Chapter 10

ENVIRONMENTAL CONSIDERATIONS

Environmental considerations for coal refuse disposal facilities generally involve potential impacts to streams and wetlands, air quality, and water quality. Impacts to streams and wetlands originate with facility siting. Air quality issues arise from dust and burning associated with coal refuse embankments. Water quality issues are typically related to the generation of acid leachates by coal refuse or to erosion and sedimentation at refuse surfaces or disturbed areas under development. Liner systems have been used to provide protection of groundwater, and reclamation of coal refuse disposal embankments can mitigate air and water impacts.

Federal and state air and water quality regulatory programs govern site discharges and must be considered in coal refuse disposal facility design. Thus, review of applicable regulatory programs and permit requirements should precede the design of coal refuse disposal facilities. Similarly, liner systems are generally regulated by states.

In light of the above, this chapter provides a general discussion of environmental issues associated with coal refuse disposal facility design, construction, and reclamation.

10.1 STREAMS AND WETLANDS

Coal refuse disposal facilities often impact streams and wetlands regulated by the Clean Water Act (CWA). This legislation was originally enacted in 1972 and was subsequently amended in 1977. When a planned coal refuse disposal facility will impact streams and wetlands, several types of permits and certifications may be required by CWA regulations. Although the U.S. Environmental Protection Agency (USEPA or EPA) has regulatory authority over the CWA, the permits and certifications may be administered and enforced by other federal, as well as state or local agencies. These agencies may include the USEPA, the U.S. Army Corps of Engineers (USACE), the U.S. Fish and Wildlife Service and state Departments of Environmental Protection (state DEPs).

The CWA was enacted with the intent of restoring and maintaining the chemical, physical and biological integrity of the waters of the United States. The term “waters of the United States” includes the following:

1. All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

2. All interstate waters including interstate wetlands;
3. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:
    i. Which are or could be used by interstate or foreign travelers for recreational or other purposes; or
    ii. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
    iii. Which are used or could be used for industrial purpose by industries in interstate commerce;
4. All impoundments of waters otherwise defined as waters of the United States under the definition;
5. Tributaries of waters identified in paragraphs 1-4 of this section;
6. The territorial seas;
7. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) (1)-(6) of this section.

    Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR § 123.11(m) which also meet the criteria of this definition) are not waters of the United States.
8. Waters of the United States do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other federal agency, for the purposes of the Clean Water Act, the final authority regarding Clean Water Act jurisdiction remains with the EPA.

Coal refuse disposal facilities that impact waters of the United States must be permitted and certified under the federal regulations outlined in the CWA. The various sections of the CWA regulate the activities described below:

- **Section 401 – Water Quality Certification**

  This section of the CWA requires that any applicant for a federal permit to construct and operate a coal refuse disposal facility that may result in the discharge of any pollutant must obtain certifications for those activities from the state in which the discharge originates. This certification is referred to as the Water Quality Certification for the project.
- **Section 402 – NPDES Regulations**

  The 1972 amendments to the CWA established the National Pollutant Discharge Elimination System (NPDES) permit program to control discharges of pollutants from point sources. The NPDES permit may be administered and enforced by a local USEPA branch or state DEPs. Some states have additional requirements for stormwater discharges that may impact planned coal refuse disposal facilities and are not covered by the CWA.
- **Section 404 – Dredge/Fill Permitting**

  This section of the CWA established a permit program to regulate the discharge of dredged or fill material into waters of the United States. This permit program is administered by the USACE under a memorandum of agreement between the

Department of the Army and the USEPA. Under Section 404 of the CWA an individual or general permit may be needed based on the proposed activities.

In addition to the Clean Water Act, other statutes and regulations such as the Surface Mining and Reclamation Act (SMCRA) of 1977 and the Safe Water Drinking Act (1974) may be applicable to coal refuse disposal facilities with respect to streams and wetlands. These regulations may result in additional permitting not covered by the CWA. The Office of Surface Mining (OSM), U.S. Department of the Interior, is responsible for the national program to regulate the surface effects of coal mining activities, although each state may take on primary responsibility if the state's regulatory program is approved by the OSM.

Consideration should be given early in the design process to the permits and certifications required for coal refuse disposal facilities as they relate to streams and wetlands. The time involved in the permitting process is typically lengthy and must be accounted for in coal refusal disposal facility design. Agencies such as the USEPA, USACE, U.S. Fish and Wildlife Service, state DEP, and local municipalities should be contacted prior to permit preparation to determine what permits and certifications will be required and which agencies will administer and enforce them. Once the required permits are determined, it may be beneficial to hold a pre-submittal meeting with the appropriate agencies. After the meeting, the permit applications should be submitted in a timely manner, allowing for responses to permit application comments. Some states have moved to a combined application process, although generally permit applications are submitted separately and at various times during the design process.

10.2 AIR QUALITY

Coal refuse disposal can create two types of air quality problems: (1) fugitive dust and particulate matter and (2) noxious gases originating from burning refuse embankments. Fugitive dust becomes airborne due to wind and coal refuse handling and placement. Sources may include: emissions from haul roads; wind erosion from exposed surfaces, storage piles and spoil piles; reclamation operations; and other material or earth disturbance activities. Fugitive dust can be ingested by humans and animals and can also be harmful to vegetation. High concentrations of sulfur dioxide associated with the combustion of coal refuse are toxic to nearby vegetation. Also, sulfur dioxide, organics (polynuclear aromatic hydrocarbons such as benzo(a)pyrene), and metals (mercury and arsenic) are harmful if inhaled in significant volumes by humans.

Dust is regulated as an air emission by state DEPs or, if no approved state program exists, by the USEPA. If amendments are being considered or co-disposal with combustion waste is planned, dust control requirements can take on greater significance than with normal construction. If accidental combustion occurs at coal refuse disposal facilities, air emissions can become a significant health and safety concern, and methods to address burning may need to be developed and implemented as part of a remedial action.

The following sections discuss measures for controlling dust and for reducing the potential for combustion or controlling burning should it occur.

10.2.1 Dust Control

The transportation and placement of coal refuse can create a considerable amount of fine particulate matter that is susceptible to wind erosion. Coal refuse is compacted and crushed by machinery during placement and further deteriorates through physical weathering and chemical decomposition. When refuse-related dust problems occur, they can be mitigated by stabilizing the surface layer of the refuse. This can be accomplished by applying water or a dust suppressant solution over disturbed areas, establishing windbreaks of trees or hedgerows that alter both the direction and the velocity of wind over the refuse material, or performing reclamation by covering and vegetating the disturbed surface (Coalgate et al., 1973).

In situations where a relatively quick dust control procedure is needed or where vegetation is for some reason impractical, stabilization has been achieved using various commercially available chemical agents. Chemical seals have been accomplished through application of: (1) a lime chip-sodium or potassium silicate topdressing over the refuse material, (2) a resinous or bituminous-base adhesive, (3) calcium, ammonium and sodium lignin sulfonates and bark extracts, (4) resin and wax emulsions or neoprene, and (5) elastomeric organic polymers (Coalgate et al., 1973; Dean and Havens, 1972; and Eigenbrod, 1971). When applying such products to areas such as haul roads that will experience truck or heavy-equipment traffic, the effect on traction should be considered.

Erosion control mats that have plant seeds incorporated within the binding material have been successfully used to vegetate disturbed construction areas and to control dust.

10.2.2 Combustion Control

Current practices in the mining industry have virtually eliminated coal refuse fires. The reason is two-fold. First, the amount of coal in coal refuse has been greatly reduced because of more efficient removal of coal during mining and processing. Secondly, current embankment construction practices involve thorough compaction of refuse material, thus restricting the flow of air and moisture that can create a favorable environment for heat generation. Thus, the discussion provided herein is mainly applicable to older existing embankments.

Components of air emissions from burning coal refuse may include carbon, nitrogen, sulfur compounds and metals such as arsenic and mercury. These emissions can impact human health and the environment. Air emissions along with elevated temperatures can degrade existing vegetation and make establishment of new vegetation impossible.

Coal refuse embankment fires have been caused by spontaneous combustion and in some instances from careless burning of trash or other debris. Coal refuse fires have also been intentionally started to obtain "red dog" material for use as a road construction base or have been accidentally ignited by natural causes such as lightning or forest fires. Historically, the most common cause of coal refuse fires has been spontaneous combustion resulting from the self-heating tendencies of coal. The potential for spontaneous combustion is greatly increased if oxidizing materials such as pyrites are present and if these oxidizing materials are wet (Coalgate et al., 1973; Mihok and Chamberlain, 1968; Nicholas and Hutnik, 1971).

Self-heating of coal refuse generally occurs due to exposure of organic and carbonaceous materials to moisture and oxygen, creating reactions that generate heat. When the generation rate of heat exceeds the rate of heat loss, temperatures within a refuse pile can reach the ignition temperature of the remaining coal and carbonaceous materials. The generation rate of heat is a function of the concentration of reactants (thermophillic bacteria, carbon and oxygen), surface area of the pile, particle sizes of the coal refuse and ambient air temperature (Kim and Chaiken, 1990). When coal refuse is exposed to water and oxygen, heat can be generated from the respiration of bacteria up to a temperature of about 120 to 170 degrees Fahrenheit (° F), when the bacteria die. Beyond this temperature range, oxidation of carbon and carbonaceous materials has to occur if the ignition temperature of coal (in the approximate range of 620 to 788° F for bituminous coal and 842 to 950° F for anthracite coal) is to be reached (Maneval, 1969).

In addition to creating air quality problems, burning refuse embankments can also create potentially dangerous working situations. The most common of these is the creation of burned-out voids or pockets within the interior of the refuse embankment that can lead to surface cave-ins and/or hazardous slides. Attempts to extinguish smoldering refuse facilities with water can cause violent explosions if these burned-out voids become filled with pressurized steam. Explosions can also occur in the vicinity of burning material as a result of airborne coal dust produced during the handling of coal refuse.

Under current disposal conditions, the likelihood of coal refuse igniting is extremely low because of low pyrite and/or coal content. When coal refuse is spread and compacted in lifts in stable embankments, fires rarely occur. Other standard construction practices that should be followed for mitigating combustion potential include:

- Prior to placement of any coal refuse material at a new site, all vegetation and other combustible materials should be removed from the area where refuse will be placed.
- All refuse materials with high pyritic and coal content should be compacted as the facility is constructed, and all large rocks should be crushed or removed to a separate location to prevent the creation of air pockets in the embankment (Coalgate et al., 1973).
- If present, waste materials with high pyritic and coal content should be allowed to weather separately prior to their placement at a refuse facility in order to lessen the chance of a thermal buildup due to oxidation.
- If oxidation is a potential problem, coal refuse facilities should be designed and constructed in a manner that minimizes the amount of exposed surface area in order to decrease the air infiltration (Coalgate et al., 1973).

Typically, detection of burning is based upon on-site visual observation (i.e., noting the presence or absence of smoke and/or sulfur dioxide fumes). However, there is no inexpensive means of detecting overheated refuse materials below the embankment surface prior to their combustion. Methods that have been used to detect combustion of conditions leading to combustion include:

- Gas Emission Monitoring – Carbon monoxide (CO) is a by-product of coal refuse oxidation and can be detected very early in the oxidation process. Surface monitoring of CO emissions can thus indicate the potential for spontaneous combustion. Hydrogen sulfide (H_2S) is also a by-product of coal oxidation. Concentrations of this noxious gas will be present prior to combustion and can also be detected through monitoring (Chamberlain and Hall, 1973; Chamberlain et al., 1970; Guney, 1968).
- Direct Thermal Monitoring – The internal temperatures of refuse embankments can be monitored by inserting temperature probes into driven pipes or drilled holes. The temperature buildup associated with oxidizing refuse material can thus be profiled.
- Remote Sensing – Thermal and optical images from an airborne platform can be used to identify the location, depth, size and propagation of hot spots and fires (Zhang et al., 2004). Landsat TM imagery and airborne thermal scanner data have been employed in remote sensing studies for measuring ground surface temperatures. The surface temperature data can then be used for estimating the extent and depth of coal fires using thermodynamic models.
- Electrical Resistivity Geophysical Survey – Some researchers have employed surface DC electrical resistivity for distinguishing burnt sedimentary rock with relatively high resistivity from non-impacted sedimentary rock. The burnt rock has a higher porosity, more cracks and lower water content, which allows it to be distinguished from the non-impacted rock.

10.2.3 Refuse Fire Extinguishment

Extinguishing coal refuse fires is normally not a problem confronting engineers and designers of new coal refuse facilities. However, when an existing facility is being modified or added to, fire abatement can be an important part of the engineering and design process. Fire extinguishment can also be a critical consideration when a refuse embankment is being prepared for abandonment.

Studies have determined that refuse embankment fires generally burn in a temperature range between 600° and 2000° F. It has also been found that once refuse materials have reached a temperature of approximately 200° F, either through spontaneous heat buildup or through heat transfer from adjacent areas, they will eventually self-ignite given favorable conditions such as an abundant supply of air and moisture (Magnuson and Baker, 1974).

Since the reactions that create heat are inherently variable, no single safe temperature has been identified below which heat buildup and refuse ignition will not occur. Ignition temperatures vary with each embankment and with location within the embankment and are largely a function of available air and the site-specific characteristics of the coal refuse. It is therefore not enough to extinguish the burning portion of a refuse embankment. Steps must also be taken to: (1) lower the temperature of the refuse below the point of re-ignition and (2) eliminate embankment conditions that could lead to temperature buildup and future re-ignition.

Temperatures in coal refuse embankments that are sufficient for combustion have been measured at depths of 100 feet or more. However, at that depth the amount of available oxygen is minimal and ignition will not occur. If, however, "hot spots" are exposed through the excavation of overburden or through some other embankment modification, the additional available oxygen may cause these areas to ignite. Critical extinguishment depths are therefore related to site-specific conditions and may be affected by future actions that may alter these conditions.

As indicated previously, the most critical concerns facing those attempting to extinguish a coal refuse fire are the unique dangers involved in using water and in excavating materials in ways that may cause airborne dust. Explosions that can result from such practices can hurl hot debris over nearby areas and can lead to failure of the refuse embankment. Similarly dangerous are smoldering internal voids created when a refuse embankment burns. These areas of potential cave-in can be extremely dangerous to workers and fire fighters alike. Carbon monoxide poisoning is also a danger.

Despite these potential dangers, a number of fire-fighting techniques have proven successful in certain situations. For purposes of discussion these techniques can be grouped into three general categories: (1) physical removal of the burning refuse, (2) quenching and/or sealing by surface treatment, and (3) quenching and/or sealing by injection into the burning refuse. These methods are briefly discussed in the following paragraphs and are also summarized in Table 10.1.

10.2.3.1 Excavation and Removal

Excavation and removal has historically been the predominant method for extinguishing refuse embankment fires (Kim and Chaiken, 1993). This approach has several variations, each generally involving the removal of burning materials from the refuse embankment. The removed materials may be extinguished by quenching, cooling, and suffocation, or they may simply be allowed to burn out. This method can be effectively used when the burning areas are relatively small and accessible and when removal activities do not adversely affect embankment stability. Extreme care must be taken to minimize airborne coal dust when handling burning refuse materials. This dust can ignite and cause violent explosions. Also, any time that equipment is working over burned-out areas, there is a danger that large voids created by the fire will collapse under the weight of the equipment. Variations of the excavation and removal approach include:

- Excavation – Small and readily-accessible burning areas can be extinguished by removing the burning refuse material from the embankment using construction equipment. The removed material can then be extinguished through quenching, or

TABLE 10.1 FIRE EXTINGUISHMENT TECHNIQUES

	Method	Brief Description	Limitations
Physical Removal	Excavation	Burning refuse excavated from embankment; extinguished or allowed to burn itself out; facility regraded and sealed	• Dust and noxious fumes • Access to burning material • Possible cave-ins • Weakens refuse facility
	Water cannons	Water cannons used to dislodge and quench burning refuse; quenched material replaced and recompacted on refuse facility	• Source of quenching water • Weakens refuse facility • Potential for dust explosion
	Isolation	Burning zone isolated by excavating trenches; burning zone quenched or buried with inert sealing material; trenches refilled with inert material	• Access to burning material
	Controlled burnout	Burning refuse is allowed to burn under monitored and controlled conditions	• Access to burning material • Duration is uncertain • Weakens refuse facility
Surface Treatment	Blanketing or sealing	Entire burning embankment covered with mantle of clay or soil; compacted; burning is smothered	• Limited to small facilities • Maintaining seal's integrity • Possible cave-ins • Source of clay or soil
	Foam covering	Entire refuse facility is sealed with a commercial foam blanket; oxygen denied the refuse; burning is extinguished	• Facility size • Maintaining a seal • Can't use where burning is near surface
	Rice paddy technique	Suited for flat refuse areas; dikes constructed around perimeter and area flooded; water percolates into burning zone; fire quenched.	• Supply of water • Possible cave-ins • Slow • Stability
	Water sprinklers	Burning refuse facilities are "wet-down" or saturated by a system of sprinklers until burning is extinguished	• Water source • Saturation weakens structure • Reignition possible
Internal Treatment	Multiple well-point system	Horizontal insertion of perforated metal piping near base of embankment; water injected; pipes removed and reinserted in higher strata; process repeated for total structure	• Source of quenching water • Slow • Weakens refuse facility
	Slurry injection	Vertical or angle holes drilled into burning embankment at various depths; liquid slurry injected into burning voids; steam vent pipes inserted; heat reduction monitored	• Slow • Stability

it can be allowed to burn at a safe distance from the refuse embankment. Once the burning material has been removed from the embankment, the excavated portion should be backfilled, regraded, compacted and covered with a sealing material that will limit air flow (Coalgate et al., 1973; Jolley and Russell, 1959). A major drawback to this approach is that machinery operators may be exposed to large doses of noxious and toxic gases that are dangerous if exposure is prolonged. Health and safety monitoring, air monitoring and use of personal protective equipment are required for this activity.

- <u>Water cannons</u> – Water cannons similar to those used by fire departments have been used to dislodge and quench burning refuse materials when they are near embankment surfaces. Removal of the quenched material can be accomplished by: (1) hydraulic sluicing using a water cannon, (2) excavation by dragline, and (3) loading on trucks for dumping elsewhere. For all three alternatives the extinguished material should be re-spread and compacted in accordance with facility plans and specifications. The use of this technique is contingent upon the availability of water and the stability of the embankment during hydraulic excavation (McNay, 1971).

- Isolation – Burning materials can be isolated from the remainder of the refuse facility by cutting trenches around them. To eliminate heat transfer, such excavations should be at least 6 feet wide and should extend into the embankment foundation. Once the burning material is isolated, it can be extinguished with water, by applying a sealant, or by burying under a blanket of non-combustible material. The exposed trench faces should be sealed with clay or fine-grained soil to restrict air flow, or the trenches should be backfilled with non-combustible material such as soil. To prevent heat transfer from the burning portion of the embankment to non-burning areas, sand or other heat-conducting material should not be used as backfill (Coalgate et al., 1973; Jolley and Russell, 1959).

To mitigate the potential for explosions, excavations into refuse materials that are known or suspected to be burning must be performed with extreme care if hot or burning materials will be exposed to airborne coal dust and/or moisture. Through monitoring, areas of high material temperature can be mapped (if boreholes are used, they should be sealed to prevent airflow). Excavation should be performed in stages and monitored with the intent of avoiding opening up burning areas to moisture and coal dust in confined spaces. Work should proceed downwind (from upwind areas) using equipment that can operate from above and away from burning areas. Upon completion of the excavation, backfill materials should be placed in lifts and compacted, which will minimize the potential for rekindling.

10.2.3.2 Surface Treatment

The methods described in this section require that the embankment be relatively small and have accessible slope faces. Basically, surface treatment involves sealing of the entire surface of an embankment to restrict air flow to the fire. The primary problem with surface seals is maintaining them until sufficient cooling has occurred to prevent re-ignition. This maintenance period can exceed 20 years (Kim and Kociban, 1994), which is greater than the effective life of many types of surface seals. Common surface treatment methods are described in the following:

- Blanketing or sealing – In some instances, it may be practical to extinguish burning refuse by blanketing the entire embankment with about 2 feet of non-combustible material such as fly ash, clay or other soil. This cover should be compacted as it is applied, thereby smothering the burning refuse. Breaks in the seal can occur through water erosion, heat cracks, cave-in of burned-out voids, or even wind erosion (Coalgate et al., 1973; Jolley and Russell, 1959; McNay, 1971; Myers et al., 1966). In extreme cases, where the need to extinguish an embankment fire exceeds normal economic constraints, commercial foam sprays (e.g., polyurethane) have been applied (Magnuson and Baker, 1974).
- Rice-paddy technique – This procedure is only suited for large, stable, flat-topped refuse facilities. Since minimal fumes and dust are created, it is ideal for sites located near residential areas. Dikes are constructed around the top perimeter of the burning refuse facility and at appropriate intermediate locations. Each diked area or pond is then flooded, and the impounded water percolates into the embankment. Draglines can be used periodically to stir the bottoms of the ponds to increase the rate of percolation. The use of this fire-abatement procedure is dependent upon an abundant

supply of water and is further dependent upon the ability of the burning embankment to support earth-moving equipment during dike construction (Coalgate et al., 1973; McNay, 1971). The impact of dike construction and water irrigation on the stability of the coal refuse embankment must be evaluated prior to implementation of this method.

- Water sprinklers – In some instances, water sprinklers have been used to wet down burning embankments and to provide a continuous supply of water over and through the refuse material. The success of this procedure is largely dependent upon the hydraulic conductivity of the embankment, and vertical drilling may be required to increase percolation into the embankment interior. The saturation of an impounding embankment can be dangerous, as its stability may be greatly reduced (Coalgate et al., 1973; Myers et al., 1966).

Surface treatment methods should be implemented sequentially with monitoring of explosion and emission hazards, particularly if concurrent or subsequent excavation activities are planned, as previously discussed.

10.2.3.3 Water and Slurry Injection

This approach involves injection of water or slurry into the burning zones under pressure. The injected material quenches and smothers the burning material. The use of an injection method can offer one or more of the following advantages:

- While usually more expensive on a unit volume basis, injection is well suited to spot treatment of smaller burning areas within a larger embankment in contrast to excavation and removal or surface treatment, which require remedial work over a much larger area.
- Inaccessible areas on steep slopes can be treated. Pipes can be driven with air hammers while other equipment (mixers, pumps, etc.) can be placed at a nearby level location.
- Men and equipment do not have to work directly over burning areas.

There are basically two types of injection methods:

- Multiple well-point system – This procedure entails driving perforated pipes in a single horizontal plane near the toe of the embankment and pumping water into the pipes. The pipes are placed relatively close to each other (approximately 2 feet on center) so that the injected water thoroughly saturates the entire zone. Once the burning is extinguished in that zone, the pipes are withdrawn and then re-inserted a short distance above their previous location. Water is again introduced to extinguish the fire in this new area. This procedure is repeated until all the burning areas within the embankment are extinguished. It should be emphasized that in order to minimize the potential for re-ignition of the refuse material, this procedure should progress from the bottom of an embankment upward. Because the burning portion of the embankment becomes saturated, the use of this method is not recommended if stability is an issue.
- Slurry injection – When slurry is injected into an embankment, voids and air channels are blocked and air access is restricted (McNay, 1971). The slurries most commonly used are suspensions of fly ash, limestone dust, vermiculite, sodium bicarbonate or mine drainage sludge in water. Pipes are typically driven vertically into the burning zone on 10- to 15-foot centers. Slurry is injected under low pres-

sure (usually 10 to 15 psi) to depths of 40 feet or more. When the slurry is no longer accepted, the pipes are raised and injection is resumed. The interior or deepest portion of the burning zone is treated first in order to prevent further penetration of the fire. Injection then progresses toward the surface of the embankment. Because of the danger of explosions, open pipes should be inserted next to the injection holes to vent steam. Use of cryogenic slurry consisting of liquid nitrogen and granular carbon dioxide to enable quick cooling of the burning material has been proposed. Some initial testing demonstrating the ability of this approach to lower temperatures over an extended period was conducted (Kim and Kociban, 1994).

10.3 WATER QUALITY

As indicated previously, coal refuse facilities can substantially degrade the quality of water in nearby drainage courses if they are improperly constructed. In addition to adversely affecting surface-water, drainage from refuse facilities can also affect the groundwater. Although a variety of water quality problems can be created by coal refuse drainage, the most common effects are: (1) increased turbidity and suspended solids and (2) water quality degradation due to acidic leachates (Martin, 1974).

Water pollution problems created by coal refuse can be substantial. Coal refuse leachates can be acidic, can contain elevated concentrations of metals such as iron, aluminum and manganese, and can also be corrosive. When leachates enter a stream, aquatic environments may be greatly altered and desirable organisms may be reduced or eliminated entirely. When refuse leachates percolate into the groundwater, aquifers can be significantly impacted. The following sections provide a discussion of mine refuse water quality issues and various procedures and techniques for controlling and/or mitigating their adverse effects.

10.3.1 Erosion and Sedimentation

Erosion and sedimentation control plans must be submitted to state and local regulatory authorities as part of refuse disposal facility designs. These plans typically include a variety of measures for diverting drainage from disturbed areas, for controlling erosion, and for removing sediment from runoff before release of surface water from the refuse disposal site. As part of these plans, effluent monitoring programs are typically established to verify that erosion and sedimentation control measures are effective.

10.3.1.1 Prevention

When coal refuse and earthen materials are exposed to weathering, erosion and sedimentation can occur. The following practices can be implemented to minimize erosion and sedimentation:

- Stripping of vegetation from a disposal site should be limited to only the area that is needed for construction. Future fill areas should be stripped immediately prior to construction.
- Topsoil that is removed from a construction area and stockpiled for future use should be stored in a manner that minimizes erosion and should be revegetated as soon as possible.
- During the construction process, care should be taken to preserve vegetation on areas surrounding the disturbed construction area.
- Collection ditches and sedimentation ponds should be constructed at the downstream end of the construction site.
- All fill material exposed during construction should be graded in a manner that minimizes the potential for runoff over the downstream face of the embankment. This is particularly important for the crest and downstream face of the refuse embankment.

- Completed embankment surfaces should be reclaimed and vegetated as soon as practical, while accommodating seepage control measures such as extension of underdrains or installation of collection and discharge systems at the embankment toe.

10.3.1.2 CONTROL

Control procedures for reducing the amount of suspended material entering streams are presented in the following subsections.

10.3.1.2.1 SEDIMENTATION PONDS

Sedimentation ponds are structures designed to intercept and retain water-borne sediment and debris. They are primarily intended for use during construction prior to the establishment of effective vegetation on the disturbed area. Sedimentation ponds should be sized and constructed in accordance with criteria prescribed by state mining regulation agencies. These structures normally do not retain water for long periods and are usually maintained with low water surface levels except following rainfall. Engineering design criteria and standards for sedimentation ponds have evolved from requirements for surface mining operations. In most instances, these standards are also applicable to coal refuse (Davis, 1973).

OSM rules for sedimentation ponds under 30 CFR § 816.46 to 49 generally include the following:

- Sedimentation ponds can be used individually or in series.
- They should be located as near as possible to the disturbed area and not in perennial streams.
- They should provide adequate detention time to meet effluent standards and should contain or treat the runoff from the 10-year, 24-hour precipitation event.
- They should provide sediment storage capacity with periodic sediment removal sufficient to maintain adequate volume.
- Ponds with embankments that meet or exceed the impoundment size criteria or other conditions indicated in 30 CFR § 216 (20 acre-feet capacity or 20 feet in height) should have principal and emergency spillways designed to safely pass the runoff from a 100-year precipitation event or larger, depending upon the hazard potential classification. For ponds that do not meet or exceed the impoundment size criteria, the principal and emergency spillways should be designed to safely pass runoff from the 25-year precipitation event or greater, as specified by the state regulatory authority.

State agencies generally provide additional guidance regarding determination of the sediment storage capacity and may require specific design storm parameters or values for sizing the principal and emergency spillways.

In situations where very fine particulate material is suspended in the refuse drainage, the amount of time required for natural settlement or clarification in a settling basin can be long. If the drainage is carrying a significant volume of suspended solids, clarification can be accelerated through use of chemical flocculants. This practice may also be considered when the capacity of a sedimentation pond is relatively small.

Sediment/sludge removal is required in order to sustain sedimentation pond capacity. In the event that such removal is not practical, sedimentation ponds should be designed with a capacity large enough to accommodate sedimentation over the appropriate operating period.

10.3.1.2.2 Sediment Traps and Check Dams

Sediment traps and check dams may be useful as intermediate structures between erosion sources and sedimentation ponds or can be employed where sedimentation ponds are prohibited or unfeasible. They should be located within site drainage structures and should not cause channel overflow under design flow conditions. Design and installation should be in accordance with state regulations.

10.3.1.2.3 Silt Fences

Silt fences are temporary structures for detaining sediment-laden overland (sheet) flow long enough that the larger-sized particles are deposited and silt-sized particles are filtered out. State regulatory publications provide design and construction guidance for silt fences, and manufacturers provide similar information for their products. The following are general guidelines for silt fences:

- The drainage area should not exceed 0.25 acres per 100 feet of silt fence length.
- For slopes between 50:1 and 5:1, the maximum allowable upstream flow path length to the silt fence should be 100 feet.
- The filter material should be able to retain at least 75 percent of the sediment.
- The bottom edge of the silt fence should be tied or anchored into the ground to prevent underflow.
- There should be no ponding behind silt fences.
- Silt fences should be regularly maintained.

Appropriate state guidelines should be reviewed prior to installation of silt fences.

10.3.1.2.4 Erosion Control Blankets and Reinforcement Mats

Erosion control blankets can be used to stabilize freshly seeded slopes and drainage or ditches until such time that a cover of vegetation is established. Typically, they are most effective on slopes up to 3:1 and in drainage ditches with slopes up to 20:1. Erosion control blankets typically degrade within 6 to 24 months of installation, depending on their composition (straw, fiber, and plastic systems). Design and installation guidance are available in state regulatory publications and manufacturers' literature.

Reinforcement mats are similar to erosion control blankets, but provide greater protection because of the use of synthetic fibers that reinforce vegetation and result in more erosion-resistant construction. Reinforcement mats are used for steep slopes (greater than 3:1) and channels with slopes in the range of 15:1 to 10:1. Design and installation guidance are available in state regulatory publications and manufacturers' literature.

10.3.1.2.5 Vegetation

Erosion and stream turbidity are best minimized by establishing a protective layer of vegetation on embankment slopes and along exposed ditch surfaces. The establishment of grasses in drainage ditches reduces flow velocity and, consequently, erosion.

Vegetation covers on embankment slopes are not practical until construction has proceeded far enough that relatively stable slope conditions are achieved. Vegetation is further discussed in Section 10.5.5.

10.3.2 Acid Generation and Control

The potential for acid generation from coal refuse materials can be estimated, and measures can be implemented to control acid formation or migration. State regulatory programs vary in terms of prediction methodology and the measures required to control or contain acid mine drainage.

10.3.2.1 Background

Acid generation is principally the result of pyrite oxidation. Pyrites are commonly associated with coal formations and surrounding strata. Several types of pyrites may be present, and the reactivity of different forms varies significantly (Kleinmann, 2000). Acidity is produced by the oxidation of pyrites (sulfide components and iron components), which leads to the dissolution of metals (ferric iron, manganese, and aluminum, and occasionally other metals such as copper, zinc, and nickel). Rock strata may contain carbonate materials that neutralize acidity; however, coal refuse is material segregated from coal and generally includes minimal overburden materials that will neutralize acidity.

Acid mine drainage is a major problem in the northern Appalachian Basin (particularly within the Allegheny Group stratigraphic section) and less significantly in the Midwest (Kleinmann, 2000; Appalachian Regional Commission, 1969; Wetzel and Hoffman, 1989). Kleinmann (2000) provides a discussion of geology, hydrology and prediction of acid generation, including acid-base accounting (static or whole rock analysis) and simulated weathering tests (kinetic testing such as leaching tests in various columns and chamber arrangements). Testing procedures associated with acid-base accounting can be applied to individual samples of overburden and spoil materials for predicting acid generation or reclamation performance. Table 10.2 presents a summary of suggested criteria for interpreting the results of acid-base accounting analysis. While simulated weathering tests are not routinely used for coal mine drainage prediction, they can provide data for estimating the relative concentrations of net acidity, metals and sulfate, and they can be useful for evaluating the effectiveness of various amendments for mitigating problem water quality conditions. Kleinmann (2000) provides a detailed discussion of criteria for determining whether to conduct kinetic testing as well as testing methods.

Mitigation of acid generation can also be accomplished by hydrologic controls that minimize water contact with air and refuse. This typically involves: (1) compaction of the refuse surface, (2) sealing of the refuse surface and diversion of runoff from active disposal areas, and (3) capping and covering of completed refuse disposal areas. The USEPA (2000) developed a best management practices guidance manual for remining of refuse disposal sites providing specific guidance related to erosion and sedimentation controls and mitigation of acid generation.

10.3.2.2 Grading, Compaction and Sealing

Grading, compaction and sealing of coal refuse embankment surface areas will minimize the potential for infiltrating water contacting pyrites and thus reduce the potential quantity of acid generation and groundwater migration. Grading facilitates control of surface water flows, and compaction reduces the hydraulic conductivity of the refuse material. Regular sealing of the refuse embankment surface using smooth-drum rolling equipment facilitates runoff and thus reduces infiltration and the generation of acid leachates. Before subsequent placement of additional lifts, the sealed surface should be scarified to enhance bonding between lifts and to minimize potential stratification.

10.3.2.3 Amendments

A number of amendments for neutralizing acidity have been used with coal refuse, including coal combustion waste (lime-containing materials), kiln dust, phosphate rock, lime and other products. The amount of amendment material required for neutralizing acidity is a function of several factors, as described by Kleinmann (2000), USEPA (2000), and Brady et al. (1998). Stewart et al. (1997, 2001) evaluated neutralization and leaching from various blends of combustion waste and acid-producing refuse based upon a series of multi-year unsaturated column experiments. With sufficient combustion ash (20 percent and greater for the cited ash and coal refuse), no evidence of acid conditions was detected and low levels of most metals were observed, although high concentrations of boron and sulfate were reported. In column tests where the combustion ash

TABLE 10.2 SUMMARY OF SUGGESTED CRITERIA FOR INTERPRETING ACID-BASE ACCOUNTING

Criteria	Application	References
Rocks with NNP less than -5 parts/1000 considered potentially toxic.	Coal overburden rocks in northern Appalachian basin for root zone media in reclamation.	Smith et al., 1974, 1976; West Virginia Surface Mine Drainage Task Force, 1979; Skousen et al., 1987
Rocks with paste pH less than 4.0 considered acid toxic.	Coal overburden rocks in northern Appalachian basin for root zone media.	Smith et al., 1974, 1976; Surface Mine Drainage Task Force, 1979
Rocks with greater than 0.5% sulfur may generate significant acidity.	Coal overburden rocks in northern Appalachian basin, mine drainage quality.	Brady and Hornberger, 1990
Rocks with NP greater than 30 parts/1000 and "fizz" are significant sources of alkalinity.	Coal overburden rocks in northern Appalachian basin, mine drainage quality.	Brady and Hornberger, 1990
Rocks with NNP greater than 20 parts/1000 produce alkaline drainage.	Coal overburden rocks in northern Appalachian basin. Base and precious metal mine waste rock and tailings in Canada.	Skousen et al., 1987; British Columbia Acid Mine Drainage Task Force, 1989; Ferguson and Morin, 1991
Rocks with NNP less than -20 parts/1000 produce AMD.	Base and precious metal mine waste rock and tailings in Canada.	British Columbia Acid Mine Drainage Task Force, 1989; Ferguson and Morin, 1991
Rocks with NNP greater than 0 do not produce acid. Tailings with NNP less than 0 produce AMD.	Base and precious metal mine waste rock and tailings in Canada.	Patterson and Ferguson, 1994; Ferguson and Morin, 1991
NP/MPA ratio less than 1 likely results in AMD.	Base and precious metal mine waste rock and tailings in Canada.	Patterson and Ferguson, 1994; Ferguson and Morin, 1991
NP/MPA ratio classified as less than 1 (likely AMD), between 1 and 2 (possible AMD), and greater than 2 (low probability of AMD).	Base and precious metal mine waste rock and tailings in Canada.	Ferguson and Robertson, 1994 Price et al., 1997
Theoretical NP/MPA ratio of 2 needed for complete acid neutralization.	Coal overburden rocks in northern Appalachian basin, mine drainage quality.	Cravotta et al., 1990
NP/MPA ratio used with NP threshold to determine confidence levels for acid producing samples. 80% confidence of no acid production if NP/MPA ratio of 6.5 and NP threshold of 3.3%.	Coal overburden samples from 4 states: PA, WV, TN, and KY.	Bradham and Caruccio, 1995
Use actual NP and MPA values as well as ratios to account for buffering capacity of the system.	Base metal mine waste rock, United States.	Filipek et al., 1991

Note: NP = Neutralization potential
NNP = Net neutralization potential
MPA = Maximum potential acidity

(ADAPTED FROM KLEINMANN, 2000)

was insufficiently alkaline or where insufficient ash was combined with the refuse, acid generation ultimately exceeded the neutralizing alkalinity of the ash, resulting in a decline in pH and increased concentrations of metals. Stewart et al. (2001) recommend that careful attention be paid to balancing the acid-generating potential of refuse with the alkalinity of combustion ash. Some practitioners recommend increasing the alkalinity by some factor in order to prevent acidic conditions (Daniels et al., 1996).

Daniels et al. (2002) evaluated various combustion ash and coal refuse mixing strategies (including layering and partial blending) to determine their effectiveness in reducing acidity; they demonstrated the value of blending in alkaline materials as close as possible to the area where acid generation is occurring. Rich and Hutchison (1990) discuss the use of kiln dust for neutralizing combined coal refuse. Use of limestone, oxides, phosphate rock and other materials for neutralization is addressed by Skousen et al. (1998).

If amendments are used, provisions should be included in the design plans to verify that proper placement and/or mixing are achieved. The effect of amendments on the geotechnical characteristics of the refuse materials, particularly the strength and hydraulic conductivity of materials placed in structural embankment zones, should be assessed, as discussed in Sections 5.1.5 and 6.2.3.5.

10.3.2.4 Reclamation and Vegetative Cover

Reclamation and vegetative cover following completion of disposal operations provides drainage control and limits contact of the coal refuse with infiltrating water. The USEPA (2000) provides a qualitative discussion of improvements in the control of acid generation associated with reclamation and vegetation and cites supporting quantitative studies. Gentile et al. (1997) describe a cover system for an Illinois refuse disposal facility consisting of a compacted clay liner and protective soil cover designed to reduce infiltration by 84 percent. Meek (1994) describes the use of a PVC liner that reduced acid loads from a spoil pile by 70 percent.

While placement of barriers to infiltration as part of reclamation can address acid generation, provisions such as drainage systems should also be incorporated, so that internal seepage can discharge from the toe of a refuse embankment without raising the phreatic surface.

10.3.3 Water Quality Control

10.3.3.1 Diversion of Runoff

Drainage from undisturbed portions of a watershed should be conveyed around coal refuse disposal facilities to the extent practical using diversions. Thus, the amount of drainage contacting coal refuse and potentially subject to water quality impacts will be minimized. State regulatory guidelines provide criteria for the design and construction of diversion systems for control of runoff from undisturbed areas. While use of diversion ditches for impoundments can assist with controlling runoff, their capacity can only be considered in the impoundment flood routing if they are designed and constructed to handle the associated impoundment design storm (e.g., the Probable Maximum Flood for a high-hazard potential impoundment).

10.3.3.2 Treatment

Treatment of acid mine drainage typically involves neutralization of acidity and precipitation of metal ions to meet applicable effluent standards (USEPA, 1983). To meet the required standards, a variety of treatment methods including active and passive treatment technologies can be employed.

Selection of an active treatment system involves evaluation of the flow rate, pH, total suspended solids, acidity/alkalinity, iron and manganese concentrations, the receiving stream's flow rate and use, availability of electric power, the distance from the point of chemical addition to the point where the water enters a settling pond, and the volume and configuration of the settling pond. Most active chemical treatment systems consist of an inflow pipe or channel (sometimes a raw water storage pond and aerator for large flows), a storage tank or bin for treatment chemicals, a chemical metering system, a settling pond for precipitated metal oxyhydroxides, and a discharge point for treated water. Table 10.3 presents a summary of chemical compounds used for acid mine drainage (AMD) treatment and an equation for estimating the quantity of chemicals required based on the stream flow and the acidity of the AMD. Aeration enhances oxidation of metals such that chemical treatment is more efficient. Oxidants and pH adjusters are also sometimes used in the oxidation process to enhance metal oxyhydroxide precipitation and reduce metal floc volume. Mechanical surface aerators are generally used for large flows where aeration is required; simpler aeration systems using gravity to cascade water over rocks or splash blocks may be useful in smaller applications. Chemicals for neutralizing acidity are generally selected based on technical and cost factors. Skousen et al. (1998) discuss active treatment system design and costs and provide case studies.

Passive treatment technologies that take advantage of naturally occurring chemical and biological processes to cleanse impacted water and do not require continuous chemical inputs have been developed. The primary passive technologies include constructed wetlands, anoxic limestone drains (ALD), vertical flow systems such as successive alkalinity producing systems (SAPS), limestone ponds, and open limestone channels (OLC). Table 10.4 presents design factors and references for passive treatment systems. Skousen et al. (1998) discuss passive treatment system design and costs and provide case studies.

10.3.4 Water Quality Impacts on Construction Materials

The corrosive nature of coal refuse and leachates from coal refuse makes construction material selection important if facility appurtenant structures are to function as intended for long periods of time

TABLE 10.3 CHEMICAL COMPOUNDS USED IN AMD TREATMENT

Common Name	Chemical Name	Formula	Conversion Factor(1)	Neutralization Efficiency(2)
Limestone	Calcium Carbonate	$CaCO_3$	1.00	50%
Hydrated Lime	Calcium Hydroxide	$Ca(OH)_2$	0.74	95%
Pebble Quicklime	Calcium Oxide	CaO	0.56	90%
Soda Ash	Sodium Carbonate	Na_2CO_3	1.06	60%
Solid Caustic Soda	Sodium Hydroxide	NaOH	0.80	100%
20% Liquid Caustic Soda	Sodium Hydroxide	NaOH	784	100%
50% Liquid Caustic Soda	Sodium Hydroxide	NaOH	256	100%
Ammonia	Anhydrous Ammonia	NH_3	0.34	100%

Note: 1. The conversion factor may be multiplied by the estimated tons of acid per year to get tons of chemical needed for neutralization per year. For liquid caustic, the conversion factor gives gallons needed for neutralization.

2. Neutralization efficiency is an estimate of the relative effectiveness of a chemical in neutralizing AMD acidity. For example, if 100 tons of acid per year is the amount of acid to be neutralized, then 78 tons of hydrated lime would be needed to neutralize the acidity in the water (100 x 0.74 / 0.95).

(ADAPTED FROM SKOUSEN ET AL., 1998)

TABLE 10.4 DESIGN CONSIDERATIONS FOR AMD PASSIVE TREATMENT SYSTEMS

Treatment System	Raw Water Conditions	Construction	Design Factors to Size Treatment System	References
Aerobic Wetland	Net alkaline water	Overland flow, cattails planted in substrate	• 10 to 20 g $Fe/m^2/d$ • 0.5 to1.0 g $Mn/m^2/d$	Hedin et al. (1993)
Horizontal-Flow Anaerobic Wetland	Net acidic water, generally low flow rate	Horizontal flow above organic substrate	• 3.5 g acidity/m^2/d • Hydraulic conductivity of substrate generally 10^3 to 10^4 cm/sec • Rate of sulfate reduction (~300 mmoles/m^3/day) • Hydraulic loading	Hedin et al. (1993), Eger (1994), Wildeman et al. (1993)
Anoxic Limestone Drain (ALD)	Net acidic water DO, Fe^{3+}, Al < l.0 mg/l	Horizontal flow through buried limestone	• 15 hours contact time • 6- to 15-cm-diameter limestone • Lifetime limestone consumption	Hedin et al. (1994)
Successive Alkalinity Producing Systems (SAPS)	Net acidic water	Vertical flow through an organic layer overlying a limestone bed	• 15- to 30-cm organic matter with adequate permeability • 15 hours contact time in limestone • Lifetime limestone consumption • 6- to15-cm-diameter limestone	Kepler and McCleary (1994)

(SKOUSEN ET AL., 1998)

including abandonment. Table 11.6 lists common construction materials used for facility appurtenant structures and corrosion or deterioration mechanisms. The potential for chemical reaction and for clogging of drainage materials are critical considerations in the design of drainage systems. For drainage structures that are in contact with coal refuse or leachate, measures such as sulfate-resistant cement and coatings applied to metal surfaces should be used, as appropriate.

10.3.5 Hydrogeology

Groundwater recharge, unsaturated groundwater flow and saturated groundwater flow are hydrogeologic mechanisms that can affect migration of coal refuse constituents from a refuse disposal site. Groundwater flow is the primary migration mechanism, as erosion and sedimentation control measures are generally capable of controlling overland flow processes. Table 10.5 presents an overview of the hydrogeologic process and significance of the saturated and unsaturated groundwater regimes. Some hydrogeologic features and their effect on the design of coal refuse disposal facilities include the following:

- Springs – To minimize the potential for contact of water with coal refuse, natural hillside spring flows should be collected and controlled. Spring collection drains provide a means to collect and convey spring water from the source to downstream locations.
- Mine discharges and underground mine workings – In some instances, discharges to and from mines may be important hydrogeologic features, because mines collect and convey groundwater. Similar to springs, discharges from mine openings can be controlled by collection drains that convey the mine water from the source to down-

stream locations. Impoundments may require construction of a barrier to control flow of slurry into the mine workings. Additionally, the underground workings may act as a sink for groundwater migration, including seepage from the impoundment.

- Groundwater – Groundwater flow beneath a disposal site may be affected by seepage from refuse materials. If adverse water quality impacts are anticipated, liner systems and amendments can be used to mitigate these concerns.
- Surface water – Surface-water bodies may be a recharge source or receiving body. Disposal sites located near surface water bodies or impounding facilities may require measures such as liners, cutoffs, and other barriers to protect the hydrogeologic regime.

In addition to provisions for protecting the hydrogeologic regime, state regulatory agencies will require monitoring systems for detecting potential impacts to groundwater quality. This require-

TABLE 10.5 OVERVIEW OF THE HYDROGEOLOGIC PROCESS

Source and Flow Process	Description	References
Recharge	Recharge into the disposal facility may occur from: • Infiltration of precipitation and runoff • Seepage from impoundment waters	Kleinmann, 2000
Unsaturated flow in embankment materials	Unsaturated flow in embankment materials is influenced by the recharge rate and unsaturated hydraulic conductivity and generally migrates vertically toward saturated embankment zones.	Hutchison and Ellison, 1992
Saturated flow in embankment materials	Saturated flow in the embankment materials is influenced by underlying barriers such as foundation materials and internal drainage structures designed to control phreatic levels. Saturated flow generally migrates horizontally along foundation surfaces, although a component of flow can be into foundation soils. A liner system may be employed to restrict this component of flow.	Hutchison and Ellison, 1992
Groundwater flow in embankment foundation soils	Saturated groundwater flow in foundation soils is influenced by underlying aquicludes or bedrock barrier and generally migrates horizontally along such surface, although a component of flow can be into deeper horizons or bedrock. Monitoring well systems are typically employed to monitor groundwater quality conditions beyond the limits of disposal sites.	Hutchison and Ellison, 1992
Groundwater flow in bedrock fracture system	Saturated groundwater flow in the bedrock is influenced by the fracture system (and, in some cases bedrock primary porosity) and generally migrates horizontally toward groundwater discharge zones. Monitoring well systems may be employed to monitor groundwater quality conditions beyond the limits of disposal sites.	Kleinmann, 2000
Groundwater interaction with underground mines	Saturated groundwater flow may interact with underground mines, which may act as a discharge zone. Flow may follow discharge gradients in response to coal seam dip or pressure head within the mine. Monitoring well systems may be employed to monitor groundwater quality conditions.	

ment is usually satisfied through installation of monitoring wells located upgradient and downgradient from the disposal facility. Guidance for monitoring programs is typically available from state regulatory agencies. General guidance for groundwater monitoring systems is provided by Hutchison and Ellison (1992).

10.4 LINER SYSTEMS

Site-specific factors that should be considered in liner system design are summarized in Table 10.6. Liner systems are generally used for containment in situations where acid generation from coal refuse may impact the groundwater. Liner systems are an option in addition to amendments that can be considered for neutralizing acid generation.

Liner systems for protection of groundwater are cited in some state regulatory guidance for coal refuse disposal. Generally the reference is to a single-component, low-hydraulic-conductivity layer. Liner systems employed for other waste containment systems such as combustion waste (DiGioia et al., 1995) generally comprise multiple layers. The layers from the bottom up typically include: (1) sub-

TABLE 10.6 SITE-SPECIFIC FACTORS TO CONSIDER IN LINER SYSTEM DESIGN

Potential Waste Material Toxicity
• Chemical properties of refuse and coal preparation additives • Net acid generation potential • Soluble constituents for anticipated environmental conditions • Special treatment or neutralization procedures utilized • Total mass of soluble constituents
General Water Resource Values at Site
• Adequate quality for beneficial use • Adequate quantity for beneficial use • Existing or identified beneficial uses • Probable locations of future beneficial uses
Leachate Availability to the Environment
• Waste material characteristics • Thickness of waste • Site climatic conditions • Provisions at closure to restrict infiltration
Site Factors
• Topography • Geology, including predictability of uniformity and/or potential for discontinuities • Unsaturated zone thickness, continuity, hydraulic conductivity and natural water content • Potential migration time for seepage to groundwater • Effects of climatic conditions on long-term unsaturated zone mitigation characteristics • Constituent attenuation potential
Waste Disposal Facility Management Practices
• Facility type • Waste placement method • Protection of liner system from environmental damage • Controls on the hydraulic head • Risk reduction practices such as placement of underdrains, sub-aerial deposition, limited time of operations • Non-liner barriers such as cutoff walls • Installation of special early warning monitoring systems

(HUTCHISON AND ELLISON, 1992)

grade or cushion materials, (2) leak detection zone, (3) liners (primary, secondary and/or composite), and (4) leachate collection layer.

10.4.1 Design Requirements

Design and performance requirements for liner systems are generally determined by the following (Hutchison and Ellison, 1992):

- Waste material characteristics including chemical composition, grain-size distribution, hydraulic conductivity, and the presence of free liquids.
- Waste disposal facility characteristics including liner hydraulic conductivity, slope of the liner, depth and slope of waste placed on the liner, waste placement method, hydraulic head controls, and the duration of operation for all or portions of the facility.
- Site characteristics including location and depth of the water resource to be protected, unsaturated zone conditions, and climatic conditions.

The potential for release of leachate is a function of the magnitude of the hydraulic head above the liner, the thickness and effective hydraulic conductivity of the liner material (considering the frequency of discontinuities in the liner such as cracks or holes), and the length of time the hydraulic head is applied to the liner. Leachate from coal refuse is generally not reactive with liner materials, but, if organic chemicals or strong bases are used in the coal preparation process and remain present in the waste, the issue of liner material compatibility may need to be addressed.

A liner system generally consists of a single low-hydraulic-conductivity layer (clay soil or geosynthetic material). Clay soil liners may include an overlying protection layer to protect the liner from erosion and desiccation. Where a geosynthetic material is used, an underlying cushion layer and an overlying protection layer are usually employed to minimize the potential for penetrations. Additionally, single liner systems may include overlying hydraulic head controls such as a pervious layer above the liner. Such systems reduce the head on the liner and thus further limit potential migration of leachate from the disposal facility. Composite double liners and leachate collection and removal systems are used when redundant systems are needed, although such liner systems are not generally used at coal refuse disposal facilities. Table 10.7 summarizes materials and handling and construction procedures associated with individual components of liner systems.

Major considerations in choosing materials for soil liners are availability and composition. Soils must contain a sufficient portion of clay material such that the constructed liner has low hydraulic conductivity, high plasticity, and chemical stability. Suitable soils are usually classified CL, CH, or SC in the Unified Soil Classification System (USCS) with a liquid limit between 35 and 60 and a plasticity index of 10 or greater. Material for soil liners can consist of on-site or local borrow materials, imported bentonite, or mixtures thereof. To achieve the low hydraulic conductivity required for a containment layer, soils must have consistent properties and may need thorough mixing, preprocessing (e.g., removal of rocks, breakdown of soil clods, addition of bentonite), conditioning (e.g., adjustment of water content), placement in controlled lifts, and compaction. Imperfections such as gravel zones, organics and roots should be removed during construction. Protection against cracking from drying or shrinking may also be required.

The required thickness and hydraulic conductivity of the barrier layer are a function of the hydraulic heads, refuse material characteristics, and state policies or regulations. Typically, requirements for a soil liner or barrier layer are a minimum thickness of 2 feet and a hydraulic conductivity less than 5×10^{-5} cm/sec (≈ 50 ft/yr) and in some applications less than 1×10^{-7} cm/sec (≈ 0.1 ft/yr). Variations from these criteria are generally dependent upon in-situ conditions.

TABLE 10.7 AVAILABLE MATERIALS OR PROCEDURES FOR LINER SYSTEM COMPONENTS

A. Low-Hydraulic-Conductivity Liners

A.1 Low-Hydraulic-Conductivity Natural Soil or Rock – Natural soils or rock may be used as a low-hydraulic-conductivity liner so long as it is possible to demonstrate by field investigations that the material is continuous and of sufficient thickness and properties over the entire area requiring the liner. This demonstration may be particularly difficult for rock because of jointing and fracture conditions.

A.2 Constructed Low-Hydraulic-Conductivity Liners – Low-hydraulic-conductivity liners that are constructed beneath a mine waste disposal facility may consist of any of the following materials:

- Compacted, low-hydraulic-conductivity soils (e.g., clayey-silt to clay depending upon the required hydraulic conductivity)
- Soil and bentonite or cement mixtures
- Pre-formed flexible geotextile impregnated with bentonite or pre-formed, granulated bentonite laminated to a geomembrane, referred to as geosynthetic clay liner (GCL)
- Pre-formed flexible membrane liners made from a variety of available polymeric material, generally referred to as geomembranes; varying in thickness from about 20 to 100 mils
- Field-applied liners, varying from about 80 mils of spray-on asphaltic materials to 6 inches of conventionally-placed asphaltic materials
- Composite liners, consisting of combinations of soil and geomembrane low-hydraulic-conductivity layers

A.3 Waste Material – Settled or mechanically placed tailings often have a low hydraulic conductivity and can be used as part of the long-term liner system, provided the tailings serve one of the low-hydraulic-conductivity liner functions.

B. Cushion or Liner Protection Materials

B.1 Geotextiles – Synthetic geotextile materials varying in weight from 4 to 20 ounces per square yard may be used above or below geomembranes to protect against penetrations from rock particles due to loads from construction activities or the weight of the waste material. The suitability of a geotextile to act as a cushioning layer varies and is defined by the method employed by its fabrication (needle-punch non-woven versus woven).

B.2 Fine-grained Soil for Geomembrane Protection – Soils varying from clay to sand can also be used to protect most geomembranes from equipment traffic or static loading of the waste material. Small gravel-size material has also been used to protect thick geomembranes. The protective soil must be relatively free of large rock particles that could cause stress concentrations on the liner.

B.3 Cover Material for Clay Liner Protection – Cover protection may also be required for a compacted soil liner if the liner could be subjected to extreme loads, such as construction equipment traffic, or exposed to drainage or desiccation.

C. Hydraulic Head Control Components

C.1 Free-Draining Gravel Layer – Several inches of free-draining gravel (including coarse sand) are usually adequate to rapidly remove small volumes of leakage. However, thicker layers (8 to 18 inches) are usually placed to facilitate construction and protect the liner layer from being damaged. The waste material itself may serve this purpose if the material is granular, durable and relatively free draining.

C.2 Perforated Pipes – Closely-spaced perforated pipes can be used to control hydraulic head above the liner. The required spacing is calculated based on the maximum desired head and the flow rate and hydraulic conductivity of the waste material between the pipes.

C.3 Geocomposite Systems – Composite systems consisting of synthetic drainage associated with geotextile filters have been developed for a wide range of drainage control functions. Performance of these systems under load must be confirmed.

D. Leachate Collection and Removal Systems

D.1 Synthetic Geonet Materials – Geonets are net-like polymer products designed to allow high rates of transverse flow. Typical thicknesses of these materials vary from 0.16 to 0.30 inches.

D.2 Free-draining Gravel Layer – (See Item C.1)

(HUTCHISON AND ELLISON, 1992)

Geomembranes made from high-density polyethylene (HDPE), polyvinyl chloride (PVC) and very low density polyethylene (VLDPE) have been used as liners. Important considerations in the selection of geomembranes are thickness, strength, durability, chemical resistivity, cost, cover material needed for cushioning above and below the barrier, method of construction, and the method for seaming the liner (Hutchison and Ellison, 1992). Most geomembranes are manufactured with ultraviolet inhibitors (e.g., carbon black) and can be expected to last more than 50 years even when exposed to sunlight. Geosynthetic clay liners (GCLs) consisting of bentonite sandwiched between two geotextiles (woven or non-woven synthetic fabrics) that are glued or sewn together or bentonite laminated to an HDPE geomembrane have also been used. GCLs are resistant to damage due to handling during installation, but they lose shear strength as the bentonite is hydrated, thus decreasing stability.

Geotextiles and soil materials above and below the geomembrane layer may be needed for protection against penetrations by underlying rocks or sharp objects during construction. The protective soil layers should be relatively free of large rocks and roots that could cause concentrated stresses in the liner. State agencies can provide guidance on the use of geomembranes and may specify a minimum thicknes and requirements for compatibility with the refuse materials.

An effective QA/QC program is essential for installation of soil liners, geomembranes and GCLs. Past failures have been attributed to poor material placement, seaming, and protection (Daniel and Koerner, 1995). Composite systems that consist of a combination of soil and a geomembrane have less potential for quality control problems, but may only be economically feasible when suitable soils are available on site.

Figure 10.1 shows three examples of soil and geomembrane liner designs used at coal refuse disposal facilities. Compacted subgrade, as shown in Figure 10.1a, is acceptable in many situations for containment of coal refuse. Soil liners and synthetic liner systems, as shown in Figures 10.1b and 10.1c, respectively, may be attractive in some situations. Some soil and synthetic liner systems may require a prepared subgrade and protective cover materials.

Other layers can be added to a liner system if warranted, including a leachate collection layer and a leachate detection layer. The leachate collection layer should be positioned above the liner to collect and convey seepage from the refuse and to limit the buildup of hydraulic head on the liner. The thickness and hydraulic conductivity of the leachate collection layer should be designed based upon the potential leachate flow, liner configuration (slopes and other geometry that affect seepage), and any restrictions on hydraulic head associated with the liner. The leachate collection layer typically consists of sand and/or gravel designed to be more hydraulically conductive than the waste itself. Geotextiles may be used between this layer and the liner for cushioning and to improve stability.

A network of perforated pipes is sometimes provided within the leachate collection layer to increase capacity, and these pipes must be properly designed to withstand crushing under the embankment weight. The leachate collection layer typically drains to one or more central collector or header pipes. Solid-wall pipes convey the leachate from the disposal area to holding areas for eventual treatment (if required) and discharge. Manholes may be installed at bends and at regular intervals for pipe inspection and cleaning; cleanout fittings may also be used.

Geonets and geocomposite drainage products have been used in some applications for leachate collection (DiGioia et al., 1995) if chemical compatibility and flow capacity under the applied load is acceptable. These products are also sometimes used for leak detection zones beneath the primary liner when conditions warrant.

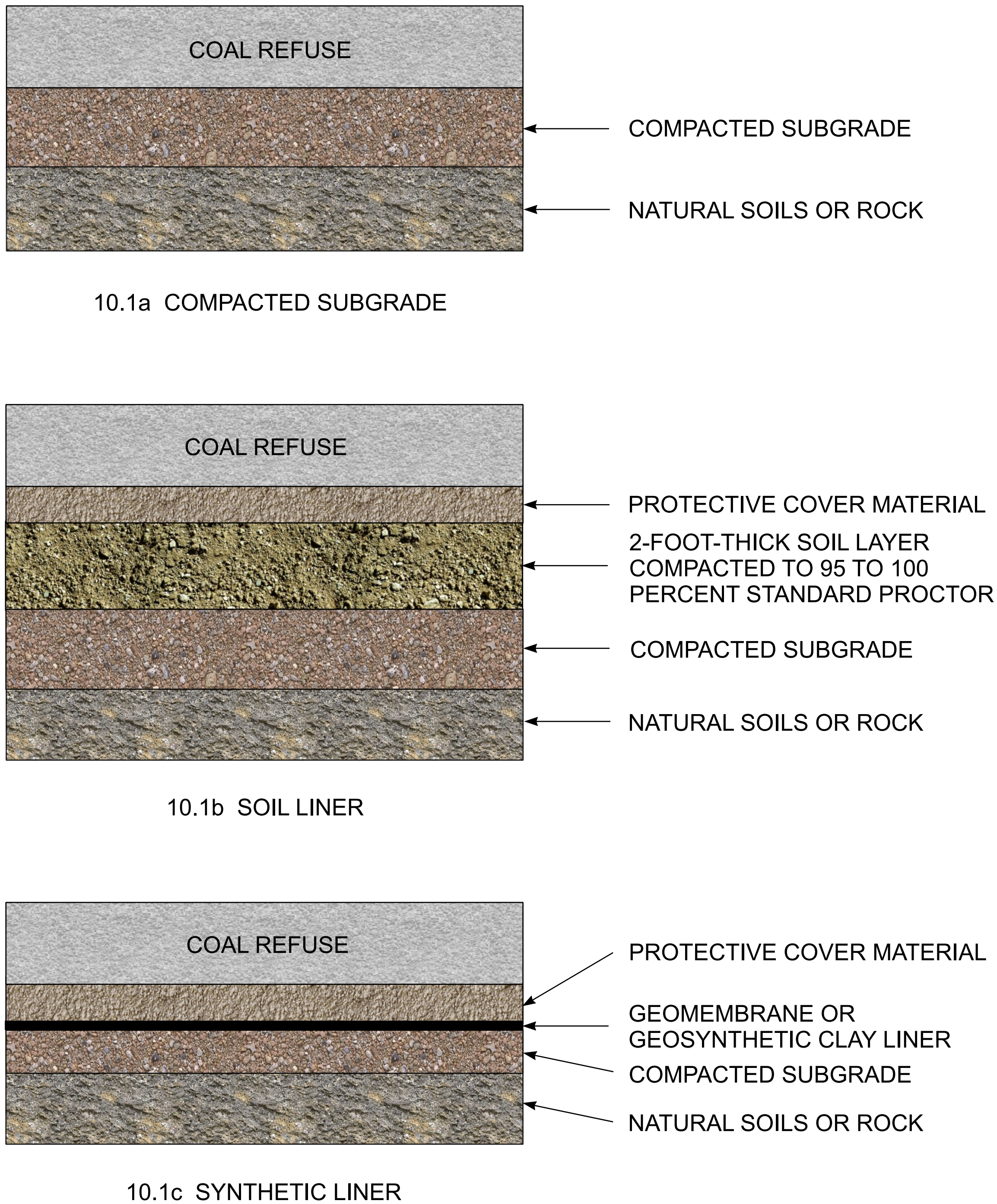


FIGURE 10.1 LINER SYSTEMS USED AT COAL REFUSE DISPOSAL FACILITIES

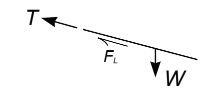
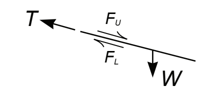
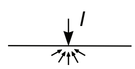
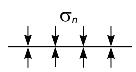
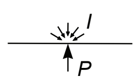
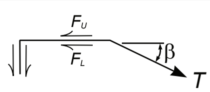
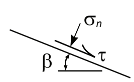
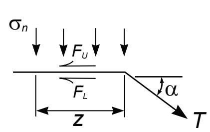
10.4.2 Stability

Structural stability of a liner system is a critical element in design. For embankments, the following types of waste stability issues could cause liner damage: (1) sloughing of loose uncompacted material from surficial zones, (2) block failure of the waste material moving laterally with shearing occurring predominantly within the liner system (particularly for sloping liner system), and (3) dynamic slope instability and permanent displacement related to earthquake or other dynamic loading. Liner damage in the vicinity of the impoundment can arise from erosion due to slurry discharge or from natural runoff, as well as instability of adjacent hillsides. A more detailed discussion of slope stability for situations involving liners is provided in Section 6.6.4. Koerner (2006) also presents procedures for analysis of liner stability. Table 10.8 summarizes stability issues associated with liner system design.

10.4.3 Performance Considerations

Liner system performance is measured in terms of the extent of control of leachate seepage from the refuse disposal facility. Liner system performance is related to the types of waste material present, the hydraulic head, and subsurface conditions, and these factors can mitigate or exacerbate the potential hydrologic impacts. Table 10.9 provides a summary of guidance related to performance

TABLE 10.8 STABILITY CONSIDERATIONS IN LINER DESIGN

Problem	Liner Stress	Free Body Diagram	Required Properties		Typical Factor of Safety
			Geomembrane	Landfill	
1. Liner self-weight	Tensile		G, t, σ_{allow}, δ_L	β, H	10 to 100
2. Weight of filling	Tensile		t, σ_{allow}, δ_U, δ_L	β, h, γ, H	0.5 to 10
3. Impact during construction	Impact		I	d, W	0.1 to 5
4. Weight of landfill	Compression		σ_{allow}	γ, H	10 to 50
5. Puncture	Puncture		σ_p	γ, H, P, A_p	0.5 to 10
6. Anchorage	Tensile		t, σ_{allow}, δ_U, δ_L	β, γ, ϕ	0.7 to 5
7. Settlement of landfill	Shear		τ, δ_U	β, γ, H	10 to 100
8. Subsidence under landfill	Tensile		t, σ_{allow}, δ_U, δ_L, z	α, γ, H	0.3 to 10

Legend:

G	=	specific gravity	β	=	slope angle
T	=	tensile force	H	=	landfill height
t	=	thickness	γ	=	unit weight
σ_{allow}	=	allowable strength	h	=	lift height
τ	=	shear strength	α	=	subsidence angle
I	=	impact resistance	ϕ	=	friction angle
σ_p	=	puncture strength	d	=	drop height
δ_U	=	friction coefficient with material above	W	=	weight
δ_L	=	friction coefficient with material below	P	=	puncture force
F_U	=	friction force upper	A_p	=	puncture area
F_L	=	friction force lower	z	=	mobilization distance

(ADAPTED FROM KOERNER, 2006)

TABLE 10.9 LINER SYSTEM PERFORMANCE FACTORS AND CONSIDERATIONS

Liner Type	Thickness (ft)	Hydraulic Conductivity (cm/sec)	Example Hydraulic Head	Estimated Min. Steady-State Leakage Rate Q(gpad)	Travel Time through Liner (years)	Equations
Clay	2	1 x 10^{-6}	10	3,500	0.1	$q = k_l \left[\dfrac{D_t + D_l - h_f}{D_l + D_t \dfrac{k_l}{k_t}}\right]$
	2	1 x 10^{-7}	10	510	1	$T = \dfrac{(n - \phi_i)}{k_l}\left[D_l - (H\text{-}h_c) \ln\left(\dfrac{2D_l + H - h_f}{D_l + H - h_f}\right)\right]$
Geomembrane	Membrane with single perforations of 0.03 cm^2/acre (for liner evaluations)		10	7.9(1)	NA	$q = \dfrac{\pi k_s}{4} q_r^2$
	Membrane with single perforations of 1 cm^2/acre (for leakage detection capacity calculations)		10	13.7(1)	NA	$d = \dfrac{4}{\pi^2} q_r \exp\left[\dfrac{-\pi(H - h_f)}{q_r}\right]$

Note: 1. Subsoil hydraulic conductivity = 1 x 10^{-5} cm/sec.

Legend:

- Q = seepage flow in gallons per acre per day (gpad)
- q = seepage per unit area (length/time)
- k_l = hydraulic conductivity of liner (length/time)
- D_l = thickness of liner (length)
- k_t = hydraulic conductivity of waste (length/time)
- d = diameter of hole in geomembrane (length)
- q_r = reduced specific leakage (length)
- T = travel time
- D_t = thickness of saturated waste (length)
- h_f = soil pore-water pressure below liner (length)
- n = effective porosity (dimensionless)
- ϕ_i = initial in-situ volumetric moisture content (dimensionless)
- h_c = soil pore-water pressure (length)
- k_s = hydraulic conductivity of subsoil (length/time)
- H = depth of ponded liquid (hydraulic head) above top of liner (length)

(ADAPTED FROM HUTCHISON AND ELLISON, 1992) evaluation and provides some specific examples. Measuring the performance of a liner system typically involves monitoring of drain discharges and down gradient groundwater conditions.

10.5 RECLAMATION

Reclamation requirements vary according to land use, climate, and state regulations. The purpose of this section is to provide general guidelines for reclamation grading, impoundment elimination, soil and topsoil covering, and revegetation of coal refuse disposal facilities.

10.5.1 Design Considerations

The content of a reclamation plan is related to the planned post-mining land use, site terrain and disposal facility configuration, climate, and pre-mining and adjacent area conditions. Generally, post-mining land use is open space and wildlife habitat and may be oriented to specific wildlife species and vegetation biodiversity (e.g., forest and grass land mix). Other land use possibilities, although rarely considered, include agriculture, recreation, and site development. All of these land uses typically require the establishment of persistent, low-maintenance vegetation for controlling erosion. Site access and topography significantly affect future land use, and the engineering properties of the embankment and the method of construction are important if structural foundations are planned. Table 10.10 presents a summary of potential final land uses and related key requirements and considerations.

In evaluating potential land uses, the availability of resources, and specifically soils for revegetation, must be determined. Other resources include water, access roads and existing site infrastructure. Preparation of an inventory of resources is an integral step in the development of a reclamation plan. Because soils are used for a variety of applications besides reclamation (e.g., starter dams, liners, etc.), an understanding of the quantity and quality of soils available at or near the site is essential. During the planning and design phases, geotechnical exploration should include field characterization of soil

TABLE 10.10 POTENTIAL FINAL LAND USES

Land Use Examples	Key Requirements and Considerations
Wildlife Habitat and Open Space	Adequate cover of appropriate vegetation for desired wildlife species.
Agriculture • Pasture and Hay • Fiber Crops • Tree Nursery	Agricultural land uses should include assessment for trace elements.
Recreation	
• Active Recreation (sports fields, golf courses, ski/biking facilities)	Access to site, topography, erosion and drainage control.
• Passive Recreation (hunting, hiking, nature study)	Access to site, topography.
Site Development • Commercial and Industrial (buildings, storage areas) • Residential (housing, parks) • Infrastructure (highways, airports)	Access to site, topography, structural support, erosion and drainage control.

(DIGIOIA ET AL., 1995)

properties such as thickness, texture, and color. Evaluation of soil pH and potential lime requirements during geotechnical laboratory testing of soils will enable improved planning of complex reclamation sites. Analyses related to soil and other material handling should be performed with the capabilities and limitations of the available excavation equipment in mind, so that costs associated with recovery and segregation of soils during excavation, stockpiling, and redistribution are realistic.

Soils in the eastern U.S. and the Midwest tend to be neutral to acidic and, with addition of appropriate amounts of lime and fertilizers, can support plant growth without irrigation if appropriate species are selected. For practical purposes, lime will neutralize soils only to the depth of incorporation (plow depth). If lime cannot be incorporated to a sufficient soil depth, plant species with tolerance to low pH should be selected. Soils from arid or semi-arid regions in the west tend to be high in soluble salts and/or sodium, and revegetation in this material can be challenging. All soils should be tested for nutrient availability before lime and fertilizer application is specified (Page et al., 1982). Table 10.11 presents design considerations for reclamation soils.

10.5.2 Grading

Final grading plans for reclamation should include development of surfaces and slopes in order to achieve effective site drainage and to facilitate access for placement of soil and topsoil, vegetation, and maintenance. While plans for a refuse disposal facility provide an anticipated final configuration and slopes, the facility may not reach its planned capacity prior to reclamation. In such circumstances, a reclamation grading plan providing site drainage (eliminating impounding conditions as necessary) and minimizing erosion potential should be developed. The configuration of embankments, slopes, benches and drainage channels at abandonment is subject to state regulatory criteria, which generally include requirements for overall embankment slopes, benches, and top surface grades.

TABLE 10.11 DESIGN CONSIDERATIONS FOR RECLAMATION SOILS

Support for Plants	Non-toxic for plants, capable of root penetration and storing sufficient amounts of plant-available water
Soil Type and Thickness	Typical regulatory requirements are up to 4 feet in total thickness, with equivalent topsoil placement to pre-mining condition. Alternate cover and growth medium may be considered.
Root Anchorage	For large shrubs and trees, soil thickness of greater than 4 feet may be required for anchorage against wind and gravity.
Water Storage	Field capacity and wilting point can be measured or estimated from texture or grain-size distribution.
Establishment of Vegetation	Ability to add nutrients, pH adjustments, soil conditioners for acceptable growth medium
pH	Most plant species grow best at a pH between 6.0 and 7.5. Soils between pH of 3.5 and 6.0 can be limed; the cause of excessive pH should be determined before adjustments are made.
Salt Stress	Sodium and salt soils can be evaluated using electrical conductivity and sodium adsorption ratio.
Nutrient/Trace Element Availability	Nutrient and toxic element testing (Baker, 1988) can be used to identify fertilizer and amendment requirements.
Species Selection	In addition to soil conditions, species should be selected based on short- and long-term availability of irrigation water, short-term erosion control requirements, and maintenance intensity and methods.
Yield of Vegetation for Land Use	Adequate balance of nutrients and trace metals for sustained yield
Engineering Properties	Acceptable erosion resistance, hydraulic conductivity, load bearing capacity, resistance to traffic, etc.

(ADAPTED FROM DIGIOIA ET AL., 1995)

10.5.3 Impoundment Elimination

Elimination of slurry impoundments requires special measures for grading and reclamation. The impoundment surface may be wet, dry, dessicated, or vegetated, but the underlying materials typically remain soft and can exhibit sudden shearing under equipment operation. The impoundment elimination plan should address factors associated with: (1) fine refuse properties, (2) impoundment size and depth, (3) the presence of water, and (4) the availability of and access to borrow sources for regrading and covering materials. Preparation of an impoundment elimination plan may require characterization of the fine refuse materials (including drainage and consolidation properties), specification of the borrow material for covering the fine refuse, and specification of the equipment for implementing the work. Section 11.5.2 provides guidance for upstream construction that should be considered in developing and implementing plans for covering of an impoundment. The following are typical guidelines for impoundment elimination:

- Drainage toward the impoundment should be collected and routed away, and ponded water should be removed.
- Access into the impoundment area for delivery of borrow materials to cover the fine coal refuse should be developed. This may involve construction of access roads and designation of temporary stockpile areas in preparation for initial pushout of borrow materials over the fine refuse.
- An initial lift of borrow materials should be pushed out over the fine refuse using a bulldozer. This initial lift should typically be between 4 and 6 feet thick, with the lower end of this range more desirable for minimizing displacement of the fine refuse. The pushout should not be performed into standing water, and dewatering measures in the fine refuse (prolonged drying, drainage sumps, wick drains, etc.) may be needed to facilitate placement of the initial lift. The initial lift should be advanced from firm areas along the perimeter of the impoundment, creating a wide area of operation rather than a narrow one. The initial lift should generally be advanced a distance of at least 50 feet before additional lifts are placed or trucks or haulage equipment are allowed onto covered areas. This distance should be maintained until the impoundment surface has been covered, and trucks should generally not be allowed into this zone for delivery of borrow materials. Monitoring should be conducted throughout the initial pushout period.
- Subsequent lifts should be placed in accordance with geotechnical requirements for the disposal embankment and should not exceed a thickness of 2 feet. Generally, material for impoundment elimination is considered placed fill unless structural fill is required by final land use. Depending on the geotechnical design requirements, restrictions on the rate of fill placement may be warranted in order to limit loading and to allow consolidation of the fine coal refuse.
- Should displacement of fine refuse occur during pushout, the following measures should be considered: (1) slowing the advance of the pushout to allow dissipation of pore pressure in the fine refuse, (2) use of low-ground-pressure equipment, (3) improving drainage within the fine refuse (e.g., sumps, wick drains), and (4) stabilization of the fine refuse or reinforcement of the pushout lift using geotextiles or geogrids. If displacement is unavoidable, the impoundment elimination plan should include provisions for containment of the displaced material.
- The material used to cover the fines and eliminate the impounding capability should be cambered such that when settlement occurs due to consolidation of the underlying fines, the surface will always provide positive drainage off the site. The amount of long-term settlement should be estimated based on the consolidation characteristics of the fines.

In the development of an impoundment elimination plan, the safety of equipment operators covering slurry deposits should be addressed as well as monitoring of the work. The following general guidance applies:

- Initial and periodic review sessions covering the procedures and anticipated performance of the initial pushout, delivery of borrow material, and subsequent lift placement should be held by engineering personnel for equipment operators and supervisors.
- The impoundment should be maintained in a dewatered condition to the extent practical.
- Initial pushouts should be restricted to daylight hours or times when the work area is sufficiently illuminated to provide good visibility.
- Radio communication for pushout equipment operators and supervisors should be provided, and it is recommended that equipment operations be within sight of mine personnel during the initial pushout and that operators be provided with floatation devices (e.g., life jackets).
- The work area should be examined frequently for signs of instability such as cracking or sinking, and work should be suspended in areas exhibiting such indications.
- Monitoring of the work should be performed by engineering personnel with an understanding of technical issues such as slope stability, displacement, and deformation.
- Pore pressures within the fine refuse and deformations or displacements may be monitored with instrumentation, if warranted.

10.5.4 Soil and Topsoil Cover

Soil and topsoil cover materials with the properties that meet regulatory requirements for reclamation should be stockpiled and recovered from locations near the disposal facility. While OSM and state regulations typically require 4 feet of soil and topsoil cover, there are situations where a variance in cover thickness may be considered. Also, isolation of the refuse materials from infiltrating water may be necessary. In these circumstances, supplemental materials and/or modified placement procedures may be needed:

- In Appalachian regions, there may be insufficient soil and topsoil for reclamation, and reduced cover thicknesses may be necessary. Dove et al. (1987) and Daniels (2005) evaluated direct seeding and reduced topsoil thickness alternatives to determine the optimal combination of soil amendments and topsoil thicknesses for successful vegetation of refuse with varying levels of potential acidic leachate generation. Daniels (2005) indicates that for moderately acid producing refuse, acceptable vegetation can be established with less than 12 inches of soil cover if lime is added to the refuse surface.
- Alternatives such as bio-solids and combustion ash may be considered. Bio-solids (sewage sludge) can be plowed into refuse surfaces and used to establish an alternative growth medium. Combustion ash can also be applied or mixed into the refuse surface to establish an alternative growth medium.
- If isolation of the refuse materials requires a low-hydraulic-conductivity cap, use of clay or a geomembrane may be appropriate. The evaluation and design of caps generally follows the procedures for liner systems presented in Section 10.4.

Achieving good adhesion of soil placed on refuse surfaces may require special procedures. The refuse surface should be scarified by tracking up and down slopes with a bulldozer, by shallow tillage along contour lines, or by other methods that will loosen the surface. Soil should be placed in a relatively dry condition with low-ground-pressure equipment, avoiding excessive compaction (unless required for construction of a low hydraulic conductivity cap). If soils have a low pH (below 5) and require amendment with lime or gypsum, it may be appropriate to place and amend the soil in lifts, with incorporation (plowing in) of amendments through the entire lift prior to placement of the next lift. Table 10.12 presents a summary of reclamation guidelines (DiGioia et al., 1995).

TABLE 10.12 SUMMARY OF RECLAMATION GUIDELINES

Task	Recommended Guidelines
Application of Lime Gypsum and Fertilizer	Lime and gypsum should be plowed into the entire lift thickness, and fertilizers and other plant nutrient sources should be applied evenly and plowed under within 24 hours and to a depth of at least 2 inches. If seedbed preparation includes creation of furrows, seedbed preparation may be done in concert with fertilizer incorporation. If hydroseeding is utilized, apply no more than 40-80-40 pounds N-P_2O_5-K_2O per acre with seed and do not leave seed and inoculants in contact with fertilizer-containing solutions for more than 1 hour.
Furrowing and Land-Imprinting	Where management of water or reduction in wind or salt stress is desired, deep furrowing (6 to 10 inches), land imprinting, or other methods should performed. Furrows should be oriented parallel to site contours or on flat surfaces, perpendicular to prevailing winds.
Seedbed Preparation	If the furrowing or land imprinting procedures are performed more than a few days before seeding, or a crust has formed on the soil surface, these procedures should be repeated just prior to seeding.
Seeding and Inoculating	Seeding depths using the drill seeding method should be set for the shallowest seeded species. To maximize the opportunity for biological nitrogen fixation, legume seed can be inoculated with Rhizobium strain specific to the species being sown. Broadcast and hydroseeding work best when the seeds are promptly covered with soil and mulch.
Selection of Planting of Woody Species	The emphasis is on establishment of herbaceous, not woody plants. Guidance on selection, planting, maintenance and specification of woody plants is presented in Vogel (1987) and Himelick (1981).
Mulching and Tacking	Mulch should be applied within a day of seeding and before rain. Straw and/or hay applied at a rate of 3,000 to 6,000 pounds per acre and wood cellulose fiber mulch applied at a rate between 1,200 and 2,500 pounds per acre are acceptable mulch for most purposes. Tacking can be performed by crimping mulch into soil with large disks set along the direction of travel or by application of wood cellulose fiber mulch over the straw/hay using a hydroseeder. Crimping techniques that leave some straw/hay standing up in the soil crease and in rows at right angle to the prevailing wind are desirable for dry, windy sites.
Watercourse Protection	For watercourse protection (swales, ditches) wood excelsior, coconut fiber, nylon, and/or jute blankets should be used according to manufacturers' instructions.
Irrigation	Irrigation should be considered during the establishment year in arid and semi-arid regions and other areas where the gains from improvements in establishment rate and long-term survival outweigh the risk of failure.

(ADAPTED FROM DIGIOIA ET AL., 1995)

10.5.5 Vegetation

Species for vegetation and reclamation should be selected based on their adaptability and tolerance to site climate and soil (or alternative media) conditions and their suitability for the final land use and compatibility with regulatory provisions. Additional considerations include erosion and sedimentation control requirements, the need for irrigation water, and maintenance requirements. To the extent possible, local expertise should be sought for development of vegetation plans for specific land uses. Where available, state erosion and sedimentation publications and university agronomy studies can provide important guidance related to seeding/planting mixtures and cultivation practices. Potential vegetation species and their adaptability to various climates and soil conditions are summarized in Table 10.13 (DiGioia et al., 1995).

In humid regions, winter rye and redtop mixed with more slow-to-establish perennial species such as birdsfoot trefoil and deertongue grass are often used to provide cover. Too high a seeding rate of

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
NC, SC, W	Thickspike Wheatgrass	Agropyron dasystachyum	peren./ grass	cool	yes	poor-well	10-17	5.0-8.5	H, A, R, D	4-6	Sod-forming bunchgrass.
NC, W	Crested Wheatgrass	Agropyron desertorum	peren./ grass	cool	no	well	10-17	5.5-8.5	R, D	4-6	Establishes slowly. Intolerant to flooding. Bunchgrass. Stratify seed.
NC, SW, SC	Tall Wheatgrass	Agropyron elongatum	annual/ grass	cool	yes	poor-well	12-20+	6.0-8.0	H, A	4-6	Use adapted cultivars. Establishes easily. Sod-forming bunchgrass. Boron intolerant.
NC, W	Streambank Wheatgrass	Agropyron riparium	annual/ grass	cool	yes	poor-well	11-19	6.5-8.5	R, D	2-4	Spreads rapidly. Sod-forming.
NC, SC, M, W, NE	Western Wheatgrass	Agropyron smithii	peren./ grass	cool	yes	poor-well	5-20+	4.5-9.0	H, A, R, D	4-6	Use adapter cultivars. Sod-forming.
NC, SC, W	Slender Wheatgrass	Agropyron trachycaulum	peren./ grass	cool	yes	med.-poor	15-20+	6.5-8.5	H, A	2-4	Grows fast, short-lived.
SC, M, NE, S	Redtop	Agrostis alba	peren./ grass	cool	no	med.-poor	20+	4.0-7.5	R, D	2-4	Sod-forming short-lived.
NC, SC, M	Big Bluestem	Andropogon gerardi	peren./ grass	warm	yes	med.-poor	16-20+	5.5-7.5	H, A, R,D	4-8	Use adapted cultivars. Deep roots.
All	Common Oats	Avena sativa	annual/ grass	cool	no	well	10-5	5.5-7.0	H, A, R, D	30-50	Use adapted cultivars. Cover crop. Cold tolerant. Needs N.
S	King Ranch Bluestem	Bothriochloa ischaemum	peren./ grass	warm	no	well	20+	5.0-7.0	A	2-6	Mix with Sercica Lespedeza.
NC, SC, M	Sideoats Grama	Bouteloua curtipendula ‘Vaughn’ or ‘Elreno’	peren./ grass	warm	yes	med.-well	12-20+	6.0-7.5	H, A	2-4	Calcareous soils. Bunchgrass.
NC, SC, W	Blue Grama	Bouteloua gracilis ‘Lovington’	peren./ grass	warm	yes	well	8-20	6.0-8.5	H, A, R, D	10-12	Use adapted cultivars. Sod-forming bunchgrass. Animal forage.

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
All	Smooth Brome	Bromus inermus	peren./ grass	cool	no	med.-well	17-20+	5.5-8.0	R, D	10-15	Use adapted cultivars. Establishes easily for quick cover. Sod-forming.
NC, SC	Buffalo Grass	Buchloe dactyloides Sharps 'Improved' or 'Texoka'	peren./ grass	warm	yes	med.-poor	12-20+	6.5-8.0	H, A, R, D	5-10	Sod-forming, stolon-iferous. Stratify seed. Monoecious.
NC, SC, W	Prairie Sandreed	Calamovilfa longifolia 'Goshen'	peren./ grass	warm	yes	well	10-20	6.0-8.0	H, A, R, D	6-9	Sod-forming, rhizomatous.
S	Rhodes Grass	Chloris gayana	peren./ grass	warm	no	med.	20+	4.0-7.0	H, A, R, D	8-12	Very tolerant to salinity. Stoloniferous.
NC, S, SC, NE	Bermuda Grass	Cynodon dactylon Quicksand 'Common'	peren./ grass	warm	no	med.-poor	16-25+	4.5-7.5	A, R, D	3-5	Four-year cover. Rhizomatous and seed spreading.
NC, M, NE, S	Orchard Grass	Dactylus glomerata	peren./ grass	cool	no	med.-well	20+	5.0-7.5	H, A, R, D	5-8	Use adapted cultivars. Bunchgrass.
M, NE, S	Deertongue Grass	Dichanthelium clandestinum 'Tioga' (Panicum c.)	peren. /grass	warm	yes	poor-well	20+	3.8-8.0	H, A, R	6-20	Stratify seed. Wet and dry sites. Establishes slowly.
NC, SC, W	Saltgrass	Distichlis stricta	peren./ grass	warm	yes	med.-poor	14-20+	6.0-8.5	H, R, D	4-9	Salt tolerant.
NC, W	Basin Wildrye	Elymus cinerius	peren./ grass	cool	yes	poor	14-20+	6.0-8.0	H, A, R	4-8	Long-lived bunchgrass.
NC, W	Russian Wildrye	Elymus junceus	peren. /grass	cool	no	med.-well	13-20	6.0-8.0	R, D	4-8	Drought tolerant.
NC, W	Beardless Wildrye	Elymus triticoides	peren./ grass	cool	yes	poor	16-20+	6.0-8.0	H, A, R, D	4-8	Establishes slowly.
W	Boer Lovegrass	Eragrostis chloromelas 'A-84'	peren./ grass	warm	no	med.-well	12-19	6.0-8.0	R, D	4-8	Hot, dry climates. Bunchgrass

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
SC, M, NE, S	Weeping Lovegrass	Eragrostis curvula 'Ermelo'	peren. /grass	warm	no	well	20+	4.5-8.0	R, D	1-3	Bunchgrass, short-lived in the NE.
All	Tall Fescue	Festuca arundinacea 'Kentucky-31'	peren./ grass	warm	yes	med.- poor	18-20+	5.0-8.0	R, D	10-12	Use adapted cultivars Bunchgrass Use only endophyte-free varieties for agricultural land uses.
SC, M, NE, S	Red Fescue	Festuca rubra	peren./ grass	cool	no	poor- well	20+	5.0-7.5	A, R, D	4-6	Use adapted cultivars. Establishes slowly. Sod-forming.
W	Galleta	Hilaria jamesii 'Viva'	peren. /grass	warm	yes	med.- well	6-12	6.0-8.0	H, A, R, D	6-10	Very drought tolerant, rhizomatous.
W	Big Galleta	Hilaria rigida	peren. /grass	warm	yes	med.	9-14	6.0-8.0	H, A, R, D	6-10	Very drought tolerant, rhizomatous.
NC, SC M, NE, S	Barley	Hordeum vulgare	annual/ grass	cool	no	med.- well	20+	6.0-7.8	H, A, R, D	10-25	Winter cover crop.
NC, SC, M	Annual (Italian) Ryegrass	Lolium multiflorum	annual/ grass	cool	no	med.- well	20+	5.5-7.5	A, R, D	4-6	Quick cover crop.
SC	Klein Grass	Panicum coloratum 'Selection 75'	peren. /grass	warm	yes	med.	18-20+	6.0-8.0	A, R, D	6-10	Texas.
NC, SC, M, NE, S	Switchgrass	Panicum virgatum	peren./ grass	warm	yes	med.- poor	18-20+	5.0-7.5	H, A, R	2-5	Use adapted cultivars and ecotypes. Blackwell variety is competitive. Rhizomatous. Good winter cover.
S	Bahia Grass	Paspalum notatum 'Pensacola'	peren./ grass	warm	no	med.- well	20+	4.5-7.5	H, A	25-35	Stratify seeds. Sod-forming semi-bunchgrass.
NC, NE, M	Reed Canary Grass	Phalaris arundinacea	peren. /grass	cool	no	poor	18-20+	5.0-7.5	H, A	5-8	Wet sites.

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
M, NE, S	Timothy Grass	Phleum pretense	peren./ grass	cool	no	poor-well	20+	4.5-8.0	H, A, R	4-7	Use adapted cultivars Rhizomatous. Short-lived.
NC, SC, M	Big Bluegrass	Poa ampla	peren. /grass	cool	yes	well	12-20	6.0-8.0	H, A	6-10	Bunchgrass. Pheasant nesting habitat.
ALL	Little Bluestem	Schizachyrium scoparium (Andropogon scoparius)	peren./ grass	warm	yes	well	12-20+	6.0-8.0	H, A, R, D	4-8	Use adapted cultivars.
NC, SC, M, S, NE	Rye	Secale cereale 'Balbo'	annual/ grass	cool	no	well	20+	5.5-7.5	H, A, R, D	30-60	Cover crop.
NC, SC, M, S, NE	Indian Grass	Sorghastrum nutans	peren. /grass	warm	yes	med.-poor	15-35	4.0-7.5	R, D	2-4	Sod-forming, short-lived.
SC, S	Johnson Grass	Sorghum Sudanese	annual/ grass	warm	no	med.-well	20+	5.5-7.5	A, R, D	15-20	Use adapted cultivars. Cover crop.
NC, SC, W	Alkali Sacaton	Sporobolus airoides	peren./ grass	cool	yes	poor-well	6-18	7.0-8.5	H, A, R, D	6-10	Use local ecotypes. Bunchgrass. Needs initial Irrigation.
SC, W, M	Dropseed	Sporobolus spp.	peren. /grass	cool	yes	med.-well	10-20+	6.0-8.5	H, A, R, D	4-8	Bunchgrass. Seeds prolific.
NC, SC	Cicer Milkvetch	Astragalus cicer 'Lutana'	bien./ legume	cool	no	poor-well	18-35	5.5-7.5	R, D	2-5	Drought tolerant, sod-forming. Establishes slowly. Scarify Seed.
NC, M, NE, S	Crown Vetch	Coronilla varia	peren. /legume	cool	no	well	23+	5.0-7.5	R, D	5-8	Establishes slowly. Excludes tree seedings. Emerald variety for dry sites. Boron tolerant.
M, SC, S	Illinois Bundleflower	Desmanthus illinoensis	peren./ legume	warm	yes	med.-well	15-20+	5.0-7.5	H, A, D	2-5	Drought resistant.
NC, SC, M, NE, S	Soybean	Glycine max	annual/ legume	warm	no	poor-well	25+	5.0-7.0	H, A	30-50	Cash crop. Flooding intolerant.

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
NC, SC, M, NE, S	Lathco Flatpea	Lathrus sylvestris 'Lathco'	peren. /legume	cool	no	med.-well	23+	4.5-7.0	R, D	20	Seeds, toxic, excludes tree seedlings. Establishes slowly.
SC, M, NE, S	Sericea Lespedeza	Lespedeza cuneata	peren./ legume	warm	no	well	20+	4.5-7.0	A, R, D	10-20	Use adapted cultivars. Scarify seeds. Woody stems.
SC, M, NE, S	Prostrate Lespedeza	Lespedeza daurica var. schimadai	peren./ legume	warm	no	well	20+	4.5-7.0	A, R, D	15-20	Prostrate form used with tree seedlings.
M, NE, S	Korean Lespedeza	Lespedeza stipulacea	annual /legume	warm	no	med.-well	20+	4.5-7.0	H, R	6-12	Persistent cover Iowa-6 variety for cold sites.
All	Birdsfoot Trefoil	Lotus corniculatus 'Empire'	peren./ legume	cool	no	poor-well	18-20+	5.0-7.5	H, A, R, D	6-8	Use adapted cultivars. Boron tolerant. Does not cause livestock bloat.
NC, SC, W	Alfalfa	Medicago sativa	peren./ legume	cool	no	med.-well	17-20+	6.5-7.5	H, A, R	4-12	Use adapted cultivars. Needs Ca and P. Disease susceptible, flooding intolerant.
All	White Sweet Clover	Melilotus alba	bien./ legume	cool	no	well	16-20+	6.0-8.0	A, R	4-7	Invasive and competitive. Scarify seed. May cause livestock bloat.
M, NE, S	Yellow Sweet Clover	Melilotus officinalis	bien./ legume	cool	no	well	14-20+	6.0-8.0	A, R	4-7	Invasive. More drought tolerant than M.alba. Scarify seed. May cause livestock bloat.
W, SC	Sanfoin	Onobrychis vicaefolia	peren./ legume	cool	no	well	10-16	6.0-7.5	H, A, R, D	10-20	Use adapted cultivars.
M, SC, NE, S	Purple Prairie Clover	Petalostemum purpureum 'Kaneb'	peren./ legume	warm	yes	med.	12-18	6.0-8.0	H, A, R, D	6-8	Showy display of flowers.
NC, W	Strawberry Clover	Trifolium fragiferum	peren./ legume	cool	no	poor	18-20+	6.0-7.0	A, R, D	2-3	Scarify seed. Provides pasture.

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
NC, W	Alsike Clover	Trifolium hybridum	peren./ legume	cool	no	poor-well	18-20+	5.0-7.5	H, A, R	3-5	Attracts bees. Short-lived.
SC, S	Crimson Clover	Trifolium incarnatum	bien./ legume	cool	no	med.	20+	5.5-7.0	A, R, D	15-25	Cover crop, but persistent with adapted cultivars.
NC, SC, W	White Clover	Trifolium repens	peren./ legume	cool	no	med.	18-2-+	6.0-7.0	H, A, R, D	2-4	Sod forming. Attracts bees.
S, SC	Arrowleaf Clover	Trifolium vesiculosum	annual/ legume	cool	no	med.	20+	5.0-7.0	H, A	10-15	Use adapted cultivars. Persistent cover.
NC, SC, W	Hairy vetch	Vicia villosa	annual/ legume	cool	no	well	18-20+	5.0-7.5	R, D	20-30	Sod-forming cover corp.
All	Common Yarrow	Achillea millefolium	peren./ forb.	warm	yes	med.-well	10-20+	5.0-6.0	H, R, D	1-2	Forms ground cover. Drought resistant.
W	Western Yarrow	Achillea millefolium landulosa	peren./ forb.	warm	yes	med.-well	12-18	6.0-8.0	H, A, R, D	1-2	Drought resistant.
NE, S	Dwarf-eared Coreopsis	Coreopsis auriculata	peren./ forb.	cool	yes	well	20+	5.0-7.0	R, D	2-3	Showy display of flowers. Stoloniferous.
SC, W	Rattlesnake Weed	Euphorbia albomarginata	peren./ forb.	warm	yes	well	14-20+	6.0-8.0	H, R, D	1-2	Cold tolerant.
All	Annual Sunflower	Helianthus annauas	annual/ forb.	warm	yes	well	15+	5.0-7.0	H, A, D	6-8	Showy display.
NC, W	Annual Sunflower	Helianthus annuas 'Jaegeri'	annual/ forb.	warm	yes	poor-well	6-14+	6.0-8.0	H, A, D	6-10	Showy display.
SC, NC, M, NE, S	Gayfeather	Liatris pycnostachya 'Eureka'	peren./ forb.	warm	yes	poor-well	10-20+	6.0-7.5	H, A, R, D	2-4	Showy display. Drought resistant.
M, SC, NE, S	Smartfeed	Polygonum pennsyl-vanicum	annual/ forb.	warm	yes	poor	15+	5.0-7.0	H, A	10-12	Wet sites. Roots at nodes. Scarify seed.
NC, SC, M, NE, S	Coneflower	Ratibida columnifera 'Sunglow'	peren./ forb.	warm	yes	poor-well	16+	6.0-7.5	H, A, R, D	2-4	Showy display of flowers.

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TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
NC, SC, W	Four-wing Saltbush	Atriplex canescens	peren. / shrub	cool	yes	pool-well	5-15	7.0-8.0	H, A, R, D	8-12	Use adapted ecotypes. Evergreen. Seeds prolific. Drought tolerant. Very salt tolerant.
SC, W	Saltbush species	Atriplex spp.	peren./ shrub	cool	yes	poor-well	6-12	7.0-8.5	H, A, R, D	8-12	Some species deciduous.
NC, SC, W	Siberian Pea Shrub	Caragana arborescens	peren./ shrub	warm	no	well	12-20+	4.0-8.5	H, A, R, D	1-2	Aboreal, deciduous.
W	Alkali Rabbitbrush	Chrysothamnus nauseosus consimilus	peren./ shrub	cool	yes	well	8-18+	6.0-8.0	H, R, D	1-2	Deciduous. Deep roots.
NC, SC, W	Russian Olive	Eleagnus angustifolia	peren./ tree	warm	no	poor-well	10-20+	6.0-8.0	A, R, D	1-2	Invasive, deciduous, shrubby. N-fixer.
NC, SC, W	Winterfat	Eurotia lanata	peren./ shrub	cool	yes	well	6-15+	6.0-8.0	H, A	1-2	Evergreen. Not for Montana.
W	Gray Moll	Kochia Americana 'Vestita'	peren./ shrub	warm	yes	poor-well	4-20	6.0-9.0	H, A, R, D	1-2	Alkaline sites.
NC, SC, W	Summer Cypress	Kochia prostrata	peren./ shrub	warm	no	well	12-18	6.0-8.0	R, D.	1-2	Long-lived very drought tolerant. Prostrate form.
NC, SC, W	Weeping Mulberry	Morus alba 'Kingan'	peren./ tree	warm	no	poor-well	12-20+	5.0-6.5	H, R, D	1-2	Deciduous.
NE, M, S, W	Norway Spruce	Picea abies	peren./ tree	warm	no	med.-poor	16-20+	5.0-6.0	R, D		Evergreen. Cold sites. Plant seedlings.
All	Lombardy Poplar	Poplus nigra 'Italica'	peren./ tree	warm	no	well	12-20	5.0-7.0	R, D		Deciduous, short-lived. Plant seedlings.
SC, S	Live Oak	Quercus virginiana	peren./ tree	warm	yes	med.	15-20+	6.0-7.0	H, R, D	1-2	Evergreen. Slow growing.
NC, SC, M	Bur Oak	Quercus macrocarpa	peren./ tree	warm	yes	med.	10-20	4.0-7.0	H, R, D	1-2	Deciduous. Plant acorns or seedlings.
M, NE, S	Bristly Locust	Robina fertilis "Arnot"	peren./ shrub	warm	yes	well	15+	3.5-7.5	H, R, D	2-5	Deciduous. Forms thickets. N-fixer. Scarify seed.

TABLE 10.13 CHARACTERISTICS OF COMMON SPECIES POTENTIALLY SUITABLE FOR RECLAMATION (Continued)

Regions of U.S.[1]	Common Name	Scientific Name and Cultivar[2]	Growth Habit/ Forms[3,4]	Growth Season[5]	Native Species[6]	Drain-age	Precip. Range[7] (in)	pH Range[7]	Land Uses[8]	Seeding Rate[9] (lb/ac)	Miscellaneous Notes
All	Black Locust	Robinia pseudoacacia	peren./ tree	warm	yes	poor-well	15+	4.0-7.5	R, D	1-3	Deciduous. N-fixer. Scarify seed. Most common reclamation tree.
SC, W	Tamarisk species	Tamarix spp.	peren./ shrub	warm	no	poor-well	8-20	6.5-7.5	H, R	1-2	Aboreal, evergreen.

Note: 1. Regions of the U.S.:

- M = mid-western states (IA, IL, IN, KY, MI, MN, MO, OH, WI)
- NC = north-central states (ND, NE, SD)
- NE = northeastern states (CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, WT, WV)
- S = southern states (AR, AL, FL, GA, LA, MS, NC, SC, TN, VA)
- SC = south-central states (KS, OK, TX)
- W = western states (AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY)

2. Species and cultivars may vary for site-specific conditions. Consult local agronomy extension agents.
3. Annual species are best suited as cover crops. Perennial species are best for persistent cover.
4. Grasses should be planted in combination with legumes and other forbs. Legumes should be inoculated with appropriate rhizobium at five times the recommended rate. Many additional forbs, shrubs, and trees are available and suitable for reclamation.
5. Warm season grasses generally are more tolerant of drought and water stress.
6. Native distribution noted as occurs in the particular region.
7. Ranges are indicated for optimal growth conditions and may be wider for some species.
8. Post-closure land uses. Much overlap is possible:
   - H = wildlife habitat and open space
   - A = agricultural
   - R = recreational
   - D = site development
9. Rate indicated for seed mixtures. Higher rates apply for monotypic stands. Seeding rates and mixes should be determined by site-specific conditions. Consult local agronomy agents.

(DIGIOIA ET AL., 1995)

the quick-cover species may choke out and prevent successful long-term establishment of perennial species. A balance between short-term erosion control from quick-cover annuals and long-term self-sustaining perennials can be achieved by two-step seeding. This involves an initial dense planting of quick-cover annuals, allowing them to be winter-killed, and then seeding perennials into the stubble remaining from the annuals the following spring. Plants and recommended cultivation practices for humid regions are discussed in Vogel (1987) and Bennett et al. (1978).

In arid and semi-arid areas, exceptionally drought- and salt-tolerant species should be selected (Packer and Aldon, 1978). Even if adaptable species are used, high seeding and planting densities without supplementary irrigation can lead to excessive water stress and failure. Supplementary irrigation may be necessary until root systems are developed. Furrowing along contour lines and planting in the furrows will generally result in efficient use of irrigation water and natural precipitation.

Selection of vegetation for impounding embankments should take into account potential impacts on dam safety inspection and performance. Inspection of vegetated surfaces of dams and adjacent areas, particularly the crest, downstream slope, toe, and adjacent foundation areas is important, as discussed in Section 12.3. Trees and woody vegetation are detrimental to both inspection and the long-term durability of the embankment. Grasses and shallow rooted native vegetation are the most desirable surface cover for an active impounding embankment and dam. Guidance on this issue is presented in Marks and Tschantz (2002).