Chapter 2

Technical Summary

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Chapter 2
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INTRODUCTION

A comprehensive national program for the regulation of surface coal m ine reclamation was instituted in the late 1970s with the enactment of the Surface Mine Control and Reclamation Act of 1977 (SMCRA; Public Law 95-87) and the prom u lgation of the permanent regulatory program in 1979. **In the** 8 **years since SMCRA, substantial improvements have been made in reclamation technologies and methodologies, and the prognosis for the long-term success of surface mine reclamation in the western United States has brightened considerably.** Yet recent analyses of surface mine reclamation have raised concerns about the adequacy and use of baseline and monitoring data; the accuracy of methodologies for predicting the impacts of mining and the success of reclamation practices; the use of lease stipulations and permit conditions to accommodate uncertainty; the development and introduction of new reclamation techniques; and the status of research on mined land reclamation in the Western United States (2,3,4,5).

This report discusses these issues in the context of permitting and reclamation for the Federal coal surface mining regions of North Dakota, Montana, Wyoming, Colorado, and New Mexico, The report evaluates the quantity, quality, and management of baseline data used to support premining permitting in the context of the SMCRA performance standards, as well as the uses of monitoring data collected during mining and reclamation; the adequacy and reliability of analytical techniques used to predict the impacts of surface coal mining, and to design and evaluate reclamation; and the scope and adequacy of criteria used to judge the success of reclamation in the West. The report also examines a variety of technical issues related to the performance and design standards for reclamation, identifies research needs, and discusses the remaining uncertainties that need to be resolved before predictions can be made about the long-term success of Western reclamation.

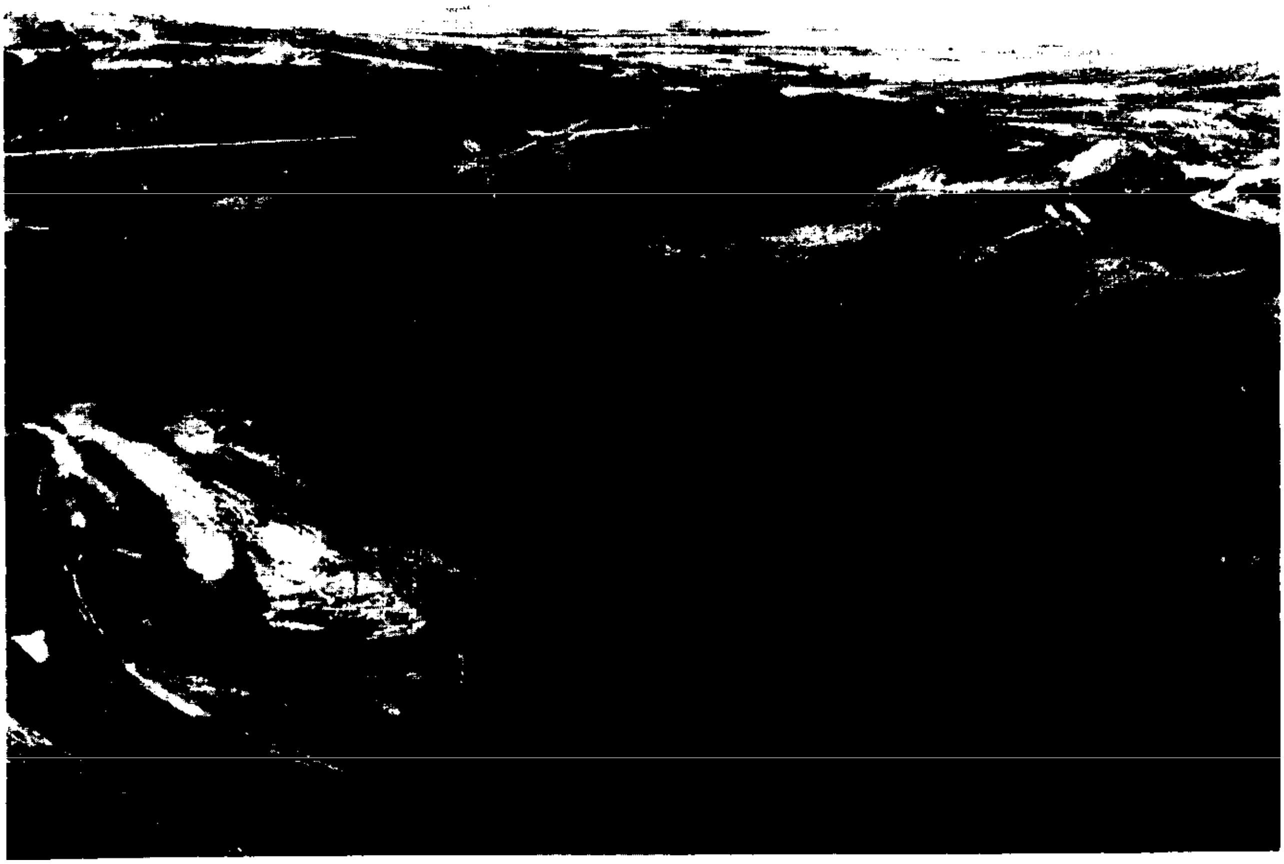
BASELINE AND MONITORING DATA

Coal operators collect ***baseline*** data–the thorough premining characterization of all surface and subsurface resources on the mine site—to formulate a mining and reclamation plan and permit application. Baseline data provide the basis for predicting the impacts of mining and reclamation and for defining the postmining land use. ***Monitoring data*** are collected during and after mining and reclamation to track the impacts of mining and to refine the reclamation plan, if necessary. Together, these two sets of data enable the operator to compare premining and postmining conditions to evaluate the success of reclamation.

OTA found that *baseline* data generally are adequate for making informed decisions, during permitting, about an individual mine's ability to meet the SMCRA performance standards. However, the limited ability to manage large amounts of baseline and monitoring data and, in a few instances, unreliability of or inconsistencies in data sets, still place limitations on both reclamation in the field and the advancement of reclamation science.

Data Collection

Collection of reliable data for some parameters can be difficult, either because there are natural obstacles to collecting the data, or standardized data collection methodologies are lacking, or laboratory techniques for generating data need to be refined. **Many data inadequacies could be overcome quickly.** For example, the unreliabil-



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ity of some laboratory analysis techniques for generating chemical data about overburden is a serious limitation on the extremely important problem of delineating overburden strata that may be detrimental to revegetation or postmining water quality. It is rapidly becoming apparent that techniques borrowed from soil science are inadequate because of the physical and chemical differences between soil and overburden, and that new tests must be devised. **Work on developing new sampling, sample preparation, and laboratory analysis techniques could produce results rapidly.**

Lack of coordination in data collection and of standardization in collection methods pose an obstacle to meaningful *regional* data compilation and analysis that also could be overcome. These are particularly a limitation on the predictive accuracy of cumulative hydrologic impact assessments (CHIAS) of all existing and anticipated mining within an area. To be valid in the quantitative models used for such mandatory assessments of regional impacts, hydrologic data must be collected throughout the entire region over the same time periods and with the same methods. Statistical techniques currently are used to accommodate differences among data sets, with the magnitude of the predictive error increasing with the magnitude of the differences and the number of assumptions that must be made.

Operators and regulatory authorities are beginning to move toward the necessary standardization. The Wyoming regulatory authority, for example, requires operators in the vicinity of Gillette, Wyoming, to coordinate their groundwater data collection efforts. These operators formed the Gillette Area Groundwater Monitoring Organization (GAGMO), and they collect data on or around October 1 of every year and subsequently publish it for interested parties. Such coordination of data collection is rare, however, and the operators and regulatory authorities should consider extending it to other areas and disciplines.

The lack of standardized methodologies for collection of some data seriously limits their usefulness. Standardized surface water quality data collection methods do not exist for ephemeral streams, which comprise the majority of streams in the Western mining regions. Because such streams flow only in response to runoff events, their infrequent and unpredictable flows will continue to limit the availability of data. As a result, the usefulness of ephemeral stream data is severely limited in predictions of the probable hydrologic consequences (PHC) of mining and reclamation and in CHIAS, and it is difficult for regulatory authorities to assess compliance with hydrologic performance standards.

Standardized data collection methodologies also are lacking for wildlife. The mobility and adaptability of wildlife make it unlikely that accurate animal population data suitable for quantitative impact assessments ever will be available. The difficulty in collecting accurate population data has prompted a shift in focus in the wildlife baseline studies required in most States from collection and analysis of population data to the description and delineation of habitat extent and quality. But the development of standard methodologies for quantitative measurement of the various physical and floral features of wildlife habitats has not kept pace. Such standardized collection methods are necessary for the reliable prediction and analysis of wildlife impacts, and for the development of design criteria for impact mitigation measures such as rock piles and nest boxes, Standardization is particularly important when wildlife data are of regional concern, as large mammal, raptor, and game bird data are, because such data have many potential users. At present, impact analyses and mitigation design are based on the professional judgment of wildlife biologists, which has proven accurate in the few attempts at statistical verification based on available population data.

While these data collection problems introduce some uncertainties in the reliability of methods for predicting and evaluating mining impacts and reclamation success, OTA did not find them to to be a large problem in the permitting or monitoring of Western surface coal mines. Their primary effect has been to increase the cost of reclamation due to the need to design for worst-case impacts. It also might be more difficult for regulatory authorities to review permit applications because of the need to verify statistical analyses.

Data Management

The large quantity of data being collected has caused serious data management problems for both mine operators and regulatory authorities. First, data collection has outpaced analysis. OTA found that it is not uncommon for the Office of Surface Mining (OSM) or the State regulatory authorities to require operators to collect data that are never analyzed or reviewed. This problem is most apparent in monitoring data for disciplines that tend to be data intensive (overburden and hydrology), although OTA also found a few instances of lack of analysis of baseline data. SMCRA requires extensive hydrologic monitoring, but **the amount of hydrologic monitoring data operators submit to regulatory authorities is so large that personnel and resources rarely are available to review it.** Only in Wyoming has the regular review of monitoring data become a standard part of the State's annual review of mining operations; even there, available personnel are unable to analyze all of the monitoring data that have been submitted. In many areas, the operators' collection and submission of monitoring data has become perfunctory. **"Scoping" processes to examine which baseline and monitoring data actually are needed for permit compliance and reclamation success evaluations, and subsequent revision of data collection requirements, could facilitate data management and analysis.**

The lack of review or analysis of monitoring data also means that an important opportunity is being lost to validate the analytical techniques used to predict the impacts of mining and to design and evaluate reclamation. Optimizing the quantity and format of such data would facilitate its use in confirming the validity of the predictions based on it.

The problems with data quantity and management are compounded by the format in which data are submitted to the regulatory authorities. The permit applications themselves are a prime example of costly data collection whose utility is circumscribed by an inaccessible format. Western surface mining permit applications typically consist of 25 to 30 3-inch thick 3-ring binders of data (and analysis), all in hard copy, which reside on shelves in regional OSM and State regulatory authority offices. The data generally are not reduced or made computer accessible and, with the exception of more recent permit applications in Wyoming and Colorado, there is no standard format for the applications. As a result, only the preparer of the application and the regulatory agency staff who review it can find information in the numerous volumes without an extraordinary commitment of time and effort. Although **the** data **in permit applications could be useful to parties other than the permittee and the regulatory authority (for instance, the Bureau of Land Management (BLM) in fulfilling its responsibilities under the Federal coal leasing program), the sheer volume and inaccessible format of the data at best discourage, and at worst prohibit, such uses.**

Data collection and management for permit applicants and regulatory authorities also could be more efficient if the data in the general literature were of uniform quality and format. Data on the soils, geology, hydrology, vegetation, and wildlife of the Western coal provinces are collected by Federal and State agencies, universities, and independent research organizations, but their usefulness in preparing a permit application varies. Most regional data collected by government agencies are too few over too large an area to fulfill permitting requirements, while data from academic and independent research usually have the opposite problem. Much of this information also has quality control problems due to the lack of standardization in the data collection techniques used. In many cases, the data have not been made accessible by computer or published.

Although such data rarely meet all the regulatory requirements for baseline or monitoring data, they may serve as a good starting point. U.S. Geological Survey hydrologic and geologic data and U.S. Soil Conservation Service soils data frequently are incorporated in permit applications but must be augmented with more detailed, site-specific information to meet regulatory requirements. Most of the available vegetation and wildlife information, however, is useful only to provide a preliminary profile of the mine site and to highlight potential reclamation problems or other factors to guide the applicant's data collection efforts.

The large amounts of data in permit applications and the general literature about the resources of Western mining regions have led operators and regulatory authorities to question whether there is significant duplication of data collection efforts that could be eliminated through the compilation of comprehensive, computerized disciplinary databases, Because **the data requirements for permit applications are highly site-specific,** OTA **did not find redundancy in data collection to be a significant problem *within* the mine permitting process.** However, the development of comprehensive databases from permit applications and other sources would improve the background information available to permit applicants and regulatory authorities.

Because of the data management problems outlined above, OTA did find redundancy be*tween* permit application and monitoring data and the data collection efforts of other groups. Comprehensive disciplinary databases could eliminate this redundancy. Such databases would be especially useful to Federal and State agencies and research groups working in the areas of hydrology, soils and geology, and wildlife. As mining in the West expands and the amount of permit data collected grows, these groups will continue to repeat permit applicants' data collection efforts if the data in the applications are not made more accessible and useful.

ANALYTICAL TECHNIQUES

Operators and regulatory authorities use a wide range of methods to interpret and analyze data when predicting the impacts of mining and reclamation and in designing reclamation, and the ultimate success of reclamation may depend on the validity of those methods. **Some analytical techniques in use, however, do not consistently produce realistic predictions or valid interpretations with available data, or must rely heavily on assumptions to compensate for data inadequacies.**

Predicting the Impacts of Mining and Reclamation

In predicting the impacts of mining and reclamation, assessments of the quality and quantity of surface and groundwater resources and of the soil resource and the material within the postmining root zone are of major concern because they are critical to the postmining ecology, yet they are subject to a high degree of uncertainty. Impacts on vegetation, and to a limited extent wildlife, are determined indirectly from the predicted characterization of the postmining soil and water resources.

Hydrologic Impacts

SMCRA requires mine operators to conduct assessments of the probable hydrologic consequences (PHC) of mining and reclamation both on and off the mine site, and requires regulatory authorities to perform the CHIAs.[1] The PHC determination covers all potential impacts to surface and groundwater from a single mine, and, historically, has addressed the 5-year term-of-permit mining area. The CHIA expands on PHC determinations to encompass offsite components of the hydrologic system that are likely to be adversely affected by the cumulative effects of all existing and anticipated mines for the proposed life of the mines. PHC determinations and CHIAS use combinations of analytical techniques for predieting impacts on surface and groundwater quantity and quality.

Groundwater Quantity.—The development and use of quantitative methods for predicting impacts to groundwater quantity during ***mining*—pit inflows and associated drawdowns—has tended to lag behind other quantitative developments in groundwater science.** The effects of this are evident in the wide range of analytical techniques used in the mine permit applications reviewed for this assessment, which varied from simple linear extrapolations based on historical trends to sophisticated computer models. State regulations and guidelines for analysis provide essentially no assistance in selecting the appropriate technique for site-specific conditions.

Where substantial amounts of accurate and consistent data are available, simple linear extensions of historical trends can predict groundwater quantity impacts during mining with reasonable accuracy, provided that no changes are made in mining rates or methods, and no unforeseen boundary effects are encountered. The impact assessments in earlier (roughly pre-1 980) permit applications generally are based on one or more of the basic methods available for such linear extensions of historical trends.

The more recent permit applications show an evolution toward the use of more sophisticated mathematical models for predicting pit inflow rates and drawdowns. These techniques usually involve the repetitious solution of several groundwater equations, each suited to a particular aspect of the local hydrogeology or the pit progression, or to both. Because the premining understanding of the groundwater hydrology of the area is incomplete, simplifying assumptions about the hydrologic system and about initial and boundary conditions have to be made.

Relatively simple analytical models are widely known among industry and regulatory personnel and can be duplicated easily, which facilitates regulatory review. However, they cannot account for the wide variations in aquifer hydraulic characteristics and boundary conditions normally encountered in mining, and their results can only

[1] The discussion of PHCS and CHIAs reflects the typical practices in the mine permit applications reviewed for this assessment. Recent court decisions require the regulations governing hydrologic assessments to be revised, and the scope of these assessments may change in the future (see ch. 4).

reflect a limited range of possible pit configurations and "worst-case" predictions. Their accuracy can be improved by using monitoring data to continually refine the predictions.

More complicated numerical flow models are becoming more common among large operators in the West, who have the personnel and resources to use them. Such models are better able to represent the wide range of physical and temporal variations in a system, can incorporate more sophisticated sensitivity analyses, and are not limited by some of the restrictive assumptions necessary for simpler analytical models. However, numerical flow models are time-consuming to set up initially in that they require extensive input data and substantial calibration and verification. They also can be more difficult for the regulatory authority to review without proper documentation. Of 138 numerical models surveyed in 1980, only 20 were fully documented, were not proprietary, and had been applied in the field, and thus met all the requirements for a "usable" model (1).

A continuing problem **in most mine permit applications is the applicant's failure to justify, based on its suitability for mine-site hydrogeologic conditions, the selection of a particular analytical technique for predicting groundwater quantity impacts during mining, and to describe the assumptions inherent in the analysis.** In many instances, the lack of this information renders the analysis difficult to evaluate even for an experienced hydrologist, and hinders the regulatory authorities' evaluation of the mining and reclamation plan until the necessary documentation is prepared by the permit applicant.

After mining, the geology, geochemistry, and hydrology of the site have been altered, and it **is necessary to predict: 1) the nature and sources of spoils recharge, including postmining spoils aquifer characteristics; 2) the time of spoil resaturation and reestablishment of hydraulic equilibrium; and 3) postmining spoils water quality.** Groundwater recharge to the spoils is difficult to quantify without monitoring data because it is a function of the spatial and temporal distribution of precipitation, topography-runoff relationships, and the unsaturated and saturated hydraulic properties of a spatially heterogeneous geologic environment.

Where field data on spoil hydraulics and groundwater recharge are available—primarily the older mines in Montana and North Dakota—spoil-aquifer hydraulic characteristics and spoils recharge can be measured directly. Unfortunately, few field data have been collected due to the youth of the Western surface mining industry. As a result, most operators must estimate recharge from surface sources using a water budget approach that calculates soil moisture storage and infiltration. They also must predict postmining spoils aquifer flow characteristics using groundwater modeling techniques similar to those outlined above. The regulatory authorities use similar predictive techniques in order to set recharge parameters.

The time required for spoil resaturation and reestablishment of hydraulic equilibrium is a function of both the spoils aquifer characteristics and the sources and amount of recharge. Estimates in the Western mining regions range from as few as 10 to as many as 2,900 years for the replaced spoil aquifers to reach a steady-state condition whereby groundwater flow patterns are fully reestablished. While this introduces uncertainty about the long-term success of hydrologic restoration in some areas, that uncertainty was recognized in SMCRA and not considered so great that mining should be foreclosed in such areas. Continued analysis of field data on spoils recharge would reduce the level of uncertainty.

Groundwater Quality .—The validity **and accuracy of predictions of groundwater quality impacts—primarily levels of total dissolved solids (TDS)-are critical because, given the long period of time some spoils may require to become fully saturated and groundwater flow patterns to be reestablished, there may be no way to verify predictions with actual results. Analysis and prediction of postmining groundwater quality impacts are very difficult,** however, because the magnitude of such impacts is highly variable, the processes governing water-quality changes are poorly understood, and the processes controlling recharge rates are unknown. As a result, there is little agreement as to the best method for producing consistent, valid predictions.

Most operators in the West measure water-soluble constituents in the spoils and relate those values to observed spoil water quality at the mine site, However, the samples of water and overburden selected for testing and the mixing ratios and contact times may not be representative of postmining conditions. Deterministic models of the chemical processes responsible for the evolution of spoil water quality are under development.

Monitoring programs can be used to verify assumptions made about the trends of spoils-water quality over time. Monitoring will not necessarily provide information on the final postmining groundwater quality, however, because it cannot be assumed that the predictive model itself was valid or that monitoring will be continued throughout the tens to hundreds of years it may take for groundwater systems to establish a postmining equilibrium.

Surface Water.–Surface mining can reduce or augment streamflows, but these impacts generally are not significant in relation to the normal flows in ephemeral and perennial streams in the West (except for the cumulative impacts of sediment control ponds; see discussion of technical issues, below), and the primary concern is the effect of any change in flow on surface water quality. **Surface water quantity and quality impacts are more readily observable than groundwater. Therefore, the analytical techniques for predicting these impacts are less hypothetical and more reliable than groundwater impact predictions.** An exception is the difficulty gathering

Photo credit; Jenifer Robison, OTA staff

Surface water is more readily observable than groundwater. Therefore, premining estimates of impacts on surface water quantity and quality usually are less hypothetical and more reliable than groundwater impact assessments, which are based on predictive techniques that rely heavily on assumptions about groundwater conditions.

data about ephemeral streams, mentioned previously, due to their infrequent and unpredictable flow events.

The greatest potential impact to surface *water quality* from mining and reclamation is an increase in sediment loads, measured as total suspended solids (TSS). In the absence of site-specific data (the usual case for ephemeral streams), a well-accepted method is available to estimate the amount of sediment that will erode from the mine site and be subject to transport downstream during a precipitation event.

Surface water quantity impacts are estimated primarily to support surface water engineering design, and valid statistical techniques are available for computing runoff volumes and peak flows. Deterministic models also are available, but require that assumptions be made about the hydrologic regime of the site; these influence the input parameters and therefore the results, However, **there appears to be no consensus among regulatory authorities on preferred methods for estimating or verifying increases and decreases in streamflows,** and selection of a particular method depends on the capabilities or preferences of the person performing the calculations. As a result, conflicts can arise over the validity of such estimates and the adequacy of the resulting engineering designs, To avoid these conflicts and the potential for expensive redesign, most operators are intentionally conservative in their calculations.

Cumulative Hydrologic Impact Assessments. —A reasonable assessment of impacts to the various components of the hydrologic system can be made at most Western surface coal mines over the life-of-mine area using some combination of available analytical techniques. The predictive accuracy of PHC determinations should improve with time as data become more abundant and more reliable within each permit area due to monitoring as mine development progresses. In areas farther from existing operations, however, fewer data are available about the physical system, and impact assessments are less reliable. **Because of the absence of data from areas in which there is no active mining, and because of the lack of coordination and standardization in data collection mentioned above, the uncertainties are greater in CHIAS than in PHC determinations.**

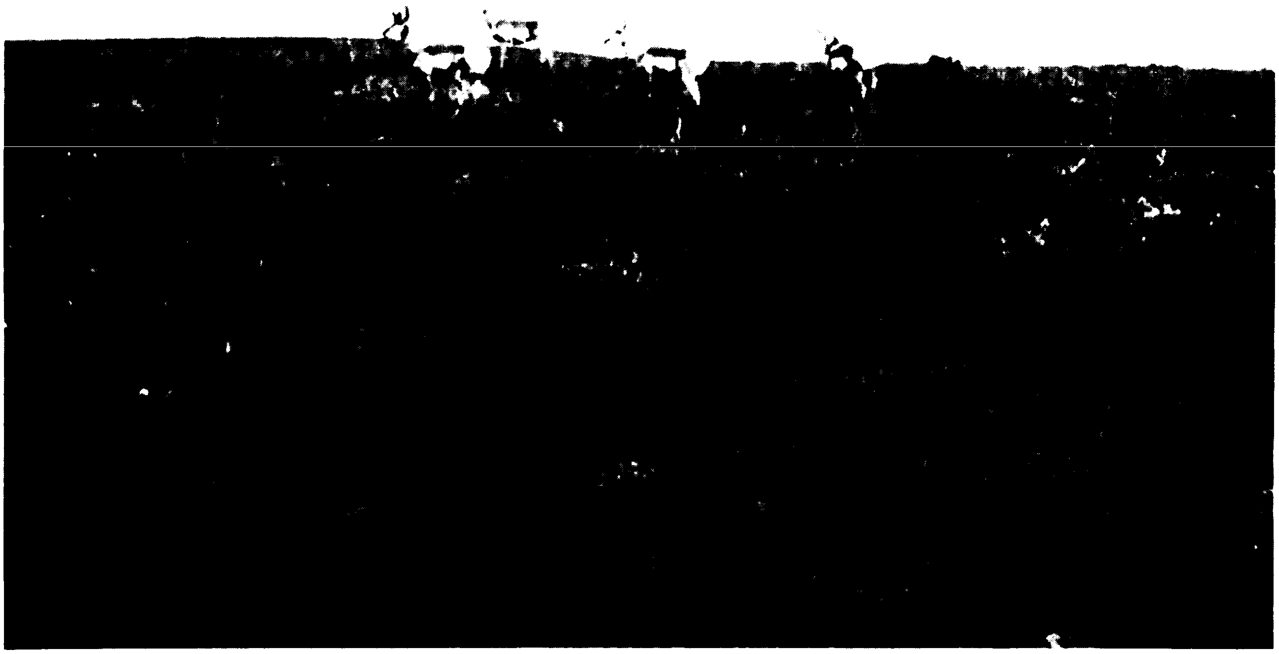
Regulatory authorities generally require worst-case analyses to compensate for these uncertainties. As uncertainty about the system increases, assumptions made for input to the various analytical techniques become more conservative. Although this strategy avoids errors from underestimating the potential environmental impacts, it may entail other consequences from overstatements of those impacts, including higher reclamation costs.

The uncertainty in CHIAS could be minimized if regulatory authorities used monitoring and repermitting data to check and recalibrate the models used in CHIAS and to assess the validity and sensitivity of the various input assumptions. Periodic sensitivity analyses of the variables would provide valuable information about data inadequacies and could be used in the scoping process mentioned above to focus data collection.

Wildlife Impacts

Among the resources subject to impacts from mining and reclamation, wildlife have certain unique characteristics that make their response to environmental change difficult to predict. Most species are highly mobile, and may move to a new locale for any number of reasons unrelated to mining activity. Wildlife species also are capable of unpredictable responses and varying degrees of adaptation to change, and it is extremely difficult to identify and isolate those responses or adaptations that are directly caused by mining and reclamation from all the other possible environmental factors present. As a result, quantitative techniques **for predicting the impacts of surface coal mining and reclamation activities on wildlife populations are essentially lacking.** Instead, as noted above, these assessments generally are made by intuitive professional judgment based on a knowledge of the operational aspects of the mine and of the ecological resources of the mine site and surrounding area.

Statistical analyses of the effectiveness of wildlife mitigation measures are possible but very



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costly. Where such analyses have been undertaken, their results are consistent with these intuitive professional judgments, indicating that **a subjective approach to wildlife impact assessment based on measures of habitat quality from key ecological parameters appears to be a satisfactory way to predict impacts on wildlife resources.**

Revegetation

Revegetation analyses focus on predicting the success of revegetation. **While OTA found little emphasis on the development or use of analytical techniques for predicting long-term revegetation success, the lack of quantitative models does not appear to diminish the potential for accurate predictions.** The most common, and probably most valid available technique for predicting revegetation success is to consider results of the most recent technology at other mining operations in the region with similar soil, overburden, and climatic characteristics, under the usually valid assumption that, given similar environmental factors, the results of particular revegetation and other reclamation methods will be similar.

There are two problems with this approach, however. First, there are few vehicles for disseminating information on the results of different revegetation techniques. Indeed, some companies may be reluctant to share such information for competitive reasons. Second, some techniques may show initial promise but poor results over the long term, and vice versa. The former may be adopted at several mines before their long-term problems are fully understood, while the latter may be rejected prematurely. *A* continuing commitment to research on the long-term success of various revegetation techniques for different ecological regimes in the West, and means of disseminating the results of that research, are needed to resolve these problems.

Analytical Techniques Used in the Design of Reclamation

Accurate characterization of the overburden and delineation of potentially deleterious overburden material, design of an optimum soil-salvage plan, design of well-stabilized stream channels, and design of efficient sedimentation control measures are important factors in the ultimate success of reclamation. When design rather than performance standards are used to determine reclamation success, the importance of the reliability of the techniques used to design reclamation is heightened.

Overburden Characterization

Overburden–all material between the soil and the coal resource, including bedrock or other rock material—forms the basic material for the reclamation process. Therefore, the chemical and physical character of the overburden are key factors in determining impacts on postmining spoils hydraulics and water quality, as well as revegetation success. However, the geology of the overburden in many of the mining regions of the West is highly variable and/or complex, the science of overburden characterization is neither old nor well-established, and the overburden is not easily observed.

As a result, **analysis of the physical and chemical properties of overburden is difficult. Even with a low drilling density and vertical sampling intensity, thousands of overburden data points will be generated at the average Western surface mine. There are no well-established procedures for interpreting these data to determine the chemical suitability of the overburden materials.** Most available laboratory methods for generating chemical suitability data were developed for soil characterization and have proven unreliable when applied to overburden. Also, while acid formation is recognized as a possible problem in some areas of the West, available tests have proven inaccurate in determining the acid-base potential of Western overburden (see below).

The State regulatory programs exhibit wide variation in their requirements for chemical analyses. The methods for characterizing overburden and for handling potentially deleterious materials generally are determined on a case-by-case basis. The primary risk is the cost of reconstructing an area if such materials are not identified prior to backfilling.

Soil Characterization

The redressed soil serves as a chemical and physical buffer between the disturbed mine spoil and surface water, vegetation, and wildlife resources, and also is a critical element for successful reclamation. Most undisturbed soils are in relative chemical and physical equilibrium with the surface environment, and thus are less likely to be sources of exceptional release of sediments or toxic elements than disturbed soils. Ideally, the restored soil material also will be in approximate equilibrium with the surface so that unforeseen and undesirable chemical and physical changes will not occur. Therefore, the operator must determine the premining physical and chemical character of the soil and the amount of suitable soil available for redressing, and must design a redressing plan to ensure physical and chemical suitability and stability of the postmining soil.

Soils are relatively easy to observe and the science of soil characterization is well-established. Each State regulatory authority has developed unsuitability criteria for soils that generally accommodate the differences in reclamation objectives or emphasis that occur from site to site. A low sampling density can result in significant errors in estimating the volume of salvageable soil material, however.

In the Western coal regions, where natural soils in many areas are typically thin and marginally productive, optimization of the soil resource is essential. Most State soil inventory and handling requirements make it more likely that the best available soil will be used to provide an adequate root zone and to minimize impacts from potentially deleterious overburden materials occurring in that zone. However, **State programs that require salvage of all suitable soil ma-**

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terials and redressing in uniform thickness may not promote optimization of the soil resource in all mining and reclamation situations, and may add unnecessarily to reclamation costs. Lack of consideration of the soil's organic and biological suitability—especially in deep soils—can detract from optimization of soil quality for revegetation unless the topsoil and subsoil are hand led separately (two-lift topsoiling).

The regulatory requirement for uniform topsoil thickness in redressing at each mine facilitates inspection and enforcement, but ignores the fact that topsoil depth varies naturally as a function of topography and vegetation types. Thus landform position may be as important as depth for some vegetation species. The soil thickness required to reach maximum plant production also varies with average effective precipitation, depending on the soil and vegetation type. Furthermore, redressing uniform topsoil thickness can discourage direct-haul topsoiling in areas where premining soil depths vary naturally. Although non-uniform thickness is common over an entire site postmining, each parcel or reclaimed unit generally has uniform thickness. Additional regulatory flexibility in this matter, on a case-by-case basis, could facilitate achievement of vegetative diversity in many areas (see below).

Design of Restored Surface Drainage Systems

Replacement of an erosionally stable surface drainage system is critical to the long-term success of surface mine reclamation. A number of valid approaches to design are available, from direct field measurement of channel cross-sections and profiles with duplication of the undisturbed channel, to computer-assisted, detailed hydraulic analyses. **In the case study mines reviewed for this assessment, the amount of detail in such**

designs ranged from virtually none to very elaborate geomorphic and hydraulic studies, although an encouraging trend toward a comprehensive, multidisciplinary approach to design of surface drainage systems was observed. Greater attention to design in permitting could reduce the potential for costly repairs of erosion damage during reclamation.

Mines that cover large areas or contain watersheds must be concerned not with just the design of restored channels but with the reconstruction of entire drainage basins. The goal in this case is to attempt to create a new steady-state by manipulating the surface, slope, and channel configuration so that the newly formed system will be in approximate equilibrium with the surrounding area with respect to erosion and sediment transport processes. The premining geomorphic analysis generally is modeled after classical concepts, and the relationships developed in that analysis are applied to the design of the postmining drainage system. However, improper applications of even the most well-understood analytical techniques have resulted in incomplete or incorrect designs. Furthermore, when the overburden-to-coal ratio is very large or very small, the postmining drainage basin characteristics may differ substantially from the premining characteristics, further complicating the design problem.

Hydrologic and Sediment Control Structures

Techniques for the design of hydrologic and sediment control facilities have changed very little since SMCRA, although there has been an increasing use of computers in design, and a gradual standardization of estimating techniques for runoff and sediment. The techniques in use accommodate the lack of site-specific data for sediment erosion and transport rates by providing relative estimates for comparison of alternative designs, Use of a computer allows faster and more accurate analysis than hand calculations, so larger areas can be simulated in greater detail and over shorter time steps. **Monitoring data could be used to calibrate the models used, but OTA found lit-de indication that this is occurring.** Issues related to the use of sediment control ponds are discussed under "Technical issues," below.

Designing Reclamation of Alluvial Valley Floors

SMCRA allows mining in alluvial valley floors (AVFS) only if they are not significant to farming. Because only 7 years have elapsed since the implementation of the permanent Federal regulatory program, however, no AVFS not significant to farming have yet been completely mined and finally reclaimed under the SMCRA standards, although several plans for the restoration of such AVFS have been approved by the regulatory authorities.

The premining hydrologic studies required for AVF areas under SMCRA are unique in the surface mine permitting process in that they must include an analysis of the relationships between surface and groundwaters and land use, soil characteristics, and vegetative productivity. Thus AVF restoration combines some of the more rigorous design aspects of surface and groundwater restoration discussed previously. **The criteria for premining analysis of the essential hydrologic functions of AVFS and postmining evaluation of AVF reclamation are relatively standardized among the regulatory authorities of the Western States. These criteria are based on accepted engineering and hydrogeologic principles, and the probable success of reclaiming AVFS is viewed by the industry and the regulatory authorities with confidence.** As with hydrologic restoration in non-AVF areas, however, it may be decades or centuries after mining and reclamation before the success of hydrologic reclamation in AVFS can be assessed completely.

EVALUATING THE SUCCESS OF RECLAMATION

Few aspects of the process for final evaluation of reclamation success have been firmly established under the Federal or State regulator programs. The five States studied in this assessment have established criteria for evaluating reclamation for Phase I of bond release (backfilling the pit, and in some cases, redressing soil), but not for Phases II and III (preliminary revegetation and full release). Furthermore, most existing evaluation techniques and standards have serious limitations, especially for hydrology and revegetation—the two areas emphasized in the SMCRA performance standards.

To date, **no method for evaluating revegetation has been developed that adequately addresses both temporal variations in environmental conditions** (i. e., seasonal and annual climatic variations) **and the spatial diversity that occurs over large areas.** There is general agreement that revegetation standards should incorporate, or be able to be adjusted for, climatic and temporal variations. The most practical method for achieving such adjustment has been to use standards based on reference areas, but such standards are based on the assumption that the vegetation on a few acres can adequately represent revegetation over hundreds or thousands of acres. Furthermore, although the predominant postmining land use in the study area is native range land, little test grazing has occurred on revegetated areas as yet. Of the five States, only Montana has established guidelines for test grazing plans and data collection.

The methods for evaluating hydrologic restoration are even more unclear. **Although the SMCRA performance standards emphasize hydrology, most past experience in judging reclamation has concentrated on revegetation success.** The tens to thousands of years that may be required to resaturate spoil aquifers in some parts of the study area make it impractical to measure either spoil water quantity or quality directly. Thus evaluations will have to be made with incomplete knowledge and available predictive tools. Similarly, because surface drainage systems are designed to accommodate peak flows that may occur only once every 10 to 100 years, many channels are unlikely to experience peak flow events during the bond liability period, necessitating the use of predictive techniques and design criteria for evaluation.

It **is unclear whether successful revegetation and hydrologic restoration are sufficiently reliable indicators of success for the other disciplines—soils, overburden, and wildlife.** Of particular concern is the potential for materials adverse to vegetation to appear in the root zone long after the regraded spoil is sampled, and the topsoil redressed and revegetated. If the presence of such material becomes evident before bond release, it may require expensive rehandling or total reconstruction of the reclaimed soil and overburden, and repetition of the revegetation process. if it appears after bond release, it is unclear how it would be mitigated and by whom. A similar concern is raised by the potential for unsuitable material to be inadvertently placed in the recharge zone, with the water quality impacts not becoming manifest until after final bond release.

TECHNICAL ISSUES IN WESTERN SURFACE MINE PERMITTING AND RECLAMATION

OTA'S assessment of surface mine permitting and reclamation in the West highlighted several technical issues that are affected by many of the data and analysis concerns summarized above, and that have significant implications for the long-term success of Western reclamation. These issues encompass the technologies, data, and analytical methods for determining the potential for acid formation in overburden, the impacts of sediment control methods, the effects of soil handling methods on revegetation, the potential for meeting woody plant revegetation standards, the designation and implementation of postmining land uses, and the value of landscape diversity.

Acid Potential in Western Mine Spoils

In characterizing overburden for the planning of reclamation, one objective is to identify potentially acid-forming materials that could become detrimental to revegetation. Acid formation in mine spoils is a common problem in the

East, where the climate is relatively humid and recharge rates for groundwater systems are relatively large, which accelerates the oxidation of sulfur compounds in the spoils and the formation of sulfuric acid. Moreover, in the East, there is little lime in the overburden to serve as a buffer. A test based on leaching of overburden samples with hydrogen peroxide to extract sulfur forms is used to predict the acid-base potential (ABP) of overburden material in the East.

The potential for acid formation is much lower in the West because the climate generally is arid or semiarid, and because Western overburden typically has a high buffering capacity. **There are conditions, however, under which acid formation will occur in the West, primarily in portions of the Powder River Basin and in New Mexico. The Eastern method for determining ABP has produced unreliable results in the West** because it assumes that all sulfur forms will be completely oxidized—an assumption that may not be valid in the West where a large fraction of the sulfur occurs in less reactive, organic forms. An alternative test used in Wyoming allows isolation of the reactive inorganic sulfur compounds, but still assumes that all reactions go to completion. **As a result, estimates of ABP in the West may be inaccurate and can result either in a failure to identify materials that need special handling, or in operators being required to special handle some overburden materials unnecessarily.**

Research currently being funded by the Western mine operators, both jointly and individually, is making progress in resolving this problem, and the regulatory authority in at least one State, Wyoming, is prepared to rewrite State guidelines to reflect any changes in analytical techniques or overburden suitability criteria that may result from this research.

Sediment Control

Sedimentation in streams results from accelerated erosion caused by removal of the vegetative cover; topsoil stripping; and construction of stockpiles, roads, and other mine facilities. The Office of Surface Mining has taken the position that the best currently available technology to control sedimentation is a properly designed and constructed sedimentation pond. Construction of sedimentation ponds is governed by both design and performance standards adopted by each State, which generally require that the pond be designed to meet effluent standards established under the Clean Water Act.

Sedimentation ponds are expensive to build and maintain, and they increase the amount of land that must be disturbed during mining and reclamation. The water discharged from sedimentation ponds also is unnaturally clear and therefore can result in erosion and channel degradation downstream in ephemeral streams, which have a naturally high sediment content. Moreover, the cumulative effect of water storage in sediment control ponds at multiple mines in one area can be a significant loss of water—the West's most scarce resource—to downstream users.

Alternate means of maintaining sediment production at or below the level produced from undisturbed terrain are available, including preventive measures that retard the velocity and reduce the quantity of runoff, thus reducing erosion rates, and remedial designs that reduce erosion by avoiding sensitive areas and increased sediment deposition. In addition to mitigating the impacts

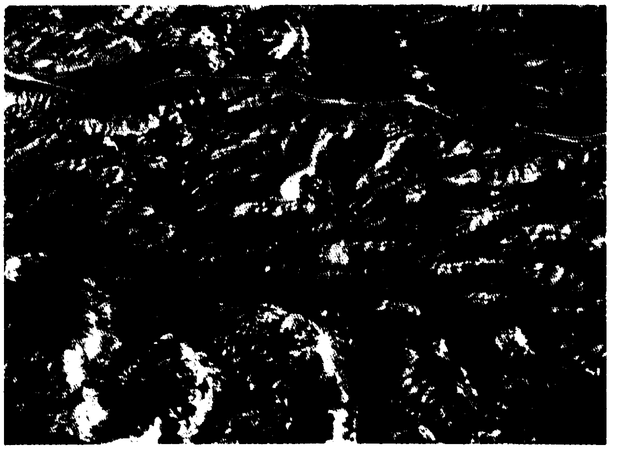


Photo credit: Office of **Surface Mining**

Erosion and associated sediment production are natural processes in the Western United States, but few data are available on natural erosion and sedimentation rates from undisturbed areas. These data are needed to demonstrate that alternate means of sediment control are as effective as sedimentation ponds.

of sedimentation ponds noted above, the alternate control methods can aid revegetation by reducing runoff and thus increasing soil moisture, and by reducing erosion. They also eliminate the risk of sediment pond dam failure. **Such alternate sediment control techniques are considered proven technology and have been implemented successfully in agriculture, highway construction, and other land-disturbing activities.**

Two sets of data are needed in order to demonstrate that alternate means of sediment control are as effective as sedimentation ponds: empirical data on sediment yields (the total amount of eroded material that reaches a control point) and on natural sediment concentrations **in streams, and monitoring data from areas where alternate means are in use.** The data on sediment yields and concentrations could be obtained during baseline and monitoring studies, but OTA found little evidence that anyone is gathering such data. Two m i nes i n Wyoming currently are collecting data from experimental practices undertaken to demonstrate that alternate control measures are equally effective in controlling sedimentation as ponds and thus are adequate to protect water quality in ephemeral streams.

As the needed data become available, regulatory authorities could become more flexible in interpreting design and performance standards for sediment control in discharges to ephemeral streams where a permit applicant is able to demonstrate that proposed controls will be at least as effective as sedimentation ponds. Discharges to perennial streams, however, still will require sedimentation control ponds to protect their naturally high quality water.

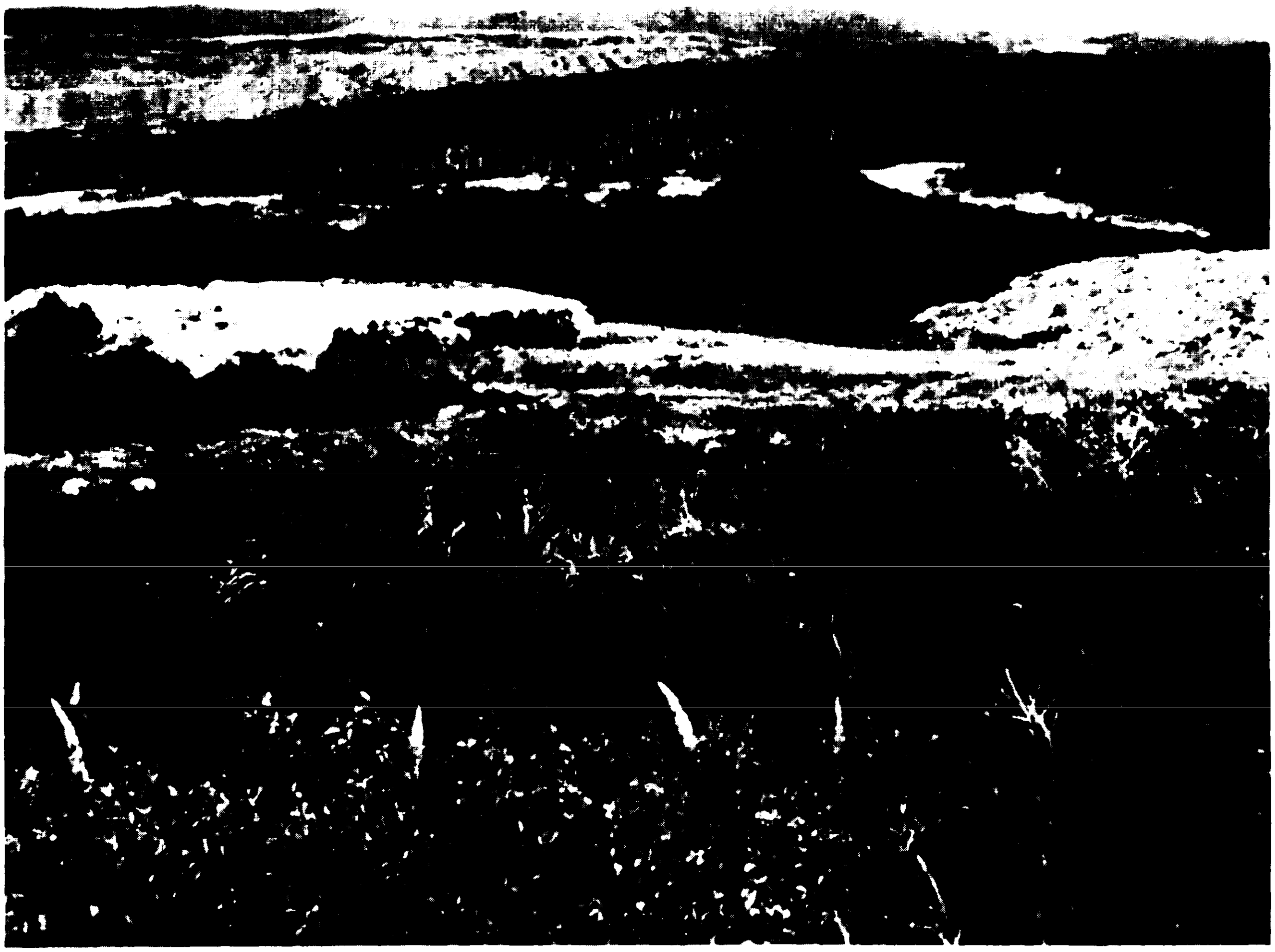
Soil Handling and Revegetation

Recognition of the relationship between soil quality and revegetation success—the primary criterion for reclamation success—has produced substantial innovation in soil handling methods. **The results of long-term studies of the effects of topsoil stockpiling indicate that it adversely affects the success of revegetation efforts. Direct haul topsoil, on the other hand, preserves the biologically active component of the soil and enhances maintenance of nutrient cycles. This improves the establishment of planted and volunteer species and can produce superior life-form and species diversity within a relatively short time. Recent research indicates that, under certain conditions, combining direct haul topsoil with other innovative reclamation techniques can further enhance revegetation success.** Because the direct haul technique eliminates the middle step i n the process of stripping, stockpiling and respreading topsoil, it can be less expensive depending on haul distances.

Research in deep soils in Montana and North Dakota also has shown that careful identification and separate handling of the biologically most active surface soil layers, without dilution by underlying subsoil–''two lifts''-can improve revegetation sufficiently to justify the cost. **The limited monitoring data available suggest that the combination of two lifts with direct hauling may produce the best results in reestablishing rangeland diversity, and in some areas may be enhanced even further by the use of mulch produced from native vegetation. No** research data comparing these and other methods for different geographical areas are available to verify these hypotheses, however. As noted previously, **greater flexibility in the Federal and State regulations on topsoil salvage and redressing thickness could promote optimization of the soil resource in permitting and implementing soil handling for revegetation.**

The Revegetation of Woody Plants

Woody plants—shrubs—are ecologically important in the Western United States as forage and cover for livestock and wildlife, and for improving soil moisture conditions and protecting herbaceous plant species. In some combinations of slope and substrate, woody plants also may improve slope stability because their more extensive root systems can anchor a greater volume of material than many herbaceous species. Because of these considerations, the revegetation requirements i n SMCRA, the regulatory program performance standards, and the standards for revegetation success are tied, in part, to the reestablishment of native woody plant species of the same type and density that existed on the site before mining.



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Tying woody plant density standards to the premining density raises several concerns, especially in areas where the premining density is relatively high (primarily Wyoming, Colorado, and New Mexico). First, even with the most advanced shrub establishment technology, there is little field evidence that high densities can be reestablished over an entire reclamation site during the lo-year liability period. In the sagebrush-steppe ecosystems which occur in the northern part of the study area, operators have found it difficult to establish any shrubs other than fourwing saltbush, with big sagebrush being especially difficult. In these ecosystems, the prospects of meeting the proposed Wyoming regulatory standard of one stem per square meter on 10 percent of the area may depend on which plant species are counted as shrubs for density purposes.

Second, while shrubs **in moderate to high densities improve habitat quality for a variety of animal species, uniformly high woody plant density can detract from the quality of land for livestock grazing.** Woody plants provide critical winter food and cover for wildlife species with a high recreational and economic value in the West (particularly pronghorn antelope, deer, elk, and sage grouse). But cattle, and to a lesser extent sheep, prefer herbaceous vegetation to shrubs. As a result, ranchers have undertaken large-scale programs to thin or kill sagebrush and other woody species on range lands, frequently with financial or physical support from BLM's rangeland management programs. If a postmining landowner undertakes such range management, it negates the purpose and expense of reestablishing woody plant density. For the most part, this conflict can be traced to the lack of specificity in designation of the postmining land use (see below) and to inadequate coordination among Federal and State regulatory authorities and land management agencies.

Many State regulatory and mining industry personnel feel that lower overall shrub densities, if accomplished in high-density groupings based on premining habitat mapping, provide as valuable wildlife habitat as uniform densities at high premining levels. In this context, rangeland management programs also can benefit wildlife if done selectively. For example, thinning big sagebrush to increase herbaceous production can improve the forage for pronghorn as long as shrubs remain available in critical winter browse areas and are not totally removed from summer range. **This approach to mitigating the conflicts between the forage and cover needs of different livestock and wildlife species has begun to be recognized in the West (e.g.,** the proposed Wyoming standard). However, uniform high shrub density standards still are the norm in most areas.

Postmining Land Use

SMCRA and the regulatory programs require detailed characterizations of the premining and postmining land uses in the permit application and reclamation plan. These characterizations must include ***quantification*** of the capability of the land prior to any mining to support a variety of uses considering soil and foundation characteristics, topography, and vegetative cover; and of the premining productivity of the land, including the average yield of food, fiber, forage, or wood products obtained under high levels of management.

Despite these requirements, the characterization of pre- and postmining land uses is at best perfunctory in most of the permit applications reviewed for this assessment. A number of the applications contained land use characterizations with little more information than the statement: "The premining land use is grazing and the postmining land use is grazing, " In some cases, this lack of specificity can be attributed to inadequate baseline information in the permit application. In other cases, it is the fault of the Federal surface management agency (e.g., BLM, U.S. Forest Service), which is required to determine, or at least consent to, the postmining land use.

Lack of specificity and quantification in describing pre- and postmining land uses can adversely affect postmining vegetative and landscape diversity, the implementation of surface owners' or management agencies' land use recommendations, and the difficulty and cost of reclamation. Moreover, at mines where reclaimability is an issue during permitting, a much more rigorous approach to characterizing premining land uses and to predicting the capability and productivity of the reclaimed surface is necessary before findings of reclaimability can be made objectivel y.

Regulatory authorities should enforce the requirements for pre- and postmining land use characterization more strictly. For privately owned lands, the land use description and the quantification of capability and productivity must remain the responsibility of the permit applicant, with the cooperation and concurrence of the landowner. For public lands, BLM and the Forest Service currently are preparing land use plans that should provide the basis for quantitative characterizations of pre- and postmining land uses. Until these documents are completed, **Federal surface management agencies should ensure, during their review of permit applications and reclamation plans, that careful attention is paid to the applicants' quantitative characterization of pre- and postmining land use, productivity, and capability.**

Implementation and management of the postmining land use after bond release raises issues about changes in land use and conflicts among land uses. At some mines, **conflicts arise between land uses—particularly between agricultural**

uses and wildlife habitat—because the surface owners, usually farmers or ranchers, desire that all land be returned to cropland, pastureland, or grazingland. This conflict is common in States where reclamation standards for native rangeland and wildlife habitat (e.g., woody plant density standards and overall vegetative diversity) are more difficult to attain than those for other land uses, such as pastureland.

Another concern is **the lack of incentives for post-reclamation landowner or manager compliance with land management plans.** Even the best reclamation methods can be negated quickly by postmining land management decisions or techniques (e.g., overgrazing, range mismanagement), leaving the operator open to allegations of reclamation "fail ure." This underscores the importance of restoring the land's capability, rather than a narrowly defined "use." Moreover, there are no regulatory mechanisms to ensure that the surface owner will not convert lands reclaimed for one use (especially wildlife habitat) to other uses after bond release.

Landscape Diversity

The concept of "landscape diversity," which encompasses the entire ecosystem, recognizes the mosaic nature of Western landscapes resulting from localized differences in the physical environment, plant communities, wildlife populations, and land uses. Strict application of a full restoration concept might be inflexible in its ability to adapt to changing technology and to climatic and other uncontrollable variables. Moreover, full restoration of landscape diversity would go beyond the premises of SMCRA in focusing on the long-term quality of reclamation, rather than rehabilitation of the land to a particular level of viability specified in the permit or in the criteria for reclamation success. Somewhere in between is an approach that ensures long-term ecosystem function and viability, and that requires restoration of features that were critical to the premining ecosystem, but allows flexibility in the means of achieving such restoration. Implicit i n this approach is an understanding that ecosystem dynamics change over time, and a reclaimed site cannot achieve a natural level of equilibrium with the surrounding area in the 10-year bond liability period.

No statewide requirements for full restoration of landscape diversity currently exist in the Western States studied, although requirements for specific mines have been established on a case-by-case basis, primarily in relation to vegetative communities. The restoration of ponderosa pine woodlands in Montana, woody draws in Montana and North Dakota, sage grouse strutting grounds in Montana, and wetlands in North Dakota are examples of reclamation that attempts to preserve features that contribute to landscape diversity.

Surface features that have been eliminated include rim rock and escarpments, ridges, bad land topography, and "microsites" (small premining surface features important to premining hydrology or wildlife habitat). **In some cases, it is impossible to reestablish a particular landform.** For example, hogback ridges and badlands are supported by strata that would be removed during mining, precluding their reestablishment on the reclaimed surface. Moreover, disturbance of some badland strata can result in physical and chemical changes that significantly affect erosivity. In other cases, **restoration of landforms may be too costly or difficult for all but the most elaborate reclamation plans.** Microsites, for instance, often are dependent on hydrologic, soil, or overburden characteristics that are very expensive to duplicate with available mining and reclamation equipment.

Finally, **some regulatory requirements may actually discourage diversity in some mining and reclamation situations.** The SMCRA requirement to return mined areas to their approximate original contour typically has resulted in gently undulating land with little topographic variety, because the features that provide diversity frequently are the most difficult to design and reestablish. Requirements for uniform topsoil depths over the regraded surface and for uniformly high revegetation density further homogenize site conditions and limit the ability to restore full vegetative community diversity.

However, the postmining topography can be designed to *mimic* premining features such as rimrock and microsites. Variances have been granted at a few mines for sections of unreduced highwall as a means of leaving artificial cliffs or bluff extensions that simulate the original premin-

Photo credit Jenifer Robison, OTA staff

The regulatory requirements to return mined areas to their approximate original contours and to reduce all highwalls typically have resulted in gently undulating land with little topographic variety (foreground). Surface features that are eliminated by mining include rimrock (background), which provide nesting sites for eagles and other raptors, habitat for small animals, and aid in moisture retention near the base.

ing features and aid in the accumulation of additional surface moisture near the highwall base. The restoration of microsites and features such as playas and prairie potholes may be expensive, but some mines are restoring them to preserve or enhance wildlife habitat.

If attention is to be paid to landscape diversity, it needs to begin with the reclamation plan and permit application. A full consideration of geomorphology would require integrated analyses of the consistency among the postmining topography, the hydrologic characteristics of the reconstructed soils, the revegetation communities, the reconstructed drainage systems, the proposed postmining land use, and the geomorphology of the contiguous areas. Thus baseline data collection would provide an interdisciplinary ecological characterization of the proposed mine area that could be used in the design of a diverse postmining landscape, as well as a set of numbers to demonstrate that the performance standards will be met. **Promoting such an interdisciplinary approach to design and implementation of landscape diversity would require some additional effort, and thus cost, both in premining baseline studies and specification of the postmining land use, and in implementing the reclamation design. Long-term research efforts are needed to demonstrate whether the potential benefits of such an approach for the quality of reclamation would outweigh the costs.**

Photo crecdit: Office of Surface Mining

The postmining topography can be designed to mimic premining features. For example, portions of unreduced highwall have been used at some sites to substitute for rimrock lost to mining.

TECHNOLOGICAL INNOVATION AND RESEARCH

Since the first State reclamation laws were enacted in the early 1970s, mining companies, a wide range of Federal and State agencies, universities, and other organizations have undertaken a significant amount of research and developed a variety of new techniques for reclaiming surface mined lands in the arid and semiarid regions of the West. Historically, revegetation has been the principal subject of research at Western surface mines, primarily because the regulatory standards for reclamation success focus on revegetation success. This emphasis is now shifting toward hydrology, soils, and overburden as the complexities in these systems are recognized.

Most of the reclamation-related research programs sponsored by Federal agencies were discontinued in the late 1970s or early 1980s, primarily for budget reasons, but also because the responsibility for the majority of such research was consolidated within OSM. Of the discontinued programs, the most extensive were conducted by the U.S. Forest Service's Surface Environment and Mining Program (SEAM) and the Bureau of Land Management's Energy Minerals Rehabilitation Inventory and Analysis (EMRIA). The failure to transfer funding for these programs to OSM meant not only the loss of over 150 research and development projects, but the discontinuation of valuable data sources: SEAM compiled a quarterly computerized listing of reclamation studies related to the Rocky Mountain West (the only bibliographic reference of its kind), while EMRIA gathered information about the reclamation potential on coal lease tracts and developed lease stipulations to assure the achievement of reclamation goals for Federal coal lands.

OSM has only two basic vehicles for research under SMCRA: the State mining and mineral re-

sources and research institutes, and the Abandoned Mine Land (AML) reclamation program. The Federal share of AML funds has yet to be allocated, and co-funding for the mineral and resources research institutes was discontinued in fiscal year 1982, although specific applied research projects continue to be funded by OSM, either alone or in cooperation with other agencies. The OSM budget for such projects has declined from a peak of around $1.47 million in 1981-82 to a request for $970,000 for fiscal year 1986, of which almost half was allocated to subsidence control and coal wastes (primarily Eastern or abandoned mine reclamation problems), and one-fourth to staff and administrative support. **Attention should be paid to the allocation of available funds and priorities for research among Eastern, Midwestern, and Western reclamation problems.**

To compensate for inadequate Federal research funding, OSM treats experimental practices and permit conditions at active reclamation sites as substitutes for research. Under SMCRA, experimental practices were intended to encourage advances in mining and reclamation, or to allow special postmining land uses, if they potentially provide as much environmental protection as the performance standards and are no larger or more numerous than necessary to determine the effectiveness and economic feasibility of the practice. Of the five experimental practices approved for the Rocky Mountain West since 1979, two (ongoing) address alternative sediment control; one (completed in 1982) was a court-ordered compromise on a variance for an excess spoil disposal area; one (still undergoing monitoring) involves a variance from approximate original contour in order to leave a portion of a highwall to preserve eagle nests; and one (ongoing) allows the disposal of mine spoil offsite to suppress an underground fire at an abandoned mine.

OSM personnel have indicated that they would like to see more applications for experimental practices. The permitting and monitoring requirements are so difficult and expensive to meet, however, that few companies are willing to undertake an "experiment" that can only be implemented on a portion of the mine site unless the potential long-term economic benefits of demonstrating the effectiveness of the practice are substantial. Moreover, OSM approval of an experimental practice takes so long that the mine usually proceeds beyond the area where the practice might have been effective long before it can be permitted. Establishing strict schedules for OSM approval of experimental practices could alleviate this problem.

Under a more flexible regulatory system, the experimental practices listed above might have been handled through site-specific variances or permitting of alternative reclamation techniques, or under the AML program. If applications for such variances or techniques are not approved, however, additional time and money is required to revise the permit application and reclamation plan. Moreover, permit applications requesting such variances still must be approved by OSM, which can require that the proposed reclamation method be permitted as an experimental practice or not allowed. **These possibilities pose major constraints on innovation in reclamation methods.**

Mine operators also have conducted applied research on specific reclamation situations, either to aid in the design of reclamation, or to meet or develop bond release criteria. Frequently, such applied research projects are the result of permit stipulations that require the collection and analysis of monitoring data or the development of criteria for judging the success of particular types of reclamation. Ongoing research at Western mines from all sources of funding is shown in table **2-1.**

While significant advances have been made in Western reclamation technologies, and the prospects for the long-term success of reclamation in the West have brightened considerably, OTA identified a number of areas in which additional research or analysis still is needed. These include:

1. development or improvement of techniques for the collection of baseline and monitoring data, especially improved laboratory techniques for generating data about overburden chemistry, and standardized methods for collecting hydrologic and wildlife data;

Table 2-1.—Summary of Ongoing Research and Innovation at Case Study Mines[a]

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
North Dakota: ND-A: Special handling of clayey soils for wetlands ND-D: Landform position and mixing of soil types to aid moisture retention in prime farmland —Effect of soil type on soil/spoil interface for optimum moisture-holding capacity	***North Dakota:*** ND-A: Restoration of wetlands	***North Dakota:*** ND-A: Transplanting native vegetation plugs for reestablishing wetlands ND-D: Restoration of woody draws —Planting, cultural and management practices for achieving grassland diversity —Irrigation, grazing, mulch, seed mixes, and topsoil handling and depth studies	***North Dakota:*** ND-A: Reconstruction of wetlands —Developing criteria for the success of wetland habitat restoration —Restoration of woody draws and native prairie on an "acre-for-acre" basis ND-D: Reconstruction of woody draws for wildlife habitat
Montana: MT-B: Retention of highwall portion as bluff extension —Use of scoria and similar soil over compacted overburden for ponderosa pine substrate —Monitoring vegetation trace metals contents to judge the success of soil reconstruction —100 percent two-lift direct-haul topsoiling MT-D: Sodium migration from sodic and clayey overburden —Topsoil erosion runoff plots	***Montana:*** MT-B: Extensive site-specific and regional groundwater database —Special handling of overburden to protect water quality MT-C: State-of-the-art PHC and CHIA analyses for proposed mine adjacent to perennial stream classified as an AVF MT-E: Management and use of very large hydrologic database —Spoil aquifer hydraulic analyses	***Montana:*** MT-A: Ponderosa pine reestablishment MT-E: Reestablishment of ponderosa pine —Coulee bottom restoration —Sodding of native grassland —Special soil handling for landscape diversity —Topsoil depth, surface manipulation, native species, legumes, phased seeding, shrub reestablishment, native hay mulch, temporary stabilizer crop, and fertilizer studies	***Montana:*** MT-D: Relocation of sage grouse strutting ground —Nest box program for American kestrels —Use of radio-telemetry and other methods to develop monitoring data to determine when impacts are due to mining versus natural variation in populations —Landscape diversity through replacement of microsites —Identification of preferred forage plants through fecal analyses to develop seed mix
Wyoming: WY-A: Detailed highwall map from stratigraphical-geochemical correlation —Intensive overburden sampling to delineate acid-forming and other deleterious strata as well as wet areas, defining highwall stability, planning shovel moves, etc. WY-B: Composite sampling of regraded spoils —Watershed erosion monitoring WY-D: Nonuniform topsoil thickness —Acidic spoil treatments —Erosion monitoring —Reclaimed geomorphology —Monitoring swell and settling WY-G: Two-lift direct-haul topsoil in desert ecosystem —Use of boron-tolerant species WY-K: Nonuniform topsoil thickness	***Wyoming:*** WY-C: Potentially acid-forming overburden WY-E: Computer modeling to predict groundwater impacts WY-G: Alternative sediment control experimental practice —State-of-the-art streamflow sampling WY-H: Restoration of essential hydrologic functions of an AVF WY-K: Formation of surface drainage channels through erosion and deposition	***Wyoming:*** WY-A: Effects of nurse crop on establishment of perennials —Effects of grazing on species composition —Mulching —Use of sagebrush "potlings" WY-C: Annual grains grown as source of soil organic matter WY-D: Methods to reduce competition between vegetation species —Planting cottonwoods in drainages WY-G: Need for irrigation in arid area WY-K: Annual rotation of experimental species WY-1: Reconstruction of a playa	***Wyoming:*** WY-J: Experimental practice to leave a highwall portion for raptor habitat

Table 2-1.—Summary of Ongoing Research and Innovation at Case Study Mines[a]—Continued

Soil and overburden	Surface and groundwater	Revegetation	Wildlife
Colorado:	***Colorado:***	***Colorado:***	***Colorado:***
CO-B: Aerial and field surveys to monitor swell factors for postmining topography CO-D: Shredded mountain shrub vegetation as mulch in direct-haul topsoiling —Erosion monitoring	***CO-C:*** Experimental practice for valley fill for excess spoil disposal CO-F: Burial of power-plant wastes in backfill	CO-A: Reclamation of pinon-juniper on massive sandstone CO-D: Live mulch for woody plant reestablishment and complete topsoil removal —Direct transplanting of tree and shrub pads using modified bucket —Omitting seeding of direct haul topsoil CO-E: Use of snowfences for water harvesting —Mulch studies CO-F: Direct transplanting of mature native shrub pads	CO-D: Detailed characterization and delineation of physical and floral features of elk calving habitat CO-F: Reestablishing premining land uses on postmining topography to facilitate best management practices
New Mexico:	***New Mexico:***	***New Mexico:***	***New Mexico:***
NM-B: Use of overburden as topsoil substitute —Use of topsoil quality evaluation system NM-D: Nonuniform topsoil thickness over spoil of varying quality —Sodium migration in a very low precipitation regime —Burial of fly ash with elevated selenium levels	NM-C: Comprehensive erosion monitoring program NM-D: Burial of power-plant wastes in backfill	NM-B: Use of overburden strata as topsoil substitute growth medium NM-D: Irrigation	NM-D: Annual monitoring to provide data on wildlife use of reclaimed areas NM-E: Computer analysis of mapping and telemetry data to determine effects of mining on wildlife

aFor the key to case study mines, see appendix A in this volume

SOURCE Off Ice of Technology Assessment

2. development of a "scoping" process to determine which baseline and monitoring data actually are needed for permit compliance and reclamation success evaluations;
3. the refinement and validation of analytical techniques for predicting the impacts of mining and for designing reclamation, including better predictive techniques for groundwater quantity and quality impact assessments in cases where there are few field data, and methods for determining the acid-base potential of overburden;
4. the development of methods and criteria for evaluating reclamation success for Phases II and III of bond release; and
5. comparative analyses of the long-term effectiveness of various reclamation methods in different types of mining situations.

In many cases, these research needs cut across disciplines. For example, the ability to delineate and characterize deleterious overburden material clearly affects groundwater quality, but problems with such overburden also would affect the quality of revegetation and, therefore, the land capability.

Although work is ongoing at Western mines that addresses most of these needs, it frequently is limited to site-specific conditions. Without comprehensive comparative analyses of the full range of Western mining environments, research at individual mines will do little to improve the cost-effectiveness of reclamation techniques or to advance the science of reclamation in the West.

The most critical constraint on such research is the lack of available funding. OTA recognizes

the realities of Federal budget cuts in the face of massive deficits, yet other sources of reclamation research funding could be found at the Federal level, in State governments, and in the private sector. These might include, at the Federal level, existing permit fees (which cover the administrative cost of permitting), royalty and bonus payments for Federal coal leases (which go into the general fund), and AML funds (yet to be distributed). It should be noted that the reallocation of these revenues to reclamation research would be controversial.

These same sources of funding are available at the State level, plus the States collect substantial revenues from severance taxes. **Among the State regulatory authorities, however, only North Dakota considers reclamation research within its purview.**

The surface mining industry also should consider investing in cooperative research efforts that would improve the prospects for the long-term success of reclamation and reduce the costs of that reclamation. This is the approach taken by five companies operating on prime farmlands in Illinois (6).

A second constraint is raised by legislation and regulations that impose inflexible design standards that can discourage innovation and do not take into account the tremendous variability among sites. The difficulty and cost of demonstrating alternatives to strict design standards through experimental practices or by obtaining a variance pose a significant obstacle to the extension of these research substitutes to other mining areas, and, in some cases, can unnecessarily increase the cost of reclamation. On the other hand, design standards may be the only available means of ensuring protection of public health and safety in some mining and reclamation situations.

Finally, **the commitment to reclamation in the West that has emerged among coal companies and Federal and State regulatory authorities since 1977 must continue to grow to encompass needed research.** While all parties agree that it is time to "move off of square one" in the implementation of SMCRA, each group tends to downplay the need for continued advancements in baseline and monitoring data, analytical techniques, and reclamation methods because of their potentially high costs. Yet efforts in these areas could result in substantial increases in the quality of, and the likelihood of the long-term success of, reclamation, and could yield significant economic benefits in terms of reduced operating, reclamation, or regulatory costs.

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