Chapter 3

COAL REFUSE DISPOSAL FACILITIES AND OTHER IMPOUNDING STRUCTURES

This chapter presents an overview of the types of coal refuse disposal facilities and other impounding structures that are employed at mine sites and provides a discussion of terminology applied to these embankments and impoundments. Refuse disposal facilities are generally classified in the following terms: (1) refuse piles (non-impounding facilities), (2) impounding facilities, (3) slurry cell facilities, and (4) underground injection facilities. Non-impounding refuse piles typically consist of an embankment fill where drainage is directed away from the site without retention. These facilities are employed for disposal of coarse coal refuse and dewatered fine coal refuse.

Impounding facilities have the capacity to retain water, sediment and/or fine coal refuse slurry. Under MSHA regulations, a facility or structure requires an approved impoundment plan when it exceeds a threshold height or has the potential for impounding a threshold volume of water and/or fine coal refuse slurry and/or represents a potential hazard to miners. In practice, MSHA also considers any potential hazard to the public downstream. While not always true, slurry disposal facilities typically exceed impoundment threshold parameters, resulting in their being subject to MSHA impoundment plan regulations. Slurry disposal may also occur in slurry cell facilities that do not exceed the impoundment threshold height or volume. In addition to disposal in embankments, impoundments and cells, fine coal refuse slurry may also be disposed in underground mine workings at underground injection sites.

3.1 HAZARD POTENTIAL FOR DISPOSAL FACILITIES AND OTHER IMPOUNDING STRUCTURES

Coal refuse disposal facilities and other mining impoundments are evaluated relative to their hazard-potential classification, which dictates the design criteria that must be incorporated in their planning, development, and construction. While hazard-potential classification primarily relates to impoundments, it can also be applied to non-impounding facilities where dewatered fine coal refuse may exhibit flowable characteristics after disposal. Consistent with the hazard-potential-classification system and criteria for dams in use by federal agencies (FEMA, 2004a), the three hazard-potential classifications for disposal facilities are as follows:

- Low hazard potential – Facilities where failure would result in no probable loss of human life and low economic and/or environmental losses. Such facilities are usually located in rural or agricultural areas where losses are limited principally to the owner's property or where failure would cause only slight damage to farm buildings, forest and agricultural land, and minor roads.

- Significant hazard potential – Facilities where failure would likely not result in loss of human life, but can cause economic loss, environmental damage, or disruption of lifeline facilities. Such facilities are generally located in predominantly rural areas, but could be in populated areas with significant infrastructure and where failure could damage isolated homes, main highways, and minor railroads or disrupt the use of service of public utilities.
- High hazard potential – Facilities where failure will probably cause loss of human life. Such facilities are generally located in populated areas or where dwellings are found in the flood plain and failure can reasonably be expected to cause loss of life; serious damage to homes, industrial and commercial buildings; and damage to important utilities, highways or railroads.

The purpose of hazard-potential classification is not to determine the likelihood of a failure occurring, but rather to assess the potential impacts should a failure occur and to establish appropriate criteria for use in the design and operation of the facility. Thus, more conservative design and operations criteria apply as the potential for loss of life or property damage from failure increases. For example, more subsurface exploration and material property testing is normally performed for a facility with high hazard potential than for one with low hazard potential. An impoundment dam with high hazard potential would be designed to accommodate the probable maximum flood (PMF), while a dam with low hazard potential would be designed for a smaller storm event. While this chapter introduces hazard-potential classification, specific design criteria that are associated with the hazard-potential classification are discussed in later chapters. The application of the hazard-potential classification to storm water management is discussed in Chapter 5; stability considerations are discussed in Chapters 6 and 7; and hydrology and hydraulic engineering issues are addressed in Chapter 9.

Determination of possible damage due to failure of an impounding refuse disposal facility must be based upon an evaluation of conditions for an appropriate downstream distance. This distance is normally determined by performing a breach analysis that defines an inundation area resulting from a breach of the impounding embankment. This analysis is particularly important in mountainous mining areas where complementary industrial, commercial, and residential developments are usually located in valley bottom. Conditions downstream from the disposal facility may also be important even if the facility embankment is incapable of impounding water. An example is failure of an embankment that blocks a stream, temporarily forming a dam that impounds water that suddenly fails, releasing a flood wave of water and coal refuse.

Many mine impoundments currently under MSHA jurisdiction have underground mine works either beneath or near the dam or reservoir. This creates a situation where a failure of the impoundment may release flowable fine coal refuse and water into the underground mine workings. A release of flowable fine coal refuse and water can also occur due to failure of natural ground or man-made barriers, resulting in breakthrough into the mine workings. In the event of breakthrough, not only will mine personnel potentially be endangered, but the water or slurry may subsequently discharge from the mine and potentially affect an area different from that affected by a dam failure. MSHA addresses this possibility as follows:

- The official hazard-potential classification for an impoundment facility is based on the three classifications discussed previously and is assigned regardless of whether the potential hazard is from a failure of the dam or from a breakthrough into the mine workings and subsequent discharge.
- For the purpose of selecting appropriate design criteria for a coal refuse dam, the hazard classification is based on the appropriate rating for the type of failure con-

sidered. For example, an impoundment could have a high-hazard-potential rating based solely on the potential for breakthrough into the underground mine workings, with low consequences associated with a failure of the dam itself. In such a case, the dam embankment can be designed based on the low-hazard-potential classification (e.g., the 100-year design storm), while the breakthrough evaluation and prevention measures, with respect to the extent of exploration, testing, monitoring, etc., would need to be appropriate for a high-hazard-potential facility.

3.2 COAL REFUSE IMPOUNDMENT FACILITIES

Coal refuse dams are typically designed using coarse refuse and soil or rock fill materials for construction with placement of fine coal refuse slurry in the associated impoundment. The development frequently initiates with a starter dam constructed of earthen materials, coarse refuse or a combination of both for the period of initial slurry disposal. Coarse refuse generated by the coal preparation plant is then used to expand and raise the starter dam, thus providing additional disposal capacity for the fine coal refuse slurry. Typical features and construction practices associated with a slurry impoundment facility include:

- Temporary surface drainage diversion away from areas of embankment dam construction.
- Removal and stockpiling of topsoil and soils for future reclamation.
- Removal of unsuitable foundation materials that would adversely affect the construction of the embankment dam.
- Collection and conveyance of groundwater springs.
- Construction of impoundment and embankment liners, as required by state regulations.
- Construction of the dam and emergency spillway to design grades to provide ample freeboard for design storm runoff storage and discharge capacity.
- Construction of a foundation cutoff, underdrains and internal drainage structures within the embankment dam to control seepage and phreatic surface development.
- Construction of decant pipe structures for removal of accumulated water (surface runoff and/or clarified water) from the impoundment.
- Construction and maintenance of haul roads on the embankment or adjacent areas to transport refuse to the disposal area.
- Grading of the refuse embankment surface to maintain drainage toward collection and/or diversion ditches.
- Grading and sealing of the refuse embankment for drainage control and minimizing water retention on the embankment.
- Collection of surface drainage on the embankment and delivery to sediment control structures.
- Reclamation of completed surfaces such as the embankment downstream face and, at completion of slurry disposal operations, covering of the settled fine coal refuse by evacuating accumulated water, covering the fine coal refuse with coarse refuse or earthen materials, and placement of soil and topsoil, and vegetation.

A significant issue in the development of a slurry impoundment is the design and construction of the starter dam. The size, materials, and hydraulic appurtenances associated with the starter dam impact future operations of the disposal facility, require substantial engineering oversight during construction, and can represent a significant part of the development cost for the facility. The schedule for construction of a starter dam for a new mine is normally critical, as the coal preparation plant will not usually be able to operate at full capacity until there is a functioning slurry disposal area that meets initial short-term design storm criteria. The starter dam must also be designed so that it can be transitioned to meet long-term criteria. For existing preparation plants, the designer should coordinate the closure of an existing impoundment with the activation of a new impoundment to avoid lapses in available refuse disposal capacity and to facilitate reclamation of completed areas.

Coarse refuse embankment dams are usually large in cross section in order to accommodate the production of refuse from the preparation plant. They may be constructed either as a homogeneous or zoned embankment. If an embankment dam is constructed as a zoned embankment, it may be built with earthen materials of finer gradation in upstream areas of the cross section and with coarse refuse in downstream zones. While the term homogeneous is often applied to coarse refuse embankment dams, the coarse refuse may exhibit variability in grain size and specific gravity, but still have adequate shear strength to meet design assumptions and be sufficiently competent to support construction equipment.

3.2.1 Size and Hazard Considerations

3.2.1.1 Impoundment Definition

MSHA currently requires that plans be prepared and approved for the design, construction, operation and maintenance of structures that impound water, sediment or slurry if such structures:

- Impound water, sediment, or slurry to an elevation of 5 feet or more above the upstream toe of the structure and have a storage volume of 20 acre-feet or more; or
- Impound water, sediment, or slurry to an elevation of 20 feet or more above the upstream toe of the structure; or
- Are determined by the MSHA District Manager to present a hazard to coal miners.

For purposes of determining inclusion under MSHA regulation, the height of an embankment dam is measured from the upstream toe of the structure to the lowest point on the crest of the dam. Other regulatory agencies may define height differently. Figure 3.1 illustrates this measurement for a cross-valley impounding embankment. If the lowest point on the crest of the structure is the invert of a properly designed open-channel spillway capable of conveying the maximum water flow from the design storm with sufficient freeboard and erosion protection, then that point is the proper location for the upper measurement. Where decant pipes and pipe/box spillways are used, the elevation must still be measured to the lowest point on the crest of the structure or embankment, not to the invert of the decant riser or spillway pipe.

The storage volume of a dam is calculated using either the invert elevation of the spillway or the lowest point on the crest of the structure. However, the storage volume based on a measurement to the invert of the spillway may only be used if two conditions are satisfied. First, the spillway must be an open-channel configuration. Second, the open-channel spillway must be designed to convey the flow from the design storm with adequate freeboard and must have appropriate erosion protection. If either of these requirements is not met, the capacity of a dam must be determined based on a measurement made to the lowest point on the crest of the structure without reference to the spillway. The design of the open-channel spillway can be verified using a flood routing analysis of the design storm (selected based on the purpose of the structure and projected hazard potential classification) through the impoundment's open-channel spillway and other outlet works (if applicable).

Small ponds are sometimes used for disposal of fine refuse slurry and are referred to as slurry cells. These cells may be located within an embankment and sized and sequenced to preclude classification

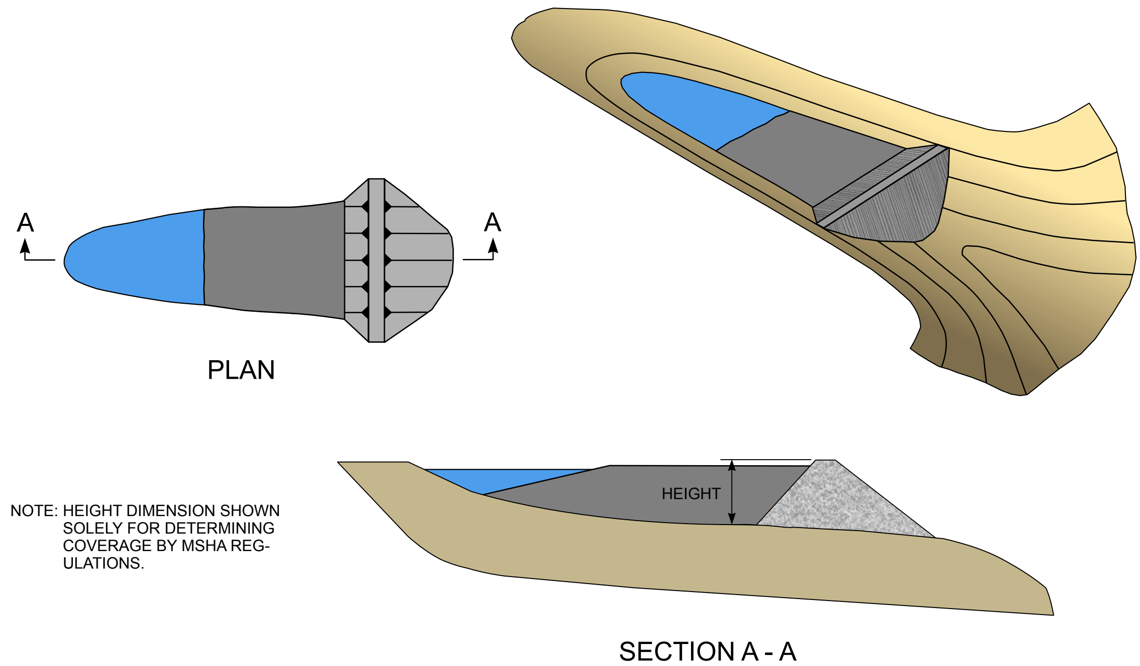

FIGURE 3.1 CROSS-VALLEY IMPOUNDING EMBANKMENT

of the embankment as an impoundment. However, there are also situations where the slurry cells are of sufficient size and are operated such that the facility may be classified as an impoundment. Section 3.4 addresses slurry cell facilities. If a pond or impoundment meets any of the preceding criteria, the facility is subject to regulation by MSHA as an impoundment. It is important to note that state regulatory agencies may define structures that are regulated as dams using different dimensions or definitions.

3.2.1.2 Impoundments in Series

In the case of multiple impounding structures in series that individually do not meet the size criteria cited in Section 3.2.1.1 and where a failure of one of these structures can result in the failure of another, the cumulative storage capacity should be used when applying the impoundment size criterion.

In the case of multiple slurry cells (addressed separately in Section 3.4) that individually do not meet the size criteria cited in Section 3.2.1.1 and where failure of one slurry cell can lead to the failure of others, or where a slope failure can result in the release of water, sediment or slurry from multiple cells, the cumulative capacity of the potentially affected cells should be used when applying the impoundment size criterion.

3.2.1.3 Incised Impoundments

An incised impoundment is one created by excavating below the natural ground surface, as illustrated in Figure 3.2. An impoundment may be totally below natural ground, or an embankment may be constructed so that only a portion of the impoundment is below natural ground. For purposes of determining the height or storage volume of an impoundment with respect to the criteria presented in Section 3.2.1.1, the portion contained below natural ground is not included in the height or storage volume calculation. However, even for an incised impoundment, if it is determined that the impoundment could become a hazard, appropriate design and construction requirements should be implemented. In situations where mining is planned or occurs near an incised impoundment, mine operators should be sure that there is a sufficient thickness of undisturbed ground left in place to preclude failure.

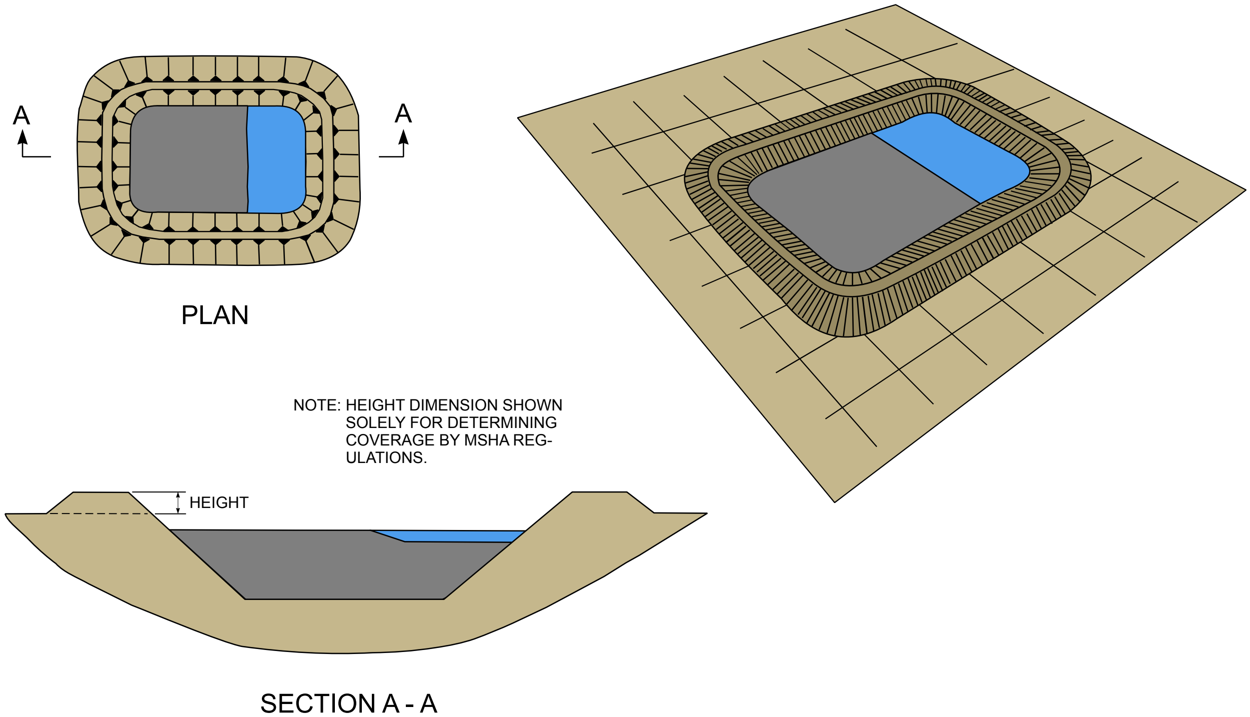

FIGURE 3.2 INCISED IMPOUNDING FACILITY

Cases may arise where a surface mining pit is used as an impoundment. If any portion of the ground creating the impoundment is mine spoil or fill, then that portion should not be considered to be incised (MSHA, 2007).

3.2.2 Disposal Facility Configuration

Impounding coal refuse disposal facilities are classified based on their configuration and development/construction staging. The disposal facility configuration is dependent upon the terrain and size requirements, and the development staging reflects the general sequence or direction of disposal activity. The facility configuration categories are: (1) cross-valley impounding embankment (Figure 3.1), (2) incised impoundment (Figure 3.2), (3) side-hill impounding embankment (Figure 3.3), and (4) diked impounding embankment (Figure 3.4).

Planning and design of an impounding embankment generally involves distinct development/construction stages that are associated with intermediate points in the facility construction and the general timing and directional development of the disposal operations. These stages typically reflect a few months to a few years of disposal operation and usually reflect the direction in which development occurs. The direction of construction normally falls into two categories: upstream and downstream. Upstream construction, as shown in Figure 3.5, involves initial construction and placement of coarse refuse in downstream areas to form the impoundment with sequential placement during subsequent stages in upstream locations, typically at higher elevations. Downstream construction, as shown in Figure 3.6, involves initial construction and placement of coarse refuse in upstream areas with placement during subsequent stages in downstream locations. It is common to have both upstream and downstream construction stages as part of a disposal facility design.

An intermediate development condition is centerline construction (which is essentially the same as alternating upstream and downstream construction), where refuse stages are constructed both upstream and downstream of the previous stage, with the crest of the two stages generally in alignment, but separated by the elevation increment of the stage (Figure 3.7). This terminology for

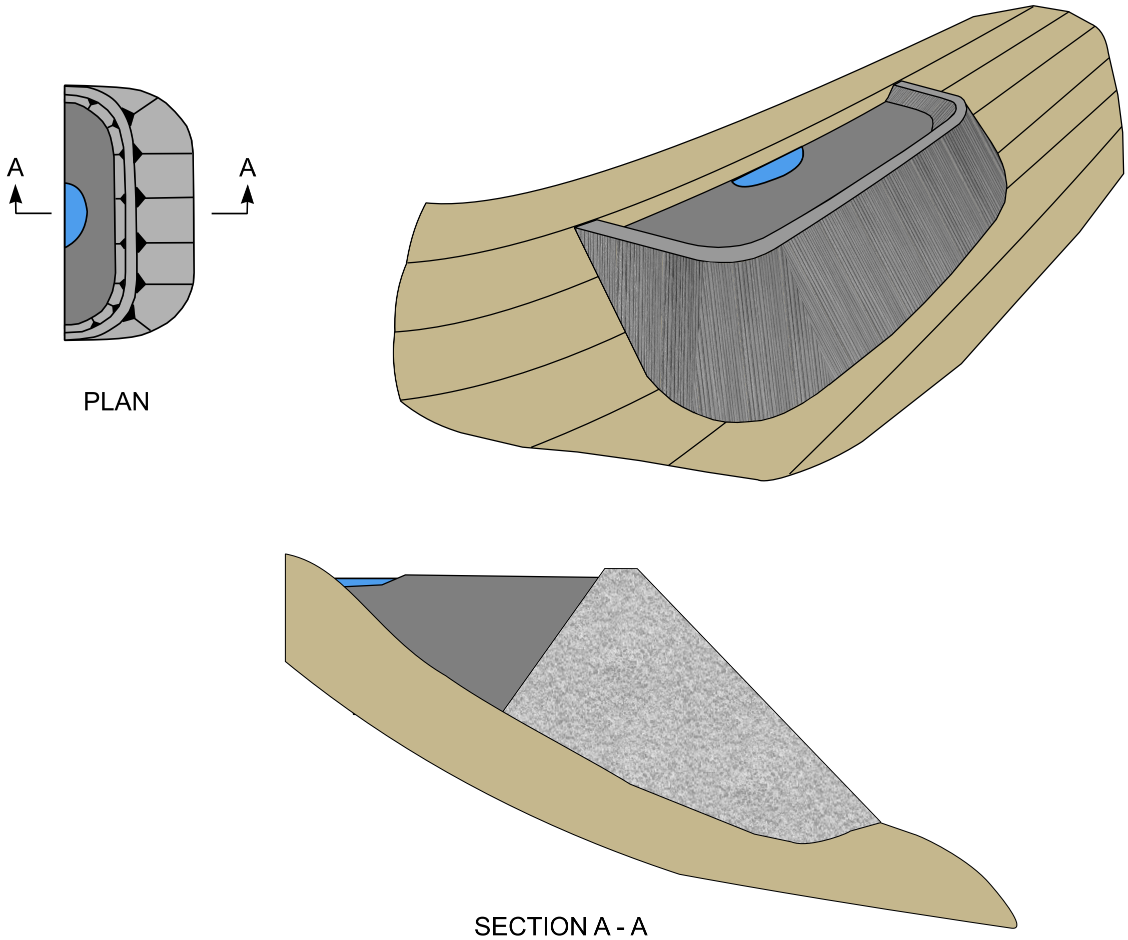

FIGURE 3.3 SIDE-HILL IMPOUNDING EMBANKMENT

impounding embankments is relevant primarily for identifying whether portions of the coarse refuse embankment will be constructed on settled fine coal refuse slurry and the timing for reclamation of completed surfaces of the embankment.

Upstream construction, and to a lesser degree centerline construction, with placement of coarse refuse embankments on settled fine coal refuse, introduces stability concerns due to the potentially low strength of the fine coal refuse during initial covering and the potential for seismically-induced strength degradation. The field exploration, testing and analysis, and design methodology and criteria used for upstream construction plans are typically more extensive than for downstream or centerline construction. On the other hand, upstream construction, when the final toe and lower elevations of the embankment face are established early in the disposal facility development, allows concurrent reclamation of the completed face and thus improved erosion and sediment control.

Downstream construction mitigates issues related to the stability of the embankment due to the soft foundation conditions associated with fine refuse, but the reclamation of the embankment face is delayed until much later in the facility life, thus requiring more comprehensive erosion and sediment control measures.

At some sites, both upstream and downstream stages are constructed in order to: (1) fit site terrain conditions, (2) meet disposal capacity requirements, and (3) provide multiple coarse refuse dis-

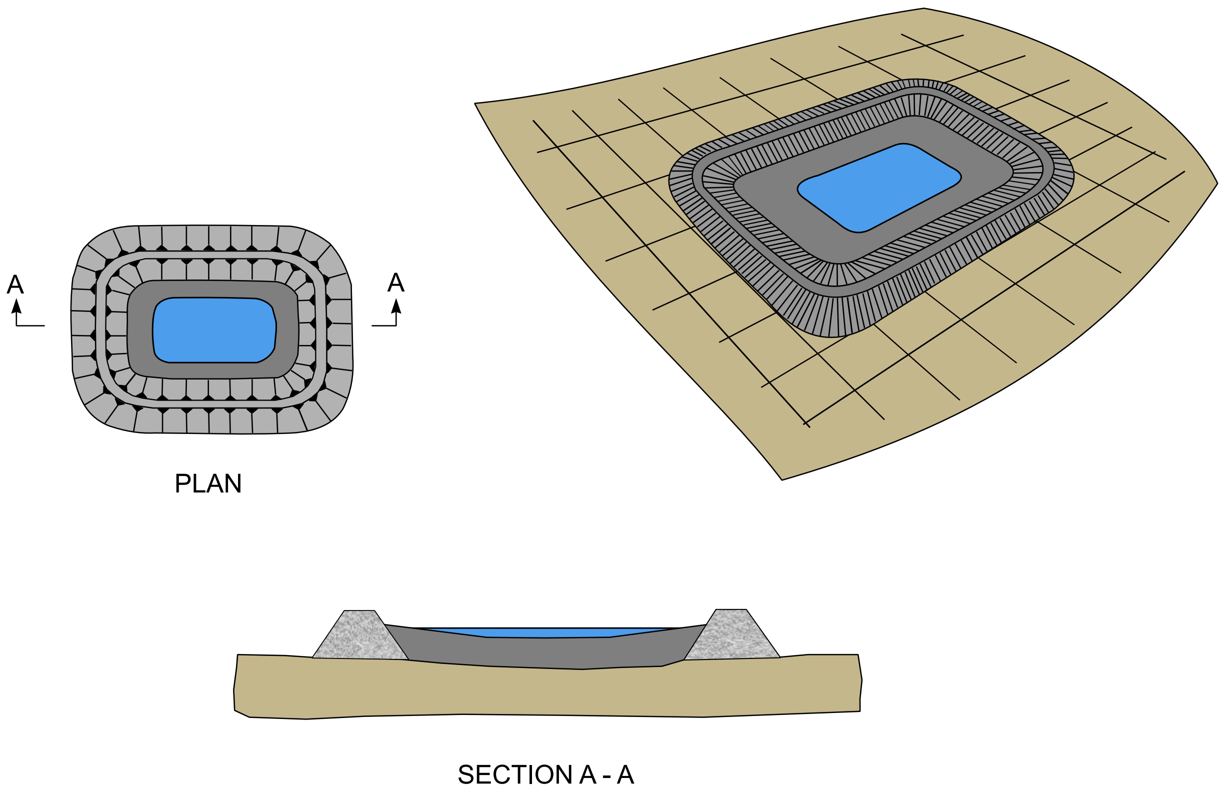

FIGURE 3.4 DIKED-POND (IMPOUNDING) EMBANKMENT

posal areas. This type of construction is sometimes referred to as the modified upstream construction method. Thacker (1997) recommends initiating upstream construction early in the project life, with subsequent placement of coarse refuse in a downstream buttress zone to allow pore pressure to dissipate in the previously loaded fine refuse.

The decision whether to construct a refuse facility utilizing upstream, downstream and centerline construction sequencing is also dependent upon the geometry of the valley and the refuse disposal capacity requirements. For instance, downstream construction generally requires use of greater quantities of coarse refuse to gain embankment elevation than upstream construction. Centerline construction normally requires a greater amount of coarse refuse during the initial stages of the facility with lesser amounts required as construction progresses. Additional discussion of the advantages and disadvantages of various types of embankment construction is provided in Chapter 5.

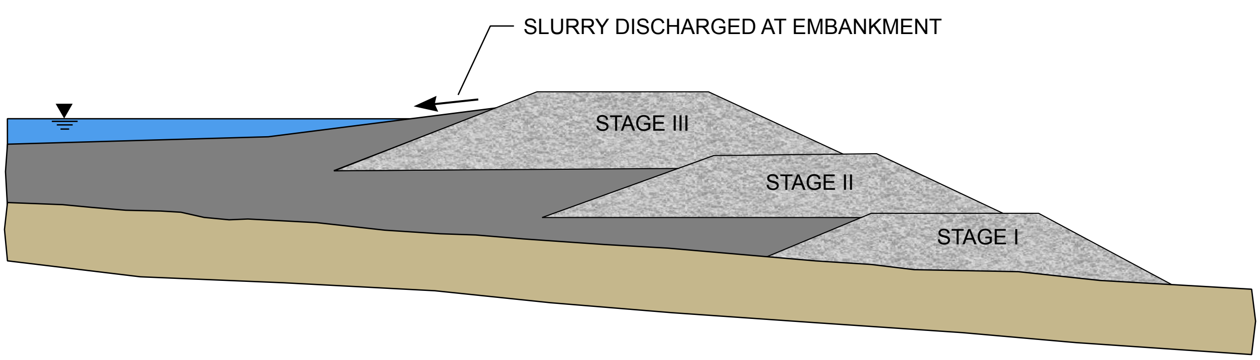

FIGURE 3.5 UPSTREAM STAGING METHOD

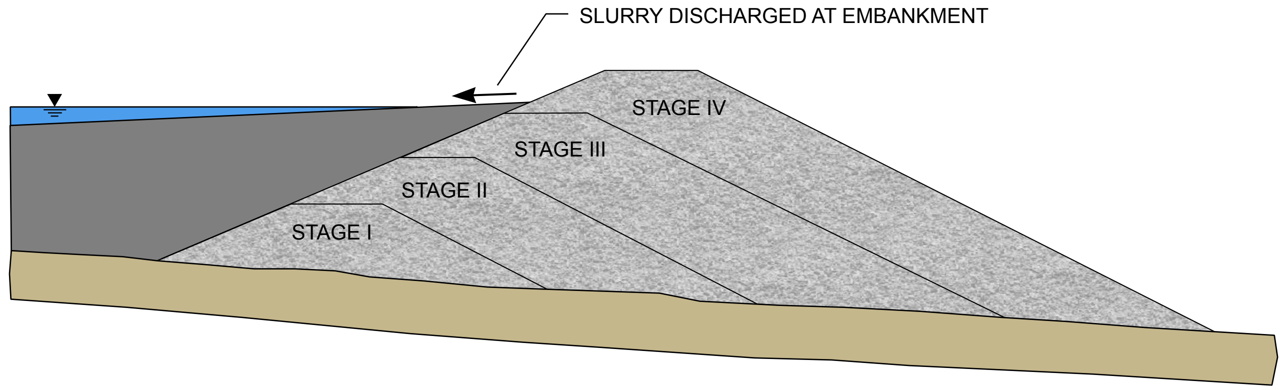

FIGURE 3.6 DOWNSTREAM STAGING METHOD

3.2.3 Hazard Potential Rating

The determination of the hazard-potential classification for impoundments discussed in Section 3.1 is based on the probable loss of life in the downstream area and the presence of structures and infrastructure that could be affected if the dam were to fail. It may be apparent from the presence of nearby, downstream mining facilities or off-site occupied structures that a dam failure could result in loss of life and that the classification should be high hazard. Since this is the most severe hazard classification, no further analyses may be necessary for hazard potential determination, although the evaluation of potential downstream impacts would still be required for preparation of an emergency action plan. If the hazard potential classification is not apparent, dam breach analyses should be performed, with evaluation of the resulting flood inundation levels and flow velocities at downstream structures to determine the potential for loss of life and severity of impact to structures and infrastructure. Dam breach analyses are discussed in Section 9.9.

The assignment of high hazard potential principally hinges on the determination of probable loss of human life. In situations where there is no probable loss of human life due to the dam failure, other site-specific factors are applied to determine the hazard potential. Estimates of economic loss and damage to infrastructure can be generated to provide guidance in differentiating between low and significant hazard, but assessment of environmental damage is more controversial.

Where there are mine workings beneath or near a refuse embankment or impoundment, a release of water and slurry into the mine could result due to failure of the natural ground or a man-made barrier between the impoundment and mine workings. Such a potential failure is referred to as an

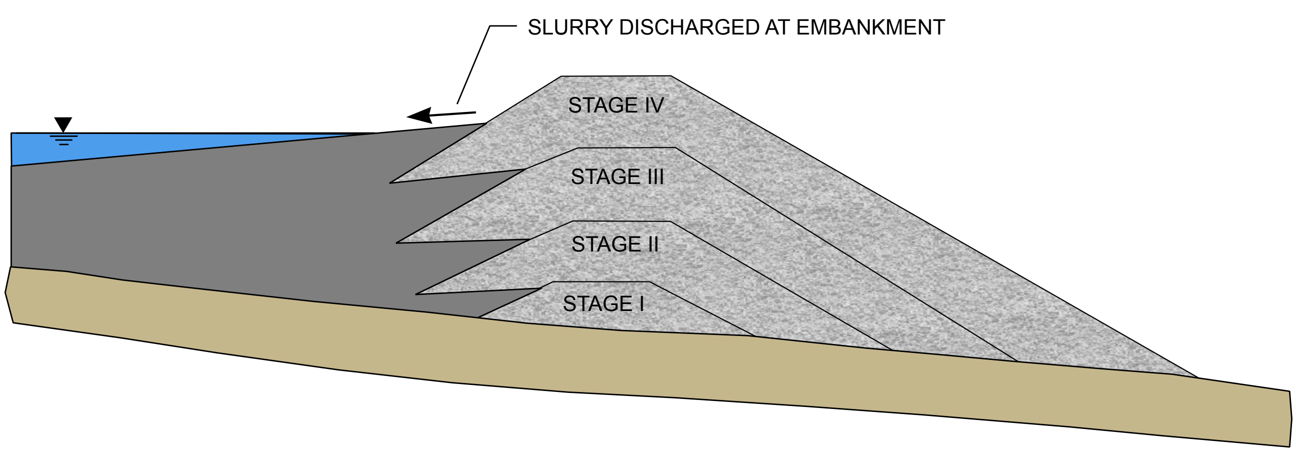

FIGURE 3.7 CENTERLINE STAGING METHOD

impoundment breakthrough and not only poses a threat to mine workers, but the water and slurry could discharge from the mine and potentially affect an area different from the one that would be affected by a dam failure. Chapter 8 addresses the design requirements for this situation, and MSHA (2007) provides the following guidance on hazard potential classification:

- The official hazard-potential classification for an impoundment is based on the three classifications indicated in Section 3.1 and is assigned regardless of whether the potential hazard is from a failure of the dam or a failure into mine workings.
- For the purpose of selecting the appropriate design criteria for the impounding embankment, the hazard-potential classification is based on the appropriate rating in the event of a failure of the embankment itself. For example, an impoundment could have a high-hazard-potential rating based solely on the potential for a failure into underground mine workings, but have low consequences due to a failure of the dam itself. In such case, the dam can be designed based on low hazard potential (e.g., the 100-year design storm), while the breakthrough evaluation and prevention measures (with respect to the extent of exploration, testing, monitoring, etc.) must be appropriate for a high-hazard-potential site.

3.3 COAL REFUSE NON-IMPOUNDING FACILITIES (REFUSE PILES)

Coal refuse disposal facilities that do not retain water or slurry are considered to be non-impounding structures and are also referred to as refuse piles. As indicated in the *MSHA Coal Mine Impoundment Inspection and Plan Review Handbook* (MSHA, 2007), a refuse pile may have small isolated sediment control facilities and cells for the disposal of filter cake, sediments, etc. provided that the size of these cells would not result in the classification of the structure as an impoundment, their location would not affect structural stability, and the configuration does not impede drainage (e.g., block a drainage course). Where this material is not compacted in two-foot lifts, the disposal should be approved by the MSHA district manager. In addition to filter cake, fine coal refuse slurry can also be disposed in appropriately designed cells, as discussed in Section 3.4.

3.3.1 Coarse Refuse Embankments

If not part of an impoundment plan, a coarse refuse embankment is typically designed for separate disposal of coarse coal refuse and fine coal refuse. Typical features and construction practices associated with a coarse refuse disposal facility include the following:

- Surface drainage diversion away from the limits of the disposal embankment.
- Removal and stockpiling of topsoil and soils for future reclamation.
- Removal of unsuitable foundation materials that would adversely affect the construction or stability of the embankment.
- Collection of discharges from springs under the foot print of the embankment that may adversely affect stability.
- Placement and compaction of run-of-plant coarse refuse in lifts to the designed lines and grades of the embankment.
- Construction and maintenance of haul roads on the embankment for transporting the refuse to the disposal area.
- Grading and sealing of the refuse embankment to maintain drainage control and to prevent water retention behind the embankment.
- Collection of surface drainage on the embankment and delivery to sediment control structures.
- Reclamation of completed surfaces, consisting of placement of soil and topsoil and re-vegetating.

Coarse refuse embankments are usually developed as homogeneous embankments, without multiple zones. While the term homogeneous is applied to such embankments, the coarse refuse materials may exhibit some variability in grain size and specific gravity. Typically, however, coarse refuse has the strength to support construction equipment and to meet the embankment design assumptions.

3.3.2 Combined Refuse Embankments

Combined refuse embankments are designed for disposal of coarse refuse and dewatered fine coal refuse as a mixed material. While combined refuse embankments may be homogeneous, they can also be constructed as zoned embankments where more workable refuse materials such as coarse refuse are used (either periodically, or in sufficient continuous quantity) to construct a well-compacted downstream shell of sufficient width (sometimes referred to as a structural zone) to contain the combined refuse and to construct haul roads within the disposal area. Typical features of a combined refuse disposal facility are similar to those for a coarse refuse embankment. Because of the presence of dewatered fine coal refuse and overall wetter material conditions, large disposal areas are generally needed so that the dumped materials can drain before spreading and compaction, and more extensive internal drainage systems may also be required. In some cases amendments may be needed to stabilize the wet materials.

3.3.3 Segregated Refuse Embankments

Dewatered fine coal refuse can be disposed in segregated areas of a coarse refuse embankment. This approach results in a zoned embankment in which coarse refuse forms a downstream zone or shell that supports the overall stability of the embankment, and isolated areas are provided within the upstream or interior of the embankment for depositing the dewatered fine coal refuse. Typically, these segregated refuse embankments are designed with provisions for haulage routes within the embankment and for containment of the dewatered fine refuse without creating depressions that could be classified as impoundments. Such containment structures require measures to control surface drainage that collects in the dewatered fine refuse disposal area. Typical features of segregated refuse embankments are similar to those for coarse refuse embankments, but with more extensive internal drainage systems and control of drainage within the dewatered fine refuse containment area.

3.3.4 Configuration and Development Staging

Non-impounding facilities are constructed with a range of configurations and development staging. The disposal facility configuration depends upon the terrain, and the development staging reflects the general sequence or direction of disposal activity. Non-impounding facility configuration categories are: valley-fill (Figure 3.8), cross-valley (Figure 3.9), side-hill (Figure 3.10), ridge-dump (Figure 3.11), and heaped (Figure 3.12).

Planning and design of a non-impounding embankment generally involves development stages related to intermediate points in the facility construction and the general development direction of the disposal operations. The development staging is characterized by the direction in which development occurs. Upstream construction involves the construction and placement of refuse in downstream areas initially, with sequential placement during subsequent stages in upstream locations, typically at higher elevations. Downstream construction involves the construction and placement of refuse in upstream areas initially, with sequential placement during subsequent stages in downstream locations. This terminology for non-impounding embankments is more relevant for valley-fill configurations, where upstream and downstream directions reflect the shape of the valley.

Cross-valley non-impounding embankments (Figure 3.9) can potentially impound water, and they may be classified as impoundments by MSHA if they can impound water for such a period

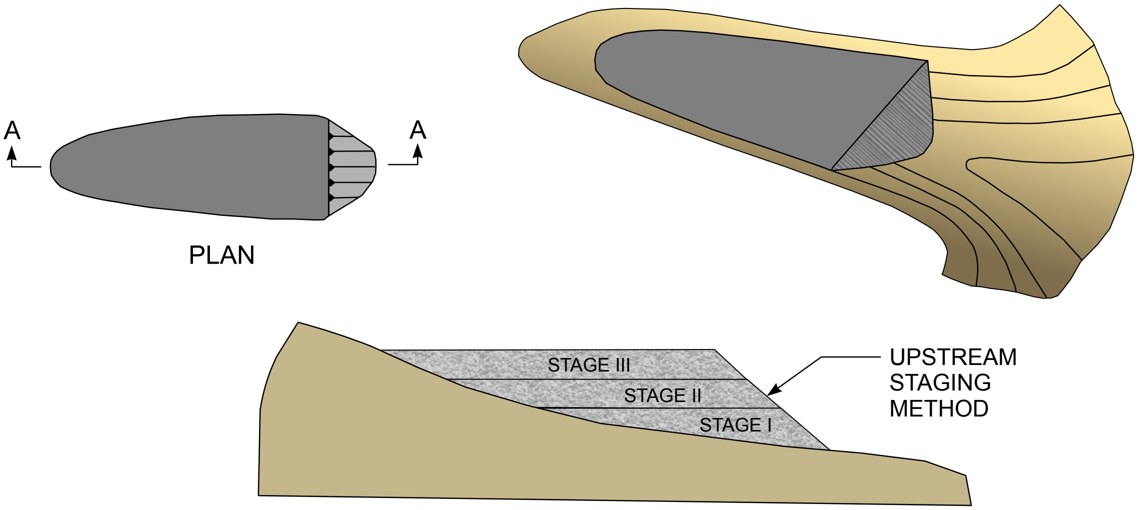

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FIGURE 3.8 VALLEY-FILL, NON-IMPOUNDING EMBANKMENT

of time that they can create a hazard. MSHA (2007) presents factors considered for such classification. Abandonment of cross-valley non-impounding embankments can require substantial regrading in order to satisfy long-term drainage concerns. Therefore, this type of embankment is generally avoided.

3.4 COAL REFUSE SLURRY CELL FACILITIES

Small cells or ponds in a coarse refuse facility that receive fine refuse are commonly referred to as slurry cells. Disposal of fine coal refuse using slurry cells has been implemented at sites where con-

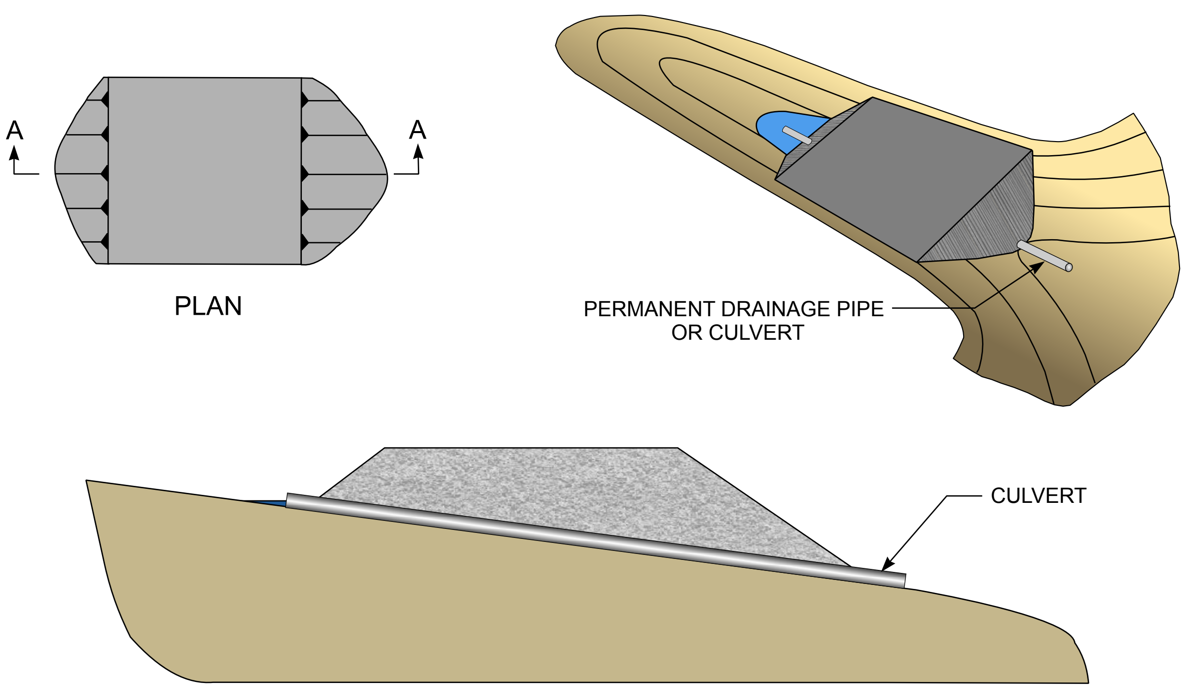

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FIGURE 3.9 CROSS-VALLEY, NON-IMPOUNDING EMBANKMENT

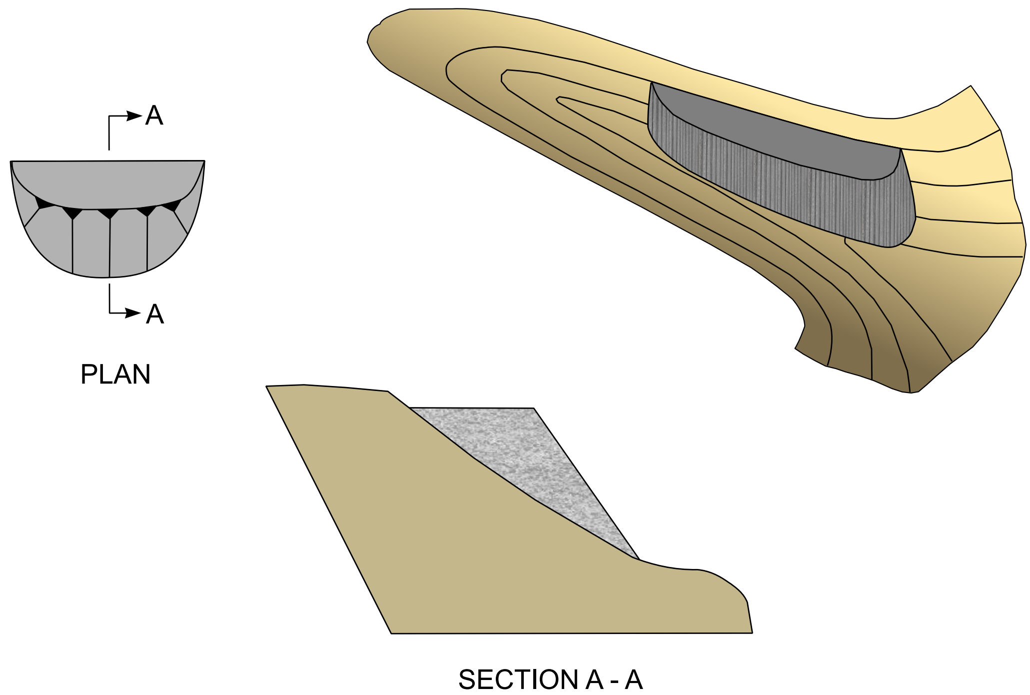

FIGURE 3.10 SIDE-HILL, NON-IMPOUNDING EMBANKMENT

straints may deter or preclude the construction of a large slurry impoundment, and/or the quantity of fine coal refuse slurry is relatively small and can be reasonably accommodated with a small cell structure. Small cells are created, usually within the upstream zone of a coarse refuse embankment, and are filled with slurry. The upstream zone and cells are contained by a well-compacted downstream shell (sometimes referred to as a structural zone). Once an individual cell is filled, it is allowed to drain, and the fine coal refuse is covered with coarse coal refuse while another cell is operated. Because of the typical small cell size, operation of multiple cells intermittently will facilitate settling and draining of fine refuse and optimize the capacity of each cell.

Slurry cells may also be used to dewater fine refuse prior to final disposal. Instead of encapsulating the slurry cell in a coarse refuse embankment, the fine refuse is excavated from the cell after substantial dewatering has taken place and then is typically mixed with coarse refuse prior to being incorporated into an embankment for final disposal.

3.4.1 Size and Hazard Classification

The slurry cell concept is typically focused on: (1) sequencing the construction of cells to match the slurry generation rate, (2) accommodating drainage and covering of each cell, and (3) maintaining a total capacity of all open cells at a level that does not meet impoundment classification or, if classified as an impoundment, has a low hazard potential. In the case of multiple slurry cells where they individually do not meet the size criteria requirements of 30 CFR § 77.216(a), if the failure of one cell can result in the failure of another or if a slope failure can result in the release of water, sediment, or slurry from multiple cells, then the cumulative storage capacity of the affected cells is used for application of the impoundment size criteria. This includes cases where the initial slurry cells are covered with coarse refuse and additional cells are to be placed above the initial set of cells (MSHA, 2007).

The operation of multiple cells, particularly if subsequent cells are built on previously covered cells similar to the upstream construction method for an impoundment, can lead to classification as an impoundment. If multiple cells are arranged such that they affect structural stability and there is a possibility of sequential failure and a large release with significant downstream impacts,

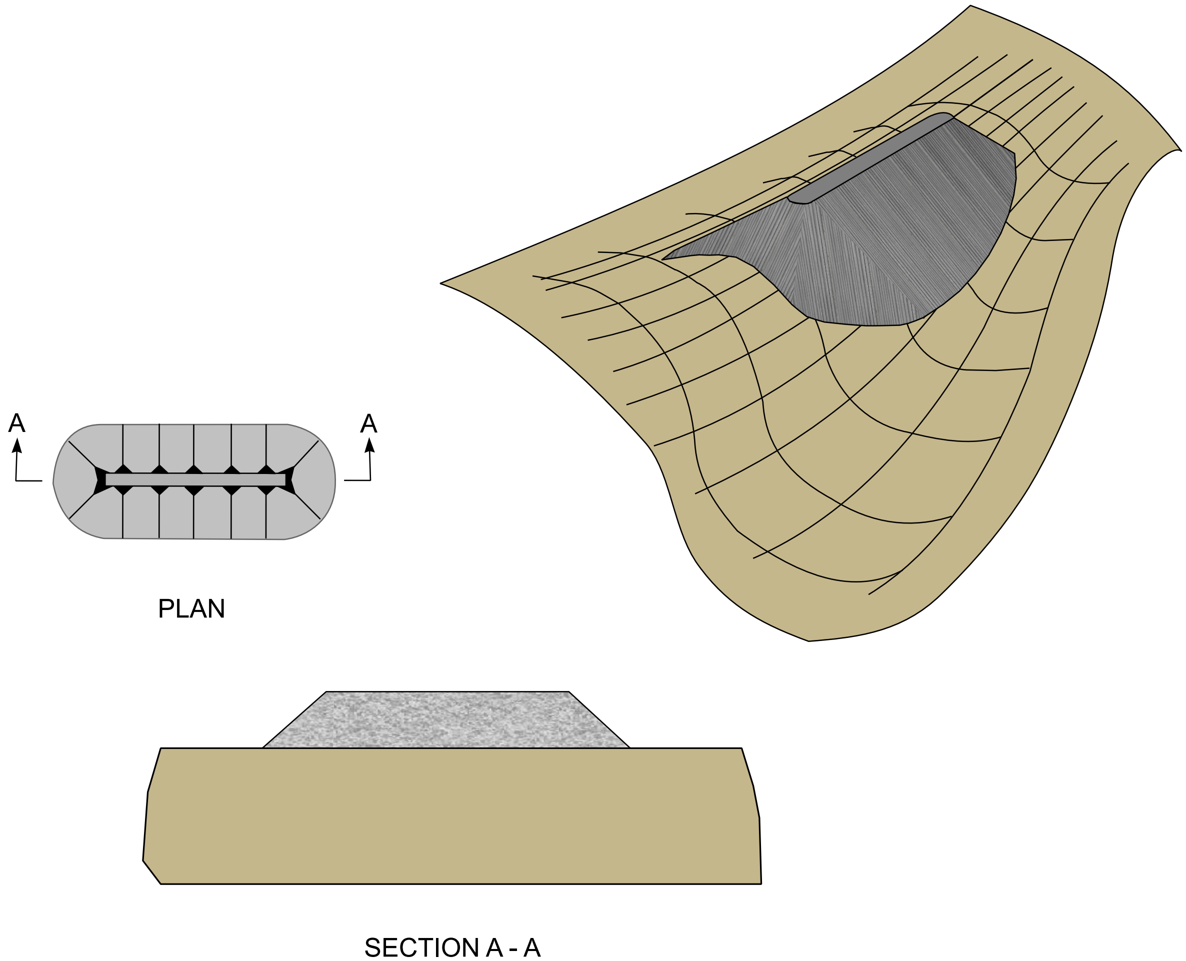

FIGURE 3.11 RIDGE (NON-IMPOUNDING) EMBANKMENT

the impounding facility could receive a significant- or high-hazard-potential classification, as discussed in Section 3.1. In such a case, the design storm requirement will increase, necessitating greater diversion and freeboard, thus limiting the feasibility of the concept for some configuration categories (e.g., valley fills).

The advantages of the slurry cell concept are the following:

- As a low-hazard-potential facility with limited cell size, managing the design storm runoff can generally be accommodated with minimal storage, enabling more capacity for disposal of slurry and clarification of process water. Control of surface drainage from the surrounding embankment area is critical, along with effective diversion of runoff from watershed areas around the facility.
- Slurry cells have limited capacity, comprising generally a thin deposit of slurry with coarse refuse containment and covering layers that allow the fine refuse to dewater and consolidate, making the total mass less flowable. This limited capacity is viewed as an advantage at sites that are undermined and have the potential for breakthrough.
- With the fines compartmentalized in cells, a problem at one location is less likely to affect the entire facility, which also helps to mitigate concerns for breakthrough potential.

- As a low-hazard-potential facility, fewer and less extensive hydraulic appurtenances are required, with lower associated construction costs.

The features of a slurry cell facility are similar to those discussed for a non-impounding facility. It has become common practice to design a well-compacted shell (sometimes referred to as a structural zone) at the face of the disposal facility embankment as the downstream containment structure for cells. The design of the well-compacted shell is based upon evaluation of factors such as width, slope, benches, internal drainage, and access or haul roads. Similar to non-impounding refuse embankments, diversion of runoff from upstream and hillside areas is accomplished by locating ditches and channels, which are separate structures from the slurry cells, either above or on the embankment surface. To keep runoff from entering the disposal area, the construction and maintenance of the diversion ditches requires sequential planning and periodic construction activities apart from disposal operations. Additionally, control and discharge of process water from the slurry operation is required at each cell. Typically, this will require small-diameter decant systems or stabilized channels. These structures usually have limited service requirements because of the low capacity of the cells.

In addition to the critical sequencing of cells to match the fine refuse generation rate and maintain low-hazard-potential classification, a slurry cell facility has many of the same design considerations as impoundments: (1) geotechnical investigation to determine embankment and foundation characteristics, (2) testing for relevant material properties including shear strength and hydraulic conductivity, (3) static and seismic slope stability analyses, (4) underdrains to control the phreatic level, (5) a dam breach analysis, unless the hazard potential is otherwise apparent, to determine the appropriate hazard potential rating and design storm, (6) instrumentation to confirm design assumptions and performance, (7) preparation of construction specifications, and (8) construction monitoring.

Some disadvantages of slurry cell facilities include requirements for: (1) frequent construction of diversion ditches, new cells, and cell spillways (decant structures) as the site elevation increases, (2) a

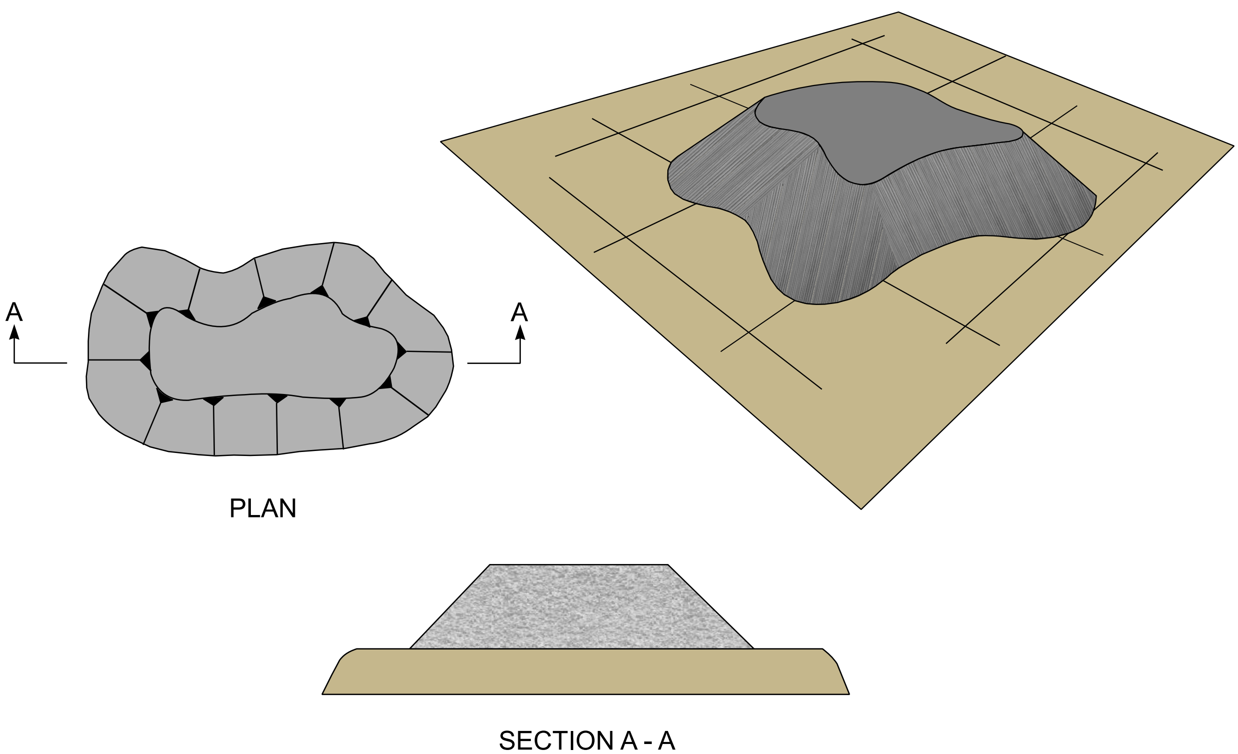

FIGURE 3.12 HEAPED (NON-IMPOUNDING) EMBANKMENT

relatively large ratio of coarse refuse to fine refuse, and (3) more detailed planning and supervision of the site so that the construction, filling, and covering of cells is accomplished in the proper sequence. Also, a slurry cell facility can potentially be reclassified as having high hazard potential, increasing the diversion and cell spillway requirements and impacting the long-term feasibility of the concept.

While one of the attractions of the slurry cell concept is disposal of fine refuse slurry in a structure with low-hazard-potential classification and thus less stringent design storm requirements, it may be advantageous to employ the concept at an impoundment site to mitigate potential impacts from underground mining and breakthrough potential. In such a case, the embankment design would be in accordance with the appropriate impoundment criteria, and additional operating plans would be required for disposal of slurry within cells constructed in the impoundment area.

3.4.2 Disposal Facility Configuration and Development

Non-impounding facility configurations established by MSHA may be developed using the slurry cell concept, although the quantity of available coarse refuse typically requires a valley-fill or side-hill configuration. The valley-fill configuration is generally developed in the upstream direction after a sufficient embankment height and top surface is reached to enable individual cells to be constructed. Consequently, beginning a slurry cell system may require operation of another disposal facility (e.g., underground injection), an existing disposal facility (e.g., old impoundment), or available fill material (e.g., mine spoil from other site development work) in order to achieve a sufficient working surface and embankment configuration to initiate slurry cell operation. As the disposal embankment is raised in height and additional cells are constructed over covered cells, hazard classification may become an issue. Therefore, the use of a valley fill for a slurry cell facility will likely have limitations. Figure 3.13 shows a slurry cell facility developed in a valley-fill configuration.

Use of slurry cells with side-hill and heaped configurations is less common, unless backup disposal capacity is required in conjunction with the underground injection of fine coal refuse. These configurations require a larger quantity of coarse refuse for development of the structural shell, but this

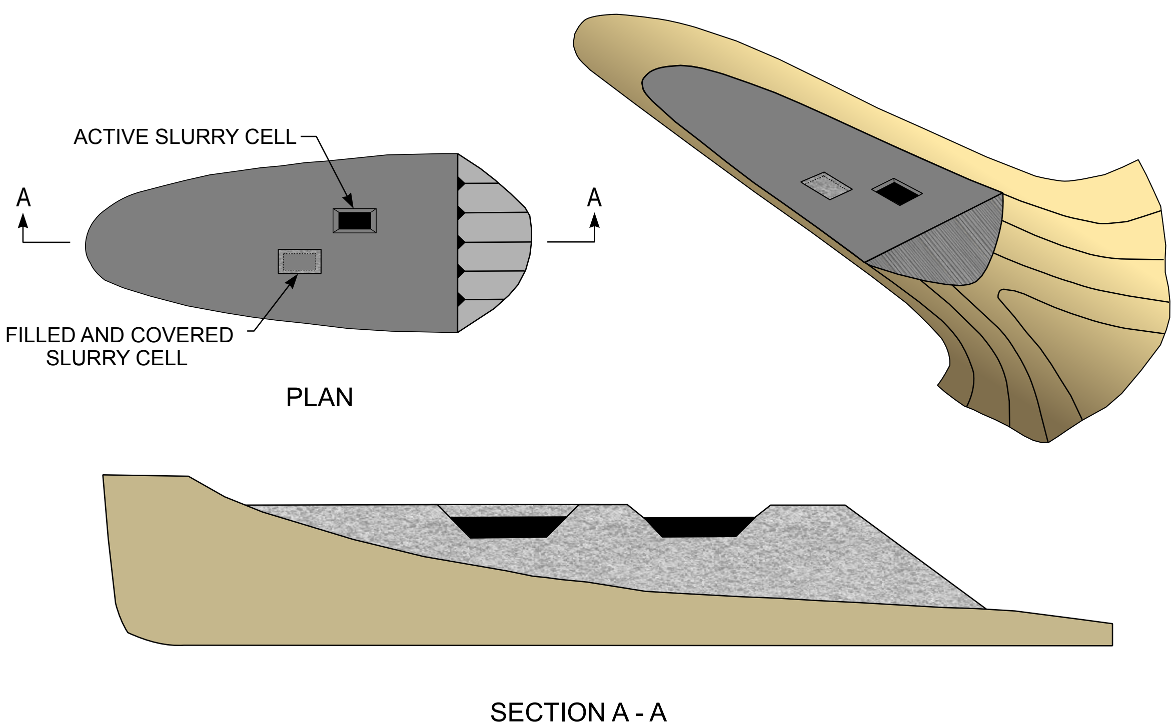

FIGURE 3.13 SLURRY CELL IN VALLEY FILL, NON-IMPOUNDING EMBANKMENT

material may not be available considering the need for coarse refuse to construct individual small cells. Figure 3.14 illustrates a slurry cell facility developed with a side-hill configuration.

Slurry cells may also be incorporated into an impoundment configuration, if issues of underground mining and breakthrough potential cause concern over the quantity of flowable impounded material. Figure 3.15 illustrates a slurry cell facility developed at an impounding embankment.

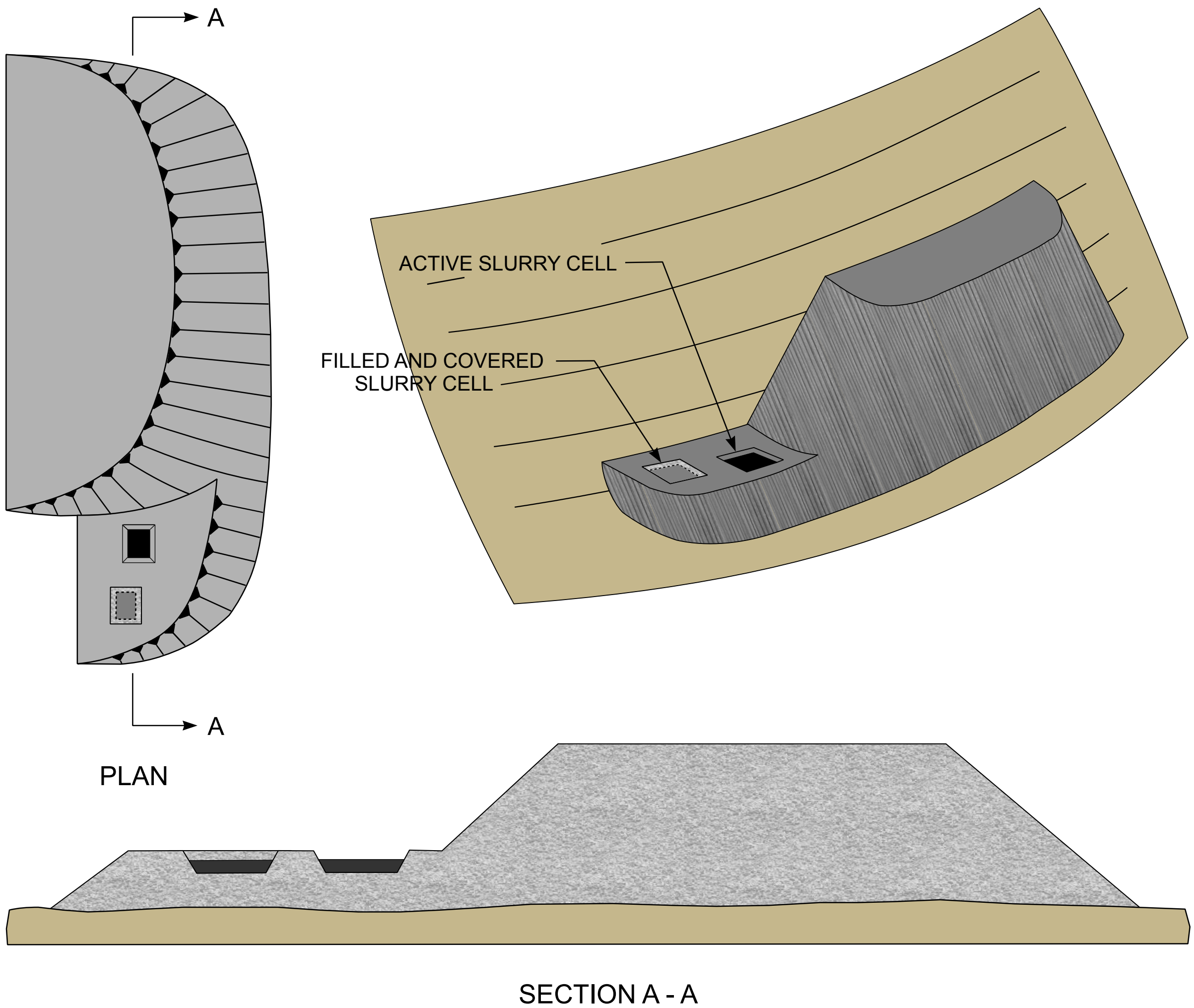

FIGURE 3.14 SLURRY-CELL, SIDE-HILL, NON-IMPOUNDING EMBANKMENT

3.5 UNDERGROUND INJECTION SITES

Fine coal refuse slurry can be disposed within underground mines by injection. Background information for the technical feasibility of underground disposal can be found in a publication by the National Academy of Sciences (NAS, 1975). There are state and federal regulatory programs for these operations, and the Virginia Department of Mines, Minerals and Energy, Division of Mined Land Reclamation has developed guidance for planning, design, operation and monitoring (VA DMLR, 2006). Planning and design for underground slurry disposal is discussed in the following subsections.

3.5.1 Siting

Background information useful for planning and design includes property ownership, geologic strata, hydrogeologic conditions, and data describing the mine workings to be used for disposal, including mapping, extraction information, mine dewatering and discharge conditions, proximity to active mine areas and associated barrier information (coal barrier and bulkheads). The capacity of the underground workings should be determined, and the potential duration for slurry disposal should be estimated based upon settling and the ultimate solids content of deposits. Consideration should be given to the following:

- Lineaments, faults, and fractures as possible conduits of slurry.
- Recharge and discharge of groundwater into the mine workings as an indication of the hydraulic connection of the mine works with the fracture flow system.
- Surface openings that could or will become a discharge point, and coal barrier requirements and stability, with an assessment of the amount of weathering of outcrop, jointing, and previous or planned surface or auger mining.
- Presence of groundwater users, radius of influence of withdrawal wells, and connectivity with mine voids.
- Mine works overlying and underlying the mine work receiving injected slurry, including inventory and assessment of vertical dewatering holes, subsidence fracturing, and associated surface openings.
- Proximity of and impacts on active mines.
- Slurry injection and movement through mine workings, including water balance analysis of injection flows and surface and groundwater conditions.
- Leaching of contaminants from emplaced slurry, including potential impacts from process chemicals, and sorption characteristics of processing chemicals on coal and sand/clay particles.
- Hydrologic conditions that could develop after cessation of injection, including development of equilibrium groundwater conditions.
- Potential impacts to near-surface groundwater resources

3.5.2 Injection System Design

The following issues related to injection system design should be addressed:

- Drilling methods for penetrating the abandoned mine to reduce the potential of creating an ignition source.
- Design of bulkheads and seals that may be required to control the deposition of slurry or direct drainage toward acceptable discharge locations.
- Injection site and slurry line/alignment, including construction and service access, drainage control, and secondary containment.
- Injection well design including maximum pressure (below level for hydraulic fracturing of overburden or mine barriers, and system components such as casing), complete casing of overburden (with double casing provisions when penetrating upper mine voids), casing grouting methods through overburden, and wellhead completion with air gap to prevent pressurization of the well, if applicable, or pressure control and monitoring. Where pressure injection is required, a control system to limit pressures to the maximum design value must be employed, along with backflow prevention in the event of slurry line rupture.
- Secondary containment for piping and injection site, including monitoring and controls that shut down the slurry pumps in the event of piping failure.
- Operating procedures and flow rates, including hours of slurry disposal/process water pumping, and measures to prevent the introduction of oxygen into the mine.

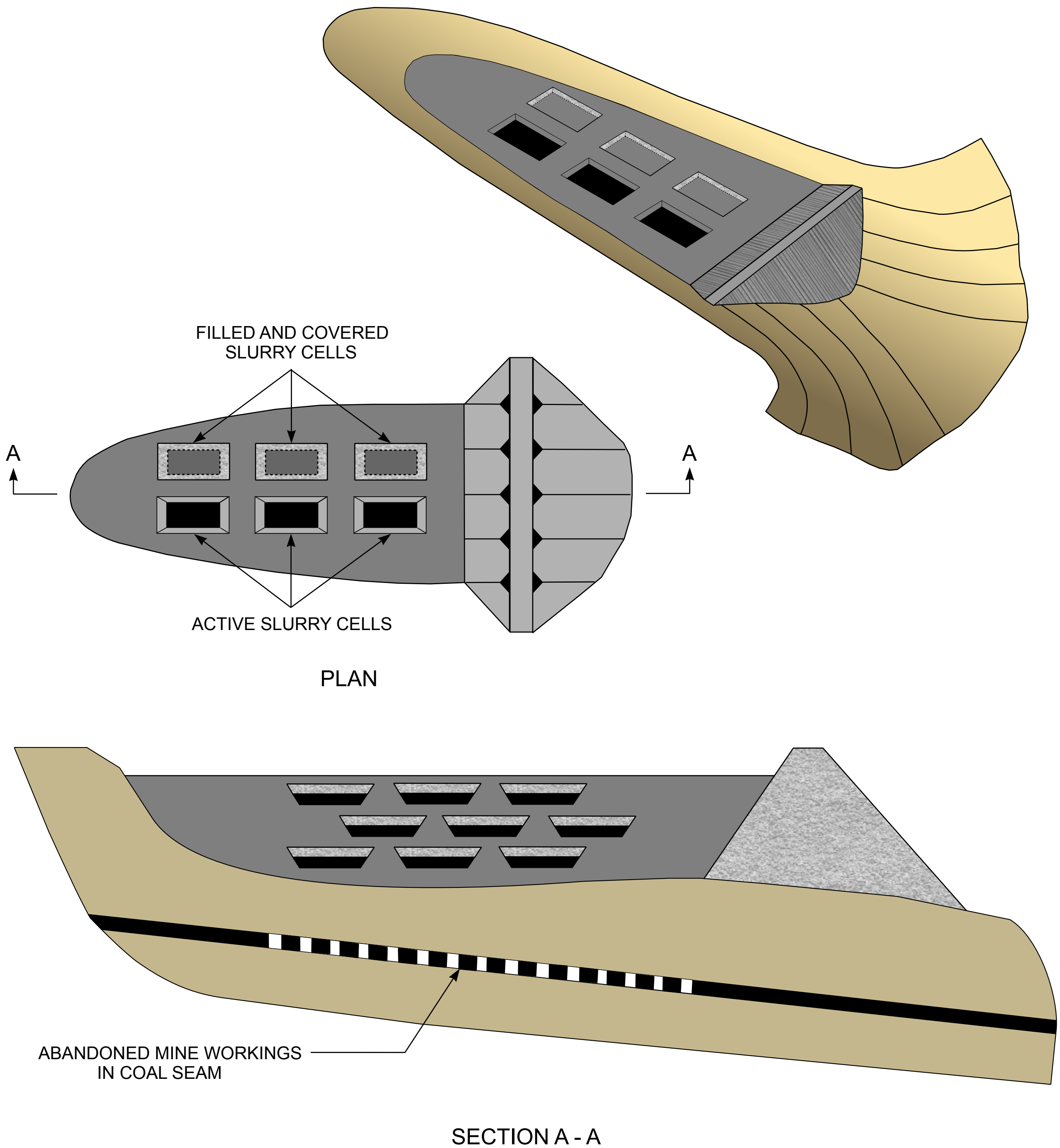

FIGURE 3.15 SLURRY CELLS IN CROSS-VALLEY-FILL, IMPOUNDING EMBANKMENT

3.5.3 Risk Assessment and Response Plan

The following are issues that should be considered in the evaluation of risks associated with release and potential response actions:

- Avenues of release (both surface and underground) and human exposure pathways. A concern is ingestion through drinking water wells with capture zones that may draw water from underground mine works or be connected to mine works through fracture systems.

- Blowout potential associated with the injection pressures, slurry and water accumulation, and barrier stability. The barrier stability evaluation should reflect subsequent surface, auger, or highwall mining that may have thinned or penetrated the barriers. Future restrictions on mining in barriers should be considered if such potential exists.
- Environmental receptor identification relative to groundwater and surface water, considering contamination potential due to acid forming materials and petroleum solvents or other chemicals used in the coal preparation plant and solids deposition within streams.
- Response to release, including: (1) steps to determine the extent of release, (2) identification of emergency containment and cleanup resources (in-house and contracted) and associated steps to initiate action, (3) disposal of wastes generated during cleanup, and (4) implementation of operational contingency plan for ongoing slurry disposal.

3.5.4 Contingency Plan

Contingency disposal options should be established for fine coal refuse slurry if injection is suspended for emergency or performance reasons. The plan should include steps to be taken to shut down the current injection operation; facilities and designs for interim slurry disposal such as alternate injection locations (in the event of performance based shutdown) or emergency ponds and drying cells, dewatering equipment, etc.; and longer-term options for disposal such as slurry disposal cells.

3.5.5 Monitoring Plan

Monitoring for slurry injection, emplacement, mine water levels and mine discharge rates/quality for the injection target and adjacent mines, as applicable, should be developed, along with groundwater and surface water monitoring. The parameters, methods, and frequency for monitoring should be established based on site conditions, sound engineering judgment, and applicable regulatory programs.

- Slurry injection monitoring for organic and inorganic parameters should be performed to assess potential groundwater and surface water impacts, as required by regulatory programs.
- Slurry emplacement monitoring should include monitoring wells and discharge points within the mine works for detecting the presence of slurry solids for comparison with predicted slurry and water accumulation and movement, and planning subsequent injection sites.
- Mine pool/discharge water monitoring should be performed and the data should be compared to the maximum predicted mine pool level and discharge rates, and water balance analysis.
- Groundwater monitoring should include wells located in hydrogeologic units most likely to be influenced by the injection operation, such as the fracture flow system, the subsidence fracture zone overlying workings, and the coal seam adjacent to mine workings impounding the slurry. Lineaments should also be considered when selecting locations to be monitored. Potable wells within the expected zone of influence of the injection operation should be monitored, but these wells should not be considered as groundwater monitoring unless well construction details are known.

With the use of an underground injection site for slurry, the coal preparation plant will also require a surface disposal facility for coarse coal refuse. As indicated above, contingency disposal options should be developed if underground injection proves to be infeasible. Such options could include use of slurry cells or conversion to combined refuse if the preparation plant is equipped for fine refuse dewatering.

3.6 RECOVERY (REMINING) OF COAL REFUSE DISPOSAL FACILITIES

Recovery (sometimes referred to as remining) of coal refuse from existing active or previously abandoned embankments and impoundments is performed at some sites and involves the use of advanced processing methods to obtain additional coal for fuel or power generation. In such situations, a ground control plan addressing safety issues associated with remining operations should be submitted to MSHA. The remining process involves the excavation and removal of coal refuse and, where processing is performed on site, disposal of waste from the coal processing plant. Thus, a modification of the existing site refuse disposal plan will generally be necessary.

Recovery or remining may involve exploration, excavation and handling, final grading, and reclamation on soft or loose materials including operation in wet, saturated or submerged conditions. Exploration will typically include initial as well as periodic operational borings and test pits for evaluation of geotechnical and groundwater conditions as well as marketability of the excavated coal refuse. Low-ground-pressure equipment, upstream pushout of a coarse refuse pad, or barge operation may be needed depending on impoundment conditions, and procedures and safety precautions appropriate to the method used should be developed.

Under relatively dry conditions, dozers, excavators, end-loaders, scrapers, or a clamshell can be used for excavation of refuse and fines from an impoundment. Procedures and safety precautions that are suitable for the conditions encountered should be developed, and when soft or loose fine refuse is present, stability analyses to determine if the excavation slopes will be stable should be conducted. For impoundments built by the upstream construction method, a buffer zone or distance should be maintained between the area of excavation and the upstream slope of the impounding embankment or other fill that may be present.

Surface runoff should be diverted around the operation area to the extent possible, and the active work area should be graded so that water drains toward ditches and sumps. Lowering the phreatic level in the fine coal refuse to the extent possible by surface runoff control and removal of groundwater will improve ground conditions for equipment operation, allowing maximum recovery of coal. Consideration should be given to grading, deep sumps, and other dewatering measures for lowering the phreatic level, and the phreatic levels should be continually monitored during operation. At sites where control and removal of surface and groundwater is not practical at all times of the year, safe and economic removal of fines may only be possible during dry periods. In such instances, evaluation of the degree and depth of saturation of the fines should be made prior to resumption of operations.

When wet and submerged conditions are present, dredges and hydraulic sluicing (water cannons) are sometimes employed to remove fines from an impoundment. Accidents have occurred when steepened slopes of fines have collapsed, sending a wave of material across the impoundment. Besides the operating concerns discussed above, additional safety concerns must be addressed, and it is important to establish guidance for equipment operation. Land anchors used to position dredges should be located on solid ground and kept well back from areas that might be susceptible to slope failure as the dredging progresses. The safe distance that any operator or equipment not on solid natural ground (including anchor equipment) approaches the working face should be evaluated and should generally be limited to no closer than twice the vertical height of the working face. When dikes built across the impoundment to divide it into sections are present, personnel and equipment should not be allowed on dikes adjacent to active dredging operations until dredging has ceased and the stability of the area has been assessed. Personnel and operating equipment must have the proper safety equipment for working at a dredging operation.

Upon completion of the recovery operation, final grading and reclamation should provide long-term stability of slopes and drainage channels. This work is typically performed with conventional earth-moving equipment, and many of the operating procedures and safety precautions for this phase of recovery are similar to typical reclamation requirements.

For embankments or impoundments that are to be remined, engineering plans addressing the following should be prepared for review and approval:

- Excavation of coal refuse, including the method of removal, temporary slopes, sequence, and resulting configuration of the facility, with associated provisions for controlling drainage and maintaining stability during operations and following completion.
- Slope stability analyses (for both permanent and temporary slopes) demonstrating acceptable factors of safety where miners are subject to potential slope failure hazards. The slope stability analyses should include consideration of rapid drawdown conditions associated with the removal of fine refuse. If excavated slopes that are intended to be temporary and are designed for short-term conditions remain in place much longer than planned (or become permanent because of the idling of recovery operations), they should be re-designed with long-term factors of safety.
- Changes in seepage resulting from pooling of water as fine coal refuse is removed.
- Operating procedures and precautions specific to the excavation and recovery methods used (e.g., conventional construction equipment, barge and dredge equipment, water cannon operation) to provide for safe access and mining.
- Monitoring of compliance with the excavation plan and inspection of slopes and drainage control structures.
- Disposal plans for waste from the reprocessing of the coal refuse.
- Reclamation and abandonment of the disposal facility.

If fine coal refuse is to be removed from a slurry impoundment, the potential impacts on the safety of the impoundment should be addressed in the plans. This should include potential impacts on the outlet structures and facility operation during the design storm and limitations on the extent and slope of the excavation so that other parts of the facility are not compromised. For instance, if there is upstream construction or barriers related to mine workings are built over slurry, removal of fines could remove support for the embankment crest or barrier structure. In such cases, an analysis for determining the necessary buffer and excavation slope such that fines recovery can take place without compromising the stability of the embankment or barrier structure is required.

3.7 OTHER IMPOUNDING STRUCTURES

In addition to coal refuse disposal facilities, mine sites may have other impounding structures such as fresh-water reservoirs to provide make-up water for the processing of coal and sedimentation and treatment ponds to handle runoff and drainage from refuse embankments, surface mined areas and other disturbed surfaces. In some limited surface mining situations primarily in the western U.S., dams may be used for flood control during the temporary period when the mine pit advances near a water course. These structures are generally traditional dams and reservoirs that, while having many of the same features as a slurry impoundment, may also have additional features associated with influent and effluent controls. Additionally, these impoundments are generally constructed during a limited time period that may or may not be related to mining or coal processing rates.

Fresh water impoundments are typically located close to the coal preparation plant and are sized and located within a watershed to provide an adequate quantity of process water. These structures are

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typically dams, generally built of soil and rock fill, with primary and emergency spillways and piping tied into the preparation plant. They are differentiated from slurry impoundments by their design to maximize water storage and the presence of gated spillways and distribution pipelines. Additionally, they may have a significant depth of water and thus be subject to greater hydraulic head than would be expected for a slurry impoundment.

Sedimentation ponds are required as part of erosion and sediment control measures for runoff from disturbed mining areas, including coal refuse disposal facilities. These ponds are smaller structures than slurry impoundments and fresh water reservoirs, and they are sized to meet state regulatory criteria based on the contributing disturbed area and other hydrologic factors. They are frequently designed so as not to be classified as an impoundment regulated by MSHA. They typically have primary and emergency spillways.

Treatment ponds are similar to sedimentation ponds and are used to treat drainage from disturbed mining areas, including drainage from coal refuse disposal facilities and water pumped from underground mine workings to meet suspended solids and water quality effluent requirements. In many cases, chemicals are added to these ponds to neutralize acidic conditions and to precipitate metals such as iron and manganese. Because they are used for treatment of drainage to improve water quality, the associated drainage area is limited and the surface runoff entering the ponds is minimal. These ponds are generally small structures, frequently below the MSHA size classification for impoundments. They typically have primary and emergency spillways, and gated controls are often part of the primary spillway.

Flood-control dams are sometimes constructed in a water course to prevent or mitigate flooding of a surface mine pit. The water course may have significant flow, particularly during thunderstorms or periods of snowmelt. These dams may be small or large temporary structures, generally located in the western U.S., and are required only during the period when the mine pit could be affected by flooding from the water course. In situations where there is no threat to the public off of mine property, it may be possible to design the dam using low- or significant-hazard-potential hydrologic criteria, provided that a warning system and plan is developed and maintained for notifying and evacuating personnel involved with the mining operation when the water behind the dam reaches a specified level. Table 3.1 presents guidance that should be considered or evaluated as part of the MSHA impoundment plan if a warning system is being used to support the selection of low- or significant-hazard-potential hydrologic criteria for a flood-control dam at a surface mine pit.

The geotechnical and hydrology/hydraulic engineering requirements for fresh water impoundments, flood control dams, sedimentation ponds, and treatment ponds are substantially the same as for slurry impoundments, and design criteria are typically identical. Aspects of engineering analyses and design that may be different for fresh water impoundments than for slurry impoundments are addressed in other chapters of this Manual.

3.8 SMALL PONDS AND SIMILAR STRUCTURES

Some structures that are capable of impounding water or temporarily storing slurry on mine sites may not exceed the threshold size that would require an approved MSHA plan, but they should be designed in a manner consistent with the engineering guidance provided herein. Many sedimentation ponds and emergency slurry holding ponds at preparation plants are deliberately sized below impoundment threshold criteria and generally do not have significant hazard potential. These structures are typically regulated by states as ponds or small dams and are designed in accordance with applicable state criteria.

TABLE 3.1 GUIDANCE FOR FLOOD WARNING SYSTEMS AT SURFACE MINE PITS[1]

1. A warning system should typically consist of power supply equipment (primary and emergency back up), water level monitors, and automated communications equipment. The entire system should be designed by a qualified engineer.
2. The evacuation warning level should be established based upon the potential time required for evacuation of the surface mine pit and the potential rate of inflow. Ideally, the warning should be triggered at a level that allows for evacuation before overtopping of the dam by the PMF and resulting inundation within the pit to a critical level. The flood control structure should typically be maintained either in a dry condition of with a limited water level and storage volume that would not present a hazard to downstream personnel. When determining the water level for the warning system, any water stored behing the dam must be taken into account.
3. Multiple warning levels should be considered. For example, in addition to the evacuation warning level, an alert should also be issued at a lower level that would result in mine personnel coming to the dam to verify that the system is working correctly and to monitor the situation.
4. While the mining operation is immediately downstream of the dam, the warning system should be tested on a frequent basis and, if practicable, before expected large meteorologic events.
5. The warning plan should clearly define the procedures to be followed when the warning system is activated, and mine personnel should be trained on the appropriate response to a warning.
6. The warning plan should address the status of the dam after the mine pit has advanced beyond the influence of the water course. The plan should state whether the dam will be removed or will remain in place. If the dam is to remain in place, it should be evaluated, as necessary, to verify that the hazard potential classification is appropriate for the downstream area potentially affected by a dam failure. The warning system approach should only be in effect for the potential hazard posed to the mining operation for the temporary period when the pit could be affected.

Note: 1. Use of a warning system must not be a substitute for appropriate dam design and construction. MSHA has indicated that a warning system may be acceptable on a case-by-case basis for support of the use of low- or significant-hazard-potential design criteria at flood-control structures to prevent or mitigate flooding of a surface mine pit. The guidance presented herein reflects conditions that should be considered or evaluated as part of an MSHA impoundment plan.

(FREDLAND, 2008)