Chapter 5

COAL REFUSE DISPOSAL FACILITY DESIGN COMPONENTS

Coal refuse disposal facility design involves the evaluation of a number of interrelated components for development of an embankment that can accommodate refuse generation rates, storm water and environmental control requirements and provide a stable structure consistent with the operational demands of the mine and post-mining, land-use intentions. The detail and extent of analysis required for evaluation of each of these components depends upon the type of refuse facility being considered. The process of designing a disposal facility normally starts with determination of the refuse disposal volume requirements and, for slurry impoundments, includes consideration of the refuse generation rates and the design storm runoff volume that may need to be temporarily retained. Foundation conditions and possible required treatment, either resulting from existing soil conditions or past mining practices (underground or surface), may influence the locations of disposal facility structures and the overall configuration of the site, resulting in a need for special structures and instrumentation. The following components are normally evaluated as part of the design of a refuse disposal facility:

- Disposal capacity requirements, facility configuration/staging and scheduling
- Design storm management and erosion and sediment control
- Facility configuration, geometry and stability
- Foundation and mine subsidence considerations
- Stability of all embankment, channel and other site slopes affected by construction
- Internal drainage for embankment/foundation seepage control
- Decant and emergency spillway requirements
- Surface drainage controls
- Instrumentation and monitoring requirements
- Reclamation, abandonment and post-mining land use

5.1 DISPOSAL CAPACITY REQUIREMENTS AND SCHEDULING

5.1.1 Refuse Generation Rates and Design Capacity/Life

Refuse generation rates are the basis for determining disposal facility construction scheduling and the life of a disposal site. The refuse generation rate can be estimated based upon process flow and coal preparation studies for the new mine development and sampling, testing and volume data from existing disposal sites. Process flow data typically provide refuse generation rates for coarse refuse

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and fine refuse separately on a dry-weight basis, along with estimates of the moisture content (either as percent moisture or percent solids for slurry). To estimate the disposal capacity and life of a facility, a conversion of the process data on a weight basis to in-place disposal data on a volume basis is required. Where sampling and testing data are not available, estimates of the in-place refuse properties must be developed, typically by using data from similar processing plants, coal strata, and refuse disposal sites. The in-place refuse properties required for initial estimation of the life and scheduling of a facility normally include unit weight/density and moisture content of both coarse and fine refuse. Ultimately, engineering properties of the refuse will also be required for designing the facility. These properties should be verified during the initial phases of the operation of the facility and at periodic intervals during the facility life. Available test data should be scrutinized to verify that they are representative, and the reliability and potential for variability of the refuse material should be evaluated. Provisions for verification of material properties and a schedule for doing so should be indicated in the design plans.

The design capacity and construction scheduling for a disposal site is also dependent on the planned configuration of the facility, as well as the type of handling of the fine refuse (slurry, filter cake, or mixed with coarse refuse). Based on an assumed site configuration, the capacity and life can then be estimated based upon the computed volume and refuse generation rates.

While the type of handling and processing used for the fine refuse is typically an operational decision, physical characteristics of fine refuse when disposed may impose certain limitations at the disposal site. For instance, past undermining may preclude the option of a slurry impoundment or may entail extensive foundation treatment that makes that option infeasible. Therefore, knowledge of the planned type of handling proposed for the fine refuse prior to selecting a site configuration for the refuse facility is important.

5.1.2 Slurry Impoundment Staging and Scheduling

The staging and scheduling of the construction of a slurry impoundment must be carefully analyzed so that the embankment elevation is sufficient to provide storage to contain the slurried fine refuse generated as well as the runoff from a design storm. Additional embankment height to account for material consolidation or permanent seismic deformations may also be needed. In general, additional embankment height and width can be added to provide design conservatism and enhance safety. Although the overall capacity of a slurry impoundment disposal site configuration can be estimated from the refuse generation rates, the rate of incremental construction of embankments or dikes must be sufficient to accommodate the generation and deposition of fine refuse slurry (referred to as staging). Additionally, storm runoff entering the impoundment will need to be stored temporarily, increasing capacity requirements. Short-term design storm criteria are applicable during initial site construction with transition to long-term criteria during subsequent development. Other factors that may enter into the staging of a slurry impoundment include the following:

- Initial construction of the beginning embankment or dike for impounding slurry (termed “starter dam,” “starter embankment” or “starter dike”) typically requires borrow material. The size of this embankment is optimized based upon the available borrow material, topography of the disposal site (which affects the initial slurry capacity), and the ability to schedule subsequent embankment or dike construction using solely coarse refuse to impound slurry at the expected refuse generation rates. Therefore, the reliability and consistency of refuse generation rates is important to the construction of embankment stages and operation of the impoundment.
- Availability and capacity of existing disposal facilities at the mine that could be used for temporary disposal during site development activities and while the starter embankment is being constructed.

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- Amendments to the refuse or co-disposal of combustion waste with refuse, particularly when such additional material is a significant fraction of the refuse.
- The type of construction staging (upstream, downstream and centerline) will affect the capacity and schedule for the facility. Upstream construction utilizes less coarse refuse to achieve a comparable impoundment capacity because the stages are constructed partially on the settled fine refuse in the impoundment. Downstream, and to a lesser extent, centerline construction staging require greater quantities of coarse refuse to achieve equivalent impoundment capacity in comparison to upstream staging. At some sites a combination of upstream and downstream staging is employed to meet site configuration or specific refuse disposal requirements and to control excess pore pressures by initiating loading and consolidation of the fines early in the project life.
- In areas subject to seismic loadings, where deformation of the embankment may occur, additional freeboard between the impoundment surface and embankment crest may be necessary.
- Other special considerations such as impoundment breakthrough potential into underground mines, mine subsidence, reclamation, and post-mining land use can also influence the staging and configuration of the disposal facility.

When determining the type of construction staging (downstream, upstream, centerline, or a combination thereof), the ratio of coarse refuse to fine refuse generated by the preparation plant is a major factor. When the coarse refuse to fine refuse ratio is relatively high, downstream and centerline staging is normally preferred. As the coarse to fine ratio decreases, upstream staging is normally employed so that sufficient embankment height and containment is provided. As indicated above, both upstream and downstream staging may be employed at a site. Figure 5.1 illustrates a construction sequence with upstream and downstream staging through Stage II. In this example, an early stage of upstream construction (Stage II-A) is incorporated in order to initiate consolidation of fine refuse, while disposal simultaneously occurs in a downstream stage (Stage II-B). The figure also shows several of the key components in facility design.

The amount of refuse generated and the coarse to fine ratio must be confirmed from actual production measurements and must be rechecked periodically during operation. These parameters should be periodically evaluated so that the staging of the refuse facility can be modified, if needed. In general, downstream construction results in more predictable embankment performance and may require substantially less testing and engineering to address seismic loading, but this type of staging is more sensitive to changes in the coarse to fine ratio.

5.1.3 Slurry Cell Staging

If slurry cells are designed and operated as small ponds with size and hazard potential classification that do not require impoundment plans under 30 CFR § 77.216, or are arranged such that a low-hazard-potential impoundment classification results, their staging and construction may be more complex than construction of an impounding refuse facility. A slurry cell facility typically has surface diversion to prevent runoff from collecting in the cells. Thus, the design storm plays a significantly smaller role in slurry cell staging than would be the case with a significant- or high-hazard-potential slurry impoundment. Additionally, when the slurry cells are covered sequentially with layers of coarse refuse, the fine refuse may be densified, but this effect typically does not greatly affect the capacity of a slurry cell facility.

Figure 5.2 illustrates the components of a slurry cell facility. The small size of individual slurry cells necessitates operation of multiple cells, and in some instances, continuous cell construction, putting greater operational demands on the disposal facility. Thus, staging can be critical with a slurry

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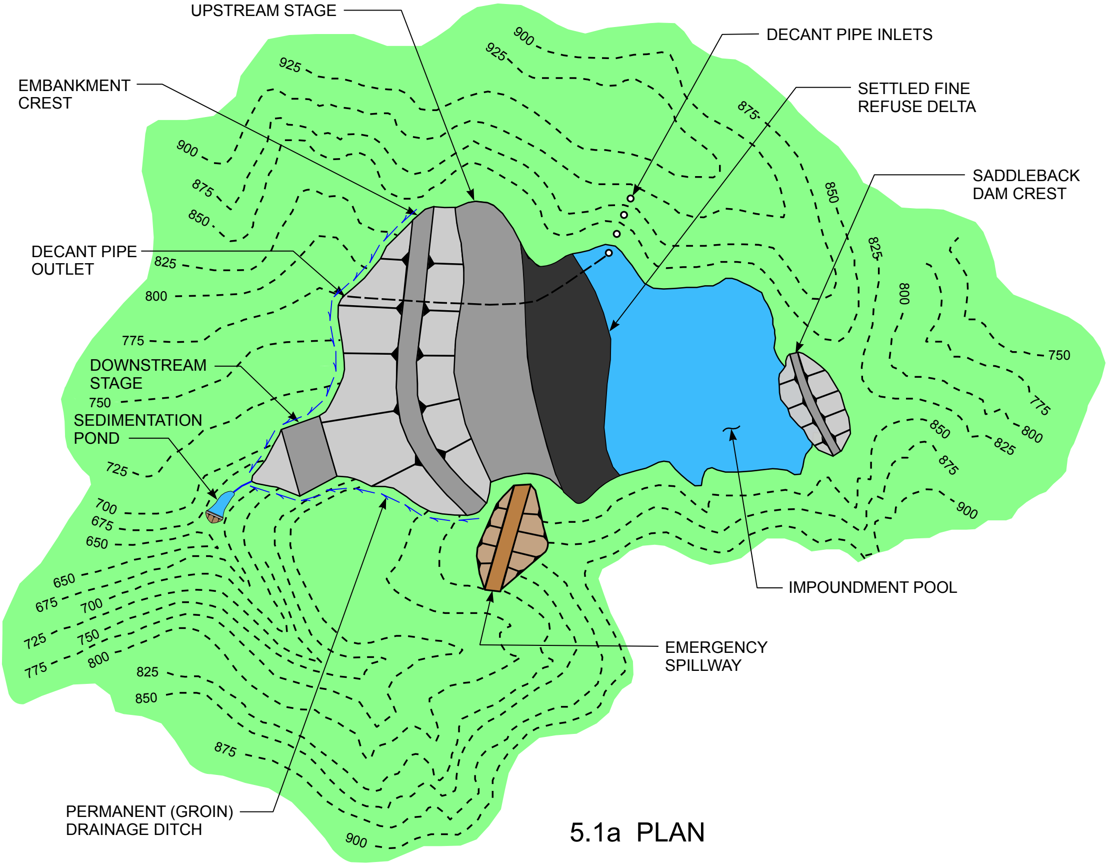
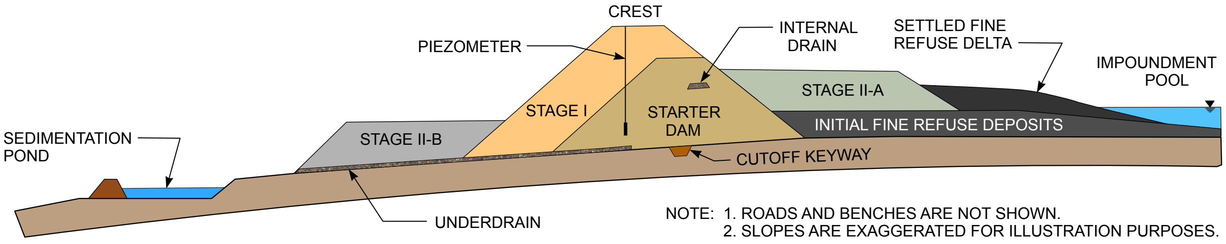
cell facility because the need to divert runoff around the cells and to periodically cover the cells can require as much or more coarse refuse than with slurry impoundment staging. Thus, the consistency of the refuse generation rate is critical to successful operation of slurry cells. Slurry cells are an attractive option only when there are limitations to developing an impoundment at a disposal site, or when the ratio of coarse refuse to fine refuse is quite large. Slurry cells are sometimes used as a contingency alternative when underground injection is employed.

When slurry cells are operated only to dewater fine refuse slurry, operation and staging difficulties are significantly reduced. For this type of operation, slurry is placed in cells for dewatering and subsequent removal and mixing with coarse refuse prior to final disposal. Typically, these slurry cells are utilized for refuse processing plants with lower production rates that are operated over a longer period of time, thus reducing the burden of continually constructing storm water diversion structures for new cells.

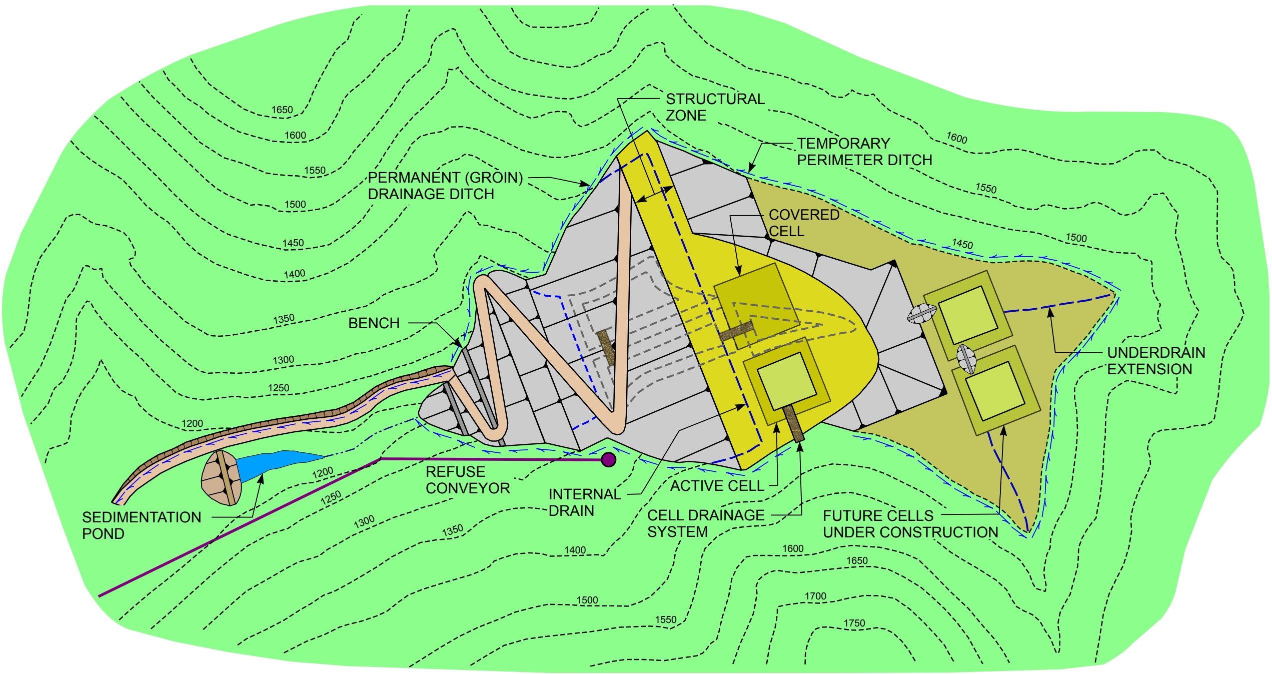


5.1a PLAN



5.1b LONGITUDINAL CROSS SECTION

FIGURE 5.1 TYPICAL SLURRY IMPOUNDMENT COMPONENTS



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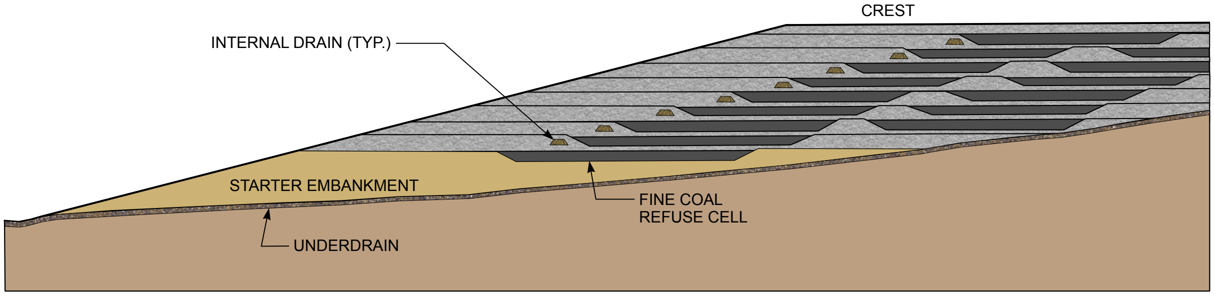

NOTE: ROADS AND BENCHES NOT SHOWN
ON CROSS SECTION.

5.2b LONGITUDINAL CROSS SECTION UPON COMPLETION

FIGURE 5.2 TYPICAL SLURRY CELL FACILITY (IMPOUNDING EMBANKMENT)

5.1.4 Non-impounding Refuse Embankment Staging

Staging for non-impounding embankments involves surface runoff diversion, drainage provisions for significant springs or groundwater flow, erosion and sedimentation control, construction sequencing (upstream or downstream construction), and reclamation. When dewatered fine refuse is disposed within upstream zones of a non-impounding embankment, staging is a function of: (1) the required quantity of coarse refuse and the rate of construction of the well-compacted downstream shell (sometimes referred to as the structural zone), (2) haul road requirements, and (3) surface runoff diversion requirements. The construction sequence and reclamation planning will also affect the staging.

Figure 5.3 illustrates the components of a coarse refuse disposal facility. Surface runoff diversion and erosion and sedimentation controls influence staging. Because the working surface and some por-

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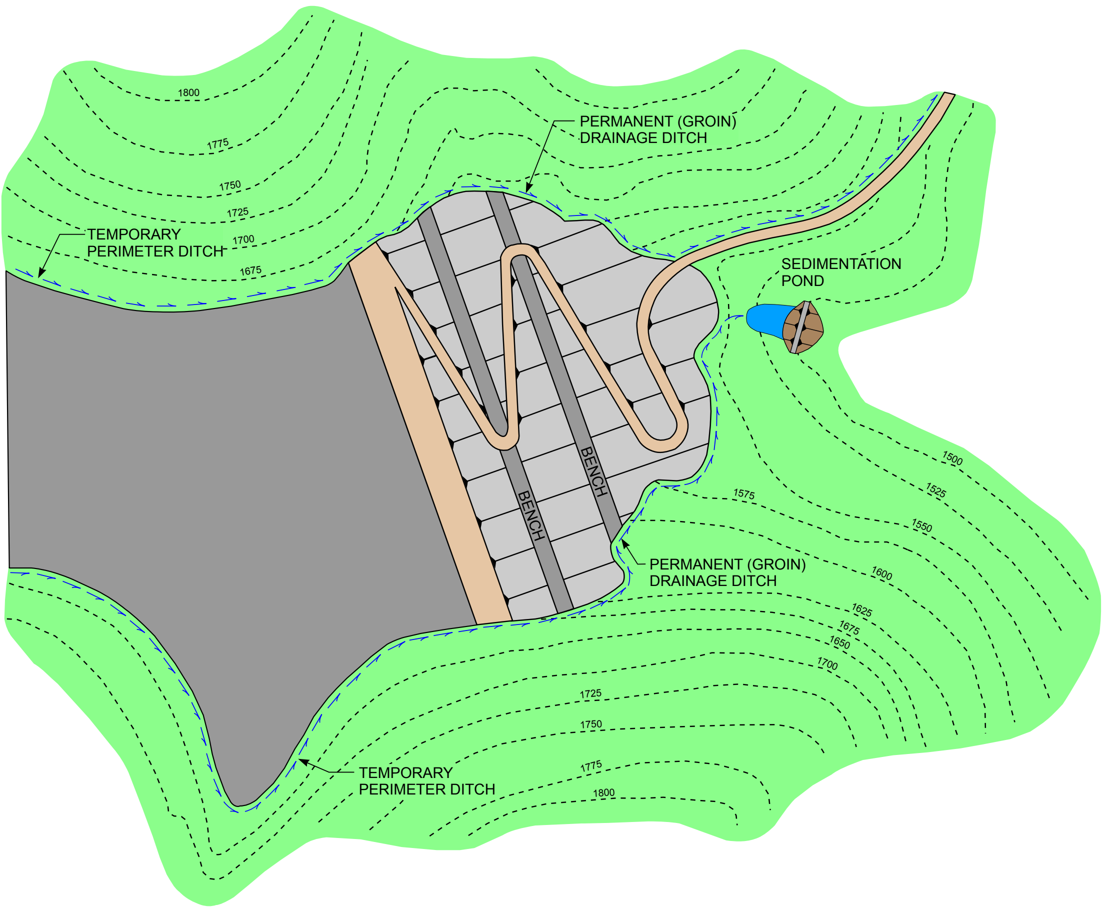
tions of the embankment slopes will be exposed refuse, surface runoff from the embankment must be controlled separately from runoff from non-disturbed areas and must be directed to erosion and sedimentation control structures. This requires that flows from the contributing natural watershed be diverted around the disposal facility, which may require ditches or channels constructed upstream from the embankment or integrated into the embankment perimeter.



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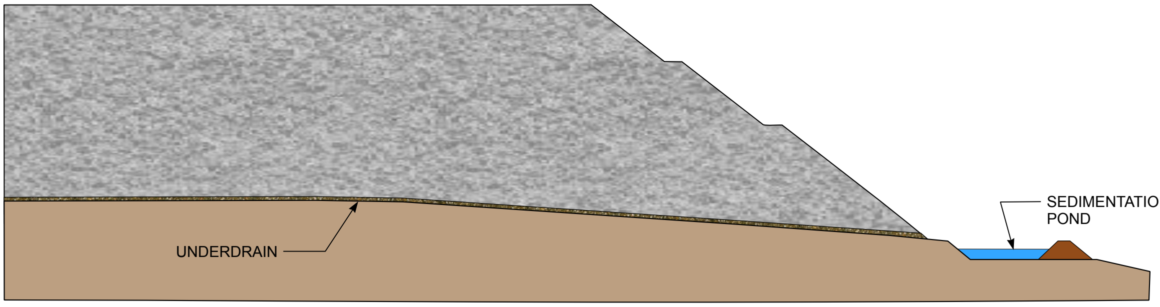

NOTE: 1. ACCESS ROAD NOT SHOWN IN CROSS-SECTION VIEW.
2. SLOPES ARE EXAGGERATED FOR ILLUSTRATION PURPOSES.

5.3b LONGITUDINAL CROSS SECTION

FIGURE 5.3 TYPICAL REFUSE EMBANKMENT COMPONENTS

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5.1.5 Amendments and Co-disposal of Combustion Waste

The use of amendments applied to coal refuse and co-disposal of combustion waste and coal refuse will influence staging dependent upon the quantity of the materials disposed. Other aspects of embankment design may be affected because the engineering properties of the amended/combined materials may be different from those of the coal refuse.

5.1.5.1 Amendments for Neutralization and Stabilization of Refuse

Amendments applied to coal refuse have included a variety of materials typically used to neutralize the potential acidity of coal refuse or to absorb moisture for stabilization of the refuse during placement and compaction. Amendments have included lime and lime products, kiln dust, and combustion waste.

The inclusion of amendments for neutralization or stabilization of refuse may also have the following influences on design of the disposal facility:

- Neutralizing agents if applied in quantity can affect the strengths of the fill (either increase or decrease), and may alter handling and placement equipment requirements and embankment slopes. The thoroughness of mixing the amendments with the refuse is important to their application as neutralizing or stabilizing agents and affects the properties of the combined material.
- Runoff from neutralizing agents can have a high pH and thus may need to be retained within treatment ponds prior to discharge into a receiving water body.
- The hydraulic conductivity of the amended embankment materials may be lower than the refuse materials, necessitating additional internal drainage measures and resulting in precipitates that clog filters and internal drainage structures unless they are appropriately designed.
- Final reclamation of completed surfaces of amended embankment materials may be facilitated, allowing a thinner soil and topsoil cap.

To assess the behavior of mixed refuse and amendments, physical properties, including strength and hydraulic conductivity should be evaluated.

5.1.5.2 Co-disposal of Combustion Waste

Several types of combustion waste have been co-disposed with coal refuse at disposal sites, including: fly ash and bottom ash, fluidized bed combustion (FBC) ash, and flue gas desulfurization (FGD) sludge (dewatered). Depending on the characteristics of the waste, it has typically been disposed with coal refuse as: (1) part of contracting opportunities, (2) for structural or filter zones, (3) for stabilization of refuse due to wet conditions, (4) for neutralization of potential acidity of refuse, and (5) for reclamation improvements.

Co-disposal of combustion waste may have the following effects on the design of a disposal facility:

- The extent of mixing of combustion waste with coal refuse will affect the homogeneity of the embankment, particularly with respect to strength and hydraulic conductivity because of the influence of the combustion waste on these characteristics. The presence of mixed and unmixed layers may result in stratified conditions within the embankment.
- Combustion waste if incorporated within a refuse embankment in quantity may result in different (higher or lower) strength characteristics of the fill, requiring different handling and placement equipment and modified embankment slopes. FBC ash, if pozzolanic, will exhibit high strength at low strain similar to soil cement.

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- The hydraulic conductivity of the embankment materials mixed with combustion waste may be different (typically lower, but possibly higher) than the refuse materials alone. This may result in precipitates that clog filters and internal drainage structures necessitating additional internal drainage measures. Combustion waste may also increase the anisotropy of embankment materials.
- FBC may have expansive characteristics that can affect instrumentation performance and monitoring, influencing the position and elevation of survey monuments and the verticality and integrity of casings for piezometers and inclinometers.
- Use of combustion waste may increase dust control requirements at the embankment surface.
- Runoff from combustion waste can have high pH and thus may need to be retained within treatment ponds prior to discharge to the receiving water body.
- Final reclamation of completed surfaces of embankment materials with co-disposed combustion waste may be facilitated, allowing a thinner soil and topsoil cap.
- Combustion waste may contain metals that can result in leachate and groundwater impacts.

Research on the beneficial use and co-disposal of combustion waste with coarse coal refuse is reported in Daniels et al. (2002). Research on co-disposal of combustion waste with fine coal refuse is presented in Kumar et al. (2001).

5.2 EROSION AND SEDIMENTATION CONTROL AND DESIGN STORM RUNOFF MANAGEMENT

Erosion and sedimentation control features are required for all disposal facilities, and their design must be integrated into the overall drainage control plan. Management of runoff from design storms is a function of the type of refuse disposal facility and associated design storm. Impounding facilities are typically designed to retain a portion of design storm flows within the impoundment, thus attenuating the peak flow. Non-impounding embankments utilize diversion channels and ditches that are designed to handle the peak discharge. Embankments for both impounding and non-impounding facilities typically have associated drainage channels and ditches that are designed to handle storm flows. For larger refuse facilities, erosion and sedimentation controls can represent a significant component in the overall design of the facility and can occupy a relatively large portion of the site that should be accounted for during the initial phases of design.

5.2.1 Erosion and Sedimentation Control

Erosion and sedimentation control requirements are generally based on state regulatory criteria. Their function is to divert runoff from undisturbed areas of a site and to collect and treat runoff from disturbed areas. Diversion systems are normally required for all refuse embankments; however, impoundments can serve to provide sediment control for their contributing watershed. The design of the erosion and sedimentation control system is based upon the disturbed area at the disposal facility during operation and as reclamation is performed.

Sediment control is typically provided by ponds that receive drainage from the embankment and disturbed areas, and these are typically located near the downstream toe of the disposal facility. As discussed in Chapter 9, the ponds are designed with decant systems and inlet structures that provide adequate capacity and settling time for removal of sediment and control of storm events without activating the emergency spillway. The design of the emergency spillway is based on the pond's hazard-potential classification and applicable state criteria.

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5.2.2 Slurry Impoundment Inflow Design Storm

Selection of the appropriate design storm (short- and long-term) is a function of the hazard potential of the planned slurry impoundment. Based on the design storm and site conditions, the runoff rate and volume can be determined. The facility can then be configured to manage the design storm through a combination of storage and routing. The runoff volume is important because frequently the size and configuration of the outlet system (decant pipe or spillway) for impoundments are determined by the volume of water that must be evacuated from the impoundment within a certain specified time period after the storm event (Chapter 9). Similarly, the staging of the facility must be adequate to retain the runoff from the design storm with adequate freeboard.

High-hazard-potential facilities must be able to handle the most severe design storm, while a lesser magnitude storm will be suitable for a significant- or low-hazard-potential classification facility. The determination of the hazard-potential classification is discussed in Section 3.1. Dam breach analyses may be performed as part of hazard-potential determination, as discussed in Chapter 9.

Short- and long-term embankment design criteria must be evaluated in the determination of the design storm, typically to address conditions during the first two years of construction and operation, as the impoundment is being developed, and during the last two years of the facility's life, when it is being reclaimed. Short- and long-term design criteria are discussed in Chapter 9, as part of the hydrologic and hydraulic engineering analyses, and are primarily a function of the hazard potential and the size of the planned impoundment. For example, during the initial year of construction and operation of a large, high-hazard-potential impoundment, the capacity to handle the 100-year storm may be needed; during the second year the ½ Probable Maximum Flood (½ PMF) event; and within two years the full PMF event. Short-term criteria are intended for unavoidable construction conditions during initial start-up and abandonment and should only be utilized when absolutely necessary.

Impoundments are typically designed to: (1) store the runoff from the design storm with slow release of the runoff through a decant pipe system, (2) release the design storm runoff without storage through an open-channel spillway, or (3) store a portion of the design storm runoff and release the balance through an open-channel spillway. Figure 5.4 illustrates the concepts of 100-percent storage of the design storm runoff and the use of an open-channel spillway to route the design storm runoff. An impoundment that is designed to store the design storm runoff with release through a decant (Figure 5.4a) requires greater surcharge storage capacity than an impoundment that employs an open-channel spillway (Figure 5.4b). The determination of the magnitude of the design storm, including the short- and long-term criteria upon which the design storm is based and associated runoff rates and volumes, is discussed in Chapter 9.

Drainage channels at other locations at impoundment facilities, such as the downstream embankment face, are typically designed for the 100-year storm, and these structures do not affect the overall configuration, geometry and staging of embankment construction. However, if impoundment decant systems discharge to embankment drainage channels, the discharge should be added to the surface flow collected by the drainage channels. If the drainage channels intercept a substantial amount of runoff, the design storm criteria for the impoundment may need to be applied to the channel design in order to protect the embankment from erosion during a severe flood.

5.2.3 Slurry Cell Facilities

Slurry cell systems are attractive in situations where they can be kept under the size and hazard thresholds of 30 CFR § 77.216, or where they can be classified as having low hazard potential, so that design storm management can be based on the 100-year event and not the PMF. A low-hazard-potential determination requires information to substantiate that, in the event of a failure, the facility will not release water, sediment, or flowable fine refuse that would cause loss of life or significant property damage, as discussed in Chapter 3. Thus, the sequence of active and open

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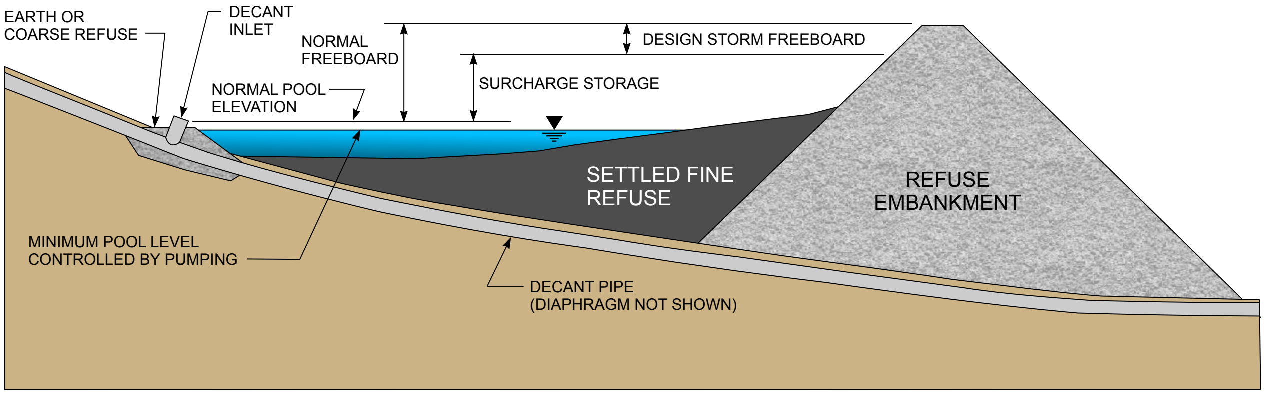
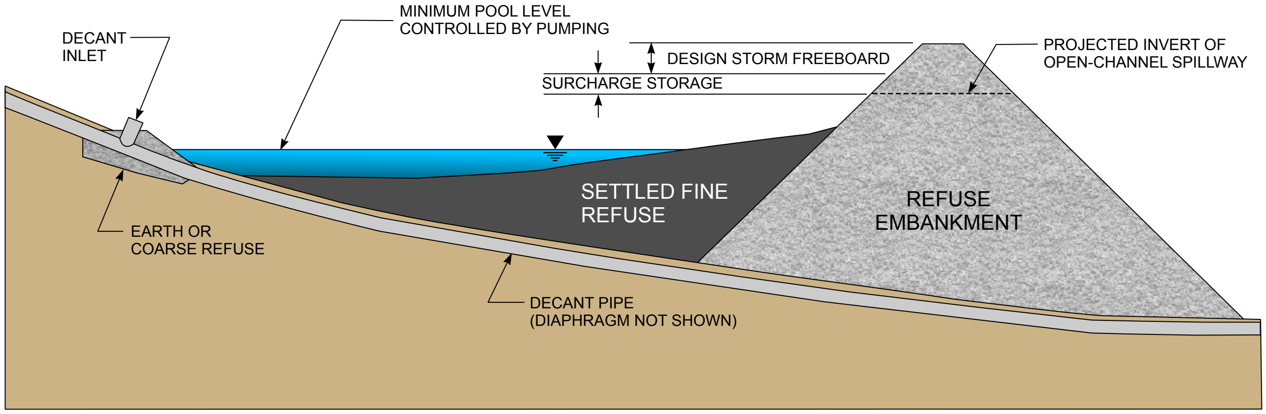
cell operation must be designed to minimize impounding capacity. Also, the closed and covered slurry cells must be oriented and dewatered such that they do not collectively represent a potential release of flowable material that would severely impact downstream development.

By achieving a low-hazard-potential classification or avoiding classification as a regulated impoundment, slurry cell systems can be designed for lesser design storm criteria (i.e., 100-year storm). Because the watershed area contributing to the slurry cells is minimal, only a small quantity of runoff has to be managed as part of the slurry disposal operation. While this reduces the influence of the design storm runoff on the overall configuration and staging of the slurry cell system, runoff from adjacent areas, particularly upstream watershed areas, must be diverted, which requires construction and maintenance of diversion channels that are incorporated into the embankment or disposal site configuration.



5.4a IMPOUNDMENT DESIGNED FOR 100-PERCENT STORAGE OF DESIGN STORM



NOTE: SLOPES ARE EXAGGERATED FOR ILLUSTRATION PURPOSES.

5.4b IMPOUNDMENT DESIGNED WITH OPEN-CHANNEL SPILLWAY

FIGURE 5.4 ILLUSTRATION OF IMPOUNDMENT DESIGN STORM CONTROL

Drainage structures for slurry cells must have the capacity to control runoff from the design storm collecting within the cell, along with clarified water produced as the slurry is deposited. This drainage may be achieved by using a decant pipe with an appropriately sized inlet or riser to facilitate settling of the fine refuse. An open-channel spillway may also be needed depending on the slurry cell arrangement and contributing drainage area.

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As with other site drainage not related to impoundments, the channels and ditches on the downstream face of a slurry cell embankment must be designed for the 100-year storm and do not affect the overall configuration or staging. If a slurry cell facility is designed as a significant- or high-hazard-potential impoundment, the associated design storm criteria may need to be used also for the design of embankment drainage channels that receive decant discharge.

5.2.4 Refuse Embankment Design Storm

The design storm for non-impounding refuse embankments is primarily used for sizing channels and ditches that divert or collect and convey drainage from the embankment, as part of the erosion and sedimentation control for the site. Diversion ditches are typically constructed around the perimeter of refuse embankments so that channel runoff from undisturbed portions of the site is conducted around the disturbed areas to sedimentation ponds. If a diversion ditch must be relocated to a higher elevation as an embankment is expanded, a plan of ditch relocation that provides for drainage diversion from disturbed areas during the associated construction must be prepared.

Permanent channels and diversion ditches should be designed for the peak discharge from the 100-year storm. Temporary channels may be designed for a lesser magnitude event, as discussed in Chapter 9. Long-term drainage control required during reclamation and abandonment should be incorporated into the drainage channel design.

5.3 FACILITY CONFIGURATION AND GEOMETRY

The configuration and geometry of a refuse disposal facility is a function of staging/construction methods, capacity requirements, engineering properties of the refuse, initial site topography, storm water management, regulatory criteria and overall facility stability requirements. Operational factors, such as refuse transport and handling equipment also influence the design and overall configuration of the facility.

5.3.1 Regulatory Criteria

Criteria have been established by federal (Office of Surface Mining) and state agencies that address some parameters for design of coal refuse disposal facilities. These parameters include embankment slope, which should not be steeper than 2:1 (horizontal to vertical) between benches. Benches are used to control erosion, retain soil moisture, or facilitate reclamation and are typically integrated into embankment slopes.

For slurry impoundments that are classified as dams by state agencies, regulatory criteria for the width of the crest and maximum slopes should be reviewed. Other regulatory criteria may affect the design configuration and geometry, as a result of required right-of-ways, buffer zones, and related off-sets from natural features, structures, utility lines and property lines. State and federal criteria may change with time.

Federal and state regulatory agencies require engineering analyses for demonstrating that certain design criteria are satisfied, such as the ability of the facility to safely route the design storm or to provide a specified factor of safety relative to stability. State criteria are sometimes different from federal criteria. Both should be considered, and the most stringent criteria should be applied.

5.3.2 Embankment Design Considerations

The following subsections provide a discussion of issues related to embankment design.

5.3.2.1 Stability under Normal Operating Conditions

Stability analyses are performed to determine the embankment configuration and slope. The parameters associated with these analyses include the following:

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- <u>Embankment material strengths</u> – These strengths are dependent upon the types of refuse, borrow materials, and amended/co-disposed materials used in embankment construction, as well as the method of placement and compaction. Sufficient exploration and testing must be performed such that all applicable material properties can be accurately characterized.
- <u>Foundation material strengths (as determined by exploration and testing)</u> – These may be improved if necessary by removal and replacement or by ground improvement measures. Sufficient exploration and testing must be performed such that in-situ material properties can be adequately characterized.
- <u>Seepage and phreatic level</u> – These are a function of normal pool level, internal drainage systems and liner systems.

Non-impounding coal refuse disposal facilities are normally developed over several years, and, as with impounding facilities, the configuration may vary considerably during various stages of the facility's life due to upstream and downstream development. Stability analyses should be conducted at various points or critical stages in the embankment development. A detailed evaluation of the facility staging and construction should be performed to identify critical configurations that require stability analysis. Chapter 6 presents guidance related to stability analyses and other geotechnical engineering issues.

5.3.2.2 Stability under Extreme Events

Embankment stability under design storm and earthquake loading conditions (assumed to not occur simultaneously) must be evaluated. For design storm conditions, the embankment stability and configuration may be affected by the following:

- Flood level (peak pool level resulting from the design storm event) at an impoundment, which may affect the embankment phreatic surface and seepage conditions, depending on the depth and duration of the elevated reservoir level and the effectiveness of internal drainage measures.
- The location and elevation of decant and spillway structures.

Seismic analyses are performed on impounding embankments and sensitive embankments such as slurry cell facilities. Guidance for these analyses is presented in Chapter 7 and includes evaluation of strength loss or degradation of embankment or foundation materials as a result of seismic loading and evaluation of seismic deformations that may affect embankment performance. Design features that may be considered for mitigating the adverse effects of earthquake loading and associated embankment response include providing extra freeboard, enhancing internal drainage and related consolidation of the fine refuse, widening the embankment, and adding a buttress.

5.3.2.3 Settlement and Subsidence

Settlement of foundation soils or refuse materials, particularly if upstream construction is employed for an impounding embankment, may require placement of additional material to maintain crest elevations and grades of drainage structures. Large differential settlements may represent a risk of cracking of strain-sensitive materials (e.g., clay zones) or barriers, thus requiring measures to limit differential settlement. Chapter 6 provides guidance for settlement and other geotechnical analyses.

Subsidence associated with underground mines may affect the design configuration of the embankment and is discussed further in Section 5.4.

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5.3.2.4 Environmental Issues, Impoundment Elimination and Site Reclamation

Amendments to refuse or the presence of a liner system beneath an embankment or zoned embankment (for an impoundment facility) can affect the stability of the embankment, requiring modifications to configuration or slope. Reclamation, post-mining land use, and abandonment practices can also affect the embankment configuration and slope.

5.3.3 Impoundment Design Considerations

The impoundment configuration can also be affected by a range of design considerations, as described in the following paragraphs.

5.3.3.1 Settling and Clarification

Facilities such as polishing ponds, baffles, clear water cells, and similar structures may be required in order to produce water quality that is acceptable for discharge or preparation plant use. Clarification may also be accomplished in ponds downstream of the impoundment facility.

5.3.3.2 Seepage Control and Containment

To mitigate environmental impacts, seepage control and liner systems may be necessary for containment of the fine coal refuse.

5.3.3.3 Spillway and Decant Systems

Decant systems often serve as primary spillways and, if the watershed and impoundment sizes are compatible, may be sufficient to manage the design storm without an open-channel spillway. This will require that significant freeboard be maintained under normal operating conditions. In some instances, including during the final years of operation of a facility, open-channel spillways sized to handle the design storm are constructed, thus allowing more of the impoundment to be used for refuse disposal.

5.3.3.4 Subsidence and Breakthrough Potential

Subsidence analyses may identify potential impacts to an impoundment area, requiring changes in layout or other design features that affect the site configuration. Where mine workings are in proximity to an impoundment, evaluation of breakthrough potential may indicate that measures such as constructed barriers (embankment fills) are needed to buffer the zone of impact and maintain internal stability. These and other measures are addressed in Chapter 8.

5.4 FOUNDATION AND MINE SUBSIDENCE CONSIDERATIONS

5.4.1 Foundation Materials

Foundation materials must be evaluated relative to their strength, compressibility and hydraulic conductivity. Foundation materials without adequate strength, or with high compressibility, may not provide adequate support for the disposal facility, leading to detrimental movement or actual failure. Hydraulic conductivity is an issue primarily with impounding embankments, where high-hydraulic-conductivity foundation materials can lead to elevated pore pressures affecting local stability and creating the potential for internal erosion or piping of fine soil particles that can threaten the overall stability of the disposal facility. High-hydraulic-conductivity foundation materials can also lead to unacceptable loss of clarification water or, in extreme situations, release of impounded materials.

Strength and compressibility are typically concerns for foundation soils, while hydraulic conductivity may be a concern for both soil and bedrock conditions. Bedrock strength conditions can be an issue where weak layers, such as claystones, underlie an embankment and behave similarly to a soil (primarily where shallow or surface outcrop conditions occur). Weak or fractured bed-

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rock conditions may also become an issue where underground mine workings are in proximity to an embankment or impoundment such that subsidence could cause differential movement and impose strain on structural components or drainage features of the disposal facility. An additional concern, as discussed in Section 5.4.3, can be actual breakthrough of the disposal facility into mine workings.

A variety of measures to address foundation material concerns are available. These may include accommodations in the disposal embankment and impoundment design or in-situ foundation treatments ranging from removal and replacement of shallow, weak soils to grouting of fractured bedrock conditions. Seepage control within foundation materials typically is accomplished by constructing cutoff trenches through high-hydraulic-conductivity natural soils and weathered bedrock and backfilling with low-hydraulic-conductivity soils. Cutoff trenches may disclose geologic features such as alluvial deposits, sand dikes, and relief fractures that require treatment and that would not be revealed by exploration borings.

5.4.2 Abutment and Foundation Geometry

The geometry of the abutments and foundation (steep slopes and bedrock exposures) of an impounding embankment can lead to differential settlements resulting in cracking of embankment materials, disruption of drainage control features, and seepage concerns. This situation may be exacerbated at former surface mine sites where embankment construction is planned in areas of former highwalls. For non-impounding embankments, such concerns may also need to be addressed in the design of drainage control systems.

Measures to address steep foundation geometry may include benching and cutting back of slopes, zoning with select structural materials, and planned compensation fills in the embankment design to offset cumulative settlements. These issues are addressed in Chapter 8.

5.4.3 Mine Subsidence Potential

The presence of underground mines or the potential for future underground mining in the vicinity of a coal refuse disposal facility may influence the location and design of facility features. Additionally, auger or highwall mining can lead to subsidence and seepage concerns. Location of an impoundment facility in the vicinity of mine workings is of concern because of the potential impacts of subsidence on embankment stability and the related potential for release of impounded materials, as well as the risk of a breakthrough into the mine, which is discussed in Section 5.4.4. Non-impounding facility design may also be influenced by potential mine subsidence, particularly related to impacts on structural elements and drainage and liner systems.

Depending on the depth to mine workings and proximity to the disposal facility, subsidence analyses may be needed for determination of the potential magnitude, tilt, curvature, and strain associated with ground movement related to subsidence. These analyses provide a basis for evaluation of the subsidence impact on the disposal facility and can help to identify potential mitigation measures. The engineering methodology for performing these analyses is presented in Chapter 8, and the potential impact of differential movement on coal refuse materials and structures is discussed in Chapters 6 and 8.

Similar analyses should be performed for proposed mining in the vicinity of disposal facilities. Only under very favorable conditions and where development is essential for haulage or ventilation should mining be performed under impounding embankments. The extent of mining that may be conducted under an impoundment is dependent upon the overburden and mining conditions. It is current practice that subsidence analyses are performed for longwall mines in order to establish a “safety zone” where extraction is precluded for protection of an impounding embankment.

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Subsidence impacts associated with drainage control systems (liners, internal drains, and surface drainage systems) may be addressed through evaluation of potential differential movement and strain during design. When mine workings are present beneath or in the vicinity of an impoundment, the following design measures may be employed to mitigate potential subsidence effects on embankments:

- Maintenance of ample freeboard to compensate for the anticipated subsidence.
- Broad embankment configuration design that is less sensitive to subsidence impact or enhanced zoning of embankments with self-healing characteristics (e.g., cohesionless sand) to mitigate potential cracking and internal erosion.
- Allowance for potential subsidence effects in the design of internal drainage structures or implementation of enhanced seepage control measures (barriers and chimney drains) to minimize the effects of potential subsidence.
- Backfilling or grouting of mine entries in critical support areas to minimize the amount of movement that can occur.
- Installation of monitoring systems for detecting subsidence and associated impacts such as increased seepage and preparation of contingency plans for mitigating such impacts.

To address the potential for subsidence and seepage in areas of auger or highwall mining, backfilling and/or protection berms or embankments may be employed, as discussed in Chapter 8.

5.4.4 Impoundment Breakthrough Potential into Mine Workings

In addition to subsidence concerns, if the overburden separating an impoundment from existing mine workings is relatively thin, there is a potential for sinkholes or even catastrophic breakthrough of the impoundment into the mine workings. In general, areas where the cover over a mine entry comprises less than 100 feet of intact rock strata are a concern for sinkhole development. Even greater amounts of cover are cause for concern in some situations. In addition to possible sinkhole development, shearing or punching of a coal outcrop is another potential failure mechanism that must be prevented. Without proper design, failure can occur through the coal seam itself, through strata above the coal, or along material interfaces or discontinuities. Internal erosion along these interfaces and discontinuities must also be prevented.

The presence of auger or highwall mining workings adjacent to an impoundment can also be cause for concern. The potential for subsidence should be evaluated in design, and measures to control seepage and to address the potential for breakthrough into neighboring underground mine workings should be developed, as needed. Figure 5.5 illustrates the presence of mine workings immediately adjacent to and beneath an impoundment and the use of a berm or barrier and internal drainage system to mitigate potential seepage and breakthrough potential.

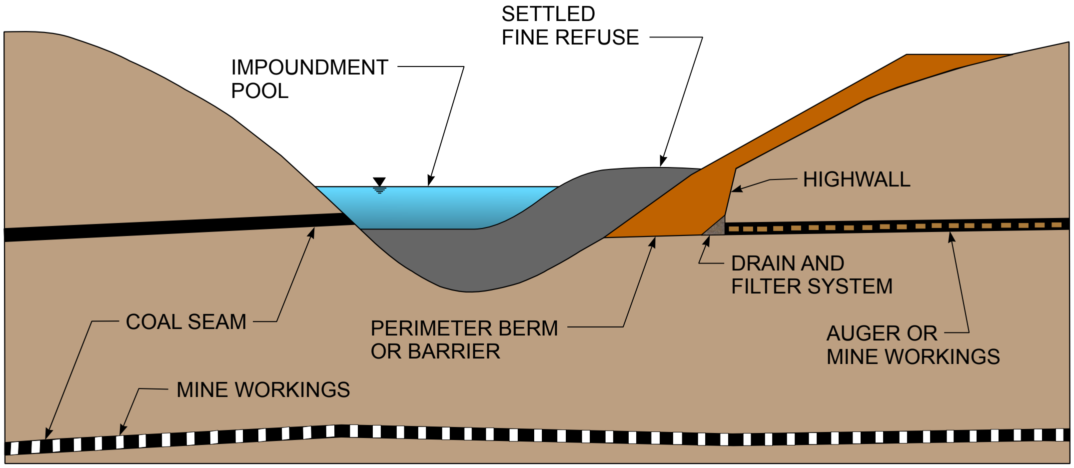
Chapter 8 presents guidance for analyzing breakthrough potential and preventing breakthroughs. Some basic design measures that may be useful for mitigation of the potential for breakthroughs include:

- Development of a safety zone (based on verifiable data related to mining and outcrop or overburden conditions) that provides sufficient undisturbed ground between the mine and the impoundment so that the ground movement induced by mining will not affect the impoundment.
- Development of measures to provide adequate support for the impoundment considering potential failure mechanisms such as some combination of: (1) an engi-

neered barrier (soil or synthetic barrier) or berm (coarse refuse) to mitigate the failure mechanisms, (2) an internal drainage system to control seepage and to reduce pressures in the areas of potential breakthrough, or (3) stabilization of the fine coal refuse to increase strength and reduce flowability. Any mitigation measure employed must also be resistant to subsidence.

- Development of containment or diversion structures, such as bulkheads, within the affected mine workings.
- Stabilization of the mine workings that may affect the impoundment by mine filling and/or grouting to improve strength and resistance to failure mechanisms.

As an alternative to the berm illustrated in Figure 5.5, slurry cell configurations have been employed at some impoundment sites with breakthrough potential, or the operation has been converted to fine coal refuse paste in order to restrict the potential release of flowable material.



NOTE: SLOPES ARE EXAGGERATED FOR ILLUSTRATION PURPOSES.

FIGURE 5.5 UNDERGROUND MINING AT SLURRY IMPOUNDMENT

5.4.5 Mine Entry Barriers and Bulkheads

Where mining is occurring in the vicinity of a coal refuse disposal facility, barriers and bulkheads may need to be constructed for the purpose of controlling drainage and mitigating the potential for internal erosion and piping in the embankment. Mine entries may include mine openings, ventilation boreholes, auger holes, or highwall mining areas. The design requirements for barriers and bulkheads are dependent on the type of disposal facility, location of the entry, and presence of drainage entering into or discharging from the mine. For support of non-impounding embankments, only a barrier may be required, particularly if drainage conditions are not an issue. Entries beneath impounding embankments or beneath impounded water will probably require installation of a bulkhead and/or barrier along with additional measures for addressing drainage at the entry location or within the mine. As an additional line of defense, bulkheads should be considered at critical discharge locations. Chapter 8 provides guidance for the design of barriers and bulkheads.

5.5 INTERNAL DRAINAGE AND EMBANKMENT SEEPAGE CONTROL

Internal drainage and seepage control features are designed to accomplish: (1) collection of springs and hillside subsurface drainage and conveyance to a point downstream of the refuse embankment (and sedimentation ponds), (2) environmental containment using liner systems to control seepage to subsurface groundwater beneath the site, (3) collection of seepage and conveyance downstream to treatment or sedimentation ponds, (4) control of the phreatic surface or foundation pore pressures to maintain embankment stability, and (5) prevention of seepage along penetrations (decants, etc.) through the embankment. Reclamation may also involve construction of a low-hydraulic-conductivity cap to limit infiltration and reduce internal drainage requirements.

Technical guidance for internal drainage and embankment seepage control is provided in Chapter 6 and covers the following:

- Seepage analyses for embankments (homogeneous and zoned), including analysis of the effects of foundation cutoffs, liners, and internal drains.
- Filter criteria for zoned embankments.
- Design of internal drains, including filters.

The environmental aspects of reclamation, internal drainage and seepage control are addressed in Chapter 10.

5.6 DECANT AND EMERGENCY SPILLWAY SYSTEMS

Hydraulic structures for controlling impoundment levels and providing storm routing are designed based on design storm runoff management, as discussed in Section 5.2, with specific features influenced by the type of embankment staging employed (upstream versus downstream) and configuration (height and length of the disposal facility), site terrain, and foundation issues.

5.6.1 Decant Performance Considerations

Decant systems provide for discharge of clarified water from an impoundment. While a decant system may be a component of the design-storm water management system, in many cases the impoundment level may actually be controlled by pumping when the water surface level is below the decant invert. In cases where a decant system is part of the design storm management system, it is typically designed to provide sufficient capacity to evacuate at least 90 percent of the design storm runoff retained within the impoundment within 10 days, assuming that no design-storm runoff storage is available below the lowest ungated decant inlet. The 10-day period is measured from the time of peak impoundment pool during the design storm.

The design of decant systems involves the following considerations:

- Hydraulic capacity evaluation (head versus discharge analysis).
- Material selection, as affected by the length and depth of cover, foundation conditions, installation method, and other factors such as strength, flexibility, durability, corrosion protection, and joint type.
- Inlet design features, including riser pipe structural stability and support, trash guards, anti-vortex devices, and sealing requirements upon discontinuation of use.
- Alignment and grade, including variation in grade due to terrain, potential foundation settlement, the need for reaction blocks, resistance to flotation, and venting systems.
- Outfall design, energy dissipation requirements, and erosion protection.
- Pipe backfill, drainage diaphragms and seepage control.
- Monitoring/testing requirements.

If decant systems are designed to discharge to a groin ditch adjacent to the downstream embankment slope, additional design considerations may apply. In such instances, the peak decant discharge should be added to the surface flow collected by the groin ditch. If the ditch intercepts a substantial

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amount of runoff, the design storm criteria for the impoundment may need to be applied to the ditch design in order to protect the embankment from erosion during a severe flood.

5.6.2 Open-Channel Spillway Performance Considerations

Many impoundments are designed such that the reservoir storage capacity and decant system discharge capacity provide for design storm runoff management, but sometimes a separate open-channel spillway is also required. These should be designed with a capacity that will allow routing of the design storm flow through the impoundment while maintaining adequate freeboard. Open-channel spillways are less commonly employed at refuse disposal embankments because of staged development. The following should be considered in the design of open-channel spillways:

- Hydraulic capacity (head versus discharge capacity) and minimum freeboard for the approach channel, control section, and discharge channel or conduit so that sufficient capacity is available for releases up to the design peak outflow. Measures to control floating debris or hillside trees that could cause obstructions may be required at the approach channel.
- Channel geometry, including considerations for transition sections (e.g., contraction section), changes in alignment (e.g., super-elevation at bends), and grade (e.g., sufficient capacity for hydraulic jumps).
- Stable channel conditions, considering excavation slopes as well as potential for erosion due to water flow associated with velocity/tractive force/duration on the channel lining. Channel linings require suitable foundation and drainage systems and should be designed for tractive and uplift forces.
- Energy dissipation structures at the spillway outlet.

If large-diameter conduits are used in conjunction with open channels or in place of an open channel, material selection, inlet design, alignment and grade, backfill, seepage control, and outlet design issues are similar to those for decant systems.

5.7 SURFACE DRAINAGE CONTROLS

Surface drainage controls at coal refuse disposal embankments typically consist of drainage ditches and channels, bench and haul road gutters, and culverts that collect and convey runoff to downstream structures.

5.7.1 Permanent Drainage Controls

Permanent drainage controls are structures that will be in service during operation of the disposal facility and following reclamation and abandonment of the facility. These structures should be designed for the 100-year-recurrence-interval storm. Typically, the 100-year, 24-hour-duration storm is used for design, consistent with state regulatory criteria.

The design of permanent drainage controls should be based upon the following considerations:

- Hydraulic capacity considering the peak discharge rate from the design storm for the contributing drainage area.
- Channel geometry, including accommodation for transition sections and changes in alignment (e.g., super-elevation at bends) and grade (e.g., additional capacity for hydraulic jumps in subcritical flow sections).
- Stable channel conditions, considering flow velocity/tractive force/uplift/duration for the channel lining, if the channel is not excavated in competent rock.
- Energy dissipation structures at channel outfalls.

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5.7.2 Temporary Drainage Controls

Temporary drainage channels function periodically during operation, but are not part of the long-term surface water controls related to reclamation and abandonment. These may include temporary ditches for diversion or runoff collection within the disposal facility, bench and haul road gutters (before topsoil placement and reclamation), and most culverts. Temporary ditches and culverts may be designed with a hydraulic capacity lower than for permanent drainage controls, because of shorter service life and other criteria. For instance, state regulations or recommendations for some drainage structures may specify a 10- or 25-year-recurrence-interval storm. Temporary ditches may be designed without linings provided that: (1) their service life is relatively short and potential erosion damage can be readily repaired and (2) lack of linings will not cause adverse impacts to the safety of the disposal facility or compromise downstream sedimentation controls.

5.8 INSTRUMENTATION AND PERFORMANCE MONITORING

Instrumentation is typically a component of coal refuse disposal plans and is recommended for all high or significant-hazard-potential sites. Instrumentation records should be reviewed as they are accumulated. The data are best evaluated by maintaining a continuous plot of the readings versus time. The data should be reviewed as part of annual inspections and certifications and should be maintained for the life of the facility. The data review provides a basis for: (1) assessment of facility performance relative to design intentions, (2) detection of trends and problems that may develop, and (3) operational plan modification or facility expansion. Design plans should indicate maximum acceptable levels for instrument readings or percentage changes that trigger further investigation or actions. Facility performance will typically be enhanced by monitoring the parameters discussed in the following paragraphs with appropriate instrumentation:

5.8.1 Seepage

Seepage from the impoundment should be monitored for flow rate and changes in appearance (discoloration or appearance of fine particulates and precipitates). This monitoring should include seepage through the embankment, through internal drainage structures, and through underground mines that receive seepage from the impoundment. Weirs should be installed, preferably with a staff gauge in the weir approach pool, so that flow rates can be easily and accurately measured. To evaluate changes in seepage rates, it is important to know the impoundment pool level and to have data pertaining to rainfall and groundwater levels, so that possible correlations can be evaluated.

5.8.2 Piezometric Levels

Saturation levels and water pressures within an impounding embankment or embankment foundation, as well as within any earthen barriers, should be monitored and recorded to determine whether hydrostatic pressures are within design limits and whether changes or trends are reasonable. Selection of the type of piezometer and installation location is based on site-specific requirements and the potential for rapid or sudden changes in pore water pressure (as may occur upstream of construction areas). Open standpipe piezometers provide direct measurement of groundwater levels, while vibrating-wire and pneumatic piezometers allow for monitoring of phreatic conditions in fine-grained deposits where rapid changes in pore pressure may be important. A table indicating maximum allowable readings for piezometers should be included with the design report.

5.8.3 Pool Levels

Records for the pool level in the impoundment should be maintained for freeboard monitoring and for determining correlations between piezometric levels and seepage quantities. Pool level can be monitored by installation and reading of staff gauges. When water in nearby mine workings has the potential to affect an impoundment or may indicate the performance of a barrier, the mine pool level should be monitored.

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5.8.4 Rainfall Data

A rain gauge installed near the disposal site can provide site-specific precipitation data for correlations with piezometric levels and seepage quantities, and these data may be essential in situations where there is breakthrough potential and where discharges from a mine are related to seepage from an impoundment. Rainfall data should be routinely collected and recorded so that changes in seepage, mine discharge, or water level data can be correlated to rainfall infiltration/runoff.

5.8.5 Deformation or Movement

Where significant embankment settlement can occur or there is a potential for subsidence in the vicinity of an impoundment, movements should be monitored and recorded. Monitoring of the slopes and crest of an impounding embankment should be conducted at regular intervals during both operating and dormant phases for evaluating performance and for demonstrating conformance with flood routing assumptions. When subsidence is a concern, both horizontal and vertical movements should be measured. Movements should also be monitored if evidence of slope displacement is detected. In situations where deformation is occurring, the rate of movement, and especially any acceleration of the rate, provides valuable information for assessing its significance. Methods for monitoring surface deformation include survey monuments and extensometers. Movements below the ground surface can be monitored with inclinometers and extensometers. These types of instruments are discussed in more detail in Chapter 13.

5.9 RECLAMATION, ABANDONMENT AND POST-MINING LAND USE

A coal refuse disposal plan should address reclamation, abandonment and post-mining land use requirements.

General provisions for and plans related to abandonment of a coal refuse embankment are part of the final operational stage of the disposal facility and should address elimination of the impoundment, unless the impoundment is a component of planned post-mining land use. Reclamation should incorporate the following provisions:

- Stockpiles of soil and topsoil for reclamation should be located near the facility on stable ground and within sedimentation controls.
- Reclamation materials should meet the growth medium and nutrient requirements of the vegetation plan. Topsoil amendments and alternatives may be necessary.
- To protect against erosion and sedimentation and potentially negative environmental impacts, surface drainage and infiltration should be controlled.

Elimination of impoundments should address the following:

- Regrading of the impounding embankment and backfilling of the impoundment should be performed in a manner such that proper surface drainage is established and the fine coal refuse is stabilized. Final backfill elevations should facilitate drainage and accommodate settlement of the fine refuse that will occur over time.
- During the final periods of disposal and progressive elimination of the impoundment capacity, the outlet works such as the decant structure or spillway should remain operational until impoundment regrading is complete.
- Decant systems should generally be sealed by grouting.

Post-mining land use will affect the reclamation plan, particularly if existing structures such as the impoundment or ponds are to be retained.

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