for smaller tracts of land. In general, CSP systems require robust foundation installations that may be challenging for CCR pond sites.

PV Systems. PV systems include both flat panel and flexible (e.g., PV integrated geomembrane) panels. Figures 11-3 and 11-4 show conceptual layouts and project examples for applications of PV systems at waste containment facilities.



Rigid



Flexible

Figure 11-3
Conceptual layout of rigid and flexible solar panels over a waste containment facility



Tracking rigid panel system installed on a lined brownfield site. Photo provided by American Environmental Group [9]



Flexible panels at Hickory Ridge Landfill in Conley, Georgia. Photo provided by American Environmental Group [9]

**Figure 11-4
Photos of solar panel layouts over landfills**

Table 11-2 describes design considerations for the various solar power system options.

Table 11-2
Design considerations for PV systems

PV System	Design Considerations
Flexible Panel (PV Integrated Geomembranes)	• Made from amorphous silicon laminates • Less efficient per area of panel than crystalline panels (6-8% efficient [10]) – Installed capacity per acre varies depending on panel spacing – General rule of thumb: 100-300 kilowatt (kW)/acre installed • Lighter weight than flat panels • Can be installed without mounting systems • Can be applied directly to landfill geomembrane cover systems if designed as an exposed geomembrane cover (EGC) (cover soil cost savings, but geomembrane life is 20 to 30 years) • Relatively flat profile of the pond cover systems (compared to landfill slopes) provides resistance to wind uplift, but wind uplift design should be performed • Tolerable to differential settlement • Water requirements – 10,000 gallons per megawatt (MW) per year required for cleaning PV components [11].
Flat Panel	• Three main types: monocrystalline, polycrystalline silicon, and thin-film • Thin-film not covered here due to low efficiency and large land requirements, but more information is available [10]. • Silicon is an abundant, nontoxic material • More efficient than PV integrated panels (12-18% efficient) [10] • Heavier than PV integrated panels • Require mounting on supports • If open space is limited and maximum electricity generation is the goal, these systems will be preferred. • The National Renewable Energy Laboratory (NREL) assumes installed capacities as follows for the lower 48 states for an efficiency of 13.5% [12]: – 65 Watts (W) per square meter (m^2) (263 kW/acre) for fixed-tilt – 48 W/m^2 (194 kW/acre) for single-axis tracking – 20 W/m^2 (81 kW/acre) for double-axis tracking • NREL provides interactive maps which predict energy production potential per location [13]. • Water requirements – 10,000 gallons per MW per year [11] required for cleaning PV components.

Table 11-2 (continued)
Design considerations for PV systems

PV System	Design Considerations
CSP	- Require significant contiguous land to be cost-effective - CSP systems are set up to track the sun throughout the day in order to function efficiently. - Require sophisticated tracking systems, increasing capital and O&M costs - Are of particular interest in the southwestern United States - Commercially available CSP modules have demonstrated efficiencies of 20-26% [12]. - Water requirements – 1.5 to 2 million gallons per MW per year if water is used as the fluid in the system [11]. Water will be lost as steam in the energy generation process.

NOTE: energy output per unit area calculated based on mean efficiency, the assumption that a typical location in the United States receives 5 hours of full sun per day, and a solar flux of 1,000 W/m².

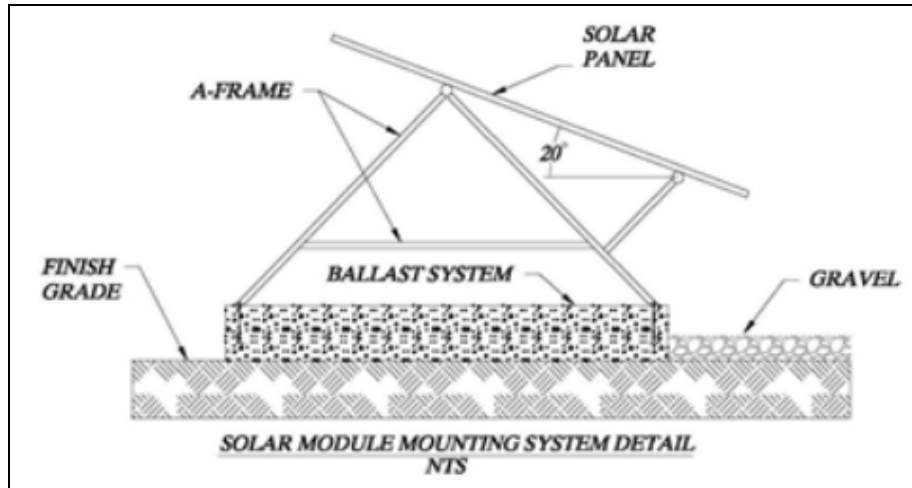
11.3.2 Permitting

If using a Subtitle D cover system over the closed CCR pond, standard permitting can be expected, including stormwater discharge permits. If using an exposed membrane cover, state regulators will additionally require demonstration of hydraulic equivalency with a regulatory (Subtitle D) cover. Regulators may have concerns about additional maintenance requirements and may require high reserves for post-closure care. Regulators may view EGC as a temporary cover, although it can be designed as either an interim or a final cover. Zoning requirements are likely to be favorable for renewable energy generation at sites where CCR ponds are being converted.

11.3.3 Foundation Design for Ground-Mounted Systems

Concentrator systems and PV systems will require mounting onto foundations. These systems typically consist of aluminum or galvanized steel frames (stanchions) mounted onto concrete foundations. The size and depth of foundations should be designed to ensure adequate load carrying capacity and tolerable settlement.

Ideally, above-ground footings will be designed so that they are large enough to bear the weight of system components without penetrating the final cover system geosynthetics. One example of a foundation system that does not penetrate the cover system and can be adjusted after installation is a ballasted system, as presented in Figure 11-5. If deeper piers are required, they will require cover penetration and will increase the weight on the ponded CCRs, which may increase settlement. Tracked mounting systems will be heavier than fixed tilt mounting systems and will require greater foundation support. Any cover system penetrations must be sealed (e.g., using geomembrane boots) so as to prevent rainwater intrusion into the cover. It is possible to design foundation systems that are bolted above ground to facilitate adjustments to account for differential settlements and realign.



Detail of a ballast foundation system



Photo of a ballast foundation system from Nellis Air Force Base, Nevada (courtesy of SunPower Corporation)

Figure 11-5
Details of foundation systems for solar panels

11.3.4 Wind and Snow Loading

Solar system components, including mounting systems, panels, and foundation systems, should be designed to meet the local maximum wind speed design criteria. Wind and snow loads increase the weight on solar system components, which can stress these components as well as their support structures and the cover system. Additionally, if cover maintenance requires installation of solar systems at a height that will allow for mowing the vegetative cover on the

pond, the longer pier lengths used to achieve desired structure height will increase the stress on the cover.

Where snow accumulation is a possibility, this additional loading should be considered in the design. If the panels need to be raised and/or tilted to avoid being covered by accumulated snow, the additional potential wind loading posed by the increased pier length should also be considered in the system design. If snow accumulation is a possibility in areas where PV integrated geomembranes are being considered, snow removal may be required on these covers.

11.3.5 Settlement

CCRs do not have significant post-closure settlement if the vertical loading is not significantly increased. Therefore, even if the equipment is settlement sensitive, there is less concern for ongoing maintenance and realignment for CCR landfills/closed ponds. Track-mounted PV installations may be acceptable for CCR landfills/closed ponds if it can be shown that anticipated settlements will not impact the angle of the tracking system. Impacts to fixed-mounted systems are normally minimal unless the angle of the array is significantly disrupted. PV integrated geomembrane installations are most appropriate for installations where settlement is a concern.

Solar applications are better suited for CCR ponds than MSW landfills, because the potential for settlement can be reduced significantly using dynamic compaction, geogrid/geotextile reinforcement, or preloading, or by redeveloping with a phased approach in which structures are built on the oldest areas of the CCR pond first where rates of settlement would have decreased with time.

11.3.6 Cover Selection and Design

The two most common cover systems used in conjunction with solar power system installations are EGCs and Standard Subtitle D or soil covers. Design considerations for cover types are discussed in Table 11-3.

The following design considerations are applicable for EGCs:

- Wind uplift is an important design consideration when using EGCs for CCR pond covers. Wind uplift is a function of wind velocity, altitude above sea level, and mass per unit area of geomembrane. Sufficient anchoring is needed to prevent wind uplift. Anchors can be designed as trenches or benches, which can doubly serve as access for roadways and surface water control for swales and down chutes [14]. Earthen anchors can also be used. If earthen anchors made of corrosion resistant materials are used to prevent wind uplift, the penetrations the anchors make through the EGC can be covered by flexible solar panels adhered to a carrier geomembrane. The combination of anchors with flexible PV panels will create an effectively impervious surface preventing infiltration of rainwater into the closed CCR pond [15].

Table 11-3
Design considerations for cover systems

Cover System	Design Considerations
Exposed Geomembrane Cover (EGC)	• Can be installed as intermediate or final cover • Integrates well with Flexible PV solar panels • Prevents leachate seeps • Prevents CCR exposure • Minimizes rainwater intrusion • Effectively eliminates veneer failure and erosion • Wind uplift concern • Increases ease of inspection and repairs
Standard Subtitle D or Soil Cover	• Integrates well with CSP, Fixed, or Flexible PV systems • Allows for installation of footings for rigid panels • Prevents CCR exposure • Reduces stormwater runoff compared with EGCs • Reduces concern of wind uplift • Increased cost compared with EGC, but lifespan is improved

- Stormwater ponds will need to be designed appropriately to capture the runoff from EGCs. The use of EGCs creates an effectively impervious surface which will reduce particulate matter in the stormwater runoff from the cover compared with a vegetative cover, but the flow volume and rate of runoff will be increased. This increased flow will induce higher erosive forces that need to be addressed to avoid scour of the earth surrounding the EGC. The use of EGCs requires a well-designed collection and conveyance system around the cover. Note that anchors can be designed to prevent wind uplift and double as stormwater control.
- Mechanical damage can be caused by a variety of sources, including falling or blown debris, burrowing animals, human vandalism, and motorized vehicles. Falling debris can be a concern where EGCs are installed near slopes where erosion of rocks, trees, or other debris may impact the cover, or where EGCs are installed in areas near roadways or industrial facilities. Installing small embankments or other debris barriers can mitigate potential damage from debris. Vandalism can be reduced by installing fences and restricting access to the cover. Motorized vehicles should be kept off the cover except in areas specifically designed to accommodate them. An armor system, typically consisting of a layer of crushed stone, shotcrete, or concrete can be installed to prevent damage from debris or other sources [16].
- Factors that can contribute to environmental damage and durability issues for the EGC include temperature fluctuations, ultraviolet radiation, wind, and precipitation. The EGC

should be constructed of a material that will provide appropriate protection from these stressors for the design life of the cover. Routine inspection and maintenance are important.

Detailed discussion about standard Subtitle D or soil covers is not provided herein as this technology is more common than EGCs. Table 11-3 includes the design considerations for these covers for solar applications. Penetrations through these covers if required for foundation systems should be designed properly to avoid tear of geosynthetics or leakage, by the use of boots. Soil could be mounded around the foundations to prevent the development of low points leading to accumulation of stormwater.

11.3.7 Utilities

Considerations for electric and water utilities are similar to those discussed for athletic fields and parks in Section 11.2.5. Utility lines (pipes, cables, wires, etc.) are not expected to run across/over the EGC. However, should this be necessary, there are geotechnical design methods (see Sections 5 and 8) that can be applied. For example, geotextile cushions and protective soil (partial cover) can be constructed over the EGC and the utility lines can be placed in the partial soil cover without impacting its performance.

11.3.8 Access

Access roads will be needed for construction and O&M of the solar power system. The following should be considered when constructing access infrastructure on the cover system:

- During and after construction, access roads will be required to allow construction and maintenance traffic to access the cover. The need to accommodate construction loads (e.g., trucks, cranes, etc.) may affect the design of the cover.
- Paved surfaces can be incorporated into the cover system to act as a barrier layer.
- Paved surfaces will increase runoff and must be incorporated into the stormwater management plan.
- The materials used to construct access roads must be integrated with the cover system.
- The additional loading on roads and parking lots from vehicle traffic may lead to differential settlement. Reinforcement may be required to prevent differential settlement.
- Maintenance of vegetated areas of the cover system may require mower access. Layout of the PV system should be designed to accommodate these types of activities.
- EGC anchors can be designed as trenches or benches, which can doubly serve as access for roadways [14].
- Dust from dirt roads must be controlled.

Note that O&M of solar power systems may require more access roads than typical for a cover system.

11.3.9 Construction-Related Considerations

Construction considerations previously discussed for athletic fields and parks are also applicable for solar power systems. Additional considerations include construction of EGC and use of cranes to install ballasted solar panel foundation systems. Connecting PV systems to the electricity grid requires an interconnection agreement, typically handled through the local electric utility, which specifies the terms, conditions, and equipment requirements for a grid-interactive PV system. Because the PV system is near a power generating station, access to an existing power grid may be expedited. For larger PV systems, this process may take from 6 to 12 months.

Some states have specific rules and capacity limits for small generators interconnecting with the electricity grid. Standards regarding fees, timelines, applications, legal agreements, and other factors vary by state. Information is available on the Database of State Incentives for Renewable and Efficiency website [17].

11.3.10 Operational Considerations

There are several operational considerations, including the following:

- Security should be considered during the design process to reduce the risk of theft and vandalism and to maintain safety of persons around high voltage equipment. Site security most typically includes perimeter fences, security lighting, and/or cameras.
- Mowing should be performed carefully to not cause damage to the solar panels.
- All repair activities that may affect the cover system should be coordinated with engineers and properly documented.

11.3.11 Long-Term Care and Monitoring

Monitoring active PV systems is critical to maintain reliable system functionality. Power production on a daily and cumulative basis should be measured for consistency, and module temperature, ambient temperature, solar radiation, and wind speed can also be measured to gain a greater understanding of site conditions and improve predictions of electricity generation. These data can also aid in improving system efficiency and performance by identifying underperforming arrays, arrays requiring maintenance or cleaning, and shaded arrays. Remote connections are available for monitoring, and alerts can be automatically generated and sent electronically. Data loggers can also be used to store data.

Solar arrays must be cleaned during routine system O&M activities to maintain system performance. In areas of heavy rainfall, the cleaning process may happen naturally. In areas of infrequent rainfall or limited water resources, stormwater from the site can be collected and reused to clean the PV panels, but minerals may need to be removed from the stormwater prior to cleaning to limit residue deposition on the panels during cleaning.

The cover system will require inspection and maintenance. Periodic mowing will be required for a vegetated cover, and inspections are typically conducted on a quarterly or semiannual basis to look for cracks or fissures in the cover, erosion caused by stormwater runoff, and differential settlement. Inspections of EGC systems must be performed to locate damage to the

geomembrane layer or slumping of the cover material due to differential settlement. Damages must be repaired.

11.4 Wastewater Treatment Systems

After CCR pond closures, alternate wastewater treatment technologies may need to be installed at facilities where CCR ponds are currently in place to treat wastewater. Constructed wetlands, leachate treatment ponds, wastewater treatment units, and water storage basins may need to be constructed at power plant sites. Closed or closing CCR ponds may provide valuable space to site these facilities if feasible. Phytoremediation final cover systems can also be installed as a component of wastewater treatment.

11.4.1 Treatment Process Considerations

When designing wastewater treatment processes (i.e., constructed wetlands, prepackaged wastewater treatment systems, systems of clarifiers, biofilters, trickling filters, etc.), the water budget must be understood, including flow into and out of the system from:

- Surface water
- Groundwater
- Process CCR streams
- Precipitation
- Stormwater runoff
- Evaporation
- Transpiration

The treatment objectives must be well defined and the system must be able to accommodate an influent with varying characteristics, because for some systems the influent characteristics can change dramatically over time (e.g., a constructed wetland following a rain event). A treatment system that is appropriate to the site will be able to treat the wastewater stream produced at the site and will be able to be sited on the land available. Table 11-4 provides design considerations for various treatment options.

11.4.2 Settlement

All components of wastewater treatment systems must be designed and constructed with consideration for the additional loading they will place on the cover and the interaction they will have with the cover system. Differential settlement is a significant consideration for foundations. Structures which are intolerant to settlement should not be placed on the cover system. Potential for settlement can be reduced using dynamic compaction, geogrid reinforcement, or preloading, or by redeveloping with a phased approach in which buildings or other structures are built on the oldest areas of the CCR pond first, where rates of settlement would have decreased with time.

Table 11-4
Design considerations for various wastewater treatment options

Treatment Option	Design Considerations
Constructed wetlands	• Require a large area and specific types of soils, depending on the geography of the site and plants selected. • If soils are difficult or expensive to source, wetlands may not be a good option. • Plants should be selected appropriately.
Wastewater treatment systems	• Require smaller footprint. • Large foundations to support treatment system components may be expensive on CCR ponds.
Bioreactor/biofilter	• Gravel-bed bioreactors have been demonstrated to treat dissolved inorganics (perchlorate, chromium, selenium). • Low cost, low maintenance. • Sized to provide residence time of 12 to 24 hours, so applicability depends on wastewater flow rate from power plant. Equalizer basins can be paired with bioreactors to provide predictable flow rates.

11.4.3 Cover System Design

The treatment system and cover system must be integrated. The specific design of the waste water treatment system's liner will be heavily influenced by the treatment system selected, but any system that has the potential to allow water to enter the closed pond through the cover system will likely require the installation of a leak detection layer or an equivalent robust liner system.

The cover system must be designed to accommodate the weight of the treatment system and to integrate with the foundations supporting the treatment system. Both the cover and the treatment system should be able to accommodate differential settlement which will occur as a result of installing the treatment system. Cover system penetrations must be sealed (e.g., using geomembrane boots) so as to prevent rainwater intrusion into the cover.

11.4.4 Other Considerations

Construction, operations, and long-term care related considerations with regard to the CCR pond performance are similar to those discussed in the previous sections.

11.5 Industrial Buildings and Storage and Staging Areas

The installation of buildings, storage and staging areas, or other structures (e.g., cell phone or transmission towers) on closed CCR ponds offers a number of benefits. First, the property is a brownfield development; there may be local or state financial benefits and local public relations benefits to redevelop a brownfield property. Further, the area should be a relatively flat expanse of land so there should be less contour grading than on more irregular terrain to reach foundation subgrade. Also, the property is located near the plant so transportation distances are reduced

over distant properties. These options allow for use of land that is typically difficult to redevelop and provides land owners with funding to offset the costs of cover system O&M.

11.5.1 Foundation Design

Buildings and other structures must be designed and constructed with consideration for the additional loading they will place on the cover and the interaction they will have with the liner system. The size and depth of foundations should be designed to ensure adequate load carrying capacity while minimizing settlement. Potential foundation designs to support structures on top of CCR pond covers are described in Table 11-5.

Table 11-5
Comparison of foundation types for use on CCR ponds

Foundation Type	Design Considerations
Ballasted Platforms	- Typically used for installation of solar systems - Lighter weight - Present low risk of settlement - Do not require penetration through the cover system
Concrete Slabs	- Heavier than other foundation types - Increase risk of settlement, which can damage foundations - Performs poorly in situations where significant differential settlement is expected - Best for lighter structures - Do not usually require penetration through the cover system
Poured and Pre-Fabricated Concrete Footings	- Most appropriate for heavy loads on cover - Will require sealing if they penetrate through the cover system, to prevent infiltration into ponded materials - May be subject to lateral loading at depth if ash liquefies
Deep Footings (steel, reinforced concrete, pre-tensioned concrete)	- Appropriate for heaviest loads - Used to transfer weight of overlying structure onto deeper subsurface layers capable of supporting heavier loads - Will penetrate cover materials and will require sealing around the covers - Groundwater flow around deep footings may cause channeling or scouring around footings; engineering solutions should be implemented - Sulfur/sulfate compounds in ash material may cause brittleness in steel footings and attack chemical bonds in concrete. Options to combat concrete degradation include - Using low water/cement ratio in concrete - Using Type V sulfate resistant cement - Use finely divided pozzolanic admixtures

Although footings should be designed so as to minimize settlement of final cover soils and underlying CCRs, support footings should be designed of sufficiently flexible material to allow for adjustment to slight changes that might occur due to settlement. Buildings or other structures may be affected where differential settlement is significant. Ideally, above-ground footings will be designed so that they are large enough to bear the weight of the building or other structure

without penetrating the final cover system geosynthetics. Any cover system penetrations must be sealed (e.g., using geomembrane boots) so as to prevent rainwater intrusion into the cover. An example foundation system detail for a communication tower on top of a CCR containment unit is shown in Figure 11-6.

If settlement cannot be controlled or if ponded materials do not offer sufficient bearing capacity for footings, it may be necessary to install footings into native soil or bedrock beneath the CCR pond. Note that installing deep foundations or footings can lead to a situation where the cover settles more than the structure, leaving the structure in an elevated position. The potential for settlement can be reduced using dynamic compaction, geogrid/geotextile reinforcement, or preloading, or by redeveloping with a phased approach in which buildings or other structures are built on the oldest areas of the CCR pond first, where rates of settlement would have decreased with time.

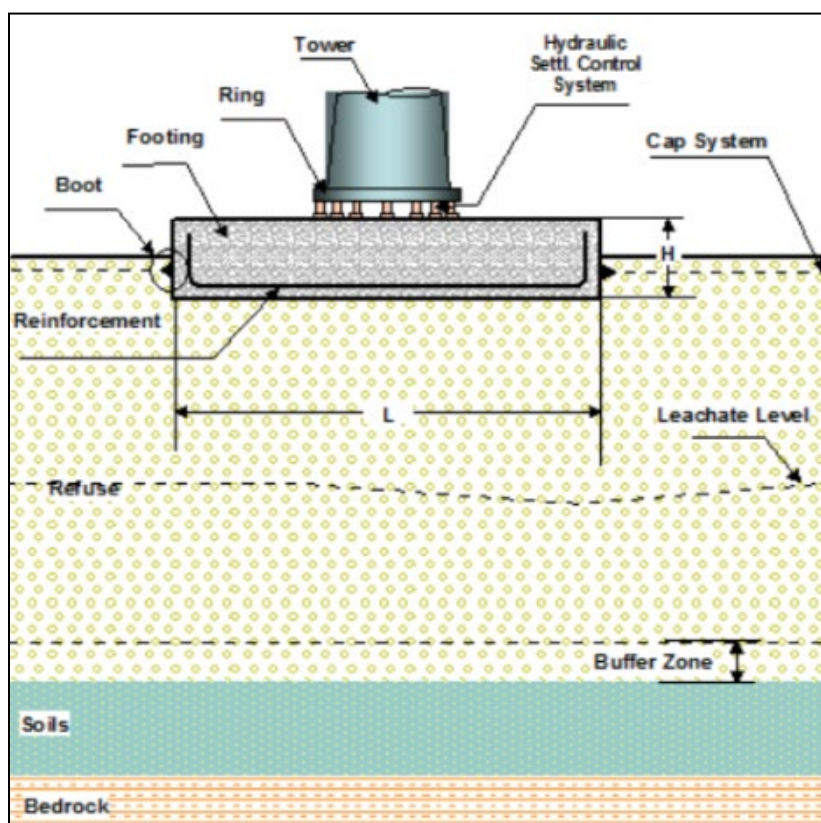


Figure 11-6
An example foundation system detail for a communication tower on top of a CCR containment unit

11.5.2 Other Considerations

Most of the other considerations related to stormwater, cover integrity, access, utilities, construction, operations, and long-term care are relevant for installation of buildings, storage and staging areas, or other structures (e.g., cell phone towers) on closed CCR ponds as well. These were discussed earlier in this section.

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A

EXAMPLE SITE CONDITIONS CHECKLIST – FEASIBILITY EVALUATION

Site Conditions Item	Information Source
Access and Topography ☐ Site and vicinity access ☐ Site and vicinity topography Pond Construction and Filling History ☐ Pond configuration including containment structures ☐ Pond base grades and range of thickness of the ponded materials ☐ Types, character, extents, and periods of filling for various ponded materials ☐ Processes used to place ponded materials ☐ Current and past pond water levels ☐ Identify if the containment structure was periodically raised to allow for additional disposal capacity and how this raising was designed and constructed Geotechnical Conditions ☐ Soil and rock boring logs, CPT data, piezocone soundings, and monitoring well and piezometer static water level data ☐ Geologic cross-sections ☐ Laboratory and field testing data for CCR materials ☐ Laboratory and field testing data for native soils and rock under CCR materials ☐ Design analyses and calculations for settlement, static and seismic stability and liquefaction, and seepage ☐ Construction specifications for containment structure soils ☐ Pond instrumentation monitoring data including surface elevation monitoring (survey) points, slope indicators, settlement plates, and piezometers Geohazards ☐ Karst features and other fissured or porous rock formations ☐ Fault lines or significantly fractured geologic structures and information on recent fault activity ☐ Seismic impact zones ☐ Abandoned and underground mines ☐ Landslide prone areas ☐ Shore erosion prone areas Hydrologic Conditions ☐ Flood plains and wetlands ☐ Perennial streams and navigable waterways ☐ Existing pond topography, including low points, slopes, drainage patterns, diversion, and culverting and channeling	

Example Site Conditions Checklist – Feasibility Evaluation

☐ Stormwater inflows other than precipitation ☐ Stormwater management structures such as dam spillways Hydrogeologic Conditions ☐ Critical groundwater resources such as drinking water source protection areas for public water systems, sole source aquifers, and high-yield unconsolidated aquifers ☐ Private or public drinking, irrigation, or livestock water supply wells ☐ Springs, sand and gravel pits, and limestone or sandstone quarries connected to groundwater resources ☐ Geologic cross-sections ☐ Site-specific hydrogeologic conditions ☐ Uppermost aquifer system and other significant zones of saturation ☐ Interconnection of zones of saturation ☐ Flow direction and rate, hydraulic conductivity ☐ Groundwater level elevation, including temporal (seasonal) fluctuations ☐ Existing separation between the base of the CCR pond and groundwater levels ☐ Regional and site-specific groundwater quality ☐ Regional and local groundwater recharge and drainage areas Other Relevant Conditions ☐ Designated natural and wildlife areas, residential development, utility corridors, transportation routes, and historic districts ☐ Borrow sources for landfill construction materials (e.g., liner, drainage, and cover materials)	
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B

EXAMPLE OPTIONS COMPARISON MATRIX – FEASIBILITY EVALUATION

Example Options Comparison Matrix – Feasibility Evaluation

Evaluation Criteria	Primary Components	Weighting Factor	Option 1			Option 2			Option 3		
			Summary	Rating	Weighted Rating	Summary	Rating	Weighted Rating	Summary	Rating	Weighted Rating
Location and Access	-----		-----			-----			-----		
Geotechnical Conditions	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Geohazards	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Hydrologic Conditions	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Hydrogeologic Conditions	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Other Relevant Site Conditions	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Constructability	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Economics	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
Sustainability	-----		-----			-----			-----		
	-----		-----			-----					
	-----		-----			-----					
TOTAL WEIGHTED RATING											

Rating: 10 (most favorable) to 1 (least favorable)

Weighting Factor: 3 (most important) to 1 (least important)

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