# MANAGING COAL COMBUSTION RESIDUES IN MINES

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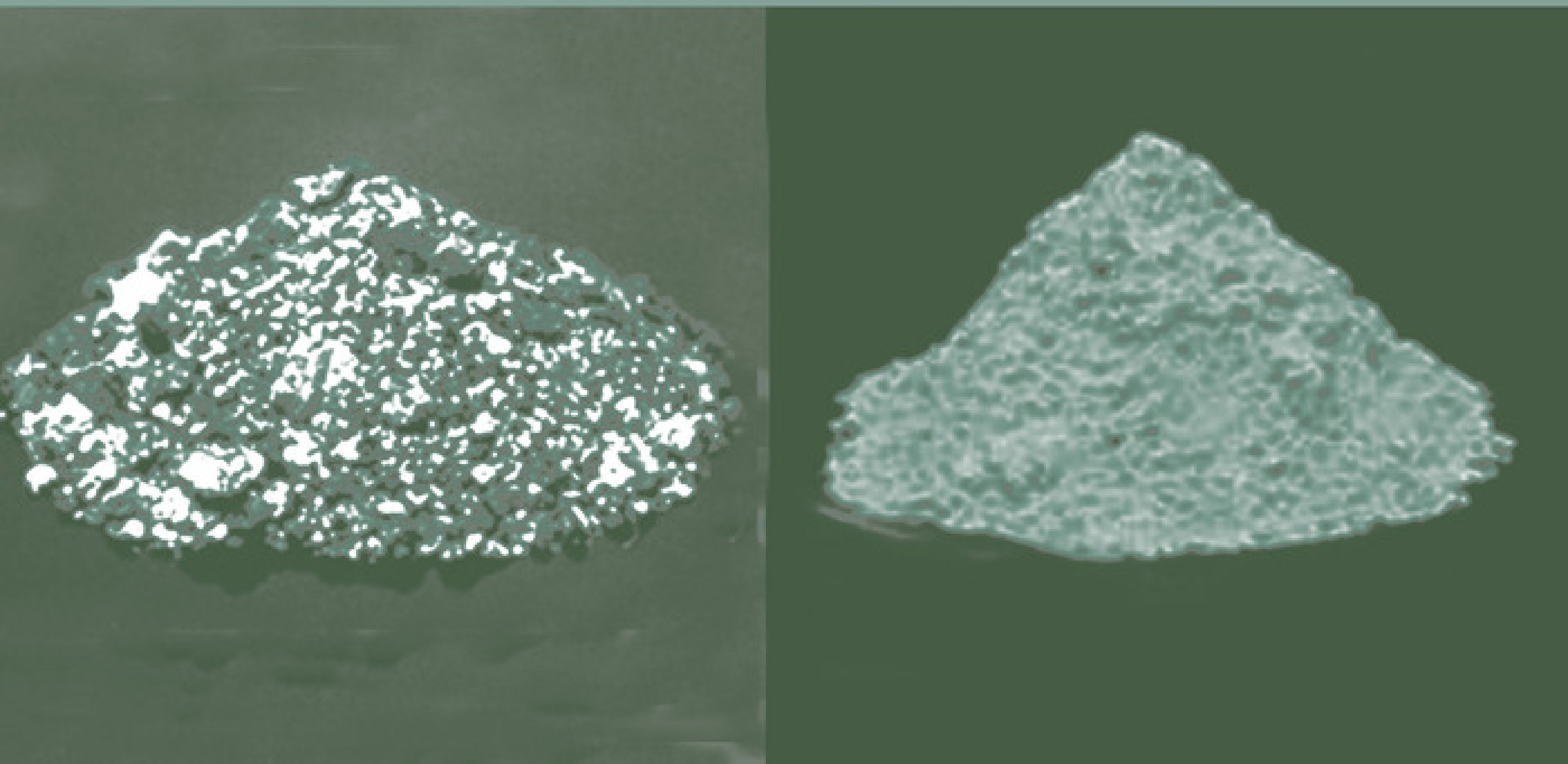

# MANAGING
# COAL COMBUSTION
# RESIDUES IN MINES

Committee on Mine Placement of Coal Combustion Wastes

Committee on Earth Resources

Board on Earth Sciences and Resources

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
*OF THE NATIONAL ACADEMIES*

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# Acknowledgments

This report represents the integrated efforts of many individuals. The committee thanks all those who shared their insights and knowledge to bring the document to fruition. We also thank all those who provided information and who participated in our public sessions (see Appendix B).

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

**David Carpenter**, State University of New York, Albany
**Subhash Chander**, The Pennsylvania State University, University Park
**James H. Clarke**, Vanderbilt University, Nashville, Tennessee
**James N. Galloway**, University of Virginia, Charlottesville
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**Stanley Suboleski**, Federal Mine Safety and Health Review Commission, Washington, D.C.

Although the individuals listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **George M. Hornberger**, University of Virginia, and **Jonathan G. Price**, Nevada Bureau of Mines and Geology, University of Nevada. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

# Preface

Coal is an abundant source of fossil fuel in the United States and because of its availability and therefore its low cost, coal is used as a major energy source in a world of limited competitive alternatives. Burning coal in electric utility plants produces, in addition to power, residues that contain constituents which may be harmful to the environment. What to do with them poses management challenges for the industry and for state and federal environmental regulatory agencies. A major management issue is the lack of reliable information on the behavior of coal combustion residues when placed in mines.

The Committee on Mine Placement of Coal Combustion Wastes, appointed by the National Research Council, addressed this issue. During the deliberation process, the committee provisionally agreed that placing coal combustion residues in coal mines as part of the mine reclamation process is a viable management option as long as it can be done responsibly. This report describes approaches to addressing that management challenge across a range of conditions.

The committee heard from relevant federal and state officials, representatives of the coal mining and utility industries, concerned citizens, and various technical and scientific specialists in public meetings. It examined the relevant scientific literature and other pertinent materials. It was helped throughout by the hard-working and able staff of the National Research Council.

The committee members thoroughly discussed the report's conclusions and recommendations through several iterations. In the end, the committee met its goal of writing a consensus report, for which it and the National Research Council bear sole responsibility. The committee thanks all who helped along the way.

Perry Hagenstein
*Chair*

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APPENDIXES

# Summary

Coal is the world's most abundant fossil fuel and the largest single source of fuel for electricity production in the United States. More than 90 percent of the coal mined in the United States is used by commercial power plants to generate electricity.

A by-product of coal combustion is the formation of coal combustion residues (CCRs), the noncombustible portion of the coal itself and residues from various air pollution control technologies. The amount of CCRs produced annually is currently more than 120 million tons, which is enough to fill about one million railroad coal cars. This amount will likely continue to increase as demand for coal-based energy in the United States grows and as air pollution control technologies for capturing residues are more widely used.

The management of large volumes of CCRs is a challenge, particularly for utilities that must dispose offsite or find secondary uses for this material. Coal combustion residues can be recycled for use into engineering applications or products such as cement or wallboard, which relaxes disposal needs. The remainder must be disposed in landfills, surface impoundments, or mines. Each method for disposing of CCRs has advantages and disadvantages in terms of cost and potential impacts. Placement of CCRs in mines for mine reclamation, the focus of this study, is not currently a major national practice. However, the use of CCR in mine reclamation has been increasing (ACAA, 1995, 2005a; PADEP, 2004). *The committee concluded that putting CCRs in coal mines as part of the reclamation process is a viable management option as long as (1) CCR placement is properly planned and is carried out in a manner that avoids significant adverse environmental and health impacts and (2) the regulatory process for issuing permits*

## SIDEBAR S.1
## Statement of Task

In response to a request from Congress, the National Research Council conducted a study that examined the health, safety, and environmental risks associated with using coal combustion wastes (CCWs)[a] for reclamation in active and abandoned coal mines. The study looked at the placement in abandoned and active, surface and underground coal mines in all major coal basins. The study considered coal mines receiving large quantities of coal combustion wastes. The committee focused its efforts on coal combustion wastes from utility power plants and independent power producers, rather than small business, industries, and institutions. A profile of the utility industry was taken into consideration in designing the study to focus on the sources producing the greatest quantities of coal combustion wastes.

Specifically, the committee addressed the following points:

1. The adequacy of data collection from surface-water and groundwater monitoring points established at CCW sites in mines.
2. The impacts of aquatic life in streams draining CCW placement areas and the wetlands, lakes, and rivers receiving this drainage.
3. The responses of mine operators and regulators to adverse or unintended impacts such as the contamination of groundwater and pollution of surface waters.
4. Whether CCWs and the mines they are being put in are adequately characterized for such placement to ensure that monitoring programs are effective and groundwater and surface waters are not degraded.
5. Whether there are clear performance standards set and regularly assessed for projects that use CCW for "beneficial purposes" in mines.

*includes clear provisions for public involvement.* The main advantages of CCR mine placement are (1) it can assist in meeting reclamation goals (such as remediation of abandoned mine lands), and (2) it avoids the need, relative to landfills and impoundments, to disrupt undisturbed sites. However, the placement of CCRs in coal mines is a multidimensional issue that involves consideration of potential human health and environmental impacts, as well as a comparison to the economic, health, and environmental impacts from other uses or disposal options.

Concerns about the potential public health and environmental risks associated with using CCRs for reclamation in active and abandoned coal mines led Congress to direct the Environmental Protection Agency (EPA) to commission an independent study to examine this topic (Sidebar S.1). As a result, the National Research Council established the Committee on Mine Placement of Coal Combustion Wastes study to address issues outlined in the statement of task.

6. The status of isolation requirements and whether they are needed.
7. The adequacy of monitoring programs including:
    a. The status of long-term monitoring and the need for this monitoring after CCW is placed in abandoned mines and active mines when placement is completed and bonds released;
    b. Whether monitoring is occurring from enough locations;
    c. Whether monitoring occurs for relevant constituents in CCW as determined by characterization of the CCW; and
    d. Whether there are clear, enforceable corrective actions standards regularly required in the monitoring.
8. The ability of mines receiving large amounts of CCW to achieve economically productive post-mine land uses.
9. The need for upgraded bonding or other mechanisms to assure that adequate resources are available for adequate periods to perform monitoring and address impacts after CCW placement or disposal operations are completed in coal mines.
10. The provisions for public involvement in these questions at the permitting and policy-making levels and any results of that involvement.
11. Evaluation of the risks associated with contamination of water supplies and the environment from the disposal or placement of coal combustion wastes in coal mines in the context of the requirements for protection of those resources by the Resource Conservation and Recovery Act (RCRA) and the Surface Mining Control and Reclamation Act (SMCRA).

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[a] Although the term “coal combustion wastes” (CCWs) was used in the statement of task, after much discussion the committee chose to use the term “coal combustion residue” (CCR) for the purpose of this report. This term was chosen to avoid implying that these materials are destined for particular fates.

## POTENTIAL IMPACTS FROM COAL COMBUSTION RESIDUE PLACEMENT IN MINES

Coal combustion residues (CCRs) may be effective in neutralizing acid mine drainage and, therefore, reducing the overall transport of contaminants from acid-generating mine sites. However, CCRs often contain a mixture of metals and other constituents in sufficient quantities that they may pose public health and environmental concerns if improperly managed. In a mine setting, subsurface water flow is the primary mechanism for transporting contaminants from CCRs to potential human and ecological receptors. Risks to human health and ecosystems may occur when CCR-derived contaminants enter drinking water supplies, surface water bodies, or biota. Impacts on downgradient water quality will depend on the concentration of the contaminant, the flow rate and volume of contaminated water entering the flow system, and the ability of the aquifer or receiving water body to dilute or attenuate the contamination. The concentration, volume, and flow rate of contaminated water, in turn, depend on the leachable mass of toxic constituents in the CCR, the emplacement design, and the local hydrogeologic setting.

*Of the three methods currently available for disposal of CCRs (surface impoundments, landfilling, and minefilling), comparatively little is known about the potential for minefilling to degrade the quality of groundwater and/or surface waters particularly over longer time periods. Additionally, there are insufficient data on the contamination of water supplies by placement of CCRs in coal mines, making human risk assessments difficult.* The committee was presented with numerous testimonies in which public citizens, industry, and state regulatory agencies disagreed about the extent of the degradation of water quality associated with CCR placement in mines. The Environmental Protection Agency (EPA) has not identified any cases in which water quality standards were not met as a direct result of CCR mine placement. However, the committee's review of literature and damage cases recognized by EPA supports the EPA's concerns about proper management of CCRs.

Thus, *the committee concludes that the presence of high contaminant levels in many CCR leachates may create human health and ecological concerns at or near some mine sites over the long term.* The two most common CCR disposal options, surface impoundments and landfills, provide insights into the types of issues that can emerge when the soluble constituents of CCRs are not contained within the waste management system. Although disposal conditions may differ substantially from mine settings, landfills and surface impoundments are useful for understanding the specific conditions under which CCRs can potentially impact humans and ecosystems. The EPA has identified numerous cases of water contamination related to CCR landfills and surface impoundments that, in many cases, have caused considerable environmental damage. In some landfill settings, groundwater has been degraded to the point that drinking water standards were exceeded off-site. In other landfills and surface impoundments, contamination of surface waters has resulted in considerable environmental damage; in the most extreme cases, multiple species have experienced local extinctions. Such cases are instructive because these impacts can be clearly related to CCR disposal, and they help guide the selection of mining environments for CCR placement that are most protective of human and ecological health.

## PLANNING FOR CCR USE

A variety of steps are involved in planning for and managing the use of CCRs as minefill. The report discusses practices that could reduce the potential impacts associated with the use of CCRs in reclamation.

## CCR Disposal and Use Options

A variety of alternative uses and disposal options is available for CCR, including its secondary use for the manufacture of products or its disposal in landfills, surface impoundments, and mines. The chemical and physical characteristics of a particular CCR stream, coupled with consideration of issues such as the demands for alternate uses, costs and locations of disposal options, and the local regulatory environment, are keys to determining the best option for CCRs. In its 2000 regulatory determination, EPA concluded that CCRs used for beneficial purposes other than minefilling should remain exempt from regulation as a hazardous waste under the Resource Conservation and Recovery Act (RCRA). They further determined that in many uses, CCRs would be bound or encapsulated in construction materials and, therefore, were not likely to present a significant risk to human health or the environment. Although the focus of this study is the use of CCRs as minefill, the loss of valuable residues to the waste stream may represent missed opportunities for waste reduction and environmentally sound management. Therefore, **the committee recommends that secondary uses of CCRs that pose minimal risks to human health and the environment be strongly encouraged**.

Many CCRs are not suitable for secondary uses and must be disposed in landfills, impoundments, or mines. In cases where placement in a mine site during reclamation is determined to be a viable option, an integrated process of CCR characterization, site characterization, management of placement activities, and post-placement monitoring is required. The volume of CCR material to be used and the relative risk that emerges from the site and material characterization should help determine the level of additional effort that will be required to manage and monitor the mine site.

While recognizing the potential risk of negative environmental impacts associated with CCR minefilling, it has been shown that, in some cases, benefits can accrue and should be considered in the permitting process. Some states have designated the use of CCR in the reclamation of coal mines as a beneficial use. The evaluation of risks and benefits is always a complicated analysis, compounded by determining who may bear the risks and who may accrue the benefits. The process for permitting beneficial use varies among the states, and in many states, the designation of beneficial use may limit the regulation or oversight of CCR placement. *With regard to CCR placement in minefills, the committee concludes that while potential advantages should not be ignored, the full characterization of possible risks should not be cut short in the name of beneficial use.*

## Characterizing a Mine Site Disposal Option

Characterization of the CCR material and the mine placement site is essential to engineering design, permitting decisions, reclamation management, and the development of monitoring programs. Successful predictions of CCR behavior in the mine environment require a thorough understanding of the complex physical and biogeochemical processes, associated primarily with subsurface flow, that control the release and transport of CCR-derived constituents. The mobility of CCR-derived constituents varies widely in the mine environment depending on the physical and chemical characteristics of the CCRs and geologic materials, and the pH, oxidation-reduction potential, and chemical composition of the water encountered at a mine site. All of these factors must be considered in characterizing the mine site disposal option.

## CCR Characterization

The characterization of CCRs involves analyses of bulk chemical and physical properties, including trace element leaching potential, cementitious properties, and any other ash characteristics (i.e., permeability upon compaction) that might impact their behavior in the mine setting. **To contribute to evaluation of the risk of placing CCRs at mine sites, the committee recommends that CCRs be characterized prior to significant mine placement and with each new source of CCRs. The CCR characterization should continue periodically throughout the mine placement process to assess any changes in CCR composition and behavior.**

Leaching tests are commonly applied to assess the potential release of trace elements from CCRs. The limitations of single-point batch tests are well recognized, although they remain in widespread use and have a major role in the regulation of CCR mine placement in many states. Alternative leaching methods are being developed to address these limitations but, until they are more thoroughly evaluated, the committee suggests some simple improvements to current leaching protocols. In particular, the CCR characterization methods used should provide contaminant leaching information for the range of geochemical conditions that will occur at the CCR placement site and in the surrounding area, both during and after placement. Samples that exceed pre-determined leaching criteria should be rejected for mine placement, although samples that meet the criteria may still need additional evaluation depending on the potential risks of CCR placement determined from the site characterization.

## Site Characterization

Site characterization is a dynamic process of developing and continually refining a site conceptual model that captures the relevant aspects affecting the behavior of CCRs in the mine environment. When integrated with CCR characterization data, site characterization provides the information necessary to locate the best places within the mine for placing CCRs, to design the CCR emplacement, and to develop the monitoring plans. Current site characterization requirements under the Surface Mining Control and Reclamation Act (SMCRA) focus on assessing the potential impacts of coal mining and reclamation but do not specifically address the impacts of CCR placement.

**The committee recommends that comprehensive site characterization specific to CCR placement be conducted at all mine sites prior to substantial placement of CCRs.** Site characterization should encompass a full description of the hydrogeological setting, including aquifer locations and groundwater flow patterns, surface-water drainage and flow, and soil and overburden characterization. Site characterization should define the mine site hydrogeology and geochemistry in both undisturbed areas and reclaimed mining areas and should also consider local factors, such as surrounding land use, proximity to human and ecological receptors, and designated future land use. In addition, site characterization should assess the potential for human exposure to drinking water impacts that might occur related to CCR placement.

## CCR Use in Reclamation Operations

The site and material characterization data, including the description of the hydrogeological and biogeochemical setting of the mine and the bulk chemical and physical properties of the CCRs, should be integrated to develop a plan for CCR placement. The engineering design should consider the mass of material to be placed as well as placement locations within the mine site. This plan should be informed by the risks associated with the site and the CCR material present.

### Reclamation

The use of CCR for minefill should be viewed in the context of general reclamation management activities. The primary reclamation operations most readily impacted by CCR placement are backfilling and grading, topsoil replacement, and revegetation. The disposal of CCRs in coal mines occurs under highly variable conditions, ranging from small quantities to massive minefills, from arid to wet regions, from remote to semiurban locations, from surface to underground mines, and from active to abandoned mines. Thus, **the committee endorses the concept of site-specific management plans, including site-specific performance standards.** A flexible approach to managing CCRs in mine sites has advantages since it can embrace the unique characteristics of the CCRs, the total mass of CCRs, and the environment into which they are placed. However, the need to incorporate site-specific factors should not be a basis for adopting management plans that lack rigor. Such plans should be developed in compliance with enforceable standards for using CCRs in minefilling, as recommended below.

In addition, many issues should be considered when CCRs are used in reclamation. The following are some examples:

- Do the characteristics of the site and CCR material make mine placement a viable disposal option?
- Is simple backfilling mixed with mine spoil adequate or are more controlled placement approaches needed?
- Should the cementitious properties of the ash be enhanced to minimize interaction with groundwater?
- Should the CCRs be put down in small lifts and compacted to lessen its hydraulic conductivity and reduce contaminant transport?
- Can CCRs be emplaced in a manner that neutralizes acidity at the mine over the long term and reduces overall contaminant transport?
- Will placement of CCRs above the water table be sufficient to minimize contaminant transport, given local recharge rates?
- Are additional bonding or other financial assurances necessary to cover potential off-site contamination from CCRs?

Given the known impacts that can occur when CCRs react with water in surface impoundments and landfills, special attention should be paid in reclamation operations to the interactions of water with CCRs. **Specifically, the committee recommends that CCR placement in mines be designed to minimize reactions with water and the flow of water through CCRs.** Several methods are described for reducing the interaction of CCRs with water, including placement well above the water table, compaction and cementation, and the use of liners and low-permeability covers. In all cases, proper covers should be placed over CCRs to prevent erosion as well as root penetration by plants and subsequent upward mobilization of CCR constituents. However, the committee recognizes that none of these methods will totally prevent CCRs from coming into contact with infiltrating water.

## Monitoring

Monitoring is an essential tool to confirm predictions of contaminant behavior and detect if and to what extent contaminants are moving into the surrounding environment. Because SMCRA monitoring regulations are not very prescriptive, states have a great degree of flexibility and control, and monitoring programs required at CCR mine placement sites vary widely by state. *Based on its reviews of CCR post-placement monitoring at many sites visited during the course of this study, the committee concludes that the number of monitoring wells, the spatial coverage of wells, and the duration of monitoring at CCR minefills are generally insufficient to accurately assess the migration of contaminants.* Additionally, the committee found quality assurance and control and information management procedures for water quality data at CCR mine placement sites to be inadequate.

The committee believes that a more robust and consistent monitoring program is needed in situations involving CCR mine placement. **The committee**

**recommends that the number and location of monitoring wells, the frequency and duration of sampling, and the water quality parameters selected for analysis be carefully determined for each site, in order to accurately assess the present and potential movement of CCR-associated contaminants.** Such an approach would also allow the specifics of the monitoring plan to be tailored to accommodate the unique combination of CCR characteristics, emplacement techniques, and overall site characteristics, while considering estimates of ecological and human health risks and the uncertainties in the site conceptual model.

Although monitoring plans should be site-specific, downgradient wells should be sited with an understanding of the travel times for contaminants to reach these monitoring points. Depending on the individual site characteristics and the distances to downgradient wells, a longer duration of groundwater monitoring may be necessary at some sites to adequately assess the temporal release of contaminants, which can occur over several decades. To address these concerns, several monitoring points should be established along predicted flow paths that will yield early (i.e., during the established bonding period) information that can be used to confirm predicted CCR leachate transport. At least one well or lysimeter, and preferably two, should be placed directly in the CCR to assess the field leaching behavior and confirm predicted contaminant flux. As part of the monitoring plan, quality assurance and control plans should be developed prior to CCR placement with clearly defined protocols for sampling and analysis, for data validation, and for managing systematic errors in analytical procedures.

### Performance Assessment

**The committee recommends that the disposal of CCRs in coal mines be subject to reasonable site-specific performance standards that are tailored to address potential environmental problems associated with CCR disposal.** In areas where CCR leachate may interact with surface water (directly or through groundwater interaction), more stringent requirements may be necessary to protect aquatic life. Where violations of permit requirements or performance standards occur, authority for appropriate penalties or corrective actions must be available to mitigate the damage and prevent future violations.

## CCR Use in Abandoned Mine Lands and Re-Mining Sites

Any regulatory standards for CCR use adopted under SMCRA for active coal mining would most likely apply to remining activities but would not apply directly to CCR use in abandoned mine lands. To ensure adequate protection of ecological and human health, **the committee recommends that placement of CCRs in abandoned and remining sites be subject to the same CCR characterization, site characterization, and management planning standards rec-**

**ommended for active coal mines**. However, when developing performance standards, adequate consideration should be given to the significant differences between active mines, abandoned mines, and the remining of previously abandoned mine sites. At such abandoned mine sites, the CCR placement process begins with a degraded site, and the same management options available in an active mine site may not always be feasible. The plans should consider the benefits of CCR use for reclamation at these degraded sites but should also factor in the potential adverse impacts of CCRs.

## OVERARCHING ISSUES AND CONCERNS

### Research

The committee considered a variety of information in its deliberations including: published technical reports; letters and reports (in both final and draft form); data compilations (both formal and informal materials); and other materials from citizens' groups, industry groups, and state and federal regulatory agencies. Much remains unknown about the long-term behavior of CCRs and their potential impacts in the mine setting. In addition, predictive characterization tools (e.g., leaching tests) are not adequate to guide management decision making. Available information is typically from short-term field or laboratory-based studies. In many cases there were differences in interpretation of the data and, in several cases, clear discrepancies in the data themselves. The committee often found itself wanting additional information that was not available.

**The committee recommends that research be conducted to provide more information on the potential ecological and human health effects of placing CCRs in coal mines**. Specific attention in such a research program should be directed at improved understanding of the following:

1. The environmental behavior of CCR at mine sites under differing climatic and geologic settings, to identify the types of mine settings, CCRs, and placement techniques that are most protective of human and ecological health. This research should include studies to determine under what conditions CCRs can effectively ameliorate the adverse effects of acid mine drainage in surface waters, particularly over protracted time scales. This research should also include the application of existing reactive transport models to CCR mine placement sites to evaluate whether the transport and reaction processes in the model adequately describe the processes taking place at CCR mine disposal sites, including those processes that occur over protracted time scales.
2. The potential ecological and human health effects of placing CCR in coal mines—this program should include studies to clarify the fate and transport of contaminants from CCRs and the potential for human exposure from contaminated drinking water. It should include studies to determine the effects (or lack

thereof) on biological communities over protracted time scales in mine placement sites where nearby streams or wetlands are likely to be connected to groundwater.

3. The continuous improvement and field validation of leaching tests for better prediction of the mobilization of constituents from CCRs in mine settings—specifically, post-placement field studies should be conducted that would allow the comparison of leaching test results to detailed water quality monitoring.

### Public Participation

In recognition of public concern over the potential for adverse environmental and health impacts from improper CCR disposal, government agencies responsible for regulating CCRs should ensure that the public receives adequate advance notice of any proposals to dispose of CCRs in mine sites. **The committee recommends that any proposal to dispose of substantial quantities of CCRs in coal mines be treated as a "significant alteration of the reclamation plan" under SMCRA**. This will ensure that the public is afforded adequate notice and an opportunity to comment officially on the CCR placement proposal.

### Alternatives for Regulatory Authority

The SMCRA and RCRA are the basic federal laws for mine reclamation and environmental protection that can be applied to placement of CCRs in coal mines. Activities such as mining and environmental protection involve locally specific conditions that can be difficult to address through national rules. Hence, many federal programs are delegated to the states for their implementation to enable more focused incorporation of local conditions and needs. Neither SMCRA nor its implementing regulations, however, currently address the use or placement of CCRs in an explicit manner. As a consequence, states vary in their approach and in the rigor with which they address CCR use in mines.

After reviewing the laws and other relevant literature, *the committee concludes that although SMCRA does not specifically regulate CCR placement at mine sites, its scope is broad enough to encompass such regulation during reclamation activities.* Furthermore, while SMCRA and its implementing regulations indirectly establish performance standards that could be used to regulate the manner in which CCRs may be placed in coal mines, neither the statute nor those rules explicitly address regulation of the use or placement of CCRs, and some states have expressed concern that they do not have the authority to impose performance standards specific to CCRs. Therefore, **the committee recommends that enforceable federal standards be established for the disposal of CCRs in minefills.** Enforceable federal standards will ensure that states have adequate, explicit authority and that they implement adequate minimum safeguards. As with current federal regulations, these rules should provide sufficient flexibility to allow states to adapt permit requirements to site-specific conditions, while providing the needed focus on the protection of ecological and human health.

There are three primary regulatory mechanisms that could be used to develop enforceable standards:

- Changes to SMCRA regulations to address CCRs specifically;
- Joint Office of Surface Mining (OSM) and EPA rules pursuant to the authority of SMCRA and RCRA; or
- RCRA-D rules that are enforceable through a SMCRA permit.

Under SMCRA, the OSM and related state agencies that implement SMCRA currently have the regulatory framework in place to deal with CCRs used in mine reclamation, and have considerable expertise in review, permitting, and management of mine lands. On the other hand, under RCRA, EPA and its counterpart state and local agencies have developed significant technical and regulatory expertise in monitoring and oversight of waste disposal operations (e.g., landfills) that involve groundwater and toxic substances. Regardless of the regulatory mechanism selected, coordination between OSM and EPA efforts is needed and would foster regulatory consistency with EPA's intended rule-making proposals for CCR disposal in landfills and impoundments.

In all cases, guidance documents will also be necessary to help states implement their responsibility for managing CCR. However, guidance alone is not adequate to achieve the needed improvements in state programs for CCR minefills. Only through enforceable standards can acceptable minimum levels of environmental protection from CCR placement in coal mines be guaranteed nationally.

## CONCLUSIONS

The committee believes that placement of CCR in mines as part of coal mine reclamation may be an appropriate option for the disposal of this material. In such situations, however, an integrated process of CCR characterization, site characterization, management and engineering design of placement activities, and design and implementation of monitoring is required to reduce the risk of contamination moving from the mine site to the ambient environment. Enforceable federal standards are needed for the disposal of CCRs in minefills to ensure that states have specific authority and that states implement adequate safeguards.

# 1

# Introduction

On August 14, 2003, more than 50 million people across the northeastern United States and Canada experienced an electrical blackout. While the blackout was caused not by a fuel shortage but by faulty controls in the grid, this event underscores the United States dependence on electricity. Municipalities faced urgent challenges related to contaminated drinking water, fighting fires, looting, health care, and transportation services. Train and airline traffic was canceled, and thousands of passengers were trapped when more than 600 subway and commuter rail cars stopped in the middle of tunnels. Road travel was also affected as traffic lights stopped functioning, and many gas stations were unable to pump fuel because there was no electric power. Hundreds of people were trapped in elevators. Hospitals struggled to treat their most serious patients. Some areas lost water pressure because pumps did not have power, causing possible contamination of water supplies. Individuals quickly realized how difficult simple daily tasks became without electricity, because they could not charge their cell phones, refrigerate or cook food, ride in elevators, or turn on air conditioning (Answers.com, 2005). It took New York City 29 hours to restore power, while other areas did not have electricity restored for up to four days. It is estimated that the economic cost to New York City alone due to the blackout was more than $500 million (Figure 1.1). Even though Americans depend on electricity for most everyday activities, the majority of people do not realize that electricity is provided primarily by coal-fired electric utilities.

Coal-fired utilities represent the largest single source of electrical generation in the United States. In 2003, total U.S. coal consumption was nearly 1,095

**FIGURE 1.1** Pedestrians and vehicles clog New York's Brooklyn Bridge, August 14, 2003. SOURCE: AP, 2003. Courtesy of the Associated Press.

million short tons,[1] with the U.S. electric power industry consuming 1,004 million short tons of that total (USDOE, EIA, 2003a). The combustion of coal results in the formation of coal combustion residues (CCRs), the noncombustible portion of the coal itself and residues from various air pollution control technologies, such as sulfur dioxide scrubbers, installed at the combustion facility. Specific examples of CCRs include fly ash, bottom ash, boiler slag, and flue gas desulfurization sludge.

During 2003, the combustion of coal resulted in at least 121 million short tons of CCRs (USDOE, EIA, 2003b) produced by utilities and an additional 5 million short tons produced by independent power producers firing coal refuse (PADEP, 2004). This mass is approximately 890 pounds per capita,[2] which is roughly the amount of municipal solid waste disposed in landfills throughout the United States per capita each year (USEPA, 2005a). To paint a better picture, the

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[1] The U.S. ton is the short ton, which is equal to 2,000 pounds; the British ton is the long ton, which is equal to 2,240 pounds (see Glossary for more detail).

[2] Calculated from 126 million tons divided by the 2003 census population of 283 million.

amount of CCRs produced annually would fill about one million standard railroad coal cars, which, if hitched together, would create a train about 9,600 miles long (Conrail Cyclopedia, 2005) that would span the United States from New York City, New York, to Los Angeles, California, 3.5 times.

The management of large volumes of CCRs is a challenge for utilities, because they must either place the CCRs in landfills, surface impoundments, or mines, or find alternative uses and markets for the material, such as the use of fly ash in concrete production. Each of these methods for disposing of CCRs has advantages and disadvantages pertaining to various factors including cost and environmental risk. To meet their CCR disposal needs, utilities often, as part of their contractual relationship with coal suppliers, require that a mine take the CCRs for use in reclamation, the process by which land-use capability is restored at a mine site.

This report examines the management, benefits, and health and environmental risks associated with the placement of CCRs in active and abandoned coal mines. To begin, this chapter provides an introduction to coal mining and CCRs to set the stage for the more in-depth discussion of CCRs and their placement in mines in the following chapters. This introduction briefly reviews coal production and use in the United States, including where and how coal is mined; management of CCRs, including how they are produced and disposed of; and the purpose of this study.

## COAL PRODUCTION AND USE IN THE UNITED STATES

Coal is the world's most abundant fossil fuel and the largest single source of fuel for electricity production in the United States (Sidebar 1.1). More than 90 percent (USDOE, EIA, 2003a) of the coal mined in the United States is used by

### SIDEBAR 1.1
### Geological Origin of Coal

Coal is a fossil fuel formed from the remains of organic plants that existed millions of years ago. The plant matter was buried by sediment, and the weight of these overlying deposits compacted the buried plant organic matter. Heat, pressure, and chemical and physical changes took place while the plant matter was buried, driving oxygen out of it and leaving rich hydrocarbon deposits. Through this process, the plant matter was gradually transformed into coal. Coal has a highly variable composition, affecting both its chemical and its physical properties. It may contain significant amounts of sulfur, arsenic, and other materials that can lead to environmental concerns as the coal residue is produced.

SOURCES: Rice et al., 1979; Hoffman, 2002.

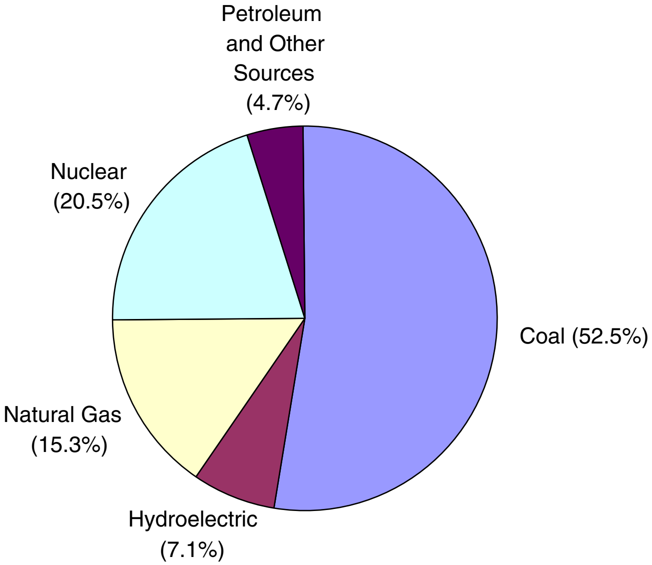

**FIGURE 1.2** Electricity generation in the United States, showing proportion generated by energy source, 2003.
SOURCE: USDOE, EIA, 2004a.

commercial power plants to generate electricity. In 2003, 1,004 million short tons of coal generated more than 50 percent of all the electric power produced in the United States (Figure 1.2; USDOE, EIA, 2004a). In 2003, coal consumption for electricity production increased by 2.7 percent (USDOE, EIA, 2003a, 2004a), and the percentage of electricity produced from coal is expected to increase through 2025 (Figure 1.3).

Coal has a highly variable composition affecting both its physical and chemical properties. Four types of coal and coal refuse (called culm when derived from anthracite mines and gob when derived from bituminous mines) with widely varying characteristics are used in the production of electricity and heat (Table 1.1).

The United States has approximately 25 percent of the world's coal reserves (USDOE, EIA, 2004b). More than 400 coalfields and small deposits cover a total of 458,600 square miles in 38 states, split nearly evenly between the eastern and western United States (Figure 1.4; Chircop, 1999). Although approximately 300 different coal deposits are mined each year, almost 47 percent of total production comes from just 10 of the largest deposits. In 2003, 51 percent of the country's total coal production of 1,071.8 million short tons came from western mines, 36 percent from the Appalachian area, 13 percent from Midwest area mines, and less than 1 percent from coal refuse recovery (USDOE, EIA, 2003a).

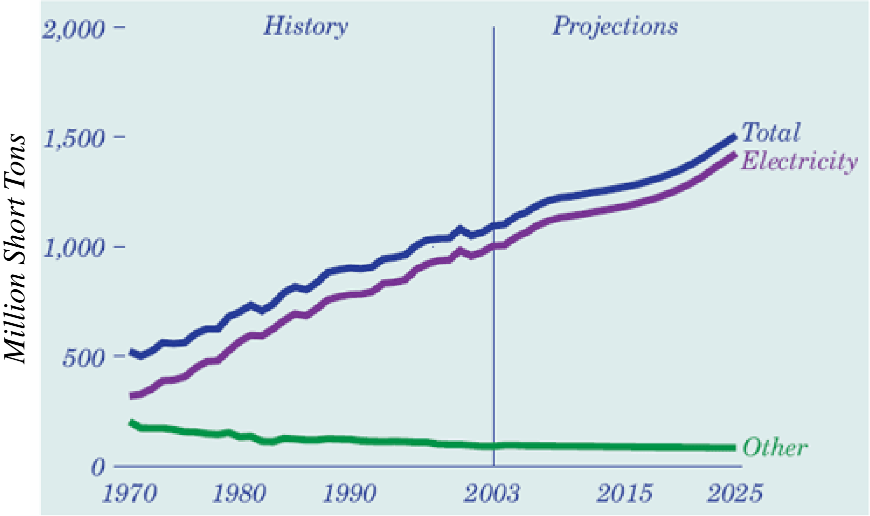

**FIGURE 1.3** Consumption of coal for electricity generation and other uses (million short tons), 1970-2025.
SOURCE: USDOE, EIA, 2005a.

**TABLE 1.1** Types of Coal and Their Characteristics

| Coal Type | Moisture Content[a] (percent) | Average Heat Content (Btu per pound) | Average % Sulfur by Weight | Average % Ash by Weight |
|---|---|---|---|---|
| Lignite (or brown coal) | Up to 45 | 6,500[b] | 0.91[b] | 14.2[b] |
| Subbituminous | 20-30 | 8,800[b] | 0.35[b] | 6.3[b] |
| Bituminous | <20 | 12,000[b] | 1.45[b] | 10.1[b] |
| Anthracite | <15 | 12,700[d] | 0.7[d] | 11[d] |
| Coal refuse (culm or gob) | Not Available | 6,000-9,500[c] | Culm–0.46[c]<br>Gob–2.3[c] | 32-72[c] |

NOTE: Btu = British thermal unit.

[a] USDOE, EIA, 2003a.
[b] USDOE, EIA, 2001.
[c] ARIPPA, 2000.
[d] The Pennsylvania Academy of Science, 1983.

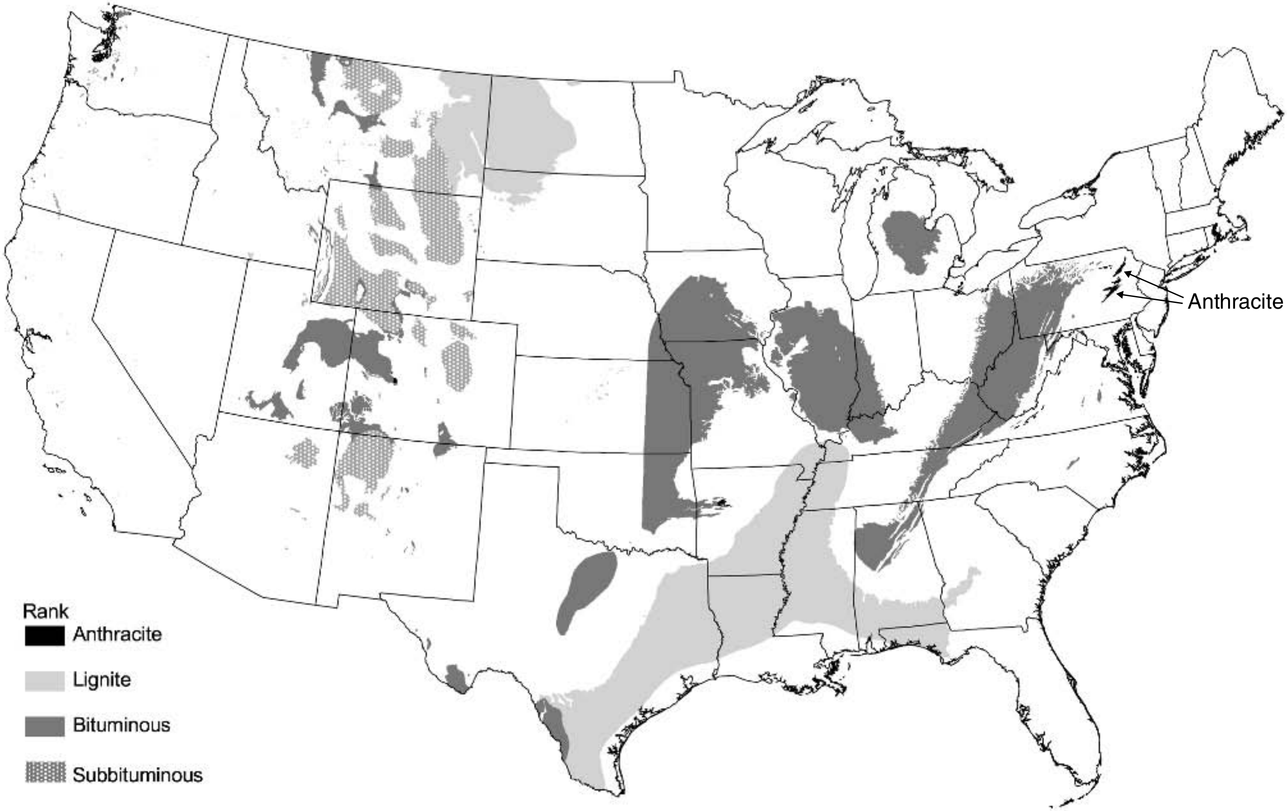

**FIGURE 1.4** Coal-bearing areas of the United States.
SOURCE: Susan Tewalt, U.S. Geological Survey.

In 2003, 1,316 mines were actively operating in the United States. Of these, approximately 67 percent were surface mines and the remaining were underground mines (USDOE, EIA, 2003c). Surface mining is used when coal is found close to the surface and involves removing the topsoil, the subsoil, and other rock units, called overburden, and setting them aside. After the coal is removed, the area is reclaimed, refilled with the overburden, and covered with the soils that were saved; then the land is reshaped and reseeded. Underground mining is used to extract coal that lies deep beneath the surface; an underground mine's coal is removed mechanically and transferred by shuttle car or conveyor to the surface.

Besides utilities, other industries and manufacturing plants use coal. Steel production accounts for the second largest use of coal; coal is placed in hot furnaces to produce coke, a form of coal that is used to smelt iron ore for making steel. Other industries use coal directly for the production of chemicals, cement, paper, ceramics, and various metal products. Coal is also an ingredient in products such as plastics, tar, synthetic fibers, fertilizers, medicines, dyes, paint, disinfectants, shampoo, soap, detergents, and cosmetics (University of Pittsburgh, 2000; Solid Energy, 2002; Cosmetics Programme, 2005; USDOE, EIA, 2005b).

## MANAGEMENT OF COAL COMBUSTION RESIDUES

The combustion of coal produces heat. The heat is used to make steam that is then used to drive electrical generators or perform other types of steam-driven work. The combustion of coal also generates various forms of solid residues, including fly ash, bottom ash, boiler slag, and flue gas desulfurization sludge. These materials are known by a variety of terms including coal combustion waste, coal combustion product, fossil fuel combustion waste, coal combustion material, coal combustion ash, coal combustion by-product, and coal combustion residue. For the purpose of this report the committee chose to use the term "coal combustion residue." This term was chosen to avoid implying that these materials are destined for particular fates. The characteristics of CCRs are influenced by several factors such as the source coal, combustion technology, and power plant air pollution control technology. The characteristics of CCRs are discussed in more detail in Chapter 2.

Burning coal and coal refuse to generate electricity produced more than 120 million short tons of CCRs in 2003 (USDOE, EIA, 2003c; PADEP, 2004). The amount will likely increase as the demand for coal-based energy in the United States grows and as air pollution control technology is more widely used for capturing residues. Utilities dispose of CCRs by placing them in landfills, surface impoundments, or mines (Sidebar 1.2 and Figure 1.5) or by finding alternative uses and markets for the material. Alternative uses for CCRs can include the production of concrete, wallboard, filler for paint and other products, and manufacturing of mortars (ACAA, 2005b). Of the approximately 126 million short tons of CCRs reported to have been produced in 2003, 46 million short tons (37

## SIDEBAR 1.2
## Placement Options

In 1999, it was estimated that approximately 600 fossil fuel combustion waste management units, defined by the Environmental Protection Agency (EPA) as landfills and surface impoundments, were in operation at approximately 450 coal-fired utility power plants. At the time, the 600 units included equal proportions of landfills and surface impoundments, although the trends in 1999 suggested an increasing preference for landfills (USEPA, 1999a).

**Surface impoundments** are natural depressions, excavated ponds, or diked basins that usually contain a mixture of liquids and solids. CCRs managed in surface impoundments typically are sluiced with water from the point of generation to the impoundment. The solid CCRs gradually settle out of this slurry, accumulating at the bottom of the impoundment. This process leaves a standing layer of relatively clear water at the surface, which is commonly termed head. Solids that accumulate at the bottom of a surface impoundment may be left in place as a method of disposal. The impoundment also may be dewatered periodically and the solids removed for disposal elsewhere, such as a landfill (USEPA, 1999a).

**Landfills** are facilities usually constructed in sections called cells, in which residues are placed for disposal on land. Residues are placed in the active cell and compacted until the predetermined cell area is filled. Completed cells are covered with soil or other material, and then the next cell is opened. Cells constructed on top of previously completed cells are called lifts. Landfills are usually natural depressions or excavations that are gradually filled with residue, although the construction of lifts may continue to a level well above the natural grade. Coal combustion residues managed in landfills may be transported dry from the point of generation, or they may be placed after dredging from a surface impoundment. Residual liquids may be placed along with the dredged solids. Also, liquids may be added during the construction of the landfill for dust control purposes (USEPA, 1999a).

**Minefills** involve the placement of CCRs in surface or underground mine voids (USEPA, 1999a). When used in surface mines, the CCRs are incorporated into the mine reclamation plan and generally are deposited in the mine as backfill combined with the overburden or as a monofill. They can be used in mine reclamation to achieve the approximate original contour. CCRs can also be used to form a grout to fill underground mines in order to prevent subsidence (USEPA, 2002a). Because the transportation of CCRs to the disposal site can be costly, disposal in mines is commonly done when the utility and the mine are located near one another.

percent) went to alternative uses (AACA, 2005a); 73 million short tons (58 percent) were placed by utilities into surface impoundments, landfills, and other on-site locations (USDOE, EIA, 2003b); and approximately 7 million short tons (5 percent)—2 million short tons from traditional utilities and 5 million short tons from independent power producers fueled by coal refuse—were used in mine applications. According to the American Coal Ash Association Coal Combustion

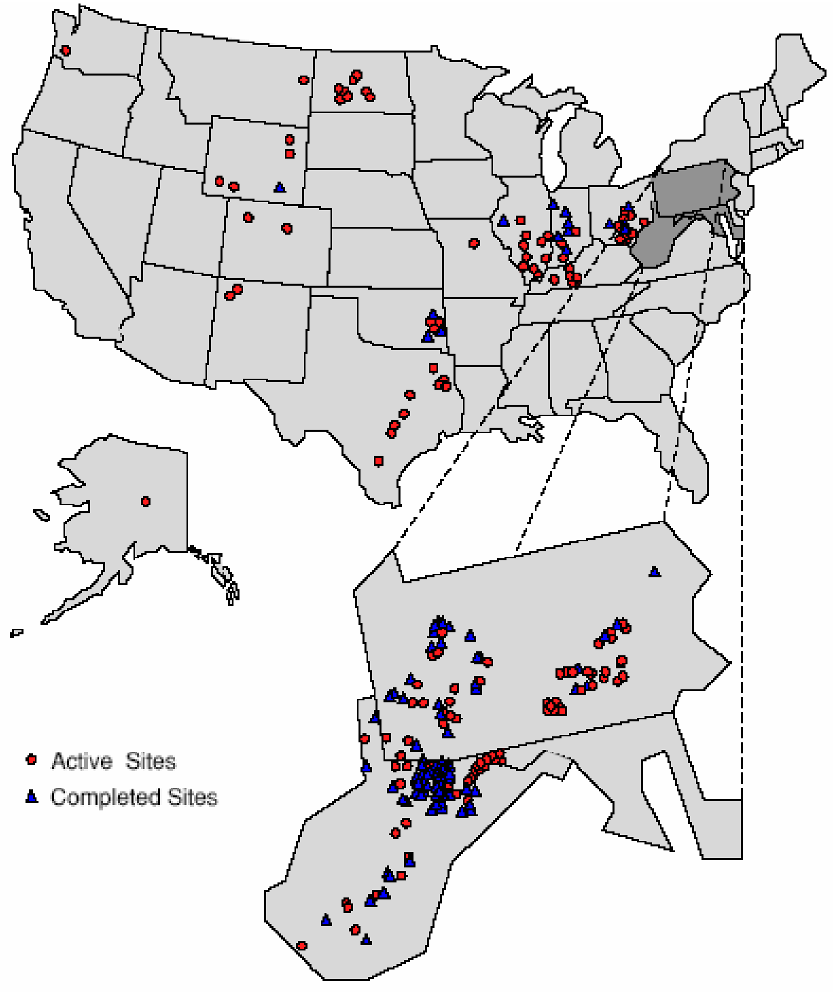

**FIGURE 1.5** Coal combustion residue mine placement sites in the United States.
SOURCE: National Research Council; data collected through individual state surveys.

Product Production and Use Survey (2005a), such mine applications may include use in surface mine reclamation, underground mining projects, and use in other mining industries such as sand and gravel pits. The available data are likely to underestimate the actual tonnage of CCRs being placed in coal mines due to deficiencies and inconsistencies in the current reporting framework (see Chapter 2, Sidebar 2.4).

## SIDEBAR 1.3
## Statement of Task

In response to a request from Congress, the National Research Council conducted a study that examined the health, safety, and environmental risks associated with using coal combustion wastes (CCWs)[a] for reclamation in active and abandoned coal mines. The study looked at the placement in abandoned and active, surface and underground coal mines in all major coal basins. The study considered coal mines receiving large quantities of coal combustion wastes. The committee focused its efforts on coal combustion wastes from utility power plants and independent power producers, rather than small business, industries, and institutions. A profile of the utility industry was taken into consideration in designing the study to focus on the sources producing the greatest quantities of coal combustion wastes.

Specifically, the committee addressed the following points:

1. The adequacy of data collection from surface-water and groundwater monitoring points established at CCW sites in mines.
2. The impacts of aquatic life in streams draining CCW placement areas and the wetlands, lakes, and rivers receiving this drainage.
3. The responses of mine operators and regulators to adverse or unintended impacts such as the contamination of groundwater and pollution of surface waters.
4. Whether CCWs and the mines they are being put in are adequately characterized for such placement to ensure that monitoring programs are effective and groundwater and surface waters are not degraded.
5. Whether there are clear performances standards set and regularly assessed for projects that use CCW for “beneficial purposes” in mines.

## PURPOSE OF THE STUDY

Whether CCRs should be placed in coal mines and, if so, under what conditions, are important policy issues. Many CCRs can be recycled for use in engineering applications or products such as cement or wallboard—uses that avoid other environmental impacts and the consumption of other natural resources. The remainder must be disposed. Using CCRs in mine reclamation avoids having to dispose of them in landfills and/or surface impoundments, limiting the environmental disturbance of other land. Concerns have been raised about public health and environmental risks posed by mine placement of CCRs, especially when they come in contact with water. Burning coal concentrates metals and metalloids, such as arsenic, cadmium, chromium, and lead, in the CCRs, compared to the original coal, and alters the leachability of the contaminants by changing the mineralogy of the material (USGS, 2002). As an example of the risks to be

6. The status of isolation requirements and whether they are needed.
7. The adequacy of monitoring programs including:
    a. The status of long-term monitoring and the need for this monitoring after CCW is placed in abandoned mines and active mines when placement is completed and bonds released;
    b. Whether monitoring is occurring from enough locations;
    c. Whether monitoring occurs for relevant constituents in CCW as determined by characterization of the CCW; and
    d. Whether there are clear, enforceable corrective actions standards regularly required in the monitoring.
8. The ability of mines receiving large amounts of CCW to achieve economically-productive post-mine land uses.
9. The need for upgraded bonding or other mechanisms to assure that adequate resources area available for adequate periods to perform monitoring and address impacts after CCW placement or disposal operations are completed in coal mines.
10. The provisions for public involvement in these questions at the permitting and policy-making levels and any results of that involvement.
11. Evaluation of the risks associated with contamination of water supplies and the environment from the disposal or placement of coal combustion wastes in coal mines in the context of the requirements for protection of those resources by the Resource Conservation and Recovery Act (RCRA) and the Surface Mining Control and Reclamation Act (SMCRA).

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[a] Although the term “coal combustion wastes” (CCWs) was used in the statement of task, after much discussion the committee chose to use the term “coal combustion residue” (CCR) for the purpose of this report. This term was chosen to avoid implying that these materials are destined for particular fates.

considered, the Safe Drinking Water Act places limits on the presence of some of these constituents in public water supplies. The placement of CCRs in coal mines is a complex issue that involves consideration of possible human health and environmental impacts, as well as a comparison of the economic, health, and environmental impacts from other disposal options or uses (see Chapter 4).

CCR mine placement is indirectly regulated under the Surface Mining Control and Reclamation Act (SMCRA). This act gives states the option of developing and implementing their own programs, subject to national standards and federal oversight (see Chapter 5). Thus, at present, regulation of CCR mine placement is primarily a state issue.

Concern about the potential public health and environmental risks associated with using CCRs for reclamation in active and abandoned coal mines led Congress to direct the Environmental Protection Agency (EPA) to commission an independent study to examine this topic. As a result, the National Research

Council (NRC) established the Committee on Mine Placement of Coal Combustion Wastes to undertake a study to address issues outlined in the statement of task (Sidebar 1.3). The committee consists of 14 experts from academia, industry, and state government with expertise in hydrogeology, geology, geochemistry, nuclear chemistry, biology, ecology, toxicology, epidemiology, occupational and environmental medicine, natural resource economics, environmental policy, environmental law, mining regulations, environmental engineering, mining engineering, geotechnical engineering, and coal mining. Brief biographies of the committee members appear in Appendix A.

This report is intended for multiple audiences including the general public. It contains advice for EPA and the Office of Surface Mining (OSM), other federal agencies, and state regulatory agencies, as well as policy makers, the coal industry, and its consultants, scientists, and engineers.

## THE COMMITTEE'S APPROACH

To address the statement of task, the committee reviewed relevant government documents and materials, pertinent National Research Council reports, information submitted to the committee by various sources (see Appendix B), and other technical reports and literature published through July 2005. In addition, the committee held seven meetings, six of which included information-gathering sessions that were open to the public, between October 2004 and August 2005. The information-gathering sessions included presentations by and discussions with personnel from EPA, OSM, and other federal, state, and local government agencies and representatives of industry, academia, environmental organizations, and citizens' groups (Appendix B). To obtain input from the public, the committee also held six public testimony sessions, in conjunction with the information-gathering meetings, in Washington, D.C.; Farmington, New Mexico; the Navajo Nation, New Mexico; Austin, Texas; Evansville, Indiana; and Harrisburg, Pennsylvania. During the information-gathering meetings the committee, subgroups of the committee, and individual committee members also visited several mine sites that were currently using or had previously used CCRs for minefilling.

In addition to published technical reports, the committee considered numerous letters and reports (in both final and draft form), data compilations (both formal and informal materials), and other materials from citizens' groups, industry groups, and state and federal regulatory agencies. The information ranged from materials dealing with individual mining and CCR disposal sites (a few that the committee visited, as well as other sites) to compilations of monitoring data and interpretive reports of monitoring data. Further, at the information-gathering meetings the committee received public testimony pertaining to more than a dozen sites where CCR has been placed in mines, including sites where CCR has been implicated in the degradation of environmental quality. In total, the committee heard presentations or received testimony from more than 120 individuals.

The committee considered all of this information during its deliberations. The information helped to identify data needs, as discussed in more detail later in this report. The reports and presentations often communicated conflicting views and interpretations of the environmental impacts of particular sites. Citizens' groups presented information on environmental degradation (e.g., water quality contamination) that may be related to CCR placement in mines and/or overall mining operations. This information was contrary to industry information that was presented, and many of these presentations were questioned or the interpretations were challenged by state agency personnel. In the committee's review of these data, it noted not only differences in their interpretation, but in several cases clear discrepancies in the data themselves. Although these discrepancies were quite informative, it is well beyond the committee's charge to review and resolve these local disputes. Hence, these local issues are not discussed in this report. To the extent possible, the committee has attempted to use and cite independently peer-reviewed reports and other information and government agency reports that are typically independently reviewed and available to the scientific community for review and comment.

In addition, during public testimony, citizens raised concerns about various public health and environmental issues related to CCRs and mining operations, such as traffic hazards, fugitive dust, and respiratory problems related to transporting CCRs to mine sites. Although these issues may be important health and safety concerns for the affected communities, they are beyond the charge and capability of this committee to address in this report.

Although CCRs have also been placed in other mine settings, including sand and gravel mines and base metal mines, the committee restricted its considerations to the placement of coal combustion residues in coal mines. Also, some coal-burning facilities add other combustible materials with coal (e.g., municipal wastes, old tires, waste oil), and a few mines accept other materials, such as dredge spoils, for minefill. To stay within its charge, the committee decided to include only materials derived directly from coal.

Related to its statement of task, the committee also limited its consideration to the impacts of placing large quantities of CCR in coal mines. With the limited data directly applicable, the committee did not attempt to evaluate or comment on possible impacts from relatively small-scale applications of CCRs such as their use on mine roads. The committee also did not consider occupational safety issues.

The committee's analysis focuses on the use of CCRs in surface mine reclamation, the largest use of CCRs for minefilling. The principles and standards presented in this report apply to placement of CCRs in underground mines as well, although such applications are relatively minor.

While the statement of task may not have specified that the committee evaluate impacts from the disposal of CCRs in landfills and surface impoundments, or the recycling of CCRs for other purposes, it was not feasible to address the impacts of CCR use in minefilling without comparison to other disposal and use options. Particularly, limitations in data available on the practice necessitated the review of environmental impact data from landfills and surface impoundments because these case studies illustrate how CCRs may affect human and environmental health (see Chapter 4).

## REPORT ROADMAP

The chapters that follow address the statement of task and present the committee's findings and recommendations. Chapter 2 describes coal combustion residue production, characteristics, reuse, and placement technologies. Chapter 3 examines the behavior of coal combustion residues in the environment. Chapter 4 looks at the potential environmental impacts, considerations for human health, and reasons for concern regarding placement of CCRs in mines (statement of task numbers 2 and 3). Chapter 5 provides an overview of the regulatory framework governing the placement of CCRs in mines (statement of task number 5). Chapter 6 discusses the risk management framework for CCR disposal, as well as material and site characterization and prediction (statement of task number 4). Chapter 7 addresses site management strategies including reclamation and monitoring practices (statement of task numbers 1, 6, 7, and 8). Chapter 8 summarizes the committee's overall management approach and other overarching issues (statement of task numbers 9, 10, and 11). Technical terms and acronyms are defined in Appendixes C and D.

# 2

# Coal Combustion Residues

This chapter provides an overview of the basics of CCRs, including their production, characteristics, and disposal and use options (see Figure 2.1). It then examines how CCRs are generated, including the combustion technologies used and the pollution control equipment utilized, which contribute to the type, quantity, and characteristics of CCRs generated. Finally, it considers the possible options for CCR management, which include disposal in landfills or surface impoundments, use of the CCR as a component of an engineered product, or use or disposal in a coal mine. Although placement of CCRs in coal mines is the focus of this report, a brief presentation of the alternatives to mine placement is included in this report to illustrate the available CCR management alternatives.

## TYPES OF COAL COMBUSTION RESIDUES

Coal does not completely convert to a gas upon combustion; therefore, all coal-fired boilers produce solid materials in the form of CCRs. The amount of CCRs produced by utilities has increased as the demand for energy in the United States has grown.

A variety of solid materials may be generated from the combustion of coal, including fly ash, bottom ash, boiler slag, and residues from air pollution control technologies, such as flue gas desulfurization (FGD) materials (Figure 2.1). Fly ash represents a major component (62 percent) of CCRs, followed by FGD material (19 percent), and bottom ash and boiler slag (18 percent) (USDOE, EIA, 2003b). The major types of CCRs are described in detail below. An overview of common coal combustion technologies is provided in Sidebar 2.1.

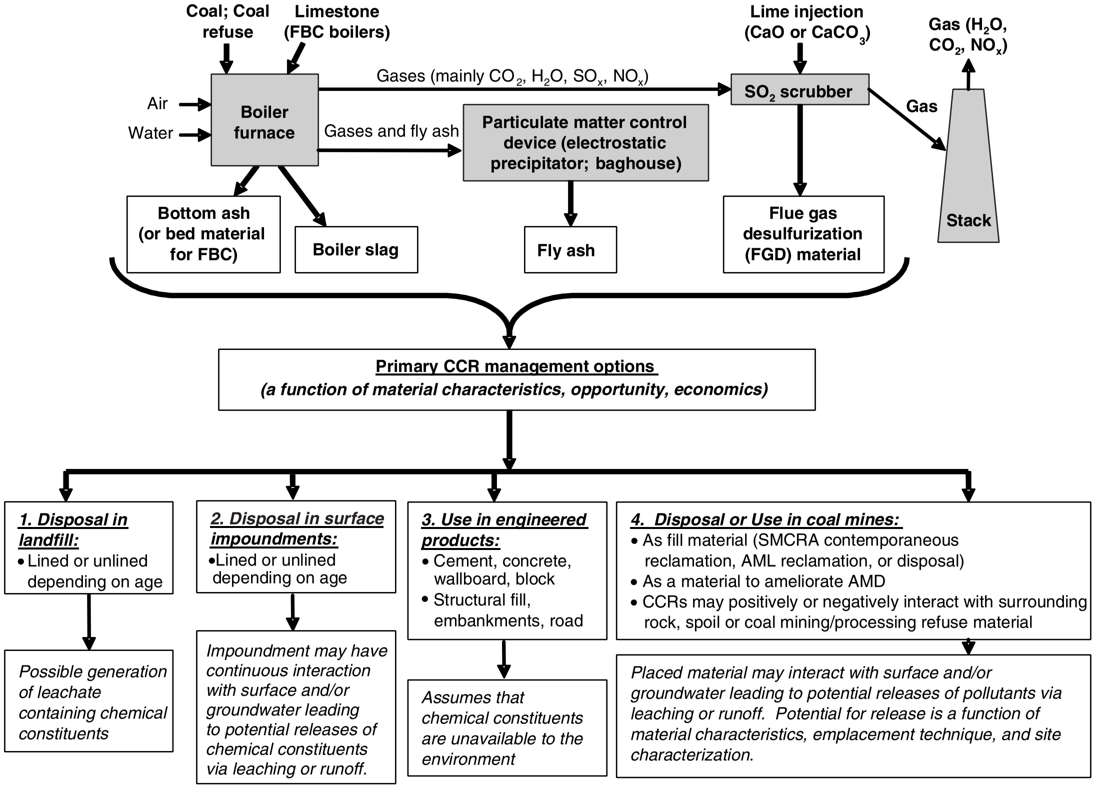


**FIGURE 2.1** CCR production and disposal or use options in a coal-fired facility. Note: AMD = acid mine drainage; AML = abandoned mine lands; FBC = fluidized bed combustion; SMCRA = Surface Mining Control and Reclamation Act.
SOURCE: Adapted from USGS, 2001.

## SIDEBAR 2.1
## Technologies for Coal Combustion

Many industrial and utility boilers use coal as the primary source of fuel. The boiler is the unit that encloses the furnace, where the fuel is combusted. When coal is fed into the furnace, the heat generated is used to heat water circulating in tubes surrounding the furnace. As the water heats, it turns to steam. The steam is captured and used within the facility to turn the blades of an electricity generator or a compressor for refrigeration, to heat a process or a building, or for many other uses.

There are three primary coal combustion technologies used in boilers:

1. **Grate firing**, where coal is combusted while residing on a grate within the furnace;
2. **Suspension firing (e.g., pulverized coal (PC) firing),** where coal is crushed to a fine powder prior to entering the boiler's furnace and subsequently combusted in suspension with the combustion air; and
3. **Fluidized bed combustion (FBC)**, where coal is combusted in a suspension with a solid sorbent (usually limestone) or an inert material such as sand (Davis, 2000).

Utility boilers generate steam to drive turbine generators for the production of electricity. Utility boilers are commonly suspension-fired boilers, such as pulverized-coal boilers. The coal-refuse-fired facilities generally use FBC technology.

### Fly Ash

Fly ash consists of fine particles carried out of the boiler by the flue gases. Most fly ash is captured by dust-collecting systems before it escapes the boiler's stack. Common particulate matter control devices include mechanical collectors, electrostatic precipitators, and fabric filters (Sidebar 2.2). Other constituents mobilized in the coal combustion process may be associated with fly ash. For example, mercury tends to adsorb to fly ash unless another material, such as activated carbon, is added to the flue gas to capture the mercury preferentially.

### Bottom Ash and Boiler Slag

Bottom ash typically consists of large ash particles that accumulate at the bottom of the boiler. Boiler slag is a molten inorganic material that is collected at the bottom of the boiler and discharged into a water-filled pit, where it is cooled with water (quenched) and removed as glassy particles resembling sand. The form of the ash or slag produced is dependent on the type of furnace and the fusion temperature (or melting point) of the ash generated from the coal. Some pulverized coal (PC) furnaces (see Sidebar 2.1) fire coals of high ash-fusion

## SIDEBAR 2.2
## Particulate Matter Control Devices

There are three common particulate matter control devices used with coal-fired furnaces, described below.

*Mechanical Collectors*, most commonly known as cyclones or multicyclones, force a cyclonic flow of the exit gas. This flow causes ash particles to be thrown against the walls of the collector and to drop out of the gas. Cyclones are most effective for larger particles; collection efficiency drops well below 90 percent for the smallest particles.

*Electrostatic Precipitators (ESPs)* are the most common particulate control technology used by coal-fired utilities. An ESP generates a high-intensity electrical field that causes ash particles to acquire an electrical charge and migrate to an oppositely charged collection surface. For typical coal-fired utilities, this process results in a collection efficiency of greater than 99 percent.

*Fabric Filters*, also known as baghouses, capture ash as the exit gas passes through a series of porous filter bags. Baghouses have an efficiency of greater than 99 percent.

SOURCE: USEPA, 1999b.

temperatures and use a dry ash removal technique (Davis, 2000). Others fire coal with a low ash-fusion temperature causing much of the ash to form a liquid slag, which is then drained from the bottom. Boiler slag is a CCR that is expected to be produced in diminished quantities in the future because of the retirement of the older boilers that produce liquid slag in significant quantities.

## Residues from Air Pollution Control Technologies

Several air pollution control regulations have been enacted to improve air quality in the United States. To implement these regulations, many coal-fired plants use pollution control devices, in addition to particulate matter controls, which can generate their own type of residue or change the characteristics of existing residues. The characteristics of the residue generated are dependent on the type of pollution control equipment installed, which varies widely between plants (and even between units at the same plant) depending on space constraints, compatibility with existing equipment, and regulatory performance requirements.

### Sulfur Dioxide Emissions Control Technology

Sulfur dioxide ($SO_2$) emissions controls are the most common devices added to augment the control of particulate matter. $SO_2$ is a component of fine airborne particulate matter in the form of aerosols and is the primary component of acid

## SIDEBAR 2.3
## Desulfurization Technologies

Post-combustion desulfurization technologies (or $SO_2$ scrubbers) are categorized as recovery systems and non-recovery systems. Recovery systems are those that produce FGD wastes that are suitable for use in engineered products, such as wallboard. Non-recovery systems produce FGD waste that must be disposed of. Non-recovery systems are further classified as wet and dry systems. Wet systems scrub and saturate flue gas with a slurry of water and a sorbent (usually lime or limestone) that reacts to remove sulfur from the gas in the form of a sludge. Dry systems typically contact flue gas with a sorbent slurry in a spray dryer without saturating the gas with water. The dry reaction product is then collected along with fly ash in a fabric filter or ESP. Wet systems are more effective at removing sulfur dioxide and, therefore, are used by a larger proportion of generators. However, because of their use of liquids, wet systems produce more waste than do dry systems (USEPA, 1999b).

Desufurization can also be accomplished within the coal combustion process itself. In systems utilizing FBC technology, desulfurization can be accomplished by co-firing the coal with limestone. The limestone then serves a dual purpose: a bed material for the furnace and an $SO_2$ sorbent (Woodruff et al., 1998).

rain. Units that remove $SO_2$ emissions from flue gas are referred to as flue gas desulfurization (FGD) systems (see Sidebar 2.3). Since the implementation of the Clean Air Act's Acid Rain Program (40 CFR 72-75) in 1990, FGD technologies have added a significant non-ash component to CCRs (Figure 2.2). In 2005, the Environmental Protection Agency enacted the Clean Air Interstate Rule (70 FR 25162) establishing a new emission reduction program for $SO_2$ and $NO_x$ (nitrogen oxide) generating reductions of these pollutants in 28 states and the District of Columbia. The Clean Air Interstate Rule incorporates and goes beyond the existing Clean Air Act Acid Rain Program and may lead to more FGD materials being produced or to a new material produced by the introduction of new technologies.

### Nitrogen Oxide Emissions Control Technology

There are several types of $NO_x$ emissions control technologies. The simplest is called a low $NO_x$ burner, which reduces the formation of $NO_x$ by controlling the environment in which the coal combusts (flame temperature and chemical environment). Selective Catalytic Reduction and Selective Non-Catalytic Reduction are post-combustion control technologies used for $NO_x$ emission reduction. These processes utilize ammonia reacted with the flue gas to convert it to elemental nitrogen and water (CURC, 2005). These processes may increase the ammonia content of CCRs making them less marketable (Butalia and Wolfe, 2000).

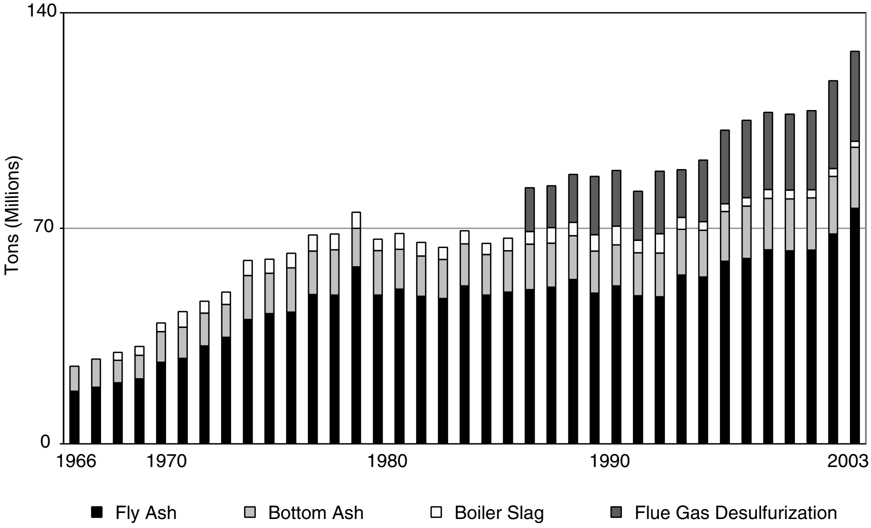


**FIGURE 2.2** Generation of fly ash, bottom ash, boiler slag, and FGD by utilities (1966-2003).

NOTE: This figure does not include the approximately 5 million short tons of CCR produced by independent power producers firing coal refuse.

SOURCE: American Coal Ash Association, Aurora, CO, written communication, October 2005. Courtesy of the American Coal Ash Association.

## Mercury Emissions Controls Technology

The implementation of the Clean Air Mercury Rule in 2005 (70 FR 28606) is expected to increase the use of mercury control technologies. The Clean Air Mercury Rule is intended to reduce nationwide utility emissions of mercury by creating a market-based cap-and-trade program occurring in two distinct phases. The first-phase cap of 38 tons will likely be achieved by taking advantage of "co-benefit" reductions—mercury reductions achieved by reducing $SO_2$ and $NO_x$ emissions under the Clean Air Act Amendments and the Clean Air Interstate Rule. The second phase, due in 2018, caps coal-fired power plant emissions at 15 tons and will likely necessitate installation of controls specific to mercury capture.

Some of these technologies, such as activated carbon injection, will result in a separate waste stream, but it is also possible that emerging technologies may simply change the characteristics of existing CCRs by increasing their mercury content. The characteristics and potential environmental impact of residues generated from mercury control is currently being studied by the EPA's National Risk Management Research Laboratory. Preliminary studies indicate that leaching of mercury from activated carbon injection materials may not be of concern. Preliminary results of Heebink et al. (2004) show that leachate mercury concentrations were low, regardless of the concentration of mercury in the original sample. All concentrations were below the primary drinking water standard of 2 μg/L. Early results from studies of mercury leachates from FGD associated with mercury controls, however, show that there is potential for undesirable release of mercury into the environment from this type of CCR (Thorneloe, 2005).

## PHYSICAL AND CHEMICAL CHARACTERISTICS OF COAL COMBUSTION RESIDUES

The chemical and physical characteristics of CCRs vary widely. For example, a dry scrubber FGD material may contain a relatively low concentration of metals, but a high concentration of sulfur compounds. Alternatively, a fly ash collected with a baghouse after being treated with activated carbon may have a relatively high concentration of mercury as well as carbon. This section describes the factors influencing the characteristics of CCRs and presents information on the physical and chemical characteristics of various CCRs.

### Factors Influencing the Characteristics of Coal Combustion Residues

There are several factors that influence the physical and chemical characteristics of the CCRs produced, including

1. Chemical characteristics of the source coal,
2. Chemical characteristics of any co-fired materials,
3. Combustion technology,
4. Pollution control technology used by the CCR producing facility, and
5. Residue handling technology used by the CCR producing facility.

#### Source Coal

Because CCRs largely represent the noncombustible constituents in coal, their characteristics are strongly influenced by the source coal itself. As described in Chapter 1, coal is comprised of carbonaceous materials and a complex mixture of various minerals. Both the major and the minor mineral constituents of coal contain metals and other elements that could be of concern if they were released in the environment in the proximity of sensitive receptors (Schweinfurth, 2003). Both the form and the concentrations of these trace elements vary with coal type (e.g., lignite, bituminous) and coal region. The United States Geological Survey (USGS) maintains an extensive database of coal quality characteristics of the major coal basins throughout the United States (Bragg et al., 2005).

## Co-Fired Materials

Some facilities co-fire coal with other fuels such as wood, biomass, plastics, petroleum coke, tire-derived fuel, refuse-derived fuel, and peat or manufactured gas plant wastes. Fifty-nine percent of non-utilities, encompassing industrial, commercial, and institutional facilities, co-combust other fuels with coal (e.g., oil, gas, wood chips; Carrell, 2002). Co-firing coal with other materials can result in a variety of chemical constituents in the final CCR. In its 1999 report to Congress, the EPA examined data provided by the Electric Power Research Institute regarding the residues generated from these co-fired fuels and determined that there was a potential for some of the mixtures to contain elevated levels of metals in the bulk material. The organic chemical constituent composition of the CCRs generated from co-fired fuels was generally below detection limits (USEPA, 1999a). Other facilities, such as the independent power producers in Pennsylvania, utilize fluidized bed combustion (FBC) boilers and co-fire coal refuse with limestone, resulting in a highly alkaline CCR.

## Combustion Technology

The effects of combustion technology on the characteristics of CCRs vary based on the source coal and the operating conditions. However, different technologies (Sidebar 2.1), especially FBC, can have an effect on the ash characteristics. Generally, given the same source coal and operating conditions, an FBC boiler will yield CCRs with a higher calcium concentration (as an oxide or sulfate) and lower silicon dioxide and aluminum oxide concentrations than a suspension-fired combustion boiler due to the addition of limestone during combustion (Sellakumar et al., 1999). Fluidized bed combustion also operates at a lower combustion temperature than PC combustion technology, resulting in different mineral transformations in the ash (discussed in more detail later in this chapter).

Several utility-scale technologies are emerging in the commercial market to allow the combustion of coal without the addition of post-combustion pollution controls, including integrated gasification combined cycle (IGCC) and pressurized fluidized bed combustion (PFBC). These emerging technologies have low air emissions relative to conventional coal-firing technologies and may also allow for capture of $CO_2$ from the exhaust gases (Booras and Holt, 2004). Today, the use of these technologies is minor relative to the use of standard combustion technologies; however, they hold promise for expanded use in the future. Research has shown that the characteristics of CCRs from IGCC differ markedly from those from traditional combustion technologies. Specifically, IGCC produces primarily slag, elemental sulfur, and sulfuric acid, all of which may hold economic value as salable by-products (Shilling and Lee, 2003). However, additional processing may be needed to remove excess carbon in IGCC slag, before it can be used in cement (Ratafia-Brown et al., 2002).

### Pollution Control Technology

As mentioned earlier in this chapter, air emissions control technology has the potential to affect the characteristics of an exiting CCR stream. It may improve or diminish the marketability of CCRs for productive uses, and it may change the profile of the toxic constituents of the CCRs. For example, $NO_x$ emission controls by themselves do not cause the production of a solid residual stream, but their use may lead to high ammonia content in the resulting fly ash, thereby changing the opportunities for utilization as opposed to disposal (Rathbone and Robl, 2002). For this reason, regulatory agencies responsible for imposing pollution control standards should carefully consider the implications of air pollution control requirements for the marketability of CCRs to ensure that the full suite of environmental consequences is analyzed and understood.

### Residue Handling Technology

Residue collection systems from the boiler and its auxiliaries vary between facilities and from unit to unit. Some units use a collection system that results in a combined residual in either a dry or a wet form. The type of materials that may be combined prior to leaving a plant is a function of individual plant collection logistics and/or any requirements to facilitate final disposal. Because residues are being produced constantly during the combustion process and must be removed regularly, facilities usually have a storage system such as a silo for dry materials or a surface impoundment (pond) for wet materials. Whether a CCR is in a wet or dry form and whether several CCR streams have been commingled are important factors in the management opportunities that may be available to the CCR generator.

## Physical and Chemical Characteristics

Understanding the physical and chemical properties of CCRs is important because these properties influence the opportunities for CCR use and disposal and affect the leachability of contaminants from CCRs. The physical and chemical properties discussed include mineralogy, grain size, bulk chemical content, trace element content, organic chemical content, and radioactive content.

### Mineralogy

The mineralogical characteristics of CCRs reflect the source coal, the combustion process itself, and any pollution control technologies used. Pulverized coal combustion occurs at high temperature (typically above 1400ºC) and therefore causes significant transformations of the inorganic minerals in coal (e.g., clay minerals, carbonates, sulfides, quartz) (Kim, 2002a). At such temperatures, minerals may decompose or oxidize (Clarke and Sloss, 1992). Amorphous aluminosilicate glass typically represents more than 60 percent of the mineral mass in PC fly ash (Hower et al., 1997; McCarthy et al., 1999). Other major mineral phases in PC fly ashes may include mullite ($Al_6Si_2O_{13}$), quartz ($SiO_2$), lime ($CaO$), anhydrite ($CaSO_4$), periclase ($MgO$), hematite ($Fe_2O_3$), magnetite ($Fe_3O_4$), and tricalcium aluminate ($Ca_3Al_2O_6$). Coal combustion residues containing substantial quantities of lime will have high levels of alkalinity, because lime forms a strong base, $Ca(OH)_2$, upon reaction with water. The lower temperature of the FBC process (approximately 800ºC), combined with the added limestone produces different assemblage of minerals in the fly ash and bottom ash. The primary minerals in FBC ash are anhydrite, lime, iron oxides, and quartz. Flue gas desulfurization residues consist primarily of gypsum ($CaSO_4 \cdot 2H_2O$) and calcium sulfite hemihydrate ($CaSO_3 \cdot 0.5H_2O$) (Tishmack, 1996).

## Grain Size

The grain size of CCRs is related to where the residues are collected (e.g., fly ash versus bottom ash). Both PC and FBC fly ash are fine grained, with a mean particle size of approximately 20-30 mm (Chugh et al., 2000). Pulverized coal fly ash particles tend to melt at high combustion temperatures and condense as spheres, resulting in relatively low surface area for this small grain size (0.7 to 37 $m^2/g$) (Nagataki et al., 1995), while FBC fly ashes maintain a more irregular shape (Figure 2.3). The FGD residues are also fine grained, with a mean particle size of 20-40 μm (Tishmack, 1996). Boiler slag particles are typically the size of fine gravel to coarse sand with 90 to 100 percent passing a 4.75 mm sieve, 40 to 60 percent passing a 2.0 mm sieve, and 10 percent or less passing a 0.42 mm

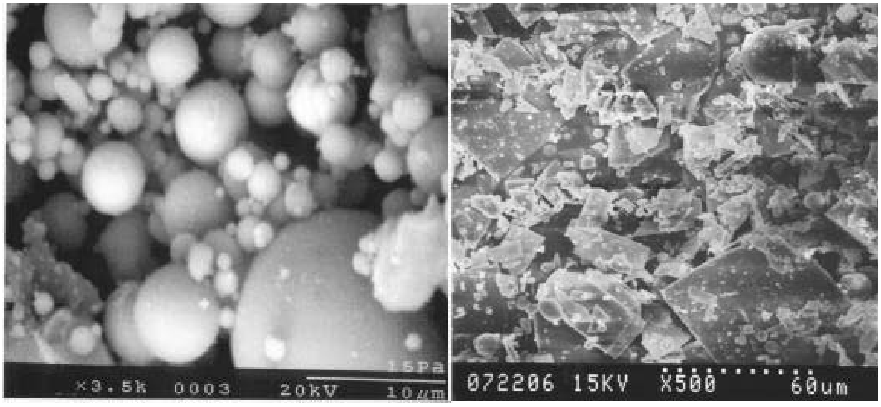


**FIGURE 2.3.** Scanning electron microscopy images of (left) pulverized coal fly ash and (right) fluidized bed combustion fly ash.
SOURCE: Chugh et al., 2000.

**TABLE 2.1** Typical Bulk Chemical Compositions of PC and FBC Fly Ash, FBC Bed Material, and FGD Scrubber Sludge

| | PC Fly Ash (% by wt) | FBC Fly Ash (% by wt) | FBC Bed Material (% by wt) | FGD Scrubber Sludge (% by wt) |
|---|---|---|---|---|
| $SiO_2$ | 55.90 | 22.10 | 9.7 | 0.45 |
| $Al_2O_3$ | 15.40 | 6.80 | 3.69 | BDL |
| $Fe_2O_3$ | 16.10 | 6.67 | 2.16 | BDL |
| $SO_3$ | 1.15 | 15.67 | 24.42 | 58.73 |
| CaO | 5.06 | 38.70 | 53.10 | 41.0 |
| MgO | 0.78 | 1.29 | 0.88 | BDL |
| Total $Na_2O$ | 1.48 | 0.50 | 0.16 | BDL |
| Total $K_2O$ | 1.93 | 1.12 | 0.39 | 0.02 |
| Loss on ignition | 0.58 | 5.46 | 0.80 | 0.00 |

NOTE: These data reflect the weight percent of major elements as oxides; they do not describe the actual mineralogy in the CCRs. BDL= below detection limit.

SOURCE: Chugh et al., 1998.

sieve. Bottom ash is predominantly sand sized, although bottom ash particles range in size from a fine gravel to a fine sand with very low percentages of silt-clay-sized particles (usually with 50 to 90 percent passing a 4.75 mm sieve and 10 percent or less passing a 0.075 mm sieve) (Moulton, 1973).

### Bulk Chemical Content

Typical bulk chemical compositions of several common CCRs are presented in Table 2.1. Silicon, aluminum, and iron are major constituents in both PC and FBC fly ash, while calcium content varies substantially with source coal type. The FBC residues from bituminous coal combustion are typically higher in calcium and sulfur than PC CCRs because of the co-combustion of limestone for $SO_2$ control in FBCs. The pH of CCRs is primarily a factor of the amount of alkaline metal oxides (e.g., calcium oxide, magnesium oxide) present (Daniels et al., 2002). Although many CCRs are alkaline, Furr et al. (1977) reported pH values of 23 fly ashes across the United States ranging from 4.2 to 11.8. The acidic fly ashes generally came from power plants burning bituminous coal extracted from southeastern or mid-Atlantic states.

### Trace Element Content

The trace elements contained in CCRs are derived from naturally occurring minerals present in the source coal. Non-volatile constituents (e.g., lead, cadmium) tend to be concentrated in CCRs as a result of the combustion process. The extent of concentration is related to the ash content (percentage of non-combustible material) in the coal. For example, with an ash content of 12.5 percent, nonvolatile metals should be found at eightfold higher concentrations in bulk CCRs than in the source coal. The trace element content of coal varies across coal types (Figure 2.4), which results in regional variations in the trace element content of CCRs produced, based on the primary coal source. For example, bituminous coals generally contain higher quantities of arsenic and selenium relative to other ranks of coal, but they have the lowest boron, mercury, and cadmium content. Lignite coals tend to have the highest mercury and lead contents.

Trace element content also varies with the individual types of CCRs coming out of a single boiler (Figure 2.4). Fly ash, in particular, tends to be enriched in arsenic, boron, and lead, whereas FGD and boiler slag residues tend to be the most enriched in mercury. FBC residues are less enriched than traditional CCRs in selenium, lead, cadmium, boron, and arsenic. Concentration data for an expanded list of trace elements in fly ash, bottom ash, boiler slag, and FGD are presented in Table 2.2.

The modes of occurrence of trace elements vary in different CCRs and ultimately influence the leachability of these constituents. For example, trace elements may be sorbed to particle surfaces or associated with surface coatings on CCR grains. They may be evenly distributed throughout glassy fly-ash grains or tightly bound within the mineral structure itself (USGS, 2002).

Although some of these trace metals have nutrient value at low concentrations, they can also present toxicity problems at higher concentrations (see Chapter 4). One example of a metal with a fairly narrow difference between concentrations that are nutritionally essential and those that are toxic is selenium. Thus, small enrichments of an element such as selenium can pose risks to human health and the environment.

## Organic Chemical Content

Coal combustion residues may contain a variety of organic chemicals, although many of the organic compounds in coal are volatilized or destroyed by high combustion temperatures. The EPA (USEPA, 1999a) reported that “based on available information, total and leachable organics are generally reported to be at or below analytical detection limits.” Research on the concentrations of organic chemicals in CCRs is fairly limited and focused primarily on organic constituents in fly ash.

***Dioxins.*** The Electric Power Research Institute (EPRI, 1998) conducted a study of dioxins in CCRs from 11 sites at which the CCRs were co-managed with other power plant wastes. The most toxic of the dioxins (2,3,7,8-tetrachlorodibenzo-p-dioxin; 2,3,7,8-TCDD) was not detected in any of the samples. For each of the samples, researchers calculated toxicity-weighted composite concentrations considering 17 dioxins of interest. They observed that the composite dioxin concentrations for the CCRs tested were well below EPA risk-based concentrations for soil ingestion at residential and industrial areas (4 and 40 ng/kg, respectively).

***Polycyclic Aromatic Hydrocarbons.*** Polycyclic aromatic hydrocarbons (PAHs) form during the combustion of coal and adsorb onto fly ash particles. Gohda et al. (1993) determined the concentrations of 16 PAHs in coal fly ash samples from a coal-gas production plant. The total PAH concentration detected was 184 mg/kg. Gohda et al. (1993) speculated that the occurrence of PAHs in the coal-gas plant fly ash was due to incomplete combustion or low combustion temperatures. PAHs have low solubilities in water and tend to sorb to solids (Smith et al., 1988). Therefore, leaching of PAHs from CCRs is anticipated to be low. Elevated risks from PAHs will likely require direct exposure of biota to CCRs, although the exposure risk would depend on the bioavailability of PAHs (see NRC, 2003).

### Radioactive Content

A few trace elements found in source coal are inherently radioactive; therefore, concern has been raised that CCRs may also be radioactive. The most common potentially radioactive elements found in coal are uranium and thorium and their decay products radium and radon (USGS, 1997). The range of uranium concentrations in source coal is 1-4 parts per million (ppm), which is similar to that in many common rocks and soils (USGS, 1997). Radon gas present in the source coal is transferred almost entirely to the stack gases. Uranium and thorium are less volatile and are therefore almost completely captured in the solid-phase particulate matter resulting from combustion. The uranium concentration that may be found in a fly ash (~10-30 ppm) is similar to that of many shales, granites, and phosphate rocks (USGS, 1997a). A German study of health effects of FGD reported lower levels of radium and potassium-40 and equal levels of thorium-232 in FGD gypsum compared to natural gypsum (Beckert et al., 1991; EPRI, 1994).

## DISPOSAL AND USE OPTIONS FOR COAL COMBUSTION RESIDUES

As shown in Figure 2.1, once CCRs are generated at a coal-fired facility, the facility can pursue a variety of management options that may or may not include placement in a coal mine. For example, CCRs may be disposed of in landfills or surface impoundments. CCRs may be used as raw materials for the manufacture of products (e.g., wallboard) or for civil engineering applications (e.g., friction agents on snow). CCRs may also be disposed of in mines as a fill material for reclamation or used for other applications in mines, such as subsidence control. Many factors enter into the decision-making process when weighing the manage-

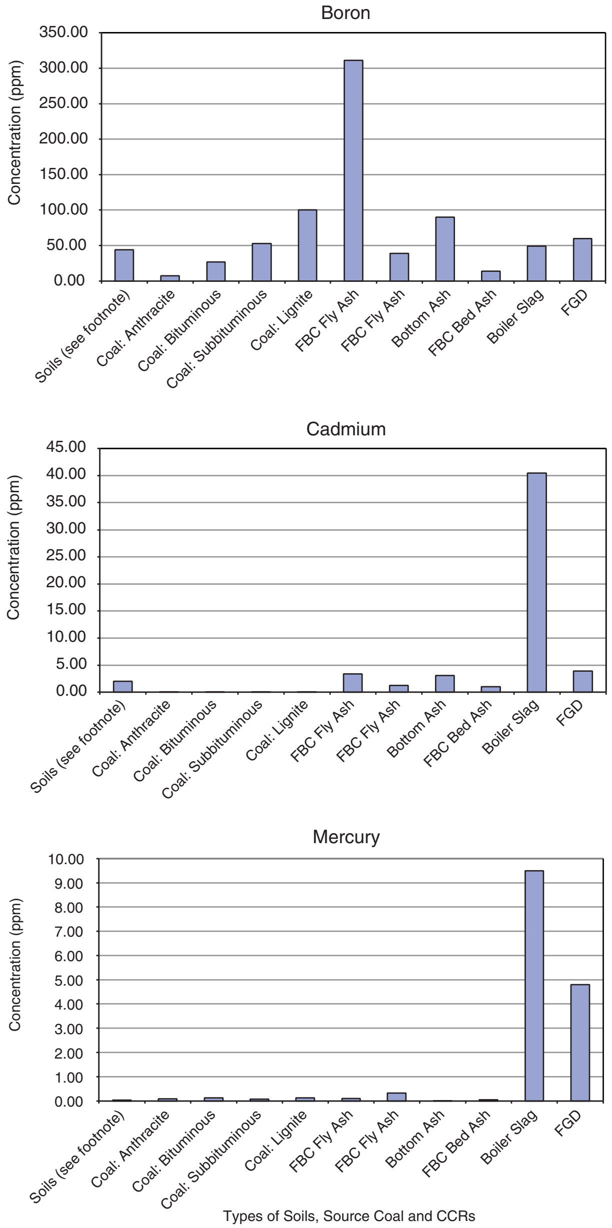
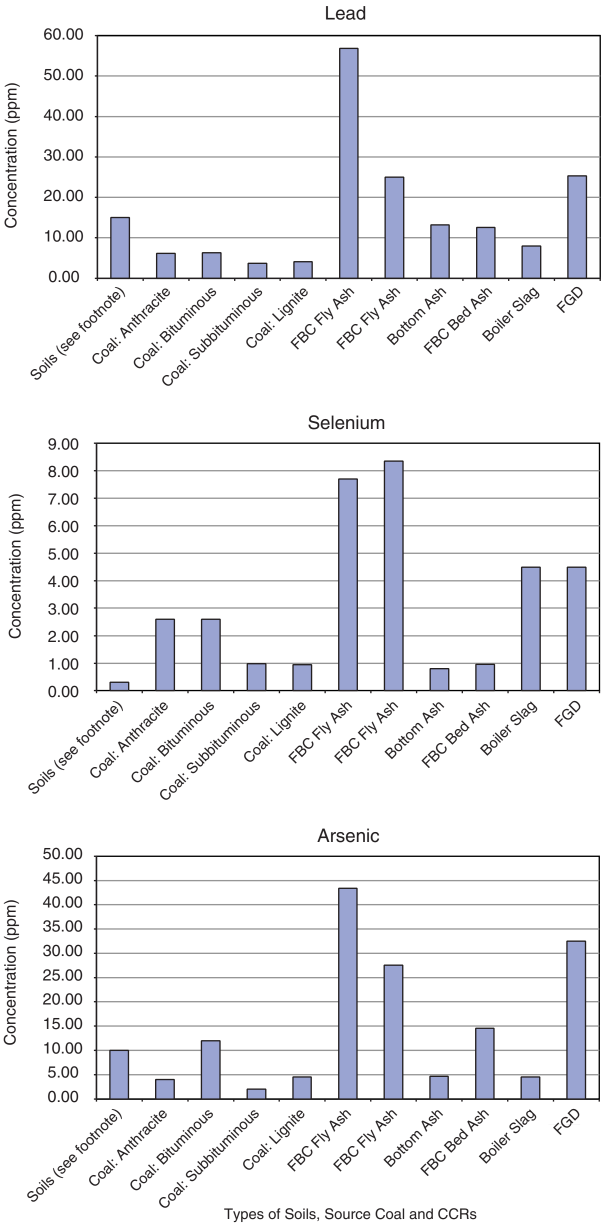


**FIGURE 2.4** Bulk selected trace metal constituent concentrations in soils, source coal, and CCRs. For comparison with a familiar natural material, trace metal concentrations in soil are also presented.

NOTE: All graphs show concentration data in parts per million (ppm), however the scales vary



between graphs. Soil data reflect a median value from the USGS soils database of the following states: Texas, New Mexico, Pennsylvania, Louisiana, Oklahoma, West Virginia, Maryland, Michigan, Arizona, Kentucky, New Jersey, Illinois, Indiana, New York, Tennessee.
SOURCE: USDOE, EIA, 2001; USGS, 2001.

**TABLE 2.2** Ash Constituent Table

| | Fly Ash (ppm) | | Bottom Ash (ppm) | | Boiler Slag (ppm) | |
|---|---|---|---|---|---|---|
| Constituent | Median | Range | Median | Range | Median | Range |
| Aluminum[a] | — | — | — | — | — | — |
| Antimony[b] | 4.6 | 0.2-205 | 4.0 | 0.18-8.4 | 0.8 | 0.25-1.0 |
| Arsenic[b] | 43.4 | 0.0003-391.0 | 4.7 | 0.80-36.5 | 4.5 | 0.01-254 |
| Barium[b] | 806.5 | 0.02-10,850 | 633 | 24-9,630 | 413 | 6.19-1,720 |
| Beryllium[b] | 5.0 | 0.200-2,105 | 2.2 | 1.4-2.9 | 7.0 | 7.0-7.0 |
| Boron[b] | 311 | 2.98-2,050 | 90.0 | 1.79-390 | 49.5 | 0.10-55.0 |
| Cadmium[b] | 3.4 | 0.01-76.0 | 3.1 | 0.050-5.5 | 40.5 | 0.01-40.5 |
| Chromium[c] | 136 | 3.6-437 | 120 | 3.4-350 | — | — |
| ChromiumVI[b] | 90 | 0.19-651 | 121.0 | 3.41-4,710 | 158 | 1.43-5,981 |
| Cobalt[c] | 35.9 | 4.90-79.0 | 24 | 7.1-60.4 | — | — |
| Copper[c] | 112 | 0.20-655 | 61.1 | 2.39-146.3 | 32.0 | 1.37-156 |
| Fluorine[c] | 29.0 | 0.40-320 | 50.0 | 2.5-104 | — | — |
| Iron[a] | — | — | — | — | — | — |
| Lead[b] | 56.8 | 0.02-273 | 13.2 | 0.86-843.0 | 8.0 | 0.40-120 |
| Manganese[c] | 250 | 24.5-750 | 297 | 56.7-769 | — | — |
| Mercury[b] | 0.1 | 0.013-49.5 | 0.009 | 0003-0.040 | 9.5 | 0.016-9.5 |
| Molybdenum[a] | — | — | — | — | — | — |
| Nickel[b] | 77.6 | 0.1-1,270 | 79.6 | 1.9-1,267 | 83.0 | 3.3-177 |
| Potassium[a] | — | — | — | — | — | — |
| Selenium[b] | 7.7 | 0.0003-49.5 | 0.8 | 0.007-9.0 | 4.5 | 0.10-14.0 |
| Silver[b] | 3.2 | 0.01-49.5 | 3.0 | 0.06-7.1 | 37.0 | 0.01-74.0 |
| Strontium[c] | 775 | 30.0-3,855 | 800 | 170-1,800 | — | — |
| Thallium[b] | 9.0 | 0.15-85.0 | na | 2.0 | 38.5 | 33.5-40.0 |
| Vanadium[b] | 252 | 43.5-5,015 | 141 | 24.0-264 | 75.0 | 75.0-320.0 |
| Zinc[b] | 148 | 0.28-2,200 | 52.6 | 3.80-717 | 35.8 | 4.43-530 |

NOTE: FGD = flue gas desulfurization; ppm = parts per million.

[a] CIBO, 1997.
[b] 1993 regulatory determination in USEPA, 1999b.
[c] Tetratech analyses in USEPA, 1999c.

ment options and economic impacts of CCR utilization or disposal. Such factors include the characteristics of the CCR, local applications for utilizing the CCR, costs and demands for alternate uses (considering the availability of virgin material), transportation distance to industries able to use CCRs, location and costs of CCR disposal options, and the local regulatory environment. Therefore, understanding both the characteristics of CCRs and the options available for disposal and use is critical to sound CCR management. The various alternatives for the disposal and use of CCRs are discussed in more detail below.

For the purpose of this study, data were sought on the amounts of CCR generated and how these CCRs are subsequently disposed of or used, including how much is placed in coal mines. In the process of gathering these data, it

| FGD (ppm) | | FBC: Fly Ash (ppm) | | FBC: Bed Ash (ppm) | |
|---|---|---|---|---|---|
| Median | Range | Median | Range | Median | Range |
| — | — | 42,300 | 20-88,900 | 18,000 | 9-68,800 |
| 6.0 | 3.65-90.0 | 7.75 | 0.125-259 | 10 | 0.125-361 |
| 32.5 | 0.0075-341.0 | 27.55 | 2.8-176 | 14.6 | 2.5-80 |
| 162.5 | 0.08-2,280 | 348 | 31.3-2,690 | 184 | 7.3-453 |
| 29.3 | 0.900-49.5 | 2.23 | 1.08-11.5 | 1.21 | 0.5-8 |
| 60.0 | 5.00-633 | 39.1 | 0.025-2,470 | 14.1 | 0.025-304 |
| 3.9 | 0.005-81.9 | 1.25 | 0.013-6.68 | 1.02 | 0.0125-7.16 |
| — | — | 44.8 | 5.17-97.1 | 37 | 4.1-86 |
| 73.0 | 0.17-312 | — | — | — | — |
| — | — | 19 | 2.5-79.8 | 11.3 | 1.4-75.8 |
| 46.1 | 0.04-251.0 | 41.1 | 2-99 | 13.8 | 1.65-37.1 |
| — | — | — | — | — | — |
| — | — | 25,300 | 22.2-76,500 | 11,100 | 6.2-19,300 |
| 25.3 | 0.01-527.0 | 25 | 1.03-105 | 12.5 | 0.848-58 |
| — | — | 165 | 0.05-548 | 241 | 52.2-751 |
| 4.8 | 0.073-39.0 | 0.323 | 0.00005-129 | 0.05 | 0.00005-16.2 |
| — | — | 6.25 | 2.35-48.6 | 14.7 | 6-63.4 |
| 68.1 | 3.7-191.0 | 41.4 | 6.25-923 | 22 | 1-945 |
| — | — | 3510 | 1.13-10,200 | 584 | 1.3-8,980 |
| 4.5 | 0.0150-162.0 | 8.36 | 0.47-166 | 0.952 | 0.152-45 |
| 3.3 | 0.01-10.3 | 1.03 | 0.05-11.6 | 1 | 0.05-87.6 |
| — | — | — | — | — | — |
| 9.0 | 9.0-9.0 | 3.28 | 1.25-39 | 3.03 | 0.5-25 |
| 65.0 | 0.01-302.0 | 194 | 36.4-3,830 | 69 | 12-5,240 |
| 90.9 | 0.01-5,070 | 38.5 | 25-143 | 34 | 17.4-399 |

became evident that the data-gathering instruments currently used are varied and inconsistent. As a result, the committee was not able to collect accurate and inclusive data regarding CCR generation and subsequent disposal or use. The data contained in this report are based on the best available information, although the numbers are likely to be underestimates due to incomplete reporting and the fact that all major generators of CCRs are not included in the surveys (see Sidebar 2.4). The committee concludes that the available data regarding CCR generation and disposal or uses are inadequate. The committee recommends that existing data-gathering mechanisms be expanded to include comprehensive reporting of CCR generation quantities and classifications, and clarified to allow for a clear determination as to its disposal or use.

### SIDEBAR 2.4
### Data Gathering Mechanisms for Tracking CCR Generation, Disposal, and Use

The three main sources of CCR generation and disposal information are the U.S. Energy Information Administration (EIA) plant-level annual report (F767), an annual voluntary survey of utilities conducted by the American Coal Ash Association (ACAA), and state-level information.

The EIA requires any fossil fuel facility with a generation greater than 100 megawatts to report how much of the major types of CCRs the facility generates (e.g., fly ash, bottom ash, FGD). Even though independent power producers who fire coal refuse contribute a significant annual tonnage of CCRs to the total placed in mines for reclamation, most coal refuse-fired facilities are smaller than 100 MW; thus, their data are not contained in the EIA database. Additionally, facilities that report to the EIA are required to report only the amount of CCR placed in landfills and surface impoundments and the amount sold. Facilities do not have to report the purposes for which the CCRs were sold, and minefill is not listed as a reporting option. Facilities that give away their CCRs differ in how they report to EIA; some record given-away material as “off-site disposal,” whereas others record it as “sold” but with a footnote indicating that no money exchanged hands.

ACAA’s annual survey of utilities is voluntary, and on average, only 65 percent of U.S. utilities report to ACAA. The survey requests specific information on the final disposition of CCRs in a variety of categories, making it a fairly thorough report regarding utilization activities. ACAA’s survey includes a category for mining applications; however, the category does not differentiate between placement in minefills and other uses in mine settings. ACAA’s survey also does not include non-utilities (e.g., coal refuse-fired facilities).

Individual states may also collect data regarding the generation or disposition of CCRs. For example, the committee received information from the State of Pennsylvania on the annual quantity of CCRs generated from coal refuse-fired facilities. Because of the large volumes of CCRs generated at Pennsylvania’s coal refuse-fired facilities that are subsequently used in mine reclamation, those numbers were included in this report. However, the committee recognizes that these data represent an underestimate of the total amount of CCRs generated from coal refuse-fired facilities in the United States, since data from other states were not readily available.

## Non-Mine Disposal and Use Options

There are many disposal options and uses for CCRs outside the mine setting. Disposal in landfills and surface impoundments is the most commonly used CCR management option (see Chapter 1); however, there are many alternative uses, such as the use of fly ash in cement. The utilization of CCRs in these productive alternatives has been increasing steadily. The cumulative CCR utilization rate increased from 24.8 percent in 1995 (ACAA, 1995) to 38.1 percent in 2003

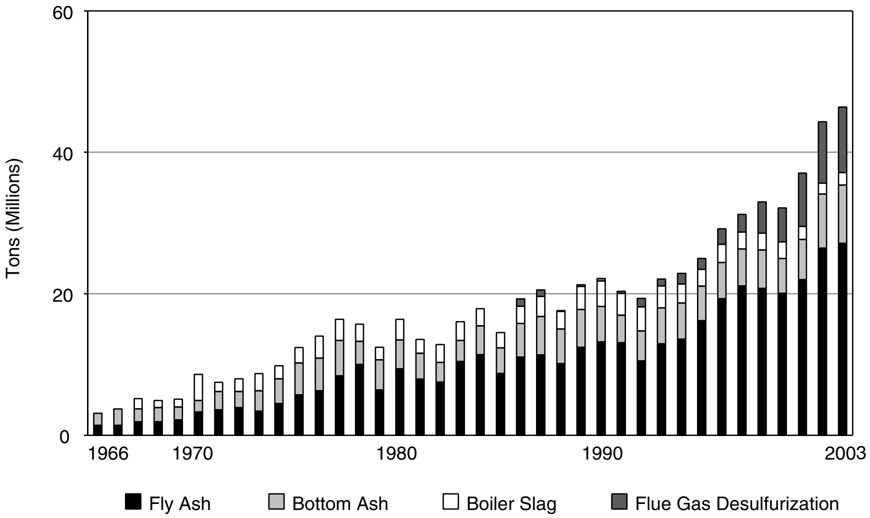


**FIGURE 2.5** Alternative uses of CCR by year (for purposes other than disposal). Note that the figure data may also include CCR mine placement that has been classified as "beneficial use."
SOURCE: American Coal Ash Association, Aurora, CO, written communication, October 2005. Courtesy of the American Coal Ash Association.

(ACAA, 2005a) as markets for CCRs increased.[1] Figure 2.5 illustrates the steadily increasing amounts of CCR products in the United States that are being utilized for purposes other than disposal.

Alternative uses of CCRs may help to conserve resources by reducing the consumption of virgin materials (e.g., gypsum for wallboard production) and thereby lessen the impacts of associated mining operations (e.g., gypsum mines). It should be noted that many states refer to these alternative uses as "beneficial uses" (see Chapter 5 for a more complete discussion of the term "beneficial use"). In its 2000 regulatory determination EPA determined that, with the exception of minefilling, these uses are not likely to present significant risks to human health or the environment. Of the reported 126 million short tons of CCRs produced in 2003 by utilities and independent power producers, approximately 44 million short tons were used outside of mine settings for a variety of alternative applications such as concrete, structural fill projects, or waste stabilization (ACAA, 2005a). The sections below describe a few of the uses of CCRs that can occur outside the mine setting.

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[1] These percentages include CCRs used in what ACAA defines as "mining applications", which may include alternative uses or minefilling.

## SIDEBAR 2.5
## Fly Ash Classifications

Fly ash is commonly used for construction purposes in structural fills, cement, and concrete. To help the concrete industry ensure that the use of a particular type of fly ash meets applicable concrete performance standards, the American Society for Testing and Materials (ASTM) has developed classifications for fly ash in its circular C618 (Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete): Class C and Class F. It should be noted that many fly ashes do not meet either ASTM designation, rendering them unsuitable for commercial use in concrete.

Class C fly ash is generally produced during the burning of lignite or subbituminous coal most likely from deposits in the western United States. This ash generally contains more calcium, less iron, and a lime (CaO) content in the range of 15 to 30 percent. This classification may include fly ashes with either pozzolanic or cementitious properties (ASTM, 2002a).

Class F fly ash is produced during the burning of anthracite or bituminous coal most likely from deposits in the eastern and midwestern United States. It contains silica, aluminum, and iron in combinations greater than 70 percent. This class of fly ash has pozzolanic properties (ASTM, 2002a).

### Definitions

**Pozzolanic** fly ash has little or no cementitious properties unless chemically reacted with calcium hydroxide and water, resulting in a compound with cementitious properties (ASTM, 2002a).

**Cementitious** fly ash has the properties of, or acts like, a cement (American Geological Institute, 1997) when mixed with water.

## Cement and Concrete

Perhaps the most widely known use of CCRs is the application of fly ash to replace natural materials in the production of portland cement. Fly ash that contains the silica, alumina, calcium, and iron oxides needed in portland cement are sometimes used as raw materials (Sidebar 2.5). Fly ash also lowers the heat of hydration and can contribute to the long-term strength of the cement product. CCRs can also be used as an aggregate addition in the production of concrete blocks and other pre-cast concrete products (ACAA, 1998).

## Engineered Fill

Fly ash and bottom ash can be used to produce road base materials, manufactured aggregates, flowable fills, structural fills, and embankments. CCRs can also be used as flowable fill for civil engineering applications where conventional backfilling may be difficult or undesirable and minimal subsequent settlement of the fill material is desired.

CCRs can be used as engineered fill to alter a site's topography; for example, in urban areas or areas where borrow material is in limited supply or expensive, CCRs are commonly used for embankment construction on roadways (ACAA, 1998).

Although FBC ash is not suitable for large-volume use in cement and concrete because of its high sulfur content, its calcium content and cementitious or pozzolanic behavior make it well suited for other applications. The FBC ash can sometimes be substituted for lime in cement for road base construction and also shows potential for use as a synthetic aggregate (Conn et al., 1999). The FBC and FGD residues also have characteristics that make them usable for the construction of low-permeability liners or caps (Wolfe et al., 2000).

To ensure that material or structures containing CCRs meet or exceed industry performance standards for traditionally used materials, many technical organizations issue standards or guidelines for the use of CCRs in their applications (e.g., Sidebar 2.5). These include the ASTM, the American Concrete Institute (ACI), the Federal Highway Administration (FHWA), and the American Society for Civil Engineers (ASCE), among others (ACAA, 2005c).

### Wallboard

Increasing amounts of FGD residues are used as synthetic gypsum in the wallboard industry. The use of synthetic gypsum in the wallboard industry is often economically attractive, which has resulted in several gypsum companies opening wallboard manufacturing plants near utility generating facilities (Kalyoncu, 1999).

### Soil Amendments

Coal combustion residues can also be used to modify soils chemically or physically. Chemically, they may be used to add micronutrients and to change the pH of soils. Studies have shown that fly ash may be used to improve nutrient-deficient soils, providing a source of essential nutrients for plants (e.g., boron) and animals (e.g., selenium); however, elemental concentrations must be monitored closely to prevent toxicity to both plants and animals (Carlson and Adriano, 1993). Alkaline fly ash can be used to reduce soil acidity (Adriano et al., 1980; Carlson and Adriano, 1993). Physically, CCRs can increase the water-bearing capacity and increase water infiltration. Fly ash can increase aeration in clay soils or increase the water-bearing capacity of sandy soils (Carlson and Adriano, 1993). It may also increase the water-bearing capacity of soils because of its tendency to cause cementation, which can be especially useful in geotechnical applications (Carlson and Adriano, 1993; ACAA, 1998).

### Other Applications

There are also numerous other uses of CCRs. For example, boiler slag is commonly used as a component in the manufacture of roofing tile and shingles.

Boiler slag, when processed, also generates a material that can be used for sandblasting abrasives, which does not contain the free silica of sand, making it safer for workers. The abrasive quality of many CCRs makes them suitable for use as traction control materials on snow- and ice-covered roadways, and the dark color of the materials aids in the absorption of radiant energy, which enhances the melting process. A portion of fly ash, called cenospheres, can be used as a performance enhancing product in paints, coatings, and adhesives.

## Mine-Specific Disposal and Use Options

As the consumption of coal for electric power generation has increased, so has the demand for disposal sites for CCRs. Although the recycling of various CCRs into engineered products is the preferred alternative, conditions do not always lend themselves to such a solution. In these cases, CCR disposal alternatives are usually limited to surface impoundments, landfills, or placement in coal mines where the CCRs are utilized in mine reclamation. The use of CCRs in mine reclamation reduces other environmental impacts, such as disturbance of new land areas required for landfilling such materials. Nevertheless, there is a potential for other impacts to occur, which are explored in later chapters.

Coal mines have a number of attributes that may support large volume placement of CCR in mines. Among these features are the following:

- *Existing Excavation*. Surface coal mining creates large excavations that often require bulk materials for proper reclamation. Minefilling requires no new land disturbances, whereas there is often strong public opposition to the siting of new surface impoundments or landfills.
- *Infrastructure.* Active mines generally have adequate existing infrastructure, equipment, and know-how for the economical handling and engineered placement of bulk materials.
- *Geology.* Coal is generally contained in a sedimentary rock sequence that includes low-permeability shales and clays (see Chapter 3). These materials may impede groundwater flow, including potential contaminants that might be associated with such flow.

It should be emphasized that not all prospective coal mine disposal sites have all of the favorable features noted above. As stressed throughout this report, each site should be evaluated on its own merits. Furthermore, the existence of the above beneficial features should not deter a full assessment of the potential environmental risks of disposing of CCRs in any site. Final site selection involves the due consideration of such risks, but it is appropriate also to include a consideration of benefits in the selection process.

There are two different sources of the CCRs that are typically disposed of in mines. The first is the conventional coal-fired power plant that consumes virgin coal. The CCRs produced are typically hauled by truck back for disposal at the mine (or mines) that supplied the original coal, which may be many miles from and under different ownership than the power plant. The second major source of CCRs used in mines is the independent power producer that uses coal refuse from nearby abandoned mines (Sidebar 2.6). The refuse material typically has poor

### SIDEBAR 2.6
### Pennsylvania's Program for Coal Mine Reclamation and Mine Drainage Remediation

Pennsylvania's coal miners have extracted approximately 16.3 billion short tons of anthracite and bituminous coal from the state's mines since commercial mining began in 1800. While mines permitted under the Surface Mining Control and Reclamation Act (SMCRA) are required to be reclaimed after the coal is extracted, many pre-SMCRA mines were abandoned prior to reclamation. In Pennsylvania, there are more than 5,000 abandoned, unreclaimed mining areas covering approximately 189,000 acres and more than 820 abandoned coal refuse piles. The coal refuse piles cover 8,500 acres, contain a volume of more than 200 million cubic yards of waste material, and can be substantial in size (see Figure 2.6).

It is estimated that the acid leached from the coal refuse in these abandoned coal mines in Pennsylvania contributed to the degradation of more than 3,100 miles of streams. Pennsylvania's Bureau of Abandoned Mine Reclamation estimates the cost to eliminate these abandoned mine problems to be $14.6 billion. Pennsylvania receives an average of $30 million annually from the Office of Surface Mining (OSM) Abandoned Mine Lands (AML) fund; at this rate, it would take Pennsylvania nearly 500 years to complete the cleanup of its AML sites.

One approach that Pennsylvania has taken to its AML problem is encouraging private funding for reclamation of abandoned coal refuse piles. The advent of FBC technology in the late 1980s enabled the once-useless coal refuse to be used as fuel. As of 2004, 15 independent power producers constructed plants near Pennsylvania's coal refuse piles, using the refuse as fuel for their FBC boilers. Between 1987 and 2002, these plants used 88 million short tons of coal refuse for the generation of electricity and process steam—energy that would otherwise have been derived from another virgin fuel source. The FBC CCRs generated by coal refuse-fired facilities are highly alkaline and have been used in mine reclamation and for treatment of acid mine drainage in areas near the plant. For example, the Mount Carmel co-generation plant consumed a total of 8 million short tons of coal refuse from 1990 through 2002 and produced 5 million short tons of CCR for mine reclamation neighboring the plant during that period, reclaiming 209 acres.

The FBC plants' ability to use the coal refuse as fuel, coupled with the potential to place the CCRs into nearby mines, makes the arrangement economically viable and has enabled privately funded reclamation of 3,400 acres of AML as of 2002. An example of this cost offset is the Big Gorilla Project (Sidebar 2.7), which was reclaimed by the Northeastern Power Company (the independent power producer operating the cogeneration plant at the site) at a total estimated cost of $3.4 million. That reclamation cost is less than or approximately equal to the estimated cost of conventional AML reclamation of the site with federal AML funds (National Mining Association, Washington, D.C., written communication, July 2005 and April 2006).

SOURCE: PADEP, 2004.

**FIGURE 2.6** Westwood FBC plant near Tremont in the southern anthracite field showing a coal refuse pile by the plant.
NOTE: Photograph courtesy of Pennsylvania Department of Environmental Protection.

thermal qualities and a large waste rock content such that it can only be fired in FBC boilers.

Over the last decade, traditional utilities have increased their utilization of CCRs in mining applications. ACAA reports that CCR utilization in mines (including minefilling) increased from approximately 1 percent in 1995 to about 1.9 percent in 2003 (ACAA, 1995, 2005a).[2] The data currently available on CCR use and disposal do not differentiate between the amount of CCRs being used in engineered products outside of coal mines, the amount being used in coal mines as minefill, and the amount being used in smaller engineering applications (e.g., road aggregate) within the mine area. In total, ACAA reports that 2.3 million short tons of CCRs were used in mining applications in 2003. However, this total is known to be an underestimate of the use of CCRs in mines. In New

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[2] These numbers represent information obtained from ACAA's voluntary survey (Sidebar 2.5) and therefore may not include all utilization of CCRs in mining applications.

## SIDEBAR 2.7
## The Big Gorilla Demonstration Project

The Big Gorilla pit was an abandoned anthracite surface mine located near Hazelton, Pennsylvania, in the Silverbrook Basin. The pit was approximately 1,400 feet long by 400 feet wide and 90 feet deep. It was filled with about 120 million gallons of water that had been significantly affected by acid mine drainage (see Figure 2.7). The Silverbrook Basin is approximately five miles long and 1 mile wide. It is drained by the Silverbrook outfall, which forms the headwaters of the Little Schuylkill River.

The demonstration project involved the dry-to-wet placement of approximately three million tons of fluidized bed combustion (FBC) ash into standing mine water. Placement began in August 1997 and was completed in 2004 (see Figure 2.8). The ash was dumped onto two working platforms by 45 ton trucks and then dozed into the pool. As the mine pool was filled, compaction was accomplished using the trucks and dozers. The ash came from Northeastern Power Company's co-generation facility in McAdoo, Pennsylvania, which fires approximately 1,700 tons of coal refuse and 60 tons of limestone per day.

Five monitoring wells and three test boring locations have been monitored continuously. Numerous studies of the mineralogy of the ash and the evolution of the pit lake water chemistry have been conducted. The project used approximately three million tons of CCRs to eliminate the acidic mine pool. The results of the demonstration project include a possible reduction in the acid loading of the Silverbrook outfall, a decrease in concentrations of some metals, a slight increase in concentrations of some cations, and a test of the dry-to-wet placement method.

SOURCE: Loop et al., 2004.

Mexico alone, the two largest coal mines together place approximately 2.5 million short tons back into their mines annually (BHP Billiton, 2004). Although Pennsylvania's coal refuse-fired facilities consume a significantly smaller quantity of coal annually, they generate almost twice the amount of mine-placed CCRs as compared to that reported by traditional utilities in the United States. The placement of CCRs generated by coal refuse-fired facilities in Pennsylvania for mine reclamation rose steadily from 89,000 short tons in 1988 to the almost 5 million short tons in 2002 and is expected to continue to increase as more facilities are developed (PADEP, 2004).

### Common Mine-Specific CCR Applications

There are a variety of disposal and use options for CCRs in mining operations. This section highlights the CCR applications that are unique to surface and underground mines, such as minefilling, capping, mine sealing, and treating acid mine drainage (AMD). Because knowledge of the methods and geometries of

**FIGURE 2.7** Big Gorilla pit prior to 1995 showing the 120 million gallons of water that had been significantly affected by acid mine drainage.
NOTE: Photograph courtesy of Barry Scheetz, Pennsylvania State University.

placement is needed to understand the behavior of CCRs in the environment (discussed in Chapter 3), this section also describes methods for emplacing CCRs in mines.

In surface mines, minefilling generally involves the placement of CCRs as a monofill, a layered fill, or a blended mixture of coal refuse and CCR (Figure 2.9). Surface mine placement of CCRs is part of the reclamation process, which involves rehabilitation of the mine site for the purpose of reestablishing the prior use or creating the capability for an alternate land use (see also Chapter 7). In situations where surface mines lack sufficient spoil, CCRs have been used to achieve the approximate original contour of the land surface.

In some cases, CCR material is used as a cover on the overburden or backfill in addition to soil. The FBC ash may also be used to form low-permeability caps when acid-producing spoil is present.

Surface soils in the mine setting, often used for reclamation, may have adverse characteristics. Coal combustion residues have been used as soil amendments to ameliorate problems with infiltration rate, water retaining capacity, and soil acidity (Daniels et al., 2002; also see "Soil Amendments" above).

Coal combustion residues may be used to abate or prevent subsidence of underground mines in conjunction with conventional materials or concrete. Cementitious fly ash is especially effective for such use, and FBC fly ashes have

**FIGURE 2.8** Big Gorilla pit showing the dry-to-wet placement of approximately three million tons of FBC ash into standing mine water. (A) Big Gorilla in the midst of the placement project. (B) Aerial shot of the filled Big Gorilla pit.
NOTE: (A) Courtesy of Barry Scheetz, Pennsylvania State University; (B) Courtesy of Daniel Koury, Pennsylvania Department of Environmental Protection.

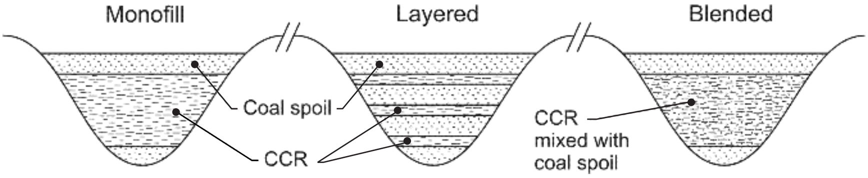

**FIGURE 2.9** Methods of large-volume CCR emplacement in surface mines.

been shown to have sufficient bearing capacity for most post-mining uses (Scheetz et al., 2004). For example, in Pennsylvania, CCRs have been used to fill cropfalls, which are long, narrow vertical surface openings that are created by subsidence in underground mines. The costs of using CCRs for subsidence control is substantially lower than using concrete; for example, costs may range between $2.50 and $4.50 per ton for CCR as compared to $60 to $70 per ton for concrete (Dwyer, 2004).

Underground mines may be sealed off to decrease the possibility of AMD from polluting the surface waters, to reduce the occurrence mine fires, or for the overall safety of the general public. Mine sealing generally involves injecting a fly ash grout mixture into boreholes in the underground mines to seal off problem areas.

Certain CCRs may also be used to treat pyritic spoils that result in acid mine drainage. Alkaline CCRs (especially FBC CCRs) can be used to neutralize existing acidity in groundwater (see Chapter 3). Coal combustion residues can also act as a seal to reduce the oxidation of pyrite in the coal spoil, thus slowing the rate of generation of additional AMD. The FBC ash grout can be pressure-injected through drill-holes into subsurface voids in previously backfilled surface mines and in voids in abandoned underground mines to encapsulate the pyritic materials with the cementitious mixture (Sheetz et al., 2004). However, the long-term efficacy of this practice is still questionable because of lack of data.

## Methods for Placement of CCRs in Coal Mines

As mentioned earlier, CCRs can be placed in mines for a variety of purposes. CCRs can be placed for both low-volume (e.g., paving pit floors, grouting fractured country rock, capping and encapsulating potential AMD-producing material) and high-volume applications (e.g., backfilling of pits and underground workings, alkaline addition for neutralization of AMD). In large-volume applications, CCRs can be placed as distinct monofills, multiple layers, or blended mixtures of CCR and coal refuse materials (PADEP, 2004; Figure 2.9).

CCR placement in mines currently occurs above or below the water table (see Chapter 3, Sidebar 3.1). Placement below the water table may involve the use of slurry methods or direct dumping of CCR into standing water (see Sidebar 2.7). The permeability of CCRs after placement will depend on the CCR properties, with highly compacted cementitious fly ash having the lowest permeability and coarse bottom ash having higher permeability (see Chapter 3). Lime or cement can be added to CCR to increase its structural stability, to make it more cement-like, and to decrease its permeability.

The method of emplacement of CCRs at the mine site is an important factor that will influence the structural stability and hydrogeological and geochemical processes taking place there. The flow of water through and around CCRs will depend on the geometry of emplaced zones and the hydraulic properties of the surrounding materials. Similarly, geochemical reactions taking place within CCR zones and between CCR and surrounding materials will depend on the relative surface area of the CCR zones and surrounding materials and the potential for transport of reactants between materials (see Chapter 3). For these reasons, it is important to consider the exact method and location of CCR placement in the design plan, and to accurately predict the structural, hydrological, and geochemical processes that will occur after emplacement.

There are three common methods of placing CCRs in mine settings: gravity, hydraulic, and pneumatic. These methods are described in detail below.

***Gravity.*** Gravity placement is by far the most common method of placing CCRs in or around surface mines. Typically, CCRs are brought to the mine and put in place by end-dumping off trucks, although occasionally belly-dump vehicles or conveyor belts may be used. Bulldozers or scrapers may be used for the final placement. Generally there is no formal compaction in any manner (e.g., rolling, vibrating) unless the layer is being used as a liner or final cover over a previously placed fill. However, the committee did visit minefills where the CCRs were placed in small lifts and then compacted using a traditional compaction method. More typically, trucks that bring the material drive over the previously placed CCR layers, resulting in some degree of compaction. This is not a systematic compacting procedure and is not an effective compaction method over sizable lift thicknesses. Systematic compaction can increase the strength of the fill material and produce a uniform fill (ASTM, 2002b).

***Pneumatic***. Pneumatic placement is applicable primarily to underground mines and was used commonly in Europe and in non-coal mines in the United States two or three decades ago. However, pneumatic placement is no longer a common practice because of the hazards associated with the technique, such as the generation of a considerable amount of static electricity, which could result in sparking. Sparking would be hazardous in both working and abandoned underground coal mines that may have accumulations of methane gas.

*Hydraulic.* The hydraulic method, applicable to CCR placement in both underground and surface mines, consists of making a slurry of the CCR with water and then pumping it to the location where it is to be placed. The process is straightforward and is similar to grout placement. The CCRs are stored and may be mixed with other substances. The CCR mixture is then transferred to a mixer where water is introduced in the proper proportion. The designed mixture may require testing prior to use in order to ascertain the desired setting time and fluidity. The material is then pumped to the placement location through pipes. On exiting the pipe, the velocity of the slurry decreases and water separates from the solids. Fine particles from the CCR may remain suspended in water for quite some time; thus, discharge water may have to be decanted in a sludge pond for further settling.

## SUMMARY

The combustion of coal generates large quantities of solid materials, collectively referred to as CCRs, which are grouped into two categories: the noncombustible portion of the coal itself (fly ash, bottom ash, boiler slag) and products from various air pollution control technologies installed at the combustion facility (e.g., FGD materials). The physical and chemical characteristics of the CCRs produced are determined by several factors including the source coal, the combustion technology, the air pollution control equipment technology, and the residue handling equipment. The characteristics of CCRs vary greatly and are the major determinants of the possible uses of the residue. **Thus, the committee recommends that regulatory agencies responsible for imposing pollution control standards carefully consider the implications of air pollution control requirements for the marketability of CCRs to ensure that the full suite of environmental consequences is analyzed and understood.**

For the purpose of this study, data were sought on the amounts of CCRs generated and how these CCRs are subsequently disposed of or used, including how much is placed in coal mines. However, *the committee found the available data regarding CCR generation and disposal or uses to be inadequate.* **The committee recommends expanding existing data gathering mechanisms to include comprehensive reporting of CCR generation quantities and classifications, and clarifying those mechanisms to allow for a clear determination as to disposal or use.**

This chapter outlines the many alternatives available for CCR disposal and use, including applications in surface and underground coal mines. Many factors enter into the decision-making process when weighing the management options and economic impacts of CCR utilization or disposal. Such factors include the local possibilities for utilizing a particular CCR, the costs and demands of CCRs for alternate uses, the substitution of CCRs for unrecycled materials, the transportation distance to industries able to use CCRs, the location and costs of CCR placement options (e.g., availability of CCR-receiving coal mines; availability of new land for landfills and surface impoundments), the local regulatory environment, and the potential effects on human health and the environment. The characteristics of a particular CCR stream, coupled with the aforementioned considerations, are key to determining the best options for disposal and use of CCRs. *Therefore, the committee concludes that understanding both the characteristics of CCRs and the options available for their disposal and use are critical to sound CCR management and that such characteristics and options are highly site specific.*

# 3

# Behavior of Coal Combustion Residues in the Environment

Contaminants derived from CCRs have the potential to enter drinking water supplies, surface water bodies, or biota at unacceptable concentrations (discussed further in Chapter 4), thereby creating risks to human health and the environment. The extent of contaminant release from CCR depends on the volume and characteristics of the CCR emplaced and the disposal environment. In the surrounding environment, hydrogeological conditions determine the potential for water to enter the CCR and transport contaminants away from the disposal area. Additional biogeochemical processes control the rate and distance of movement of contaminants from CCR disposal areas. This chapter provides an overview of the hydrologic and biogeochemical processes controlling the release and transport of contaminants from CCR mine disposal sites to locations where uptake may occur.

## HYDROLOGICAL PROCESSES AFFECTING CCR BEHAVIOR

Recharge, unsaturated water flow, and saturated groundwater flow will all affect the behavior of CCRs in the environment (see Sidebar 3.1). In a mine setting, subsurface water flow will normally be the primary mechanism for transporting CCR-derived contaminants from the disposal area to potential receptors (e.g., aquatic life in streams supported by groundwater flow, local residents relying on groundwater as a drinking water source). Transport of CCR contaminants through overland flow processes (Figure 3.1) is also possible in a mine setting, especially where CCRs are used as capping material or as soil amendments;

## SIDEBAR 3.1
## Overview of Relevant Hydrologic Processes

A brief review of the water cycle provides perspective to understand the hydrologic processes affecting CCRs that are placed in the subsurface at mine sites. Precipitation that falls on the land surface will either enter the soil through infiltration processes or flow over the land surface (overland flow) before eventually reaching nearby streams (see Figure 3.1). Some of the water that enters the soil will be lost through evaporation and plant transpiration (evapotranspiration), and the remaining water will flow downward through the subsurface, eventually recharging the underlying aquifer.

Recharge rates vary from location to location and year to year, depending on precipitation rates, evapotranspiration rates, topographic relief, and the ability of the geologic materials to transmit water. Thus, recharge is difficult to quantify. In humid, temperate climates, recharge can be 50 percent of precipitation, whereas in dry, warm climates recharge can be as low as one percent or less of precipitation (NRC, 1990).

Recharge water travels downward by gravity through the unsaturated zone, where the pore space may be partly filled with air and partly filled with water, which is held in the pores by the forces of surface tension (or capillary forces) (see Figure 3.2). A capillary fringe exists at the base of the unsaturated zone, where all pores are saturated with water held by surface tension. Beneath the capillary fringe lies the saturated zone, defined as the zone in which the pores are completely filled with water at a pressure greater than atmospheric (Fetter, 1994). The boundary between the saturated and unsaturated zones is called the water table. The water level in a shallow well intersecting the saturated zone defines the height of the water table. The elevation of the water table can fluctuate, rising into what was previously the unsaturated zone or falling to create a thicker unsaturated zone. Perched water tables may exist within the unsaturated zone in locations where lenses of low-permeability material (e.g., clay layers) impede downward flow and create a local saturated area.

Groundwater flow can occur in downward, upward, and lateral directions, depending on the hydraulic properties of geologic materials and their relative orientation. Groundwater may travel long distances until it eventually discharges as a spring or as seepage into a stream, lake, or ocean.

however, in most minefill scenarios, CCRs are covered by several feet of soil or coal spoils, lessening the potential for overland transport of contaminants.

### Water Flow in the Saturated Zone

Groundwater flow at CCR mine placement sites is controlled by the local hydrogeology, which may be significantly altered by mining activities. Groundwater flow in the saturated zone will depend on the thickness and orientation of

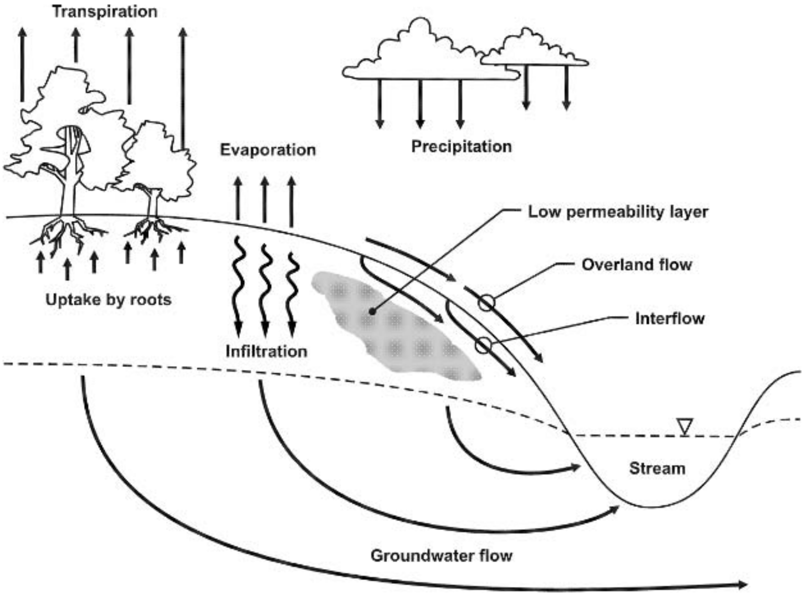

**FIGURE 3.1** Near-surface hydrologic processes.
SOURCE: Modified after Drever, 1997.

individual geologic strata and the hydraulic conductivity of the geologic materials (Figure 3.3). Hydraulic conductivity describes the capacity of a porous medium to transmit water in response to an applied pressure. If the same pressure is applied, saturated water flow is relatively rapid through porous media with high values of hydraulic conductivity, such as sand and gravel, but much lower through low-hydraulic-conductivity materials. Coal seams can occur as either thick or thin beds that are typically layered between low-hydraulic-conductivity, fine-grained shale or clay and higher-conductivity, coarse-grained silt or sandstone sequences (Figure 3.4). The strata in coal-bearing areas may be flat-lying, moderately undulating, or highly folded, leading to widely variable patterns of groundwater flow. The strata in lignite and bituminous regions tend to be relatively uniform and flat-lying or gently sloping. The coal seams are often more permeable than the interbedded sandstone and shale layers, and groundwater flow is relatively more rapid through coal beds and fractured sandstones (Figure 3.4). In anthracite deposits, the geologic materials are rigid, with low porosity and water flow where the strata remain unfractured. However, the stresses placed on these more brittle materials as the result of folding can lead to the development of fractures, which facilitate preferential groundwater flow (NRC, 1990, 1996a).

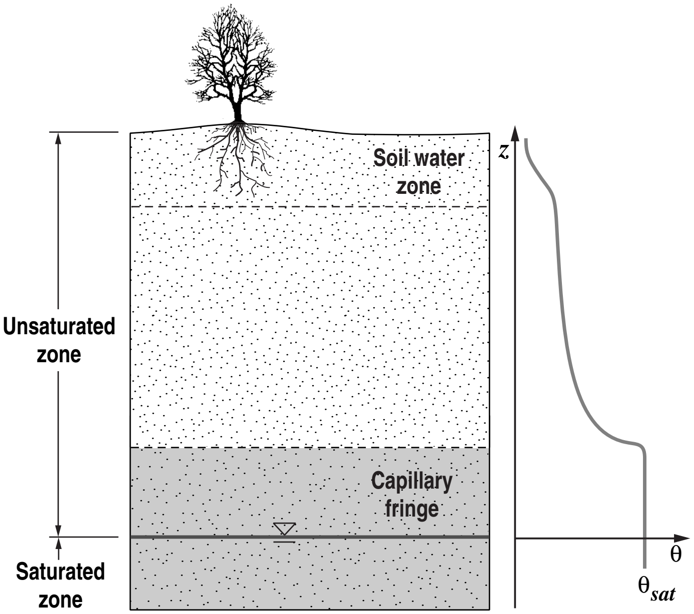

**FIGURE 3.2** The distribution of water in the unsaturated zone and the classification of groundwaters according to Meinzer (1923). The figure shows the increasing volumetric moisture content, $\theta$, with depth, until it reaches saturation, $\theta_{sat}$, at the capillary fringe. The volumetric moisture content is defined as the volume of water per bulk volume of soil sample.
SOURCE: George Hornberger, University of Virginia. Modified from Hornberger et al., 1998.

There is a tendency for fractures to be most abundant near the surface and then terminate at depth (Figure 3.5) (Callaghan et al., 1998). In this case, groundwater flow might be directed primarily through the fractures near the surface but through the pores of the rock matrix at greater depths. Groundwater velocities can be quite high within an individual fracture. If the fractures are sufficiently wide, groundwater flow volumes and velocities can be many times greater than in unfractured materials (NRC, 1996a).

Removal of coal and reclamation of the mine site with coal spoils will alter the pre-mining groundwater flow characteristics, often significantly. In some surface mine settings, large volumes of rock are removed to gain access to the coal, and during reclamation these materials are redeposited in the mine pit and surrounding area. Water flow through coal spoils and similar materials can occur both through discrete conduits or macropores that form between large pieces of spoil material (pseudokarstic flow) and, more uniformly, through the finer spoil particles (matrix

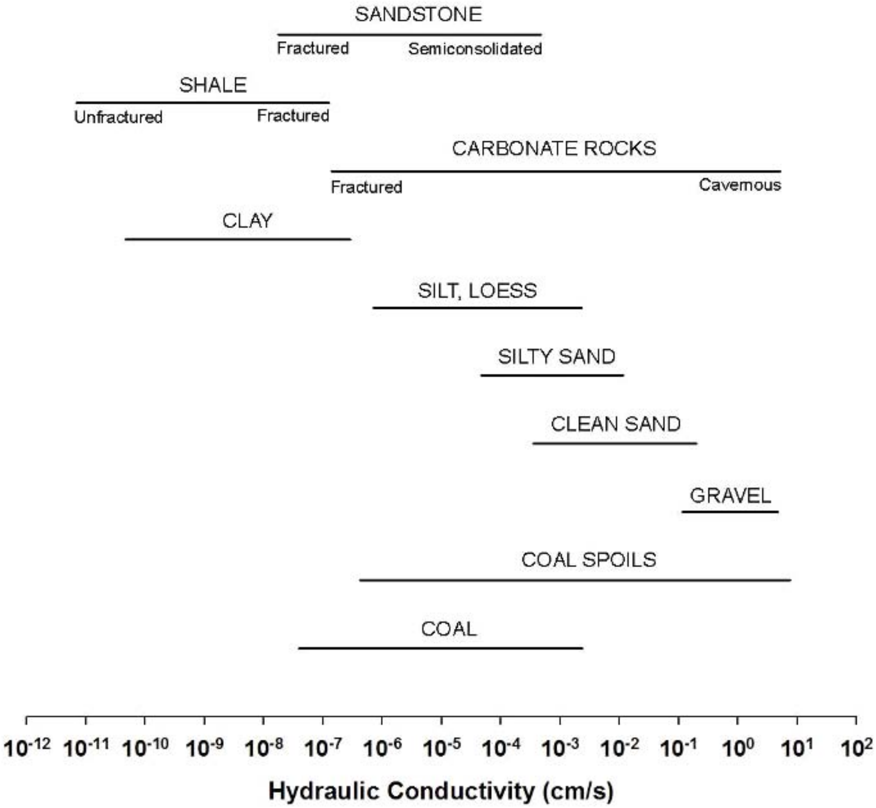

**FIGURE 3.3** Typical values for hydraulic conductivity of selected geologic materials. SOURCE: Adapted from Heath, 1982, considering data from Hawkins, 1998; Harlow and LeCain, 1993; VanVoast and Reiten, 1988; and Minns, 1993.

flow), leading to a wide range of hydraulic conductivities in coal spoils (Figure 3.3) (Hawkins and Aljoe, 1991; Hawkins, 1998; Smith and Beckie, 2003).

Open pit lakes might also remain after large-scale surface mining operations. Other mining methods, such as underground mining, may cause less disturbance of surface materials, but large underground chambers are created during mining. Mining often causes subsidence and increased fracturing in the surrounding strata (Hornberger et al., 2004). Mine reclamation activities aim to restore surface water flow paths and recreate similar recharge conditions, but, no effort is made to restore the specific subsurface water flow paths (NRC, 1990). At most sites, a new water flow field will be established that reflects the changes caused by excavation and reclamation activities.

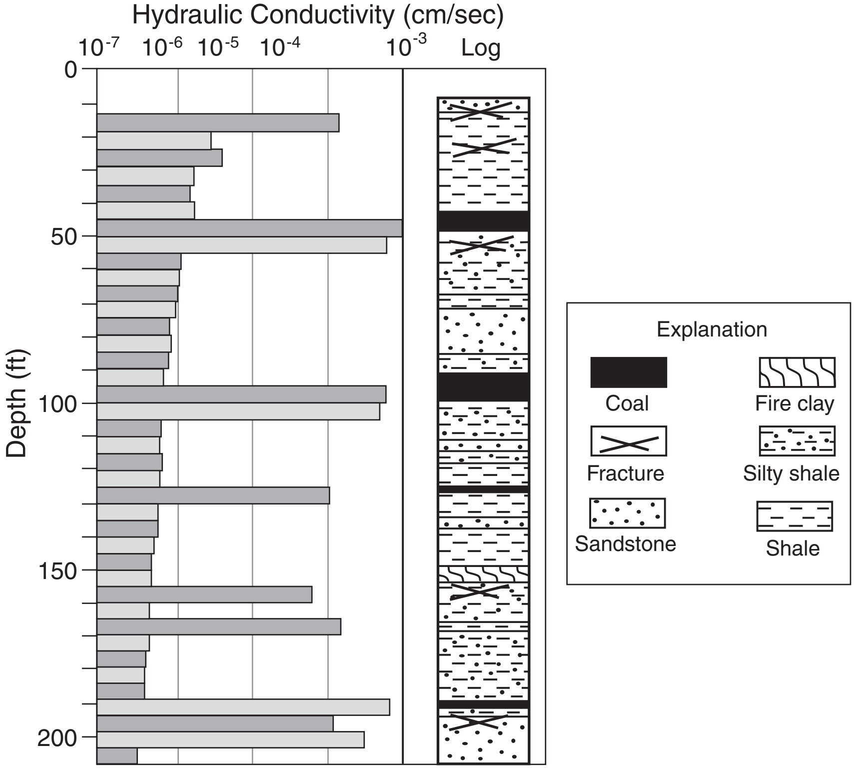

**FIGURE 3.4** Range of hydraulic conductivity values with depth from a borehole in a bituminous coal-bearing area of Kentucky. Hydraulic conductivities vary widely with depth, and the highest values are generally found in the coal layers and fractured strata. SOURCE: Modified from Wunsch, 1992. Courtesy of the University of Kentucky.

## Water Flow in the Unsaturated Zone

Above the water table, water flow occurs in response to gravitational and capillary forces and is therefore relatively complex. In homogeneous porous media (e.g., well-sorted sand), unsaturated zone water will migrate predominantly downward to the water table as the result of gravitational forces. However, depending on the soil moisture levels, the distance below the ground surface, and the extent of evapotranspiration, unsaturated zone water may flow upward toward the root zone. In porous media with layers or lenses of varying hydraulic conductivity, lateral flow of water will also occur. Unsaturated flow through coarse-grained coal spoils can occur in conduits, along the surfaces of large spoil

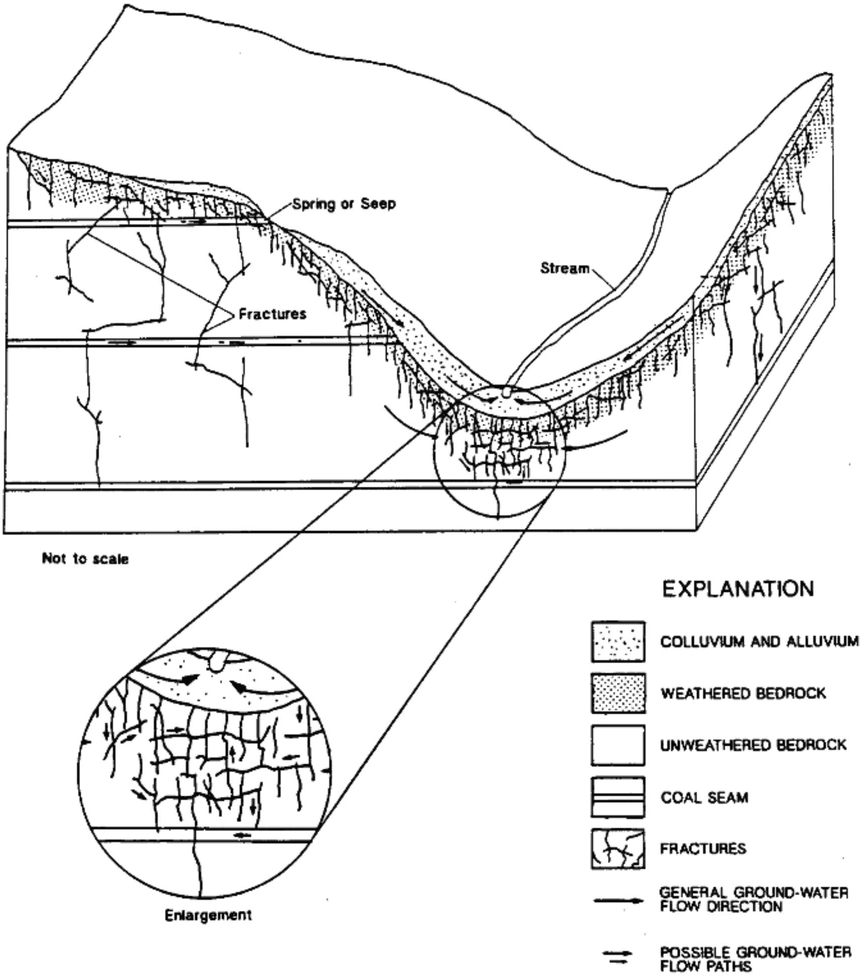

**FIGURE 3.5** Conceptual model of the hydrogeologic flow system characteristic of central Appalachian coal-bearing regions, showing the distribution of fractures with depth. SOURCE: Harlow and LeCain, 1993.

fragments, or within the finer-grained matrix materials (Smith and Beckie, 2003). Flow is strongly dependent on the orientation and the hydraulic conductivity of the different spoil layers.

Hydraulic conductivity in the unsaturated zone is a function of moisture content. In homogeneous porous media, the highest hydraulic conductivity in the unsaturated zone occurs within the capillary fringe, where all pores are saturated with water (Figure 3.2). As the water content of unsaturated geologic materials decreases, large decreases in hydraulic conductivity—up to several orders of magnitude—are observed. Because coarse-grained materials (e.g., gravel, some coal spoils) have large pore spaces that drain more quickly than fine-grained materials (e.g., silt, CCR), the hydraulic conductivity of coarse-grained materials can be lower than that of fine-grained materials at the same moisture content (Hillel, 1998). For example, at low to moderate moisture contents, unsaturated water flow may be greater in fine-grained materials than in coarse-grained coal spoil (Newman et al., 1997; Wilson et al., 2000).

## Implications of CCR for Subsurface Flow

As noted in Chapter 2, emplacement of CCR at mine sites can occur above or below the water table. The physical properties of CCRs can differ greatly from the physical properties of coal spoils and surrounding geologic materials (Table 3.1; Figure 3.3). As a result, large-volume CCR disposal can substantially alter groundwater flow paths. CCRs can be disposed as large monofills, as layers of CCR interbedded with coal spoils, or as blended mixtures of CCR and coal spoils (Figure 2.9). Considerations of potential saturated and unsaturated water flow in and around these CCR emplacement zones have implications for mine disposal of CCRs.

### CCR Impacts on Saturated Flow

In the saturated zone, given the same pressure conditions, groundwater flow will be greatest in high-hydraulic conductivity materials. Where monofills of fine-grained CCR are placed within coarse-grained coal spoils, the water will have a tendency to flow around the CCR monofill because the lower hydraulic conductivity of the CCR will impede flow. Where CCR fills an entire surface mine pit, the impacts on groundwater flow will depend on the hydraulic conductivity of the surrounding geologic materials as well as the extent of compaction during emplacement. If the surrounding materials are relatively intact strata with a lower hydraulic conductivity than the CCR, groundwater will flow through the CCR. Alternatively, if the hydraulic conductivity of the surrounding geologic materials is higher than that of the CCR, water will tend to flow around the CCR.

When coal spoils and CCR are placed as interbedded layers during the mine reclamation process (Figure 2.9), the contrasts in hydraulic conductivity will further alter the groundwater flow. Under these conditions, the impacts on groundwater flow will depend on the orientation of the groundwater flow direction relative to the orientation of the layers of CCR and spoil. If the groundwater flow direction is parallel to the CCR layers, water will flow preferentially through the coarse spoil layers, with only minor flow through the CCR. If the groundwater flow direction is perpendicular to the CCR layers, the fine-grained CCR will impede the flow and reduce groundwater velocities through the emplacement zone.

**TABLE 3.1** Hydraulic Conductivity at Saturation ($K_s$) and Particle Diameter (d) for Some Soils and Typical CCRs After Placement

| | $K_s$ (cm/sec) | d (mm) |
|---|---|---|
| Clay[a] | $10^{-8}$ to $10^{-6}$ | <0.002 |
| Silt[a] | $10^{-6}$ to $10^{-4}$ | 0.002-0.05 |
| Sand[a] | $10^{-3}$ to $10^{-1}$ | 0.05-2 |
| Gravel[a] | 1.0 to $10^{-3}$ | >2 |
| Fly ash: | | 0.006 – 0.130(g) |
| Unstabilized, compacted | $4 \times 10^{-5}$(b) | |
| Stabilized with lime | $10^{-7}$(b,c) | |
| Bottom ash | $10^{-3}$ to $10^{-2}$(d) | 0.2 – 10(h) |
| Boiler slag | $10^{-3}$ to $10^{-2}$(d) | 0.6 – 3(h) |
| FGD residue: | | 0.02 – 0.04*(i) |
| Dewatered unstabilized FGD | $10^{-5}$ to $10^{-4}$(e) | |
| Stabilized or fixated FGD | $10^{-7}$ to $10^{-6}$(f) | |

*Mean diameter.

Note that hydraulic conductivities of CCRs may vary significantly based on the degree of compaction methods. Particle size diameter data for CCRs reflect the mean grain sizes at the 10th and 90th weight percentiles, unless otherwise noted.

SOURCES: [a]Hillel, 1998; [b]Ghosh and Subbarao,1998; [c]Koury et al., 2004; [d]Majizadeh et al., 1979; [e]Prusinski et al., 1995; [f]Smith, 1985; [g]Morenoa et al., 2005; [h]Moulton, 1973; [i]Tishmack, 1996.

As described in Chapter 2, some CCRs have cementitious properties, while others can become cementitious with the addition of lime or some other base. Table 3.1 shows the notable reduction in hydraulic conductivity that can occur when CCRs are "stabilized" with the addition of lime. It should be noted that some uncertainty remains regarding the long-term stability of cementitious ash and whether these low hydraulic conductivities can be maintained in the environment over time (McCarthy et al., 1997; Weinberg and Hemmings, 1997).

## CCR Impacts on Unsaturated Flow

Predictions of unsaturated flow are complex, even without the addition of CCRs, and research on unsaturated flow through CCRs is extremely limited. Nevertheless, some observations of the potential impacts of CCRs on unsaturated flow at mine sites are provided here based on relevant studies of unsaturated flow through layered fine- and coarse-grained materials and through waste rock piles at coal and metal mine sites.

The impacts of CCRs on unsaturated flow will depend on a number of factors, including the degree of contrast in hydraulic properties between the CCR and the surrounding spoil or geologic strata, the moisture content, and the geometry of CCR emplacement (Hillel, 1998; Smith and Beckie, 2003). As discussed previously, research on unsaturated flow suggests that at times of low infiltration, water in the unsaturated zone may flow preferentially through fine-grained CCR layers rather than through the coarser-grained spoil materials. During periods of high infiltration rates, research suggests that flow might be dominantly through the coarse-grained spoils (Bussière et al., 2003; Smith and Beckie, 2003). Thus, large uncertainties remain regarding flow in the unsaturated zone in complex mine settings, especially those with great contrasts in hydraulic conductivity.

When CCRs are placed close to the water table, a thick capillary fringe could form within the materials. Studies of groundwater flow through mine tailings with similar particle size distributions and hydraulic conductivities as fly ash, noted a thick capillary fringe, ranging from tens of centimeters up to six meters in thickness (Blowes and Gillham, 1988; Al and Blowes, 1996a,b). Under such conditions, the addition of only a small amount of water, such as a minor precipitation event, can lead to a pronounced rise in the water table and increased potential for contaminant transport to surface water bodies.

## BIOGEOCHEMICAL PROCESSES AFFECTING CCR BEHAVIOR

As groundwater comes in contact with CCR in the mine environment, the material will be impacted by an array of geochemical and biological processes. Dissolution and desorption processes can release constituents into water from the CCR through an initial set of rapid reactions, which will be followed by slower reactions over months or years. Once these constituents enter the groundwater, they may be transported away from the CCR. Some contaminants will be transported conservatively, moving with the flow of water because they are unaffected by adsorption to aquifer materials. However, other contaminants may be attenuated by adsorption or precipitation reactions or transformed by microbially mediated biological reactions.

The biogeochemical environment in the coal mine setting can vary widely between sites and within a single site. Oxidation-reduction conditions at a mine site are generally oxic, but suboxic conditions may occur at depth. The groundwater pH may be near neutral at some coal mine sites, particularly western mines, and highly acidic at others due to sulfide mineral oxidation reactions that cause acid mine drainage (AMD) (Sidebar 3.2). A large range of pH and oxidation-reduction conditions may develop within a single site as the result of variability in the amount of acid-generating materials and the availability of acid-consuming materials (Cravotta, 1994). When CCRs are emplaced at a site, there is potential for the pore water pH to rise to very high values ($\mathrm{pH} > 9$) due to the substantial alkalinity in many CCRs.

## SIDEBAR 3.2
## Acid Mine Drainage

Coal mine drainage waters can vary widely in composition, from highly acidic to alkaline. Acid mine drainage (AMD) is a common problem at coal mines in the eastern United States and is formed by the oxidation of sulfide minerals (e.g., pyrite, $FeS_2$), which exist in coal spoils and surrounding geological materials. Acid mine drainage contains elevated concentrations of acid, iron, manganese, aluminum, and associated trace elements, such as zinc, nickel, and arsenic, which can be transported to surrounding waters (Williamson and Rimstidt, 1994; Blowes et al., 2003a). The following reactions characterize the various steps in the generation of acidity by pyrite oxidation (Stumm and Morgan, 1996):

$$FeS_{2(s)} + \tfrac{7}{2}\,O_2 + H_2O = Fe^{2+} + 2\,SO_4^{2-} + 2\,H^+ \qquad (3.1)$$

$$Fe^{2+} + \tfrac{1}{4}\,O_2 + H^+ = Fe^{3+} + \tfrac{1}{2}\,H_2O \qquad (3.2)$$

$$FeS_{2(s)} + 14\,Fe^{3+} + 8\,H_2O = 15\,Fe^{2+} + 2\,SO_4^{2-} + 16\,H^+ \qquad (3.3)$$

$$Fe^{3+} + 3\,H_2O = Fe(OH)_{3(s)} + 3\,H^+ \qquad (3.4)$$

Oxygen entering pyrite-rich coal spoils is usually consumed through sulfide and iron oxidation reactions catalyzed by bacteria (e.g., *Thiobacillus ferrooxidans*) (Singer and Stumm, 1970; Nordstrom and Southam, 1997; Nordstrom and Alpers, 1999). Acid mine drainage can be neutralized by reactions with carbonates (e.g., limestone) or aluminosilicate minerals (Campbell et al., 2001; Skousen et al., 2002; Blowes et al., 2003b; Jambor, 2003; Weber et al., 2004). The rate and extent of acid production will depend on a number of factors, including the amount of pyrite present, the amount of neutralizing minerals, the rate of oxygen influx, the pH, and the microbial community. It may take several decades to many centuries for all available sulfide minerals to oxidize and for minerals contributing to acid-neutralization reactions to be consumed (Banwart and Malmström, 2001; Blowes et al., 2003b).

## Leaching Behavior of CCR

Trace elements can be tightly bound within the CCR minerals, or they can occur as leachable coatings on grain surfaces (see Chapter 2). Water chemistry—primarily pH—influences the solubility of CCR-derived constituents. Many metals and metallic compounds found in CCRs exhibit the highest solubilities at very low and very high pH, with lower solubilities at near neutral pH (Figure 3.6). Under acidic (low-pH) conditions, elevated dissolved concentrations of many constituents can be expected due to the high mineral solubility (Pankow, 1991; Stumm and Morgan, 1996). Under alkaline (high-pH) conditions, the formation of soluble hydroxide and carbonate complexes leads to increased dissolution of many metals (Pankow, 1991). There are other elements—in particular, oxyanion-forming elements such as arsenic, selenium, and molybdenum—that remain soluble under near-neutral pHs.

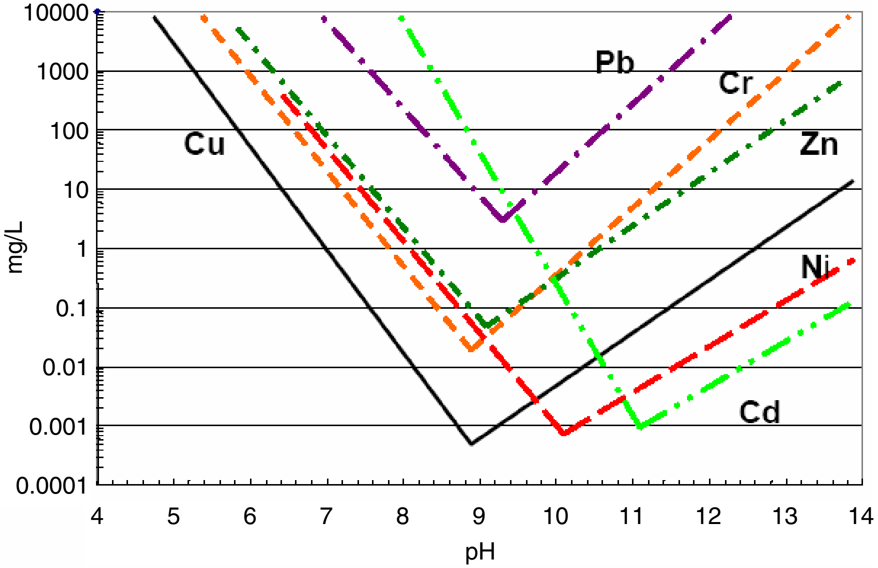

**FIGURE 3.6** Calculated solubilities of selected metallic elements with pH based on systems containing metal hydroxide and water, without other complexing agents present. SOURCE: Scheetz et al., 2004. Courtesy of Pennsylvania Department of Environmental Protection.

Laboratory research has examined the potential for fly-ash leaching under a broad range of pH. Kim et al. (2003) conducted a series of 30- to 90-day column leaching experiments to evaluate the leaching of 32 fly ash samples by several different leaching fluids, including deionized water, simulated acid mine drainage (pH 1.2), and an alkaline solution (pH 11.1) representative of pore fluids that might develop in alkaline fly ash. Analyses of the effluent showed that the greatest extents of leaching occurred with the acidic leaching solutions for many of the cations analyzed, including aluminum, cobalt, chromium, copper, manganese, nickel, and zinc (see Figure 3.7), due to the enhanced dissolution of the ash particles. In contrast, the leaching of arsenic, antimony, and selenium, was greatest for alkaline solutions. The committee was unable to find any research on the effects of various oxidation-reduction conditions on CCR leaching, although suboxic conditions may occur when CCRs are placed beneath the water table.

Limited research has been done to understand the field leaching behavior of CCRs. However, one major research study was recently completed and collected field leachate samples at 37 CCR landfill and surface impoundment disposal sites (Ladwig et al., 2006). In this study, leachate samples were collected from leachate wells, lysimeters, drive points, core samples, sluice lines, and from ponds at the

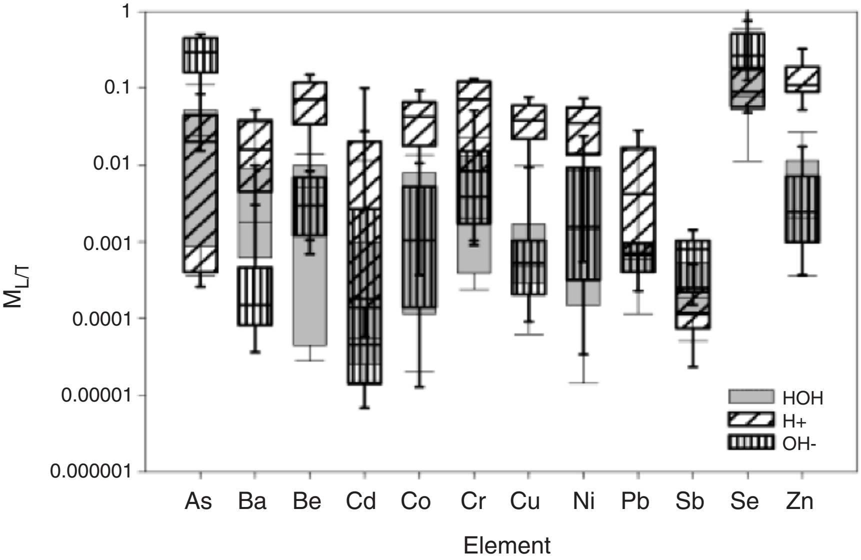

**FIGURE 3.7** Box plot showing the relative solubility ($M_{L/T}$: total mass leached divided by total initial mass in the fly ash) for trace elements leached from 32 fly ash samples using acidic ($H^+$), neutral (HOH), and alkaline ($OH^-$) leaching solutions in laboratory column experiments. The box represents the 10th and 90th percentiles; the solid line within the box represents the median; and the whiskers (or error bars) represent the 5th and 95th percent confidence intervals.
SOURCE: Kim et al., 2003. Courtesy of the American Chemical Society.

ash/water interface. The field data show fairly wide ranges of trace element concentrations in the leachate at these sites, with some species (e.g., chromium, cobolt, selenium) showing variability up to four orders of magnitude between the maximum and minimum concentrations detected (see Figure 3.8).

### CCR Interactions with Acid-Generating Coal Spoil

Coal spoil when exposed to water and oxygen can generate AMD (Sidebar 3.2). Many CCRs, however, are alkaline and may be capable of neutralizing the acidity, depending on the manner of emplacement (Daniels et al., 2002). As discussed in Chapter 2, mine placement of alkaline CCRs has been used explicitly for treating AMD, and AMD reduction is often considered an added benefit in large-volume CCR mine disposal operations. This section discusses research on the interactions between acid-generating coal spoils and alkaline CCRs, highlighting the implications for CCR placement design in the mine reclamation process.

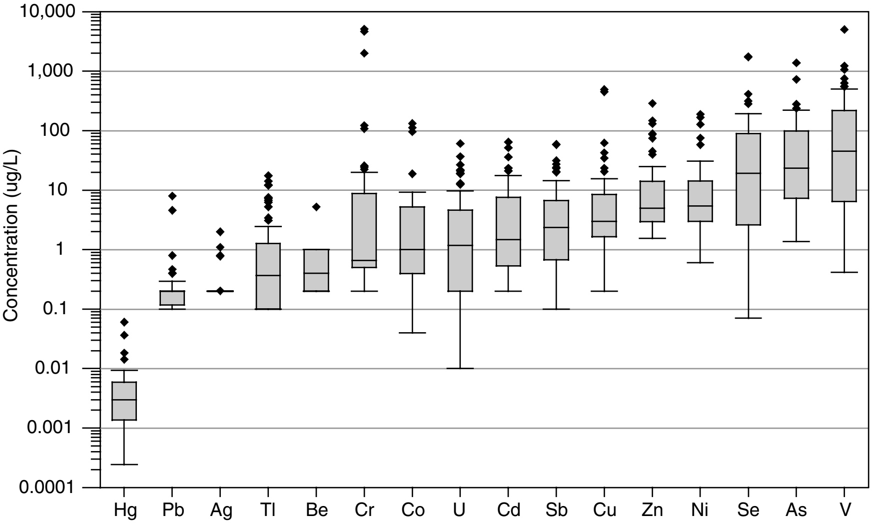

**FIGURE 3.8** Data showing field leachate concentrations from 37 CCR sites. Data were collected from fly ash, bottom ash, and flue gas desulfurization ash placed in landfills and surface impoundments. Boxes represent the range of data within the 25th and 75th percentiles (or the inter-quartile range, IQR), and whiskers (or error bars) reflect the minimum and maximum non-outlier concentrations detected. Outliers are considered to be values that are greater than the 75th percentile + 1.5*IQR or less than the 25th percentile – 1.5*IQR and are shown as diamonds.
SOURCE: Data from Ken Ladwig, Electric Power Research Institute.

Stewart et al. (1997, 2001) evaluated leaching from different blends of fly ash and acid-producing coal refuse[1] using a series of multi-year unsaturated column experiments. Ash-free coal refuse columns showed a rapid decline in leachate pH values from 8.0 to less than 2.0 and substantial increases in concentrations of dissolved metals (iron, manganese, aluminum, copper, and zinc). In contrast, columns with the highest proportions of alkaline fly ash (20 percent and 33 percent by weight) showed no evidence of AMD, maintaining a relatively constant pH (above pH 7) throughout the course of the experiment (Figure 3.9). Low concentrations of metals leached from these ash-amended columns, although high concentrations of boron and sulfate were detected. In columns with lower proportions (5-10 percent) of fly ash and in columns blended with low-alkalinity

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[1] The coal refuse used in these studies was primarily waste rock material mined with coal and subsequently removed at the coal preparation plant.

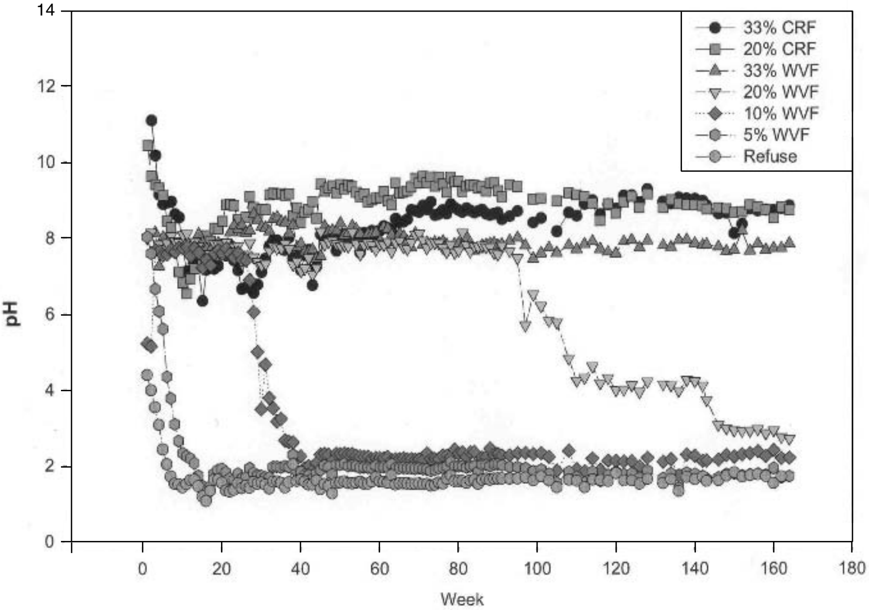

**FIGURE 3.9** Mean pH in column leachate over a three-year column experiment to examine the impacts of different blending ratios of coal refuse and two types of fly ash (Clinch River fly ash [CRF] and WestVaco fly ash [WVF]). The CRF is moderately alkaline, whereas the WVF is a lower-alkalinity CCR. Error bars represent one standard deviation above and below the mean.
SOURCE: Lee Daniels, Virginia Polytechnic Institute and State University. Modified from Stewart et al., 2001. Courtesy of Virginia Polytechnic Institute and State University.

fly ash (up to 20 percent), the pH eventually declined to low values during the course of the experiment. This decline was attributed to insufficient alkalinity addition. Once the pH declined, concentrations of metals increased substantially in the leachate.

These findings suggest that the addition of fly ash to coal spoils in a sufficient quantity can prevent AMD formation. However, less is known about the ability of CCRs to prevent AMD over extended time frames. For example, it is not known how the presence of $Fe^{3+}$ and other oxidized metals in the CCRs may enhance pyrite oxidation in the surrounding spoils (see Sidebar 3.2). Stewart et al. (2001) speculated that the high pH of the CCR suppresses the microbially mitigated oxidation of pyrite while also limiting the movement of oxygen to the sulfide minerals, so that the acid generated through slower abiotic sulfide oxidation reactions can be effectively neutralized by the CCR. However, if there is an insufficient addition of alkalinity, low-pH conditions will eventually be generated, perhaps after several years, potentially leaching metals and other elements from the ash at high concentrations. Stewart et al. (2001) recommend that if coal ash is to be used in reclamation activities, close attention should be paid to balancing the acid-generating potential of coal refuse with the alkalinity of the ash. Many sources of alkalinity in the aquifer material may not be available for reaction because of the formation of surface coatings or due to dissolution kinetics. Therefore, some practitioners recommend increasing the alkalinity by some safety factor to prevent the unanticipated return of acidic conditions (Daniels et al., 1996).

If the CCR is thoroughly mixed with coal spoils, the alkalinity of the CCR will contribute to acid neutralization reactions close to where acid generation occurs. Daniels et al. (2002) examined various CCR and coal refuse mixing strategies to determine their effectiveness in reducing acidity. However, none of the CCR placement strategies tested, including layering the CCRs within the coal refuse and partially blending the CCRs with refuse before layering, proved as effective at preventing acid generation as the bulk-blending approach of the previous column experiments. Thus, understanding the mobility of CCR constituents in mines with the potential to generate AMD requires information on acid-base accounting (see Chapter 6) and the manner of CCR placement relative to acid-generating materials. Much less is known about the effectiveness of CCRs for treating AMD under suboxic conditions.

### Mobility of CCR Constituents in Mine Environment

The degree to which CCR-derived constituents are mobile in the mine environment depends on both aqueous speciation and reactions with surrounding geologic materials. Trace elements released from CCRs can form neutral, positively, or negatively charged species in one or more valence states in solution (Table 3.2). The speciation of elements is dependent on pH, oxidation-reduction potential in the mine setting, and the concentrations of other species in solution that might contribute to the formation of soluble complexes.

The mobility of these CCR-derived species varies widely in the mine environment. Some species do not interact strongly with the surrounding geologic materials (e.g., coal spoils, shale, clay) over the entire range of pH and oxidation-reduction potential likely to be encountered at a coal mine site. Other species will be mobile under a limited range of pH and oxidation-reduction potential; still others will have low mobility under all conditions. Only limited information is available on attenuation reactions influencing the fate of CCR elements of concern at coal mine sites where large-volume CCR disposal has occurred. However, insights can be gained through other studies on the transport of metals and metallic compounds under geochemical conditions that develop in mine settings or other types of sites, since many of the constituents of interest are the same as those found at CCR disposal sites (Table 3.3). Examination of these data provides information about the potential mobility of CCR-derived elements under near-neutral conditions at coal mine sites.

**TABLE 3.2** List of Selected Elements Observed to Leach from CCR, Including Common Hydrolysis Species

| Element | Important Species Between pH 2 and 12 |
|---|---|
| Ag | Ag (II): $Ag^{2+}$<br>Ag(I): $Ag^{+}$ |
| Al | $Al^{3+}$, $Al(OH)_2^{+}$, $Al(OH)^{2+}$, $Al(OH)_4^{-}$ |
| As | As(III): $H_3AsO_3^{0}$, $H_2AsO_3^{-}$<br>As(V): $H_2AsO_4^{-}$, $HAsO_4^{2-}$ |
| B | $H_3BO_3^{0}$, $H_2BO_3^{-}$, $HBO_3^{2-}$, $BO_3^{3-}$ |
| Ba | $Ba^{2+}$ |
| Be | $Be^{2+}$, $BeO_2^{2-}$ |
| Cd | $Cd^{2+}$, $CdO_2^{2-}$ |
| Co | Co(III): $Co^{3+}$<br>Co(II): $Co^{2+}$, $HCoO_2^{-}$ |
| Cr | Cr(VI): $HCrO_4^{-}$, $CrO_4^{2-}$<br>Cr(III): $Cr^{3+}$,$Cr(OH)^{2+}$, $Cr(OH)_2^{+1}$, $Cr(OH)_3^{0}$, $Cr(OH)_4^{-1}$ |
| Cu | $Cu^{2+}$, $CuO_2^{2-}$ |
| Fe | Fe(III): $Fe^{3+}$, $Fe(OH)^{2+}$, $Fe(OH)_2^{+}$, $Fe(OH)_3^{0}$, $Fe(OH)_4^{-}$, $Fe_2(OH)_2^{4+}$<br>Fe(II): $Fe^{2+}$, $Fe(OH)^{+}$, $Fe(OH)_3^{-}$, $Fe(OH)_2^{0}$ |
| Hg | Hg(II): $Hg^{2+}$, $HgOH^{+}$, $Hg(OH)_2^{0}$, $Hg(OH)_3^{-}$<br>Hg(0): $Hg^{0}$ |
| Mn | $Mn^{2+}$, $MnOH^{+}$, $Mn(OH)_3^{-}$ |
| Mo | Mo(VI): $MoO_4^{2-}$, $HMoO_4^{2-}$, $H_2MoO_4^{0}$, $MoO_2^{2+}$<br>Mo(V): $MoO_2^{+}$<br>Mo(III): $Mo^{3+}$ |
| Ni | $Ni^{2+}$, $NiOH^{+}$, $HNiO_2^{-}$ |
| Pb | $Pb^{2+}$, $PbOH^{+}$, $Pb(OH)_2^{0}$, $Pb(OH)_3^{-}$ |
| S | S(VI): $HSO_4^{-}$, $SO_4^{2-}$<br>S(0): $S^{0}$<br>S(II): $H_2S^{0}$, $HS^{-}$ |
| Sb | $SbO^{+}$, $SbO_2^{-}$ |
| Se | Se(VI): $HSeO_4^{-}$, $SeO_4^{2-}$<br>Se(IV): $H_2SeO_3$, $HSeO_3^{-}$, $SeO_3^{2-}$<br>Se(0): $Se^{0}$<br>Se(II): $H_2Se$, $HSe^{-}$ |
| Tl | Tl(III) :$Tl(OH)_2^{+}$, $Tl(OH)^{2+}$<br>Tl(I) : $Tl^{+}$ |
| U | U(VI): $UO_2^{2+}$, $UO_2OH^{+}$, $(UO_2)_3(OH)_5^{+}$<br>U(V): $UO_2^{+}$<br>U(IV): $U^{4+}$, $UOH^{3+}$, $U(OH)_2^{2+}$, $U(OH)_3^{+}$, $U(OH)_4^{0}$, $U(OH)_5^{-}$ |
| V | V(V): $H_2VO_4^{-}$, $HVO_4^{2-}$, $VO_4^{3-}$<br>V(IV): $VO^{2+}$ |
| Zn | $Zn^{2+}$, $ZnOH^{+}$, $ZnO_2^{2-}$ |

Under near-neutral pH conditions, constituents such as sulfate, magnesium, ferrous iron ($Fe^{2+}$), zinc, nickel, arsenic, selenium, and boron often migrate readily, especially in the suboxic conditions that exist in many coal spoils. In contrast, the concentrations and mobility of some other constituents, such as aluminum, lead, and cadmium, are expected to be limited due to adsorption to solids within the aquifer or because of the formation of secondary precipitates (e.g., carbonates, sulfates). The transport of these sparingly soluble constituents, however, may be enhanced in coarse-grained or fractured media by colloids (particles that generally range in size from 1 nm to 10 μm) (McCarthy and Zachara, 1989; Russel et al., 1989; Kretzschmar et al., 1999). Over time, geochemical conditions at a site (e.g., pH, redox conditions) can change as the more reactive or soluble minerals dissolve and are flushed from the CCR, thereby affecting the transport potential of trace elements from the CCR.

As groundwater moves away from the CCR disposal area, this water has the potential to discharge contaminants to surface water bodies, where additional geochemical processes can occur that may affect their mobility and bioavailability. Abundant information is available on the transport and bioavailability of contaminants in surface waters downstream from coal mine sites without CCR. In contrast, virtually no information is available for sites with CCR placement. Coal mines that generate acid mine drainage (Sidebar 3.2) can contribute large quantities of iron to streams adjacent to mine sites. Oxidation of the iron results in the precipitation of ferric (oxy)hydroxide solids, which can scavenge some trace elements of concern, lowering their concentrations in the stream. However, at many sites this process is inefficient, and trace elements can migrate long distances from the mine in surface water, at unacceptable concentrations.

## POTENTIAL FOR CONTAMINANT TRANSPORT FROM COAL COMBUSTION RESIDUES IN COAL MINES

Contaminants entering groundwater can be transported away from the CCR source area potentially resulting in the degradation of drinking water supplies or of surface-water quality. The degree of degradation of downgradient water quality will depend on the concentration and volume of contaminated water entering the flow system and the ability of the aquifer or receiving water body to dilute or attenuate the contamination. The concentration and volume of contaminated water, in turn, depend on the leachable mass of toxic constituents in the CCR, the emplacement design, and the local hydrogeologic setting. The leachable mass of toxic constituents is a function both of the leachability of the constituents of concern and the total mass of CCR materials disposed at a site.

For example, if CCRs are placed in the unsaturated zone at a site where unsaturated water movement is slow, there might be potential for dilution of the contaminants to acceptable concentrations if groundwater velocities in the saturated zone are relatively high. This situation would most likely occur when the areal extent of CCR emplacement and the total leachable contaminant mass are relatively small. Similarly, if CCRs are placed in low-hydraulic-conductivity geologic materials so that the volume of groundwater discharging to a surface water body is small and if the contaminant concentrations are also low, there

**TABLE 3.3** Examples of Mobile Contaminants Under Near-Neutral Groundwater Conditions Based on Case Studies of Non-CCR-Contaminated Sites

| Source | Location | Environmental Media | Mobile Constituents | References |
|---|---|---|---|---|
| Porewater from gold mine tailings impoundment | Red Lake, Ontario | Tailings material and underlying aquifer | As | McCreadie et al. (2000) |
| Controlled tracer injection | Cape Cod, MA | Sand and gravel aquifer | As, B, Cu, Cr(VI), Mo, Ni, Se, Zn | Stollenwerk (1998); LeBlanc et al. (1991); Kent et al. (1995, 2000); Davis et al. (2000) |
| Gold mine wastes | Mine site, Pinal Creek Basin, AZ | Alluvial aquifer | Mn, Zn | Brown et al. (1998) |
| Mine wastes | Western Finland | Aquifer | Ni | Heikkinen et al. (2002) |
| Industrial wastes | U.S. contaminated sites | Mixed aquifer types | Cr(VI) | Palmer and Wittbrodt (1991) |
| Pore waters from uranium mill tailings | Naturita, CO | Alluvial aquifer | U(VI)—mobility increased in presence of high $HCO_3^-$ | Curtis et al. (2004) |

might be sufficient dilution in the surface water body to reduce concentrations of contaminants to acceptable levels. If the leachate contaminant concentrations from the CCRs are low and the distances to sensitive water bodies are long, the contaminant removal capacity of the aquifer solids may be sufficient to reduce the concentrations to acceptable levels. There are, however, other scenarios where the outcome of CCR mine disposal may not be positive. Large contaminant plumes could form where leaching rates are moderate to high, where there is substantial water flow through the CCRs (in either the saturated or the unsaturated zone), and where the CCR emplacement zone covers a sizable aereal extent. At numerous mine sites, contaminant leaching from other materials placed in the unsaturated zone has resulted in the development of large plumes of contaminated groundwater downgradient of the disposal area (Dubrovsky et al., 1984; Moncur et al., 2005).

These general scenarios provide some guidance as to the types of mine settings that may contribute to higher- or lower-risk CCR disposal. To fully assess the potential for degradation of groundwater and surface-water quality, a detailed analysis is required that takes into account the specific characteristics of the CCR and the hydrogeology and geochemistry of the site, which are discussed further in Chapter 6.

The time frame for contaminant transport depends on local rates of unsaturated and saturated groundwater flow and potential attenuation reactions in the surrounding environment, but it is worth noting that it may take many years before groundwater contamination from CCR mine disposal reaches downgradient monitoring wells. Changing geochemical conditions (e.g., the depletion of alkalinity from CCR) add further uncertainty regarding the potential for mobilizing contaminants over extended time frames. Sizable uncertainty is associated with our current understanding of CCR behavior in the mine environment because few, if any, studies have analyzed the long-term behavior of CCRs in the mine setting. Long-term (>10 years) studies that encompass a range of climatic and geologic settings are needed to accurately characterize CCR behavior in mine sites so that the types of mine settings, CCRs, and placement techniques most protective of human and ecological health can be identified. Additional research is also necessary to determine whether placement of CCR in mines can ameliorate the adverse effects of AMD in surface waters, particularly over protracted time scales.

## SUMMARY

Successful prediction of CCR behavior in the mine environment requires a thorough understanding of the complex physical and biogeochemical processes that control the release and transport of CCR-derived constituents. This chapter provides an overview of the hydrologic and biogeochemical processes controlling the release and transport of contaminants from CCR mine disposal sites to locations where uptake may occur. In a mine setting, subsurface water flow will be the primary mechanism for transporting CCR-derived contaminants from the emplacement area to potential receptors. Subsurface flow at CCR mine placement sites is controlled by the local hydrogeology, which may be significantly altered by mining activities, and the addition of CCR further alters groundwater flow paths. The manner and degree to which the pathways are altered will depend on the manner of CCR emplacement and the location of the disposal site relative to the water table. When CCRs are placed in close proximity to the water table, a thick capillary fringe could form, which increases the potential for downgradient contaminant transport.

As water comes in contact with CCR in the mine environment, the material will be impacted by a broad array of geochemical and biological processes. The mobility of CCR-derived constituents varies widely in the mine environment depending on the pH, oxidation-reduction potential, and chemical composition of the water encountered at a mine site. Low-pH water can mobilize metals and nonmetallic constituents in the CCR. Depending on their acid-neutralizing potential and the methods of emplacement, CCRs may be effective in neutralizing AMD and therefore reducing the overall transport of contaminants from the mine site. However, several potentially toxic constituents in CCRs are mobile at neutral or alkaline pHs. Thus, *the committee concludes that acid neutralization will not reduce the mobility of all contaminants of concern from the CCR.*

Impacts on downgradient water quality from CCR disposal at mine sites will depend on the concentration and volume of contaminated water entering the flow system and the ability of the aquifer or receiving water body to dilute or attenuate the contamination. The concentration and volume of contaminated water, in turn, depend upon the leachable mass of toxic constituents in the CCR, the emplacement design, and the local hydrogeologic setting. General scenarios are presented to provide some guidance as to the types of mine settings that may contribute to higher- or lower-risk CCR disposal. Specifically, one high-risk scenario occurs where leaching rates are moderate to high, where there is substantial water flow through the CCRs (either in the saturated or the unsaturated zone), and where the CCR emplacement zone covers a sizable areal extent.

Abundant information exists regarding the transport of toxic metals and metalloids in groundwater, which may assist our understanding of the behavior of CCR-derived constituents in the mine setting. However, *the committee concludes that there remains a poor understanding of the conditions influencing the field behavior of CCRs, such as pH, oxidation-reduction conditions, and hydraulic conductivity, over extended time frames at CCR placement sites.* Sizable uncertainty exists in our current understanding of CCR behavior in the mine environment because few, if any, studies have analyzed the long-term behavior of CCRs in the mine setting. **The committee recommends additional research to exam-**

**ine the long-term (>10 years) environmental behavior of CCR at mine sites, including differing climatic and geologic settings, so that the types of mine settings, CCRs, and placement techniques most protective of human and ecological health can be identified.** This research should include studies to determine under which conditions CCRs can effectively ameliorate the adverse effects of AMD in surface waters, particularly over protracted time scales.

# 4

# Potential Impacts from Placement of Coal Combustion Residues in Coal Mines

This chapter evaluates the potential human health and environmental impacts posed by the placement of CCRs in mines. As discussed in previous chapters, the concentrations of sulfate and metallic compounds in CCRs are often elevated relative to the parent coal and/or surrounding deposits (see Chapter 2). Once in contact with water, these constituents can leach from CCRs and subsequently become mobilized in both ground- and surface water (see Chapter 3). However, the composition of this leachate varies widely based on parent coal composition, the combustion and waste-handling technologies utilized by a particular power plant, and the geochemical environment in which the CCRs are placed. This chapter examines known cases of damage that have occurred from disposing of CCRs in a variety of environmental settings to understand what conditions pose the greatest risk to human health and the environment. The review of these cases assists the assessment of the potential impacts of CCR placement in coal mines.

The incidents presented in this chapter are from published accounts in the peer-reviewed scientific literature and/or are damage cases reviewed and recognized by the U.S. Environmental Protection Agency (EPA). In the late 1990s and revised in 2005 (USEPA, 2005a), the EPA reviewed monitoring data and identified damage cases, defined as sites where contaminants exceeded drinking water or other health-based standards, usually from wells or in surface waters downgradient of CCR management sites. The EPA considered the evidence of proven and potential environmental impacts along with factors that may have contributed to these impacts, including the interaction of CCRs with water. It did not independently investigate most damage cases, but relied primarily on information contained in state files. The EPA also acknowledged in the Regulatory Determination of May 22, 2000 (40 CFR Part 261) that it did not use a statistical sampling method and reviewed possible damage cases in only a subset of states. The EPA noted that given the volume of CCRs generated nationwide and the number of facilities that lack sufficient environmental monitoring and controls, especially groundwater monitoring, other cases of proven and/or potential environmental impacts are likely to exist.

For the 2000 regulatory determination, EPA cited 11 proven damage cases (i.e., that met its "tests of proof"), all of which involved landfills (including some CCR monofills) or surface impoundments. Since then, the number of damage cases recognized by EPA has nearly doubled; as of 2005, EPA had recognized 24 proven damage cases involving CCR landfills and surface impoundments, and one CCR minefill is now under investigation as a potential damage case (USEPA, 2005b; Table 4.1). According to the EPA, a damage case is proven if it satisfies one or more so-called tests of proof, which include (1) scientific investigation, such as formal investigations and technical tests that demonstrate significant impacts on human health or the environment; (2) administrative ruling, such as an enforcement action; (3) court decisions, which include official court rulings and out-of-court settlements; and (4) sufficient evidence that the damages could be attributable to CCR wastes (USEPA, 1999a).

During the course of the EPA's 2000 regulatory determination, public comments contained information on 59 additional potential damage cases. Similarly, this National Resource Council (NRC) committee received public testimony on numerous sites where it was alleged that CCR placement in coal mines has been implicated in the degradation of ground- or surface-water quality. In most of these cases, industry disputed the claims of environmental impacts made by public citizens, and in several cases, clear discrepancies in data, or in the interpretation of data, existed among stakeholders (EarthTech, Inc., 2000; Richardson, 2004; Kyshakevych and Prellwitz, 2005; Zimmerman, 2005). Because these purported environmental impacts have not withstood the scrutiny of review by the scientific and/or regulatory communities, they are not explicitly discussed in this report. However, as discussed in Chapter 1, these local controversies were noted by the committee during its deliberations and helped it to identify research needs and formulate recommendations.

## ENVIRONMENTAL IMPACTS

Currently, there are very few data available to indicate directly that placement of CCRs in abandoned or active coal mines is either safe or detrimental. In 2000 the EPA noted, "For minefilling, although we have considerable concern about certain current practices (e.g., placement directly into groundwater) we have not yet identified a case where placement of coal wastes can be determined to have actually caused increased damage to groundwater" (65 FR 32214). In its

**TABLE 4.1** Environmental Protection Agency Proven Damage Cases

| Facility | Type | State |
|---|---|---|
| Vitale Fly Ash Pit | Landfill | MA |
| Salem Acres | Landfill | MA |
| Don Frame Trucking | Landfill | NY |
| PEPCO Faulkner Off-site Disposal Facility | Landfill | MD |
| VEPCO/Virginia Power Possum Point | Surface impoundment | VA |
| VEPCO/Virginia Power Chisman Creek | Landfill | VA |
| Chestnut Ridge Y-12 Steam Plant Operable Unit 2 | Surface impoundment | TN |
| Georgia Power Bowen | Surface impoundment | GA |
| South Carolina E&G Canadys Plant | Landfill | SC |
| Savannah River Project | Surface impoundment | SC |
| Belews Lake | Surface impoundment | NC |
| Hyco Lake (CP&L Roxboro) | Surface impoundment | NC |
| Lansing Board Power & Light North Lansing Landfill | Landfill | MI |
| Dairyland Power Old E.J. Stoneman Ash Pond-Cassville Site | Surface impoundment | WI |
| WEPCO Highway 59 Landfill | Landfill | WI |
| Alliant Nelson Dewey | Landfill | WI |
| WEPCO Cedar Sauk Landfill | Landfill | WI |
| WEPCO Port Washington | Landfill | WI |
| Yard 520, Pines | Landfill | IN |
| Martin Creek Reservoir | Surface impoundment | TX |
| Brandy Branch Reservoir | Surface impoundment | TX |
| Welsh Reservoir | Surface impoundment | TX |
| Basin Electric WJ Neal Station Surface Impoundment (BESI) | Surface impoundment | ND |
| Cooperative Power Association-United Power Coal Creek | Landfill | ND |

SOURCE: USEPA, 2005b.

1999 report to Congress, EPA found the assessment of impacts from CCR minefilling exceedingly difficult due to several factors, including insufficient data and inadequacy of groundwater models. EPA stated, “With its existing data the Agency is unable to determine if elevated contaminants in groundwater are due to minefill practices, or rather are associated with pre-existing problems or conditions,” such as those of nearby mining operations (USEPA, 1999a).

A variety of studies have shown environmental impacts attributable to CCR placement in non-coal mines (e.g., sand and gravel), and the EPA (65 FR 32214) has identified numerous cases of water contamination related to CCR landfills and surface impoundments that, in some cases, have caused environmental impacts. Such cases are instructive because unlike the data currently available for minefilling sites, these impacts can be clearly related to CCRs. Although landfills and surface impoundments represent disposal conditions that may differ substantially from mine settings, they are useful for understanding the specific conditions under which CCRs threaten human health and ecosystems. Because mine environments differ substantially across the United States, insights drawn from CCR landfills and surface impoundments are ultimately useful for selecting the least hazardous mining environments for CCR placement.

## Landfills

Of the disposal options currently available for CCRs, landfills represent the most analogous disposal method to surface minefills (see Sidebar 1.2). When CCRs are managed in landfills with up-to-date liners and caps, reactivity with water can be minimized. Thus, understanding the situations in which CCR landfills fail can be useful for inferring the types of mine environments that may be least preferable for CCR placement. The EPA currently recognizes a variety of potential and proven ecological damage cases attributable to landfilling CCRs. Several of these and others are highlighted below. It should be noted here that the landfills discussed in relation to damage cases are typically not the well-designed structures with covers, compaction, and other characteristics discussed in the definition of landfills provided in Chapter 1, but rather are less engineered locations used to store wastes.

Although no landfill damage cases quantified adverse effects to fauna, several cases document adverse effects on plant communities and others document contamination of surface waters at concentrations sufficient to harm invertebrates, fish, and wildlife. For example, from 1969 to 1979, CCRs were placed in the Cedar Saulk Ash Landfill, an abandoned sand and gravel mine in Wisconsin. In 1980, vegetation in a wetland downstream from the landfill began to show symptoms of stress (e.g., leaf discoloration, defoliation) and plant die-offs were subsequently observed (see Plate 1). The impacts on plants resulted in a shift from a community dominated by woody species to a marsh community dominated by grasses, sedges, and rushes. Tissue analyses revealed that boron leaching from the landfill was the cause of toxicity to plant populations and the observed shift in community composition (Wisconsin Electric Power Company, 1982, 1988). State officials reacted promptly to this situation by increasing monitoring efforts to identify the problem and taking mitigation measures (e.g., installing groundwater extraction wells and covering the site with a geomembrane cap; USEPA, 2001a).

### Factors Contributing to Adverse Consequences from CCR Disposal at Landfills

A review of CCR landfill damage cases (Table 4.1) reveals one commonality among the incidents: when CCRs react with water and the resulting leachate is not contained, adverse consequences can result. Importantly, reactions with water appear to be exacerbated by at least one of four factors. The first two factors

## SIDEBAR 4.1
## Faulkner Landfill, Maryland

The Faulkner CCR landfill site associated with the PEPCO Morgantown generating station in Maryland is a recognized damage case by the EPA. This site differs from other CCR damage cases in that fly ash, bottom ash, and pyrites were comanaged there. In the early 1990s, it became clear that the contaminants migrating into the groundwater eventually reached surface waters, injuring vegetation and leaving orange coatings from iron oxide precipitates in a nearby wetland and stream. Pyrite oxidation at the site appears to have also resulted in low pH, a situation analogous to many mine sites where pyrites are exposed. A shallow groundwater table combined with the absence of liners appears to be a major driver for environmental impacts at the site, but the EPA also concluded that the low-pH conditions created by pyrite oxidation may have enhanced the mobility of trace elements. Given the geochemical conditions of many coal mine sites, this conclusion is particularly pertinent to issues surrounding minefilling of CCRs. In response to the impacts occurring at Faulkner, the State of Maryland required capping and installation of protective liners to prevent leaching of additional disposal units at the site. In addition, further disposal of pyrites was separated from CCR disposal in an effort to avoid interactions between these materials and subsequent pH-enhanced mobility.

SOURCE: SAIC, 2000.

relate to the permeability of the strata underlying the CCRs and the depth of the water table. CCR placement in sand and gravel mines has resulted in environmental impacts at CCR landfills in several localities including Wisconsin, Virginia, and Massachusetts. The EPA concluded that at each of these sites the permeable nature of the underlying substrate allowed CCR constituents to leach into ground- and surface waters. Shallow water tables aggravate the problem by enhancing the interaction of water with the CCRs and increasing the likelihood of leachate reaching the water table. For example, the EPA concluded that the shallow water table at the Faulkner Landfill in Maryland was at least partly responsible for the contamination of groundwater that eventually resurfaced and impacted nearby wetland and stream communities (Sidebar 4.1; SAIC, 2000).

The third characteristic that appears to increase the likelihood of environmental impacts from CCR placement in landfills relates to improper cover. In at least one site, the Vitale Brothers Fly Ash Pit in Massachusetts, CCRs were left uncovered, resulting in erosion and off-site migration of CCRs into a nearby swamp and stream, the latter of which was a tributary to a local source of drinking water. Surface waters were contaminated with iron and manganese, and groundwater quality was compromised with high concentrations of arsenic, selenium, aluminum, iron, and manganese. Other sites, such as the Cedar Saulk Ash Land-

## SIDEBAR 4.2
## Chisman Creek Disposal Site, Virginia

In one of the most severe landfill damage cases, approximately 500,000 tons of fly ash were placed in a series of abandoned sand and gravel mines between 1957 and 1974 in York County, Virginia. By 1980, groundwater contamination was clearly evident. Excessive concentrations of vanadium, nickel, selenium, and sulfates were found in groundwater near the 27-acre disposal area. Water in adjacent residential wells actually turned green, and subsequent testing revealed they were contaminated with selenium and sulfate at levels in excess of maximum contaminant levels (MCLs). Ecological systems were also threatened at the site; on-site ponds and creeks were contaminated with the aforementioned pollutants, as well as beryllium, arsenic, chromium, copper, and molybdenum. There was also considerable concern about contamination of the downstream Chisman Creek Estuary.

As a result of the proven contamination at the Chisman Creek disposal site, a variety of regulatory and remedial responses ensued. In 1983, the site was listed on the EPA's National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as Superfund. This Superfund site subsequently underwent aggressive cleanup that included supplying city water in substitution for the 55 residential wells that were eliminated, capping the CCR-containing pits, installing a leachate collection system, diverting surface-water runoff, and rerouting a nearby stream. In addition, extensive post-closure monitoring was established and continues today.

SOURCE: USEPA, 2001a.

fill (discussed above), covered CCRs but used insufficient quantities of post-placement cover material. In both cases, the EPA and state officials concluded that proper cover could have reduced the magnitude of impacts observed at the site (USEPA, 2001a).

The final characteristic that is commonly cited by the EPA as contributing to environmental impacts is the proximity of a CCR placement site to drinking water supplies and/or aquatic habitats. In some cases, streams and wetlands occur within the disposal site's boundaries, increasing the risk of environmental impacts. For example, at the Chisman Creek site (Sidebar 4.2), a stream actually passed so close to the waste site that the channel had to be redirected during the remediation process. The site was also in close proximity to residential wells, increasing the potential for human exposure (USEPA, 2001a).

### Surface Impoundments

Disposal of CCRs in aquatic surface impoundments or settling basins has been the most conspicuous mechanism by which surface environments have been contaminated by CCRs, resulting in degradation at a variety of sites in the United States (Rowe et al., 2002). For example, the environmental impacts caused by CCRs at Belew's Lake, North Carolina (Sidebar 4.3), was so severe that it became one of the primary drivers behind the EPA's 1987 regulatory determination for selenium in surface waters (USEPA, 1987). Unlike landfills and minefills, the use of surface impoundments requires that CCRs be slurried with water and the wastes remain ponded on the land surface until the system is dewatered and dredged or covered. Therefore, opportunities for flora and fauna to interact directly with CCRs or CCR-contaminated waters are much more likely than at minefills and landfills. There is a large body of peer-reviewed scientific literature highlighting the impacts of CCR surface impoundments (Rowe et al., 2002), and in most cases these impacts are clearly attributable to elemental constituents of CCRs. However, in several cases other physicochemical characteristics of CCRs give rise to changes in pH, conductivity, and physical smothering due to siltation and can play important roles in the toxic potential of the effluent (e.g., Birge, 1978; Cherry et al., 1979a). Because of the known risks associated with surface impoundments, CCR disposal in this manner is being phased out. According to the Department of Energy Energy Information Administration, 25 percent of CCRs produced in 1996 were placed in surface impoundments compared to only

### SIDEBAR 4.3
### Belews Lake, North Carolina

The Belews Lake story is the most widely recognized and cited damage case associated with CCR disposal and offers an example of the adverse environmental consequences that can occur when CCRs leach trace elements into surficial systems. In 1974, Duke Power began discharging surface water from fly ash settling basins into Belews Lake, a large reservoir that provided cooling water for a coal-fired power plant. Within a year, fish population declines were documented, and by 1978, 16 of 20 fish species had been eliminated completely from the reservoir. Ultimately, three additional species were rendered sterile, leaving only one species of fish in the reservoir. Intensive studies revealed that selenium, a highly mobile and reproductively toxic element associated with CCRs, was the source of the problem. Subsequent studies revealed that female fish accumulated high concentrations of selenium in their tissues and then transferred selenium to their offspring, resulting in grotesque developmental abnormalities and high mortality rates. In 1985 after 10 years of thorough study, Duke Power ceased discharge of CCRs into the settling impoundments. Subsequent monitoring efforts have revealed slow recovery of the system. By 1996, selenium levels and adverse effects on fish reproduction had decreased but were still higher than normal background levels.

SOURCE: Lemly, 1985, 1996.

19 percent in 2003 (USDOE, EIA, 1996, 2003b) As a result, increasing quantities of CCRs may be placed in landfills or used as minefill.

Although surface impoundment environments are conspicuously different from subsurface disposal in landfills and mines, they provide useful insight into the severity of effects that can emerge when organisms come in contact with CCRs or CCR-contaminated waters. Thus, they help to emphasize the importance of proper placement of CCRs so that surface impacts do not occur. The following section highlights the range of environmental effects that have been observed in systems impacted by CCR surface impoundments, ranging from individual-level responses (e.g., reductions in reproduction and survival) to population- and community-level effects (e.g., local extinctions of species).

## Bioaccumulation and CCR as a Stressor

As a consequence of CCR disposal in surface impoundments, contaminants have been found to accumulate in the tissues of organisms utilizing the impoundments or downstream habitats. Contaminants originating in CCRs enter food chains by a variety of mechanisms. These mechanisms include direct uptake by plants, epithelial accumulation by organisms in contact with the sediments and/or porewater (e.g., benthic invertebrates), and direct sediment ingestion by grazing (e.g., amphibian tadpoles) or dabbling wildlife (e.g., waterfowl). Uptake of some contaminants can be high, exceeding the concentrations known to be toxic to many organisms. For example, benthic invertebrates collected from streams and wetlands downstream from CCR surface impoundments have concentrations of arsenic, cadmium, and selenium that can exceed the concentrations in uncontaminated sites by orders of magnitude (Cherry et al., 1979a; Brieger et al., 1992; Rowe, 1998; Lohner and Reash, 1999; Reash et al., 1999; Hopkins et al., 2004). Of the contaminants associated with CCRs, selenium has received the greatest attention in surface impoundment systems because of its high mobility, propensity to bioaccumulate in food webs, and reproductive toxicity. However, in some CCR-impacted systems, other constituents (e.g., arsenic, boron) may be important and should always be considered in the risk assessment process.

Accumulation of metals and metalloids in animal tissues is important because it can have a variety of adverse health consequences in organisms. For example, studies on fish inhabiting reservoirs contaminated with effluent from surface impoundments reveal high tissue levels of selenium associated with liver and kidney necrosis, inflammation of heart tissue, disruption of respiratory tissue, and abnormal female reproductive tissue (Sorensen et al., 1982a,b, 1983a,b; Garrett and Inman, 1984). More recent studies have demonstrated that predators that feed on fish from CCR disposal sites are also at risk of tissue damage. For example, water snakes experimentally fed fish collected from a CCR disposal site accumulated high concentrations of arsenic, cadmium, selenium, strontium, and vanadium in their tissues (Hopkins et al., 2002) and exhibited necrosis of the liver (Rania et al., 2003). In addition to tissue abnormalities, bioaccumulation of CCR constituents can lead to various symptoms indicative of physiological stress including blood, enzymatic, hormonal, and metabolic abnormalities (Farris et al. 1988; Hopkins et al., 1998, 1999; Rowe, 1998; Rowe et al., 1998, 2002; Lohner et al., 2001).

### Impacts on Growth, Survival, and Reproduction

Taken together, the diverse physiological disruptions described above may contribute to the changes in growth, survival, and reproductive success that have been observed in organisms exposed to CCRs. Early developmental stages of fish and amphibians appear particularly sensitive to CCRs and CCR effluent (Lemly, 1996; Rowe et al., 2001; Snodgrass et al., 2004, 2005), with some species exhibiting 100 percent mortality after exposure in the laboratory (Birge, 1978) and the field (Rowe et al., 2001). However, some amphibian species exhibit high survival even after full larval period exposure (Snodgrass et al., 2004) but display reduced growth and abnormal development (Snodgrass et al., 2004). Similarly, juvenile benthic fish exposed to CCRs exhibit reductions in growth even when ample uncontaminated food is provided (Hopkins et al., 2000). When predatory fish are fed smaller fish from CCR disposal sites, predatory fish exhibit reductions in food consumption, growth, and body condition (Coughlan and Velte, 1989).

Most importantly, reproductive failure has repeatedly been observed in organisms exposed to CCRs or CCR effluent (Lemly, 1996; Sidebar 4.3). Decades of study of fish populations in North Carolina and Texas suggest that selenium from CCRs is readily accumulated in reproductive tissues and subsequently transferred to offspring (Lemly, 1985, 1996, 1997). Maternal transfer is not isolated to fish, but has been documented in a wide variety of wildlife exposed to CCRs including birds, turtles, alligators, and amphibians (King et al., 1994; Nagle et al., 2001; Bryan et al., 2003; Roe et al., 2004; Hopkins et al., 2005). For example, research has demonstrated that high concentrations of selenium and strontium can be maternally transferred in frogs, and these same frogs experienced a 19 percent reduction in reproductive success compared to individuals from uncontaminated sites (Hopkins et al., 2005). Reduced hatching success has also been observed in bird eggs collected from nests at one CCR disposal reservoir, suggesting that effects on wildlife reproduction may not be restricted to aquatic habitats (USDOI, 1988).

### Population and Community Effects

From an ecological perspective, the greatest concerns regarding CCRs are not the effects on individual organisms as described above, but the impacts of CCR on the integrity of populations and communities. Changes in zooplankton and benthic invertebrate community composition have been observed in waters receiving CCR effluent from surface impoundments (Spencer et al., 1983; Bamber, 1984; Specht et al., 1984; Walia and Mehra, 1998), as well as in experimental settings (Hopkins et al., 2004). Similarly, the diversity and density of macroinvertebrates have been adversely affected in streams receiving surface impoundment effluent (Cairns et al., 1970; Cherry et al., 1979a,b; Forbes and Magnuson, 1980; Magnuson et al., 1980; Forbes et al., 1981). Such changes in invertebrate composition can have widespread environmental implications, including changes in nutrient and energy cycling and effects on predatory organisms that depend on invertebrates as a food source (Hopkins et al., 2004).

### Applicability of Landfills and Surface Impoundments to Coal Mine Settings

As noted above nearly all of the damage cases cited and discussed in this chapter reflect CCR disposal in sites other than coal mines. Because the committee's statement of task (see Chapter 1) specifically addressed the disposal of CCRs in coal mines, it is important to note the committee's view on the applicability of landfill and surface impoundments impacts to coal mine settings.

Many of the damage cases discussed in this chapter involve older legacy sites that were developed under less rigorous regulations than now exist. Many were either slurry impoundments that drained to nearby surface waters or abandoned aggregate quarries that, by their very nature, were in highly permeable geologic environments. In contrast, coal mines are generally, but not always, located in less permeable rock formations, more remote areas, and further from surface-water courses. Furthermore, while current regulations covering coal mine placement of CCRs may require strengthening, as will be discussed in later chapters, they are generally more demanding than those that were applicable when the damage case sites were permitted. For example, landfills developed before the implementation of RCRA were not subjected to requirements for covers, compaction, liners, and other characteristics discussed in the definition of RCRA-compliant landfills provided in Chapter 1.

In spite of these dissimilarities, however, the damage cases do illustrate the types of adverse ecological impacts that may arise from CCR disposal that is not properly managed. The damage cases illustrate many of the same processes that are at work in coal mine sites, but on an accelerated time scale due to more permeable hydrogeologic conditions at many of the damage case sites. Thus, the committee, while aware of the limitations of using data from non-coal mine settings, concluded that the damage cases contained important and relevant information. The following section details some of the lessons that can be discerned from non-mine settings.

### Lessons Learned Relevant to CCR Placement in Mines

Taken together, available landfill and surface impoundment case studies clearly indicate that environmental impacts can emerge when CCRs react with water and constituents are mobilized in significant concentrations and volume. Surface impoundments represent an extreme example of such an interaction, because the CCRs are slurried directly with water for disposal purposes and the impoundments themselves often serve as suboptimal wildlife habitat or discharge directly into streams. In contrast, CCR landfills offer a more analogous situation to surface minefilling. Impacts can occur in landfilling situations when water flow through CCRs results in leachate that is not adequately contained within the landfill or attenuated in the surrounding subsurface environment. Reactivity with water and off-site migration of soluble constituents can be enhanced in landfills with permeable substrata, shallow water tables, insufficient post-fill cover, and/or close proximity to drinking water supplies or aquatic habitats. With current liner, placement, and leachate collection technologies, landfills can be designed to minimize contact with water and/or minimize the rate of water flow through the material, thereby reducing contaminant transport. In its 2000 regulatory determination, the EPA stated that minefilling can contaminate groundwater when not sufficiently isolated or when the wastes and sites are not matched properly based on geochemical characterization. Thus, for minefilling to be a safe and effective disposal option, proper site selection, site and waste characterization, and placement technologies are of utmost importance to avoid adverse interactions between water and CCRs (see Chapters 6 and 7). Pre-placement characterization and careful site management are also important considering that the placement of CCR in mines is effectively irreversible, because the removal of CCRs from a mine is not likely to be a practical remediation solution.

Environmental impacts can be reduced at CCR minefilling sites by preventing off-site migration of CCR constituents into surficial systems. The two primary mechanisms by which such migration of CCR constituents can occur are transport via groundwater flow into interconnected surface waters and improper cover of the CCRs. Each of these mechanisms is discussed briefly in an effort to identify high-risk situations for CCR placement in mine settings.

Surface waters are most likely to be impacted by CCR placement in mines when connected groundwater sources are contaminated. The CCR landfills at Chisman Creek, Virginia, and Faulkner, Maryland (described above), provide good examples of proven EPA damage cases that emerged from this process. In both cases, unlined landfills were situated in areas with shallow water tables, resulting in contaminated leachate that was transported into nearby wetlands and streams. Some mining areas have similarly shallow water tables, making these sites potentially higher-risk locations for CCR placement. Likewise, mine settings that are in close proximity to streams are higher-risk settings for CCR placement than areas more isolated from surficial waters. The Chisman Creek landfill had additional risks of groundwater contamination because of the highly permeable substrate characteristic of abandoned sand and gravel mines. To the extent that similar highly permeable substrates exist at some coal mine sites (e.g., overburden, spoils, fractured shales; see Chapter 3), a similar potential may exist

## SIDEBAR 4.4
## Environmental Impacts of Surficial CCR Deposits Along the Savannah River, South Carolina

The CCR settling basins associated with the D-area power plant in South Carolina comprise one of the most thoroughly studied CCR management units in the world. The settling basins and receiving stream have been studied since the 1970s, but some of the most recent work has focused on an adjacent natural depression in the Savannah River floodplain where CCRs were discharged in the 1950s and caused considerable environmental impacts (Roe et al., 2005). The power plant discharged sluiced CCRs into settling basins which overflowed into the Savannah River floodplain for more than a decade. The result of this discharge is a plume of CCR up to 2.7 m deep covering approximately 40 hectares. Aerial photographs reveal that the majority of vegetation was killed as a consequence of the CCR discharge, but a mixed floodplain vegetation community has regrown since improper discharge ceased in the 1970s. Today, approximately 30 percent of the CCR plume is occasionally inundated with water after flood events, possibly resulting in significant off-site migration of CCR constituents. Based on recent surveys, a wide variety of organisms utilize the site, including at least 18 species of amphibians. Concentrations of arsenic, selenium, and strontium in some of these amphibians were as much as 11-35 times higher than in the same species collected from unpolluted wetlands (Roe et al., 2005).

for groundwater contamination to occur when CCRs are placed in contact with these highly permeable units.

The second primary mechanism for CCR contamination of surface environments in mine settings is direct exposure to CCRs. However, exposure to CCR constituents can most likely be prevented at minefills by placing CCRs at appropriate depths and covering them with overburden and topsoil that was removed as overburden during coal mining. When CCRs are left uncovered or improperly covered, wildlife can be exposed directly to CCR-related contaminants (Sidebar 4.4). For example, the environmental impacts caused at the Cedar Saulk and Vitale Brothers landfills occurred at least partly due to improper cover. Similarly, Sample and Suter (2002) demonstrated that selenium and arsenic concentrations found in small mammals inhabiting a filled CCR surface impoundment that was left uncapped and allowed to naturally revegetate were an order of magnitude higher than concentrations in mammals from a reference site. Sample and Suter (2002) also found that deer consumed the CCRs directly, presumably for its salt content.

A series of studies (Palmer, 1986) conducted in the mid-1980s at the San Juan and Navajo mines in New Mexico further illustrates the importance of proper mine placement and coverage of CCRs. The studies demonstrated that considerable selenium was mobilized by plants (*Atriplex canescens*) from CCRs that were buried at a depth of approximately three feet at the Navajo mine.

Average selenium concentrations in plants exceeded seven parts per million (ppm)—more than enough to pose substantial risk to herbivorous wildlife. In contrast, selenium uptake by plants at the nearby San Juan mine was considerably less than at the Navajo site. At least two factors appear to account for the observed differences between the mines: burial depth and characteristics of the interface between the CCR and the overlying soil cap. Burial depths of CCR at the San Juan mine were approximately twice those at the Navajo mine. Based on comparative excavations between the sites, a distinct interface (i.e., lack of blending) between the cap and the CCR was better maintained at the San Juan mine, and this interface appeared to prevent root penetration into the CCR (Palmer, 1986). Taken together, the findings suggest that further research is needed to understand the influence of various vegetation types on the mobilization of soluble CCR constituents, but that the depth of cap covering the CCRs may be the most important factor in preventing their upward mobilization by rooted plants. When determining placement depth and burial procedures, consideration should be given to site-specific characteristics. For example, plant communities and soil conditions in the eastern United States will likely influence the mobility of CCR constituents differently than the examples noted above from New Mexico.

Upward mobilization of contaminants into plant tissues not only impacts plant health but also introduces mobilized contaminants into terrestrial food webs. Some CCR-related contaminants (e.g., boron, selenium) can bioaccumulate in plants to high concentrations. In such cases, the contaminants may subsequently be transferred to organisms foraging in terrestrial communities. Thus, plant transport serves as an important mechanism driving environmental risk when CCR disposal systems are improperly capped (Sample and Suter, 2002). Upward mobilization of contaminants could cause adverse impacts at CCR minefill sites that are utilized for hay production and grazing after reclamation. Elements, such as selenium, which are readily taken up by many grass species, could therefore be introduced into the diet of livestock. Selenium toxicity is well studied in livestock and manifests itself as abnormal tissues, musculoskeletal abnormalities, reductions in growth, and death (O'Toole and Raisbeck, 1998).

In conclusion, given the increasing quantities of CCRs likely to be placed in mines, the potentially toxic constituents of CCRs, the conditions in some mine sites that may favor leaching of these constituents, and the inadequacies in our understanding of the potential environmental impacts of CCR placement in mines, the committee concluded that additional research is needed. This research should include studies to determine the effects (or lack thereof) of CCR on biotic communities over protracted time scales at mine placement sites where nearby streams or wetlands are likely to be connected to groundwater. It is important to note that, as discussed in Sidebar 4.5, chemical concentrations needed to adequately protect ecological health can be significantly lower than those prescribed to protect human health. Thus, research into the possible impacts of CCRs placement on biotic communities may also aid in the assessment of possible human health impacts.

## SIDEBAR 4.5
## Contaminant Concentration Limits Needed to Protect Human and Environmental Health

Drinking water standards for the protection of human health are established by the MCL, the highest level of a contaminant that is allowed in drinking water. The MCL is set as close as technologically and economically feasible to the level at which there is no known or expected risk to human health. In contrast, thresholds for the protection of environmental health are set through EPA water quality criteria, including the freshwater chronic water quality criteria. The freshwater chronic water quality criteria represent the highest pollutant concentrations to which freshwater aquatic organisms can be exposed for an extended period of time without deleterious effects. A partial summary of relevant CCR constituents with established MCLs and freshwater chronic water quality criteria is presented in Table 4.2. Beyond EPA, many states have established even lower levels of mercury to protect aquatic life, such as Nevada's freshwater chronic water quality criteria of 0.012 μg/L (NEC, 1991).

In general, water quality criteria designed to protect aquatic life are often lower than drinking water standards in part because aquatic biota spend their entire life in the water and, hence, are constantly exposed, whereas drinking water constitutes only a portion, sometimes a small portion, of the exposure of humans. Other reasons for differences between aquatic life and human health criteria include the physiological sensitivity of some species and the exposure of early life stages of aquatic organisms.

**TABLE 4.2** A Comparison of EPA Freshwater Chronic Water Quality Criteria with Drinking Water MCLs for Select Constituents Relevant to CCRs

| Constituent | Drinking Water MCL (ug/L) | EPA Freshwater Criteria (μg/L) |
|---|---|---|
| Cadmium | 5.0 | 0.25 |
| Mercury | 2.0 | 0.77 |
| Selenium | 50.0 | 5.0[a] |

[a] USEPA is currently replacing its water quality criterion for selenium with a tissue-based criterion (Fed register EPA-822-D-04-001, Draft Aquatic Life Criteria for Selenium-2004).

SOURCE: USEPA, 2002b.

## HUMAN HEALTH

Coal combustion residues contain a wide variety of constituents that are potentially of concern for human health. The primary concern for human health noted by EPA from the placement of CCRs in landfills, surface impoundments, or minefills is the contamination of actual or potential sources of drinking water, particularly groundwater, by metals that may be leached from the material (65 FR 32214; USEPA, 1999a). Surface waters that may be used as drinking water are also of concern. This section first examines what is known about the potential impacts of CCR leachate on drinking water sources and the characteristics of the contaminants of concern. Although information is limited, the section provides a qualitative assessment of the potential health risks to the public from exposure to CCR-derived contaminants in the water supply. The section then describes the tools available to further evaluate the potential for adverse human health effects due to CCR placement in active or abandoned coal mines.

This section is not intended to provide a comprehensive examination of potential health risks attributable to CCRs. Such an examination is beyond the information available and the committee's task. CCRs, like many industrial effluents, represent a complex mixture of contaminants. Although the vast majority of established exposure and health effects standards are for single compounds, these contaminants can have complex interactions (e.g., antagonism, synergism) in the environment. Also outside the scope of this report is a treatment of the health risk associated with fugitive dusts that can be created in the transfer of CCRs or by other handling procedures. Airborne particulate matter, such as fugitive dust, poses a potential health risk through inhalation exposure. A full evaluation of human health risk due to CCRs would consider cumulative risk, meaning the combined risk to human health posed by exposure to multiple agents or exposure through multiple pathways.

### Current State of Knowledge

The only CCR coal minefill currently being considered as a potential damage case by the EPA is the Center Mine in North Dakota. At this site there are at least eight years of monitoring data that reveal probable groundwater contamination. Although maximum contaminant levels (MCLs) have been exceeded for chromium, iron, manganese, pH, sulfates, total dissolved solids (TDS), selenium, cadmium, lead, and aluminum at the site, the origin of these contaminants is a source of uncertainty. Conditions at the site were also degraded due to mining activities, making it challenging to distinguish between leachate from mined materials and from CCRs. A review of monitoring data by Beaver et al. (1987) concluded that leachate was migrating from the CCR disposal areas. However, no municipal or private wells have been identified as being threatened by this contamination (USEPA, 1988).

A variety of CCR landfills have degraded groundwater and raised human health concerns. As discussed in the previous section, the committee considers landfills to represent the most analogous disposal method to surface minefills. The landfills in Wisconsin, Massachusetts, Maryland, and Virginia, discussed above in environmental damage cases, also exceeded drinking water MCLs in groundwater. In the case of the Chisman Creek disposal site, remedial actions included the closure of residential wells to reduce the risk of human exposure (USEPA, 2001a). An additional damage case not discussed above is the North Lansing CCR landfill that posed risks to drinking water wells for Lansing, Michigan. The placement of CCRs results in contamination of groundwater with lithium in a shallow aquifer below the landfill. Although initial reviews of the site suggested the presence of other known or potential sources of groundwater contamination, further data collection and analysis resulted in EPA recognition of the site as a damage case linked to CCR disposal. The landfill is located in an unlined former gravel quarry. The permeable nature of the disposal site's substrate, coupled with CCR coming into contact with a rising water table, appears to have accelerated the contamination. However, no contamination was observed to have migrated to wells used for drinking water (SAIC, 2003).

The EPA's review of CCR characterization and leach test data, as well as monitoring data and evaluations of potential damage cases, points to several contaminants of concern. In particular, EPA identified potential risks from arsenic and cadmium. The concern for arsenic in part stems from EPA's recent decision to lower the National Primary Drinking Water Standard MCL for this contaminant (66 FR 6976; NRC, 2001; USEPA, 2001b). Also, in the EPA's review of monitoring data and damage cases, various drinking water standards were identified not to have been met, usually from wells on-site, downgradient off-site, or from nearby surface waters impacted by surface impoundments or landfills containing CCR. While MCLs were exceeded in cases that were not in public drinking water wells, and hence not violations, the EPA considered them examples of its concern. The EPA noted that arsenic, selenium, and fluoride exceeded MCLs; sulfate, iron, chloride, manganese, and TDS exceeded secondary MCLs; and lead and boron levels exceeded state standards (65 FR 32214).

As indicated previously, quantitative estimates of human health risks are not made in this report due to inadequacies in available information. Table 4.3 offers a brief description of some examples of chemical contaminants of concern in CCRs that can be transported in groundwater and that are regulated under the Safe Drinking Water Act. This table provides a basis to develop a qualitative perspective of potential health risks that might be associated with CCRs.

Another area of concern for potential adverse health effects is the impact of CCR on surface-water quality. For example, a recent peer-reviewed study indicates that changes in microbial communities in CCR-impacted streams may have human health implications. Stepanauskas et al. (2005) demonstrated that microbial communities from three CCR effluent discharge sources were more resistant to metal exposure than upstream microbial communities, suggesting that the community composition had changed due to the selective pressures imposed by contaminants in CCRs. These metal-resistant communities were also more resistant to antibiotics, a finding that could have broad public health consequences (Stepanauskas et al., 2005).

## Tools for Evaluating Health Effects

This section examines the tools available to further evaluate the potential for adverse human health effects from exposure to contaminated water supplies such as could occur from improperly managed CCR disposal. The two primary tools or analytical techniques for health risk evaluations are environmental epidemiology and risk assessment, both of which have been the subject of NRC reports (e.g., NRC, 1991, 1994).

### Epidemiological Studies

Epidemiological studies are concerned with patterns of disease in human populations and the factors that influence these patterns. The most important challenge for epidemiologists is finding explanations of why a specific exposure is associated with a particular disease or condition. In general, scientists view well-conducted epidemiologic studies as the most valuable information from which to draw inference about human health risks. Compared to other techniques used in risk evaluation, epidemiology is well suited to situations in which exposure to risk agents is high (e.g., cigarette smoke), adverse health effects are clearly defined (e.g., a form or forms of cancer), and where exposure to the potential risk is known. Epidemiology is well suited to situations in which the link between the risk factor and the outcome is known, where the factor can be measured directly in the bodies of the affected population or inferred, and where high levels of the risk agent are present in the environment (e.g., soil, water).

Epidemiological studies used to assess risks have important limitations that constrain their usefulness associated with contamination of water supplies. These limitations arise not from epidemiology per se but rather from the nature of the analysis to which epidemiological data are applied. For example, one limitation of environmental epidemiological studies is that they can be conducted only for hazards to which people already have been exposed. They generally are not useful for predicting the effects of exposure to environmental toxicants, such as exposure to contaminated drinking water. Another limitation of epidemiological studies is that they have poor sensitivity and are generally unable to detect small increases in risk unless very large populations are studied. At low exposure levels, which are likely to be the case with CCR-derived contaminants, adverse effects will be difficult to detect. Still another limitation of epidemiological studies is that they fail to account for the effects of multiple sources of exposure. If

**TABLE 4.3** Examples of Contaminants of Concern from CCRs, Their Drinking Water Standards (MCL), and Potential Adverse Health Effects

| Contaminant | MCL[a] (mg/L) | MCLG[b] Public Health Goal | Potential Adverse Health Effects from Exposure Above the MCL |
|---|---|---|---|
| Arsenic<br>internal | 0.010[c] | Zero | Arsenic is a naturally occurring element present in the environment in both organic and inorganic forms. Inorganic arsenic is considered to be the most toxic form. A variety of adverse health effects including skin and internal cancers and cardiovascular and neurological effects have been attributed to chronic arsenic exposure. NRC (2001) reported that arsenic-induced (lung and bladder) cancers are the main source of concern based on multiple epidemiologic studies. |
| Boron | NA[d] | NA[d] | Boron is a short-term irritant with effects on the upper respiratory tract, nasopharynx, and eye. USEPA (2004b) toxicological review of boron cites decreased fetal weight as the greatest concern based on laboratory animal studies. |
| Cadmium | 0.005 | 0.005 | Excessive intake of cadmium has been linked to kidney damage, as well as to increased risks of prostatic and respiratory cancers. Acute cadmium intoxication is rare. Oral cadmium exposure plays a minor role in chronic toxicity. |
| Chromium | 0.1 | 0.1 | USEPA (1998a) considered the accumulation of chromium(VI) by animal tissues to be the toxicological end point of concern for setting a drinking water standard. Chromium(III) is considered a dietary essential. Deficient diets can result in hyperglycemia and glycosuria. Chromium toxicity results in dermatitis and ulceration of the digestive tract. |
| Fluoride | 4.0 | 4.0 | Fluoride is a ubiquitous component of the Earth's crust and therefore present in the potable water supply. It is incorporated into calcified tissues, where it may reduce dental caries (decay), and exhibits dose-related toxicity at high levels of intake resulting in deranged bone and tooth formation. EPA set the MCL and MCLG on the basis of crippling skeletal fluorosis where excessive accumulation of fluoride changes the bone density (50 FR 47142 [1985]). This standard was reviewed and supported by the NRC (1993). |
| Lead | TT[e],<br>AL[e]=<br>0.015 | Zero | Health effects associated with exposure to inorganic lead and compounds include, but are not limited to, neurotoxicity, developmental delay, hypertension, impaired hearing acuity, impaired hemoglobin synthesis, and male reproductive impairment. Importantly, many of lead's health |

| | | | |
|---|---|---|---|
| | | | effects may occur without overt signs of toxicity. Lead has particularly significant effects in children, well before the usual term of chronic exposure can take place (USEPA, 2004c). Studies on infants and children have shown delays in physical or mental development; children can show deficits in attention span and learning abilities. |
| Mercury (inorganic) | 0.002 | 0.002 | Mercury (Hg) is widespread and persistent in the environment. It comes from natural and anthropogenic sources. Chemical species of Hg that are of toxicological importance include the inorganic forms, elemental or metallic $Hg^0$, and mercuric ion ($Hg^{2+}$). Although there are many forms of mercury, inorganic mercury is the most critical for the drinking water standard since exposures above the MCL of 0.002 may cause kidney damage. Methyl mercury, which is formed through biotransformation of inorganic mercury in aquatic systems, is highly toxic. Human exposure to methyl mercury occurs through consumption of fish and can result in neurological and other human health impacts. |
| Selenium | 0.05 | 0.05 | Selenium intake in excessive quantities can result in hair or fingernail loss; numbness in fingers or toes; and circulatory problems. |
| | Secondary Drinking Water Standards[f] (mg/L) | | |
| Sulfate | 250 | | Excessive intake of sulfate may cause diarrhea. |
| Iron | 0.3 | | High concentrations of iron cause taste and color problems in water; and may discolor appliances and clothing |

NOTE: This list includes the constituents that EPA noted in its review of damage cases (65 FR 32214). They are listed here as examples of the potential concern for human exposure. A more comprehensive list of constituents appears in Chapter 3 of this report.

[a] Maximum Concentration Level (MCL)—The highest level of a contaminant allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.
[b] Maximum contaminant level goal (MCLG)—the level of a contaminant in drinking water below which there is no known or expected risk to health.
[c] Arsenic MCL effective 1/23/06.
[d] Not applicable; no MCL has been set for this contaminant.
[e] TT = lead is regulated by a treatment technique standard; AL = action level is a trigger for water systems to take additional control measures.
[f] National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (USEPA, 2005a).

SOURCE: After USEPA, 2004a.

the CCR-exposed population is also exposed to contaminants from numerous other sources, epidemiological analysis may not show an association even if one is actually present.

## Risk Assessment

Earlier NRC reports contain lengthy discussions of risks and approaches to its analysis, including *Understanding Risk: Informing Decisions in a Democratic Society* (NRC, 1996b). The EPA guidance on the conduct of human health and ecological risk assessments is described in USEPA (1998b, 1999a, 2001b). The EPA (USEPA, 2004d) provides an examination of current risk assessment principles and practices at the agency. NRC (1996b) sets forth an elaborate description of risk characterization, which it defines as a "synthesis and summary of information about a hazard that addresses the needs and interests of decision makers and of interested and affected parties. It is a prelude to decision making and depends on an iterative, analytic-deliberative process." Risk assessment involves (1) hazard identification, (2) dose-response assessment, (3) exposure assessment, and (4) risk characterization (NRC, 1983). Given the large number and range of factors that cannot be quantified, the risks associated with CCR placement in mines are not easily quantifiable. However, monitoring data at CCR placement sites may provide information on the types of contaminants to which the public could be exposed.

Additionally, prior studies have developed relationships between dose and response for these contaminants that could help in the risk assessment process. Improving the understanding of exposure is one area that would allow better risk characterization from CCR placement.

## Exposure Pathway

Exposure is a key element in the chain of events that leads from release of contaminants into the environment to a concentration of those contaminants in one or more environmental media (e.g., air, water, soil); to actual human exposure (internal or delivered dose of a toxicant); and ultimately, to environmentally induced disease. In other words, without exposure to the contaminant there is no risk. Different individuals or subpopulations will be exposed to different amounts of contaminants. For risk evaluation to be credible there must be measurements, or sound assumptions, made about the four basic characteristics that describe exposure: (1) route—inhalation, ingestion, or dermal absorption; (2) magnitude—the pollutant concentration; (3) duration—the length of exposure; and (4) frequency—how often exposure occurs. These estimates must also take into account that populations exposed to contaminants will have variable intakes of water, depending on age, gender, and health status. Evaluations of risk that do not account for variation in water consumption may result in underestimating the upper bounds of health risk attributable to contact with mixtures of contaminants in water supplies.

Additionally, as discussed in Chapter 3, physical and chemical processes will also impact exposure. Of relevance is the fact that contamination and exposure by the water route can be modified by transport and transformation of the mixture. Some elements (e.g., selenium, cadmium, mercury) form complexes, whose bioavailability is dependent on their thermodynamic and kinetic stability. Dilution and degradation can attenuate mixtures of chemicals, while processes that concentrate the chemicals can magnify the risk. The actual fate of mixtures, and hence the level of exposure, depends on the contaminants' physical and chemical properties combined with the characteristics of the environment to which it is released. The influence of these variables creates additional uncertainties in predicting exposures.

Despite their importance for assessing human health risks, human exposure data are not collected in a systematic or comprehensive manner for CCRs. Only limited information is available; therefore, understanding historical trends, estimating current levels, and predicting future directions for CCR exposures to population and population subgroups is difficult. In general, exposure assessment, critical to the evaluation of potential adverse health effects, is one of the most difficult problems facing environmental health scientists and public health and other regulatory officials. Without data and an understanding of these variables as they relate to exposure to CCRs, it is difficult to assess with any degree of accuracy the health risks from CCR-derived contaminants at any given location in the environment, including potential drinking water sources. Thus, as part of a recommended research program looking at potential adverse environmental and human health impacts from CCR placement, studies should assess the potential for human exposure to contaminated drinking water that might occur due to CCR placement.

## SUMMARY

The committee's review of literature and damage cases recognized by EPA supports EPA's previously stated concerns about proper management of CCRs. The two most common CCR disposal options, surface impoundments and landfills, have been utilized for decades and provide valuable insights into the types of problems that can emerge when CCRs or their soluble constituents are not contained within the waste management unit. In some landfill settings, groundwater has been degraded to the point that drinking water standards were exceeded off-site. In other landfills and surface impoundments, contamination of surface waters has resulted in considerable environmental impacts; in the most extreme cases, multiple species have experienced local extinctions. The waste management in these impoundments and landfills often involved older, unlined units, and most landfill impacts involved CCR placement in sand and gravel mines that are characterized by permeable substrata. In contrast, some contamination of lotic systems (streams, rivers) may not pose as obvious a risk because of the continual dilution and off-site migration of mobile CCR contaminants. However, total contaminant loading to these lotic systems may possibly affect downstream sites after protracted periods.

To minimize the risk of adverse impacts from disposal of CCR in mine sites, a variety of steps should be taken. The most effective strategy for avoiding contamination is proper hydrogeological characterization of the site prior to placement and employment of placement technologies that reduce the probability of reaction of CCRs with groundwater (see Chapter 6 and 7). Sites with shallow water tables, highly porous or permeable substrata, or close proximity to surface waters (e.g., streams, wetlands) likely constitute higher-risk CCR placement environments and may require additional characterization before CCR placement can be justified. In many cases, complete isolation from water will not be possible, but a variety of steps can be taken to reduce the reactivity of CCRs with water and the off-site transport of soluble constituents. In some cases, this can be achieved with proper compaction of base and/or surface cover layers, reducing the water contact with, and water flux through, the CCRs. In all cases, proper cover should be placed over CCRs to prevent erosion, as well as root penetration by plants and subsequent upward mobilization of CCR constituents.

*Of the three methods currently available for disposal of CCRs (surface impoundments, landfilling, and minefilling), comparatively little is known about the potential for minefilling to degrade the quality of groundwater and/or surface waters particularly over longer time periods. Additionally, there are insufficient data on the contamination of water supplies by placement of CCRs in coal mines, making human risk assessments difficult.* The committee was presented with numerous testimonies in which public citizens, industry, and state regulatory agencies disagreed about the degradation of water quality attributable to CCR placement in mines. The committee noted that involvement by state regulators, particularly in monitoring and early detection of potential problems, followed by the collection of additional data and appropriate mitigation, such as the proactive measures observed in Wisconsin, could be adequate to resolve these discrepancies. However, in other cases, oversight and study by independent scientists could provide much-needed answers to these emerging disputes. In assessing potential adverse health and environmental risks from CCR placement in coal mines, the committee was faced with a lack of peer-reviewed research reports and data with specific reference to CCRs in coal mines. The EPA has not identified any cases in which water quality standards that had not been met could be attributed directly to CCR mine placement. However, data limitations suggest that the absence of EPA damage cases should not be taken as conclusive evidence of no effects on human health and ecosystems. *The committee concluded that the presence of high levels of some contaminants in CCR leachates may create human health and ecological concerns at or near some mine sites over the long term.*

Peer-reviewed research relating to CCR impacts on aquatic biota from landfills and impoundments provides evidence of impacts, indicating that independent studies of water quality and environmental impacts of CCR minefilling are needed.

Given the increasing quantities of CCRs likely to be placed in mines, the potentially toxic constituents of CCRs, the conditions in some mine sites that may favor leaching of these constituents, and the inadequacies in our understanding of potential environmental and human health impacts of CCR placement in mines, *the committee concluded that additional research is needed.* **The committee recommends additional research to provide information on the potential ecological and human health effects of placing CCRs in coal mines.** In particular, clarification of the fate and transport of contaminants from CCRs is needed. It should include studies to determine the effects (or lack thereof) on biological communities over protracted time scales in mine placement sites where nearby streams or wetlands are likely connected to groundwater. Studies should also assess whether there is the potential for human exposure to drinking water impacts from CCR placement.

# 5

# Current Regulatory Framework

This chapter describes the basic federal laws for mine reclamation and environmental protection that could be applied to placement of coal combustion residues (CCRs) in coal mines. Of particular importance are the Surface Mining Control and Reclamation Act (SMCRA) and the Resource Conservation and Recovery Act (RCRA), although other directly relevant federal laws are also covered, including the Safe Drinking Water Act (SDWA) and the Clean Water Act (CWA; Table 5.1). Activities such as mining and environmental protection involve nationally variable, locally specific conditions that can be difficult to address with national rules. On the other hand, national standards are sometimes necessary to address inequities among states' authorities and regulations to ensure that minimum environmental safeguards are met. Many federal programs address these concerns by allowing the delegation of primary regulatory authority to states and state agencies that can adapt their programs to address local conditions and needs. The final sections of this chapter briefly examine the ways in which federal rules (e.g., SMCRA, RCRA) interface with state authorities and programs.

## THE SURFACE MINING CONTROL AND RECLAMATION ACT OF 1977

SMCRA establishes permitting, performance, and bonding requirements for the operation and reclamation of surface coal mining and the surface impacts of underground mining (30 U.S.C. §1201 et seq.). SMCRA is administered by the Office of Surface Mining (OSM) in the U.S. Department of the Interior. Under

**TABLE 5.1** Summary of Major Federal Regulations that Apply to CCR Generation and Placement

| Federal Law | Summary |
|---|---|
| Surface Mining Control and Reclamation Act (SMCRA), 30 U.S.C. §1201 et seq. | • Establishes standards for coal mining operations and reclamation.<br>• Sets permitting standards, bonding requirements, performance standards, and inspection and enforcement standards.<br>• Does not specifically address the placement of CCRs in mines, but its scope is broad enough to encompass CCR use in reclamation.<br>• Also establishes a program for abandoned mined land reclamation funded through a tax imposed on all mined coal. |
| Resource Conservation and Recovery Act (RCRA), 41 U.S.C. §6901 et seq. (an amendment to the Solid Waste Disposal Act) | • Establishes a cradle-to-grave management system to ensure tracking and appropriate handling of hazardous waste.<br>• In 2000, the U.S. Environmental Protection Agency (EPA) determined that regulation of CCRs as hazardous waste was not required but that regulation under RCRA's solid waste program was appropriate for CCRs disposed in landfills and surface impoundments. For minefilling, EPA concluded that regulation was warranted under either RCRA or SMCRA or some combination. |
| Safe Drinking Water Act (SDWA), 42 U.S.C. §300f et seq. | • Authorizes EPA to set standards for contaminants that may occur in public drinking water supplies.<br>• Regulates the underground injection of substances that may contaminate groundwater that is, or may be, a source of public drinking water. For example, mine backfill wells that may be used to inject CCRs into underground mines would be regulated under SDWA. |
| Clean Water Act (CWA), 33 U.S.C. §1251 et seq. | • Focuses primarily on discharges of pollutants into surface waters.<br>• Establishes separate programs for industrial point-source pollution discharges, dredge and fill activities, non-point source pollution, and ambient water quality.<br>• Coal mining operations typically obtain point-source discharge permits for their surface runoff. |
| Emergency Planning Community Right to Know Act (EPCRA), 42 U.S.C. §11001 et seq. | • Requires businesses to report the location and quantity of certain chemicals stored on-site and to report releases (e.g., the discharge or transfer off-site, or disposal on-site) of certain chemical constituents through the Toxics Release Inventory (TRI). This applies to generators of CCRs, such as electric utilities. |
| Pollution Prevention Act (PPA), 42 U.S.C. §13101 | • Promotes reduction, reuse, and recycling of waste materials before considering disposal.<br>• Requires companies that generate waste and file TRIs to prepare and file an annual report on toxic chemical source reduction and recycling for their facilities, including source reduction practices and techniques used to identify source reduction opportunities. |

SMCRA, states have the option of developing and implementing state programs, subject to strict federal standards (30 U.S.C. §1253). If a state fails to adopt an adequate program, as approved by the Secretary of the Interior, a federal program is imposed on the state (30 U.S.C. §1254).

SMCRA applies to all surface coal mining and reclamation operations, which are defined to encompass surface mining operations and "all activities necessary and incident to reclamation activities" (30 U.S.C. §1291(27)). Surface coal mining operations are defined, in turn, to encompass:

> (A) activities conducted on the surface of lands in connection with a surface coal mine and surface impacts incident to an underground mine . . . ; and
>
> (B) the areas upon which such activities occur or where such activities disturb the natural land surface. Such areas also include . . . excavations, workings, impoundments, dams, . . . refuse banks, dumps, stockpiles, overburden piles, spoil banks, culm banks, tailings, . . . or other properties or materials on the surface, resulting from or incident to such activities (30 U.S.C. §1291(28)).

## Mine Planning and Permitting

SMCRA requires surface coal mining operators to submit detailed operation and reclamation plans for approval by the state (or federal) regulatory authority before mining operations begin (30 U.S.C. §§1257-1258). A substantial performance bond must also be posted, sufficient to guarantee full reclamation of the mine site (30 U.S.C. §1259). Notice of permit applications must be advertised in local newspapers, and interested parties have an opportunity to file objections to the application, request an informal conference with the permitting agency, and request a formal hearing within 30 days of the decision to approve or disapprove a permit application (30 U.S.C. §§1263, 1264). Although the law provides for the staged release of bonds as reclamation proceeds, a portion of the bond must remain in effect during the period in which the operator is responsible for revegetation. In the case of lands that receive more than 26 inches of rainfall annually, the period is five full years after the last year of augmented seeding, fertilizing, or other work; in the case of lands that receive 26 inches of rainfall or less, the period is ten full years after augmentation work (30 U.S.C. §§1259(b), 1265(b)(20)(A)). A more detailed explanation of reclamation is found in Chapter 7.

Neither SMCRA nor the regulations developed by OSM to implement SMCRA specifically address the issue of placement of CCRs in mines as part of reclamation. Nonetheless, many SMCRA requirements should indirectly impact how such disposal is carried out. Among the permit requirements most relevant to current concerns about CCR disposal are those that relate to water and hydrology. Section 508(b)(11) of SMCRA requires the applicant to provide the regulatory agency with

> . . . a determination of the probable hydrologic consequences of the mining and reclamation operations, both on and off the mine site, with respect to the hydrologic regime, quality and quantity of water in surface and groundwater systems . . . and the collection of sufficient data for the mine site and surrounding areas so that an assessment can be made by the regulatory authority of the probable cumulative hydrologic impacts of all anticipated mining in the area upon the hydrology of the area . . . (30 U.S.C. §1258(a)(11)).

The probable hydrologic consequences determination, prepared by the permit applicant, followed by the cumulative hydrologic impact assessment, prepared by the regulatory authority, are two of the key permitting requirements relating to water resources. In addition, SMCRA requires the permit application to contain

> (13) a detailed description of the measures to be taken during the mining and reclamation process to assure the protection of:
>
> > (A) the quality of surface and ground water systems, both on- and off-site, from adverse effects of the mining and reclamation process;
> >
> > (B) the rights of present users to such water; and
> >
> > (C) the quantity of surface and ground water systems, both on- and off-site, from adverse effects of the mining and reclamation process or to provide alternative sources of water where such protection of quantity cannot be assured . . . (30 U.S.C. §1258(a)(13)).

These requirements are supplemented by detailed regulations that include, for example, requirements for baseline hydrologic information, a hydrologic reclamation plan, and surface and groundwater monitoring plans (see 30 CFR §780.21).

Another provision central to SMCRA is the requirement to restore the premining land-use capability. Section 515(b)(2) requires the operator "to restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses . . . " (30 U.S.C. §1265(b)(2)). In turn, SMCRA's permitting standards require submission of a reclamation plan. This plan must include, among other things, a statement of "the engineering techniques proposed to be used in mining and reclamation and a description of the major equipment; a plan for the control of surface water drainage and of water accumulation; a plan, where appropriate, for backfilling, soil stabilization, and compacting, grading, and appropriate revegetation; a plan for soil reconstruction, replacement, and stabilization" (30 U.S.C. §1258(a)(5); see also 30 CFR §780.18).

SMCRA also gives the regulatory authority the power to impose other permitting requirements not specifically authorized under the statute as long as it is done by regulation (30 U.S.C. §1258(a)(14)). This means that states with approved programs or OSM, using its authority to set minimum national standards, could develop and impose more specific requirements related to placement and disposal of CCRs in mines. Such standards could be promulgated only after notice and comment rulemaking procedures.

Numerous regulations implement these statutory permitting provisions. For example, OSM has established permitting rules requiring applicants to submit detailed geological information as needed to determine the hydrologic consequences of mining as well as the existence of potentially acidic or toxic-forming strata, down to and including the stratum immediately below the seam to be mined (30 CFR §780.22(a)). Chemical analysis of potentially toxic-forming materials is also required (id. at §780.22(b)). In addition, the rules specifically authorize OSM to require the collection, analysis, and description of additional geologic information as may be necessary to protect the hydrologic balance (id. at §780.22(c)).

Permits must be renewed every five years (30 U.S.C. §1256(b), (d)). Permits may also be revised and revisions that propose significant alterations are subject to the public notice and hearing requirements that generally apply to new permit applications (30 U.S.C. §1261; 30 CFR §774.13(b)(2)). However, OSM's regulations do not provide guidance as to when a revision should be treated as significant (see 30 CFR §774.13). If a regulatory agency fails to treat the modification of a reclamation plan to use CCRs as minefill as a significant revision, then no public notice or hearings on the revision would be required.

## Performance Standards

In addition to these permitting standards, SMCRA establishes performance standards for all mining and reclamation operations (30 U.S.C. §1265). Several of these performance standards could be applied without modification to mine placement of CCRs. For example, the following lists some of the most relevant performance standards that require mine operators to:

> (3) backfill, compact (where advisable to insure stability or to prevent leaching of toxic materials), and grade in order to restore the approximate original contour of the land . . . .
>
> (4) stabilize and protect all surface areas including spoil piles affected by the surface coal mining and reclamation operation to effectively control erosion and attendant air and water pollution; . . .
>
> (10) minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and ground water systems both during and after surface coal mining operations and during reclamation by—
>
>> (A) avoiding acid or other toxic mine drainage by such measures as, but not limited to—

> > (i) preventing or removing water from contact with toxic producing deposits;
> >
> > (ii) treating drainage to reduce toxic content which adversely affects downstream water upon being released to water courses;
> >
> > (iii) casing, sealing, or otherwise managing boreholes, shafts, and wells and keep acid or other toxic drainage from entering ground and surface waters; . . .
>
> (11) with respect to surface disposal of mine wastes, tailings, coal processing wastes, and other wastes in areas other than the mine working or excavations, stabilize all waste piles in designated areas through construction in compacted layers including the use of incombustible and impervious materials if necessary and assure the final contour of the waste pile will be compatible with natural surroundings and that the site can and will be stabilized and revegetated according to the provisions of this chapter;
>
> (14) insure that all debris, acid-forming materials, toxic materials, or materials constituting a fire hazard are treated or buried and compacted or otherwise disposed of in a manner designed to prevent contamination of ground or surface waters and that contingency plans are developed to prevent sustained combustion;
>
> (16) insure that all reclamation efforts proceed in an environmentally sound manner and as contemporaneously as practicable with the surface coal mining operations . . . (30 U.S.C. §1265(b)).

Beyond these statutory requirements, the federal rules establish minimum performance standards that address topsoil and subsoil management and use (30 CFR §816.22), management and protection of the hydrologic balance (30 CFR §§816.41-816.47), contemporaneous reclamation (30 CFR §816.100), and backfilling and grading (30 CFR §816.101-816.107). In particular, ground- and surface-water protection are required by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful contamination of water resources (30 CFR §816.41(b), (d)). Ground- and surface-water monitoring data are required to be submitted at least quarterly (30 CFR §816.41(c), (e)). Thus, while SMCRA and its implementing regulations indirectly establish performance standards that could be used to regulate the manner in which CCRs may be placed in coal mines, neither the statute nor those rules explicitly require regulation of the use or placement of CCRs.

## Managing Abandoned Mine Lands Including Remining

Title IV of SMCRA establishes an abandoned mined land (AML) reclamation program that is funded through a reclamation fee imposed on each ton of coal mined (30 U.S.C. §1232(a)). States are entitled to receive at least 50 percent of the fees paid by coal mining operations in their jurisdiction for AML reclamation projects if they have both an approved regulatory program (30 U.S.C. §1235(c)) and an approved AML reclamation program (30 U.S.C. §1232(g)).

Under the original law, AML money could be spent only for lands and waters affected by mining and "abandoned or left in an inadequate reclamation status . . . , and for which there is no continuing reclamation responsibility . . . " (30 U.S.C. §1234). As a result of this language, coal operators interested in engaging in activities to extract additional coal resources from coal refuse piles, particularly abandoned anthracite culm banks and coal waste piles, were not eligible to receive AML funds. Furthermore, extraction of the coal refuse potentially imposed on the operator the full regulatory burdens for any other surface coal mining operation regulated under SMCRA.

The Energy Policy Act of 1992 (Public Law 102-486) amended several provisions of SMCRA in an effort to promote such beneficial extraction and reclamation activities at abandoned mines. Under those amendments, AML money may be used to restore lands that are eligible for such refuse remining under OSM's standards (30 U.S.C. §1234). In addition, operators at refuse remining sites are not subject to having other permit applications blocked for SMCRA violations that occur at a refuse remining site, as would otherwise happen under §510(c) of SMCRA, if such violations resulted from an unanticipated event or condition. Finally, the period of responsibility for successful revegetation at AML refuse remining sites is reduced from ten to five years in areas that receive 26 inches of rainfall or less annually, and from five to two years in areas that receive in excess of 26 inches of annual rainfall.

In addition to these changes to SMCRA, the CWA was amended to make it easier for refuse remining operators to obtain a National Pollutant Discharge Elimination System (NPDES) permit. Under this provision, sometimes called the Rahall Amendment, remining operators are allowed to meet modified discharge limits for pH, iron, and manganese based on economically achievable best available technology, as determined on a case-by-case basis, subject to the requirement that the remining operation improves water quality (33 U.S.C. §1311(p)).

Congress also made changes in the policies for regulating public utilities that were designed to provide incentives for generating electricity from the combustion of coal refuse and other waste products and from renewable energy sources. These changes in federal policy contributed to the viability of the coal refuse remining and reclamation industry (Sidebar 5.1).

Both general AML and AML refuse-remining projects sometimes use CCRs to neutralize acid-forming materials or as fill for mine pits during reclamation. To the extent that these activities do not involve any remining, they are not subject to the same SMCRA standards that apply to active surface coal mining operations. Although as noted previously, remining projects may be eligible for AML money and are not subject to the same permit block and bonding standards that apply to other mines, these projects are otherwise subject to the same general regulatory standards that apply to active coal mining and reclamation activities.

Thus, OSM and its state partners are in a position to regulate CCR use in AML projects that involve refuse-remining activities.

## OTHER FEDERAL ENVIRONMENTAL LAWS

Several environmental laws are directly or indirectly applicable to the placement of CCR in mines. The section below discusses pertinent issues in RCRA, the Safe Drinking Water Act (42 U.S.C. §§300(f)-(j)-326), the Clean Water Act (33 U.S.C. §§1251-1385), the Emergency Planning and Community Right To Know Act (42 U.S.C. §§11021-11023), and the Pollution Prevention Act (42 U.S.C. §§13101-13109). In addition, the Clean Air Act (42 U.S.C. §§7401-7671q) can impact CCR management indirectly by mandating air pollution controls that affect the characteristics of the CCRs and thus its suitability for certain productive uses.

### The Resource Conservation and Recovery Act

RCRA (42 U.S.C. §§6901 et seq.) was enacted in 1976 to address the problem of hazardous waste disposal.[1] The act establishes a cradle-to-grave tracking system whereby hazardous waste is managed from the time it is generated until the time that it is properly disposed in an approved and permitted treatment, storage, and disposal facility. A written manifest, which contains information about the waste as well as the generator, transporters and treatment, storage, and disposal facility, is used to track the waste through to discharge or disposal. Because of the cost of tracking and treating hazardous waste, RCRA provides an economic incentive to minimize or eliminate wastes so that the law does not apply. Moreover, RCRA requires generators to certify that they have a program in place to minimize the quantity and toxicity of the waste generated to the extent economically practicable (id. at §6922(b)(1)).

In 1980, Congress passed the Bevill Amendment to RCRA (42 U.S.C. §6982(n)), which required the EPA to conduct a detailed and comprehensive study and submit a report on the adverse effects on human health and the environ-

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[1] Hazardous waste is defined as "solid wastes, or a combination of solid wastes, which . . . may (A) cause or significantly contribute to an increase in mortality, or an increase in serious irreversible, or incapacitating reversible, illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed. 42 U.S.C. §§6903(5). Solid wastes are broadly defined to encompass "discarded material, including solid, liquid, semi-solid, or contained gaseous material . . . ." 42 U.S.C. §§6903(27). EPA rules establish essentially two ways for a solid waste to be deemed "hazardous":

(1) by exhibiting one of four hazardous characteristics (ignitability, corrosivity, reactivity, or toxicity), or (2) by being listed as hazardous by rule.

See 40 CFR part 261.

### SIDEBAR 5.1
### One Person's Trash Is Another Person's Treasure: PURPA and Waste Coal Independent Power Producers

In the Public Utility Regulatory Policies Act (PURPA) of 1978, Congress found that "the protection of the public health, safety, and welfare, the preservation of national security, and the proper exercise of congressional authority under the Constitution to regulate interstate commerce require—(1) a program providing for increased conservation of electric energy, increased efficiency in the use of facilities and resources by electric utilities, and equitable retail rates for electric consumers . . ." (16 U.S.C. §2601 et seq.). PURPA requires that public utilities buy electricity from generating facilities that meet certain criteria, such as the use of nontraditional fuels including waste-derived fuels (18 CFR §292). These electricity generating facilities are known under PURPA as "qualifying facilities." Part of PURPA's intent was to create a regulatory environment in which small independent power producers could generate electricity from coal refuse and other waste products and be economically viable in the electricity supply market.

Under 18 CFR §292.202(b), waste-derived fuels include:

(1) anthracite culm produced prior to July 23, 1985;

(2) anthracite refuse that has an average heat content of 6,000 British thermal units (Btu) or less per pound and has an average ash content of 45 percent or more; and

(3) bituminous coal refuse that has an average heat content of 9,500 Btu per pound or less and has an average ash content of 25 percent or more

If an electricity-generating facility meets additional requirements for efficiency and ownership (see 18 CFR §§292.203-292.206) and obtains certification as a qualified facility, an electric utility is obligated to purchase any power produced from the qualifying facility at a fair rate (18 CFR §292.304).

Although PURPA was originally enacted in 1978, the circulating fluidized bed boiler technology that allowed waste coal to be used as a viable fuel option did not come on-line for commercial use until the late 1980s. As a result, nearly 10 years passed between the enactment of PURPA and the development of the waste coal independent power production industry (PADEP, 2004).

ment, if any, of the disposal and utilization of fly ash waste, bottom ash waste, slag waste, flue gas emission control waste, and other by-product materials generated primarily from the combustion of coal or other fossil fuels.

Separately, Congress provided that these coal combustion by-products would not be regulated under RCRA until at least six months after the date of the required study (42 U.S.C. §6921(b)(3)(A)(1)). On March 8, 1988, EPA released its first report to Congress under the Bevill Amendment, and on August 9, 1993, EPA concluded that the regulation of fly ash, bottom ash, boiler slag, and scrubber sludge as hazardous wastes was not warranted (58 FR 42466).[2]

## RCRA Subtitle C

Wastes determined to be hazardous are regulated under subtitle C of RCRA. Under subtitle C, EPA issues management standards tailored to particular wastes and generators. RCRA allows the EPA to delegate subtitle C hazardous waste authority to the states. As under SMCRA, states that opt to manage subtitle C hazardous waste must adopt their own laws and regulations that are consistent with federal standards. Such state programs are subject to review and approval by EPA and standards established under subtitle C are also enforceable by EPA.

## RCRA Subtitle D

The EPA also promulgates rules for nonhazardous solid wastes (such as municipal solid waste) under subtitle D of RCRA. EPA's subtitle D regulations establish minimum national performance criteria for all sanitary landfills (40 CFR part 257 (2004)). Facilities that fail to meet these criteria are considered open dumps and are illegal (40 CFR §257.1(a)(1)). In addition, EPA's rules set minimum criteria for the design, siting, operation, and closure of municipal solid waste landfills (40 CFR part 258 (2004)). Regular groundwater monitoring is part of this program, and the rules require remedial action to address releases that may pose a threat to human health or the environment. The EPA's design standards are flexible so that state and local agencies can design landfills that will accommodate local hydrogeologic and climatic conditions, as well as the particular characteristics of the site. Subtitle D provides for the promulgation of EPA regulations and guidelines for identifying units for solid waste management and to assist states in developing and implementing solid waste management plans (42 U.S.C. §6942). Unlike the subtitle C hazardous waste program, however, subtitle D is not a delegated program, and EPA does not implement or enforce standards in states that do not adopt federal standards. While all states have developed standards that govern landfills and solid waste disposal and many have adopted the RCRA D guidelines, states are not bound by the federal standards. A facility that does not comply with subtitle D regulations is in violation of prohibitions

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[2] It bears noting here that the U.S. Supreme Court struck down EPA's attempt to exempt incinerator ash from regulation under subtitle C (City of Chicago v. Environmental Defense Fund, 511 U.S. 328 (1994)). EPA claimed that incinerator ash was exempt pursuant to the "household waste exclusion"—a provision in RCRA that exempts municipal incinerators that burn household waste from regulation as a treatment, storage, and disposal facility, even though some of that household waste likely includes material that would be deemed hazardous waste under RCRA standards.

against open dumping (42 U.S.C. §6945(a)), but this prohibition is enforceable only by private citizens and the states (42 U.S.C. §6972(a)(1)).

Federal technical and financial assistance is also available to state and regional authorities to assist them in developing environmentally sound waste disposal practices (42 U.S.C. §6941). Although states are not required to submit their solid waste management plans to the EPA for approval, states whose plans are approved by the EPA are eligible for federal assistance (42 U.S.C. §6943).

On May 22, 2000, the EPA published a regulatory determination on wastes from the combustion of fossil fuels (65 FR 32214; USEPA, 2000) wherein it concluded that CCRs do not warrant regulation under subtitle C of RCRA. The EPA also determined, however, that national regulations for CCRs are warranted under subtitle D of RCRA when they are disposed in landfills or surface impoundments and that regulations under subtitle D of RCRA and/or SMCRA are warranted when these wastes are used to fill surface or underground mines. The 2000 regulatory determination summarized EPA's research and findings, which are pertinent to this study. Some of this information is presented in Chapter 4 and some is reviewed later in this chapter.

The EPA and OSM have prepared a side-by-side document that compares the language and approach of SMCRA and RCRA as they relate to the possible regulation of CCR placement in mines. The document includes citations from SMCRA and RCRA rules. For RCRA, it presents potential approaches that might be used if RCRA D regulations are proposed. For SMCRA, it offers citations of actual rules, with some interpretive additions, to show how SMCRA can be interpreted to cover CCR use in reclamation or how language might be added to address CCRs specifically. The EPA-OSM document is presented in Appendix E.

## The Safe Drinking Water Act

The SWDA (42 U.S.C. §300(f)-300(j)-326) was established to protect public health by regulating the quality of drinking water in the United States. The law focuses on all surface and groundwaters that actually or potentially provide drinking water. The SDWA authorizes the EPA to set national health-based drinking water standards.[3] These standards include maximum contaminant level goals (MCLGs), set at a level below which there is no known or expected health risk (40 CFR §141.2), and maximum contaminant levels (MCLs), enforceable standards set as close as possible to the MCLGs, taking into account feasibility and cost (42 U.S.C. §300(f)(1)). While the standards apply only to public drinking

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[3] The statute requires EPA to set both primary and secondary drinking water standards. Primary standards protect public health, whereas secondary standards protect the public welfare and might encompass, for example, standards designed to address aesthetic issues such as the odor and appearance of water (42 U.S.C. §300(f)(1), (2)).

water systems, these systems are defined broadly to encompass all systems that serve as few as 25 people (or 15 service connections) at least 60 days each year (42 U.S.C. §300(f)(4)). They do not apply, for example, to single-family, private well water supplies in rural areas. However, even where these standards do not apply directly, they offer a guidepost for determining the level of pollutants that may pose a threat to public health or the environment. For example, in many RCRA applications, drinking water MCLs may be applied as performance standards for the quality of groundwater migrating off-site from a waste disposal facility.

The SDWA also contains an underground injection control program to regulate underground injection wells. The underground injection control program is designed to protect groundwater from contamination by the injection of liquid wastes into wells. Liquid wastes are typically injected at high pressure. Injection wells must usually be cased and cemented into the surrounding foundation to avoid contamination of nearby groundwater sources.

The underground injection control program encompasses five specific classes of underground injection wells that correspond to different levels of regulation. Class I wells are those that inject hazardous, industrial, or municipal wastes below the lowest underground drinking water source. Class II wells inject liquids related to hydrocarbon storage and oil and natural gas production. Class III wells inject fluids associated with the mining of minerals. Class IV wells are those that inject radioactive or hazardous wastes into or above an aquifer and are prohibited by law. Class V wells are those injection wells not identified in Classes I-IV (40 CFR §144.6). Federal standards are designed to protect public health by preventing injection wells from contaminating underground sources of drinking water (USDWs) (40 CFR parts 144, 146). USDWs are aquifers or portions of aquifers that have water quantities adequate to supply a public water system and whose waters contain less than 10,000 mg/L total dissolved solids (i.e., water that could be treated to meet public drinking water standards). SDWA includes all current and future USDWs.

Mine backfill wells can be used to inject materials (e.g., sand and water, mine tailings, sometimes CCRs) into underground mined-out areas for subsidence control, fire control, and disposal of debris from mine operations (see Chapter 2). Underground injection control regulations would apply if CCRs were to be injected into underground mines for reclamation or other purposes. Mine backfill wells are regulated by permit or rule in various states. The EPA estimates that there are approximately 7,800 mine backfill wells in 17 states, but only a few of these inject CCRs; however, this is a common practice in underground metal mines. Ninety percent of the documented wells occur in Idaho, North Dakota, Ohio, and West Virginia (USEPA, 1999c).

The EPA can delegate SDWA authority to the states, subject to federal approval and oversight, and all states except Wyoming have approved SDWA programs. States must adopt the federal MCLs and must meet the federal Underground Injection Control Program standards as a minimum, but they can adopt more stringent standards as authorized under state law.

### The Clean Water Act

The CWA makes it illegal to discharge pollutants into navigable waters except as authorized by the act (33 U.S.C. §§1311(a), 1362(12)). Of particular relevance is section 402 of the CWA, which establishes the National Pollution Discharge Elimination System (NPDES). Section 402 requires an NPDES permit for the discharge of any pollutant (33 U.S.C. §1342(a)). Discharge of a pollutant is defined to mean "any addition of any pollutant to navigable waters from any point source" (33 U.S.C. §1362(12)). The meaning of each of the substantive terms in this definition has evolved over the course of the last 30 years.

The CWA defines a point source to mean "any discernible, confined, and discrete conveyance . . ." (33 U.S.C. §1362(14)) and the term has historically been defined broadly to include essentially any "man-induced gathering system" (Beck, 1991; CFR §53.01(b)(3) 1991). One court has held, for example, that "surface runoff from rainfall, when collected and channeled by coal miners in connection with mining activities, constitutes point source pollution."[4] Since all surface drainage from disturbed areas at surface coal mining operations must pass through a sediment discharge control structure before it leaves the mine site (see 30 CFR §816.46(b)(2)), any discharge from such structures is likely to be considered a point source requiring an NPDES permit. Hence, active mines have NPDES permits to control their discharges to surface waters. It is not clear if adding placement of CCRs into the mine during ongoing reclamation would require revisiting the terms of an existing permit.

It is also not clear whether a discharge of leachate into an aquifer from a minefill that might include CCRs would be considered a point-source discharge subject to the NPDES program. The courts are split as to whether discharges into groundwater are covered by the NPDES program. Courts have found that discharges into groundwater that are hydrologically connected to surface water are subject to the program.[5] Other courts, however, have held that the CWA does not apply to groundwater.[6] At least two circuit courts appear to agree with the proposi-

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[4] Sierra Club v. Abston Construction Company, 620 F.2d 41 (5th, 2d Cir. 1980). See also, Concerned Area Residents for the Environment v. Southview Farm, 34 F.3d 114 (2d Cir. 1994), cert. denied, 514 U.S. 1082 (1995), holding that "liquid manure spreading operations" at concentrated animal feeding operations are point sources.

[5] Williams Pipe Line Co. v. Bayer Corp., 964 F. Supp. 1300, 1320 (S.D. Iowa 1997); Friends of Santa Fe County v. LAC Minerals, 892 F. Supp. 1333, 1357-1358 (D.N.M. 1995); Washington Wilderness Coalition v. Hecla Mining Co., 870 F. Supp. 983, 989-090 (E.D. Wash. 1994); Sierra Club v. Colorado Refining Co., 838 F. Supp. 1428, 1434 (D. Colo. 1993).

[6] Umatilla Waterquality Protective Ass'n., Inc. v. Smith Frozen Foods, Inc., 962 F. Supp. 1312, 1318 (D. Oregon 1997); Town of Norfolk v. U.S. Army Corps of Engineers, 968 F.2d 1438, 1451

tion that the CWA does not apply to groundwater although they have not specifically ruled on the issue.[7] In jurisdictions that have ruled that the CWA applies to certain discharges into groundwater, companies responsible for such discharges are required to obtain an NPDES permit. Eventually, this issue will likely be settled by either the Congress or the U.S. Supreme Court. In addition, to the extent that the placement of CCRs requires any kind of federal permit, issuance of the permit may be subject to certification by the state that any discharge from the facility will comply with the requirements of the CWA (33 U.S.C. §1341).

The CWA also requires states to establish and periodically review water quality standards for water bodies. These standards consist of both designated uses, which signify the purposes for which the water body is to be protected, and water quality criteria, which are maximum ambient pollution levels that must be achieved to safeguard the designated uses (33 U.S.C. §1313). The EPA generally requires that designated uses meet at least the "fishable or swimmable" goal established under section 101(a)(2) of the CWA (33 U.S.C. §1251(a)(2)) and a "use attainability analysis" must be prepared where designated uses are set below that goal (40 CFR §131.10(j)(1)). Water quality criteria must include standards for toxic pollutants that "could reasonably be expected to interfere with those designated uses . . ." (id. at 1313(c)(2)(B)). The CWA requires states to identify waters that fail to meet the established water quality standards and to set total maximum daily loads for these waters at a level necessary to achieve the standards (33 U.S.C. §1313(d)(1)).

Like SMCRA and SDWA, the CWA is implemented primarily by state agencies. Forty-five states have been delegated the major components of the CWA with the approval and oversight of EPA.

## The Clean Air Act

Like the CWA, the Clean Air Act (CAA) addresses point sources of pollution through a complex permit program, as well as ambient air pollution, which is addressed largely through state programs called state implementation plans (42 U.S.C. §§7401-7671(q)). Although the CAA has no direct application to CCR placement in mines, it is implicated indirectly because of the impact that air pollution control technologies, required by EPA rules and individual permit decisions, can have on CCR constituents. For example, EPA's CAA rules on $NO_x$

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(1st Cir. 1992); Kelley v. United States, 618 F. Supp. 1103, 1106-1107 (W.D. Mich. 1985); United States v. GAF Corp., 389 F. Supp. 1379, 1383-1384 (S.D. Texas 1975).

[7] See Village of Oconomowoc Lake v. Dayton Hudson Corp., 24 F.3d 962 (7th Cir.), cert. denied, 513 U.S. 930, 130 L. Ed. 2d 282, 115 S. Ct. 322 (1994); Exxon Corp. v. Train, 554 F.2d 1310, 1312 n. 1, 1318-1319 (5th Cir. 1977).

controls (40 CFR part 76) could increase the chemical content in CCRs of constituents such as ammonia, which can adversely affect the pozzolanic properties of CCRs and render them less marketable (e.g., Butalia and Wolfe, 2000).

## The Emergency Planning and Community Right to Know Act

The primary purpose of the Emergency Planning and Community Right to Know Act (EPCRA) is to inform communities and citizens of chemical hazards in their local areas. Sections 311 and 312 of EPCRA require businesses to report the locations and quantities of chemicals stored on-site to state and local governments to help communities develop plans to respond to chemical spills and similar emergencies (42 U.S.C. §§11021-11022). Section 313 of EPCRA further requires EPA and the states to collect annual data on releases and transfers of certain toxic chemicals from industrial facilities that generate wastes and to make the data available to the public in the Toxics Release Inventory (TRI) (42 U.S.C. §11023). Because CCRs contain toxic constituents, facilities that produce CCRs (e.g., electric utilities, not mine operations) are generally required to file TRIs under the requirements of EPCRA. (Note that the volume of CCRs produced is not reported, only the volume of qualifying constituent chemicals, such as arsenic is reported.) EPCRA does not impose any other regulatory obligations on parties that release materials covered by the statute. Instead, it works by informing the public about the extent of releases by individual facilities. The TRI is publicly available on EPA's web site at http://www.epa.gov/tri/.

## The Pollution Prevention Act

One additional law relevant to the utilization and disposal of CCRs is the Pollution Prevention Act of 1990 (PPA) (42 U.S.C. §13101 et seq.). The PPA establishes as the national policy of the United States:

> . . . that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled shall be treated in an environmentally sound manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort. . . .

The PPA does not contain enforceable standards, but it does require that each owner of a facility required to file an annual toxic chemical release form (a TRI report under EPCRA) for a toxic chemical shall include with each such annual filing a toxic chemical source reduction and recycling report for the preceding calendar year (42 U.S.C. §13106(a)).

Since CCR producers must typically file EPCRA reports on the toxic constituents in the CCRs they produce, the source reduction and recycling reports mandated by this section afford state and federal regulators a useful tool for encouraging CCR reuse. The report is required to describe "source reduction practices," the "techniques . . . used to identify source reduction opportunities," and the amount of any chemical entering a waste stream, or "otherwise released into the environment" (42 U.S.C. §13106(b)). These provisions are implemented through TRI Form R, which is filed by all facilities subject to the TRI (EPA Form 9350-1 (Rev. 02/2004) (Form R)). Section 8 of Form R requires facilities to describe source reduction and recycling activities. This provides a vehicle for utilities to identify opportunities to recycle CCRs into useful by-products such as cement and wallboard.

## EPA'S REGULATORY DETERMINATION OF 2000

As noted above, in 2000, EPA published a regulatory determination on wastes from the combustion of fossil fuels (65 FR 32214) and concluded that CCRs do not warrant regulation under subtitle C of RCRA but do warrant regulation under subtitle D of RCRA when CCRs are disposed in landfills or surface impoundments or used as fill in surface or underground mines.[8] The EPA further indicated its interest in deciding whether regulation of CCR disposal in minefills should occur under SMCRA or RCRA subtitle D, or a combination of the two. The EPA announced its intent to issue proposed rules for public review and comment. Some of EPA's findings in making this determination are pertinent to the issues considered in this report and are summarized below.

### The Determination and RCRA C Versus RCRA D

Chapter 4 reviewed some of EPA's findings from damage cases and other considerations related to the risks of CCR disposal in non-coal mine settings. In addition to considering the risks and implications of the damage cases, EPA's 2000 regulatory determination also reviewed the management practices currently associated with CCRs. The EPA recognized that the utility industry has made significant improvements in its CCR management practices over recent years and that most state regulatory programs are similarly improving. For example, the use of liners and groundwater monitoring at landfills and surface-water impoundments has increased substantially. Nonetheless, on the basis of its own analysis and public comments, the EPA concluded that there is sufficient evidence that adequate controls may not be in place, even for landfills and surface impound-

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[8] So that CCRs are regulated consistently across all waste management scenarios, the EPA noted that it also intends to make these national regulations for disposal in surface impoundments, landfills, and minefilling applicable to CCRs generated at electric utility and independent power producing facilities that are not co-managed low-volume wastes.

ments, and that CCRs pose a risk to human health and the environment if not managed adequately. This, the EPA noted, justifies the development of national regulations.

Having decided that national CCR disposal rules are necessary, the EPA also found that the risks were not substantial enough to warrant regulation as hazardous waste under subtitle C of RCRA. Instead, it concluded that rules are more appropriate under subtitle D. While failure to comply with subtitle D disposal standards would violate the prohibition against open dumping, such a violation is enforceable only by states and private citizens, not by the EPA. One advantage to subtitle D rules, however, is that they can be applied and enforced more quickly than subtitle C rules, which must first be incorporated into the delegated state authorities and programs.

The EPA further justified its choice of subtitle D regulation by noting that it did not want to place any unnecessary barriers on the beneficial reuse of CCRs and the consequent environmental benefits associated with such reuse (see following section). In the context of minefilling in particular, the EPA noted the concern expressed by the states and industry "that regulation under subtitle C could cause a halt in the use of coal combustion wastes to reclaim abandoned and active mine sites" (40 CFR Part 261). The EPA also expressed a belief that the states would expand and upgrade programs to address the emerging practice of using CCRs in minefills, as they did for surface impoundments and landfills. Ultimately, the EPA concluded that either SMCRA or RCRA subtitle D standards, or a combination of the two, were warranted to ensure the proper handling and management of CCRs (see Appendix E, which contains a side-by-side presentation of possible SMCRA and RCRA approaches).

## Beneficial Use

There is broad recognition that the physical and chemical properties of many CCRs are applicable for a variety of uses. Some of these uses involve the recycling of CCRs into new products that are helpful to society and some involve using CCRs to mitigate certain negative aspects of mining.

In some states, uses of CCRs that have associated benefits have been designated as a beneficial use in statutes or regulations that deal with CCR utilization and disposal. This designation is not based on any federal program; however, the Energy Policy Act of 2005 may impact the use of CCRs in the future (Sidebar 5.2). In establishing the beneficial use designation, the states, while recognizing the potential risk of negative impacts of utilizing CCRs in the environment, also concluded that benefits can accrue and should be considered in the permitting process. The relative risks and benefits vary with the application (e.g., using CCRs in the production of new cement products versus their application in the environment for land reclamation).

The evaluation of risks and benefits is always a complicated analysis, con-

## SIDEBAR 5.2
## The Energy Policy Act of 2005—The Latest Laws That May Impact the Use of CCRs

On August 9, 2005, President Bush signed the Energy Policy Act of 2005. Among other things, the new law amends the Solid Waste Disposal Act by adding Section 6005, “Increased Use of Recovered Mineral Content in Federally Funded Projects Involving Procurement of Cement or Concrete” (Pub. L. No 109-58, Sec. 108). Recovered mineral content is defined to mean “(A) ground granulated blast furnace slag . . . ; (B) coal combustion fly ash; (C) any other material or byproduct recovered or diverted from solid waste that the [EPA] Administrator determines should be treated as recovered mineral component . . . for use in cement and concrete projects . . . .” The term cement or concrete project is defined to mean “the construction or maintenance of a highway or other transportation facility or a federal, state or local government building or other public facility that—(A) involves the procurement of cement or concrete; and (B) is carried out, in whole or in part, using Federal funds.”

The statute requires the EPA Administrator, in cooperation with the Secretaries of Transportation and Energy, to complete a study within 30 months that, among other things, quantifies the extent to which recovered mineral components are being substituted for portland cement and the energy savings and environmental benefits associated with the substitution; identifies barriers in procurement requirements that are preventing additional energy savings and environmental benefits; and identifies potential mechanisms for achieving greater substitution of recovered mineral component in cement and concrete products.

Unless the study identifies problems that warrant delay, the EPA Administrator has one year from its completion to “take additional actions to establish procurement requirements and incentives” to promote the increased use of recovered mineral component in cement and concrete products. Given the vast amount of concrete currently used in federal highway projects alone, the impact of this new legislation on the market for CCRs could be substantial.

founded by who may bear the risks and who may accrue the benefits. Also, there are always trade-offs. In cases such as AML and refuse-remining applications, the use of CCRs in reclamation may help to resolve serious, acute land-use and water quality problems, but may potentially produce undesirable consequences such as release of metals and other toxic elements into the environment.

The EPA recognized these issues in its 2000 regulatory determination, in which it is explicitly noted that CCRs should remain exempt from regulation as hazardous wastes under RCRA to the extent that they are used for beneficial purposes other than minefilling. In support of this conclusion, the EPA noted that it had not identified these beneficial uses as likely to present significant risks to human health or the environment. In particular, the EPA found that for many uses, CCRs would be bound or encapsulated in construction materials (e.g., cement products, wallboard) and that there is very low potential for exposure from most uses. Moreover, some aspects associated with the manufacturing of these products are separately regulated under RCRA and/or the CWA. As discussed, the EPA determined that minefilling represented a higher-risk use of CCR, warranting consideration of regulation.

The process for permitting beneficial use varies among the states and in many states the designation of beneficial use may limit the regulation or oversight of CCR placement. Such designation may also make it unnecessary for operators to obtain permit revisions for CCR minefilling. As a result, many citizen groups believe that treating mine placement of CCRs as a beneficial use translates into less rigorous permit conditions, a conclusion that is shared by some state regulators. As a consequence, the beneficial use of CCRs in minefilling has become a problematic issue. Hence, the committee elected to avoid the term "beneficial use" wherever practical in this report.

As discussed in the following chapters, the committee believes that the use of CCRs in minefilling operations can have advantages, but that such practices should not result in the circumvention of appropriate characterization and permitting processes where CCRs are used in mines. Although the potential advantages should not be ignored, the full characterization of potential risks should not be cut short in the name of beneficial use.

## STATE PROGRAMS

Activities such as mining, reclamation, and waste disposal are often subject to variable, local conditions that can be difficult to address with national rules. On the other hand, national rules prevent disparities among states in the regulation of such activities. Federal environmental legislation typically addresses this problem by offering states the opportunity to establish their own regulatory programs subject to minimum national standards and federal oversight. SMCRA, RCRA subtitle C, the SDWA, and the CWA all set minimum enforceable standards while establishing programs that allow federal agencies to delegate authority to the states for granting permits and participating in monitoring, inspection, and enforcement activities. State programs must be approved by the federal government as consistent with baseline national standards and the federal government typically retains independent enforcement authority in such delegated programs. This ensures a "level playing field" among the states. However, states typically have flexibility to adapt their program to local conditions or to implement standards that are more stringent than those required by federal law.

As new circumstances or practices arise that are not explicitly covered by national regulations, such as the disposal of CCRs in mines, state practices can vary significantly. Moreover, even when programs look similar on paper, differences in implementation and enforcement practices among the states can lead to significant differences in the performance of the program. Finally, many states have statutes that prohibit state agencies from adopting standards that are more stringent than federal standards. This led some state representatives who appeared before the committee to express concern about their authority to impose permit conditions and performance requirements for the disposal of CCRs in mines. For example, some states conduct groundwater monitoring only for the basic parameters specified in SMCRA regulations, such as total dissolved solids, specific conductance, pH, and dissolved iron. Other states require monitoring for a suite of RCRA metals, such as arsenic, cadmium, lead, and mercury.

## STATE REGULATORY AGENCIES

For active mining and reclamation operations, the primary regulatory authority is typically the state SMCRA authority. In most instances, however, the mining operation will also need an NPDES permit under the CWA, which might be issued by a different agency, usually a state department of environmental protection. When CCRs are used as minefill, CCR placement activities fall under the jurisdiction of these agencies.

In contrast to minefills, CCRs that are placed in surface impoundments or disposed of in a landfill are regulated under state rules governing waste disposal and landfills that most likely were derived from RCRA subtitle D guidelines. This typically would be authorized by the state department of environmental protection, sometimes with review by a public health agency.

## SUMMARY

This chapter describes the basic federal laws for mine reclamation and environmental protection that can be applied to placement of CCRs in coal mines. Of particular importance are the SMCRA and RCRA. Other relevant federal laws are also discussed, including the SDWA, the CWA, and the PPA. Activities such as mining and environmental protection involve nationally variable, locally specific conditions that can be difficult to address through national rules. On the other hand, national standards are necessary to ensure that basic environmental protection requirements are met. These concerns can be addressed by establishing minimum federal standards administered by the states and by affording states the option of adopting more stringent standards as necessary to satisfy local concerns.

After reviewing the laws and other relevant literature, *the committee concludes that although SMCRA does not specifically regulate CCR placement at mine sites, its scope is broad enough to encompass such regulation during reclamation activities.* Furthermore, while SMCRA and its implementing regulations indirectly establish performance standards that could be used to regulate the manner in which CCRs may be placed in coal mines, neither the statute nor those rules explicitly address regulation of the use or placement of CCRs. The committee also believes that the use of CCRs in minefilling operations has advantages, but that it should not result in the circumvention of appropriate characterization and permitting processes. With regard to beneficial use of CCRs in minefills, *the committee concludes that although potential advantages should not be ignored, the full characterization of possible risks should not be cut short in the name of beneficial use.*

# 6

# Characterization for Coal Combustion Residue Management

Many variables affect the behavior and potential impacts of CCR placement in a mine setting, including chemical and physical properties of the CCRs (see Chapter 2), the hydrogeologic and biogeochemical setting at the mine site (see Chapter 3), and the proximity of sensitive receptors (see Chapter 4). The previous chapters have shown that these characteristics vary widely from site to site or from plant to plant. Therefore, decisions regarding CCR placement cannot be made based on broad generalizations but instead require careful specific characterization of both the CCR material and the mine site in the context of CCR placement. Site characterization and CCR characterization are essential parts of CCR management and serve to guide engineering design, permitting decisions, reclamation management, and the development of effective monitoring programs (discussed further in Chapter 7). This chapter discusses the importance of site characterization and CCR characterization within a risk-informed framework for CCR management. The chapter also outlines the important categories of information that should be sought through a rigorous characterization program and summarizes the advantages and limitations of available methods and modeling tools for use in the characterization process.

## RISK-INFORMED FRAMEWORK FOR CCR MANAGEMENT

As described in Chapter 4, unmanaged disposal of CCRs can lead to contaminant exposures, which can increase the risk of adverse impacts on public health and the environment. Viable management strategies are those that reduce CCR exposure and associated risks of adverse impacts to a level considered unlikely or acceptable considering the associated benefits. At the same time, CCR management strategies should represent a reasoned application of financial resources balanced with the expectations of affected stakeholders.

Overall, CCR management strategies should be informed by an evaluation of risk. Understanding the risks associated with CCR disposal at a mine site requires knowledge of

- CCR characteristics (see Chapter 2 and "CCR Characterization" in this chapter);
- The transport potential of CCR-derived contaminants in the mine environment (see Chapter 3 and "Site Characterization" in this chapter);
- Toxicological properties of CCR constituents and an assessment of potential human or ecological impacts, including knowledge of the location of potential receptors and intended post-mining land uses (see Chapter 4 and "Site Characterization");
- The performance of various engineered CCR placement designs to mitigate any CCR impacts to some standard of acceptability (see Chapter 7); and
- Post-placement monitoring results to confirm predictions of contaminant transport and the performance of the CCR placement design (see Chapter 7).

Thus, CCR characterization and site characterization are essential components of CCR management, providing the foundation for evaluating the safety of CCR placement at a particular site. CCR characterization can be used to estimate the rate and extent of contaminant leaching likely to be observed in the mine setting. Site characterization can help identify lower-risk placement sites based on such factors as their distance from the water table, the potential for downgradient attenuation of contaminants that are leached from the CCRs, and the hydraulic conductivity of surrounding geologic materials. Other characteristics that may influence the risk of CCR placement include the volume and method of CCR emplacement, the capacity of CCRs to neutralize any acid-generating materials at the placement site, and the distance of the CCRs from sensitive biota or drinking water wells.

Just as characterization contributes to our understanding of risk, the evaluation of risk may, in turn, influence the amount of characterization needed. For example, a small volume of a relatively innocuous CCR with low leaching potential may require less rigorous characterization of the site hydrogeology. Likewise, a large volume of CCR to be emplaced in a higher-flow hydrogeological setting, close to ecological receptors or local residents that rely on groundwater as a drinking water source, may require more rigorous leaching tests and detailed characterization of the site hydrogeology and geochemistry. An assessment of potential risks may also influence the placement design by prompting further consideration of the engineering controls available to minimize the impact of CCR placement in the environment.

Uncertainty is unavoidable in predictions of contaminant behavior and transport in the environment. Therefore, recognition of the many uncertainties regarding CCR placement in mines should also influence management decision making. Uncertainties may derive from simple measurement errors, which could occur with a poorly calibrated instrument, or from sampling errors, such as insufficient sampling to accurately assess the extent of subsurface fracturing. Uncertainties are also derived from errors in our conceptual understanding of complex systems, such as the transport of contaminants in complex mine settings or the stability of cementitious ash over long time frames. Inaccuracies in mathematical simulation models also contribute to uncertainty. After all, simulation models are approximations of reality and are often predicted at a scale much coarser than the laboratory scale where our understanding of processes is usually the most reliable. Even if we could perfectly describe the processes governing CCR behavior at the centimeter scale, it is not a trivial matter to scale up these equations into a model that applies at the scale of meters or more (NRC, 2004). All of these sources of uncertainty add up to be rather significant, given the complex scenario of CCR placement in the mine environment.

Several strategies can be used to cope with uncertainty in the CCR management decision-making process. Uncertainties about long-term performance could be reduced by the incorporation of redundant engineered liners and/or impermeable caps rather than more intensive characterization of the disposal site. Uncertainties about the potential for contaminant transport may be answered by more intensive characterization, perhaps including long-term column leaching experiments, investigations of the extent of fracturing within natural geologic barrier materials, or research on the ability of geologic materials to naturally attenuate contaminant migration. Intensive subsurface monitoring could also be used to manage uncertainty and provide early warning of any problems, although site managers would have to be prepared to take additional steps to address unacceptable levels of contamination were they to occur.

Characterization is, therefore, an important process by which managers can address uncertainties, and it contributes to the understanding of risk at potential CCR mine placement sites. The components of an effective characterization program are detailed in the following sections.

## SITE CHARACTERIZATION

Site characterization is a dynamic process of developing and continually refining a site conceptual model, which captures relevant aspects of the site that affect the behavior and potential impacts of CCRs in the mine environment. According to the NRC (2001), a site conceptual model is "an evolving hypothesis identifying the important features, processes, and events controlling fluid flow and contaminant transport of consequence at a specific field site in the context of a recognized problem." It can also serve as a valuable tool to link potential sources to receptors through environmental fate and transport pathways and exposure routes (ASTM, 2003). The site conceptual model supports CCR management decisions, such as whether to place CCRs at a particular mine site. Conceptual models are qualitative (for example, see Figure 6.1), but they provide the basis for numerical models, which translate the conceptual model into mathematical equations that can be solved.

A site conceptual model can only represent an approximation of the real world because of the complexity of the mine setting and the inherent scarcity of field data. Nevertheless, the conceptual model serves as the basis for identifying critical information gaps, so that additional characterization data can be gathered to evaluate risk. This additional characterization data is then used to further refine, or, if necessary, to completely revise the site conceptual model (Bredehoeft, 2005) to capture site-specific complexities in groundwater flow, CCR leaching, and contaminant transport. Although site characterization and CCR characterization are initially discussed separately in this chapter, CCR characterization information is an integral part of the site conceptual model because the total mass and leachability of contaminants in the CCRs affect the extent of natural (or engineered) isolation necessary to prevent downgradient ecological or human health impacts.

The extent of pre-placement site characterization needed will depend on the aforementioned assessment of the risk of CCR mine placement as well as a consideration of the uncertainty in the site conceptual model. As uncertainty in the site characteristics and behavior of CCR increases, more effort should be placed on characterization. As discussed in Chapter 5, although the potential benefits of CCR mine placement are important to consider in CCR management decisions, these benefits do not reduce the need to characterize potential risks. Managers and regulators cannot make sound decisions about CCR placement unless both the benefits and the potential risks are well understood. Inadequate investment in site characterization up front may lead to an erroneous assessment of potential CCR impacts and improper placement or engineering design. The costs of adequate site characterization are likely to be far lower than the costs of remediating groundwater and surface-water contamination from a mine site with improperly sited CCRs.

## Information Needed for CCR Placement

The SMCRA outlines general site characterization requirements to obtain a mining permit and to develop the reclamation and operation plan (30 CFR §779. 25, §780.22 (2004)) (see Sidebar 6.1). However, these site characterization requirements were intended to assess the potential impacts from coal mining and do not specifically consider the impacts of CCR placement. In most cases, additional site characterization data are needed to guide CCR placement, both to evaluate the potential for contaminant transport and to support the engi-

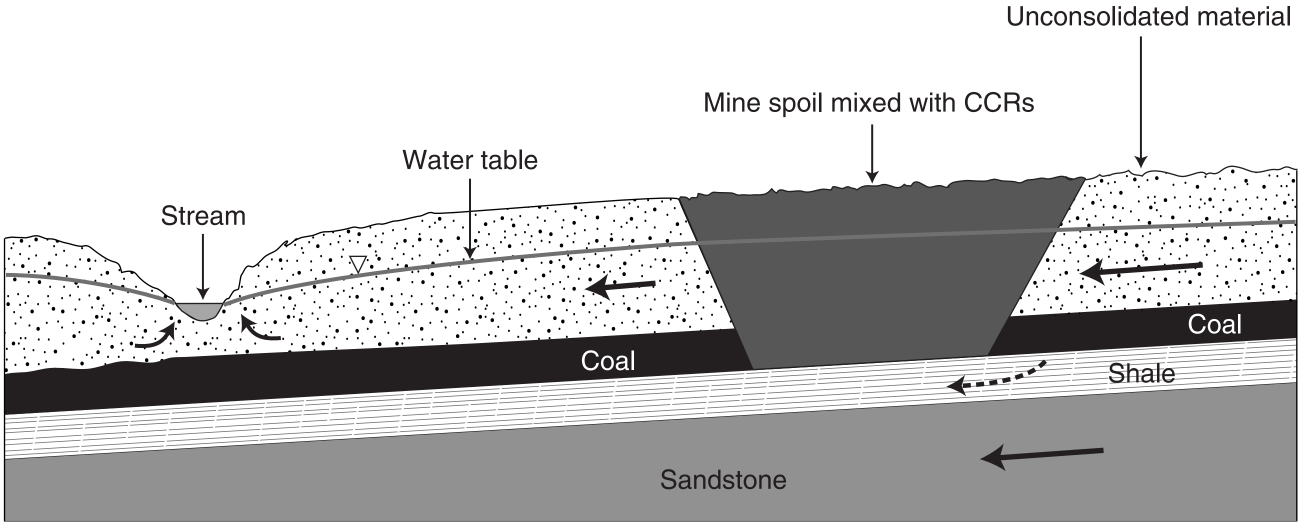

**FIGURE 6.1** A simple example conceptual model, showing water flow at a mine site with CCR placement.

## SIDEBAR 6.1
## Site Characterization Under SMCRA

The SMCRA requires mine operators to provide site characterization data before the approval of a coal mining permit, although these requirements do not specifically consider CCR placement. These site characterization data inform the determination of probable hydrologic consequences prepared by the operator, the cumulative hydrologic impact assessment prepared by the regulatory agency, and the operator's surface and groundwater reclamation and monitoring plans (30 CFR §780.21(f-j)).

30 CFR §780.22 outlines geologic characterization requirements for the reclamation and operation plan, including

> (a) . . . geologic information in sufficient detail to assist in determining:
>
> (1) The probable hydrologic consequences of the operation upon the quality and quantity of surface and ground water in the permit and adjacent areas . . . . [and]
>
> (2) All potentially acid- or toxic-forming strata . . . .
>
> (b) Geologic information shall include, at a minimum the following:
>
> (1) A description of the geology of the proposed permit and adjacent areas . . . and other parameters which influence the required reclamation and the occurrence, availability, movement, quantity, and quality of potentially impacted surface and ground waters.
>
> (2) Analyses of samples collected from test borings . . . . The analyses shall result in the following:
>
> (i) Logs showing the lithologic characteristics including physical properties and thickness of each stratum and location of ground water where occurring;
>
> (ii) Chemical analyses identifying those strata that may contain acid- or toxic-forming or alkalinity-producing materials and to determine their content . . . ; and
>
> (iii) Chemical analyses of the coal seam for acid- or toxic-forming materials, including the total sulfur and pyritic sulfur . . . .

neering plan for the placement and design of an effective groundwater monitoring network (see Chapter 7). In cases where CCR placement is proposed in a new mine permit application, some areas of overlap will undoubtedly exist between the site characterization data needed for the mine permit and those needed as part of CCR management. However, in cases where large-volume CCR placement is proposed at a permitted and operating mine, existing site characterization data from the original mine permit should be evaluated carefully before they are used to refine the site conceptual model. The purpose of this evaluation is to determine whether the mining process has altered certain site characteristics. For example, pumping and the formation of stress-relief

In addition to geologic information, SMCRA and its implementing rules require the operator to provide detailed hydrologic information. For groundwater, the rules require information on "the location and ownership for the permit and adjacent areas of existing wells, springs, and other groundwater resources, seasonal quality and quantity of groundwater, and usage. Water quality descriptions shall include, at a minimum, total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese. Groundwater quantity descriptions shall include, at a minimum, approximate rates of discharge or usage and depth to the water in the coal seam, and each water-bearing stratum above and potentially impacted stratum below the coal seam" (30 CFR §780.21(b)(1)).

For surface water, the operator must provide "[t]he name, location, ownership, and description of all surface-water bodies such as streams, lakes, and impoundments, the location of any discharge into any surface-water body in the proposed permit and adjacent areas, and information on surface-water quality and quantity sufficient to demonstrate seasonal variation and water usage." As with groundwater, "[w]ater quality descriptions shall include, at a minimum, baseline information on total suspended solids, total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese. Baseline acidity and alkalinity information shall be provided if there is a potential for acid drainage from the proposed mining operation. Water quantity descriptions shall include, at a minimum, baseline information on seasonal flow rates" (30 CFR §780.21(b)(2)).

The rules at 30 CFR §780.21 also require the operator to submit baseline cumulative impact area information and alternative water source information. Supplemental information may be required if the determination of the probable hydrologic consequences indicates that adverse impacts may occur to the hydrologic balance or that toxic-forming material may result in the contamination of groundwater or surface-water supplies. "Such supplemental information may be based upon drilling, aquifer tests, hydrogeologic analysis of the water-bearing strata, flood flows, or analysis of other water quality or quantity characteristics" (30 CFR §780.21(b)(3)).

SMCRA also allows the regulatory agency to require additional characterization data as necessary to meet the performance standards specified or to protect the hydrologic balance (30 CFR §780.22(c)).

and/or subsidence-induced fracturing during mining may alter the permeability of the strata and the groundwater flow patterns.

Because of the variability among mine sites, it is difficult to prescribe the precise site characterization data collection steps to follow prior to CCR placement. However, three broad categories of information are essential components of the site conceptual model: the hydrogeologic setting, the biogeochemical environment, and the proximity to sensitive receptors. These categories of site characterization information are discussed in detail below. The individual tools and methods available for collecting site characterization data have been described elsewhere (PADEP, 1998; ADTI, 2000) and are not discussed in detail here.

## Hydrogeologic Setting

To develop an accurate depiction of the hydrogeologic setting influencing the behavior of CCR placed in mines, information is needed about the geologic materials present at the site, climatological data, patterns of saturated and unsaturated flow, and the local surface water flow system. The site characterization information needs identified below focus on those data that may be overlooked in the standard permitting process for coal mining but are essential to site characterization for CCR placement.

***Meteorological Data.*** Local meteorological data, such as rates of precipitation, evapotranspiration, and groundwater recharge, provide information on water inputs to the mine site and the relative importance of overland and groundwater flow. CCRs are often placed in the unsaturated zone; therefore, information on recharge rates is particularly important. Local recharge data are rarely available, but regional values should be used only with the understanding that there may be large uncertainty in these estimates (NRC, 1990). Variations in temperature throughout the year can provide useful information on freeze-thaw cycles that could affect the integrity of any protective caps.

***Geologic Materials.*** The geological materials in a mine site may offer a natural means for isolating CCRs, by limiting subsurface flow. To fully evaluate the potential for natural geologic isolation, the thicknesses, orientation, and hydraulic conductivity of the strata forming the sides and bottom of the CCR placement site should be determined. The characterization should examine the potential for fracture- or conduit-dominated flow in addition to flow through unfractured porous media, such as spoil materials. The presence of thick sequences of strata with hydraulic conductivities of $10^{-7}$ cm/sec or lower should reduce off-site groundwater flow, provided the orientation of these strata is optimal relative to the direction of groundwater flow. Depending on the depth to the water table, geologic units with higher conductivities may represent higher-risk placement sites. Engineering design considerations for sites lacking natural confining layers are discussed in Chapter 7.

Soil properties may also have an impact on CCR management decisions at mine sites. Depending on its properties, on-site soil may be used for backfill, clay liners, protective soil cover, or low-permeability capping material. Hence, it may be valuable to collect data on the engineering properties of the soil at the site, such as in-place moisture density, Atterberg limits, grain size analysis and distribution, laboratory moisture-density relationships, and hydraulic conductivity relationships.

***Subsurface Water Flow.*** To understand the potential for contaminant transport from CCR placement sites, three-dimensional flow processes should be included in the site conceptual model based on current theories of unsaturated and saturated flow in heterogeneous systems. The placement of CCR calls for thorough characterization of pre-mining groundwater flow and predictions of post-reclamation flow through the entire mine area, including disturbed areas such as the mine spoil and the emplaced CCR. Site data to characterize groundwater flow would include seasonal fluctuations of the water table with respect to the CCR placement zone and hydraulic conductivities, rates, and directions of groundwater flow in all aquifers potentially influenced by the CCR. Predictions of post-reclamation groundwater flow would require an understanding of the material properties of the spoil and CCR, including the hydraulic conductivities of the material upon emplacement, and an approximation of the placement geometry. As described in Chapter 3, water flow paths can change dramatically because of CCR emplacement. Groundwater flow through fractured rock, including coal, is difficult to quantify, and adequate site characterization information about fractures is costly to obtain, because prediction of flow requires knowledge of the number, size and thickness, and continuity of the fractures (NRC, 1990, 1996a; Domenico and Schwartz, 1998). Similarly, groundwater flow through heterogeneous coal spoils, which may contain both matrix and conduit (or pseudokarstic) flow (Hawkins and Aljoe, 1991; Smith and Beckie, 2003), is difficult to quantify.

Information on unsaturated flow characteristics is required to define the rate of contaminant migration into the groundwater zone, especially when CCRs are placed above but in close proximity to the water table. Prediction of water movement in the unsaturated zone requires information on values of hydraulic conductivity for CCR, spoil, and other materials as a function of water content and wetting and drying histories. Information on surficial topography relative to hydraulic conductivity variations may provide additional information about local infiltration at the land surface.

Sufficient data should be collected to estimate travel times for contaminants to the habitats of sensitive receptors and to the nearest monitoring wells. A thorough groundwater flow characterization will also inform the design of an effective groundwater monitoring network that will intercept any contaminant plume from the CCR placement site. However, site managers should recognize the degree of uncertainty in groundwater flow data to determine the appropriate number of downgradient monitoring wells, with greater uncertainty warranting more monitoring wells. Groundwater monitoring is discussed in greater detail in Chapter 7.

***Surface Water Flow.*** Large amounts of surface water flow data are typically collected in the standard mine permit application. However, the addition of CCR placement at a mine site necessitates that there be a clear understanding of the interconnections between groundwater and surface-water flow under pre-mining, mining, and post-reclamation conditions. Due to concerns about flooding and erosion at the CCR placement site, the configuration of the site with respect to the 100-year floodplain should also be verified.

## Biogeochemical Environment

Flow characteristics alone are not sufficient to develop a site conceptual model of the behavior of CCRs in the mine setting because the biogeochemical conditions at the site have a significant influence on the mobility of contaminants. Understanding the biogeochemical environment in the mine setting requires information on the groundwater chemistry, the mass and form of mineral phases present at the site, and the dominant microbially mediated geochemical reactions. With this information, geochemical models can be used to explore the likely reactions that may attenuate or enhance transport of contaminants in the subsurface. When this information is combined with knowledge of groundwater flow and transport properties and the leaching behavior of CCRs (discussed later in this chapter), the potential impacts of CCR placement on groundwater and surface-water quality can be estimated.

***Water Quality.*** A thorough assessment of pre-placement groundwater and surface-water quality in both disturbed and undisturbed areas of the mine is essential to evaluate possible environmental impacts of the CCR once it has been emplaced. Such characterization should assess the seasonal variability in water quality both upgradient and downgradient of the proposed placement site, as well as within the mine spoil. In addition to SMCRA-recommended water quality parameters (e.g., pH, alkalinity, iron, manganese, sulfate), background water samples should be analyzed for a complete suite of metals and metalloids potentially associated with CCRs (i.e., gold, aluminum, arsenic, boron, barium, beryllium, cadmium, chromium, cobolt, copper, mercury, molybdenum, nickel, lead, antimony, selenium, thallium, uranium, vanadium, zinc). Although this list appears long, it is important that background groundwater and surface waters be analyzed for an extensive suite of metals and metalloids because the characteristics of all CCRs that will be placed in the mine cannot be known in advance. Even if the current CCR characteristics are known, the chemical characteristics of future CCRs may change with a new source fuel, different combustion technologies, or additional pollution control technologies (see Chapter 2). A complete suite of major anions and cations should also be measured to support any geochemical modeling.

As noted in Chapter 4, the EPA has encountered difficulties in evaluating the impacts of CCR placement at mine sites because of the inability to distinguish the effects of CCRs from preexisting mining-related activities (USEPA, 1999b). Improved pre-placement characterization of water quality across mine sites will help remedy this problem.

***Geological Materials.*** Coal mine spoils contain sulfide minerals (e.g., pyrite) that can have a significant impact on local water chemistry and, therefore, on the behavior of CCRs in the mine setting. Where oxygen is plentiful, as in the unsaturated zone, sulfide minerals will oxidize, releasing acid, sulfate, and trace metals (see Sidebar 3.2). Two primary forms of information can be collected to help assess the potential for AMD: (1) physical and mineralogical data and (2) acid-base accounting analyses.

Information on the mineralogy of geologic solids in the coal spoils can be used to estimate both the rates of sulfide mineral oxidation (and thus acid generation) and the rates of acid neutralization through reactions with other minerals, such as calcite. For example, framboidal pyrite is much more reactive than pyrite crystals with other morphology. Similarly, calcite is more reactive than other carbonate minerals in coal spoils, leading to higher neutralization reaction rates (Blowes et al., 2003b). Data on the physical properties of geologic materials, including moisture content, grain-size distribution, and the overall shape of the spoils, are necessary to quantify the rates of in-situ sulfide oxidation (Blowes et al., 2003a,b).

Acid-base accounting quantifies the potential for acid generation and acid neutralization in a geologic solid based on laboratory tests. This approach is frequently used to calculate the blending ratio of CCRs to spoil in order to neutralize acidity generated at the site and thereby help remediate the effects of AMD (see Chapter 3). Acid-base accounting methods fall into two categories: static testing methods (e.g., Sobek et al., 1978; Kania, 1998) and kinetic testing methods (e.g., Hornberger and Brady, 1998; ASTM, 2001). The static method commonly involves batch titrations with strong acids and/or bases to determine the potential for acid generation and acid neutralization reactions to occur. Kinetic methods are designed to emulate field conditions and may involve exposing a sample to alternating wetting and drying conditions to promote oxidation reactions before the drainage waters are analyzed for pH, alkalinity, and concentrations of sulfate and dissolved metals.

Qualitative comparison of these acid-base accounting methods to field behavior suggests that the predictions of acid generation are generally good. Nevertheless, there can be notable variability in how acid-base accounting tests are performed in the laboratory (e.g., Sobek method, modified Sobek), and those who interpret the data should understand what analytical method was used and how the results of that method relate to field behavior. There are a substantial percentage of cases where the acid neutralization potential has been overestimated, especially with static tests. For example, many sources of bases may not be available for dissolution due to the formation of coatings that prevent contact of the acid with the base. For cementitious CCRs in particular, the base may not be accessible for acid neutralization. When the results of acid-base accounting are inaccurate, the addition of CCRs may not be sufficient to neutralize acidic conditions or they may neutralize the acid over the short term, only to see the return of AMD after the source of alkalinity is exhausted. Careful attention should be given to acid-base accounting, considering the potential uncertainties in the analyses and site conditions, when CCRs are placed at mine sites. Because of the potential for error in acid-base accounting, kinetic tests have been increasingly utilized, and efforts have been made to more accurately quantify the spatial variability at mine sites in acid-base accounting calculations (Perry, 1998). Also, safety factors have been employed when determining the amount of base (e.g., carbonate minerals, lime, alkalinity in CCRs) needed to neutralize acid-generating material in the reclamation process (Hornberger and Brady, 1998; Perry, 1998).

The above tests are focused primarily on predicting the potential for acid generation at mine sites and to a lesser extent the potential for the release of toxic elements. The tests are not focused on assessing attenuation reactions other than those resulting as a direct consequence of acid neutralization. There is potential for other reactions to contribute to the attenuation of toxic elements, particularly where groundwater flow paths are long and geological conditions are such that they promote contaminant attenuation reactions (e.g., clays, reactive organic matter). This is an area of active research and a uniform approach to predicting these attenuation reactions has not been developed.

### Proximity to Sensitive Receptors

Management decisions regarding CCR disposal at mine sites require an understanding of the risks to local receptors. Therefore, the locations of sensitive receptors should be identified as part of the site characterization process. These receptors may include neighbors who rely on groundwater for their drinking water supply, local communities that may be affected by CCR placement operations, and aquatic and terrestrial biota or grazing livestock inhabiting areas that could potentially be impacted by CCR-derived contaminants.

## Prediction Methods for Site Characterization

A large portion of the site characterization information discussed can be gathered from field data collection and laboratory analyses. Nevertheless, predictive tools can also be useful to assess the potential impact of CCR placement on water flow and water quality. The advantages and limitations of using computer modeling tools for predicting subsurface water flow and contaminant transport in site characterization of CCR mine placement sites are discussed below.

### Methods for Predicting Water Flow

Methods for predicting water flow in homogeneous porous media have been well developed. There are a number of computer models available for prediction of both unsaturated and saturated groundwater flow based on site-specific data input (see Sidebar 6.2). Below the water table, flow calculations are usually conducted in two or three dimensions. Above the water table, calculations for predicting water flow are more computationally extensive, and therefore are often performed in only one or two dimensions. Porous media groundwater flow models can be successfully applied to some coal spoils, particularly those with finer-grained materials without large conduits and voids.

Most commonly applied groundwater flow models, however, are not suitable for application in aquifers with fracture-dominated flow. In fact, EPA stated that it was unable to estimate risks from minefills because its models were "not able to account for conditions such as fractured flow that are typical of the hydrogeology associated with mining operations" (65 FR 32214). Several models are available to simulate flow in fractured rock (see Sidebar 6.2) but the application of such models to mining projects has been limited due to the complexity of the models and the difficulty of obtaining the required input data. NRC (1996a) provides an overview of approaches for modeling flow in fractured media.

For model applications, uncertainty in groundwater flow calculations is often related to limited or poor-quality model input data, including inadequate representation of hydraulic conductivity variations, lack of data on water recharge rates, and lack of information on the rate of water flowing into and out of the model domain. These parameters are often estimated or extrapolated over large areas, resulting in model calculations of limited value. Unsaturated flow models require additional data on local precipitation rates, evaporation and evapotranspiration rates, and values of hydraulic conductivity as a function of wetting and drying history, which are rarely available at the local scale. Therefore, at most mine sites, model calculations to estimate water flow are generally limited to saturated flow through materials that can be treated as porous media.

## Methods for Predicting Contaminant Transport

Prediction of contaminant release requires integration of physical transport processes and biogeochemical reactions, including oxidation reactions, neutralization reactions, and attenuation reactions. Because the number of processes that require integration is large, computer models can be valuable tools for exploring the effect of various CCR placement options on contaminant release over time.

***Existing Models and Research Needs.*** A number of modeling tools have been developed to predict contaminant transport (see Sidebar 6.2), and there is potential for applying these tools to predict the rate of contaminant release and transport at CCR mine placement sites. In these models, the degree of system complexity ranges widely. The most complete models include equations describing the physical transport of oxygen in the unsaturated zone, the flow of water under unsaturated and saturated conditions, and reactions both in the solution phase

## SIDEBAR 6. 2
## Modeling Tools for Site Characterization

Numerical models are valuable tools for assessing the potential for contaminant transport from CCR mine disposal sites. Numerical flow and reactive transport models can be divided into three broad categories: water flow models, geochemical models, and models that integrate flow and geochemistry. Water flow models can be further divided into those that predict unsaturated water flow, saturated water flow, and surface water flow and those that integrate flow between two or more of these domains. Static geochemical models typically are equilibrium-based and include acid-base, oxidation-reduction, aqueous complexation, precipitation-dissolution, ion exchange, adsorption-desorption, and gas transfer reactions. Prediction of contaminant transport requires integration of water flow and geochemical processes. This integration can range from a simple mixing cell approach to fully coupled multicomponent reactive transport formulations with the possible inclusion of equations to account for slow reaction kinetics.

A number of computer models are available for integrating water flow, oxygen transport, and a broad range of geochemical reactions to predict the movement of contaminants in the subsurface (e.g., Lichtner et al., 1996; Wunderly et al., 1996; Brown et al., 1998, 2001; Stollenwerk, 1998; Kent et al., 2000; Mayer et al., 2002; Nordstrom, 2003). These models have been applied to a number of mine sites representing a range of climatic settings (e.g., Wunderly et al., 1996; Bain et al., 2000, 2001; Banwart and Malmström, 2001; Mayer et al., 2002, 2003; Garvie et al., 2003; Nordstrom, 2003; Jurjovec et al., 2004; Molson et al., 2005). For example, reactive solute transport models have been applied to assess the longevity of solute release from coal mines (Gerke et al., 1998; Banwart and Malmström, 2001) and to evaluate closure scenarios (Garvie et al., 2003). In general, the quality of the predictions is related to the quality and amount of data used for the calculations

(e.g., complexation) and between the solution and the solid phase (e.g., adsorption, cation exchange, dissolution). Reaction kinetics can be included to represent variations in mineral dissolution and precipitation rates, reaction catalysis by microorganisms, and other reaction-limiting processes.

The limitations in applying these models are primarily the acquisition of sufficient data and the commitment of sufficient resources to model development and testing for the specific application of CCR placement in coal mine sites. Successful application of these models requires detailed information on the geologic media through which the solutes are transported (e.g., moisture content as a function of wetting and drying history, grain size, solid-phase mineralogy, composition of mineral coatings, surface area, presence of organic matter). For the majority of coal mine sites, these data are not available, limiting the application of reactive solute transport models. Application of these models to CCR sites would require additional data (e.g., moisture content relationships for CCR as a function of wetting and the complexity of processes included. These models have not been applied to coal mine sites containing CCRs.

**Model Categories:**[a]

Saturated Water Flow Through Porous Media (not suitable for fractured media):
e.g., MODFLOW
Unsaturated Water Flow Through Porous Media;
e.g., SEEPW, HYDRAS, HYDRAS2D
Saturated Water Flow Through Fractured Media:
e.g., FRAC3DVS, FRACTRAN, NETFLO, SWIFT-98, TRAFRAP-WT
Unsaturated Water Flow Through Fractured Media:
e.g., FRAC3DVS
Surface Water Flow:
e.g., HEC-RAS
Geochemical Equilibrium Models:
e.g., MINTEQA2, PHREEQC, GEOCHEMIST'S WORKBENCH
Sulfide Oxidation Models:
e.g., PYROX, SULFIDOX
Reactive Solute Transport Models:
e.g., PHREEQC, MINTRAN, FLOTRANS, HYDROGEOCHEM
Reactive Solute Transport Models Incorporating Sulfide Oxidation Reactions:
MINTOX, MIN3P, MULTIFLOW

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[a] Models listed are examples and include those that fall into the public domain, proprietary codes, and those developed for research applications.

and drying history, reactions controlling the interactions between CCR leachate and coal spoil materials) and some research contributing to model development to answer questions such as: What geochemical reactions control CCR leaching? What is the influence of CCR leachate on microbial activity?

There have been only limited applications of these reactive transport models to coal spoil sites and no application at coal sites with CCR placement. Therefore, research is needed to apply the models to real field sites and to evaluate whether the transport and reaction processes included in the model adequately describe the processes taking place at CCR mine disposal sites, including those that occur over protracted time scales. Additional research may be needed to modify the models accordingly. Therefore, research is necessary before current reactive transport models can be used to make meaningful long-term predictions of the potential environmental impacts from CCR disposal in mines. Even after these models are tested and become widely available, their use may still be limited except at the largest CCR disposal sites due to the input data requirements and the need for skilled specialists to run the models.

***Interim Suggestions for Using Predictive Modeling Tools.*** Simpler models exist today that can be used to increase understanding of contaminant transport at CCR sites. The application of such models in concert with a robust field sampling campaign can allow for reasonable estimates (although still with significant uncertainty) of potential CCR-related contaminant movement. Steps can be taken to improve modeling efforts that will lead to enhanced predictions of contaminant transport from mine sites and improved placement of groundwater monitoring wells. These steps include (1) improving the quality of model input data, (2) focusing first on understanding conservative contaminant transport, (3) incorporating unsaturated zone flux, and (4) conducting a "post-audit" to evaluate the success of the modeling.

Improving the quality of model input data is one of the best ways to increase the usefulness of groundwater flow and contaminant transport modeling at CCR mine disposal sites. For example, saturated flow models are routinely used to assess groundwater flow directions based on very limited data—often water-level and hydraulic conductivity data from only a few wells. Increasing the amount of input data and including data on the hydraulic conductivity of CCRs should significantly improve groundwater flow predictions. Numerical models can also be used to examine the sensitivity of simulated outcomes to uncertainty in the input data and can potentially identify the most critical site characterization data needs to improve predictions of contaminant transport. A well-developed site conceptual model that is supported by site characterization data should form the basis of the numerical model. For example, understanding the role of fracture-driven flow is essential to determine whether a porous media model can be used to make meaningful predictions. Predicting contaminant transport rates and directions in fractured media requires extensive additional site characterization and a more involved modeling effort, and even with such an intense effort, the simulations are likely to contain sizable uncertainties.

Site managers could derive significant benefit from numerical modeling, even if it focuses only on conservative transport of contaminants. These more simplistic models can be used to estimate the directions of flow and the time of travel, which is essential information for siting monitoring wells that can detect potential contamination within an early time frame. Such models can also explore the effects of various CCR emplacement scenarios on groundwater flow.

Depending on the site characteristics and the CCR characteristics, significant leaching may occur at sites where CCR is placed above the water table. Therefore, models should incorporate, at a minimum, a contaminant flux term from the unsaturated zone, considering estimated recharge rates for the site.

Collection of subsurface flow and water quality data close to the CCR emplacement area after disposal provides valuable information for testing model predictions. A number of soluble constituents in CCRs, such as borate, are good indicators of conservative transport, and these constituents can be used to assess whether subsurface flow calculations are reasonable. Valuable lessons can be learned through these post-audits to improve the simulation at the site and to provide guidance for future modeling at CCR placement sites (Konikow, 1986). Such a review could also confirm that monitoring wells were placed in meaningful locations.

## CCR CHARACTERIZATION

CCRs vary greatly in chemical and mineralogical composition. Trace elements can be tightly bound within glasses and residual minerals in CCRs, or they can occur as easily leachable coatings on grain surfaces. Some, but not all, CCRs contain large quantities of alkaline materials (see Chapter 2). To understand the potential risks involved in placing significant volumes of a particular CCR in the mine setting, careful CCR characterization is needed.

Characterization of CCRs is an essential component in the development of a site conceptual model that will help site managers and regulators make management decisions regarding CCR placement at mine sites. Characterization of CCRs prior to mine placement may involve analyses of bulk chemical and physical properties and trace element leaching potential. The results of these characterization tests should be used in conjunction with an assessment of the mine hydrogeology and biogeochemistry to provide an evaluation of the potential for beneficial and/or deleterious impacts from CCR placement at a mine site.

Many states rely on CCR characterization tests—primarily leaching tests—to determine whether CCRs are suitable for mine placement (see Sidebar 6.3 and Table 6.1). Currently, characterization methods required to determine the safety of CCR placement are relatively simple tests compared to those that have been developed for research purposes. This section describes common and alternative CCR characterization methods, including their limitations and advantages.

### Bulk Chemical and Physical CCR Analyses

Leaching of contaminants from CCRs is dependent on a range of physical and chemical properties of the CCR, including bulk properties and microscale properties. Characterization of bulk properties provides information that can be used to assess the stability of CCRs in the mine setting.

Bulk physical properties include the grain size distribution and surface area available for reaction, permeability upon compaction, and whether or not the CCR grains are cemented together. In general, fine-grained materials will have a higher surface area, increasing the opportunity for reaction. Highly cemented materials will limit ingress of water into the CCR, thereby limiting reaction. Laboratory testing can be conducted to assess the cementitious properties of

## SIDEBAR 6.3
## Uses of Leaching Tests at the State Level

States use a range of methods to characterize CCRs and thereby evaluate the appropriateness of CCR mine placement. Most states require the Toxicity Characteristic Leaching Procedure (TCLP), although some states use alternate leaching tests such as the Synthetic Precipitation Leaching Procedure (SPLP) or the American Society for Testing and Materials (ASTM) D-3987 (see Table 6.2) (USEPA, 2002c), and other states may use multiple tests. Likewise, states differ in the standards they use to evaluate the results of leaching tests and to classify the wastes. Generally, the leaching test data are evaluated against either (1) Resource Conservation and Recovery Act (RCRA) standards for “characteristic” hazardous wastes based on the concentrations of toxic metals in the leachate or (2) an end-use water quality standard (e.g., drinking water maximum contaminant levels [MCLs]) multiplied by a factor that takes into account dilution and attenuation processes likely to occur in the environment. For example, Ohio uses a leaching test limit of 30 times the drinking water standards for specific metals, while Illinois uses class I groundwater standards as its leaching test limits (Table 6.1). It should be noted that these standards for classifying or categorizing materials do not consider site-specific conditions and are applied across an entire state. Table 6.1 presents some examples of the variability of leaching test limits across several states and includes the RCRA toxicity limits, MCLs, and secondary MCLs for the purpose of comparison.

CCRs and whether any additions to CCR such as lime can promote greater cementation.

Bulk chemical properties include the total metal content of the CCRs, the residual sulfide content, and the content of alkali or acid in the solid. The bulk chemical composition of CCRs provides an indication of the maximum concentrations of major and trace elements that can be leached from them. Materials with unacceptably high total concentrations of highly toxic elements such as mercury can be segregated and handled with greater caution. Analyses of bulk metal content also provide a basis for comparing the results of specific leach tests to assess the relative fraction of metals that can be leached under different conditions that might occur at the mine site. Analyses of residual sulfide content and form will influence the potential acid that might be generated as the CCR weathers. Similarly, determinations of acid neutralization potential are necessary to evaluate whether particular CCRs can moderate the AMD generated at the mine site. Acid-base accounting tests (discussed previously in this chapter) are applied routinely at mine sites and can be applied in a similar manner to assess the neutralization potential of CCR materials relative to the acid generation at coal sites (e.g., Kania, 1998; Perry, 1998).

## Leaching Tests

Leaching tests assess the potential release of trace elements from CCRs and are commonly applied approaches to CCR characterization (see Sidebar 6.3). Nevertheless, the effectiveness of these testing procedures for predicting CCR behavior in the mine environment has not been thoroughly evaluated. Numerous leach tests are available commercially or in the research community. Kim (2002b) provides a summary of more than 100 leaching protocols, including single-point static batch tests, multipoint serial or sequential batch experiments, and column leaching methods. The concentrations of trace elements that leach from CCRs depends on the initial composition of the CCRs, the composition of the leaching solution, and the rates of water flow. The advantages and limitations of these leaching approaches are discussed below.

### Single-Point Batch Leaching Tests

The simplest leaching tests are static batch methods in which a CCR sample is placed in a set volume of leaching solution and the mixture is agitated for a fixed time. A leachate sample is then collected and analyzed, providing water chemistry data for this single sampling point. Ideally, these tests would represent post-placement conditions; and a wide variety of single-point batch leaching tests with different leaching solutions, contact times, and solid-to-solution ratios are available. Leaching solutions can range from solutions of very low pH (e.g., < 2), as observed in high-sulfur coal fields, to highly basic solutions, similar to those associated with alkaline ash. Some examples of commonly used single-point leach tests are presented in Table 6.2.

The Toxicity Characteristic Leaching Protocol (TCLP), developed by the EPA (USEPA, 1994), is the most widely used leaching procedure to evaluate leaching of CCRs for placement in mines. The TCLP was originally developed to provide a standardized method for assessing the potential for leaching of contaminants from solid wastes disposed in a municipal solid waste (MSW) landfill and acetic acid solution was selected as the leaching solution to simulate the composition of pore waters present in MSW landfills during early stages of operation. The TCLP is specifically required in the CCR permitting process by 8 out of 23 states examined by EPA (USEPA, 2002c) and many commercial laboratories have the capability to perform this test. Other states require different single-point leaching tests. For example, New Mexico requires an 18-hour distilled water test (American Society for Testing and Materials [ASTM]-3987), while Pennsylvania requires the Synthetic Precipitation Leachate Procedure (SPLP; see Table 6.2).

The reliance on single-point batch leaching procedures, such as the TCLP, for prediction of CCR stability in mine settings has been widely criticized because (1) the composition of the initial leaching solution may not be representative of the range of leaching conditions encountered in the field; (2) the character-

**TABLE 6.1** CCR Leaching Test Methods and Standards for Evaluating Test Results Across Several

| | Maximum Acceptable CCR Leachate Concentrations (mg/L) | | | |
|---|---|---|---|---|
| | West Virginia | Ohio | Pennsylvainia | Illinois |
| Test Method: | TCLP | TCLP | SPLP | ASTM D-3987-85 |
| Al | | | 5.0 | |
| Sb | 1 | | 0.15 | 0.006 |
| As | 5 | 0.30 | 1.25 | 0.05 |
| Ba | 100 | 60 | 50 | 2 |
| Be | 0.007 | | | 0.004 |
| B | | | 31.50 | 2 |
| Cd | 1 | 0.15 | 0.13 | 0.005 |
| Co | | | | 1 |
| Cr | 5 | 3 | 2.5 | 0.1 |
| Cu | | | 32.5 | 0.65 |
| Fe | | | 7.5 | 5 |
| Pb | 5 | 0.45 | 1 25 | 0.0075 |
| Mn | | | 1.25 | 0.15 |
| Hg | 0.2 | 0.06 | 0.05 | 0.002 |
| Mo | | | 4.38 | |
| Ni | 70 | | 2.5 | 0.1 |
| Se | 1 | 1.5 | 1.00 | 0.05 |
| Ag | 5 | | | 0.05 |
| Tl | 7 | | | 0.002 |
| Zn | | | 125 | 5 |
| $SO_4$ | | | 2,500 | |
| Cl | | | 2,500 | |

NOTE: MCL = maximum contaminant level; RCRA = Resource Conservation and Recovery Act

[a] Lead and copper are regulated by a treatment technique. If more than 10% of tap water samples exceed the action level, water systems must take additional steps.

istics of the final leaching solutions are not usually controlled or even monitored in the tests and may differ markedly from those of the initial leaching solution; and (3) secondary precipitates may form due to solubility limitations in the batch experiments (USEPA SAB, 1991, 1999). The TCLP has also been criticized for its short extraction time, which might overlook the potential for slow release of constituents, and for the lack of field validation of the test (USEPA SAB, 1991). As a consequence of these limitations, leaching may either be under- or overestimated by single-point tests leading to inappropriate decisions regarding placement of CCRs in mines (Vories, 2002). To address these concerns, alternative

States Compared to RCRA Toxicity Limits, MCLs, and Secondary Drinking Water Standards

| RCRA Toxicity Limits (mg/L) | Drinking Water MCLs (mg/L) | Secondary Drinking Water Standards (mg/L) |
|---|---|---|
| | | 0.05 to 0. 2 |
| | 0.006 | |
| 5.0 | 0.01 | |
| 100 | 2 | |
| | 0.004 | |
| | Under review | |
| 1.0 | 0.0050 | |
| | | |
| 5.0 | 0.1 | |
| | $1.3^a$ | 1.0 |
| | | 0.3 |
| 5.0 | $0.015^a$ | |
| | | 0.05 |
| 0.2 | 0.002 | |
| | | |
| | | |
| 1.0 | 0.05 | |
| 5.0 | | 0.1 |
| | 0 002 | |
| | | 5 |
| | | 250 |
| | | 250 |

SOURCES: Ziemkiewicz and Skousen, 2000; USEPA, 2004a; IL Title 35 Subtitle F Chapter 1 Section 620.420; 40 CFR §261.24.

leaching procedures are being examined in hopes of finding a test that more accurately represents the potential for leaching hazardous substances from CCRs.

### Serial, Sequential, and Multipoint Batch Leaching Tests

To improve predictions of long-term leaching and address concerns about potential solubility limitations and inappropriate leaching solutions, serial and sequential batch leaching procedures have been developed (Kim, 2002b). For example, a serial batch procedure has been developed to simulate leaching ex-

**TABLE 6.2** Examples of Single-Point Static Batch Leaching Tests

| Method | Leachant | Sample Size (g) | Initial Leachant pH | Liquid/ Solid Ratio | Time (hr) |
|---|---|---|---|---|---|
| Standard Test Method for Shake Extraction of Solid Waste with Water (ASTM D3987) | $H_2O$ | 70 |  | 20 | 18 |
| Extraction Procedure Toxicity Test (EPTOX) | $H_2O$, acetic acid | 100 | 5.0 | 20 | 24 |
| Synthetic Precipitation Leaching Procedure (SPLP) | $H_2O$, nitric acid, sulfuric acid | 100 | 4.2 | 20 | 18 |
| Toxicity Characteristic Leaching Procedure (TCLP) | Acetic acid oracetate buffer | 100 | 2.88 | 20 | 18 |
| California Waste Extraction Test (CA WET) | Sodium citrate | 50 | 5.0 | 10 | 48 |
| Synthetic Groundwater Leaching Procedure (SGLP) | $H_2O$, synthetic groundwater | 70 |  | 20 | Up to 1440 |

SOURCE: Kim, 2004.

pected to be encountered in weathered coal spoils and workings. This mine water leaching procedure uses simulated AMD or actual mine water as the leaching solution and replenishes this solution until a pH of 3 is reached in the leachate (Ziemkewicz et al., 2003). Other serial batch methods include ASTM D5284 and EPA's multiple extraction procedure.

Test methods have also been developed to evaluate leaching that could potentially occur under a range of geochemical conditions that might be encountered at a site. For example, sequential batch experiments have been designed that utilize multiple leaching solutions of different compositions in a prescribed sequence (e.g., Tessier et al., 1979; Palmer et al., 1999). Similarly, multipoint procedures have been developed to evaluate leaching under a range of geochemical conditions or solid-to-solution ratios (e.g., Kosson et al., 2002). The advantage of these procedures is that the results obtained are theoretically more representative of the wide range in composition of leaching fluids that can be observed in the field, and test results can be obtained in a relatively short time (days to months).

A multipoint leaching procedure that varies solid-to-solution ratios and leaching times and covers a large range in leachate composition is described by Kosson et al. (2002). This proposed leaching framework also includes a combination of batch and column leaching methods. By combining laboratory leaching data, field data, and advanced geochemical modeling within the proposed leaching framework, a conceptual model can be developed that can be applied to evaluate leaching under the range of geochemical conditions expected to be encountered in the field. Limitations of this approach include higher skills required to perform the test and subsequent model calculations, therefore leading to higher costs.

The above methods range greatly in cost and the final selection of a method may require a trade-off between characterizing a few samples in great detail or a larger number of samples in less detail. It should also be noted that the above methods do not specifically address the potential for leaching under the suboxic conditions that often prevail beneath the water table in coal spoils. Performing leaching tests under conditions that mimic suboxic field conditions requires high technical skills and specific equipment, which would add further to testing costs.

### Column Leaching Tests

Column leaching tests evaluate contaminant leaching under continuous flow conditions. The advantage of column leaching tests is that reaction products are flushed from the column and are not allowed to build up to concentrations that may artificially lead to precipitation. Column experiments using fine-grained CCRs require slow flow rates and operation for long periods of time, on the order of months or more. Thus, column leaching experiments are more costly than batch tests.

Chapter 3 discusses two column leaching studies (Stewart et al., 2001; Kim et al., 2003) that demonstrated the potential for fly ash to exhibit notably different leaching behavior under acidic, neutral, or alkaline pH. These studies suggest that careful CCR characterization using representative leaching solutions is required to predict adequately the potential for leaching at mine sites.

### Field-Leaching Tests

A number of CCR characterization tests can be carried out at the field scale; these range from relatively small test plots to much larger instrumented pilot test areas. Test plots have been used to assess the leaching of elements from co-blended CCR and coal spoils (e.g., Stewart and Daniels, 1995). In these types of studies, CCRs are emplaced and leaching is monitored by collecting water samples in pan lysimeters. These test plot characterization approaches are more likely to approximate the behavior of CCRs in real-world settings, although one limitation of these tests is that they are usually carried out very close to the ground surface where contact with atmospheric oxygen is highest. Results obtained from the tests, therefore, may not be representative of leaching conditions that occur in deeper zones where suboxic conditions might prevail.

Recent research has compared laboratory leaching tests with field behavior at CCR disposal sites (Ladwig et al., 2006). Field leachate from sluiced ash was compared to the results from two laboratory leaching protocols—the SPLP and a synthetic sluicing procedure. The agreement between the field data and the leaching test protocols was variable. The laboratory results generally ranged about one order of magnitude both above and below the field-collected data, depending on the trace element of interest, although some trace element concentrations showed variations of more than two orders of magnitude between the laboratory and field leaching data (Ladwig et al., 2006). These results suggest that improvements in laboratory leaching protocols are necessary if they are to be considered representative of CCR behavior in the field.

### Research Needs

Currently there is a lack of detailed assessment of the applicability of laboratory test methods to predict field behavior of CCRs emplaced in mines. There has been little evaluation of whether leaching results obtained using small-scale laboratory batch and column tests correlate well with results obtained in field test cells and from field leaching monitoring at full-scale emplacement sites. Research is needed to continually improve and field-validate leaching tests that can be used to better predict the mobilization of CCR-derived constituents in mine settings.

Two approaches can be taken to fill this knowledge gap. The first is to establish a carefully planned research program designed specifically to fully characterize the leaching characteristics of CCRs at the laboratory scale and compare the results to field-leaching test plots and to highly instrumented full-scale field sites. This characterization research should utilize fully coupled reactive solute transport models that incorporate the major physical and biogeochemical processes controlling leaching behavior. This approach is currently being taken at metal mine sites to help develop meaningful laboratory tests. The major limitation of this approach is the long time required to obtain results.

The second approach for addressing these knowledge gaps is to conduct several post-CCR-placement studies at coal mine sites, such as the work under way at the Universal Mine site in Indiana (Murarka et al., 2002). Detailed monitoring systems could be installed to evaluate groundwater and leachate water quality. If sufficient site characterization data are collected, advanced numerical models can be used to integrate these data. The results could then be compared with leaching tests performed at the time of emplacement and with more detailed tests performed on original archived samples of CCR, if available. Such post-audit-type studies provide opportunities to explore many geochemical processes that occur at CCR placement sites over time, such as acid generation and neutralization, oxidation-reduction, precipitation and dissolution, adsorption and desorption, and the potential for biological catalysis of these reactions.

## Interim Suggestions for CCR Characterization

To contribute to the evaluation of the risk of CCR mine placement, CCRs should be characterized prior to significant mine placement and with each new source of CCRs. CCR characterization should continue periodically throughout the mine placement process to assess any changes in CCR composition and behavior.

Current characterization practice relies heavily on laboratory leaching tests, in particular the TCLP, to evaluate the potential hazards of CCR placement in mines. These tests do not use leaching solutions that are representative of the large range of geochemical conditions likely to be encountered in mines, and they may greatly underestimate the actual leaching that will occur. It is recommended that leaching procedures be continually improved to encompass the range of pH and oxidation-reduction conditions that might be encountered in pore-water close to the CCR placement area over an extended time (many decades to centuries). Leaching tests should also assess slower dissolution reactions.

Until some recently proposed leaching protocols are evaluated more thoroughly, some simple improvements to currently applied leaching protocols can be made. As a first step, a wider range of leaching conditions should be applied in static leach tests. These leaching conditions should include low-pH leaching solutions to represent the aggressive leaching that may occur in the most reactive areas of the unsaturated zone. The composition of the leaching solution should be monitored both before and after leaching is complete to ensure that the final leaching solution is representative of expected conditions at the mine site. Leaching tests should be conducted over longer periods (e.g., several weeks) and a few solid-to-solution ratios should be evaluated to assess whether precipitation controls are limiting leaching characteristics. Samples that do not pass a predetermined criterion should be rejected for mine placement. Samples that do pass the criterion may still have to be evaluated in greater detail, depending on the potential risks of CCR placement determined from site characterization, including column leaching tests and longer-term evaluations of leaching as CCR materials age.

## INTEGRATION OF CCR AND SITE CHARACTERIZATION DATA

Current site characterization is usually conducted independently of CCR characterization. In practice, site characterization and CCR characterization should be carried out in an integrated fashion to provide the information needed to develop a site conceptual model that adequately informs CCR management decision making in a way that is protective of the environment. For example, site characterization data are needed to inform the design of relevant leaching tests, by providing the range of geochemical conditions that might be encountered over long periods of time (decades to centuries) at the mine site. Likewise, an understanding of the total mass and leachability of the contaminants in CCRs to be disposed at a mine site is needed to evaluate the potential for attenuation through reaction with geological materials. Given the complex hydrology and geochemistry of mine sites, the site conceptual model should be reevaluated as additional site data are obtained (at least annually during active placement).

## SUMMARY

To ensure effective CCR management at mines, thorough CCR characterization and hydrogeologic and biogeochemical characterizations of the mine site are needed. Characterization is an essential part of the CCR management process and serves to guide engineering design, risk-informed permitting decisions, reclamation management, and the development of effective monitoring programs. Characterization is also one means by which managers can address uncertainties. The components of an effective characterization program have been detailed in this chapter.

Site characterization is a dynamic process of developing and continually refining a site conceptual model that captures the relevant aspects affecting the behavior of CCRs in the mine environment. Current site characterization requirements typically are focused on assessing potential impacts from coal mining and do not specifically consider the impacts of CCR placement. **The committee recommends comprehensive site characterization specific to CCR placement at all mine sites prior to substantial placement of CCRs.** The mine site hydrogeology and biogeochemical environment should be defined in both undisturbed areas and preexisting disturbed areas, and the site's proximity to sensitive receptors should be determined. Due to the variability among mine sites, it is difficult to prescribe the precise site characterization data collection steps to follow prior to CCR placement. However, specific categories of site characterization information relevant to CCR placement are detailed in this chapter.

To contribute to the evaluation of risk of placing CCRs at mine sites, **the committee recommends characterization of CCRs prior to significant mine placement and with each new source of CCRs. CCR characterization should continue periodically throughout the mine placement process to assess any changes in CCR composition and behavior.** Characterization of CCR materials prior to mine placement may involve analyses of bulk chemical and physical properties and trace element leaching potential.

Leaching tests are commonly applied to assess the potential release of trace elements from CCRs, and this chapter has discussed advantages and limitations of general classes of leaching protocols. The limitations of single-point batch tests are well recognized (e.g., solubility limitations, inappropriate leaching solutions), although these tests remain in widespread use and have a major role in the regulation of CCR mine placement in many states. *The committee concludes that information on the applicability of laboratory leaching test methods to predict CCR leaching behavior in the field is lacking.* Therefore, **the committee recommends additional research to continually improve and field-validate leaching tests to better predict the mobilization of constituents from CCRs in mine settings**. Specifically, post-placement field studies could be conducted that would allow the comparison of leaching test results against detailed water quality monitoring. Some alternative leaching tests are being developed to address these concerns, but until these proposed leaching protocols are evaluated more thoroughly, the committee recommends some simple improvements to currently applied leaching protocols. In particular, the CCR characterization methods used should provide contaminant leaching information for the range of geochemical conditions that will occur at the CCR placement site and in the surrounding area, both during and after placement. Those samples that do not pass a pre-determined criterion should be rejected for mine placement, although those samples that do pass may still need to be evaluated in greater detail, depending on the potential risks of CCR placement determined from the site characterization.

Site characterization and CCR characterization data should be thoroughly integrated into a site conceptual model, perhaps supplemented by numerical modeling tools, to predict contaminant transport potential and assess the potential impacts of CCR disposal at a mine site. Computer models are valuable tools for integrating physical transport processes and biogeochemical reactions. However, **the committee recommends additional research to apply existing reactive transport models to real field sites and to evaluate whether the transport and reaction processes included in the model adequately describe the processes taking place at CCR mine disposal sites, including those processes that occur**

**over protracted time scales**. In the interim, several steps are identified that can improve modeling efforts that will lead to enhanced predictions of contaminant transport from mine sites, including (1) improving the quality of model input data, (2) focusing first on understanding conservative contaminant transport, (3) incorporating unsaturated zone flux, and (4) conducting a post-audit to evaluate the success of the modeling against monitoring data.

# 7

# Management of Coal Combustion Residues in Reclamation Activities

This chapter describes the basic principles and minimum standards for reclamation and monitoring that should apply to all large-volume minefill applications of coal combustion residue (CCR) in coal mines. It discusses reclamation planning, bonding requirements, reclamation operations, and how CCRs can be incorporated into the reclamation process. The chapter also discusses the hydrological monitoring that accompanies the use of CCRs in reclamation. It outlines the regulatory framework for monitoring at CCR mine placement sites, highlights concerns about existing monitoring programs, and provides recommendations for effective and efficient monitoring programs. It should be noted that the principles and standards for monitoring do not apply to the use of CCR as traction material for haul roads or other incidental low-volume uses. Also, the reclamation section of this chapter does not specifically consider the placement of CCRs in underground mines, which poses more complex technological difficulties—especially abandoned underground mines, where there is no practical way to isolate the CCR from the surrounding hydrologic regime.

## RECLAMATION

Reclamation planning is an integral part of the entire mining process and begins before excavation is started. As discussed in Chapter 5, reclamation practices are, by definition, regulated by the SMCRA, which established minimum national standards for coal mining. Thus, the use of CCR for minefill has to be viewed in the context of the general reclamation management activities and requirements.

### SIDEBAR 7.1
### A Partial List of the Reclamation Plan Requirements Found in Section 508 SMCRA

- Identify lands subject to surface coal mining along with the size, sequence, and timing of the subareas;
- Document the condition of the land prior to any mining, including the capability of the land to support a variety of uses;
- Describe the use that is proposed to be made of the land following reclamation, including the utility and capacity of the reclaimed land to support a variety of alternative uses;
- Describe how the proposed post-mining land use is to be achieved, including any necessary support activities;
- Provide the engineering techniques proposed for use in mining and reclamation, and describe the major equipment to be used; included in this requirement are a drainage plan, a backfilling and grading plan, a soil replacement plan, and a revegetation plan; and
- Include a timetable for the accomplishment of the plan.

## Reclamation Planning Requirements

The surface mine permit requirements under SMCRA specify the minimum requirements of the reclamation plan (see Sidebar 7.1). The use of CCRs in reclamation would have to be reflected in this plan, especially in the engineering analysis.

In general, there are two levels of land-use planning in any reclamation. At the macro level, land-use planning is carried out by government agencies charged with land-use oversight. This results in comprehensive land-use plans that may be accompanied by zoning regulations or other performance standards. However, in many coal mining areas, such an approach to land-use planning does not occur. At the micro level, land-use planning (also called site planning) is driven primarily by economic factors that are influenced by natural environmental and cultural conditions in and around the site. The relationship between the two levels of land-use planning is illustrated in Figure 7.1. The reclamation plan that is done at the micro level and is prepared by surface mine operators includes a post-mining environmental site plan. This land-use plan is developed using site planning principles while conforming to any macro-level community plans that may exist. It also must consider the landowner's wishes in the case of leased land.

The planning process begins with a thorough analysis of the current site conditions at the mine and the site conditions that are projected to exist following the completion of mining. Site conditions can be categorized as natural environmental factors and cultural factors. In general, natural environmental factors tend

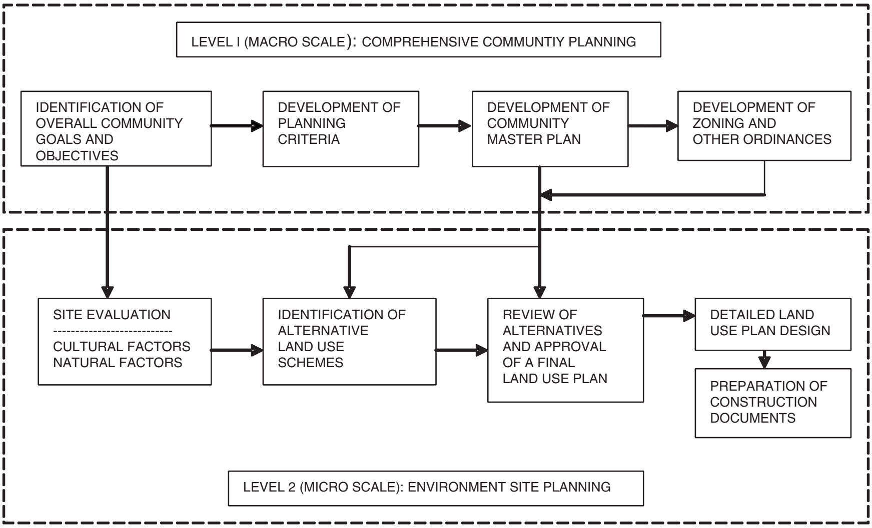

**FIGURE 7.1** Planning levels involved in the mine and land planning process.
SOURCE: Ramani and Sweigard, 1984. Courtesy of the Society for Mining, Metallurgy, and Exploration.

to set physical limits on post-mining land-use capability, while cultural factors have a significant impact on the economic feasibility of any post-mining land use. The natural environmental factors that have the greatest impact on land-use capability include topography, climatology, hydrology, geology, and soil properties. A number of these are impacted by the placement of CCR in the mine. The cultural factors that impact economic feasibility include location, surrounding land uses, and local population characteristics. Post-mining land-use plans must take into account both types of factors. The permitee (i.e., the surface mine operator) is responsible for proposing the post-mining land use, considering landowner wishes and existing macro-level community land-use plans. The SMCRA regulatory agency has the final authority to approve or disapprove of this plan.

## Use of CCR in Reclamation Operations

Coal combustion residues have been used in the reclamation of both abandoned mines, as defined by Title IV of SMCRA, and active mines that are regulated under Title V. The use of CCR in reclamation is not addressed specifically in the regulatory performance standards derived from SMCRA for either active or abandoned mines, although the regulations do allow coal mine waste to be discharged into underground mines as long as the plan is approved by the regulatory authority

(30 CFR. §817.81(f)). However, because SMCRA requires a detailed reclamation plan, including a description of all methods and materials to be used in the reclamation of an active mine, the use of CCR becomes part of the permit approval process. The extent to which the use of CCRs in reclamation operations is addressed by state regulations varies considerably from state to state.

The disposal of CCRs in coal mines occurs under highly variable conditions, ranging from small quantities to massive minefills, from arid to wet regions, from remote to semiurban locations, from surface to underground mines, and from active to abandoned mines. Because of this variability, reclamation plans have to carefully consider site-specific conditions, such as climate, quantity of CCR to be disposed, and post-mining land uses. The committee endorses the concept of site-specific management plans. A flexible approach to managing CCRs in mine sites has advantages since it can embrace the unique characteristics of the CCRs, the total mass of CCRs, and the environment into which they are placed. However, the need to incorporate site-specific factors should not be a basis for adopting management plans that lack rigor. Such plans should be developed in compliance with management and performance standards for using CCRs in minefilling (see Chapter 8 for a complete discussion of the committee's recommendations on enforceable standards).

### Primary Reclamation Operations Involving CCRs

Although reclamation operations vary regionally, they have several common elements that are conducted regularly as part of the mining cycle. Sidebar 7.2 provides a listing of reclamation operations and the sequence in which they occur for active mines. The primary reclamation operations, whether for active or abandoned mines, are backfilling and grading, topsoil replacement, and revegetation. These are also the specific reclamation operations most readily impacted by CCR placement and are discussed more fully below.

***Backfilling and Grading.*** Surface mining of coal involves the creation of an excavation down to the coal, removal of the coal deposit, and subsequent backfilling of the excavation with overburden from succeeding excavations. Backfilling and grading are significant components in satisfying the SMCRA requirement of returning the land to its approximate original contour following surface mining of coal. The method of backfilling is dependent on the type of mining that is being conducted (Sidebar 7.3).

The process of returning the site to its approximate original contour by backfilling and grading is often complicated by either a lack or an overabundance of spoil. A lack of spoil occurs when the coal seam is thick in comparison to the amount of overburden. Conversely, in areas of steep terrain, there may not be enough available space on the bench to contain the rock overburden, which increases in volume when it is fragmented and excavated. In areas of thin over-

## SIDEBAR 7.2
## Time Sequence for Reclamation Activities

I. During site preparation:
  1. Install control measures (water diversion, sediment traps and basins, etc.).
  2. Clear and grub, marketing lumber if possible; stockpile brush for use as filters; run brush through wood chipper, and use chips for mulch.
  3. Stabilize areas around temporary facilities such as maintenance yards, power stations, and supply areas.

II. During overburden removal:
  1. Divert water away from and around active mining areas.
  2. Remove topsoil or topsoil substitutes and store it if possible and/or necessary.
  3. Selectively mine and place overburden strata if possible and/or necessary.

III. During coal removal:
  1. Remove all coal insofar as possible.
  2. For the purpose of controlling post-mining groundwater flows, break—or conversely prevent damage to—the strata immediately below the coal seam as desired.

IV. Immediately after coal removal:
  1. Seal the high wall if necessary.
  2. Seal the low wall if necessary.
  3. Backfill—bury toxic materials and boulders, dispose of waste, ensure compaction.

V. Shortly after coal removal:
  1. Rough grade and contour, taking the following factors into consideration:
     a. Time of grading—specific time limit tied to advance of mining; seasonal conditions
     b. Slope steepness
     c. Length of uninterrupted slope
     d. Compaction
     e. Reconstruction of underground and surface drainage patterns
  2. If necessary, make mine spoil amendments (root zone), taking the following factors into consideration:
     a. Type of amendment—fertilizers, limestone, fly ash, sewage sludge, or others
     b. Depth of application
     c. Top layer considerations—temperature, water retention, mulching, and tacking

VI. Immediately prior to first planting season:
  1. Fine-grade and spread topsoil, taking seasonal fluctuations into consideration.
  2. If necessary, manipulate the soil mechanically by ripping, furrowing, deep-chiseling or harrowing, or constructing dozer basins.
  3. Mulch and tack.

VII. During the first planting season: Seed and revegetate, considering time and methods of seeding, and choice of grasses and legumes.

VIII. At regular, frequent intervals: Monitor and control slope stability; water quality, both chemical (pH, etc.) and physical (sediment); and vegetation growth.

SOURCE: After Ramani and Clar, 1978.

## SIDEBAR 7.3
## Backfilling Methods for Surface Mining Operations

In the midwestern United States and portions of the west where area surface mining is practiced, the overburden is removed using large fixed-base stripping equipment such as draglines or bucket wheel excavators. In those cases, the stripping equipment casts the overburden directly into the excavated pit after the coal has been removed. In the steep slope areas of the eastern United States, two different types of surface coal mining methods are commonly practiced. The contour mining method utilizes mobile equipment to haul the overburden along the contour from the area of the pit from which it is excavated to the area of the pit where coal has already been removed. The mountaintop removal method always utilizes mobile equipment to haul overburden either to an area on the bench where coal has been removed or to an excess spoil disposal area such as a valley fill. Some mountaintop removal mines also use draglines to remove overburden from lower coal seams. In these cases, the overburden is directly cast by the dragline as it would be in an area mine. In parts of the western United States, an open pit type of surface coal mining method is used. Large trucks haul the overburden around the pit and dump it in the part of the pit where coal has been removed. In almost all cases, some grading with dozers is necessary to achieve the approximate original contour after backfilling is completed.

burden, CCRs are used as structural fill material to raise the elevation of the surface and help achieve the approximate original contour. This can reduce the angle of the final slopes and, if necessary, fill in the final cut. In steep terrain, CCRs are used to backfill and seal the holes left in the highwall by augering and highwall mining. If there is sufficient alkalinity in the CCRs, they can be used in backfilling to neutralize acid formed through sulfide oxidation reactions (see Chapter 3).

When CCRs are used in mine backfilling, there are important design factors that should be evaluated in the reclamation planning process by considering the site characteristics, the levels of uncertainty in the site conceptual model, and the estimates of risk (see Chapter 6). Emplacement of CCRs can occur above or below the water table and in volumes that range from small to large. As discussed in Chapter 2, CCRs can be disposed as monofills, as layers interbedded with coal spoils, or as blended mixtures with coal spoils (Figure 2.9). Compaction and/or cementation can also be used to increase the strength of the material and decrease its permeability. If CCRs are used to moderate the effects of acid mine drainage, additional factors such as acid-base accounting and blending CCR with spoil will have to be considered. The impacts of various CCR emplacement designs on groundwater flow and contaminant transport are discussed in detail in Chapter 3.

However, site-specific conditions and CCR characteristics will ultimately influence the relative importance of each of these factors at a CCR disposal site.

***Topsoil Replacement.*** The SMCRA regulations contain specific requirements for the removal, storage, and redistribution of topsoil. The methods used to satisfy SMCRA requirements vary depending on site conditions and from region to region. The most stringent topsoil requirements apply to those areas that are designated as prime farmland. In these cases, the mine operator is required to remove, store, and replace a minimum of 48 inches of soil while segregating the topsoil (A horizon) from the lower soil horizons (the B and C horizons). They must be stored in separate stockpiles, temporarily revegetated, and then replaced in the proper order to ensure that the best growing medium is at the surface. In some steep slope areas where topsoil is extremely thin and of low quality, selected overburden materials are used as a substitute for topsoil when it can be demonstrated that the resulting medium is equal to or better than the existing topsoil for sustaining vegetation. In some cases, CCR is used as a soil additive to neutralize acidic soil. However, as discussed in Chapter 4 and in the following section, the uptake by vegetation of metals and other contaminants that may be present in CCRs is a concern.

***Revegetation.*** Revegetation operations satisfy two separate SMCRA requirements. The first requirement is stabilization of the surface to prevent erosion and sedimentation. The second requirement is to establish the type of vegetation that is needed for the proposed post-mining land use. If the vegetation does not satisfy the coverage requirements due to climatic conditions, repairs are made to the surface, and seed and mulch are reapplied as needed. Many post-mining land uses, such as prime farmland, commercial forestry, and wildlife habitat, have specific revegetation requirements with very specialized planting practices. The uptake by vegetation of metals and other contaminants that may be present in CCRs is a concern, especially when the reclaimed land will be used as farmland. Sufficient soil cover, which is appropriate for the type of vegetation, is necessary to minimize plant uptake (see Chapter 4).

### Reclamation of Abandoned Mine Lands

The purpose of the Abandoned Mine Land Program is to protect public health and safety and remediate environmental damage caused by coal mining prior to the passage of SMCRA. Abandoned mine sites do not generally have to satisfy the post-mining land-use planning requirements that are part of the permit applications for active surface mines. One of the most common uses of CCR in abandoned mine reclamation is as structural fill material used to backfill abandoned pits. This has been practiced fairly extensively in the anthracite region of Pennsylvania (Sidebar 2.7). CCRs are also used for stabilization of abandoned highwalls, sealing of abandoned underground mine openings, and capping or encapsulating material in abandoned coal refuse piles. These applications serve the dual purpose of decreasing infiltration into the refuse and helping to neutralize acid drainage from the piles. Finally, CCRs are used as either a soil amendment or a soil replacement, particularly at abandoned mine sites where topsoil may be totally lacking (see Chapter 2). However, plant uptake of contaminants must be considered when CCRs are used as a soil replacement.

## Design Considerations to Limit Interactions with the Hydrologic Regime

As discussed in Chapter 6, CCR management requires an understanding of risk, and careful placement design can be used to moderate the environmental and human health risks of CCR disposal in mines. Given the known impacts that can occur when CCRs react with water in surface impoundments and landfills, CCR placement in mines should be designed to minimize reactions with water and the flow of water through CCRs. Regardless of whether the CCR is placed in an active or an abandoned coal mine, the issue of limiting the interactions of CCRs with groundwater should be a priority. There are a number of methods for reducing the interactions of CCR with water, although none will guarantee that CCRs remain totally isolated from infiltration. These methods are described below.

Many states have specific regulations requiring CCR to be placed at a minimum distance above the regional water table and above the floodplain associated with a storm of specified frequency. Appendix F describes both SMCRA and state regulatory requirements for isolation of CCRs from contact with water. This method is sometimes referred to as "high and dry"; however, it must be understood that placing CCR above the water table does not guarantee that there will be no interaction with groundwater (see Chapter 3).

Many coal seams are underlain by a clay or shale layer. These strata generally behave as an aquitard and can minimize the amount of leachate that migrates from CCR placed above them. The effectiveness of geologic isolation depends on the nature and thickness of the aquitard and the extent of natural fracturing. The aquitard can also be damaged by heavy equipment during the mining process.

Compaction and cementation may also be used to minimize the interactions between CCRs and groundwater. Certain types of CCRs can be compacted to achieve a hydraulic conductivity of $10^{-7}$ cm/sec when they are properly placed in lifts and compacted, thus creating a zone of lower permeability. Depending on the conductivities of the surrounding strata, effective compaction of CCRs may cause groundwater to be diverted around the CCR. There may remain preferential water movement through compacted CCRs under certain unsaturated zone moisture conditions (see Chapter 3). The cementitious properties of some CCRs can also be used to limit the interaction between CCR and groundwater. Concerns have been raised, however, about the long-term stability of cementitious ash when lime is not added to ensure cementation (McCarthy et al., 1997). The degree of cementation also influences whether or not the CCR will contribute to acid neutralization reactions.

Clay or synthetic liners are often used in landfill settings to minimize the movement of leachate from the site, and liners are design options for CCR disposal at higher-risk mine sites. The construction of effective liners in mine settings, however, may be operationally challenging. When properly installed and maintained, liners form a barrier between the material placed above the liner and the underlying hydrologic regime. It should be noted, however, that liners have often been known to leak after a number of years. The design and construction of liners must follow strict quality control procedures. For example, clay must be placed in controlled lifts and compacted to meet the specified standard of hydraulic conductivity of $10^{-7}$ cm/sec or less. Ideally, the entire area to be filled is excavated, smoothed, and leveled before the liner is installed, which is generally not possible in active coal mines.

Caps and covers can also be constructed to limit infiltration into the CCR at higher-risk sites. Similar standards for clay liners apply for the design and construction of clay caps. Normally caps consist of a layer of soil covered with vegetation. There are also alternative designs to caps and barriers, including geomembrane covers, evapotranspiration covers, and capillary barriers. Evapotranspiration covers are designed to hold any infiltrating water in the soil zone until it is removed by evapotranspiration. Capillary barriers utilize differences in pore-size distributions and the corresponding differences in capillary (suction) forces to prevent percolation of water into the CCR so that no leachate is generated (USDOE, 2000). However, the design of these covers requires careful analysis of the various parameters involved and is specific to a given location (ITRC, 2003). The idea of using evapotranspiration covers or capillary barriers has not been applied to CCR backfills to date but has been successfully employed in several landfills. An issue associated with any cap or cover is whether parts may eventually become saturated and allow infiltration. If substantial reductions in across-site recharge occur as a result of CCR isolation management strategies, it is assumed that appropriate engineered recharge augmentation will occur to compensate (see NRC, 1990).

## Reclamation Bonding

Before a mine permit can be issued and mining begun, a surface coal mine operator is required to post a reclamation bond. The purpose of the bond is to ensure that the approved reclamation plan will be completed in its entirety. If the operator defaults on the conditions of the permit, the bond amount is forfeited and the regulatory authority can use the funds to contract with a third party to complete the reclamation according to the approved plan. The regulatory authority has the responsibility for determining the bond amount based on the specific conditions of the site and holds the bond until the completion of reclamation. The

### SIDEBAR 7.4
### Bond Release Phases

- Phase I requires the completion of all backfilling, grading (including topsoil replacement), and drainage control; 60 percent of the bond amount can be released at this point.
- Phase II requires that revegetation be established according to the approved reclamation plan; the amount of the bond released at this point may vary from state to state but is typically in the range of 25 percent.
- Phase III requires the successful completion of all specified reclamation activities at which point the final portion of the bond can be released except that the final bond release cannot occur before the minimum required liability period has ended.

regulations derived from SMCRA allow for a phased bond release after reclamation milestones are achieved (see Sidebar 7.4).

The minimum liability period commences "after the last year of augmented seeding, fertilizing, irrigation or other work in order to assure compliance" (*Surface Mining Control and Reclamation Act of 1992*, H.R. 4381, 102d Cong. 2d sess., 4 March 1992). It is specified as five years except where the average annual precipitation is 26 inches or less, in which case the minimum liability period is ten years. In all cases the actual amount of time that a surface mine is covered by a reclamation bond will exceed the minimum, since the liability period is related to revegetation and this is not started until all coal removal, backfilling, grading, and topsoil replacement have been done.

Surface mine operators seek bond release to unencumber financial resources that are committed to reclamation bonds. However, the reclamation bond requirements established by SMCRA present another strong incentive for the operator to satisfy all reclamation performance standards. If a company defaults on a reclamation bond, that company or any successor companies involving officers of the defaulting company are prohibited from obtaining another surface mine permit in any state. The name of the company and its officers are entered into the Office of Surface Mining (OSM) Applicant Violator System, which is used to screen any new permit applications.

The use of CCRs in active coal mines has raised questions regarding the adequacy of current SMCRA reclamation bond requirements. Specifically, concern has been expressed about the length of the liability period and the adequacy of the remaining reclamation bond to treat any groundwater impacts that may occur after the bond is released. This issue is discussed further in Chapter 8.

Possible parallels exist between impacts from CCRs and the formation of acid mine drainage (AMD) at surface coal mines requiring long-term treatment. If AMD is detected before final bond release, OSM has the authority to require the bond amount to be adjusted accordingly and held indefinitely until it is replaced by some other enforceable contract or mechanism to ensure continued treatment (USDOI, OSM, 2003). Secondly, if any violation of the reclamation standards becomes apparent after final bond release (i.e., after jurisdiction has been terminated), OSM has the authority to reassert jurisdiction if there was "misrepresentation of material fact" at the time jurisdiction was terminated.

## MONITORING

Proper waste characterization, site characterization, placement design, and reclamation practices, which have been discussed earlier in this report, contribute to the process of reducing environmental impacts from the use of CCRs in reclamation. Monitoring is an essential tool to confirm predictions of contaminant behavior and detect if and to what extent CCR constituents are moving off-site and into the surrounding environment. In this manner, monitoring is an important tool to help protect ecological and human health at CCR placement sites. This section outlines the regulatory framework for monitoring at CCR mine placement sites, highlights concerns about existing monitoring programs, and provides recommendations for effective and efficient monitoring programs.

### Regulatory Framework for Monitoring

Current monitoring programs associated with the placement of CCRs in mines have been developed and implemented by states as stipulated by SMCRA (30 CFR §700). In general, SMCRA monitoring regulations are not very prescriptive (see Appendix E). Thus, the states have a large degree of flexibility and control, and the monitoring programs required at CCR mine placement sites vary widely by state. According to an analysis of regulations from 23 states by the Environmental Protection Agency (EPA), five states have monitoring requirements for CCR disposal at mine sites that are substantially similar to SMCRA (USEPA, 2002c). Ohio and Pennsylvania have monitoring requirements for CCRs that are substantially greater than SMCRA requirements. The additional regulations that states have added to SMCRA monitoring requirements at CCR mine placement sites vary in stringency and specificity. Many states simply have provisions that allow increased monitoring or additional parameters on a site-by-site basis. Some states, such as Indiana and Pennsylvania, specifically require monitoring for particular CCR parameters. State requirements on monitoring frequency for CCR parameters vary from quarterly to annually. Additionally, some states specify a minimum number of downgradient monitoring wells, such as North Dakota and Washington, which require at least two downgradient wells, and Indiana and Pennsylvania, which require at least one.

The monitoring requirements under SMCRA can be contrasted with the more specific monitoring requirements that exist in the Resource Conservation and Recovery Act (RCRA) Subtitle D (40 CFR. §257-258) (see Appendix E). The differences between the monitoring requirements for SMCRA and RCRA stem in part from the basic objectives of these different statutes: SMCRA is motivated by the reclamation of mine lands, whereas RCRA is motivated by the containment of contaminated wastes. The relevant aspect of RCRA for such a comparison is the Subtitle D requirements designed for municipal solid waste landfills, which regulate CCRs disposed in landfills and surface impoundments. Although SMCRA and RCRA regulations both provide ample authority to address the surface and groundwater monitoring demands of CCR disposal, RCRA regulations impose more specific requirements on the groundwater monitoring network design, sampling, and analysis procedures; surface-water monitoring; and constituents sampled. For example, while the RCRA rules require the rate and direction of groundwater flow to be determined each time groundwater is sampled, SMCRA rules are more general, requiring a groundwater monitoring plan that is based on the determination of probable hydrologic consequences. SMCRA and its implementing regulations allow the regulatory agency to impose requirements similar to those established under RCRA, but they do not require it (see 30 CFR §§780.21(h), 816.41(c)). In terms of parameters monitored, RCRA requires the analysis of a wide suite of inorganic constituents commonly found in landfills. SMCRA requires monitoring to include those parameters that relate to the suitability of the groundwater for current and approved post-mining land uses and, at a minimum, total dissolved solids or specific conductance, pH, total iron, and total manganese.

## Assessment of Existing Monitoring Programs

As discussed previously, monitoring programs and requirements vary substantially from state to state, and the committee observed a range of monitoring programs in its study. Nevertheless, some broad concerns emerged in the committee's general assessment of monitoring activities at CCR mine placement sites. These concerns, which emerged from observations made during the committee's open meetings and site visits, include the appropriate placement of monitoring wells based on the location of CCRs and the characterization of subsurface flow paths and whether there were an appropriate number of monitoring wells to characterize and sample groundwater along these flow paths. Other concerns related to whether there was adequate characterization of field leachate concentrations, adequate analysis of constituents in surface and groundwater, adequate length of monitoring, and ongoing and timely data processing (including review, analysis, and distribution).

### Defining Subsurface Flow Paths

Mine permits require an assessment of the groundwater resources that could be affected by mining operations, including the determination of probable hydrologic consequences and cumulative hydrologic impact assessments (OSM, 2002). Under the current regulatory system, mine permits require that background hydrogeological and geochemical conditions are established through the integration of lithological information from drill cores, hydraulic data, and groundwater chemistry. Identification of distinct geologic units is required, and the impact of these units on groundwater flow paths is incorporated into the permit. The result of this analysis is typically a general discussion of reported aquifer characteristics, hypothesized or measured flow directions, and water quality at sites spread out across the permit area. Much of the information gathered for the coal mining permit is not substantially refined for the placement of CCRs, even though significantly more information is needed to understand potential contaminant flow paths resulting from their placement. Often the process of mining disturbs groundwater flow pathways, such that the original permit data are not sufficiently accurate to site monitoring wells for CCR placement. The result is a monitoring well network that may not intersect a contaminant plume if it were to occur or a network that generates data that lead only to confusion over the source of elevated concentrations.

### Number and Placement of Wells and Length of Monitoring

The committee is concerned about the number and placement of monitoring wells at CCR mine placement sites. In general, monitoring networks were found to be inadequate to assess accurately the movement of contaminants within a reasonable time frame. The committee notes that at some sites visited, monitoring was focused at the mine permit boundary, with large distances (up to a mile) between the CCR placement site and the monitoring network. In cases where there was a large distance between the location of CCRs and monitoring wells, monitoring over a limited time frame (e.g., <10 years) might not detect any problem, even if one existed. Early detection of any problem is highly desirable to minimize possible impacts of CCRs and reduce potential remediation costs.

Additionally, the committee observed sites at which background or upgradient wells were not situated in appropriate locations to achieve long-term baseline data for comparison. Monitoring well data from mine placement of CCRs is often difficult to interpret due to the influences of the mining process itself and the large volumes of spoil, which can impact water quality in ways similar to CCR. Nearly all sites face the difficulty of siting wells in locations where the background influences of mining operations can be separated from the influence of CCRs, even somewhat simple sites. Substantial pre-CCR-placement monitoring data (or background data) are needed to discern the contributions of

CCR from other influences. The problem is particularly severe in densely mined regions, such as the anthracite region of Pennsylvania, where several active or abandoned mines may contribute flow to a single monitoring point.

### Characterization of Field Leachates

As noted in Chapter 6, more information is needed to relate CCR characterization data obtained in the laboratory to the behavior of CCRs in field settings. While the committee saw some sites where monitoring wells were placed within the CCR itself to obtain field leaching data, such data were not universally collected. Field leaching data provide the best assessment of the potential for off-site migration of the contaminants and the information necessary to distinguish the contributions of CCR from other influences. This information will also be valuable for testing the efficacy of laboratory leachate tests. Field leachate data can be combined with hydraulic conductivity and hydraulic head data to provide an approximate assessment of contaminant flux. Comparing these data with groundwater quality and flow rates from nearby downgradient wells could provide information on adsorption, precipitation, and other attenuation processes.

### Constituents Analyzed in Surface and Groundwater

For the sites reviewed in the course of this study (which represent only a subset of the sites at which CCR mine placement is occurring), most of the monitoring programs appeared to be analyzing for appropriate constituents to assess the movement of CCR-related contaminants. While SMCRA surface-water monitoring requirements are focused upon traditional mine reclamation constituents such as iron, manganese, acidity, and sediment, most of the sites reviewed sampled for a more extensive suite of contaminants, including trace metals. However, some sites did not include an analysis of boron or selenium concentrations, even though these constituents are commonly elevated in locations where CCR is present and are rather mobile in the subsurface. Boron or selenium may be viewed as a good indicator of the presence of CCR-related contaminants in both groundwater and associated downgradient surface water bodies.

### Information and Data Management

While reviewing CCR placement sites across the country, the committee observed many instances in which the utility of analytical data was questioned, related in part to possible failures in quality assurance and quality control (QA/QC). There appeared to be an absence of clearly defined QA/QC protocols prior to project implementation, which led to disagreements about which monitoring data were to be considered in post-placement data analyses. QA/QC plans are valuable for addressing systematic errors in analytical procedures, data validation problems, and information management.

With regard to information management, the committee observed that the results from field measurements were not consistently given the level of attention and scrutiny required to recognize CCR contamination problems in their early stages of development. Coal companies supply large amounts of data to state agencies as part of the reporting requirements for CCR placement related to ground- and surface-water monitoring and waste characterization. Most of these data are required to be submitted on paper, creating a challenge for data management and interpretation because the data analysis involves wading through many pages of data or requires the time-consuming step of first entering these data into a central data management system. Some states have moved to electronic reporting data methods, which can speed the review process. Electronic reporting can also facilitate closer attention to water quality concerns if the data management system is capable of flagging exceedances for attention by state water quality staff. To ensure early recognition of CCR contamination, QA/QC plans and information and data management plans should be developed prior to CCR placement. These plans should inform the decision-making process in a timely manner and should include how the data will be made available to the public.

## Recommended Monitoring Strategies

As noted above, the committee had several concerns regarding the effectiveness of existing monitoring programs. General issues related to long-term monitoring, liability, and oversight are discussed in Chapter 8. The discussion below highlights general recommendations for a more robust and consistent monitoring program needed in situations involving CCR mine placement. In general, the overall extent of monitoring (number of sampling points, frequency and duration of sampling, and constituents analyzed) should be customized to address the level of estimated risk and the uncertainties associated with the estimate. Higher levels of potential risk (i.e., more dire consequences) warrant greater investments in field monitoring to ensure adequate protection of human and ecological health. Because uncertainty exists in CCR characterization methods and site characterization, monitoring plans should also be designed to compensate for the level of uncertainty about contaminant behavior in the local environment (i.e., more monitoring when uncertainties are large).

### Groundwater Monitoring

The monitoring network should be designed based on a careful assessment of site characterization data, CCR characterization data, and the design of the CCR emplacement and subsequently should be certified by a regulatory official experienced in contaminant transport processes. The number of monitoring wells and the spatial coverage of wells should be consistent with the potential for material damage to groundwater. For example, sites with large masses of CCR that exhibit high rates of contaminant leaching would warrant substantial engineering controls together with detailed monitoring, whereas sites with relatively inert CCR disposed in small quantities would warrant a simpler approach.

An ideal groundwater monitoring system should include wells installed at multiple depths and multiple locations, concentrated primarily in the probable directions of groundwater flow with additional wells to characterize upgradient water quality. Overall, well screens should be placed in a range of materials, including coal spoils, CCRs, blended materials, and undisturbed geologic materials, to provide information that is representative of variations present at the site. Downgradient wells should be sited with an understanding of the travel times for contaminants to reach these monitoring points. Several monitoring points should be established along predicted flow paths at distances downgradient from CCR emplacement that will yield early (i.e., during the established bonding period) confirmatory information regarding predicted CCR leachate transport (e.g., advection, dispersion, dilution, attenuation). If uncertainty exists regarding the directions of groundwater flow or if ongoing mining and associated groundwater pumping could disrupt groundwater flow, additional wells may be necessary to capture the movement of any contaminant plume. As discussed above, if wells are placed only at the permit boundary, water quality monitoring for the length of the bonding period may not detect a contamination problem, even if one exists. If downgradient contamination is detected, additional wells may have to be installed to assess the impact of CCR on groundwater resources. At least one well (or a suction or pan lysimeter for unsaturated conditions), and preferably two wells, should be placed directly in the CCR to monitor local porewater chemistry and assess the field leaching behavior. These data should then be compared to the predicted flux rates in the site conceptual model.

The effects of mining on groundwater levels and flow normally occur relatively quickly while changes in groundwater quality can take several decades (NRC, 1981). Depending on the individual site characteristics and the distances to downgradient wells, terminating groundwater monitoring at the time of bond release may lead to an underestimation of contaminant release from many sites. The duration of groundwater monitoring will have to be addressed on a site-specific basis to adequately assess the temporal release of contaminants. A longer field-monitoring period will likely be needed in some situations in recognition of the fact that subsurface migration of potential contaminants can occur over time periods in excess of a decade.

A large portion of the investment in groundwater monitoring is currently being directed at collection and analysis of groundwater samples from a very small number of wells at a high frequency (monthly to quarterly). The frequency of monitoring should be selected to more accurately reflect the variation in chemistry that is expected at a site. Monitoring of groundwater chemistry should be carried out more frequently at sites where groundwater velocities are high and less frequently at sites where groundwater velocities are low. For example, sampling of porewater within the CCR could be frequent in the first few years after placement but be reduced in frequency once flow conditions stabilize.

Rigorous CCR characterization studies should give an initial indication of the potentially leachable contaminants that should serve as the basis of the field monitoring program. Ongoing field sampling of the CCR porewater will characterize the actual field leaching behavior. Analysis of these results can guide the development of a list of the most mobile contaminants that should be analyzed for samples from upgradient and downgradient wells.

## Surface Water Monitoring

Surface-water monitoring is a key component of any monitoring program to protect the ecosystem from potential adverse impacts of CCRs. Appropriate understanding of the connectivity between local groundwater and receiving surface water bodies, however, should allow groundwater monitoring to forewarn the arrival of mobile CCR constituents through the subsurface. As described in Sidebar 4.5, contaminant levels needed to adequately protect ecological health can be significantly lower than those prescribed to protect human health (e.g., drinking water maximum containment levels). Beyond the difference in concentrations, different analytical techniques (sample collection and laboratory method) are sometimes necessary to measure these lower, yet environmentally relevant concentrations.

Coal combustion residue monitoring programs have to identify surface water bodies (streams, lakes, and wetlands) that might receive either direct surface or indirect subsurface discharge of CCR leachate. Direct surface discharges from mine sites are typically monitored in accordance with associated National Pollution Discharge Elimination System permit requirements. Surface-water monitoring should be conducted with a frequency that will adequately capture the temporal variation of the upgradient (background) condition as well as the variation of any point- and/or non-point-source loading. Surface monitoring for rivers and streams should continue at upgradient, point-source, and downgradient locations for the same duration as groundwater monitoring. At all surface monitoring locations, background water-quality data should also have been collected prior to CCR placement through the site characterization process (see Chapter 6).

Parameters for effective surface-water monitoring would include hydraulic data in addition to water chemistry. Necessary hydraulic monitoring data include flow velocity, cross-sectional area, average water depth, and reach length, as well as a calculation of hydraulic residence time for lakes or wetlands. Hydraulic monitoring data may be needed at every surface-water sampling site where water chemistry is monitored if there are important loading issues to be addressed. Water chemistry parameters include pH, temperature, conductivity, major cations and anions, hardness, total organic carbon, and CCR-related metals, which should be analyzed on both filtered and unfiltered samples. Suspended sediment should also be sampled at each site to estimate contaminant accumulation in sediments and the sediment-associated transport and to assess impacts on aquatic biota (USEPA, 2004a).

## Ecological Monitoring

Existing SMCRA regulations include the monitoring of water and sediment as it moves from mines to surface waters, but the potential impact of either direct surface or indirect subsurface discharge of CCR-related contaminants on receiving water biota is not specifically addressed within SMRCA. In the event that surface-water quality impacts are detected, they should be promptly verified with more intensive water sampling to determine the magnitude of the problem. However, such sampling may not be sufficient to detect elements like selenium that may occur in low concentrations in water, yet high concentrations in tissues due to its bioavailability, and additional ecological monitoring may be needed.

Monitoring tissue concentrations in biota upstream and downstream of CCR placement sites may be a necessary first step towards understanding potential ecological impacts of CCR-related contaminants. For example, selenium is one the CCR constituents of greatest ecological concern. Because water concentrations of selenium are often not indicative of concentrations bioaccumulated in fish, invertebrates, and wildlife (Hamilton, 2002, 2003; Lemly, 2002), the EPA is currently replacing its water quality criterion for Se with a tissue-based criterion (Federal Register EPA-822-D-04-001, Draft Aquatic Life Criteria for Selenium-2004). Tissue residues provide a valuable integrative metric of the bioavailable fraction of contaminants entering the impacted community and are especially useful for elements such as selenium that have complex biogeochemistry. Thus, tissue sampling may provide the most sensitive monitoring index for some elements associated with CCRs, and may eventually be required by EPA regulations. If tissue residues are elevated above reference conditions, additional ecological variables, such as measures of reproductive performance and/or invertebrate diversity and abundance, should be considered. Reproductive indices are among the most sensitive end points of toxicity for highly teratogenic elements such as selenium and mercury that are readily maternally transferred. Measures of animal abundance and diversity can provide insight into the ecological consequences of changes in stream water chemistry resulting from CCR contamination. As discussed in Chapter 4, macroinvertebrate and zooplankton assemblages have commonly been impacted by CCRs at surface impoundment sites, and these compositional changes appear to be a good metrics of unintended ecological impacts.

### Performance Standards for Monitoring

Performance standards should be established for the aforementioned groundwater and surface-water monitoring points to ensure adequate protection of groundwater and surface-water quality. Performance standards associated with SMCRA regulations are discussed in Chapter 5 and should be followed to develop specific metrics. These performance standards could be based on best available data, model predictions, and relevant water quality standards (including tissue-based standards developed for elements such as selenium), considering pre-placement water quality conditions. Indications that the established performance standards have not been met should trigger more intensive monitoring and, if warranted, the development of a remediation plan.

## SUMMARY

Reclamation planning and monitoring are essential components of risk-informed CCR management at coal mine sites. Reclamation planning is an integral part of the mining process, and the use of CCRs for minefill should be viewed in the context of general reclamation management activities. The reclamation planning process begins with a thorough analysis of current site conditions at the mine and the site conditions projected to exist following the completion of mining. The disposal of CCRs in coal mines occurs under highly variable conditions, ranging from small quantities to massive minefills, from arid to wet regions, from remote to semiurban locations, from surface to underground mines, and from active to abandoned mines. **Because of this variability, the committee endorses the concept of site-specific management plans, including site-specific performance standards.** A flexible approach to managing CCRs in mine sites has advantages since it can embrace the unique characteristics of CCRs, the total mass of CCRs, and the environment into which they are placed. However, the need to incorporate site-specific factors should not be a basis for adopting management plans that lack rigor.

The primary reclamation operations most readily impacted by CCR placement, whether for active or abandoned mines, are backfilling and grading, topsoil replacement, and revegetation. Reclamation requirements and potential concerns for CCR for these operations are described in this chapter. CCR management requires an understanding of risk, and careful CCR placement design can be used to moderate the human health and environmental risks of CCR disposal in mines. **The committee recommends designing CCR placement in mines to minimize reactions with water and the flow of water through CCRs.** Several methods are described for reducing the interaction of CCRs with water, including placement well above the water table, compaction and cementation, liners, and low-permeability covers. However, none of these methods will guarantee that CCRs remain completely isolated from infiltrating water.

Monitoring is an essential tool to confirm predictions of contaminant behavior and detect if and to what extent contaminants are moving into the ambient environment. SMCRA monitoring regulations provide the regulatory agency with sufficient authority to require adequate ground- and surface-water monitoring. However, while the monitoring rules at 30 CFR §780.21(i), (j) and §816.41(c), (e) require mine operators to establish and implement ground- and surface-water monitoring plans, they do not specifically address the number and location of wells, spatial coverage of wells, and duration of monitoring. Furthermore, although they require monitoring "at a minimum" for total dissolved solids, specific conductance corrected to 25°C, pH, total iron, total manganese, and water levels, they do not address the full suite of contaminants that might possibly be expected to leach from CCRs in a minefill setting. Because SMCRA monitoring regulations are not very prescriptive, states have a large degree of flexibility and control, and monitoring programs required at CCR mine placement sites vary widely by state. Based on its reviews of CCR post-placement monitoring, *the committee concludes that the number of monitoring wells, the spatial coverage of wells, and the duration of monitoring at CCR minefills are generally insufficient to accurately assess the migration of contaminants.* Additionally, the committee found quality assurance and control and information management procedures for water quality data at CCR mine placement sites to be inadequate.

This chapter highlights general recommendations for a more robust and consistent monitoring program needed in situations involving CCR mine placement. Downgradient wells should be sited with an understanding of the travel times for contaminants to reach these monitoring points. Depending on the individual site characteristics and the distances to downgradient wells, a longer duration of groundwater monitoring may be necessary at some sites to adequately assess the temporal release of contaminants, which can occur over periods in excess of a decade. To address these concerns, several monitoring points should be established along predicted flow paths that will yield early (i.e., during the established bonding period) confirmatory information regarding predicted CCR leachate transport. At least one well or lysimeter, and preferably two, should be placed directly in the CCR to assess the field leaching behavior and confirm predicted contaminant flux. As part of the monitoring plans, quality assurance and control plans should be developed prior to CCR placement with clearly defined protocols for sampling and analysis, data validation, and managing systematic errors in analytical procedures. **In general, the committee recommends that the number and location of monitoring wells, the frequency and duration of sampling, and the water quality parameters selected for analysis be carefully determined for each site, in order to accurately assess the present and potential movement of CCR-associated contaminants.** Such an approach will also allow the specifics of the monitoring plan to be tailored to accommodate the unique combination of particular CCR characteristics, emplacement techniques, and overall site characteristics, considering estimates of ecological and human health risks and uncertainties in the site conceptual model.

Surface-water and ecological monitoring are key components of any monitoring program to protect the ecosystem from potential adverse impacts. It is important to note that chemical levels adequate to protect environmental health can be significantly lower than those prescribed to protect human health. For surface-water, the frequency of sampling should adequately capture temporal variations in the background conditions as well as variations in any point- and/or non-point-source loading. Tissue residue monitoring provides valuable insights into the bioavailability of certain contaminants that can be present at low concentrations in water but accumulate in living organisms (e.g., selenium). The duration of surface-water monitoring should be consistent with the duration of groundwater monitoring. In the event that surface-water quality impacts are detected, appropriate ecological monitoring may need to be implemented.

Performance standards should be established for the aforementioned groundwater and surface-water monitoring points to ensure adequate protection of groundwater and surface-water quality. Indications that the established performance standards have not been met should trigger more intensive monitoring and, if warranted, the development of a remediation plan.

# 8

# Synthesis of Issues for Planning and Regulation of Coal Combustion Residue Mine Placement

As reviewed in previous chapters, CCRs contain an array of metals and elements in such quantities that they are of toxicological concern. Case studies of landfills and surface-water impoundments have shown that if CCRs are not managed adequately, they can adversely impact water supplies and ecosystems. The U.S. Environmental Protection Agency (EPA) has not specifically attributed significant environmental problems to CCR use in minefills, but better data are needed to fully characterize this issue. In abandoned mine lands (AMLs) and coal-refuse remining applications, two specific reclamation settings, the use of CCRs has helped to resolve serious, acute land-use and water quality problems. However, when not managed properly, CCRs may produce undesirable consequences, such as the release of metals and metalloids into the environment. As a result, although the placement of CCRs in mines is localized in coal mining districts, it has raised public and regulatory concerns. The intent of this chapter is to synthesize some key observations of this report. It discusses the steps involved in planning for CCR use as minefill. This chapter further describes some of the cross-cutting policy and implementation issues and summarizes the alternatives with regard to regulatory oversight.

## PLANNING FOR CCR MANAGEMENT

The placement of CCRs in coal mines is a multidimensional issue that involves consideration of potential human health and environmental impacts, as well as a comparison to the economic, health, and environmental impacts from other uses or disposal options.  This section outlines the steps involved in CCR management planning, highlighting for both site managers and regulators the specific considerations necessary when placing CCRs at a mine site. Several of the improved management practices presented in Chapters 6 and 7 that would reduce the risks associated with the use of this material are summarized here.

## Step One: Considering CCR Disposal and Use Options

CCRs are often characterized as coal combustion *wastes* because the generators of CCRs are in the business of producing electricity or some other product that requires coal combustion. Some of these residues, however, are valuable for other uses. Coal combustion residue use in the production of cement and wallboard, for example, results in a needed product for society and reduces the impacts of other resource extraction activities (e.g., gypsum or limestone mining). The value of these residues has produced its own industry association—the American Coal Ash Association—founded to promote the use of these CCR products.

As discussed in Chapter 2, many factors enter into the decision-making process when considering the options for CCR utilization or disposal. Such factors include the local applications for utilizing CCRs, the economic value of CCRs for alternate uses, the transportation distance to industries able to use CCRs, the location and costs of CCR disposal options, the local regulatory environment, and the potential effects on human health and the environment.

Valuable residues that become part of the waste stream may represent a missed opportunity for waste reduction and environmentally sound management. Thus, **the committee recommends that secondary uses of CCRs that pose minimal risks to human health and the environment be strongly encouraged**. Public-private cooperative efforts, such as the Coal Combustion Products Partnership, are examples of programs that can foster research and product development to further the productive uses of CCRs. Government agencies should examine ways in which they can promote CCR use or remove impediments to its use (see Sidebar 5.2 for a discussion of proposed actions in the Energy Policy Act of 2005). Careful planning for residues should also be undertaken by utilities and other CCR generators.

However, many CCRs are not suitable for such uses and must be disposed in landfills, impoundments, and mines. The committee concluded that putting CCRs in coal mines as part of the reclamation process is a viable management option as long as (1) CCR placement is properly planned and is carried out in a manner that avoids significant adverse environmental and health impacts and (2) the regulatory process for issuing permits includes clear provisions for public involvement. The main advantages of CCR mine placement are (1) it can assist in meeting reclamation goals (such as remediation of abandoned mine lands), and (2) it avoids the need, relative to landfills and impoundments, to disrupt undisturbed sites. As noted throughout this report, the volume of CCRs to be used and the relative risk that emerges from characterization of the site and the CCR material should help dictate the level of additional effort that will be required to manage and monitor the mine site.

## Step Two: Characterizing a Mine Site Disposal Option

### CCR Characterization

Routine analysis of the CCRs intended for mine placement is necessary to identify potentially toxic materials and ultimately to ensure that the CCRs are adequately emplaced and managed. CCR characterization alerts managers to potential environmental problems associated with CCR disposal in the mine environment and provides information on material properties that can be used to manage its containment. The CCR characterization should include identification of the volume of material, its physical and chemical characteristics, its trace element leaching potential, and its cementitious properties. As noted in Chapter 6, improved methods for characterization are needed.

### Site Characterization

In conjunction with the characterization of the CCRs, managers must also identify the best disposal site(s) within the mine. As described in detail in Chapter 6, site characterization should include a full description of the hydrogeological setting, including aquifer locations and groundwater flow patterns, surface-water drainage and flow, and soils and overburden characterization. The site characterization should also consider local factors, such as surrounding land use, proximity to sensitive surface waters, and designated future land use. These factors will further the assessment of the potential for human exposure to drinking water impacts that might occur related to CCR placement. Much of the information needed to characterize the site should or could be available as a result of compliance with the SMCRA's permitting requirements, including information developed in conjunction with the probable hydrologic consequences (PHC) determination and the cumulative hydrologic impact assessment. As noted in Chapter 6, however, further data may be needed to address issues that are particularly associated with CCR placement. For example, while the PHC determination will likely include baseline monitoring data for the mine site as a whole, additional data may be needed to adequately characterize groundwater flow rates and directions within a mine site that is scheduled to receive CCRs. Depending on the acid-producing potential of the mine site, acid-base accounting may be needed. Thus, permit requirements may need to call for additional characterization data related to the specific sites where CCRs will be placed.

### Integration of Characterization Data

The site and material characterization data must then be integrated to enable appropriate considerations in the design of the management, engineering, and monitoring plans at the site, including how the CCRs will be emplaced to minimize potential movement of contaminants (see Chapter 7). This should consider the mass of material to be placed, as well as options for placement locations within the mine site.

## Step Three: Developing a Long-Term Management Plan for the CCRs

Mine placement of CCRs that is protective of human and ecological health requires the development of a long-term management plan, including careful attention to engineering design and monitoring. The following sections discuss CCR management issues to be considered during active mining and reclamation activities as well as those relevant to the post-reclamation period.

### Management During Active Coal Mining and Reclamation Operations

As noted in Chapter 7, the engineering design, including the method of placement as well as the location of placement of CCRs in the mine, should be informed by the estimated risk from the CCR material and the site characteristics. Monitoring plans should include sampling sites that can specifically address potential contamination from the CCR placement. In addition, many issues should be incorporated into plans for the placement of CCRs in mines. Some examples of issues that should be considered are the following:

- Is simple backfilling, mixed with mine spoil, adequate, or are more controlled placement approaches needed?
- Should the cementitious properties of the ash be enhanced to minimize interaction with groundwater?
- Should the CCR be put down in small lifts and compacted to minimize its hydraulic conductivity and minimize contaminant transport?
- Can CCRs be emplaced in a manner that neutralizes acidity at the mine over the long term and reduces overall contaminant transport?
- Will placement of CCRs above the water table be sufficient to minimize contaminant transport, considering local recharge rates?
- How many additional monitoring wells, specific to the CCR placement, are needed?
- What additional parameters, related to CCRs, should be required for monitoring, and at what frequency?
- Are additional bonding or other financial assurances necessary to cover potential off-site contamination from CCRs?

**Disposal of CCRs in coal mines should be subject to reasonable site-specific performance standards that are tailored to address potential environmental problems associated with CCR disposal.** These requirements may be in addition to any permitting requirements associated with mine-site and CCR characterization. For example, the maximum containment levels established under the Safe Drinking Water Act might be used as a benchmark for determining unacceptable contamination levels for groundwater at some appropriate, designated monitoring site. In some mined areas, however, the natural groundwater is of poor quality, and some relative non-degradation approach may be needed. In areas where CCR leachate may interact with surface water (directly or through groundwater interactions) more stringent requirements may be necessary to protect aquatic life (see Chapter 4, Sidebar 4.5). Where violations of permit requirements or performance standards occur, authority for appropriate penalties or corrective actions must be available to mitigate the damage and prevent future violations.

## Post-Mining and Reclamation Land Management

The committee reviewed various post-mining, post-closure concerns related to long-term CCR management at mine sites. Of these, the committee could not resolve their concerns nor reach consensus on the duration of long-term groundwater monitoring, the recommended length of liability (in relation to current SMCRA reclamation bond requirements), and future land-use restrictions.

The committee believes that groundwater monitoring, linked to performance standards, is essential to confirm the performance of the management plan and to protect both human and ecological health (see Chapter 7). The overall extent of monitoring, including its duration, should be customized to address the level of estimated risk and the uncertainties associated with the site. As discussed in Chapter 3, the committee is concerned that the geochemical conditions in some settings may evolve and create long-term groundwater contamination that might have off-site impacts, particularly when large volumes of CCR are used as fill material. If monitoring sites are not critically placed to yield early data on contaminant transport, the movement of contaminants could go undetected for long periods of time. This in turn raises concerns about the length of the liability period and the adequacy of the remaining reclamation bond to deal with adverse groundwater impacts that may occur after bond release.

As described in Chapter 7, SMCRA requires mine operators to maintain a portion of their bond for at least five years and, in arid areas, for at least ten years after the completion of all reclamation activities, including revegetation. The portion of the bond that remains during this post-mining period is intended primarily to cover the costs associated with a failure of revegetation. Once a bond has been fully released, the mine operator's responsibility for compliance with SMCRA effectively ends. At some sites, particularly those with inadequate monitoring, there is potential for longer-term groundwater impacts from CCRs to go undetected under the normal reclamation bonding framework. Some committee members expressed concern that if significant contamination were detected after bond release, there would be no ready remedy available to the public. Some committee members believed that longer-term groundwater monitoring should be required in all cases and that release of the bond should be tied to such monitoring. Other committee members felt that there was insufficient evidence to require this in all cases. Some committee members also believed that the longer-term reclamation bond liability would be a significant deterrent to the use of CCRs in mine reclamation—a practice that the committee agrees can provide environmental benefits when managed properly. Part of the complexity is that the liability under SMCRA bonding requirements falls only on the mine operator—not on the generator of the CCRs—and there is little incentive for the mine operator to accept a longer term of liability.

Because the committee was unable to reach consensus on the duration of long-term monitoring and liability, it focused instead on ways that monitoring systems can be designed to enable early detection of potential problems (i.e., during the established bonding period), so that performance can be confirmed and mitigation initiated, if needed (see Chapter 7). As noted, a possible parallel exists between undesirable impacts of CCRs and the formation of AMD at surface mines requiring long-term treatment. If AMD is detected before final bond release, the OSM has the authority to require the bond amount to be adjusted accordingly and held indefinitely until it is replaced by some other enforceable contract or mechanism to ensure continued treatment (OSM, 2002). There are other long-term legal remedies after bond release, if damages occur, but they are more difficult to impose (see Chapter 7). Therefore, the regulatory authority should take care to review the management and monitoring plans, including the term of monitoring, considering the risk of CCR placement at the site, the bond release terms, and the potential corrective actions that may be warranted should significant contamination occur.

The permit application process requires that the mine operator consider and plan for the use of the land at the mine site after reclamation and closure (see Chapter 7). The committee believes that mines reclaimed with large volumes of CCRs should be able to achieve economically productive post-mine land uses as long as CCR management at the mine site is based on careful consideration of characterization data and includes appropriate design safeguards to minimize the movement of CCR-derived contaminants into the environment. However, the committee believes that deeds, or appropriate recordable instruments, should record and fully disclose that CCRs were used in the reclamation of the mine site. The records should provide CCR placement locations as specifically as possible. Such records can help guard against future inappropriate land uses (e.g., irrigated crop production at a site that was engineered to minimize water and contaminant movement under normal [natural] rainfall conditions). The committee discussed whether deed restrictions were needed, such as those used on brownfield redevelopment sites. The committee, however, could not agree if additional levels of regulatory control should be specified with respect to post-mining land use, beyond full disclosure of the site history.

***Abandoned Mine Lands and Remining Sites.*** A special consideration is the use of CCRs in reclaiming AML and remining sites and in mining coal refuse piles. As noted in Chapter 5, any regulatory standards for CCR use adopted under SMCRA for active coal mining would most likely apply to remining activities but would not apply directly to CCR use in the reclamation of abandoned mine lands. To ensure adequate protection of public health and the environment, **the committee recommends that placement of CCRs in abandoned and remining sites be subject to the same CCR characterization, site characterization, and management planning standards recommended for active coal mines**. However, when developing performance standards, adequate consideration should be given to the significant differences between active mines, abandoned mines, and the remining of previously abandoned mine sites. At such abandoned sites the CCR placement process begins with a degraded site and the same management options available in an active mine site may not always be feasible. The plans should consider the benefits of CCR use for reclamation at these degraded sites but should also factor in the potential adverse impacts of CCRs, accommodating these concerns in the overall plan.

## OVERARCHING ISSUES AND CONCERNS

The committee was tasked to address several overarching issues, including the current provisions for public involvement and the protection of natural resources from CCR mine placement offered by the RCRA and SMCRA. Detailed background information on the current regulatory framework can be found in Chapter 5, but the following section builds upon concerns addressed throughout the report and outlines the committee's recommendations and conclusions on these overarching topics.

### Public Participation

The committee heard from many individuals who were concerned about the potential for adverse environmental and public health impacts from improper CCR disposal. As noted in Chapter 1, many of the issues of concern are beyond the charge of this study. In recognition of the public concern, however, government agencies responsible for regulating CCRs should ensure that the public receives adequate advance notice of any proposals to dispose of CCRs in mine sites. The public should also be encouraged to participate actively in agency decisions for CCR disposal. Agencies could use stakeholder engagement programs to engage members of the public, identify their concerns, and obtain their input on needed programmatic improvements. **The committee recommends that any proposal to dispose of substantial quantities of CCRs in coal mines should be treated as a "significant alteration of the reclamation plan" under Section 511(a)(2) of SMCRA (30 U.S.C. §1261(a)(2))**. This will ensure that the public is afforded adequate notice and an opportunity to be heard on the CCR placement proposal. The regulation of CCR placement under SMCRA would also provide additional opportunities for public input, such as formal citizen's complaints with the appropriate regulatory agency (e.g., SMCRA, §517(h)(1); 30 U.S.C. §1267(h)), and the opportunity to accompany an inspector during the inspection related to a formal complaint (30 U.S.C. § 1271(a)(1)). Under SMCRA, the agency must provide a written response about the disposition of such a complaint. In addition, government agencies should make usable monitoring data from CCR disposal sites available to the public in a timely manner.

## Alternatives for Regulatory Authority

As noted in Chapter 5, there are existing regulatory programs that can provide for the management of CCRs placed in mines. The scope of SMCRA is sufficiently broad to allow comprehensive regulation of CCRs at mine sites. However, neither SMCRA nor its implementing regulations currently address the use or placement of CCRs in an explicit manner. As a consequence, states vary in their approach and the rigor with which they address CCR use in mines. Some states have developed their own detailed regulatory oversight programs for CCR placement in mines, while other state agency representatives expressed concern that they do not have the authority to impose permitting requirements or performance standards specific to CCRs. As discussed in Chapter 5, EPA reported in 2000 that it will promulgate regulations covering CCR disposal in landfills and surface impoundments under RCRA Subtitle D (65 FR 32214). EPA has not yet decided, however, whether regulation of CCR disposal in minefills should occur under SMCRA, RCRA Subtitle D, or some combination of the two.

Currently there are variations and gaps in the regulation of CCRs used for reclamation. These gaps create opportunities for unnecessary risks to water supplies and the environment. Therefore, **the committee recommends that enforceable federal standards be established for the disposal of CCRs in minefills**. Enforceable federal standards will ensure that states have adequate, explicit authority and that they implement adequate minimum safeguards. This would be accommodated by explicitly addressing CCR minefilling in the federal regulations that are delegated to or adopted by the states. As with current federal regulations and standards, the committee does not envision, nor recommend detailed national design standards. Rather, enforceable federal standards would require that state programs develop and implement needed management and performance standards specific to CCRs and minefilling (see Chapters 6 and 7). As with current federal regulations, these rules should provide sufficient flexibility to allow states to adapt permit requirements to site-specific conditions, while providing needed focus on the protection of ecological and human health.

There are three primary regulatory mechanisms that could be used to develop enforceable standards that would reduce the risks imposed by CCR minefilling:

1. Changes to SMCRA regulations to address CCRs specifically;
2. Joint OSM-EPA rules pursuant to the authority of SMCRA and RCRA; or
3. RCRA-D rules that are enforceable through an SMCRA permit.

Under SMCRA, the OSM and related state agencies that implement SMCRA currently have the regulatory framework in place to deal with CCRs used in mine reclamation and have considerable expertise in review, permitting, and management of mine lands. On the other hand, under RCRA, the EPA and its counterpart agencies at the state and local level have developed significant technical and regulatory expertise in monitoring and oversight of waste disposal operations (e.g., landfills) that involve groundwater and potentially toxic substances. The committee believes that OSM and its SMCRA state partners should take the lead in developing new national standards for CCR use in mines because the framework is in place to deal with mine-related issues. Nevertheless, most individuals and public-interest groups that appeared before the committee expressed a lack of confidence that SMCRA agencies can deal with these issues. This lack of public trust should be remedied. Joint rules from OSM and EPA might help in this regard, although such efforts often lead to problems in defining clear lines of authority. Regardless of the regulatory mechanism selected, coordination between OSM and EPA efforts is needed and would foster regulatory consistency with EPA's intended rule proposals for CCR disposal in landfills and impoundments.

In all cases, guidance documents will also be necessary to help states implement their responsibility for managing CCRs. However, guidance alone is not adequate to achieve the needed improvements in state programs for CCR minefills. Guidance is not enforceable, nor does it afford adequate opportunities for citizen participation otherwise guaranteed under SMCRA. As noted in Chapter 5, some states have statutes that prohibit state agencies from adopting standards that are more stringent than federal standards, thereby restricting states from strengthening their regulatory programs based on guidance documents alone. Only through enforceable federal standards can acceptable minimum levels of environmental protection from CCR placement in coal mines be guaranteed nationally.

## SUMMARY

Placement of CCRs in mines as part of coal mine reclamation may be an appropriate option for the disposal of this material. However, an integrated process of CCR characterization, site characterization, management and engineering design of placement activities, and design and implementation of monitoring is required to reduce the risk of contamination moving from the mine site to the ambient environment. The committee also recommends that placement of CCRs in abandoned and remining sites be subject to the same CCR characterization, site characterization, and management planning standards recommended for active coal mines.

The scope of SMCRA is broad enough to encompass the use of CCRs at a mine site during reclamation activities, but neither SMCRA nor its implementing regulations explicitly address the use or placement of CCRs. As a result, regulatory gaps exist that create opportunities for unnecessary risks to water supplies and the environment. To address this issue, the committee recommends that enforceable federal standards be established for the disposal of CCRs in minefills to ensure that states have specific authority and implement adequate safeguards. The chapter lists three regulatory alternatives for establishing such standards for CCR mine placement. No matter what alternative is used, enforceable federal standards are necessary to guarantee acceptable minimum levels of environmental protection wherever CCRs are disposed.

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# A

# Biographical Sketches of Committee Members and Staff

**PERRY HAGENSTEIN, Ph.D.,** *chair,* is an independent consultant on natural resources policy, economics, and management. Since 1982, he has also served as president of the Institute for Forest Analysis, Planning, and Policy, a national nonprofit research and education organization. He is the former president of Resource Issues, Inc., and former executive director of the New England Natural Resources Center. He has been a visiting professor at the Yale School of Forestry and Environmental Studies, University of Vermont, University of Massachusetts, and Vermont Law School. He served as Charles Bullard Research Fellow at the John F. Kennedy School of Government and Harvard Forest at Harvard University. He was senior policy analyst for the U.S. Public Land Law Review Commission. He is a national associate of The National Academies and has chaired several National Academies studies, including the Committee on Hardrock Mining on Federal Lands, the Subcommittee on Air Emissions from Animal Feeding Operations, the Committee on Abandoned Mine Lands, and the Committee on Onshore Oil and Gas Leasing. He has also served as a member on the Committee on Surface Mining and Reclamation, the Committee on Earth Resources, the Board on Earth Sciences and Resources, the Committee on Environmental Issues in Pacific Northwest Forest Management, and the Committee on Noneconomic and Economic Value of Biodiversity. Dr. Hagenstein has a Ph.D. in forest and natural resources economics from the University of Michigan.

**GEORGE R. HALLBERG, Ph.D.,** is a principal with the Cadmus Group, Inc., in Waltham, Massachusetts, conducting environmental research, regulatory analysis, and management services for public-sector programs. Previously he was associate director and chief of environmental research at the University of Iowa's environmental and public health laboratory and at the Iowa Department of Natural Resources. Dr. Hallberg was also an adjunct professor at both the University of Iowa and Iowa State University. He has served on the U.S. Environmental Protection Agency National Advisory Council for Environmental Policy and Technology and on the Office of Water's Management Advisory Group. He has 30 years experience in research, policy and management of environmental, natural resources and public health programs. His research interests include environmental monitoring and assessment, chemical and nutrient fate and transport, contaminant occurrence and trends in drinking water, health effects of environmental contaminants, and groundwater hydrogeology. Dr. Hallberg has served on the National Academies Board on Agriculture and Natural Resources and on several committees, including as chair of the Committee on Opportunities to Improve the USGS National Water Quality Assessment (NAWQA) Program and as a member of the Committee on Long Range Soil and Water Conservation Policy. He is currently a member of the National Academies Committee on Assessment of Water Resources Research. Dr. Hallberg received a Ph.D. in geology from the University of Iowa.

**WILLIAM A. HOPKINS, Ph.D.,** is an associate professor, Department of Fisheries and Wildlife Sciences at Virginia Polytechnical Institute and State University. Until August of 2005 he was an assistant research scientist at the Savannah River Ecology Lab. Dr. Hopkins' research interests include the effects of trophic transfer of contaminants on predatory vertebrates, effects of teratogenic compounds on reproduction and development in ectotherms, and the indirect effects of contaminants on wildlife. Much of Dr. Hopkins' work has focused on the effects of coal combustion waste on the survival, physiology, and performance of aquatic life. He has published numerous articles and book chapters on the effects of aquatic disposal of trace elements, specifically coal combustion wastes. Dr. Hopkins received his Ph.D. in biology from the University of South Carolina.

**THOMAS J. O'NEIL, Ph.D.,** recently retired from the Cleveland-Cliffs Iron Company and Cliffs Mining Company where he served as president and chief operating officer. He was responsible for five North American iron ore mines. He has experience in other mining activities ranging from coal to copper. Prior to his private-sector duties, he was professor and head of the Department of Mining and Geological Engineering at the University of Arizona. He has numerous peer-reviewed publications and has received numerous honors and awards from professional societies and universities. He was the 2003 president of the Society for Mining, Metallurgy and Exploration. Dr. O'Neil is a member of the National Academy of Engineering and has served on the National Academies Committee on Earth Resources. He received his Ph.D. in mining engineering from the University of Arizona.

**CHARLES POOLE, Sc.D.,** is an associate professor in the Department of Epidemiology at the University of North Carolina School of Public Health, where his work focuses on the development and application of epidemiologic research methods and principles. His areas of substantive research interest include environmental and occupational epidemiology. He served with the U.S. Environmental Protection Agency, worked as an epidemiologic consultant, and taught at the Boston University School of Public Health. He has served on the editorial boards of several leading epidemiological journals. Dr. Poole has served on four previous National Research Council (NRC) committees, including the Committee on Estimating the Health-Risk-Reduction Benefits of Proposed Air Pollution Regulations. He received his M.P.H. from the University of North Carolina and his Sc.D. from Harvard University.

**CAROL J. PTACEK, Ph.D.,** holds a joint appointment as a research scientist with the National Water Research Institute, Environment Canada, and a research associate professor in the Department of Earth Sciences, University of Waterloo. She has conducted research on a variety of topics in contaminant hydrogeology and geochemistry, including studies on mechanisms controlling the fate and transport of metals, nutrients, pathogens, organic solvents and petroleum products in groundwater, and the development of passive methods for remediating contaminated groundwater. Her current research focuses on passive groundwater remediation technologies, the release and transport of metals at northern mine sites, and the fate of wastewater contaminants in shallow sand aquifers. Dr. Ptacek holds a Ph.D. in groundwater geochemistry from the University of Waterloo.

**ROBIN MILLS RIDGWAY, Ph.D.,** is an environmental regulatory consultant and environmental engineer employed by Physical Facilities Radiological and Environmental Management/Utilities at Purdue University. She assists and advises the university with environmental compliance with state and federal regulations, including the Clean Air Act and the Clean Water Act. She also provides technical guidance and recommendations to the university's Wade Utility, which provides heating and cooling and approximately half of the electricity for Purdue's West Lafayette, Indiana, campus. She is a licensed professional engineer in Indiana. Dr. Ridgway holds a Ph.D. in environmental engineering from Purdue University.

**LARRY ROBINSON, Ph.D.,** is a professor in the Environmental Sciences Institute at Florida A&M University (FAMU). He previously served as director and professor of FAMU's Environmental Sciences Institute for six years and provost and vice president for academic affairs for two years before returning to the faculty ranks. Previously he was group leader of a neutron activation analysis laboratory at Oak Ridge National Laboratory (ORNL). His research interests include environmental chemistry, the application of nuclear methods to detect trace elements in environmental matrices and environmental policy and management. While at ORNL he served on the National Laboratory Diversity Council and was president of the Oak Ridge Branch of the National Association for the Advancement of Colored People. Dr. Robinson is currently a member of the National Academies Committee on Restoration of the Greater Everglades Ecosystem. He earned his Ph.D. in nuclear chemistry from Washington University in St. Louis.

**MADAN M. SINGH, P.E.,** is director of the Arizona Department of Mines and Mineral Resources. Previous positions include president of Engineers International, Inc., a faculty member at The Pennsylvania State University and manager for Soil and Rock Mechanics at IIT Research Institute. Dr. Singh's research interests and expertise encompass diverse aspects of rock mechanics, mining, hydrogeology, soil mechanics, grouting, tunneling, drilling, water jetting and pellet impact, nuclear waste disposal, geothermal energy, subsidence, geotechnical engineering, sustainable development, and environmental work. He developed a graduate-level course in mine subsidence engineering at The Pennsylvania State University and acted as advisor during the drafting of subsidence control legislation in the State of Pennsylvania. He has a Ph.D. in mining engineering from The Pennsylvania State University. Dr. Singh has served in several capacities for professional societies, including national director of the American Consulting Engineers Council, president of the Consulting Engineers Council of Illinois, member of the Board of Directors of the Society for Mining, Metallurgy, and Exploration, Inc. (SME), chair of the SME Coal Division, and chair of the American Society for Testing and Materials subcommittee on rock strength. He has authored more than 100 technical papers, in addition to serving as chapter author on mine subsidence in the SME Mining Engineering Handbook (also associate editor), and Mining Environmental Handbook. Dr. Singh has served on two NRC committees, the U.S. National Committee on Rock Mechanics (1977-1980) and the U.S. National Committee on Tunneling Technology (1974-1976). He was named a centennial fellow by the College of Earth and Mineral Sciences (1996) and honored with the Robert Stefanko Distinguished Achievement Award by the Department of Energy and Geoenvironmental Engineering (1999), both at The Pennsylvania State University. He won the SME Howard N. Eavenson Award in 2000 and was selected as a distinguished member in 2004. In 1997, Dr. Singh was elected fellow of the American Consulting Engineers Council and fellow of the American Society of Civil Engineers in 1985. He is a life member of the Society of the Sigma Xi (since 1964), life member of the American Association for the Advancement of Science (since 1965), and a charter member of the Institute of Shaft Drilling (since 1982). In 1990, he won the Minority Vendor of the Year Award (Illinois Minority and Female Business Enterprise Council). The Federal Highway Administration selected his company, Engineers International, Inc., for its 1999 Environmental Excellence Award.

**MARK SQUILLACE, J.D.,** is a professor of law and director of the Natural Resources Law Center at the University of Colorado School of Law. Before the University of Colorado he was the Charles Fornoff Professor of Law and Values at the University of Toledo. His teaching and research interests include public land law, water rights, natural resources law, environmental law, and administrative law. From 1986 through Mr. Squillace taught at the University of Wyoming College of Law. While there, he was the Winston Howard Professor of Law from 1993 to 1996. Prior to his academic career, Mr. Squillace worked as the director of litigation at the Environmental Policy Institute from 1981 through 1984 and as an attorney adviser at the Department of the Interior from 1978 through 1981, where he was involved in the early development of the Surface Mining Control and Reclamation Act. Mr. Squillace received his B.S. in mathematics from Michigan State University and his J.D. from the University of Utah College of Law. He is the author or coauthor of numerous books and articles on these subjects, including the National Environmental Policy Act Litigation Guide. In addition to his academic duties, Professor Squillace frequently offers pro bono legal assistance to conservation groups, primarily in the areas of mining law, endangered species protection, and environmental decision making.

**RICHARD J. SWEIGARD, Ph.D.,** is chairman and professor in the Department of Mining Engineering at the University of Kentucky. Prior to his academic positions, he was engineer for Betz-Converse-Murdoch and a consulting engineering geologist. Dr. Sweigard's research falls under the category of environmental impacts of mining including the alleviation of excessive compaction of reconstructed soil, post-mining land use, slope stabilization on abandoned mine lands, and disposal of coal combustion by-products. He is a registered engineer in Pennsylvania and his professional activities include the SME, the American Society for Surface Mining and Reclamation, and the ASCE. Dr. Sweigard served as a member of the National Academies Committee for the Study on Preventing Coal Waste Impoundment Failures and Breakthroughs. He received his Ph.D. in mining engineering from The Pennsylvania State University.

**BAILUS WALKER, JR., Ph.D.,** is professor of environmental and occupational medicine at Howard University College of Medicine, Washington, DC. His research interests include lead toxicity and environmental carcinogenesis. He was the commissioner of public health for the Commonwealth of Massachusetts and state director of Public Health for Michigan. He is past president of the American Public Health Association, and a distinguished fellow of both the Royal Society of Health (London, England) and the American College of Epidemiology. Dr. Walker is a member of the National Academies' Institute of Medicine. He has served on several National Academies' committees, including as chair of the Committee on Toxicology. Dr. Walker received his Ph.D. in occupational and environmental medicine from the University of Minnesota and his M.P.H from the University of Michigan.

**JOHN J. WARWICK, Ph.D.,** is executive director of the Division of Hydrologic Sciences and director of the Nevada Institute for Water Resources at the Desert Research Institute (DRI). Prior to DRI, Dr. Warwick was professor and chair of the University of Florida's Department of Environmental Engineering Sciences and the director of the National Aeronautics and Space Administration (NASA) Environmental Systems Commercial Space Technology Center. Dr. Warwick's research interests include numerical modeling of the transport and fate of contaminants in surface-water systems and quantifying the impact of imperfect knowledge on the confidence associated with model predictions (uncertainty analysis). Dr. Warwick was named as a fellow of the American Water Resources Association in 2002, has served as vice chairman of the Urban Water Resources Research Council of the ASCE, and is a past president of the American Water Resources Association. He is currently a registered professional engineer in Pennsylvania. Dr. Warwick received a Ph.D. in environmental engineering from The Pennsylvania State University.

**JEFFREY J. WONG, Ph.D.,** is the deputy director of the Science, Pollution Prevention and Technology Program for the California Department of Toxic Substances Control (DTSC) at the California Environmental Protection Agency. His office is engaged in environmental measurements, biological and exposure monitoring, toxicology and risk assessment, pollution prevention and waste minimization, and verification and evaluation of technologies involved in hazardous waste detection, containment, treatment, disposal, or cleanup. Before his current appointment, Dr. Wong served as chief of DTSC's Human and Ecological Risk Division. In that position, he directed the scientific organization that gathers site characterization data and performs risk assessments in support of the state's hazardous waste and site remediation programs. He served by presidential appointment on the U.S. Nuclear Waste Technical Review Board from 1996 until 2002. Dr. Wong has served on several National Academies committees, including the Committee on Risk-Based Approaches for Disposition of Transuranic and High-Level Radioactive Waste, the Committee on Environmental Remediation at Naval Facilities, the Committee on Remedial Action Priorities for Hazardous Waste Sites and the Panel for Review of the DOE Environmental Restoration Priority System. Dr. Wong received his Ph.D. in pharmacology and toxicology from the University of California at Davis.

## STAFF BIOGRAPHIES

**TAMARA L. DICKINSON,** *study director,* is associate director for the National Academies Space Studies Board. Prior to joining the Space Studies Board, she served as a senior program officer in the Board on Earth Sciences and Resources for the Committee on Earth Resources working on mining and energy policy issues. She has served as program director for the Petrology and Geochemistry Program in the Division of Earth Sciences at the National Science Foundation. She has also served as discipline scientist for the Planetary Materials and Geochemistry Program at NASA Headquarters. As a postdoctoral fellow at the NASA Johnson Space Center, she conducted experiments on the origin and evolution of lunar rocks and highly reduced igneous meteorites. She holds a Ph.D. and an M.S. in geology from the University of New Mexico and a B.A. in geology from the University of Northern Iowa.

**STEPHANIE E. JOHNSON** is a senior program officer with the Water Science and Technology Board. Since joining the NRC in 2002, she has served as study director for four committees, including the Panel to Review the Critical Ecosystem Studies Initiative and the Committee on Water System Security Research. She has also worked on NRC studies on contaminant source remediation and the restoration of the Greater Everglades Ecosystem. She received her B.A. from Vanderbilt University in chemistry and geology, and her M.S. and Ph.D. in environmental sciences from the University of Virginia on the subject of pesticide transport and microbial bioavailability in soils. Her research interests include contaminant transport, aqueous geochemistry, and hydrogeology.

**K. JOHN HOLMES** is a senior program officer with the NRC's Board on Environmental Studies and Toxicology. Dr. Holmes has directed several major studies while at the NRC, including those that produced *Modeling Mobile Source Emissions*, *Evaluating Vehicle Emissions Inspection and Maintenance Programs*, and *The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, Alaska*. He received his Ph.D. from The John Hopkins University in environmental systems analysis, his M.S.E. in water resources management from University of Washington, and his B.S. in geology from Indiana University. His research interests include environmental systems modeling, policy analysis, and the history of environmental management.

**TANJA E. PILZAK** is a research associate for the Board on Earth Sciences and Resources (BESR) in the Division on Earth and Life Studies. She holds an M.S. in environmental management from the University of Maryland University College and a B.S. in natural resources management from the University of Maryland College Park. Ms. Pilzak has been with the National Academies since 1997; prior to her work in BESR she was a research associate in the Board on Agriculture and Natural Resources and a proposal specialist and contract assistant in the Office of Contracts and Grants.

**SANDI M. RUDENSTEIN** is a report review and communications officer for the Division on Earth and Life Studies. She received an M.A. in government with a focus in environmental policy from The Johns Hopkins University in 2004 and a B.A. in environmental studies with a minor in political science from The George Washington University in 1999. Since joining the NRC in 2003, she has produced communications materials and managed the peer-review process for numerous reports on topics such as air quality, disaster mitigation, geography, chemical sciences, sustainability, water resources, and toxicology.

**JAMES B. DAVIS** is a program assistant for the Board on Earth Sciences and Resources. He received a B.A. in political science from Brigham Young University in 2001. He began working for the National Academies in 2004 and has primarily supported BESR activities on earth resource issues.

**ELIZABETH A. EIDE** is a senior program officer and joined the Board on Earth Sciences and Resources as staff officer for the Committee on Earth Resources in October 2005. With a background in isotope geochronology applied to crustal processes, she spent twelve years at the Geological Survey of Norway in Trondheim as a researcher prior to joining the Academies staff. While at the Survey, her responsibilities included constructing and managing the $^{40}$Ar/$^{39}$Ar Geochronology Laboratory, and directing several research departments. She completed a Ph.D. in geology at Stanford University and received a B.A. in geology from Franklin and Marshall College, Lancaster, Pennsylvania.

**NICHOLAS D. ROGERS** is a program assistant for the Board on Earth Sciences and Resources. He received a B.A. in history, with a focus on science and history, from Western Connecticut State University in 2004. He began working for the National Academies in 2006 and has primarily supported the Board on Earth Science and Resources activities on earth resource issues.

# B

# Information Provided to the Committee

## SPEAKERS AT COMMITTEE MEETINGS

David Argall, Pennsylvania House of Representatives, Tamaqua, Pennsylvania
Rusty Ashcraft, Alliance Coal, Lexington, Kentucky
Ernest Baker, U.S. Geological Survey (emeritus), Austin, Texas
Tracy Barnes, Indiana Department of Environmental Management, Indianapolis, Indiana
Robert Bessette, Council of Industrial Boiler Owners, Burke, Virginia
Bill Brancard, New Mexico Mines and Minerals Division, Santa Fe, New Mexico
Tracy Branham, Indiana Geological Society, Bloomington, Indiana
Don Bryenton, ATC Associates, Indianapolis, Indiana
Subhash Chander, Pennsylvania State University, University Park, Pennsylvania
Greg Conrad, Interstate Mining Compact Commission, Herndon, Virginia
Charles Cravotta, U.S. Geological Survey, New Cumberland, Pennsylvania
John Craynon, Office of Surface Mining, Washington, D.C.
Lee Daniels, Virginia Polytechnic Institute, Blacksburg, Virginia
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# C

# Glossary

**ABANDONED MINE** Excavations, either caved or sealed, that are deserted and in which further mining is not intended and open workings that are not ventilated and inspected regularly. (AGI dictionary)

**ACID-BASE ACCOUNTING** Procedures for quantifying the potential for acid generation and acid neutralization in a geologic solid based on laboratory test to help predict the impacts of mining on local water quality.

**ACID MINE DRAINAGE** Acidic drainage from bituminous coal mines containing a high concentration of acidic sulfates, esp. ferrous sulfate. (AGI Dictionary)

**ACTIVE MINE** The area, on and beneath land, used or disturbed in activity related to the extraction, removal, or recovery of coal from its natural deposits. (AGI Dictionary)

**ADSORPTION** Adherence of gas molecules, or of ions or molecules in solution, to the surface of solids with which they are in contact, as methane to coal or water to silica gel.

**ADVECTION** The horizontal movement of a mass of air which causes changes in temperature or in other physical properties of air. (Webster Unabridged)

**ALKALINITY** The extent to which a material exhibits the property of yielding hydroxyl ions in a water solution. (AGI Dictionary)

**ANTHRACITE** A hard, black lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. Commonly referred to as hard coal, it is mined in the United States, mainly in eastern Pennsylvania, although in small quantities in other states. (AGI Dictionary)

**AQUITARD** Low-permeability bed, in a stratigraphic sequence, of sufficient permeability to allow movement of contaminants, and to be relevant to regional groundwater flow, but of insufficient permeability for the economic production of water.

**ARSENIC** A metallic, steel-gray, brittle element. Symbol, As. Found native in realgar and orpiment, and combined with heavy metals. Used in bronzing, pyrotechny, insecticides, and poisons, and as a doping agent in transistors. Gallium arsenide is used as a laser material to convert electricity directly into coherent light. Arsenic and its compounds are poisonous. (AGI Dictionary)

**ASH** The inorganic residue after burning, esp. of coal. Ignition generally alters both the weight and the composition of the inorganic matter. (AGI Dictionary)

**ATTENUATION** A reduction in the amplitude or energy of a signal, such as might be produced by passage through a filter. (AGI Dictionary)

**ATTERBERG LIMITS** In a sediment, the water-content boundaries between the semiliquid and plastic states (known as the liquid limit) and between the plastic and semisolid states (known as the plastic limit). (AGI Dictionary)

**BAGHOUSES** See fabric filters

**BACKFILL** Material excavated from a site and reused for filling, for example the use of stones or coarse gravel for filling draining trenches. (AGI Dictionary)

**BENTHIC** Of or relating to or happening on the bottom under a body of water.

**BIOACCUMULATION** The process by which the concentrations of some toxic chemicals gradually increase in living tissue, such as in plants, fish, or people as they breathe contaminated air or consume contaminated food or water.

**BITUMINOUS COAL** A general term descriptive of coal other than anthracite and low-volatile coal on the one hand and lignite on the other. (AGI Dictionary)

**BOILER SLAG** A molten ash collected at the base of slag tap and cyclone furnaces that is quenched with water and shatters into black, angular particles having a smooth, glassy appearance. (ACAA, 2003 glossary of terms)

**BORROW MATERIAL** Soil or sediment removed from a site for use in construction, such as sandy sediment dredged and pumped to restore an eroded beach, or clay taken to build a levee or dike. (AGI Dictionary)

**BOTTOM ASH** Agglomerated ash particles formed in pulverized coal furnaces that are too large to be carried in the flue gases and impinge on the furnace walls or fall through open grates to an ash hopper at the bottom of the furnace. Bottom ash is typically gray to black in color, is quite angular, and has a porous surface structure. (ACAA, 2003 glossary of terms)

**BULK CHEMICAL CONTENT** The major mineral component of a fly ash is mullite, a mineral containing alumina silica oxide. The major mineral components of fluidized bed combustion (FBC) CCRs are anhydrite, calcite, lime (all calcium oxides), and hematite, an iron oxide (CIBO, 1997). Silicon dioxide comprises 17-52 percent by weight of fly ash and FBC CCRs. Other components in fly ashes and FBC CCRs are aluminum dioxide (7-24 percent), iron oxide (5-14 percent), and magnesium oxide (2-7 percent). FBC CCRs are typically higher in calcium oxide and sulfur trioxide than pulverized coal CCRs due to the co-combustion of limestone for $SO_2$ control in FCBs.

**CADMIUM** A soft, bluish-white metal, similar in many respects to zinc, copper, and lead ores. Almost all cadmium is obtained as a by-product in the treatment of these ores. Symbol, Cd. Used in electroplating, in solder, for batteries, as a barrier to control atomic fission, and in TV tubes. Cadmium and solutions of its compounds are toxic. (AGI Dictionary)

**CAPILLARY FRINGE** Zone of partially saturated material just above the water table. The depth of the fringe depends upon the size and distribution of the pore spaces within the geologic framework.

**CAPPING** The overburden or rock deposit overlying a body of capped mineral or ore. (AGI Dictionary)

**CEMENTITIOUS** Fly ash has the properties of, or acts like, a cement when mixed with water. (American Geological Institute, 1997)

**CENOSPHERES** A portion of fly ash that floats on the surface of ash ponds and can be harvested. They are lightweight (0.368 to 0.449 grams per cubic centimeter), inert, hollow, essentially thin-walled glass spheres (10 to 350 microns in diameter) comprised largely of silica and alumina and filled with air and/or gases and are formed from the ash when it is in a molten state. Cenospheres are also now being extracted from dry fly ash by companies using proprietary processes and subsequently marketed under registered trade names. (ACAA, 2005b).

**COAL BED** The smallest distinctive division of a stratified series of coal, marked by a more or less well-defined surface or plane from its neighbors above and below; also known as a layer or stratum.

**COAL COMBUSTION RESIDUES** Solid residues generated by coal-burning electric utilities in the production of electricity.

**COAL RESERVES** Measured tonnages of coal that have been calculated to occur in a coal seam within a particular property.

**COAL SEAM** A bed or stratum of coal.

**COAL SPOILS** Refer to spoil.

**CO-FIRED MATERIALS** Non-coal materials fired at the same time as coal in the same boiler.

**COGENERATION FACILITIES** A steam generation facility that that uses the steam for an industrial process (e.g., heating, cooling, manufacturing) as well as for electricity generation.

**COKE** Bituminous coal from which the volatile constituents have been driven off by heat, so that the fixed carbon and the ash are fused together. Commonly artificial, but natural coke is also known; e.g., where a dike has intersected a bituminous coal bed and has converted the bordering coal to natural coke. (AGI Dictionary)

**COLUMN LEACHING METHODS** Simulation of in situ leaching through the use of a long narrow column in which ore sample and solution are in contact for measuring the effects of typical variables encountered in actual in situ leach mining. (AGI Dictionary)

**COMBUSTION** The action or operation of burning; the continuous combination of a substance with certain elements, such as oxygen or chlorine; e.g., accompanied by the generation of light and heat. (AGI Dictionary)

**CULM** In anthracite terminology, it is the waste accumulation of coal, bone, and rock from old dry breakers. In bituminous coal preparation, culm corresponds to slurry or slime, depending upon the size distribution of the suspended solids. (AGI Dictionary)

**CYCLONE** The conical shaped apparatus used in dust collecting operations and fine grinding applications. In principle, the cyclone varies the speed of air, which determines whether a given particle will drop through force of specific gravity or be carried through friction of the air. (AGI Dictionary)

**DESORPTION** The reverse process of adsorption whereby adsorbed matter is removed from the adsorbent. The term is also used as the reverse process of absorption. (AGI Dictionary)

**DESULPHURIZE** To free from sulfur; to remove the sulfur from an ore or mineral by some suitable process, as by roasting. (AGI Dictionary)

**DILUTION** The contamination of ore with barren wall rock in stoping. The assay of the ore after mining is frequently 10% lower than when sampled in place. (AGI Dictionary)

**DIOXINS** Toxic, human-made chemical by-products (dibenzo-p-dioxins), released into the atmosphere from incineration and during industrial processes that use chlorine. Dioxin tends to accumulate in the fatty tissue of fish. They can have immediate and long-term health effects, including skin disease, cancer, and reproductive failure.

**ELECTROSTATIC PRECIPITATOR (ESP)** The most common particulate control technology used by coal-fired utilities. An ESP generates a high-intensity electrical field that causes ash particles to acquire an electrical charge and migrate to an oppositely charged collection surface. For typical coal-fired utilities, this process results in a collection efficiency of greater than 99 percent.

**EVAPOTRANSPIRATION** Loss of water from the soil both by evaporation and by transpiration from the plants growing thereon. (Webster's dictionary online)

**FABRIC FILTERS** Also known as baghouses, capture ash as the exit gas passes through a series of porous filter bags. Baghouses have an efficiency of greater than 99 percent.

**FUGITIVE DUST** The particulate matter not emitted from a duct or stack that becomes airborne due to the forces of wind or surface coal mining and reclamation operations or both. During surface coal mining and reclamation operations it may include emissions from haul roads; wind erosion of exposed surfaces, storage piles, and spoil piles; reclamation operations; and other activities in which material is either removed, stored, transported, or redistributed. (AGI Dictionary)

**GOB** A pile of loose waste, coal, and other minerals extracted from a mine that are not marketable. Gob may be left piled in underground workings or at the surface of the mine.

**GRADING** The relative proportions of the variously sized particles in a batch, or the process of screening and mixing to produce a batch with particle sizes correctly proportioned. (AGI Dictionary)

**GRATE FIRING** Coal is combusted while residing on a grate within the furnace.

**HEAT CONTENT** The sum of the latent heat and sensible heat contained in a substance, above the heat contained at a selected zero condition of temperature and pressure; expressed as Btu or calories per unit of volume or weight.

**HYDROCARBON DEPOSITS** Any organic compound, gaseous, liquid, or solid, consisting solely of carbon and hydrogen. They are divided into groups of which those of special interest to geologists are the paraffin, cycloparaffin, olefin, and aromatic groups. Crude oil is essentially a complex mixture of hydrocarbons. (AGI Dictionary)

**HYDRAULIC CONDUCTIVITY** Refers to the capability of subsurface materials (sand, rock, etc.) to allow a fluid (usually water) to flow through it.

**IMPOUNDMENT** General term for any confined water body, usually due to artificial structures but may be natural.

**INDEPENDENT POWER PRODUCERS** Private companies that develop, own, or operate electric power plants, often fueled by alternative energy sources such as biomass, cogeneration, small hydro, waste-to-energy, and wind facilities.

**INFILTRATION** The flow of a fluid into a solid substance through pores or small openings; spec. the movement of water into soil or porous rock. (AGI Dictionary)

**INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)** A power generation system which produces synthesis gas (syngas), mainly of CO and $H_2$, converted from fossil fuel, such as vacuum residue, heavy oil, petroleum coke, coal and Orimulsion by a partial oxidation process and then burned to generate electricity from syngas by combined cycle. (http://www/chiyoda-corp.com/biz/e/hpi/igcc.shtml)

**KINETIC TESTING METHODS** Kinetic methods are designed to emulate field conditions and may involve exposing a sample to alternating wetting and drying conditions to promote oxidation reactions before the drainage waters are analyzed for pH, alkalinity, and concentrations of sulfate and dissolved metals.

**LEACHATE** A solution obtained by leaching; e.g., water that has percolated through soil containing soluble substances and that contains certain amounts of these substances in solution. (AGI Dictionary)

**LEACHING RATE TEST** A test designed to assess the value of antifouling compositions by measuring the rate of loss of toxic ingredients from a painted surface during immersion in seawater. (AGI Dictionary)

**LIGNITE** Coal of low rank with a high inherent moisture and volatile matter; in this general sense, lignite may be subdivided into black lignite, brown lignite, and brown coal. (AGI Dictionary)

**LINER** A cover of clay, concrete, synthetic film, or other material, placed over all or part of the perimeter of a conduit or reservoir, to resist erosion, minimize seepage losses, withstand pressure, and improve flow. (AGI Dictionary)

**LITHOLOGY** The character of a rock described in terms of its structure, color, mineral composition, grain size, and arrangement of its component parts; all those visible features that in the aggregate impart mines and commonly is reliable over a distance of a few miles. (AGI Dictionary)

**MAXIMUM CONTAMINANT LEVEL (MCL)** The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards. (AGI Dictionary)

**MAXIMUM CONTAMINANT LEVEL GOAL (MCLG)** The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals. (AGI Dictionary)

**METALLOID** An element—such as boron, silicon, arsenic, or tellurium—intermediate in properties between the typical metals and nonmetals. (AGI Dictionary)

**MINE** An opening or excavation in the ground for the purpose of extracting minerals. (AGI dictionary)

**MINEFILL** Manmade deposits of natural soils and waste material into a mine.

**MONOFILLS** Locations of large-volume CCR disposal without blending or layering of the CCRs with mine spoil or other materials.

**MULLITE** An orthorhombic mineral consisting of an aluminum silicate that is resistant to corrosion and heat; used as a refractory. (AGI Dictionary)

**OVERBURDEN** Designates material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal—especially those deposits that are mined from the surface by open cuts. (AGI Dictionary)

**PARTINGS** A lamina or very thin sedimentary layer separating thicker strata of a different type; e.g., a thin layer of shale or slate in a coal bed, or a shale break in sandstone. Strata tend to separate readily at partings. (AGI Dictionary)

**PERFORMANCE STANDARD** A standard which sets an objective performance level that must be met, without specifying how this is to be achieved. For example, such a standard may impose emission limits that specify the amount and type of pollutant that may be discharged.

**PERMEABLE** Pertaining to a rock or soil having a texture that permits passage of liquids or gases under the pressure ordinarily found in earth materials. (AGI Dictionary)

**PULVERIZED COAL** Finely ground coal that can be burned as it issues from a suitable nozzle. (AGI Dictionary)

**RECHARGE** The processes by which water is absorbed and added to the zone of saturation, either directly into an aquifer or indirectly by way of another formation; also, the quantity of water so added. (AGI Dictionary)

**RECLAMATION** Restoration of mined land to original contour, use, or condition. (AGI Dictionary)

**RESIDUE HANDLING TECHNOLOGY** Residue collection systems from the boiler and its auxiliaries vary between facilities and form unit to unit. Some units use a collection system that results in a combined residual either in a dry or wet form. The type of materials that may be combined prior to leaving a plant is a function of individual plant collection logistics and or any requirements to facilitate final disposal. Because residues are constantly being produced during the combustion process and must be removed regularly, facilities usually have a storage system such as a silo for dry materials or a surface impoundment (pond) for wet materials. (AGI Dictionary)

**REVEGETATION** The process of restoring or replacing the botanical species upon an area disturbed by mineral operations. Revegetation is a customary requirement for reclamation of a mineral operation. (AGI Dictionary)

**SATURATED ZONE** A subsurface zone in which all the interstices are filled with water under pressure grater than that of the atmosphere. (AGI dictionary)

**SCRUBBER** Device for separating environmentally noxious chemical substances from waste gas streams. (AGI Dictionary)

**SHALE** One of the impurities associated with coal seams; the term should not be used as a general term for washery rejects. (AGI Dictionary)

**SHORT TON** The U.S. ton is the short ton which is equal to 2000 pounds; the British ton is the long ton which is equal to 2240 pounds. Both tons are actually defined in the same way. 1 ton is equal to 20 hundredweight. However, the definition of the hundredweight differs between countries. In the United States there are 100 pounds in the hundredweight, and in Britain there are 112 pounds in the hundredweight. This causes the actual weight of the ton to differ between countries. To distinguish between the two tons, the smaller U.S. ton is called short, while the larger British ton is called long.

**SLAG** Material from the iron blast furnace, resulting from the fusion of fluxstone with coke ash and the siliceous and aluminous impurities remaining after separation of iron from the ore. (AGI dictionary)

**SLURRY** Fine particles concentrated in a portion of the circulating water (usually by settling) and waterborne to treatment plant of any kind. (AGI Dictionary)

**SPOIL MATERIAL** Overburden, nonore, or other waste material removed in mining, quarrying, dredging, or excavating. (Global InfoMine)

**STRATA** Plural of stratum, a bed or layer of rock.

**SUBSIDENCE** The settling of waste piles or other areas at mine sites which causes the surface of the land to sink.

**SUBBITUMINOUS COAL** Coal of rank intermediate between lignite and bituminous. (AGI Dictionary)

**SURFACE MINING** Mining at or near the surface. This type of mining is generally done where the overburden can be removed without too much expense. (AGI Dictionary)

**SUSPENSION FIRING (PULVERIZED COAL FIRING)** Coal is crushed to a fine powder prior to entering the boiler's furnace and subsequently combusted in suspension with the combustion air.

**TRACE METAL CONTENT** The trace metals contained in CCRs are derived from the naturally occurring minerals present in the source coal. Trace metal content of coal varies across the coal types. (AGI Dictionary)

**UNDERGROUND MINE (DEEP MINE)** Usually located several hundred feet below the earth's surface, an underground mine's coal is reached through vertical or inclined shafts, or, if the deposit is located in a mountain, through level or nearly level tunnels. The coal is removed mechanically and transferred to the surface.

**UNSATURATED ZONE** An area underground between the ground surface and the water table where the pore spaces are not filled with water, also known as the zone of aeration.

**VALENCE** The degree of combining power of an element or a radical. (AGI Dictionary)

**VENTURI** A contraction in a tube or duct to accelerate the flow and lower the static pressure. It is used for metering and other purposes. (AGI Dictionary)

**WATER TABLE** The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere. (AGI Dictionary)

# D

# Acronyms and Abbreviations

| | |
|---|---|
| ACAA | American Coal Ash Association |
| AMD | Acid Mine Drainage |
| AML | Abandoned Mine Land |
| AOC | Approximate Original Contour |
| ASTM | American Society for Testing and Materials |
| AVS | Applicant Violator System |
| CAA | Clean Air Act |
| CAAA | Clean Air Act Amendments |
| CAIR | Clean Air Interstate Rule |
| CAMR | Clean Air Mercury Rule |
| CCB | Coal Combustions Byproducts |
| CCR | Coal Combustion Residues |
| CHIA | Cumulative Hydrologic Impact Assessment |
| CHP | Combined Heat and Power |
| CWA | Clean Water Act |
| EIA | Energy Information Agency |
| EPA | U.S. Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right to Know Act |
| ESP | Electrostatic Precipitator |
| ET | Evapotranspiration |
| FBC | Fluidized Bed Combustion |

| | |
|---|---|
| FGD | Flue Gas Desulfurization |
| IGCC | Integrated Gasification Combined Cycle |
| IPP | Independent Power Producer |
| MCL | Maximum Contaminant Level |
| MEP | Multiple Extraction Procedure |
| MSW | Municipal Solid Waste |
| NPDES | National Pollutant Discharge Elimination System |
| NRC | National Research Council |
| OSM | Office of Surface Mining |
| PADEP | Pennsylvania Department of Environmental Protection |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PC | Pulverized Coal (Boiler) |
| PFBC | Pressurized Fluidized Bed Combustion |
| PHC | Probable Hydrologic Consequence |
| PPA | Pollution Prevention Act |
| PVC | Polyvinyl Chloride |
| QA/QC | Quality Assurance and Quality Control |
| RCRA | Resource Conservation and Recovery Act |
| SDWA | Safe Drinking Water Act |
| SMCRA | Surface Mining Control and Reclamation Act |
| SOT | Science of Toxicology |
| SPLP | Synthetic Precipitate Leaching Procedure |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TRI | Toxics Release Inventory |
| UAA | Use Attainability Analysis |
| UCI | Underground Injection Control |
| USDOE | U.S. Department of Energy |
| USDW | Underground Source of Drinking Water |
| USGS | U.S. Geological Survey |

# E

# Side-by-Side Comparison of RCRA to SMCRA

Staff from the Office of Surface Mining, Reclamation and Enforcement (OSM) (within the U.S. Department of Interior) and the U.S. Environmental Protection Agency (EPA), Office of Solid Waste, prepared the following side-by-side comparison in 2002. The Committee utilized this side-by-side, and its own comparisons, in its deliberations. The document compares the language and approach of RCRA and SMCRA as they relate to the possible regulation of CCR placement in mines. The side-by-side includes citations from SMCRA and RCRA rules. For RCRA, it presents potential approaches, typical of RCRA, that might be used if RCRA D regulations are proposed. For SMCRA, it offers citations of current actual rules, with some interpretive additions (often in bold), and/or commentary, to show how SMCRA might be interpreted to cover CCR use in reclamation, or how language might be amended to address CCRs specifically.

| RCRA References | SMCRA References |
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| **I. Groundwater Monitoring**<br>The owner/operator is to monitor groundwater on-site to detect adverse impacts of ash placement on on-site groundwater such that the owner/operator will have opportunity to intervene to avoid adverse impacts on off-site users and uses of groundwater, including users and uses of surface waters affected by groundwater. | **I. Groundwater Monitoring**<br>A groundwater monitoring program should be done against a backdrop of site-specific background data. For that reason, extensive information is required on the hydrologic and geologic conditions of a proposed permit site. This information includes existing wells, seasonal rainfall amounts, stream flows, groundwater levels and other items that can be used in modeling and predicting |

| RCRA References | SMCRA References |
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|  | impacts to the permit area and adjacent areas during and after mining. This is the probable hydrologic consequences (PHC) part of the permit document. The regulatory authority, as part of the process, is then required to provide a cumulative hydrologic impact assessment (CHIA).<br>The information collected allows determination of a site-specific monitoring plan for groundwater and surface waters. Rather than using a “one size fits all” approach that may under sample one permit while over sampling another, the monitoring program can fit the site and the situation as known.<br>All known factors are required to be included in the PHC determination and the CHIA. Therefore, coal combustion byproduct placement as minefill is required in the analysis with adjustments to groundwater monitoring on a site-specific basis.<br>***SMCRA References: 30 CFR***<br>*Part 777.15 – Completeness Of Application*<br>*Parts 779.11, 783.11 – Environmental Resources*<br>*Parts 779.18, 783.18 – Climatological Information*<br>*Parts 779.21(a), 783.21(a) – Soil Resources*<br>*Parts 779.24, 783.24 – General Features*<br>*Parts 779.24(g), 786.24(g) – Surface Water Movement*<br>*Parts 779.25(a)(6), 783.25(a)(6) – Groundwater*<br>*Parts 779.25(a)(7), 783.25(a)(7) – Surface Water Bodies And Structures*<br>*Parts 779.25(a)(9), 783.25(a)(9) – Identification of Placement Areas*<br>*Parts 780.21, 784.14 – Hydrologic Information*<br>*Parts 780.22, 784.22 – Geologic Information*<br>*Parts 780.21(f) & 784.14(e) – Probable Hydrologic Consequences*<br>*Parts 780.21(g) & 784.14(f) – Cumulative Hydrologic Impact Assessment* |

| RCRA References | SMCRA References |
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| A. Well Design and Deployment: The purpose of monitoring wells is to allow the acquisition of ground-water samples from which adverse impacts on groundwater could be detected. Wells too few in number or which are located or screened in the wrong horizontal or vertical planes may fail to produce samples that adequately characterize impacts on groundwater. Location is critical to the ability to detect effects of ash placement before the effects can spread widely, thereby adversely affecting current or future uses of the water resource. | A. Well Design and Deployment: The required groundwater monitoring (**including well design, installation, sampling, and maintenance**) is permit specific. A groundwater monitoring plan is required that is based on the PHC determination and the analysis of **all** (**all includes all coal combustion material (CCB) placement**) hydrologic, geologic, and other information in the permit application. The plan must provide for the monitoring of parameters provide for the monitoring of parameters groundwater for current and approved post-mining uses. The plan shall provide for the monitoring of parameters (**including** parameters necessary to evaluate the **impact of CCB placement**) that relate to the suitability of the groundwater for current and approved post-mining land uses and to the objectives for protection of the hydrologic balance. It will identify the quantity and quality parameters to be monitored, sampling frequency, and site locations. It shall describe how the data may be used to determine the impacts of the operation upon the hydrologic balance. The data is to be submitted to the RA at least every 3 months for each monitoring location. All water quality analysis must be conducted according to the methodology of the 15th edition of "Standard Methods for the Examination of Water and Wastewater," or the methodology of 40 CFR Parts 136 and 434. The RA may require additional monitoring [30 CFR 780.21 and 816.41(c)]. The OSM technical reference on Permitting Hydrology outlines the detailed well information required for all groundwater baseline information used to determine the PHC. |
| ***RCRA References:***<br>*Part 258.51(a), (c), and (d) – Well design an deployment* | ***SMCRA References: 30 CFR***<br>*Part 780.21 Hydrologic Information*<br>*Parts 780.21(i), 784.14(h) – Groundwater Monitoring Plan*<br>*Parts 816.41(c), 817.41(a) – Groundwater Monitoring*<br>*Parts 780.23(b), 784.15(b) – Post-Mining Land Use* |

| RCRA References | SMCRA References |
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| B. Parameters: Samples are to be analyzed for specific constituents, which will detect and define adverse impacts on groundwater and for which valid statistical comparisons can be made among well samples to detect adverse impacts. Of particular concern in defining and detecting adverse impacts are the 8 metals, which define the RCRA toxicity characteristic (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). Additionally, boron and aluminum are of concern because they are often associated with ash.<br>***RCRA References:*** *Part 261.24 – Toxicity characteristic metals*; *Part 258.54(a) and Appendix I – Monitoring parameters* | B. Parameters: The required groundwater monitoring (including identification of parameters) is permit specific. The plan must provide for the monitoring of parameters that relate to the suitability of the groundwater for current and approved post-mining uses. The plan shall provide for the monitoring of parameters (**including parameters necessary to evaluate the impact of CCB placement**) that relate to the suitability of the groundwater for current and approved post-mining land uses and to the objectives for protection of the hydrologic balance. Based on the PHC, it must identify the quantity and quality parameters to be monitored, sampling frequency, and site locations (**including the parameters necessary to evaluate the impact of CCB placement**). It shall describe how the data may be used to determine the impacts (**including the potential toxicity levels of any CCB specific parameters that would impact the use of the groundwater**) of the operation upon the hydrologic balance. The data is to be submitted to the RA at least every 3 months for each monitoring location. The RA may require additional monitoring [30 CFR 780.21 and 816.41(c)].<br>***SMCRA References: 30 CFR***<br>*Parts 780.21(i), 784.14(h) – Groundwater Monitoring Plan*<br>*Parts 816.41(c), 817.41(a) – Groundwater Monitoring*<br>*Part 780.21 – Hydrologic Information*<br>*Parts 780.23(b), 784.15(b) – Post-Mining Land Use* |
| C. Frequency: Samples are to be acquired and analyzed at a frequency, which will provide early warning of adverse impacts on water use. Without regulation, samples may be obtained so infrequently as to allow adverse impacts to go undetected, thereby jeopardizing off-site users/uses. The owner/operator may use groundwater flow and attenuation studies to seek re-definition of the sampling frequency. | C. Frequency: The required groundwater monitoring (including frequency of sampling) is permit specific. The groundwater monitoring plan will identify the quantity and quality parameters to be monitored, sampling frequency, and site locations (**including the sampling frequency necessary to evaluate the impact of CCB placement**). It shall describe how the data may be used to determine the impacts (**including the** |

| RCRA References | SMCRA References |
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| ***RCRA References:*** *Part 258.53(c) and (f) and Part 258.54(b) – Monitoring frequency* | **frequency of sampling of any CCB specific parameters that would impact the use of the groundwater)** of the operation upon the hydrologic balance. The data is to be submitted to the RA at least every 3 months for each monitoring location. The RA may require additional monitoring [30 CFR 780.21 and 816.41(c)].<br>***SMCRA References: 30 CFR***<br>*Parts 780.21(i), 784.14(h) – Groundwater Monitoring Plan*<br>*Parts 816.41(c), 817.41(a) – Groundwater Monitoring* |
| D. Duration: Samples are to be acquired and analyzed over the time period for which the effects on groundwater from ash placement could be reasonably expected to be measured or observed; i.e., considering aquifer recharge times and rate of migration of groundwater through and away from the placed ash. This time period may extend beyond the completion of reclamation and the time of bond release for the overall mine site (see Section IX, below, on Post-closure maintenance). Where the owner/operator can demonstrate that there is no longer a potential for adverse impacts from the placed ash, monitoring may cease.<br>***RCRA References:*** *Part 258.50(b) – Suspension of monitoring; Part 258.61(a), (b), and (e) – Duration of post-closure period* | D. Duration: Performance bond liability will be for the duration of the surface coal mining and reclamation operation and for a period which is coincident with the operator's period of extended responsibility for successful revegetation (10 years after establishment of vegetation in areas with less than 26" precipitation; 5 years after establishment of vegetation in areas with more than 26" precipitation) or until achievement of the reclamation requirements of the Act, regulatory programs, and permit, which ever is later (this would include determination of compliance with the hydrologic performance standards at 30 CFR 816.41(a, b, and h) and 816.42. Performance standards related to the protection of groundwater must include that all mining and reclamation activities shall be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, to prevent material damage to the hydrologic balance outside the permit area, to assure the protection or replacement of water rights, and to support the approved post-mining land uses in accordance with the terms and conditions of the approved permit. Any person who conducts surface mining activities shall replace the water supply of an owner of interest in real property who obtains all or part of his or her supply of water for domestic, agricultural, industrial, or other legitimate use from an underground or surface source, where the water supply |

| RCRA References | SMCRA References |
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|  | has been adversely impacted by contamination, diminution, or interruption proximately (defined as a result that directly produces and event and without which the event would not have occurred) resulting from the surface mining activities. Discharges of water from areas disturbed by surface mining activities shall be made in compliance with **all** applicable State and Federal water quality laws and regulations and with the effluent limitations for coal mining promulgated by the U.S. EPA set forth in 40 CFR Part 434.<br>***SMCRA References: 30 CFR***<br>*Part 800.13 – Period of Liability*<br>*Parts 816.131(2)(i) & (3)(i) – Bonding Period and Annual Precipitation*<br>*Parts 816.41(a),(b) & (h) – Hydrologic-Balance Protection*<br>*Part 816.42 – Water Quality Standards and Effluent Limitations* |
| **II. Performance Standards**<br>Regulations can require compliance with either specific operating practices or performance standards. Where operating practices (which include practices for design and construction operations, as well as practices for operation of the facility) are specified, the owner/operator is restricted to the specified practices. Where performance standards are specified, the owner/operator has flexibility to use creative design, construction, and operational approaches and need only be concerned with compliance with the performance level specified. For minefill practices, the performance standard approach is preferred in order to allow increased flexibility. Performance standards are specified here for ground-water impacts only. | **II. Performance Standards**<br>All mining and reclamation activities shall be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, to prevent material damage (defined as a loss of physical property) to the hydrologic balance outside the permit area, to assure the protection or replacement of water rights (assure the continuation of pre-mining water use either by leaving it unchanged or by replacement), and to support the approved post-mining land uses in accordance with the terms and conditions of the approved permit. Any person who conducts surface mining activities shall replace the water supply of an owner of interest in real property who obtains all or part of his or her supply of water for domestic, agricultural, industrial, or other legitimate use from an underground or surface source, where the water supply has been adversely impacted by contamination (a change in water quality that would render it no longer acceptable for the pre-mining use), diminution, or interruption proximately (defined as a result that directly produces and event and without which an event would |

| RCRA References | SMCRA References |
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| | not have occurred) resulting from the surface mining activities. Earth materials and runoff will be handled in a manner that minimizes (any effect of mining and reclamation would be at a level that would reduce the pre-mining potential for use of the resource) acidic, toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbance to prevent or control the discharge of pollutants into the groundwater. Discharges of water from areas disturbed by surface mining activities shall be made in compliance with **all** applicable State and Federal water quality laws and regulations and with the effluent limitations for coal mining promulgated by the U.S. EPA set forth in 40 CFR Part 434 [30 CFR 816.41 and 816.42]<br><br>***SMCRA References: 30 CFR***<br>*Part 701.11(d) – Application of Standards*<br>*Parts 816.41 – Hydrologic-Balance Protection*<br>*Parts 816.41(h), 817.41(j) – Water Rights and Replacement*<br>*Part 816.42 – Water Quality Standards and Effluent Limitations*<br>*Parts 816.95 – Stabilization of Surface Area*<br>*Part 780.18(b)(9) – Description of Pollution Control*<br>*Part 780.15 – Fugitive Dust Control Practices* |
| A. Maximum Contaminant Levels (MCLs): For the 8 RCRA "toxicity characteristic" metals listed in item I.B. above, the MCLs specified under the Safe Drinking Water Act serve as the ground-water performance standard for mine placement of ash. The facility is to be operated so that it does not cause ground-water quality to exceed the MCLs. The point at which compliance is demonstrated is to be no more than 150 meters from the ash placement boundary and located on the facility property.<br><br>***RCRA References:***<br>*Part 141 – MCLs;*<br>*Part 258.40(d) – Point of compliance;*<br>*Part 258.2 – Definition of "boundary"* | A. Maximum Contaminant Levels (MCLs): Discharges of water from areas disturbed by surface mining activities shall be made in compliance with **all** applicable State and Federal water quality laws and regulations and with the effluent limitations for coal mining promulgated by the U.S. EPA set forth in 40 CFR Part 434. The groundwater monitoring plan included in the mine permit shall provide for the monitoring of parameters that relate to the suitability of the groundwater for current and approved post-mining land uses and to the objectives for protection of the hydrologic balance set forth in 30 CFR §780.21(h). It shall identify the quantity and quality parameters to be monitored, sampling frequency, and site |

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| | locations. It shall describe how the data may be used to determine the impacts of the operation upon the hydrologic balance. At a minimum, total dissolved solids or specific conductance corrected to 25 degrees C, pH, total iron, total manganese, and water levels shall be monitored and data submitted to the regulatory authority at least every three months for each monitoring location. The regulatory authority may require additional monitoring. See also, I.A. Parameters and II. Performance Standards.<br>***SMCRA References: 30 CFR***<br>*Part 780.21(i) – Ground-Water Monitoring Plan*<br>*Part 816.41 – Hydrologic-Balance Protection*<br>*Part 816.42 – Water Quality Standards and Effluent Limitations* |
| B. Non-degradation:<br>There are likely to be situations where the facility owner/operator can demonstrate that groundwater within 150 meters of the outermost boundary of placed ash or for potential placement of ash exceeds the MCLs solely for reasons other than impact of the ash; i.e., background levels attributable to prior mining activity or some up-gradient phenomenon unrelated to ash placement. Where this situation exists, the measured high background levels would be an affirmative defense for measured exceedences of the MCL performance standards. In such cases, the performance standard would be no degradation beyond the measured high background levels, rather than no exceedence of the MCLs.<br>***RCRA References:*** *Part 258.53(e) – Statistical procedures for detecting contamination; Part 258.40(d) – Point of compliance; Part 258.2 – Definition of "boundary"* | B. Non-degradation:<br>See II and II.A. above. |

| RCRA References | SMCRA References |
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| **III. Prohibitions**<br>Because of the permanent, irreversible nature of mine placement of ash, and the more fragile character of certain environments, specific prohibitions are appropriate to protect human health and the environment. | **III. Prohibitions**<br>No permit application or application for a significant revision of a permit shall be approved unless the applicant affirmatively demonstrates and the regulatory authority (RA) finds, in writing, on the basis of information set forth in the application, or from information otherwise available that is documented in the approval, that: (1) the application is complete and accurate and that the applicant has complied with all requirements of the Act and regulatory program; (2) the applicant has demonstrated that reclamation as required by the Act and the regulatory program can be accomplished under the reclamation plan contained in the permit; and (3) the RA has made an assessment of the Probable Cumulative Impacts of all anticipated coal mining on the hydrologic balance in the cumulative impact area and has determined that the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area.<br>***SMCRA References: 30 CFR***<br>*Part 773.15 – Written Findings for Permit Application Approval* |
| A. Aquifer Avoidance:<br>Ash is not to be placed in direct contact with an aquifer unless the owner/operator can demonstrate in advance that placement will have no adverse impact on ground-water quality. As in 40 CFR Part 259, “aquifer” means a geologic formation, group of formations, or portion of a formation capable of yielding significant quantities of groundwater to wells or springs.<br>***RCRA References:*** *Part 258.2 – Definition of “aquifer”* | A. Aquifer Avoidance:<br>An aquifer is defined as a zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use.<br>See II. Performance Standards and IV. Permitting/Planning.<br>***SMCRA References: 30 CFR***<br>*Part 701.05 – Definitions* |
| B. Unacceptable Ash Characteristics:<br>Ash characteristics vary as a result of coal composition and combustion practices. Ash may demonstrate characteristics, which indicate that they are not compatible with mine placement. When characterized by the | B. Unacceptable Ash Characteristics:<br>Toxic-forming materials are defined as earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are like to produce chemical or physical conditions in soils or water that are |

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| method described below, ash, which produced an unacceptable leachate quality is not to be placed in mines. Unacceptable leachate quality may be defined as exceeding the MCLs for the 8 RCRA toxicity characteristic metals identified in item I.B., above, and/or exceeding appropriate limits for other constituents of concern, such as boron and aluminum.<br>1. Method: To test ash for unacceptable characteristics, the ash is to be subjected to a 30-day leaching by water representative of the groundwater to which the ash would be exposed at the mine.<br>2. Frequency: Ash received for mine placement shall be tested for unacceptable characteristics every 6 months and when the source of coal or combustion changes.<br>***RCRA References:*** *Part 261.24 – Toxicity characteristic metals; Part 141 - MCLs* | detrimental to biota or uses of water. Mine operations must conduct their activities to minimize disturbance of the hydrologic balance within the permit and adjacent areas, prevent material damage to the hydrologic balance outside the permit area, assure the protection or replacement of water rights, and support approved postmining land uses in accordance with the terms and conditions of the approved permit and the performance standards in 30 CFR Ch. VII, subchapter K.<br>Encapsulation can be used for acid and toxic forming material exposed, used or produced during mining. This material must be adequately covered with nontoxic material or treated to control the impact on surface and groundwater to minimize adverse effects on plant growth and the approved postmining land use.<br>See also, II. Performance Standards and IV. Permitting/Planning.<br>***SMCRA References: 30 CFR***<br>*Part 816.41(f) – Toxic-Forming Materials*<br>*Parts 816.102(f), 817.102(f) – Encapsulation*<br>*Parts 780.21, 784.14 – Hydrologic Information*<br>*Parts 780.22, 784.22 – Geologic Information*<br>*Parts 780.21(f) & 784.14(e) – Probable Hydrologic Consequences*<br>*Parts 780.21(g) & 784.14(f) – Cumulative Hydrologic Impact Assessment*<br>*Part 816.41 – Hydrologic-Balance Protection*<br>*Part 816.42 – Water Quality Standards and Effluent Limitations* |
| C. Location Restrictions: Due to their particular sensitivities, sites of specific characteristics are not amenable to the permanent and irreversible nature of ash placement and cannot be used for ash placement.<br>1. Flood Plain: Because they are more prone to washout, areas within the 100-year flood plain are not appropriate for ash placement. Furthermore, placement in the 100-year flood plain | C. Location Restrictions:<br>Each permit application must include a description of the existing, pre-mining environmental resources within the proposed permit area and adjacent areas that may be affected or impacted by the proposed surface mining activities. The permit application must include the following baseline information upon which the mining and reclamation plan must be based: |

| RCRA References | SMCRA References |
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| could dangerously restrict the flow of waters at the 100-year or more frequent design level and/or reduce the storage capacity of the flood plain so as to pose a hazard to human health or the environment.<br>2. Wetlands: Wetlands are sensitive areas of surface water, which often serve as habitats of protected species. At mine sites ash is not to be placed in surface water or wetland in violation of State or Federal law or in a manner that would jeopardize an endangered or threatened species or critical habitats or in a manner that would degrade wetlands.<br>3. Fault Areas: It is not possible to project how ash placed in a mine site would react when subjected to major ground disturbances characterized by faults. Because of the potential for fault movements to expose ash to unanticipated forces (e.g., surface water flows and washout) and subsequently jeopardize human health or the environment, ash is not to be placed within 60 meters of faults that have experienced displacement during the Holocene Epoch.<br>4. Seismic Impact Zones: Seismic movements can cause ash to unexpectedly contact surface or groundwaters, with subsequent harm to human health or the environment. To help avoid this, ash is not be placed in seismic impact zones. These are areas having a 10 percent or greater probability that the maximum expected horizontal acceleration of hard rock, expressed as a percentage of the earth's gravitation pull (g), will exceed 0.10g in 250 years.<br>5. Unstable Areas: Placement of ash in unstable areas can cause unexpected exposure of ash to ground or surface waters, with subsequent harm to human health or the environment. To help avoid this, ash is not to be placed in unstable areas. Unstable areas are locations susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the natural or | • General Environmental Resources Information including the cultural, historic, and archeological resources, 30 CFR §779.12.<br>• Climatic Information, 30 CFR §779.18.<br>• Vegetation Information, 30 CFR §779.19.<br>• Soils Resource Information, 30 CFR §779.21.<br>• Maps: General Requirements, 30 CFR §779.24.<br>• Cross Sections, Maps and Plans, 30 CFR §779.25.<br>• Fish and Wildlife Resources, 30 CFR §779.16.<br>• Hydrologic Information, 30 CFR §780.21, (including flood plains, critical receptors such as water wells, dams, streams, water intake structures, and wetlands) including:<br>o Sampling and analysis methodology<br>o Groundwater and surface water baseline information<br>o Cumulative impact area information<br>o Modeling or statistical analysis may be required<br>o Alternate water sources<br>o PHC<br>o CHIA<br>o Hydrologic reclamation plan<br>o Surface and groundwater monitoring plan<br>• Geologic Information, 30 CFR §780.22, including:<br>o PHC<br>o All potential acid and toxic forming strata to just below coal seam<br>o Description of the geology (Detailed guidance is given in the OSM Permitting Hydrology reference including structural geologic features such as folding and faulting, strike and dip, and joints and fractures related to Fault areas, Seismic Impact Zones, and Unstable areas) in the proposed permit and adjacent areas down to just below the coal seam or any |

| RCRA References | SMCRA References |
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| artificial components responsible for preventing releases from the ash placement. Unstable areas can include: poor foundation conditions, locations near blasting events, areas susceptible to mass movements, and Karst terrains.<br>6. <u>Proximity to Critical Receptors</u>: Nearby users of surface and groundwaters, which could be adversely impacted by ash placement are of particular concern. In this context, the definition of the term “nearby” is variable and depends on hydrologic characteristics of the area and the dynamics of possibly multiple, human-induced pumping cones. Owners/operators of ash mine placement facilities are to conduct site-specific hydrologic studies to demonstrate how the practice will avoid placing nearby users in jeopardy.<br>***RCRA References:*** *Part 258.11 – Flood plains; Part 258.12- Wetlands; Part 258.13 – Fault areas; Part 258.14 – Seismic impact zones; Part 259.15 – Unstable areas* | lower aquifer impacted by mining. The description shall include the area and structural geology of the permit and adjacent areas, and other parameters which influence the required reclamation and the occurrence, availability, movement, quantity, and quality of potentially impacted surface and groundwater based on information collected in 30 CFR 779 and:<br>▪ Geologic literature.<br>▪ Analysis of samples collected from test borings and drill cores down to just below the coal seam or to the lowest aquifer affected by mining.<br>▪ Logs showing the lithologic characteristics of each stratum and related groundwater.<br>▪ Chemical analysis of any acid, alkaline, or toxic strata including total and pyretic sulfur.<br>▪ The RA may require additional information necessary to protect the hydrologic balance or meet the performance standards. |
| **IV. Planning/Permitting**<br>Institutionalized processes need to be in place to provide protection of human health and the environment. | **IV. Planning/Permitting**<br>During the course of OSM’s investigation into the placement of CCBs at mine sites, presentations by the environmental community and EPA staff have demonstrated a misconception that SMCRA based regulatory programs do not protect the environment. In fact, the Surface Mining Control and Reclamation Act (SMCRA) of 1977 was the result and in answer to severe problems caused by irresponsible mining practices. The SMCRA based programs require the permitting of coal mining operations, plans to address safeguarding environmental resources, plans showing preparations for mining, plans for the ongoing mine operations and plans for mine closure, reclamation and post-mining land use. Mining is recognized as a temporary land use that must not impair future use of the land. |

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|  | The following are purposes given in the Act (30 U.S.C. 1202) showing a bias for environmental protection and post-mining land uses:<br>• Establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations.<br>• Assure that the rights of surface landowners and other persons with a legal interest in the land or appurtenances thereto are fully protected from such operations.<br>• Assure that surface mining operations are not conducted where reclamation as required by the Act is not feasible.<br>• Assure that surface coal mining operations are so conducted as to protect the environment.<br>• Assure that adequate procedures are undertaken to reclaim surface areas as contemporaneously as possible with the surface coal mining operations.<br>• Promote the reclamation of mined areas left without adequate reclamation prior to the enactment of the Act and which continue, in their unreclaimed condition, to substantially degrade the quality of the environment, prevent or damage the beneficial use of land or water resources, or endanger the health or safety of the public.<br>• Assure that appropriate procedures are provided for the public participation in the development, revision, and enforcement of regulations, standards, reclamation plans, or programs established by the Secretary or any State under the Act.<br>• Wherever necessary, exercise the full reach of Federal constitutional powers to insure the protection of the public interest through effective control of surface coal mining operations.<br>***SMCRA References:***<br>***PL 95-87***<br>*Section 102* |

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|  | ***30 CFR***<br>*Part 701.11(d) – Application of Standards*<br>*Part 773 – Permits and Permit Processing Requirements*<br>*Part 777.15 – Completeness of Application*<br>*Part 778.17 – Permit Term*<br>*Part 779.11 – Characterization of Environmental Resources*<br>*Part 779.1, 780.1, 783.1, 784.1 – Scope of Requirements for Permit Application.*<br>*Parts 779.2, 780.2, 783.2, 784.2 – Objectives of Informational Requirements for Permitting* |
| A. Acid-Base Balance:<br>Where ash is placed for the purpose of providing a source of alkalinity to counteract a known acidic water environment, the owner/operator is to calculate an acid-base balance to demonstrate that, for the design life, the ash will provide adequate alkalinity to irreversibly achieve the intended acid mitigation.<br><br>***RCRA References:*** *None, generally not applicable to RCRA waste management units* | A. Acid-Base Balance:<br>All mining and reclamation activities shall be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, to prevent material damage (defined as a loss of physical property) to the hydrologic balance outside the permit area, to assure the protection or replacement of water rights (assure the continuation of pre-mining water use either by leaving it unchanged or by replacement), and to support the approved post-mining land uses in accordance with the terms and conditions of the approved permit. Any person who conducts surface mining activities shall replace the water supply of an owner of interest in real property who obtains all or part of his or her supply of water for domestic, agricultural, industrial, or other legitimate use from an underground or surface source, where the water supply has been adversely impacted by contamination (a change in water quality that would render it no longer acceptable for the pre-mining use), diminution, or interruption proximately (defined as a result that directly produces and event and without which the event would not have occurred) resulting from the surface mining activities. Earth materials and runoff must be handled in a manner that minimizes (any effect of mining and reclamation would be at a level that would reduce the pre-mining potential for use of the resource) acidic, toxic, or other harmful infiltration to groundwater systems and by |

| RCRA References | SMCRA References |
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| | managing excavations and other disturbance to prevent or control the discharge of pollutants into the groundwater. Discharges of water from areas disturbed by surface mining activities shall be made in compliance with **all** applicable State and Federal water quality laws and regulations and with the effluent limitations for coal mining promulgated by the U.S. EPA set forth in 40 CFR Part 434. |
| | In order to protect the hydrologic balance, surface mining activities shall be conducted according to the hydrologic reclamation plan approved at 780.21(h) and groundwater quality shall be protected by handling earth materials (**including CCBs**) and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the groundwater. Drainage from acid- and toxic-forming materials into surface water and groundwater shall be avoided by identifying and burying and/or treating, when necessary, material which may adversely affect water quality or be detrimental to vegetation or to public health and safety, if not buried and/or treated. |
| | During back filling and grading, exposed coal seams, acid- and toxic-forming materials…. exposed, used, or produced during mining shall be adequately covered with nontoxic and non combustible material, or treated, to control the impact on surface and groundwater in accordance with the hydrologic performance standards of 816.41 and to minimize adverse effects on plant growth and the approved post-mining land use [30 CFR 816.102]. |
| | **CCB (ash) characterization and leach testing would be required when the permit application involved CCB placement** under the provisions of 30 CFR 780.21(f) for the determination of the probable hydrologic consequences provisions that require |

| RCRA References | SMCRA References |
|---|---|
| | baseline hydrologic, geologic and other information in order to support the PHC findings on whether acid- or toxic-forming materials are present that could result in the contamination of surface or groundwater supplies. |
| | ***SMCRA References: 30 CFR***<br>*Part 816.41 – Hydrologic-Balance Protection*<br>*Part 816.42 – Water Quality Standards and Effluent Limitations*<br>*Parts 780.21(h), 784.14(g) – Hydrologic Reclamation Plan*<br>*Parts 816.102, 817.102 – Backfilling and Grading: General Requirements*<br>*Parts 780.21(f), 784.14(e) – Probable Hydrologic Consequences Determination* |
| B. Deed Recordation:<br>The owner/operator is to ensure that official land records note the locations and dates for all ash placement on all portions of the property, particularly where the property may be subdivided for future use.<br><br>***RCRA References:*** *Part 258.60(i) Deed recordation* | B. Deed Recordation:<br>The SMCRA permit would be required to show the location of CCB placement areas. These maps are public information. The procedure of making a deed recording is normally done to record a type of deed restriction. SMCRA requires that mining and reclamation be conducted in a manner that restores the land affected to a condition capable of supporting the uses which it was capable of supporting prior to mining, or higher or better uses [30 U.S.C. 1265 Section 515(b)(2)]. Under this scenario, there would be no need for deed restrictions. |
| | ***SMCRA References: 30 CFR***<br>*Parts 780.14, 784.23 – Map Requirements*<br>*Part 773.6 – Public Participation in Permit Processing*<br>*Parts 773.6, 840.14, 842.16 – Availability of Records*<br>*Parts 780.23, 784.15 – Reclamation Plan: Postmining Land Use*<br>*Parts 816.133, 817.133 – Postmining Land Use* |
| C. Baseline Monitoring:<br>Prior to placing ash at a mine site, groundwater monitoring is to be conducted to establish “baseline” conditions for comparison with future monitoring data. | C. Baseline Monitoring:<br>Each permit application must include a description of the existing, pre-mining environmental resources within the proposed permit area and adjacent areas that may be |

| RCRA References | SMCRA References |
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| This will aid in detection of any adverse impacts.<br>**RCRA References:** *Part 258.53(3) Establishing background* | affected or impacted by the proposed surface mining activities. The permit application must include the following baseline information upon which the mining and reclamation plan must be based:<br>• General Environmental Resources Information including the cultural, historic, and archeological resources, 30 CFR §779.12.<br>• Climatic Information, 30 CFR §779.18.<br>• Vegetation Information, 30 CFR §779.19.<br>• Soils Resource Information, 30 CFR §779.21.<br>• Maps: General Requirements, 30 CFR §779.24.<br>• Cross sections, maps and plans, 30 CFR §779.25.<br>• Fish and Wildlife Resources, 30 CFR §779.16.<br>• Hydrologic Information, 30 CFR §780.21 (including flood plains, critical receptors such as water wells, dams, streams, water intake structures, and wetlands) including:<br>o Sampling and analysis methodology<br>o Groundwater and surface water baseline information<br>o Cumulative impact area information<br>o Modeling or statistical analysis may be required<br>o Alternate water sources<br>o PHC<br>o CHIA<br>o Hydrologic reclamation plan<br>o Surface and groundwater monitoring plan<br>• Geologic Information, 30 CFR §780.22, including:<br>o PHC<br>o All potential acid and toxic forming strata to just below coal seam<br>o Description of the geology (Detailed guidance is given in the OSM Permitting Hydrology reference including structural geologic features such as folding and faulting, strike and dip, and joints and fractures |

| RCRA References | SMCRA References |
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| | related to Fault areas, Seismic Impact Zones, and Unstable areas) in the proposed permit and adjacent areas down to just below the coal seam or any lower aquifer impacted by mining. The description shall include the area and structural geology of the permit and adjacent areas, and other parameters which influence the required reclamation and the occurrence, availability, movement, quantity, and quality of potentially impacted surface and groundwater based on information collected in 30 CFR 779 and:<br>▪ Geologic literature.<br>▪ Analysis of samples collected from test borings and drill cores down to just below the coal seam or to the lowest aquifer affected by mining.<br>▪ Logs showing the lithologic characteristics of each stratum and related groundwater.<br>▪ Chemical analysis of any acid, alkaline, or toxic strata including total and pyretic sulfur.<br>▪ The RA may require additional information necessary to protect the hydrologic balance or meet the performance standards. |
| **V. Operational Requirements**<br>With a preference for the flexibility afforded by performance standards, the only area of concern for operational requirements is fugitive dust controls. Operational requirements are used for this area because monitoring to confirm compliance with a performance standard is not feasible. | **V. Operational Requirements** |
| A. <u>Fugitive Dust Controls:</u><br>Prior to discharge at a mine site, ash is to be conditioned by mixing with water to a moisture content of at least 5 percent by weight, but not to exceed 20 percent by weight. The purpose of conditioning is to reduce the likelihood that dust will become airborne during placement. | A. <u>Fugitive Dust Controls:</u><br>Requirements for large mines (over 1 million tons/year) west of the 100th meridian must submit an air pollution control plan including an air quality monitoring program sufficient to evaluate the effectiveness of fugitive dust control practices in order to comply with Federal and State air quality |

| RCRA References | SMCRA References |
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| ***RCRA References:*** *No comparable requirement under Subtitle D (see, Part 264.30 (j) – Controlling wind dispersal, under Subtitle C)* | standards and a plan for fugitive dust control practices. All other mines must submit an air pollution control plan including an air quality monitoring program sufficient to evaluate the effectiveness of fugitive dust control practices in order to comply with Federal and State air quality standards, only if required by the RA, and a plan for fugitive dust control practices.<br>***SMCRA References: 30 CFR***<br>*Part 780.15 – Air Pollution Control Plan*<br>*Part 816.95 – Stabilization of Surface Areas (Fugitive Dust Control)* |
| **VI. Risk Assessments**<br>Owners/operators are to conduct risk assessments to inform themselves, regulators, and the public of the likelihood that the placement of ash at the mine site will adversely impact critical receptors.<br>A. Impact on humans and other animals via air and surface water pathways, including potential intermingling of groundwater and surface water.<br>B. Impact on plants via air and surface water pathways, including potential intermingling of groundwater and surface water.<br>C. Impact on air quality.<br>D. Impact on water quality, including potential intermingling of groundwater and surface water.<br>E. Impact on fish, including potential intermingling of groundwater and surface water and potential air transport of contaminants to surface water.<br>***RCRA References:*** *None* | **VI. Risk Assessments**<br>Risk is defined as the chance of injury, damage, or loss. A risk assessment is necessary when an agency is contemplating an action not already adequately regulated to prevent risk.<br>The purposes or SMCRA are given in the Act as follows, 30 U.S.C. 1202:<br>• Establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations.<br>• Assure that the rights of surface landowners and other persons with a legal interest in the land or appurtenances thereto are fully protected from such operations.<br>• Assure that surface mining operations are not conducted where reclamation as required by the Act is not feasible.<br>• Assure that surface coal mining operations are so conducted as to protect the environment.<br>As such, the purpose of SMCRA is to not approve a permit until it can be established that the mining operation, including the placement of CCBs if proposed, will not place either the public or the environment at risk. |

| RCRA References | SMCRA References |
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| | Therefore, there is not a need for additional risk assessment, beyond what is already required by a SMCRA program on a permit-by-permit basis.<br>See II. Performance Standards and IV. Permitting/Planning. |
| **VII. Public Participation**<br>To be comfortable with allowing the placement of ash at mine sites, the public needs information, opportunity to raise concerns, and assurance that those concerns will be addressed. | **VII. Public Participation** |
| A. Planning and Permitting:<br>Prior to approving ash placement, the permitting authority is to inform the public of the planned operation, make public all risk assessment (item VI, above) and baseline monitoring (item IV, above) information and provide for interactive public discussion.<br>***RCRA References:*** *Part 239.6(a) and (b) – Public Participation in Permitting* | A. Planning and Permitting:<br>*Notification*: The permit applicant must publish a local newspaper notice [with minimum info listed at 773.13(a)(1)] of availability of the application at the country courthouse and the RA. The RA must notify Federal, State, and local agencies of the application. The RA must notify any persons submitting comment, parties involved in informal conferences, and appropriate agencies of permit issuance or renewal.<br>*Access:* Access to all permitting files, including **inspections and monitoring reports**, by the public must be made available by the RA.<br>*Comments:* The public may submit comments or written objections to the RA within 30 days of last newspaper notice. Any person with interest may request an informal conference with the RA. *Enforcement:* The RA must provide for public participation in enforcement. The public may also request a Federal inspection.<br>**SMCRA References: 30 CFR**<br>*Part 773.6 – Public Participation in Permit Processing*<br>*Part 773.6(a)(1) – Public Advertisement of Permits*<br>*Part 773.6, 773.9, 774.15 – Notification Requirements* |

| RCRA References | SMCRA References |
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| | *Parts 773.6, 840.14, 842.16 – Availability of Records*<br>*Part 773.6(d) – Public Availability of Permit Applications*<br>*Parts 840.15, 840.16, 842.11 – Public Participation in Enforcement*<br>*Part 842.12 – Requests for Federal Inspections*<br>*Part 842.14 – Review of Adequacy and Completeness of Inspections* |
| B. Monitoring Information:<br>All monitoring data, reports, and other forms of information should be made available to the public. Access to all information is to be readily available to the public at an accessible location such as a government library.<br><br>***RCRA References:*** *No comparable requirements under Subtitle D (see Part 260.2 – Availability of Information, under Subtitle C)* | B. Monitoring Information:<br>See VII.A. above. |
| C. Citizen Suits:<br>The public is to have the opportunity to file suit in appropriate courts to ensure compliance by the owner/operator.<br><br>***RCRA References:*** *RCRA Section 7002; Part 254 – Prior Notice of Citizen Suits; Part 239.9 – Citizen Intervention in Civil Enforcement Proceedings* | C. Citizen Suits:<br>SMCRA provides for citizen lawsuits and judicial review of decisions.<br><br>***SMCRA References: 30 CFR***<br>*Part 775 – Administrative and Judicial Review of Decisions*<br>*Part 842.12 – Requests for Federal Inspections*<br>*Part 842.15 – Review of Decision Not to Inspect or Enforce*<br>***43 CFR Subtitle A, Part 4, Subpart L*** *– Special Rules*<br>***Applicable to Surface Coal Mining*** *Hearings and Appeals* |
| **VIII. Corrective Action**<br>In the case of exceedence of the performance standards specified in item II, above, the owner/operator must undertake corrective action to protect human health and the environment. The first step in response to an exceedence may be to assess the scope of the problem through additional monitoring. The owner/operator may demonstrate that | **VIII. Corrective Action**<br>SMCRA requires regular inspections and monitoring of the permit. Corrective actions may be required through notices of violation, cessation order, or required permit revision. The permittee is required to immediately notify the RA and take corrective actions as soon as a water quality non-compliance is determined. The permittee must take |

| RCRA References | SMCRA References |
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| the exceedence results from a source other than the ash placement or that the exceedence results from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. If the exceedence is determined to result from the ash placement, however, corrective measures should be implemented. The steps in the corrective action process include: assessment of corrective measures, selection of a remedy, selection of a schedule for the remedy, and implementation of corrective action, including interim measures that may be necessary for the immediate protection of human health or the environment.<br>***RCRA References:*** *Part 258.54(c)(3) – Response to exceedences of performance standards; Part 258.56 – Assessment of corrective measures; Part 258.57 – Selection of remedy; Part 258.58 – Implementation of corrective action* | whatever steps are necessary to ensure that the public health and environment are protected based on compliance with applicable performance standards, permit terms and conditions.<br>***SMCRA References: 30 CFR***<br>*Part 840 – State Regulatory Authority: Inspection and Enforcement*<br>*Part 842 – Federal Inspections and Monitoring*<br>*Part 843 – Federal Enforcement*<br>*Part 845 – Civil Penalties*<br>*Part 846 – Individual Civil Penalties* |
| **IX. Post-Closure/Post-Reclamation Care**<br>(Post-SMCRA Bond Release)<br>Monitoring and maintenance of the ash placement area should continue throughout the time period for which the effects of groundwater from ash placement could be reasonably expected to be measured or observed. This time period may extend beyond the completion of reclamation and the time of bond release for the overall mine site.<br>A. Maintenance and Inspection: Post-closure activities are to include inspection and maintenance as needed of the vegetative cover over the ash placement area and of any other engineered controls, such as a final cover, that may have been placed.<br>***RCRA References:*** *Part 258.61(a) – Post-closure activities; Part 258.61(a), (b), and (e) – Duration of post-closure period*<br>B. Monitoring and Corrective Action: As specified in Item I.D., above, maintenance and operation of the groundwater monitoring system for the ash placement area should | **IX. Post-Closure/Post-Reclamation Care**<br>(Post-SMCRA Bond Release)<br>SMCRA enforcement ceases following the release of Phase III bond liability. Performance bond liability will be for the duration of the surface coal mining and reclamation operation and for a period which is coincident with the operator's period of extended responsibility for successful revegetation (10 years after establishment of vegetation in areas with less than 26" precipitation; 5 years after establishment of vegetation in areas with more than 26" precipitation) or until achievement of the reclamation requirements of the Act, regulatory programs, and permit, which ever is later (this would include determination of compliance with the hydrologic performance standards at 30 CFR 816.41(a, b, and h) and 816.42. Performance standards related to the protection of groundwater would include that all mining and reclamation activities shall be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, to prevent material damage to the hydrologic balance outside the permit area, to assure the |

| RCRA References | SMCRA References |
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| continue throughout the post-reclamation period. These activities are to include evaluation of results against the performance standards specified in Item II, above, and implementation, if needed, of corrective action as discussed in Item VII, above.<br>***RCRA References:*** *Part 258.61(a)(3) – Post-closure groundwater monitoring; Part 258.61 (a), (b), and (e) – Duration of post-closure period*<br>C. Financial Assurance: In the event the post-closure/post-reclamation care period for the ash placement area extends beyond the time of bond release for the overall mine site, the owner/operator is to establish financial assurance to provide for maintenance and monitoring of the ash placement area specifically and for any potential corrective action associated with ash placement.<br>***RCRA References:*** *Part 258.72 – Financial assurance for post-closure care; Part 258.73 – Financial assurance for corrective action; Part 258.74 – Allowable mechanisms* | protection or replacement of water rights, and to support the approved post-mining land uses in accordance with the terms and conditions of the approved permit. Any person who conducts surface mining owner of interest in real property who obtains all or part of his or her supply of water for domestic, agricultural, industrial, or other legitimate use from an underground or surface source, where the water supply has been adversely impacted by contamination, diminution, or interruption proximately (defined as a result that directly produces and event and without which the event would not have occurred) resulting from the surface mining activities. Discharges of water from areas disturbed by surface mining activities shall be made in compliance with **all** applicable State and Federal water quality laws and regulations and with the effluent limitations for coal mining promulgated by the U.S. EPA set forth in 40 CFR Part 434. |
| | ***SMCRA References: 30 CFR***<br>*Ch. VII, subchapter J – Bonding and Insurance Requirements for Surface Coal Mining and Reclamation Operations.*<br>*Part 800.13 – Period of Liability*<br>*Parts 816.41, 817.41 – Hydrologic-Balance Protection*<br>*Parts 816.42, 817.42 – Water Quality Standards and Effluent Limitations*<br>*Parts 816.111, 817.111 – Revegetation: General Requirements*<br>*Parts 816.116, 817.116 – Revegetation: Standards for Success*<br>*Parts 816.132, 817.132 – Cessation of Operations: Permanent*<br>*Parts 816.133, 817.133 – Postmining Land Use*<br>*Parts 780.23(b), 784.15(b) – Reclamation Plan: Land Use Information, Following Reclamation* |

SOURCE: Vories et al., 2002

# F

# Regulatory Requirements for Isolation

The following outlines the various requirements for isolation of coal combustion residues (CCRs) both within the Surface Mining Control and Reclamation Act (SMCRA) and at the state level, as reported in EPA (2002c). Throughout this discussion it should be borne in mind that States vary in their interpretation of whether CCRs are considered coal or non-coal wastes.

## RESTRICTIONS

SMCRA prescribes that non-coal wastes may not be placed in (a) a refuse pile, (b) an impounding structure, or (c) within 8 ft of a coal outcrop or coal storage area. Besides, unless specially exempted, no coal mining operations can be conducted in (a) any of the National protected areas (such as parks, scenic rivers, wildlife refuges, and the like), (b) federal lands within a national forest, (c) where the mining would adversely affect parks or historic places, (d) within 100 ft of a public road or cemetery, and (e) within 300 ft of any occupied space (house, park, building).

### Disposal

In the following states there are no changes to the above: AL, AZ, AR, MD, MT, NM, WV, and WY.

In the following states the SMCRA rules apply with additions:

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| AK | CCRs cannot be placed (a) on slopes steeper than 10% grade, (b) unstable soils, (c) within floodplains, and (d) within 10 ft of the highest aquifer level. |
| CO | Requirements are determined on case-by-case basis. Disposal in floodplain has been refused. In coal mines these need to be isolated from the hydrologic regime. |
| IL | The site should be on the mine site or close to it. |
| IN | Proximity to water supplies and critical features are considerations in granting a permit. No disposal is allowed below the 100-year flood level. |
| KS | The solid waste disposal permit may limit placement. |
| KY | Placement is allowed (a) in a pit from which coal has been mined (although the rule may be relaxed if no adverse affects occur), (b) where contact with water is minimized, and (c) if at least 4 ft above high water table. CCRs cannot be placed within 4 ft of (a) a final highwall, (b) an exposed coal seam, or (c) a coal outcrop. If permitted for beneficial use it must be 100 ft from a stream and 300 ft from drinkable water wells, wetlands, or floodplains. |
| MO | CCRs must be above the high groundwater table. Variance may be granted. |
| ND | CCRs cannot be placed within: (a) an area where it may affect human health or the environment, (b) an aquifer or wellhead protection area, (c) 1,000 ft downgradient of a potable water well (although a waiver is possible), (d) 100-year floodplain, (e) differential settlement may affect features, (f) unstable slopes, (g) woody draws, (h) mine highwalls, (i) endangered or threatened species habitats, (j) 200 ft horizontally from the high-water level or wetland (could be waived), and (k) the water table. |
| OH | Placement is forbidden: (a) near water wells, (b) above an aquifer, (c) in sand or gravel pits, (d) in limestone or sandstone quarries, (e) in subsidence-prone areas, (f) within 1,000 ft of potable water wells or springs (could be relaxed), or (g) within less than 5 ft of the uppermost aquifer (from the bottom of the liner). |

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| PA | Does not have any restrictions on disposal since CCRs placement is considered a beneficial use (discussed below). |
| TN | CCRs may not be disposed in (a) wetlands, (b) sink holes, (c) caves, (d) 100-year floodplain, (e) endangered or threatened species habitat, and (f) within 3 ft of the high-water level of the uppermost aquifer. |
| TX | Limitations exist for: (a) fault areas (within 200 ft), (b) floodplains, (c) wetlands, (d) seismic zones, (e) unstable areas, and (f) high-water table (must be above). |
| VA | Placement of CCRs cannot occur: (a) in base flood areas (with exceptions); (b) within 2 ft of the high water table; (c) less than 100 ft from a perennial stream, water well, or sinkhole; (d) within 25 ft of an outcrop or property boundary; (e) in wetlands (permit may relax this); (f) in a dump (active or inactive), unpermitted landfill, lagoon, or similar feature. |
| WA | CCRs may not be placed on unstable hill slopes. |

### Beneficial Use

Most states make no distinction between CCR disposal and beneficial use; hence they do not make allowance for the same. These states include: AL, AK, AZ, AR, CO, KS, KY, MD, MO, MT, NM, TN, VA, WA, WV, and WY.

In some states the SMCRA regulations apply: IL, IN, and TX.

A few states consider CCRs as a beneficial use, and have special requirements:

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| ND | No specific restrictions exist, but the permit application should include information on: (a) nearby communities, (b) housing, (c) parks, (d) nature areas, and (e) waterways. |
| OH | In addition to SMCRA, CCRs may not be placed within: (a) 100 ft of streams; variance is possible, but the distance may be augmented for high-value streams, (b) 100 ft of high-quality wetlands (distance may be increased), (c) 500 ft upgradient of a surface potable water source, (d) 300 ft upgradient of a groundwater source, (e) 300 ft of a inhabited house, unless a waiver from the owner is obtained, or (f) 8 ft of the groundwater table in the area, unless special permission is obtained. |

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| PA | The SMCRA regulations apply. Placement is permitted in (a) mine from which coal was mined, (b) abandoned coal mine within the permit area, (c) reclamation work approved by the State, and (d) coal refuse areas. The CCR must be 8 ft above the water table— except for demonstration projects. |

**PLATE 1** Example of plant stress from boron toxicity downgradient of the Cedar Sauk Landfill.
SOURCE: Philip Fauble, Wisconsin Department of Natural Resources.