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Surface Mining: Soil, Coal, and Society

A Report Prepared by the
Committee on Soil as a Resource
in Relation to Surface Mining for Coal

Board on Mineral and Energy Resources

Commission on Natural Resources

National Research Council

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THE COMMITTEE ON SOIL AS A RESOURCE IN RELATION TO SURFACE MINING FOR COAL

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Overview

Coal appears to be one of our most attractive energy resources for the near future. Unlike petroleum, coal is in abundant supply within the borders of the United States, and unlike nuclear, solar, or biological energy sources, coal is a power source with which we have much experience. But as we increase demand for coal, we must take into account the drastic and far-reaching effects coal mining and utilization can have. This study concentrates on the effects of surface mining for coal upon the utilization of another resource, soil. Underground mining has a different set of consequences, which are not examined here.

We define *soil* as the medium for the support of life on the land surface of the earth. Soil is a discrete, definable, dynamic complex of organic, inorganic, biologic, and geologic materials. Its ability to support life depends on its capacity to absorb, store, and transfer energy and water.

Soil formation is measured in geologic time. That is, it occurs very slowly. Soils begin with the accumulation of unproductive materials and increase in productivity as the natural processes of weathering, biological activity, and leaching take place. The formation of soil humus and the development of soil structure are probably the most important in-situ processes that enhance soil productivity. Eventually soils reach a peak of productivity, where they may remain for a long while, but in time the productivity of most soils will begin to decline. Common reasons for the decline are the erosion of the productive surface, the leaching out of plant nutrients, the formation of claypans, and the accumulation of salts. These processes do not occur uniformly across the landscape. In some areas soils remain thin because of erosion, while in others, soil materials accumulate. Different forms of life are adapted to the different conditions that result.

The many issues concerning the relation of the soil resource to surface mining for coal stem from two basic questions: What kinds of planning and management are possible with regard to the effects of surface coal mining? And how are we to choose among the possible goals of management?

WHAT CAN WE DO?

Planning for the effects of surface mining on soil requires an understanding of both soil-forming processes in general and the functioning of these processes under particular conditions in the various areas of the United States.

The relative importance of each of the five major factors affecting soil formation (climate, parent material, topography, biota, and time) varies from one major coal region to another and also varies within coal regions. Consequently, soil-forming processes operate differently on different pieces of reclaimed land. The productive capacity of soils under humid conditions reaches a peak within tens of thousands of years and then slowly declines, as nutrient depletion by leaching overbalances nutrient release, and clay accumulates to excessive levels. In the arid and semiarid West, soil-forming processes operate much more slowly, if at all, and the productive potential of soils is defined mostly in terms of the physical and chemical properties of the parent material.

Through most of the United States, land surfaces are geologically young, and the soils are either gaining productivity or are maintained in a perennially early stage of development by active geologic erosion and change. In some areas, particularly flatter areas of the humid midcontinent, where land surfaces are weathered from mineral deposits on the order of 10,000 to 100,000 years old, soils are highly productive and are widely used for agriculture. Other areas of the midcontinent and Southeast have older soils, from 100,000 to over 1,000,000 years of age. Many of these soils are overly mature, depleted soils which cannot be replenished through natural means.

On rich, prime agricultural land, whether young or old chronologically, it is difficult to restore full pre-mine productivity through reclamation. On other kinds of land, however, while productivity immediately following reclamation may be reduced, productivity may increase gradually to higher levels than are currently possible. Overdeveloped soils or soils with hardpan formations can be made more productive by a disturbance that, in effect, restarts the geologic clock. Overmature soils in Appalachia, the Gulf Coast, and parts of the Midwest may be rejuvenated by mining where high-quality substratum material is available and reclamation is carefully executed. In some parts of the West, the replacement of sodium- or salt-rich soils with other material may also be beneficial to plant growth.

Soil plays an important role in the equilibrium of watersheds, because the infiltration capacity of soil is a major factor in determining what percentage of local precipitation contributes to surface flow and to what extent soil moisture can support vegetation. Soil disturbance by surface mining may have substantial impact on the hydrologic balance by changing infiltration/runoff relationships in a watershed, and by changing stream-channel morphology through the deposition of sediment from erosion.

Vegetation can be used to provide both short-term stability of reclaimed areas and to increase fertility and content of organic matter in the soil. Stabilization of land surface by vegetation can be accomplished in relatively short periods of time (2 to 5 years), but much longer periods of time may be necessary to evaluate the stability of restored ecosystems or the long-term productivity of the reclaimed area under variable weather and other conditions.

HOW CAN WE DECIDE?

What justification is there for requiring any sort of post-mining land management? The impacts of surface mining for coal on the nation's agricultural production capacity are going to be relatively small. Of the productive land base of over 2 billion acres (0.81 billion ha) in the United States, over 20 percent is cropland, 48 percent is grassland and range, and the remainder is forest (U.S. Department of Agriculture 1980). As of 1977, about 90 million acres (36.5 million ha) of land had been removed from biological production through the urbanization process. This is equal to 4.4 percent of the current productive land base. By comparison, up to 1977 only 0.3 percent of the land base had been removed from production by surface mining, and less than half of that was by surface mining for coal. Annually about 1 million acres of prime farmland are permanently removed from production—about 80 percent through urbanization and about 20 percent through inundation by water projects. About 100,000 acres of land are surface mined per year, and most of this land is eventually returned to some level of crop production through reclamation. The total land area that will eventually be surface mined for coal is unlikely to exceed 10 million acres (4 million ha). In this frame of reference, then, loss of land to production through surface coal mining is rather minor.

But the fact that the amount of land removed from production is small does not mean this removal is an important legitimate policy issue. Mining is a significant disruption at the local level, not only in its effects on crop production and forestry but also because of its social impacts. Moreover, if the total loss of land from cropland to all other uses is an important issue—and in the long run it must be—it can only be addressed by dealing with each type of land conversion, even though it appears minor when considered individually.

In any case, the lost productivity, aesthetic values, and cultural values of the land are costs of coal mining that are not borne by either the mine operator or the consumer if reclamation is not performed. Social costs, off-site effects of surface mining, and loss of resources to future generations are other such costs. Insofar as these costs are not reflected in market prices, energy choices will be prejudiced. To correct this, the public, acting through government, can ensure that these costs are taken into account, by requiring either reclamation or some type of compensatory payments.

Whenever the economic environment is redefined through collective government action, there are complaints that government interference is stifling free enterprise. But one person's "government interference" is another person's "government protection." If government does not take steps to ensure reclamation, then one set of individuals bears the costs and another enjoys protection. If government actively supports reclamation, then different sets of individuals benefit and share the costs.

Thus, once this issue has been raised, there is no way government can avoid making a decision. As with issues such as international trade, immigration policy, air and water quality, price supports for farmers, income supplements for disadvantaged families, and human safety, government decisions about surface mining and reclamation policy influence the overall quality of American life while helping some individuals and imposing costs on others. The Surface Mining Control and Reclamation Act of 1977, PL 95-87, is the official documentation of a collective decision to reallocate some resources and shift some costs among individuals and groups. It is legitimate to question whether PL 95-87 will bring about the most efficient allocation of resources and the fairest sharing of costs, and whether, with its emphasis on regulation by design standards, it uses the most effective tools to achieve its public objectives. The PL 95-87 approach may well be modified as experience and analysis bring to light facts unavailable at the time of its enactment. Nevertheless, the regulation of strip mining and reclamation is entirely in keeping with well-established American political and legal tradition.

An appropriate goal for reclamation is to ensure that society does not lose important land-use opportunities that were available prior to soil disturbance or that can be generated in the reclamation process. This does not necessarily imply restoring precisely the characteristics of the pre-mine soil and landscape but rather involves the establishment of geologically and hydrologically stable landscapes capable of supporting a natural mosaic of ecosystems. Such landscapes provide the widest range of options for future land use.

The appropriate approach to reclamation is, then, in the committee's view, primarily concerned with the functional aspects of the soil and water resources disturbed by mining. Reclamation should aim at establishment of desirable physical, chemical, and biological processes rather than simple replacement of the soil horizons in the order in which they were found. Moreover, the goal of returning to original contours is not valid if grading to different contours will achieve useful objectives. Finally, a change in use, including a change from native vegetation, may result in a new regime that is either a more stable and productive resource or is a more efficient means of developing an equally desirable resource. Thus, changes in the nature of the soil—its contours, vegetation, and use—from the original or pre-mined conditions may be appropriate.

The goal of reconstructing soils after mining so as to equal or exceed the productivity of pre-mine soils, then, can probably best be accomplished by reorienting the reclamation laws away from selective handling and replacement of individual soil horizons and toward creating physical and chemical properties of mine soils that optimize the functions important for productivity (such as water-holding capacity, rooting depth, and fertility). Often, of course, the benefits of the surface horizon in terms of fertility, aggregation, and superior infiltration characteristics will justify selectively removing and replacing the surface soil. The soil horizons that develop through soil-forming processes are indicative of the soil's productivity but they are not necessary for a productive soil. In some cases, alteration of the pre-mine soil profile may be beneficial.

Clearly, reclamation plans must be tailored to the individual sites. Plans must recognize the physical, chemical, and biological character of the soil, the highly diverse impact of the weather, the use alternatives available, and the socioeconomic structure of the area. The major differences among the coal-producing regions—and the unique character of individual mine sites—make it imperative that laws be flexible enough to permit the most appropriate reclamation practices to be used at each site. This situation presents extraordinary challenges.

Differences in conditions also mean that reclamation costs will vary among regions. There is no reason, however, to attempt to make reclamation equally difficult and expensive in all areas in order to achieve national equity. Standards set to solve problems such as protecting uniquely valuable and fragile lands in one region should not be required in all regions simply for the purpose of maintaining equity. In the East, reclamation costs may well be high enough to influence whether an area is mined, although the cost data available do not suggest this will occur. In the West, where the coal seams are quite thick, the high per-acre costs of reclamation will translate into low costs per ton. These differences in cost of reclamation per unit of energy should quite properly be reflected in the price of coal.

In any case, the total increase in the cost of coal due to the increased cost of reclamation will not even approach making coal as expensive per unit of energy as imported oil. Thus, while increased reclamation expenses may affect the location of coal production in the United States, there is no chance that reclamation requirements will "price coal out of the energy market." Furthermore, there are reasons to believe that current estimates of reclamation costs are on the high side. To the extent that current estimates are based on actual operation, many of the observations are for small sites and "first-time" or demonstration efforts. These costs are likely to fall as operators learn by doing; and economies of scale can be realized on larger sites. In addition, most long-term coal contracts include provision for the pass-through of the increased costs of reclamation. Thus little incentive exists for companies operating under old contracts to search diligently for ways to reduce reclamation costs.

This is not to say that coal companies should *not* pass along to consumers a considerable proportion of the increased costs of coal made necessary by reclamation. With users paying somewhat more for coal, non-coal-using alternatives (e.g., solar power, conservation) will be a bit more attractive. A new constellation of relative prices will more accurately reflect social costs and benefits than did the prereclamation set of relative prices. There may, however, be alternatives to present regulations that will encourage increased efficiency in reclamation.

ALTERNATIVE APPROACHES TO RECLAMATION

Surface mining and reclamation present massive challenges to the regulatory environment because each region and locality is different, as is extensively documented here. The complexity of the interactions among the geological, hydrological, ecological, and social systems in the context of surface mining and reclamation guarantees that the best practical set of design standards nationally imposed will occasionally have unreasonable and even absurd results in particular localities. A number of alternative approaches to regulation may increase flexibility and responsiveness to local circumstances. These alternatives range from rather minor changes in the traditional practices to some rather radical departures from the status quo.

- The basic design-standards approach currently used could be applied with increased latitude in recognition of varying conditions. It would also be possible to establish design standards at the local level, subject to federal approval. A committee of experts could be appointed to review local standards, or control could actually be transferred to local areas.

- Performance standards could replace design standards. These performance standards could be controlled at the federal, state, or local level as could design standards. Enforcement of performance standards is more difficult, but if workable measures could be developed, performance standards would provide considerably more flexibility and efficiency in meeting the intent of the law.
- A system of economic incentives might be used to encourage the desired results. While it is not likely that a satisfactory effluent-charge type of system could be devised, it may be possible to develop a flexible bonding system under which the individual mine operator is returned bond funds as predetermined reclamation goals are achieved.
- New forms of property and institutions could be developed. For example, individual communities could be given the power to veto the development of new mining activities in their areas. Communities would then prevent the development of mining activities unless the plans for control of off-site damages and for reclamation were acceptable. Such plans might include compensation to the community for those adverse impacts that are not controllable.

RESEARCH NEEDS

The development of appropriate reclamation policies and practices in the diverse environments of the several coal regions in the United States depends upon adequate technical information and an efficient and effective institutional setting in which to make choices. Research is needed in both areas. Long-term studies should be made of the full impacts of alternative reclamation approaches. Research is needed to characterize mine sites; on the weathering of mine spoils; on the movement of soluble nutrients, particularly in the high-rainfall areas of the South and East; on the hydrologic properties of the mined areas; on the appropriateness of grading to original or other contours; on means of avoiding or dealing with compaction of the root zone; on methods of controlling soil erosion; on appropriate vegetation regimes in the reclamation process; on the reintroduction of biological populations, nutrient cycles, and organic matter formation in new soil; on the appropriate level of productivity to which land should be returned and the time required to do so; and on the appropriate procedures for dealing with special problem areas.

Mining is related to a number of major policy issues in this nation. Energy, environment, economic, and social policies are all related, and their relationships need to be better understood. Reclamation of strip-mined land raises important questions concerning the relationships between private industry and the several levels of governmental units. New institutional arrangements may be needed to deal successfully with the challenges of surface mining and reclamation—for both the short and the long term. Rates of resource use, rates of erosion, degree of reclamation, and extent of land conversion will all significantly influence the well-being of generations to come. We need new insights into our responsibilities to future generations.

1 The Choices Before Us

The general objective of this study is to contribute information and develop rigorous, coherent arguments that identify surface coal-mining and reclamation policies consistent with the management of soil resources in the long-term national interest. We will attempt to place the problem in perspective, identify the appropriate level of reclamation effort on land that is surface-mined for coal, and determine possible institutional mechanisms for achieving the desired outcomes.

In examining mining and reclamation in relation to the soil resource, we are immediately confronted with many of the broad policy issues facing society: food policy, land-use policy, energy policy, environmental policy, and, more generally, economic and social policy. The processes by which policy goals and instruments for surface mining and reclamation are determined are part and parcel of the whole collective decision-making system in the United States. Surface-mining and land-management policies must therefore be considered within the broader context of American institutions.

One response to the increasing price and uncertain availability of oil and natural gas is to mine more coal. Surface mining is often promoted over deep mining because it may be expanded more rapidly, is less destructive of human life and health, imposes lower capital and labor costs per ton of coal mined, and recovers a higher proportion of total coal reserves. But surface mining can have much more drastic environmental consequences and thus necessitates serious consideration of reclamation and land-use policies.

Ten million acres (4 million ha) of American soil may eventually be surface mined (U.S. Department of the Interior 1971). This sounds like a large number, but—as documented in a subsequent chapter—surface mining accounts for only a small fraction of the agricultural, range, and forest lands annually diverted to other uses. Relatively small amounts of the nation's land will be in a disturbed state at any one time as a result of surface mining, and a relatively small proportion of the potential annual agricultural output will be lost.

The relatively small size of these losses, however, does not *ipso facto* mean that they are trivial or that the nation can obviously afford them. Public concern over surface mining is not entirely due to the diversion of land and reduced food production. Surface mining is a highly visible land use, since it destroys all surface vegetation and drastically disturbs soil and subsurface geology. Natural systems have some capacity to heal themselves, but in the absence of reclamation, it is highly unlikely that areas disturbed by surface mining will recover their former productivity within any reasonable time frame. Even with considerable effort and expense, reclamation is time consuming, and success is not certain. For the interim, in any case, soil productivity is lost; off-site damages such as erosion and sedimentation, flooding, and disruption of aquifers are likely; aesthetic sensibilities are offended; and social and community relationships in the vicinity are affected. Thus, although surface mining for coal is a relatively minor land use in terms of the acreage disturbed, the impacts upon those areas disturbed are dramatic, persistent for relatively long time periods, and not always reversible.

It is possible to plan the surface-mining process at any site so as to integrate reclamation practices (i.e., those practices designed to reduce on-site and off-site damages during surface mining, and to rehabilitate the soil and revegetate the land following mining). But how much reclamation effort, in total, ought to be expended? What particular mix of reclamation activities ought to be implemented? What are the goals of the reclamation effort? These basic questions encompass other, more specific questions. Given that reclamation is an expensive activity, and that the mine operator seldom receives the benefits of reclamation, in what way can incentives for reclamation be provided? Is it appropriate to compensate certain classes of victims of unmitigated environmental damage from surface mining? If so, can workable compensation mechanisms be developed and implemented? Can compensation mechanisms be designed to provide an incentive for the mine operator to avoid these damages?

THE DIRECT EFFECTS OF MINING AND RECLAMATION POLICY

The surface-mining and reclamation policies chosen, and the methods adopted for their implementation, will have a variety of influences.

1. The cost of mining coal increases with the intensification of the reclamation effort, with obvious effects on the price at which coal can be sold and thus the quantity of coal mined, marketed, and used.

2. Agricultural, range, and forest productivity are of course affected by policies governing the diversion and reclamation of lands for these purposes.

3. Surface-mining and reclamation policy will influence the geographic pattern of surface mining, because the geological, topographical, and environmental factors that determine the appropriate mining and reclamation techniques vary across regions, as does the quality of coal that can be surface mined and hence its value.

4. The policies chosen will influence the mix of surface and deep mining in the coal industry, since the costs of surface mining are more affected by reclamation policies than are the costs of deep mining.

5. Mining and reclamation policy will influence the proportion of coal in the American fuel mix and, eventually, the aggregate availability of fuels to American society and even the world, inasmuch as surface-mining and reclamation policy directly influences the price of coal and indirectly influences the price of other fuels.

6. The stability of ecosystems and hydrosystems at the watershed level—not just within the mine site—will be directly influenced by surface-mining and reclamation policy.

7. Surface-mining and reclamation policy has considerable potential to influence social cohesion in those areas which possess coal reserves accessible by surface mining. Large-scale surface-mining projects, sometimes integrated with coal-fired power plants or synfuel production at the mine mouth, often lead to dramatic changes in the customary ways of life in relatively small and previously stable communities. Customary attitudes within the rural community and toward the land itself are strained.

8. Through all of the avenues listed above, surface-mining and reclamation policy influences the distribution of income, individual satisfactions, and social well-being between and among national and local populations; energy producers and energy consumers; land owners, the mining industry, and users of environmental amenities; and, in the American West, where considerable coal reserves underlie Indian reservations, Native American cultures and the majority culture.

SURFACE MINING AND RECLAMATION IN A BROADER CONTEXT

The resolution of these specific issues has implications for a number of broader policy issues.

Energy policy. Surface mining of coal must be weighed against the alternatives in a skeptical analysis, and a thorough evaluation of the relative costs of coal and other energy sources—including those which may become technically and economically feasible with research and development—is called for one effort in this direction was the NAS CONAES report (National Research Council 1979b). Costs must include both those reflected in financial accounts and those imposed directly on people, social structures, and the environment, bypassing the financial accounts system.

First of all, the "need" for continually increasing consumption of total energy to ensure increased economic growth and prosperity cannot be taken for granted in a country that acquired its energy-intensive habits of production and consumption in a period of artificially inexpensive energy. It may be possible for society to adapt to the new realities in the market for energy (much as it adapted when the closing of the frontier created new realities in the market for land) by making adjustments in its total energy consumption as well as its pattern of consumption.

Resource substitution is a customary and appropriate response to changing relative prices of different resources. Thus, energy can in effect be replaced by some other resource, such as time or more expensive construction materials. Such substitution is *encouraged* when scarce resources are priced at their real costs, but *discouraged* by efforts to disguise the real costs. If a policy of assisting and promoting resource substitution and conservation were followed, it is likely that less energy would be "needed" in future years.

How much energy in the future should come from coal, and how much of that coal should be surface mined? The United States has abundant coal reserves, and as the price of the other fossil fuels increases, the relative price of coal favors its increased use. To a greater extent than with other fossil fuel energy sources, however, the total costs of extracting and utilizing coal at present are only partially reflected in prices to consumers. The burning of coal can release atmospheric pollutants that are damaging to visibility, property, ecosystems, and human health. The deep mining of coal is a relatively hazardous occupation. It creates latent surface problems of subsidence, and, in spite of recent improvements in techniques, it still recovers less of the resource than surface mining. Surface mining of coal, while less destructive of the labor force, is generally more destructive of local ecosystems, scenery, and milieu than underground mining. The decisions about the place of coal in the energy mix and the place of surface mining in the production of coal should be made in full cognizance of the real costs of mining and using coal. Under almost every imaginable energy scenario, however, coal will be surface mined, and hence the problem of reclamation will arise.

Environmental policy. Surface mining has massive effects upon the immediate environment and may affect geological, hydrological, and ecological systems throughout an entire watershed. Air quality and noise levels may be affected within a more restricted area. Increased surface mining and use of coal also have implications for the environmental problems of acid precipitation and the global buildup of carbon dioxide in the atmosphere. Thus, an adequate institutional response to surface mining and reclamation questions is an integral part of a coherent environmental policy.

Conversely, surface-mining and reclamation questions must be resolved in the broader context of national environmental policy. What is the appropriate allocation of resources between environmental benefits and commodities traded and valued in organized markets? To ensure that acceptable levels of environmental quality will be maintained into the future, what restrictions ought to be placed upon short-run economic activity? What are the appropriate devices for implementing environmental policies in a society that respects individual initiative and freedom?

Land-use policy. The federal government is the owner and manager of roughly one-third of the nation's land. Decisions pertaining to the remaining land have been left to individual initiative—restricted, to varying degrees, by regulations imposed by state and local governments. There is no comprehensive national land-use policy.

PL 95-87 is a federal land-use law in that it enables very specific and exacting regulation of one dramatic kind of land use. But because many other land-use questions have not been dealt with, PL 95-87 does not exist within the context of a comprehensive national land-use policy.

Questions such as the following are decided by a society with or without a land use policy: Which lands should be left in an undisturbed state? Where disturbance by surface mining is permissable, what degree of soil and landscape reconstruction should be required? Should the reclamation goal always be to restore the *status quo ante*, or are there circumstances in which surface mining provides a useful opportunity to develop new landscapes and to convert land to different post-mining uses? How long should the process be allowed to take? How should a comprehensive land-use policy be implemented? What are the places for individual initiative, government-created incentives, and coercion of individuals by the collective interest working through government?

Food policy. Food policy is concerned with the provision of an adequate, nutritionally balanced, attractive, and affordable diet for the American people and with the exploitation of America's comparative advantage in food production in world markets. It is true, as we document in a later chapter, that surface mining for coal is unlikely to have a major impact on American food production. Its likely cumulative impact is not trivial, however, and should be considered in the development and implementation of food policy.

Economic policy. Each of the policy issues considered above has economic implications. America's balance of trade, for example, is massively influenced by imports of fossil fuels and exports of agricultural products. Surface mining for coal is an avenue available for reducing fossil fuel imports. On the other hand, gradual deterioration of America's land resources through soil erosion and mine-related disturbance presents a long-term threat to America's agricultural exports.

Surface mining and reclamation are not trivial industries in terms of directly generated employment and income. But, as suppliers of fossil fuels and feedstocks for electricity generation and petrochemicals, these industries have an economic significance far beyond these immediate impacts. Furthermore, because large quantities of materials are involved, the location of mining raises significant transportation policy issues. Modes of transportation, rate structures, and even state severence taxes are brought under consideration. In addition, the industry is often the major influence in the local economy in which it operates, directly and substantially influencing the economic well-being of land owners, local businesses, and the general population, which, in the West, may include a considerable proportion of Native Americans. Thus, the resolution of surface-mining and reclamation questions is intimately entwined with national income, employment, and distribution policy.

Social policy. Although the United States does not have a comprehensive policy on social conditions, it does have policies on education, the provision of local services, and minority affairs. Surface mining and reclamation, and related steam-electric and synfuel operations, have significant impact on such social concerns at many levels. Mining projects can change relative income levels within and among regions, alter social and economic structure—including a change in the relations among ethnic groups (especially in the case of Native American cultures)—and change the legal conception of the rights and privileges of property ownership. Surface mining tends to be highly localized; some states are disproportionately affected; and surface mining is the dominant land use in some localities. Thus important questions about the rights of local populations to control the use of area resources arise.

APPROACHES TO SOCIAL CHOICES

Governments exist to provide services that are not easily provided by individuals or private collective groups, most notably those services that ensure that relationships among individuals are harmonious and that conflicts are resolved peaceably. Government institutions both reflect and help to shape the sociocultural traditions of the citizens. A government thus evolves customary approaches to the resolution of particular kinds of conflicts and also acceptable means by which customary procedures are changed. Surface-mining and reclamation issues will be resolved as far as possible by traditional means, but in the process of resolving these issues, some changes may be made in the ways conflicts are resolved in general.

Prior to the regulation of surface mining, mine operators effectively enjoyed individual rights beyond the confines of their individual property; that is, they were allowed to interfere with what was not theirs, regardless of the impact on others. Affected parties did not enjoy protection on the basis of individual rights or through collective restraints upon the activities of surface-mine operators. Regulation of surface mining and reclamation policy involves some reassignment of rights, either from some classes of individuals to others, or from individuals to collective governmental institutions.

The rights transferred from individuals may be assigned to governmental institutions at the local, state, or federal level. PL 95-87 may be interpreted as a reassignment of rights from the private sector to the public sector, dominated by the national government. It follows in the tradition established in legislation and regulations pertaining to civil rights and equal opportunity, and to air and water quality. Insofar as the rights are assigned to the federal government, surface mining and reclamation policy are determined by the outcome of conflicts among the national energy constituency, nationally organized environmental movements, and a national bureaucracy; state, local, and individual interests must organize and compete at the national level if they are to be influential. In light of the regional differences in mining conditions and the local nature of mining impacts, however, it is conceivable that new and different assignments of rights among individuals and the various levels of government could be developed to beneficial effect. Conflict-resolution mechanisms specific to surface mining and reclamation might be improved, and in the process, relationships among governmental units and between the public and private sectors more generally could be reshaped.

There are significant time dimensions of the surface-mining and reclamation question. Coal, once extracted and burned, is gone forever. To the extent that pre-mining conditions cannot be completely restored, irreversible environmental change results from surface mining. Even if adequate reclamation is feasible and socially desirable, some social costs almost certainly will be incurred during the considerable span of time that usually elapses before reclamation is complete. Reducing the elapsed time has both technical and economic limitations.

Society has customary ways of resolving conflicts between present and future concerns. But private economic institutions are understandably biased toward present and short-term future concerns, and public institutions for arbitrating between present and future needs are not well developed in our society. Thus issues pertaining to the time dimensions of mining and reclamation will probably prove difficult to resolve. Their resolution may provide an opportunity for further development of institutional mechanisms for resolving other present-future conflicts.

CONFLICT-RESOLUTION INSTITUTIONS

For a variety of reasons, some of which have their origins in the Constitution, it has become common in the United States to resolve conflicts between individual and collective interests of the type considered here through regulation by design standards. There are other conflict-resolution mechanisms, however, each of which has its advantages and disadvantages.

Regulation by design standards. The purpose of regulation is usually to achieve some performance, that is, some specific result—here, the reclamation of the mine site and the control of off-site damages—and it is important that regulations be fairly, impartially, and systematically enforced. But in complex areas such as safety and surface-mine reclamation, even when all reasonable care is taken, the probability of failure still exists, and performance is difficult to monitor and measure. In such circumstances, operating systems are often regulated directly in lieu of performance.

Design standards regulate inputs used, procedures implemented, and tasks carried out. Performance is thus regulated only indirectly, but compliance with the design standards is believed to increase the probability of acceptable performance to some tolerable level. PL 95-87 is, for the most part, an exercise in regulation by design standards. Under this law, federally determined standards are imposed by the states under their constitutional power to promote the public welfare. The states are strongly encouraged to enforce the standards set by the federal government.

Regulation by design standards has advantages in terms of enforcement, but it suffers from several disadvantages. The operator is denied the opportunity to determine new combinations of inputs, procedures, and tasks that will achieve the desired performance less expensively. If operators are told how to reclaim rather than what goal to achieve, innovation in the development of alternative products and new techniques is stifled, and in a sense the obligations and responsibilities of the operators are diminished. It is also possible that operators will meet the letter of the design requirements without achieving truly satisfactory performance.

Regulation by performance standards. Performance standards have the advantage that they preserve considerable freedom for the operator to determine the least-cost combination of inputs, techniques, and tasks required to achieve the desired level of performance. Thus, resource allocation may be improved and innovation encouraged. There are, however, some disadvantages. Enforcement is more difficult. Operators fear that they may be locked into an open-ended commitment to continue to expend time and resources in pursuing a goal that is impossible to achieve at a given site. They want to be able to plan on a given level of effort.

Modifying incentives. The government has the power to discourage activities it considers undesirable by taxation and to encourage desirable activities by subsidy. In the air- and water-quality arena, programs subsidizing desirable pollution controls by direct grants or tax rebates are in effect. Soil-erosion control by farmers has been federally subsidized for several years.

Proposals for a comprehensive system of effluent and emissions charges or taxes have been made often over the last 15 years. Such a system would provide economic incentives for pollution control, permit polluters to select the least-cost combination of inputs, encourage the most efficient pollution abaters to do most of the abating, encourage innovation in pollution control, and provide the public sector with additional revenue, which may be regarded as compensation for pollution that remains once the program is in operation. These proposals have seldom been implemented in the United States but have been successfully implemented in parts of Europe.

This method could be used to encourage control of environmental damage during surface mining. For example, currently existing bonding procedures could be modified so that the amount of the bond for each individual mine is based on an *a priori* estimate of the economic value of environmental damage which would occur in the absence of reclamation. The amount of the bond subsequently returned to the operator would be based upon the value of environmental damages which he succeeded in preventing.

Education. Government programs can be devised to encourage the adoption of new procedures through the education of private operators. The Cooperative Extension Service of the U.S. Department of Agriculture has a long history of this type of operation. It can be expected to be most successful in those cases where the technique being promoted will increase the profitability or other desirable aspects of the operation. Less success can be expected in those cases in which the effect on the operator is perceived as being negative. Because in almost every case sound reclamation practices represent a significant cost to the operator, education alone cannot be expected to achieve the desired results, although it will surely play a role in a comprehensive policy.

Public investment. The Abandoned Strip Mine Land Reclamation Fund is an example of another form of public involvement in achieving social objectives. The public sector undertakes to reclaim abandoned mined lands, in recognition that damage persists for which the mine operator was not responsible. In this case the funds are raised via a tax on presently mined coal and are used to reclaim lands mined earlier.

It would be possible to make all future reclamation a public sector responsibility, systematically allocating general revenue funds (federal, state, or local) to reclaim lands mined by the private sector. But support for this type of program would distort energy markets by understating the real cost of coal, would redistribute costs from coal users to tax payers, would put reclamation activity in the control of a governmental unit rather than a private firm, and would completely separate the mining and reclamation functions. This separation would prevent taking advantage of any economies of integrated processes, and would almost certainly result in more time lapse between mining and reclamation. Moreover, it does not provide a means of dealing with the control of offsite damages.

Creation of new forms of property. Trade is a particularly effective conflict-resolution mechanism. Since trade is voluntary, it can occur only with the consent of all involved parties, and the outcome of trade can be presumed acceptable to all involved parties. However, trade is facilitated by a well-specified and secure system of property rights. In the absence of such rights there is no basis for trade. Many resource-allocation problems, such as those occurring when range- and forestlands were unowned, have been resolved with some considerable success by the creation of private property rights in those resources. Certainly, most would prefer such means over the forceful means used in the absence of well-specified, enforced, and accepted rights.

There have been suggestions that, with sufficient ingenuity, secure and transferable property rights in at least some aspects of environmental quality could be created. Current air-pollution control policy—in which a new polluter may enter a region in which ambient air quality is already at minimal levels only by securing agreements from other polluters to reduce their pollution sufficiently to offset the new firm's pollution—represents a move in the direction of transferable (that is, tradeable) property rights in air for waste disposal.

If rights were reassigned to permit local governments a veto power over surface mining, citizens could (perhaps by referendum, or through representative institutions) go beyond present zoning powers to establish conditions under which mining would be permitted. These conditions might limit the extent of land disturbance by mining, specify the type and level of reclamation effort, and perhaps set some minimum acceptable payment from mine operators as compensation for damage and disruption. Mine operators could then compete to offer arrangements acceptable to the locality. Such a system would ensure that mining activity was locally acceptable and that areas in which the expected damage would not be locally tolerable would be deleted from mining plans. The system could also include minimal national standards to prevent poor regions from selling out cheaply. Other new forms of property may develop that will resolve some of the conflicts engendered by surface mining and reclamation.

The particular mechanisms implemented to control surface mining and reclamation will be much influenced by the customary American approaches to conflict resolution through government power. At the same time, the opportunity exists to influence society's general approach to these problems in the course of developing innovative solutions to surface mining and reclamation problems.

2 Land, Coal, and Society

Concern over the implications of coal mining for land resources can be focused by recognizing the four dominant functions of land.

- *Soil as a life support*. Soil provides much of the raw materials for natural and managed ecosystems, the latter including croplands and rangelands, forests, game reserves, wildlife sanctuaries, recreational areas, parks, and roadsides. The minerals and other materials in soil constitute a resource that cannot always be renewed, and constant or careless use can cause serious damage: the loss of tilth through excessive cultivation and fertilization and the disturbance of soil by surface mining are examples.
- *Land as a storehouse of minerals*. Minerals provide raw materials for human industrial processes. They have been used throughout history, but increased mechanization of mining allowed large-scale extraction of fossil fuels and nonfuel minerals, sometimes through drastic disturbance of surface conditions.
- *Land as space and place*. Land serves as a stable site for human activities, and it is a locus for water, plant and animal communities, natural and artificial objects, transportation arteries, and human settlements. Land gives us our sense of location in three-dimensional space, and when the landscapes are aesthetically pleasing, they can inspire a sense of tranquility, wonder, and awe. The interrelationships of land with water, atmospheric visibility, and plant and animal ecosystems all contribute to the quality of the space in which we live. For traditional societies, particular landforms may be vested with status as gods, holy places, or shrines.

• *Land as a cultural resource*. Land provides the frame for relationships among humans and their social groupings: location is defined by landmarks, cultural identity by the location of home, and spiritual meaning by the aesthetic characteristics of the territory identified as the homeland. Land provides not only a stable, identifiable basis for the organization of culture, but also a metaphor for the things that culture holds dearest. The legal status of land and the manner in which the community specifies the opportunities for possession and the rights that accompany ownership both define and are defined by the special position of land in the culture of each society.

Public concern over land use arises when any of these four functions come into conflict. The most obvious conflict is between land as a storehouse for minerals (mining) and land as a life-support system (food production). But this should not blind us to the other conflicts that can arise, conflicts that may be more difficult to quantify since they are not so easily expressed in the familiar monetary terms of income earned and costs borne. Moreover, it is essential to realize that conflicts arise within each of the four categories. For instance, a farmer who is not mindful of good soil-conservation practices may ruin a particular plot of land for future food production. Or a mining operation in pursuit of one mineral may so disturb other minerals that their eventual recovery is rendered impossible.

Our primary interest here is the relationship between land as a storehouse of one particular mineral—coal—and the other functions of land. First consider the relationship between surface mining for coal and agriculture. In 1977 there were approximately 413 million acres (167 million ha) of cropland; 987 million acres (400 million ha) of grassland, pasture, and range; and 662 million acres (268 million ha) of forestland in the United States (U.S. Department of Agriculture 1980). To date, it is estimated that 5.7 million acres (2.3 million ha) of land have been disturbed through surface mining for all minerals including coal (U.S. Department of Agriculture 1980). Of the amount disturbed by mining between 1930 and 1971, about 40 percent was the result of coal mining (Paone et al. 1974). Applying that ratio, about 2.3 million acres (0.93 million ha) of the United States have been disturbed by coal mining through all time. Of the 5.7 million acres (2.3 million ha) disturbed by all mining, there was no legal requirement to reclaim 2.7 million acres (1.09 million ha).

It is estimated that more than 10 million acres (4 million ha) of land in the conterminous United States are underlain by strippable coal reserves (Table 2.1)—much of this land in Illinois, Kentucky, Missouri, Montana, and Ohio. For comparison, between 1967 and 1975 alone 5 million acres (2 million ha) of cropland were converted to urban use. Annually, about 1

TABLE 2.1 Estimated Acreage Overlying Strippable Coal Reserves by State

State	Estimated Acres Overlying Strippable Reserves[a]	State	Estimated Acres Overlying Strippable Reserves[a]
Alabama	365,200	Montana	1,001,000
Alaska	41,500	New Mexico	125,700
Arizona	18,400	North Dakota	362,300
Arkansas	37,500	Ohio	852,800
Colorado	175,500	Oklahoma	118,100
Georgia	100	Pennsylvania	238,100
Illinois	2,417,800	South Dakota	48,700
Indiana	246,500	Tennessee	59,400
Iowa	86,200	Texas	259,700
Kansas	303,000	Utah	10,600
Kentucky	1,294,400	Virginia	141,000
Maryland	25,700	Washington	12,600
Michigan	400	West Virginia	673,100
Missouri	998,900	Wyoming	200,100
		TOTAL	10,113,200

[a]Based on computations using average seam thickness and strippable reserve data for each state. Data may not add to total because of rounding.

Source: Data from U.S. Department of the Interior (1971, 1977).

million acres (0.4 million ha) of prime farmland are permanently removed from crop production. Surface mining is thus minor compared with the other uses that deprive us of farmland. With conversion continuing at these rates, however, every source of conversion becomes cause for concern. Moreover, we must examine the quality of land being converted to other uses and the quality of the land being used for surface mining.

Perhaps most important is that surface mining can be—and usually is—a severe and abrupt disturbance of land felt most directly by those living or working in the immediate vicinity. For those people the aggregate figure is quite irrelevant. If productive soils are destroyed, highwalls created, vegetation stripped away, and erosion induced, it is small consolation that surface mining disturbs but a small percentage of the nation's cropland.

Even if the land surface is reclaimed, recovery of soil fertility and productivity may be delayed or never fully achieved. Away from the site—especially in mountainous terrain—landslides, rockfalls, increased water runoff, water pollution, and stream siltation may occur. Pleasing landscapes may be degraded and modified beyond rehabilitation.

Surface mining also can result in the displacement of people from the land they called home, and, if the area exposed to surface mining is sufficiently large or inauspiciously located, the network of interrelationships among individuals may be effectively destroyed. Communities that relied on the soil for economic support—for example, through agriculture or forestry—may disintegrate. The introduction of a major surface-mining operation into an established rural community may bring an influx of outsiders, whose notions of land and community are quite different from those of the locals. This influx may impose stress on the existing community services or create a burgeoning need for additional services. It may irreversibly modify the institutions and communication networks of the local community in ways that the locals consider detrimental.

With the expenditure of enough resources on reclamation, many of these negative impacts upon the other functions served by soil and land resources can be mitigated. But a rational appraisal of potential costs may suggest that surface mining ought not be initiated at all in particular localities. Institutional mechanisms, from long-established concepts of common law to more recent and more specific regulations, exist to facilitate resolution of the various conflicts between land uses and their consequences. However, satisfaction with these institutions and the results they provide varies among individuals and groups, and thus political action may arise to supplement the existing legal procedures.

COAL USE IN THE UNITED STATES

About 80 percent of our fossil fuel resources are coal, but coal currently provides less than 18 percent of our national energy. Of the total coal use in the United States, about 64 percent is for electric generation, 33 percent for industrial uses, and 3 percent for residential and commercial uses. No coal is currently used directly to provide power for transportation (National Academy of Engineering 1974).

Most studies of the current energy situation agree that coal will be an important energy source for the next several decades (see, for example, Wilson 1980), although not all analysts agree that there is a need for significant increases in coal use (Council on Environmental Quality 1979). There are vast resources of coal in the world, sufficient to support greatly expanded U.S. and worldwide use well into the twenty-first century and possibly beyond. Thus even the most optimistic forecasts for energy conservation and development of renewable energy sources conclude that coal must play an important role. And coal has potential uses as a raw material for the manufacturing of organic chemicals and synthetic fuels.

The technology for mining, moving, and using coal is well established and steadily improving. While there is concern over our ability to reclaim mined areas to an acceptable end use, well-directed research should be able to supply answers to most of the environmental problems related to mining. The effects of gaseous emissions from the combustion of coal, such as the buildup of carbon dioxide in the atmosphere and the potential damaging effects of oxides of sulfur and nitrogen, are an unresolved consideration.

Table 2.2 summarizes the distribution of recoverable reserves by state and coal region according to tonnage and heat content. Recoverable reserves are deposits judged to be commercially minable by virtue of seam thickness and accessibility, under known technological, legal, and other constraints. Market factors such as the price of coal relative to other fuel prices will affect the quantity of coal demanded and will also affect supply via the level of exploration and exploitation. Significantly higher energy prices would increase these figures for reserves, as thinner and deeper seams become more attractive economically.

Table 2.2 indicates that coal reserves in the United States are fairly evenly divided by the Mississippi River. Fifty-three percent of the recoverable reserves in terms of tonnage and 49 percent in terms of heat content are found in the West. Some analysts feel reserves of subbituminous coal now accessible only by underground mining should not be really considered reserves because they are generally not commercially minable (Murray 1978). (About 80 percent—60 billion tons—of underground-minable reserves in the West are subbituminous.) If such reserves are eliminated from Table 2.2, the West's share of recoverable reserves drops to 40 percent of total U.S. reserves.

The geographic pattern of coal extraction differs substantially from that of coal reserves. Table 2.2 shows that in 1976 only 18 percent of coal production in the United States came from the West. Increasing reliance on coal, then, may lead to substantial shifts in the geographical patterns of coal mining. The extent to which production shifts from the East to the West in the future will depend on a number of factors. The northern Great Plains, for example, have reserves sufficient to support large increases in mining over present levels of production. The main factor inhibiting development of western coal is that deposits are located far from the main centers of demand for energy, which are in the East and on the West Coast.

The physical and chemical properties of the coal in the various regions will affect future mining and utilization patterns. Bituminous coals, which are found primarily in the Appalachian and midwestern regions, tend to be low in moisture and high in heat content but also relatively high in ash and sulfur. Subbituminous and lignite coals, which predominate in the western and Gulf Coast regions, tend to be higher in moisture and lower in heat content, higher in ash but often quite low in sulfur content. Conventional estimates place 86 percent of the low-sulfur coal (containing less than 1 percent sulfur) in the western coal regions (Hamilton et al. 1975, Thomson and York 1975). If sulfur in coal reserves is compared on a uniform Btu basis, however, this advantage is significantly reduced (Boulding 1976). Figure 2.1 illustrates a uniform Btu comparison of coal from 4 coal regions in terms of the amount of sulfur reduction necessary to meet the U.S. Environmental Protection Agency 1970 new source performance standard of 1.2 lb of sulfur dioxide per million Btu (equivalent to 0.6 lb sulfur/10^6 Btu or 258 g sulfur/10^9 joules).

The high sulfur content of much Appalachian and midwestern coal means that perhaps a considerable portion of the Appalachian and midwestern resource that is recoverable in engineering terms may be unattractive in economic terms as a result of Clean Air Act policies requiring high-sulfur coal to be cleaned, at considerable expense to the user. Even when adjusted for heat content, western coals, generally have lower sulfur contents than midwestern and Appalachian coals. The major exception to this pattern is that central Appalachia has significant reserves of low-sulfur coal. National sulfur standards are thus likely to affect not only overall coal-mining rates but also the regional distribution of future mining activities. The application of more rigorous standards is likely to lead to increased mining in the West, although transportation costs can partially offset the costs of installing air-pollution control measures.

The distribution of coal resources in the conterminous United States is shown in Figure 2.2. In the Appalachian area, coal resources are distributed along the length of the Appalachian mountain range from Pennsylvania to northern Alabama. West Virginia has the largest quantity of reserves within this region, followed by Pennsylvania and Ohio. In the Midwest, reserves are concentrated in the Illinois Basin. Illinois has by far the largest reserves in this region. In the West, very substantial reserves are located in Montana, Wyoming, Colorado, and North Dakota.

While the scenarios of future coal utilization vary, most project a substantial growth—about 50 percent growth to 1985 and an equal or greater growth from that date to the year 2000. One "typical" projection is shown as Table 2.3.

Appalachian Region

In Appalachia, mining generally occurs in areas remote from population centers. These areas are often heavily wooded, and forestry and recreation are the principal nonmining activities. In most areas, the topsoil is thin and other types of agricultural activity is limited. Slopes tend to be steep, limiting accessibility and many alternative uses. Throughout the region the

TABLE 2.2 Recoverable Coal Reserves as of January 1, 1976

State	Underground Heat Content, quadrillion Btu	Surface Heat Content, quadrillion Btu	Total, quadrillion Btu	Underground Minable, million tons	Surface Minable, million tons	Total, million tons	1976 Production: Underground, million tons	1976 Production: Surface, million tons	1976 Production: Total, million tons
Ohio	180	107	287	7500	4900	12,400	16.2	29.3	45.5
Pennsylvania	418	28	446	16,700	1200	17,900	43.8	39.9	83.7
Kentucky (east)	136	84	220	5200	3600	8800	41.5	48.0	89.5
Virginia	53	17	70	2000	700	2700	24.0	12.8	36.8
West Virginia	516	100	616	19,100	4100	23,200	88.4	20.5	108.9
Maryland	14	3	17	500	100	600	0.2	2.5	2.7
Alabama	27	26	53	1000	1100	2100	7.4	14.2	21.6
Tennessee	9	6	15	400	300	700	4.1	4.7	8.8
TOTAL APPALACHIA	1353	371	1724	52,400	16,000	68,400	225.6	171.9	397.5
Illinois	682	257	939	30,300	12,700	43,000	31.0	27.0	58.0
Indiana	117	29	146	5100	1400	6500	0.4	23.7	24.1
Kentucky (west)	118	69	187	4800	3200	8000	22.5	28.3	50.8
TOTAL EAST INTERIOR	917	355	1272	40,200	17,300	57,500	53.9	79.0	132.9

Arkansas	4	3	7	100	100	200	—	0.6	0.6
Iowa	23	8	31	1000	400	1400	0.3	0.5	0.8
Kansas	—	19	19	—	800	800	—	—	—
Missouri	18	57	75	800	2900	3700	—	5.4	5.4
Oklahoma	18	8	26	700	300	1000	—	3.3	3.3
TOTAL WEST INTERIOR	63	95	158	2600	4500	7100	0.3	9.8	10.1
Montana	898	794	1692	40,400	39,700	80,100	—	26.1	26.1
North Dakota	—	118	118	—	8100	8100	—	11.1	11.1
Wyoming	421	404	825	18,000	19,000	37,000	0.6	30.3	30.9
South Dakota	—	4	4	—	300	300	—	—	—
Colorado	159	61	220	7100	3000	10,100	3.4	6.1	9.5
Utah	91	5	96	3600	200	3800	7.9	—	7.9
Arizona	—	5	5	—	300	300	—	10.2	10.2
Northern Mexico	29	42	71	1200	2000	3200	0.9	8.9	9.8
Texas	—	52	52	—	2500	2500	—	14.2	14.2
Washington	—	—	—	600	400	1000	—	3.9	3.9
Alaska	—	—	—	3100	600	3700	—	0.7	0.7
TOTAL WEST	1598	1485	3083	74,000	76,100	150,100	12.8	111.5	124.3
TOTAL UNITED STATES	3931	2306	6237	169,200	113,900	283,100	292.6	372.2	664.8

Source: Adapted from U.S. Office of Technology Assessment (1979).

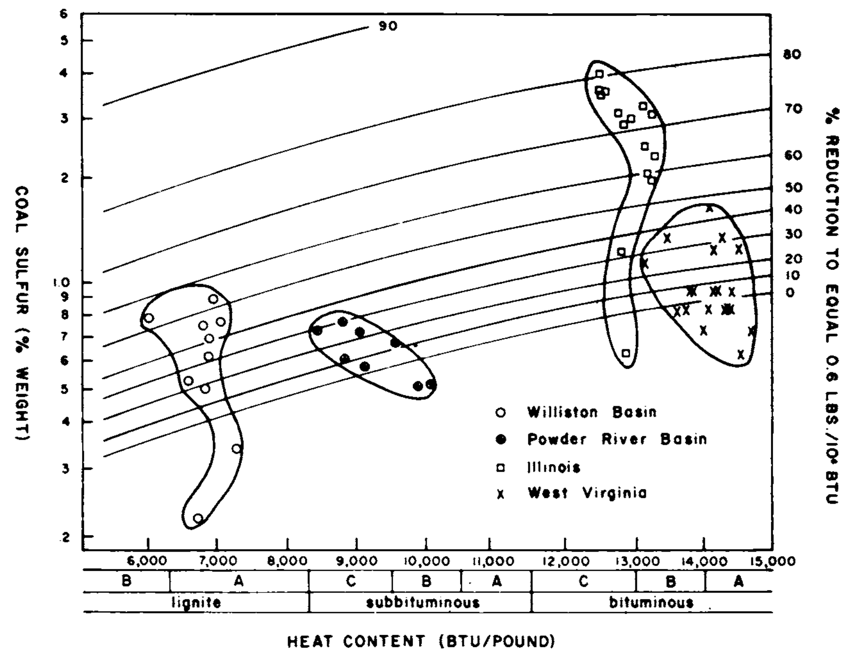


FIGURE 2.1 Sulfur/Btu comparison of four coal areas in the United States. *Source*: Murray (1978). Copyright© by Westview Press. Reprinted by permission.

value of the land has been related primarily to the value of coal, other subsurface resources, and forest resources. The value of an acre of land in the mining areas has been quite low compared to that of land closer to urban areas.

In the early development of surface mining this low value meant that there was little economic incentive to invest in reclamation activities, which might cost 10 or perhaps 100 times the market value of land mined. This neglect of reclamation has affected the environment, not only on the mined land but also in surrounding areas. The relatively high rainfall throughout the region enhances the growth of vegetation but also extends environmental damages far beyond the area of mining activity. In northern Appalachia, in particular, acid mine drainage from both underground and surface mines has polluted thousands of miles of streams. Runoff from steep slopes has carried materials into the streams and rivers and has covered many small agricultural plots in the hollows and valleys of the region with sediment.

TABLE 2.3 Projected Coal Production in the Conterminous United States (in Millions of Tons)

	1977	1985	2000
Surface mines			
Appalachia	185	130-155	130-175
Midwest	91	75-95	95-135
West	141	415-495	700-1005
TOTAL	417	620-745	925-1315
Underground mines			
Appalachia	205	225-260	380-505
Midwest	54	60-80	120-180
West	13	50-60	80-110
TOTAL	272	355-400	580-795
All mines			
Appalachia	390	355-415	510-680
Midwest	145	135-175	215-315
West	154	460-510	780-1115
TOTAL	689	950-1100	1505-2110

Source: U.S. Office of Technology Assessment (1979).

Prior to the 1977 federal law, contour mining typically left an exposed highwall, a relatively flat solid bench, and a considerable quantity of disturbed spoil materials. Some of the spoil was pushed down the slope beyond the solid bench, some was placed on the solid bench, and some was transported elsewhere for subsequent stabilization. Typically, relatively long, narrow, and irregularly shaped sections of flat land remained after mining and reclamation. In the case of mountaintop removal, relatively flat "plateaus" were created where there once had been peaked mountains.

Mine operators and many landowners have argued that flat land created by mountaintop removal and by those contour-mining methods that leave a relatively flat bench is more valuable than land following the topographical patterns typical of the region. There are cases where houses and commercial buildings have been erected on reclaimed contour benches. Several airports have been constructed on old mountaintop-removal sites. Research is under way to determine the feasibility of crop and pasture production on old mountaintop-removal sites and commercial lumber production on old contour benches. A team of scientists from the U.S. Fish and Wildlife Service is exploring the value of old, grassed-over contour benches for wildlife range. These developments suggest that the flat land remaining after mountaintop removal and contour mining may indeed have economic value.

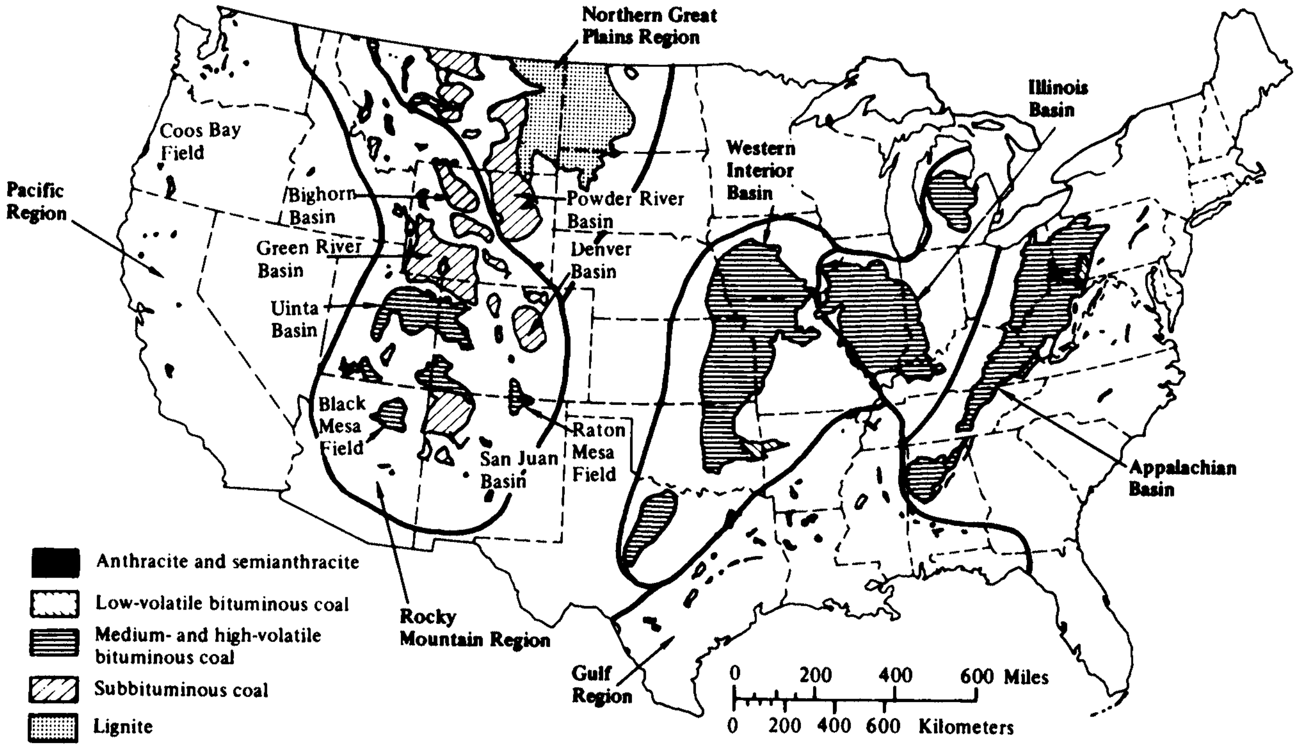


FIGURE 2.2 Coal fields of the conterminous United States. *Source*: National Research Council (1979b).

But there are serious limitations to the economic demand for such flat land. Flat benches or "plateaus" are in demand as residential, commercial, and industrial sites only to the extent that the land is located conveniently close to existing urban centers, major highways, and water supplies. Agricultural, forestry, and wildlife uses are a matter of conjecture until necessary research has been completed. A survey of reclamation inspectors and local realtors conducted in Eastern Kentucky in 1977 revealed that more than 90 percent of reclaimed surface-mined sites existing at that time had not been put to any formal or managed economic use, and it was very difficult to establish an economic value for such land, since very few economic transactions involving it had taken place (Randall et al. 1978a).

A limited quantity of mining-created flat land in desirable locations could be a valuable by-product of surface mining in central and southern Appalachia. If relieved of "back-to-contour" regulations, however, the mining industry would probably provide such land in quantities considerably in excess of the demand, and with no special regard to the locational requirements that would make such land useful for residential, commercial, or industrial purposes.

Interior and Gulf Regions

In the intensively farmed interior coal region, the major issue is the conflict of mining with agricultural production. In the leading coal states in this area, 60 to 90 percent of the area is occupied by farms. In Illinois, Indiana, and Iowa, more than 60 percent of the farmland is devoted to harvested crops, as opposed to pasture and range. The soils and climate of this region are generally very favorable for production of corn, soybeans, and other row crops. Whether extensive surface mining will reduce the region's agricultural potential is a major concern.

The Gulf Coast region, like the interior region, has a climate and topography generally favorable for reclamation. The soils of this region are not as highly productive, on the average, as in the interior region. The conflict between crop production and mining is therefore less severe.

Western Region

The coal-mining areas of the western region differ greatly from one another in terrain and climate and hence in land use. The terrain varies from the rolling plains of the western Dakotas and eastern Montana to the high and rugged mountains of Colorado. The climate ranges from cold and subhumid in the North to hot and arid in parts of Arizona and New Mexico. These variations are reflected in the land use.

Agriculture is the principal land use in most of the western coal area. Most of the farms are large; the average size in coal areas is 2865 acres (1160 ha). Most of the farmland is pasture and range. Harvested crops account for less than one-eighth of the land in farms, except in North Dakota. Much of the land not in farms in these areas is federally owned and is used for seasonal grazing by nearby ranchers or forestry. These federally owned lands are also important because of their roles as watersheds, wildlife habitats, and recreation sites. In fact, management of federal lands has involved balancing the often competing interests of livestock grazing, forestry, watershed, wildlife, and recreation.

A relatively small part of the total land in farms in the western states is irrigated—ranging from less than 0.5 percent in Arizona and the Dakotas to 1 percent in Colorado. However, because of its high productivity, irrigated land is considerably more important to the agricultural economy than the small percentages suggest. Much of the irrigated land is used to produce feed grains and forage for winter feed for livestock on ranches that use adjacent federal and private rangelands for summer grazing. Livestock is a more important source of income than crops in all the western coal areas except those in North Dakota and northeastern Montana (McMartin 1979).

COAL AND AGRICULTURE

The estimate of 10 million acres (4 million ha) of land in the 48 contiguous states underlain by strippable coal reserves gives only limited indication of the extent of competition for land between surface mining and agriculture. To achieve a more complete understanding, we must consider: (1) recent trends in agricultural land use; (2) land use in the coal-bearing portions of those states which have significant coal deposits; (3) projected land disturbance and its impact on the value of farm output in coal-producing areas; and (4) the effect of recovery time, following surface mining, on land disturbance and farm sales.

Roughly 50 percent of all land in the United States is classified as farmland, and a little more than 400 million acres (162 million ha), approximately 19 percent of all land, is cropland (U.S. Bureau of the Census 1974). Cropland is quite unevenly distributed across the nation, ranging from more than 60 percent of all land in the Corn Belt to less than 5 percent in several mountain states. A summary of farmland use in the coal-bearing states is presented in Table 2.4.

Between 1967 and 1975, a net loss of 30 million acres (12.2 million ha) of cropland (7.5 percent of the total) occurred, as 79 million acres (32 million ha) were converted from cropland and 48 million acres (19.4 million ha) were converted to cropland (Diderikson et al. 1977). The loss in cropland

TABLE 2.4 Land Area and Farmland Use in Coal-Producing Counties, 1974

Region and State	Land Area of Coal-Producing Counties (1000 acres)	Percent of Land Area in Farms	Major Use of Farmland (percent) Harvested Crops	Other Cropland[a]	Pasture, Range, Woodlands, and Other
Northern Great Plains					
Montana	25,484	88.4	10.2	8.6	81.2
North Dakota	20,462	94.7	33.0	24.2	42.8
South Dakota	6632	95.5	12.6	5.8	81.6
Wyoming	24,424	56.9	3.1	1.6	95.3
Rocky Mountain					
Arizona	25,357	75.7	0.1	0.3	99.6
Colorado	33,563	45.5	11.8	9.2	79.0
New Mexico	16,023	63.8	0.6	1.1	98.3
Utah	15,283	17.2	4.3	4.5	91.2
Pacific					
Washington	7286	12.4	21.8	16.2	62.0
Eastern					
Alabama	6337	26.4	22.6	24.5	52.9
Kentucky (east)	7560	25.5	11.2	28.9	59.9
Maryland	696	25.3	25.0	18.2	56.8
Ohio	8067	40.0	33.1	21.4	45.5
Pennsylvania	14,830	24.2	39.2	19.8	41.0
Tennessee	5044	27.8	16.7	32.9	50.4
Virginia	2072	31.1	12.4	24.7	62.9
West Virginia	12,337	18.8	13.7	24.7	61.6
Interior					
Arkansas	3095	34.2	17.8	33.1	49.1
Illinois	24,524	83.8	73.9	9.6	16.5
Indiana	4902	66.9	61.2	14.2	24.6
Iowa	9008	89.1	64.6	14.3	21.1
Kansas	4495	85.3	44.8	16.5	38.7
Kentucky (west)	3823	62.6	40.4	26.1	33.5
Missouri	15,332	81.2	44.9	25.4	29.7
Oklahoma	7831	60.7	13.8	22.2	64.0
Gulf					
Alabama	4552	43.9	18.2	19.4	62.4
Arkansas	2258	14.7	28.4	28.4	43.2
Texas	17,666	55.6	10.7	27.9	61.4
TOTAL LAND AREA	329,444				

[a]Includes idle and fallow land as well as forage cropland.

Source: Adapted from McMartin et al. (1980).

seems to have been in response to economic pressures, and there is evidence that small changes in relative prices would bring about a reversal of that trend. Diderikson and his colleagues (1977) estimate that there are about 78 million acres (31.6 million ha) in the United States with a "high potential" for conversion to cropland.

Between 1930 and 1971, a total of 1.5 million acres (0.6 million ha) were surface mined for coal, and 1 million of those acres were reclaimed to some degree (Paone et al. 1974). Only a fraction of that land was cropland. The impact of surface mining for coal on farmland nationwide has been overshadowed by changes attributable to other sources of competition for land.

The coal industry clearly has the potential to disrupt crop production in the Corn Belt states in the interior region. But in Appalachia, it is landscape amenities, forest ecosystems, and water quality that are disrupted. And in the western and Gulf Coast regions, ranching activity and its associated (Native and non-Native American) social and community values will bear the brunt of the disturbance.

Total land disturbance and the annual value of farm output lost because of coal mining, by region, have been estimated using reasonable projections of surface coal mining from 1976 through 2000 (Table 2.5). Mined land was assumed to return to agricultural production after a 5- to 10-year reclamation period. In all of the regions, the value of farm output that will be lost to coal mining will be less than one-half of 1 percent. Even in the interior region, where a large proportion of coal lands in states such as Illinois, Indiana, and Iowa are in harvested crops, the value of projected annual losses in farm output will be less than two-tenths of 1 percent of total farm sales from coal-bearing lands.

If, for whatever economic, social, and environmental reasons, it is thought important to minimize the area of land disturbed in the process of surface mining, the surface-mining industry could be encouraged to work the thickest seams first. Figure 2.3 shows the relationship between seam thickness and land disturbance per million tons of coal mined. While the figure focuses on the western region, the same procedure could be used to estimate this relationship for other coal-producing areas, although coal seams are much thinner in the Midwest and East.

Estimates of land in a disturbed condition and the value of farm output lost due to land disturbance by surface mining are sensitive to assumptions about recovery time. If recovery time is 20 years as opposed to the 5 to 10 years assumed by McMartin et al. (1980) in Table 2.5, the average number of acres in a non-productive, disturbed state in a given year would be more than doubled in each of the regions as also would be the resulting annual loss of farm production. It is not clear how savings in reclamation costs due

TABLE 2.5 Projected Effect of Surface Coal Mining on Farm Production, 1975-1990

Region[a]	Average Annual Coal Production, million tons, 1975-1999[b]	Average Coal Yield, tons per acre[c]	Average Annual Acreage Taken out of Production[d]	Value of Farm Production Displaced: Average Dollars, per acre	Value of Farm Production Displaced: Total, 1000 dollars	Ratio[e]
Northern Great Plains	296	47,870	103,606	9.06	939	0.09
Rocky Mountains	66	16,280	66,910	2.76	185	0.02
Pacific	5	31,150	1554	22.52	35	0.08
Eastern	205	5520	225,859	18.65	4212	0.33
Interior	116	5040	132,561	73.64	9762	0.14
Gulf	58	10,220[f]	37,802	26.32	995	0.16

[a]Data are for coal-producing counties given in Table 2.4.

[b]Based on expansion plans of mining companies. For Northern Great Plains, Rocky Mountain, Gulf, and Pacific regions, plans are those reported to U.S. Department of Energy (1974). For other regions, plans are those reported in Nielson (1979).

[c]Computed from data in Averitt (1975) and U.S. Department of the Interior (1971). Based on 80 percent recovery rate and yield of 1400 tons per acre-foot for lignite, 1416 for subbituminous, and 1440 for bituminous.

[d]Computed as follows: $AA = \frac{ACP \times RP}{CY} + APS$, where:

AA = average annual land out of production;
ACP = annual coal production, in tons;
CY = coal yield per acre;
RP = reclamation period = years required for reclamation = 10 years in Rocky Mountain region, 8 years in Montana and Wyoming, 5 years in North Dakota, and 5 years in other regions;
APS = acres in permanent structures, arbitrarily assumed to be 800 acres for each new or expanded mine in Northern Great Plains, Rocky Mountain, and Pacific regions, 600 acres in Interior and Gulf regions, and 400 in Eastern region.

[e]Value of production displaced as a percentage of all farm products in the coal-producing counties of the region.

[f]Includes Texas only.

Source: Adapted from McMartin et al. (1980).

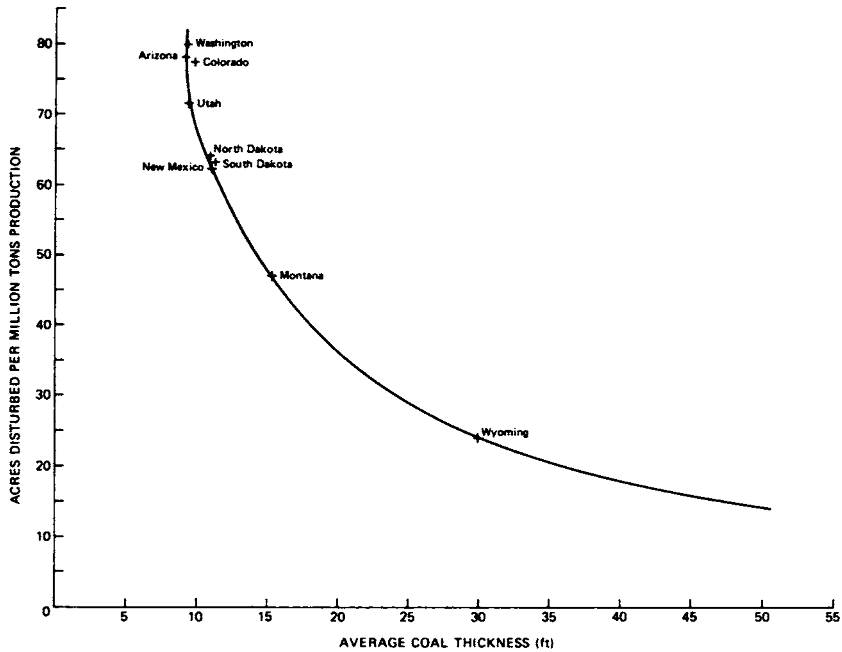


FIGURE 2.3 Relationship of coal thickness to acres disturbed per million tons production for the western United States (assuming 1750 tons per acre-ft and 80 percent recovery). *Source*: National Research Council (1974).

to longer recovery periods compare to economic losses of delayed production.

COAL AND LOCAL COMMUNITIES

Some facilities provide necessary services but are unpleasant to be near. Most would agree that such facilities ought to exist somewhere, but nobody wants to live next door to one. Perhaps the most common example has been the garbage dump, but in recent decades the list has expanded considerably. Some are small, affecting only a few city blocks—e.g., "half-way houses" for alcoholics, mental patients, and prisoners returning to society. Others may affect a significant section of a county—e.g., a state prison, sanitary landfill, or large airport. Some are much larger in scope and may affect whole counties or regions. Large-scale open-cut or strip mines are often in this category, as are major energy-conversion facilities.

Such facilities produce "spillover costs," including pollution, ugliness, or excessive noise. People considered undesirables may congregate in the vicinity. Some facilities are likely to cause sudden and substantial increases in local employment, which may be a blessing but raises possibilities of congestion and disruption of the local economy. Local public-sector services may be strained and tax increases may be required to support the expansion of such services. The newcomers may not share the regional and socioeconomic class background of the local residents. Thus, while such facilities may not be universally opposed by the local populace, they will be controversial.

The public sector, whether it functions as owner, financial backer, or regulator, is usually substantially involved in the decisions as to whether, where, and under what conditions such activities should be undertaken. Both the positive and negative social impacts must be considered in making these decisions. Here we review the major social costs of surface mining for coal and some of the methods available for assessing their magnitude.

The Social Costs

Large surface-mining operations have major consequences for communities and populations in their vicinity in several categories:

- *Social cohesion*. Surface-mining operations may introduce new residents into settlements with a history of close interaction within kin and neighborhood groups. Newcomers lack knowledge of local customs and styles of life and communication and may be contemptuous of them.
- *Socioeconomic structure*. Newcomers with income opportunities different from the traditional ones in a locality and new employment and income opportunities of local people themselves can modify the established hierarchy of income, wealth, and authority in a community. Such changes in socioeconomic structure may have desirable effects in the long run, but the disruptive effects of changing the economic patterns in a relatively stable society must be dealt with in the short term.
- *Disturbance of settlement patterns and spatial arrangements*. Surface mining may force relocation of residents and create new residential subdivisions for newcomers that differ from previous architectural patterns. Existing transportation systems may be inadequate.
- *Quality of life and economic well-being*. Large surface-mining projects generate effects similar to those of rapid industrialization and urbanization. The quality of life may be degraded in the view of the local people through changes in economic opportunities, the loss of relative self-sufficiency in

food or social facilities, the effects of increased population numbers and density, declines in social services, noise and dirt, and many other factors.

• *Aesthetic sensibilities*. Settled communities and rural neighborhoods develop an appreciation of a familiar landscape, whether this is natural or already modified by human intervention. Disturbance of this landscape on the scale required by surface mining—plus increased dust, noise, or traffic—are a source of irritation. Often protests are more vocal over aesthetic issues than over material issues. Aesthetic values are subjective, but this does not make them any less important to local populations. Further, many individuals who do not reside in the vicinity may be concerned about these qualities.

• *Personal disorganization*. Social changes have psychological effects on individuals. The disruption of accepted cultural norms and the breakdown of conventional systems of social relations and communication affect children and the aged especially strongly. Out-migration to escape the disorienting conditions is a common response. Relatively small communities affected by large facilities usually experience an increase in emotional disorders.

While some of these impacts appear immediately following initiation of the project, some of them emerge over time—often beyond the planning horizons of public agencies or private companies. These adverse social effects may be called externalities, since they are unintended side-effects that burden people powerless to control them.

Communities may well be split as some people favor the changes for reasons of business or excitement and novelty while others perceive and experience the changes as serious threats to well-being and an established way of life. Community leaders are often unable to make the adjustments required, owing to lack of funds or experience in handling such problems, and they consequently attract recrimination and blame from the citizenry or the unassimilated newcomers for their failure to cope. Federal grants can assist such adjustment, but these are not always easy to obtain and often come too slowly to be of much help.

Let us look at the example of Sweetwater County, Wyoming (Gilmore and Duff 1975). During the period 1970-74, expansion of mining for the mineral trona and the construction of the Jim Bridger Power Plant increased population from 18,931 to 36,900 and employment from 7230 to 15,225 (mining employment increased from 1530 to 2650; construction employment increased from almost 0 to 4200). The quality of municipal and other local services declined markedly. Throughout Wyoming, the average doctor:population ratio is 1:1100; in Sweetwater County this ratio decreased from 1:1800 in 1970 to 1:3700 in 1974. Mental-health clinic caseloads increased 8-fold. In 1974, there was an estimated deficit of 128 schoolrooms in the county. Capital costs for providing schoolrooms are estimated to be on the order of $5000/child, but assessed valuation for school districts increased only $2100/child from 1970 to 1974. By 1974, the backlog of homesites needing municipal services (water, sewage, roads, electricity, etc.) was approximately 1397, and 4599 mobile-home spaces were needed. Crime rates increased by 60 percent between 1972 and 1973 alone, and there was little expansion in police service.

These statistics are only gross indicators of the altered social, institutional, and economic conditions brought about by rapid, large-scale economic developments in this and other small communities. Increased rates of alcoholism, broken homes, and suicides were among the many personal manifestations of breakdowns in social order in Sweetwater County reported in Gilmore and Duff's study.

Of course, not all mineral-related developments result in disorder on this scale. For example, Ives and Eastman (1975) found that increased coal-mining activity in Cuba, New Mexico, during the 1970-74 period had socioeconomic impacts that seem to have been beneficial to all concerned, at least in the period covered by the study. Although percentage increases in population and employment (156 percent and 73 percent, respectively) were not unlike those experienced in Sweetwater, the scale of change in absolute terms was relatively small (over the 1970-74 period population increased from 230 to 590). More importantly, perhaps, Cuba seems to have had substantial excess capacity in its municipal facilities prior to the boom.

While the effects of coal development on Native American reservation communities are similar to those experienced by ranchers and farmers, there are some special impacts not found in non-Native American communities. Some tribal lands are believed to be sacred. This belief can come into conflict with financial concerns, and reservation communities are thus often deeply divided in their reaction to energy projects. Disputes within the tribes are made more acute by ambiguous relationships between the reservation government and federal and state governments. Moreover, most tribal governments responsible for controlling or modifying mining and power projects have limited training and experience—in contrast to the communities outside reservations where such abilities are more readily available.

Many tribal governments are now developing such capabilities with the assistance of organizations such as the Council of Energy Resource Tribes. And as a result of recent contracts with mining and power interests, reservation residents are being trained as engineers, environmental scientists, and machine operators. Furthermore, royalties from minerals are a welcome addition to tribal government budgets. Consequently, a pro-project faction exists in all reservations, in opposition to more traditional residents who resist the alteration of the natural landscape.

Relationships between the local population and companies that extract and use minerals can be considered instances of *adaptive coping*: methods that local people devise in order to defend themselves against the threatened costs of mining and associated developments. Political action often develops, as do legal strategies designed to obtain as much compensation as possible. Adaptive coping also involves internal techniques for adjustment to changed living conditions and failures of expectations. In extreme cases, this may include adjustment to resettlement on new land.

Social scientists have observed that adaptive coping must develop in response to real situations: it cannot be taught before the need has emerged. But a major problem with the interaction between locals and the outsiders in charge of the mining projects is that while the outsiders have a conception of the duration and magnitude of the undertaking (and hence can make their decisions accordingly), the locals often do not. Government and private agencies in charge of the projects are often reluctant to provide the full facts, fearing to arouse alarm and opposition in local groups. Consequently, the locals usually lack sufficient time to develop suitable strategies for coping with what becomes for them a kind of natural disaster, with a few immediate benefits mixed in with possible long-term costs and needs for change.

Another problem in the adaptive process is the ability of humans to tolerate extreme conditions if a sense of powerlessness prevails or if costs accumulate slowly enough that a "tyranny of small decisions" develops. Gradual habituation may proceed without the group reaching a point of resistance, even though its members are increasingly disaffected. In situations where people learn to adapt to or tolerate drastically changed and even deprived conditions, outsiders may have to speak up in their defense. That is, the case for the locals must be made by others on universalistic or ideological grounds. Yet such interference can result in well-meaning but ecologically or culturally unsound attempts at restoration of the pre-mine physical or social resources. Strong involvement of local populations in the planning of large-scale projects is clearly desirable, with intensive education concerning future consequences.

In the case of local populations with distinctive symbolic investment in the land (e.g., Native Americans, ranchers, and wilderness campers), attempts to compensate for loss are difficult since there is no currency with which to trade in such meanings. If local people can participate in the formulation of new uses and meanings for the land, reclamation can be more rationally planned.

THE ASSESSMENT OF IMPACTS

In recent years a number of techniques have emerged for acquiring information about the potential effects of surface mining and associated developments on local populations. The most familiar of these are the social, cultural, and ecological impact assessment studies, attitude surveys, and public hearings in which various groups can articulate their concerns.

None of these approaches is foolproof. The impact studies are often carried out by nonlocal people with little intimate knowledge of the social fabric, local values, or key points of vulnerability. In addition, the studies are often unable to deal with the long term, and tend to emphasize potential impacts in the immediate future—although many of the most serious problems, especially emotional problems, emerge much later. Many impact studies rely on attitude surveys, for example, which merely turn up contemporary individual reactions. The more important issues of the long-range, often accelerating, effects on an established social order are not addressed or analyzed.

Despite these and other shortcomings, impact studies are necessary in the decision-making process. Research is needed to improve these methods and clarify their role in relating the regulatory procedure to environmental and social effects.

Public hearings, like impact assessments, are being used more and more. Public hearings may help to forecast potential consequences of the project; they also provide project managers with some indication of the foci of opposition to the project and what outside organizations may intervene on behalf of the local population. But hearings procedures share many of the defects of impact assessments, and there is no clear understanding of the force or authority of public testimony.

Public-opinion surveys can be used as an indicator of the national mood with respect to large technological interventions, directions in national policy, and regulations. Polls and surveys taken by agencies such as the National Opinion Research Center, and studies on specific issues commissioned by the environmental and conservation organizations show a nationwide trend toward concern over the environmental and social disruption of large-scale technological operations of all kinds. Two surveys in those Kentucky counties most heavily affected by surface mining for coal, for example, found quite strong sentiment at statistically significant levels in favor of back-to-contour land reclamation (Randall et al. 1978a). These studies do not support the claim, often made, that jobs are more important to residents of mining areas than environmental and social disruption and that locals are hostile or indifferent toward controls.

In the last analysis, the problem of social impacts is another part of the problem of priorities in energy and technological development. Public reaction to dramatic technological change has in the past decade stimulated new government agencies and regulations established by congressional directive. All of these reflect widespread unease over single-minded dedication to economic growth, abundance, and unrestricted resource exploitation. It is vital that research and experimentation with more effective controls, and consensus-building mechanisms, proceed.

3 The Institutional Context for Surface Mining

In this chapter we describe the evolution and present status of American land-tenure institutions. These institutions provide the context in which the environmental and social impacts of surface mining for coal can be controlled. The complexities introduced by current patterns of ownership of coal resources and of coal-bearing land are examined, and the legal means by which surface mining was controlled before specific public laws regulated mine reclamation are discussed. We trace the evolution of surface-mine legislation from state laws through to passage of the Surface Mining Control and Reclamation Act of 1977 and describe the current status of the act and other regulations.

LAND TENURE

Insatiable demands and limited resources combine to ensure scarcity, and scarcity generates conflict. Societies, to ensure their continuity and to facilitate peaceable coexistence among their members, find it necessary to establish ways to resolve conflict—working rules and on-going procedures for adjudicating interpersonal conflicts—which are accepted as legitimate by their citizens. These rules and procedures are called institutions, and they may be designed to serve a variety of additional ends: protection of individual life and property; control over rate of social change; encouragement of resource mobility and efficient resource allocations; conservation of stock and renewable resources for the benefit of future generations; the protection of the existing social order, or, alternatively, the encouragement of social and economic mobility.

Given the importance of land resources to the productivity of the economy and to the social and economic status of individuals, it is not surprising that institutions dealing with land tenure are among the earliest and most important institutions to be developed.

At the societal level, the problem is to define and secure the territory. Most societies now have their territorial boundaries defined in terms of mapped space and secured by national armies, international treaties, and international law. In earlier times, in societies lacking the technology of planar surveys, other means of denoting territorial rights developed: Native Americans, for example, memorized landmarks and scenery; hence their map of their territory was a mental image, not a legal document. And lacking a means for denoting territorial rights, boundaries were flexible and preserved by stylized combat or repeated use. *Usufruct*, "use-right" over land, in which possession lasts as long as the social group uses it, is perhaps the most common type of possessory tenure the world over.

At the individual level, the problem is to allocate the land resource efficiently through secure rules of access to land. Access to and control of land resources are secured through property rights defined by society. By giving property holders stable expectations concerning their rights to use, control, and dispose of their land resources, a society permits them to make long-range plans, knowing that unilateral and capricious acts by others will not divest them of their expected gains—or at the least, that such acts will fall within certain limits.

Individual ownership, as we understand it, is in fact quite a recent development. Other societies have used various forms of common domain ownership, often with elaborate rules specifying individual use rights and corresponding duties and responsibilities. Feudal societies vest substantial, hereditary rights in the lord of the manor, with subsidiary rights according some security to subserviant individuals.

In the absence of any ownership or control over land resources (or over any object of value) we have *open access*. In this situation, any person who desires to make use of the resource is free to do so. Examples of open-access resources are the high-seas fishery, minerals on the ocean floor beyond national economic zones, the air shed, and the Great Plains when the Europeans arrived. Once access to natural resources is limited, four types of property can evolve:

- *individual* private property, in which rights are held by individual persons against all others. Most legal arrangements over land resources recognize married persons as joint owners, and hence we must apply the word "individual" with some care. Houses, automobiles, and farms are, of course, common examples.

• *group* private property, in which rights are held by corporate or other nongovernmental groups such as cooperatives, churches, and associations.

• *common* property, in which rights are held by a group of individuals who collectively decide about resource use. No one individual may be excluded from use of the resource, though the aggregate use rate is controlled by the group. The summer pastures of Switzerland are common property, as are most resources under the vast majority of simple economies in pastoral Africa. The crucial distinction between group private property and common property is that group private property can be sold, whereas common property cannot. Common property rights are generally equal among members of the group, whereas group private property rights may be differentiated by magnitude of members' investments or financial contributions.

• *public* property, in which control over resources is exercised by the government. Examples are the public grazing lands in the western United States, wilderness areas, and the national parks.

Capitalist democracies have tended to move away from open-access and common property resources to resources held as private property either by individuals or by groups.

Many of the contemporary tensions over property rights in land resources stem from transformations of some hitherto private rights in land into public property rights and some existing open-access situations into public and/or private property. An example of the former is the transformation of private rights in urban development into public rights to manage land use. An example of the latter are the termination of open access to air and water as "dumps" and the institution of public property rights in the air or water for such use.

If property rights are completely specified, exclusive, transferable, and enforced, markets in rights will emerge. If those markets are reasonably competitive and accessible to all concerned (which implies that income and wealth are not grossly unequal), conflicts can be satisfactorily resolved through markets. It is not always possible, however, to specify exclusive and transferable rights; rights to air and water quality, scenic beauty, or the social ambiance of a community, for example, elude such limitations. And markets are not always competitive and accessible. We therefore see individuals acting collectively to use the powers of government to redefine rights, reassign ownership (e.g., from private to public), and regulate individual behavior with respect to natural resources.

The government's relation to property rights may take several distinct forms: (1) The government may assign rights initially to a particular class of resource users, and their subsequent transfer may be permitted subject to the consent of all parties involved in the exchange. Conflicts are resolved via negotiation and exchange and the role of government is limited to initial specification of rights and their subsequent enforcement. (2) Government may reserve the right to appropriate privately held resources, with compensation, for public purposes. (3) Government may retain title to the resource in question, specifying and enforcing the rules under which individuals may use it or enjoy the services it provides. (4) Government may impose regulations, in the name of the public welfare, on the way private resources are used. (5) For important classes of resources (e.g., air, until the last few years), government may remain essentially silent, neither specifying rights to facilitate conflict resolution through private negotiations nor imposing regulations.

MODERN AMERICAN LAND TENURE INSTITUTIONS

It is customary to think of the U.S. economic system as one of individual enterprise, based on a legal foundation of ownership, in which choices are made on the basis of valuations reflected in market prices. In such a system the role for government (i.e., collective action in restraint of individual action) would be strictly limited to: establishment and enforcement of a system of secure property rights; the provision of national defense; the provision of a very limited set of services that can best be provided by government; and the collection of revenue with which to fund these activities.

In reality, the American economy is far from this model. To be sure, many natural resources are in private ownership. This ownership structure, however, is supported by a complicated system of services carried out by local, state, and federal governments. For example, the different levels of government cooperate in many ways to provide police protection to the user of natural resources. Erosion control, water-quality management, flood control, water conservation, protection of fish and wildlife habitat, energy conservation, and many other objectives are well established as warranting government help. Markets in land are guided and modified by constitutional law, statute laws, and administrative law (the administrative rules and regulations of public organizations)—all subject to judicial decisions as to their meanings, limitations, and legitimacy.

American concepts of civil law in general and property law in particular are based on English common law. American institutions of land possession are thus deeply influenced by the English concept of *freehold tenure*, under which an individual with "fee simple" ownership of an area of the land—defined as the earth's surface and everything beneath and above it—had the right to use or abuse it as he or she pleased. The concept has been greatly modified in practice, however. Minerals beneath the ground are commonly held to be alienable from the ground surface; collective tenure, as in the case of farming cooperatives or sectarian collectives like the Hutterian Brethren, and multiple rights, as in the land leasing and renting system, are some of the many examples of possessory customs that modify the freehold concept.

Other variations on freehold tenure have emerged in the American West, where land resources are fragile. The Taylor Grazing Act of the 1930s and the Federal Land Policy and Management Act of 1976, for example, place considerable controls on the use of land for grazing, and make provisions for mineral extraction, lumber harvest, and recreational and aesthetic land uses. More generally, the power of eminent domain (to appropriate land for the public purpose) and the police power (to regulate individual behavior for the public welfare) place bounds upon the prerogatives of land owners, even owners who enjoy fee simple title.

In modern societies that have adopted the legal device of freehold tenure, conflicts may arise between the concepts of land as: (a) an individually held, marketable, and speculative commodity, (b) an aesthetic resource for the community, and (c) a symbol of cultural meaning. The first concept permits land to acquire values other than those placed upon it by the local residents. Both the freehold ownership concept and the exercise of regulatory power by distant state and federal authorities may result in land uses other than those preferred by the community directly affected. Ownership and trade in American culture and the legal system that supports them permit immediate and direct expression of land values under concept (a), but only indirect and incomplete expression of those values which exist under concepts (b) and (c).

If the contemporary conflicts between various individuals and interest groups challenge the institution-building capacity of society, conflicts between present and future interests are even more problematic.

First of all, vastly different time horizons must be reconciled. Geological processes work slowly and geological time may be measured in millions or billions of years. Human cultures and societies develop identities independent of individuals. These reach into the past for ethical concepts and symbols, and they project these concepts and symbols into the future. Thus, "cultural time" may be measured in centuries and even millennia. Individual lifespans are almost always less than a century, and direct links to forebearers and descendents seldom span two centuries. For most purposes, the individual considers time in hours, days, or, at the most, a few decades.

There is no reason to assume that use and conservation decisions made by individuals exercising private property rights will be consistent with the long-term goals of society or the even longer-term stewardship of geological resources. Thus, all cultures develop rules and customs to direct individual resource exploitation and conservation decisions in ways compatible with human needs for posterity. For example, under Native American concepts of social and cultural continuity, the individual is obliged to temper ambitions for immediate profit and the short-run accumulation of wealth with a deliberate effort to ensure the continued usefulness and productivity of the land far beyond one lifetime.

The United States has only weak and ill-formed institutional means of controlling the condition of land in the interest of on-going society. The power of bequest is one such means: a property right, entirely compatible with the market economy, it can provide landowners with the incentive to conserve both the beauty and the productivity of the land. But this incentive is at best a tenuous force for conservation, since the desire to provide for one's heirs may well lead in the direction of indiscriminate short-term exploitation of the land under current economic pressures. For example, farmers and ranchers who respect the traditions and beauty of the landscape may resist its despoilation for other uses by outsiders. Nevertheless, they are strong supporters of the Anglo-American concept of land as a marketable speculable resource.

Given the relatively weak forces for conservation and market concepts and attitudes that obliquely (if not directly) discourage those forces, the government may seek to augment the power of bequest with public institutions designed to encourage stewardship of land resources. Institutional prerogatives by which the public, acting collectively, may resolve conflicts that do not seem amenable to marketplace resolution fall into four categories:

• *The power of eminent domain*. The government can take, for the public purpose, some or all the property rights held by private owners of land, provided that just compensation (interpreted to mean fair market value) is paid to the owner. This power may be delegated by government to quasi-independent public authorities and some privately owned (but usually publicly regulated) entities such as utility companies.

• *The police power*. The government can regulate the use of land resources without either compensating those whose options are thus restricted or acquiring title to the resource itself. In effect, some of the rights previously held by owners are transferred without compensation to other individuals or groups or to the government. The police power is limited by the constitutional prohibition of taking property without compensation: in effect, the owner must be left with at least some fruitful use of the resources owned but regulated.

• *The powers of taxation and expenditure*. The government, subject to equal protection clauses of the Constitution, can take from all in order to meet the expenses of government. Powers of taxation and expenditure are necessarily powers to allocate resources, deliberately or inadvertently. Taxation changes real and relative prices, while government expenditure changes both demand for and supply of goods and services. In recent years, governments have used the power of taxation, negatively and positively (i.e., via tax rebates or deductions and penalties), to discourage external diseconomies, and the power of expenditure to provide collective goods and to underwrite or subsidize resource-development projects. Most observers expect these governmental initiatives to become more, rather than less, prevalent.

• *The power to buy through the market*. The government, like any individual or corporate entity, can acquire title to land resources by purchases from willing sellers. It may then establish whatever constitutionally permissible rules of access it chooses. This option is the least used, because the government finds it cheaper to regulate use or acquire land through eminent domain, and tax incentives or subsidies are usually preferred by present owners. The public does, however, retain title to roughly one-third of the land area of the United States and may, of course, impose substantial restrictions on the use of this land.

Given the capacity of modern technology to change the character of air, water, and land resources over broad areas and for long times, much stronger measures may be required to restrict massive and long-lived changes in resource quality. In the extreme, the government could effectively nationalize land, reducing "owners" to a status of tenants, although such action would obviously represent a fundamental change in the nature of our society.

The concentration of property rights to land—and the freedom to transfer them—in the hands of private individuals and groups has served us well during the first two centuries of our national history, particularly in getting increased production from our land. This structure of rights is less well adapted to an era of closed frontiers and of technological potential for creating massive disturbances.

THE INSTITUTIONAL ENVIRONMENT OF SURFACE MINING

The many parties that can have rights in a piece of land—the surface owner, the holder of subsurface rights, the holder of the lease to mineral rights, the contractor who extracts the coal—may have conflicting objectives both in utilization and restoration of the land. The complexities of the present ownership situation with regard to coal can be understood best by considering the history of land tenure in this country. Under a variety of laws, much of the public domain of the United States has been transferred to private parties. But only in some instances did these transactions convey title to both surface and subsurface resources. In the establishment of reservations, for instance, Native American tribes were typically given title to both surface and subsurface resources. Federal land grants also conveyed surface and subsurface resource rights to railroads and in some cases to private owners of wagon roads or canals. Some national public land was also transferred to the states. Again, under a variety of laws, the states have disposed of a large part of their original landholdings, often but not always conveying subsurface as well as surface resources to the purchaser.

The federal government and to a lesser extent the states have also done the reverse and acquired land from private owners, for a variety of purposes. The seller generally has retained the subsurface rights, for periods of time ranging to perpetuity.

Where the federal government has title to both surface and subsurface resources, access for mining is determined in several ways. Some lands—e.g., most national parks—are closed by law to mining of any kind. Some lands have been closed to mining by executive action. Where mining is permitted, it is undertaken by private parties in accordance with the Mineral Leasing Act of 1920 (as amended), the Coal Leasing Acts, the 1872 Mining Law, and other miscellaneous legislation. The granting of leases is generally at the descretion of the federal department or agency managing the land, usually the Bureau of Land Management (BLM).

Where the title to surface or subsurface resources is in private hands, further private transactions have frequently divided the title. That is, the owner of the surface has leased some or all of the minerals to other private parties. Such leases vary greatly in form: they may be essentially perpetual for as "long as oil and gas are produced in paying quantities" or for limited periods of time. Leases written years ago often provide for payments to the owners of the land surface of rents or royalties that seem quite low today but must have seemed fair or even generous when they were made (the same is true of federal leases). Some owners of both coal and surface such as railroads and utilities are prohibited by law from conducting mining operations themselves.

BLM identified 17 million acres (6.9 million ha) of land in the West as coal-bearing in 1978 (Table 3.1). In slightly more than a third of these the surface is privately owned and the coal belongs to the federal government. In nearly as many, both surface and coal are owned privately or at least not federally. The rest are under various other combinations of ownership.

The ownership situation is further complicated by the fact that coal-

TABLE 3.1 Coal and Surface Ownership in the Major Coal-Producing States of the Western United States, 1978[a]

	Acres, 1000
Public domain surface, federal coal	3781
Public domain surface, nonfederal coal	43
Private surface, federal coal	6005
Private surface, nonfederal coal	4689
State surface, federal coal	99
State surface, nonfederal coal	951
Forest Service surface, federal coal	943
Forest Service surface, nonfederal coal	13
Other surface, federal coal	638
Other surface, nonfederal coal	194
TOTAL	17,356

[a]Data are based on known recoverable coal resource areas as defined by the U.S. Geological Survey.

Source: U.S. Department of the Interior (1979).

mining operations are sometimes carried out by firms that neither own nor lease the coal but mine either on the payment of a royalty or by contract. This is in part because economical coal-mining units have generally had to be assembled from separately owned smaller pieces of land. Most laws for transferral of land from public to private ownership and most of the private transactions for coal-bearing land have been for units of land smaller than are optimal or efficient for coal mining. A great deal of the public domain was transferred to private individuals in tracts of 160 acres or less. The railroad grants were large in total acreage, but were usually divided into tracts of 640 acres or less. The sizes of tracts were, of course, a response to economic and technological conditions at the time they were created. When land was homesteaded or otherwise transferred from public to private ownership, horse-drawn farm machinery, moldboard plows, and binders made 160-acre units reasonably suitable. The railroad grants allotted tracts in a checkerboard fashion, which compounds the problem of fragmentation.

Over the years there has been a trend toward merger of firms owning coal tracts. It is difficult to get accurate data on this trend because firms seeking to lease coal rights from owners of surface lands may use subsidiary corporations to conceal their identity. Cannon (1978) found in a study of western coal leasing and development that the five largest federal leaseholders control about 31 percent of federal coal leases and the top 5 state leaseholders control an average of 45 percent of the leases in each state.

The general trend throughout the entire economy toward conglomerates embracing business enterprises with strikingly different kinds of products or outputs has also affected the coal industry. Companies that were once solely in the oil and gas business have invested in other forms of energy resources. And as the trend continues, it is unlikely that conglomerates involving coal will be limited to firms that originated in the energy field.

Private Law and Surface Mining

Private law—that branch of law that deals with relations among individuals—offers some protection to holders of rights to the surface and to the minerals under the surface. Where the surface and mineral rights are owned by the same individual, surface mining can proceed only with the owner's consent. Presumably, such consent is granted only when the landowner is satisfied that the mine operator has provided full compensation for the on-site damage. When the surface and mineral rights are held by different individuals, however, the situation is greatly complicated. Under the broad-form deed, common in the Appalachian states, mineral rights are severed from surface rights, and mineral rights predominate. Minerals may be extracted without the permission of the surface-right holder, who may recover damages caused in the process of mining only under extremely limited circumstances. With the advent of surface-mining techniques that produce massive disturbance of the surface, courts in many Appalachian states (not including Kentucky) ruled that, since the mineral deeds were originally sold by landowners decades before large-scale surface mining became technically and economically feasible, the application of the broad-form deed to surface mining should be substantially circumscribed. Thus, the courts reassigned some rights to the owners of the surface.

The problem is slightly different in some western states, where the federal government retained rights to the minerals while transferring the surface rights to farmers and ranchers. The federal surface-mine act requires leaseholders of federal coal to have the surface-right holder's permission to mine. In some instances this may have the effect of permitting surface-right holders to extact a kind of royalty for mineral resources that they do not own.

Only limited protection against off-site damages is provided by private law. Nuisance law permits landowners to seek either injunctive relief or recovery of damages where the actions of neighboring mine operators unreasonably interfere with their use and enjoyment of their own property. However, nuisance law provides no relief to the citizen offended by, for example, scenery devastated in the course of surface mining. Stream pollution and increased frequency and severity of flooding resulting from mining may conceivably fall under riparian water law. If such effects were interpreted as unreasonable use, affected riparian users could seek injunctive relief from further damage. But so far this avenue has been of limited effectiveness, primarily because strict standards of proof of causation are applied and joinder of multiple parties is often difficult. In general, private law, as judicially interpreted, has not been adequate to control the social costs created by the mining industry.

Public Law and Surface Mining

General land-use regulation has been relatively ineffective in controlling surface-mine damages, and effective regulation of water pollution is a quite recent accomplishment. It is therefore not surprising that surface mining has attracted specific regulation at the state, and more recently, the federal level.

The Evolution of Surface-Mine Legislation

In March 1968, President Johnson proposed national legislation on surface-mining reclamation, and in a message to the 90th Congress calling for a Surface Mining Reclamation Act of 1968 he made these comments (U.S. Congress 1968):

> An air traveler over some of the richest country in America can look down upon deep scars gouging the earth, acres of ravaged soil stretching out on either side.
>
> Advances in mining technology have allowed us to extract the earth's minerals economically and swiftly.
>
> But too often these new techniques have been used unwisely and stripping machines have torn coal and other minerals from the surface of the land, leaving 2 million acres of this Nation sterile and destroyed. The unsightly scars of strip mining blight the beauty of entire areas, and erosion of the damaged land pours silt and acid into our streams.
>
> Under present practices, only one-third of the land being mined is also being reclaimed. This start has been made by responsible individuals, by mining companies, and by the States that have already enacted laws to regulate surface mining.
>
> America needs a nationwide system to assure that all lands disturbed by surface mining in the future will be reclaimed. This can best be achieved through cooperative efforts between the States and the Federal Government.

National legislation on surface mining did not exist, however, until the 95th Congress passed the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). A brief summary of the origin and history of the act are given in a recent NRC report (National Research Council 1979a), and a more detailed report on the protracted evolution of this legislation is given in Thompson and Agnew (1977).

From 1930 through 1971, more than 3.35 million acres (1.36 million ha) of land were disturbed by all surface mining, and only about 43 percent of this total was partially or totally reclaimed (Paone et al. 1974). The remaining 57 percent represents both mines that were still active and land that was abandoned in a spoiled condition. Since 1971 most surface-mined land has received at least some reclamation effort.

Some of the earliest recorded surface-mining reclamation took place in Indiana in 1918, when a mine owner planted fruit trees on a mined area. The first systematic voluntary reclamation began in 1926 when members of the Indiana Coal Operators Assocation decided to plant 5 acres of trees each year for each mining shovel or dragline used in their operations. This kind of voluntary reclamation continued until legislation was passed in that state in 1941.

Controversy over the environmental damages of surface mining developed after World War II, as the scale and technology of surface mining created more widespread environmental disturbance. West Virginia passed the first reclamation law in 1939, Indiana in 1941, Illinois in 1943, Pennsylvania in 1945, Ohio in 1947, and Kentucky in 1954 (Bowling 1978). However, the Illinois law was declared unconstitutional in 1946 and a subsequent enforceable reclamation law was not passed until 1962. By 1975 38 states had some form of reclamation law and 12 more had a form of local land-use control requiring some reclamation (Imhoff et al. 1976).

In the 1960s, continuing pressure by environmentalists led states to pass new laws or amend earlier legislation to require "back-to-original" contour and other reclamation practices. The fact that many of the laws in Table 3.2 were new or revised shortly before 1976 reflects the increase in activity at the state level. State laws were generally directed at the critical problems specific to each state. For example, where moist climates and overburden characteristics produced acid runoff, the focus of legislation was on water-quality control, while in arid regions, the problems of erosion and revegetation received greatest attention.

Some state laws went so far as to incorporate land-use planning concepts and set standards of performance for developing post-mining land uses related to the potential use of the land before mining. Mining companies in the Appalachian and midwestern coal regions found that they could successfully convert strip-mined lands to forest and pastures. In western states, surface-mined areas are less amenable to reclamation techniques that produce an economic return. Consequently there has been less incentive for companies to voluntarily return mined land to productive uses than in the East and Midwest.

Table 3.2 is a matrix of some of the standards that were in force in 24 of the states in 1976—1 year before the passage of the federal surface mine law. Clearly, state standards were not uniform. Some practices were required in some states and not others, and the degree to which particular reclamation practices were required also varied. For example, there were provisions for topsoil conservation and replacement in 16 of the 24 states listed in Table 3.2 but specific requirements varied considerably. Backfilling and grading were treated differently, the final grade varying in accordance with the end use. Most states encouraged coal companies to return the land to its pre-mining use and in regions where forestation and wildlife uses were planned only minimal grading was required.

Two major results of state regulations were the establishment of detailed permitting procedures and the education of personnel on the need for reclamation. State regulations often did not add measurably to the cost of mining coal. A few states had fairly detailed reclamation requirements that imposed significant costs on coal operators, such as the requirement in Illinois to segregate and replace up to 18 inches of topsoil where land was to be reclaimed for row crops. Even in states with relatively stringent reclamation requirements, lax enforcement often allowed coal operators to ignore the more costly requirements of the law (Morgan et al. 1975).

The Surface Mining Control and Reclamation Act of 1977 (PL 95-87) established minimum national standards for surface mining coal and reclaiming the land. The performance standards for environmental protection listed in the act were intended to control the adverse environmental effects of surface coal mining that were not receiving adequate state attention. An indication of the number of differences between state and federal standards is given in Table 3.3, which compares regulations developed under the provisions in the federal law with mining regulations that were in existance in 26 individual states prior to August 1977, when the federal legislation became law.

The general objective of PL 95-87 was to create a uniform national approach to the prevention or mitigation of off-site damage during surface mining and the subsequent reclamation of mined lands. The legislation attempted to achieve a balance in its treatment of two pairs of competing objectives: (1) it sought to restrain damage to the environment while retaining as far as possible the national benefits from exploitation of coal reserves; and (2) it sought to establish a uniform approach to developing standards and program management, in order to avoid environmentally destructive competition among states, while at the same time allowing for the diversity among regions and states. The intent of the legislation was to use federal budgetary power to encourage each of the states to establish and enforce a regulatory program consistent with the federal goals.

The major objective of PL 95-87 were:

- to establish a national program to protect society and the environment from the adverse effects of surface mining for coal;

TABLE 3.2 State Mined-Area Reclamation Standards, June 1976[a]

State	Title of Act(s)	Conserve and Replace Topsoil	Backfill and Grade	Reduce Highwall or Pitwall	Bury or Neutralize Toxic Wastes	Revegetate for Beneficial Use
Alabama	Alabama Surface Mining Act of 1969; Surface Mining Reclamation Act of 1975.	[a]	Strike-off top of spoil ridges to width ≥ 15 ft and cover coal seam with spoil to depth ≥ 10 ft.	Eliminate coal-mine highwall, except at final cut.	With 2 ft of earth or permanent water body.	Standards for forests, grasses, and legumes. Soil additives sometimes required.
Arkansas	The Arkansas Open Cut Land Reclamation Act of 1971.	Standards vary according to original natural conditions.	All grades will be ≤ 33%; blade and grade to approximate original surface conditions.	[a]	With 3 ft of earth or permanent water body.	[a]
Colorado	Colorado Open Mining Land Reclamation Act of 1973.	[b]	Strike-off top of spoil ridges to width of ≥ 15 ft. Achieve level or undulating skyline.	[b]	[b]	[a](exceptions for unsuitable areas).
Georgia	Georgia Surface Mining Act of 1968, as amended.	[a]	Blend peaks, ridges, and valleys into a rolling topography suitable for plant growth.	[a](except in solid rock).	With 2 ft of soil-supporting vegetation.	Attain high-quality permanent cover.

Illinois	Surface-Mined Land Conservation and Reclamation Act.	For row crops, up to 18 in., as shown by scs soils survey; for other uses, replace if needed to revegetate.	Varies by planned use—i.e., original grade for row crops, with top soil; ≤30% for forest and wildlife; ≤50% for hay and pasture.	To grade of ≤50%.	With 4 ft of water or suitable material.	Replant row crops if soils suitable. Detailed standards for other uses.
Indiana	Chapter 344, Acts of 1967. Indiana Statutes.	[b]	Grades: for row crops, ≤8%; for pasture and hay, ≤25%; for forest and range, ≤33% (slope lengths limited).	To grade of ≤33% or create lake in pit.	With 2 ft of soil, overburden, or water.	[a]
Iowa	An Act Relating to Surface Mining, as amended.	In coal-mine reclamation, strata more suitable than topsoil may be used.	Grade spoil to ≤25%; except where original land was steeper, then, blend with adjacent land.	To grade of ≤33%.	With 2 ft of spoil.	[a] (detailed guidelines available).
Kansas	Mined-Land Conservation and Reclamation Act.	As necessary to provide plant-growth material.	Rolling topography traversable for planned use. Grade ≤25% (slope lengths limited).	To grade of ≤25% unless supported, as by a lake.	With 2 ft of spoil or permanent water body.	[a]

TABLE 3.2 (*Continued*)

State	Title of Act(s)	Conserve and Replace Topsoil	Backfill and Grade	Reduce Highwall or Pitwall	Bury or Neutralize Toxic Wastes	Revegetate for Beneficial Use
Kentucky	Chapter 350, Kentucky Revised Statutes.	[b]	Approximate original contour. Grade bench tables to ≤10%.	Auger mining face to ≤45°; other mining, backfill and cover coal to 4 ft.	With 4 ft of overburden.	[a] (detailed guidelines available, e.g., time of planting).
Maryland	Maryland Strip Mining Law.	[a]	*Area*: Approximate contour; *Terracing*: grade the bench to ≤9% and outer slope grade to ≤70%.	Eliminate highwall by backfill and cut.	With 2 ft of overburden.	Quick cover grass crop, followed by vegetation for end uses.
Missouri	(1) Reclamation of Mining Lands; (2) The Land Reclamation Act.	[b]	Act 1: traversable for farming. Act 2: traversable for intended uses; strike off top of spoil ridges to width of ≥20 ft (forest and pasture).	Act 1: slope of face will be ≤25%.	With 4 ft of earth supportive of vegetation.	Appropriate to type of end use.

Montana	(1) Montana Strip & Underground Mine Reclamation Act; (2) Open Cut Mining Act; (3) Montana Hard-Rock Mining Reclamation Act.	[a]	Act 1: grade to ≤20%.	Slope of face will be ≤20%.	Backfill with 8 ft of overburden.	Suitable, permanent, diverse, and primarily native species.
New Mexico	New Mexico Coal Surface-Mining Act.	[b]	Topography will be "gently undulating" or consistent with proposed end use.	[b]	[a]	To serve selected end use.
North Dakota	North Dakota Century Code; Reclamation of Strip-Mined Land.	Replace all available plant growth material, up to 5 ft thickness.	Approximate original contour, or serve approved end use.	Slope of face will be ≤35%.	[b]	[a]
Ohio	(1) Strip Mine Law; (2) Surface Mine Law	[a](or other plant-growth materials).	Approximate original contour, or serve approved end use.	[a]	[a]	[a]
Oklahoma	Mining Lands Reclamation Act.	[b]	Topography will be traversable for approved end use. Grade	Suitable to serve end-use objective.	With 3 ft of overburden.	[a](exemptions: soils, with poor texture, toxicity, and

TABLE 3.2 (*Continued*)

State	Title of Act(s)	Conserve and Replace Topsoil	Backfill and Grade	Reduce Highwall or Pitwall	Bury or Neutralize Toxic Wastes	Revegetate for Beneficial Use
			of box cut overburden will be $\leq 25°$.			nutrient deficiency).
Pennsylvania	Surface Mining Conservation and Reclamation Act, as amended.	[a](12 in. of soil, conditions permitting, or all available topsoil).	Approximate original contour; terrace; or, serve approved end use.	Eliminate highwall.	Varies with existing conditions.	[a]
Tennessee	The Tennessee Surface Mining Law.	[a]	*Contour*: Fill benches prohibited on slopes $>28°$; *Area*: Approximate original land surface.	Eliminate highwall with complete backfill, sloped to bench $\leq 35°$.	With 4 ft of compacted material or permanent water body.	Where approved, permanent growth serving purpose at least as useful as pre-mining.
Texas	Texas Surface Mining and Reclamation Act.	Use stratum best for plant growth.	Approximate original contour.	[a]	[a]	Establish diverse self-regenerative cover suitable for approved end use.
Utah	Mined Land Reclamation Act of 1975.	[a]	[a] (where "practical").	[b]	[a]	[a](priority to non-noxious native plants).

Virginia	(1) 45.1-180, Chapter 16; (2) 45.1-198, Chapter 17.	[b]	"...retain spoil on bench insofar as feasible..."	"...reduce...to the maximum extent practicable."	With 4 ft of material suitable for plant growth.	[a]
Washington	Surface-Mined Land Reclamation Act.	[b]	Conform to surrounding land area.	Grade of wall in unconsolidated material, ≤66%; wall slope in rock, ≤45%.	With 2 ft of clean fill.	[a]
West Virginia	Article 6, Chapter 20, Code of West Virginia, as amended.	[a]	Fill benches denied on grades >65%; contour mined areas will be suitable for farm machinery.	[a]	With 4 ft of material suitable for plant growth.	Detailed standards.
Wyoming	Wyoming Environmental Quality Act of 1973.	Use most suitable plant growth materials.	Approximate original contour; terrace; or serve approved end use.	Stabilize slope; minimize effect on landscape.	[a]	[a]

[a]Indicates the existence of a requirement.

[b]Indicates the absence of a specific requirement.

Source: Adapted from Imhoff et al. (1976).

TABLE 3.3 Comparison of Key Federal Provisions[a] and Pre-PL 95-87 State Surface-Mining Regulations

LEGEND

- (blank) State Requirement Essentially Same as Federal
- ○ State Requirement Less Stringent
- ● No Specific State Requirement
- NA Not Applicable

STATE	KEY FEDERAL PROVISIONS AFFECTING MINING PERFORMANCE																			
	Segregated Topsoil Handling	Road Standards	Effluent Limitations	Runoff and Stream Diversion Criteria	Sedimentation Pond Criteria	Stream Buffer Zone Limit	Blasting Standards and Requirements	Head-of-Hollow, Valley Fill Standards	Coal Waste Dam and Embankment Criteria	Elimination of Highwalls	Return to Approximate Original Contour	Covering of Coal and Toxic and Acid Forming Material	Revegetation Success Standards	Subsidence Controls for Underground Mining	Maximum Recovery for Auger Operations	Alluvial Valley Floor Mining Standards	Prime Farmland Mining Standards	Woody Material Disposal Restrictions	Downslope Spoil Disposal Restrictions	Application of Surface Standards to Underground Mining
ALABAMA	●	●	○	●	●	●	○	NA	○	●	●	○		●	●	●	●	●	●	●
ALASKA[b]																				
ARIZONA[b]																				
ARKANSAS	●	●	○	●	●	●	●	NA	○	●	○	○	●	●	●	NA	●	●	●	●
COLORADO	○	●	○	●	●	●	●	NA	○	●	○	○	○	●	●	●	●	●	●	●
GEORGIA	○	●	○	●	●	●	●	NA	○	●	●	●	●	●	●	NA	●	●	●	●
ILLINOIS		○		○	○	●	●	NA	○	●			●	●	●	NA	○	●	●	●
INDIANA	●	●	○	●	●	●	●	NA	○	●	○	○	●	●	●	NA	●	●	●	●
IOWA	○	●	○	○	●	●	●	NA	○	●	○	●	○	●	●	NA	●	●	●	●
KANSAS	●	●	○	●	●	○	●	NA	○	●	○	●	●	●	●	NA	●	●	●	●
KENTUCKY	●	●	○	○	○		●	○	○	○	○	●		●	●	NA	●	●	●	●
MARYLAND	●	●	○	●	●	●	●	NA	○	○		●	○		●	NA	●	●	●	●
MISSOURI	●	●	○	●	●	●	●	NA	○	○	○	○	○	●	●	NA	●	○	●	●
MONTANA	○	●	○	●	●	●	●	NA	○	○		○	○	●	●	●	●	●	●	●
NEW MEXICO	●	○	○	●	●	●	●	NA	○	●	○	●	○	●	●	●	●	●	●	●
NORTH DAKOTA	○	●	○	●	●	●	●	NA	○	○		●	○	●	●	●	●	●	●	●
OHIO	○	○		●	●	○	○	NA	○	○		○	○	●	●	NA	●	○	●	●
OKLAHOMA	●	●	○	●	●	●	●	NA	○	○	○	○	●	●	●	●	●	●	●	●
PENNSYLVANIA			○	○	○		○	NA	○			○	○		●	NA	●	●	●	●
TENNESSEE	○		○	○	○		○	○	○	○	○			●	●	NA	●	○	○	●
TEXAS	○	●	○	●	●	●	●	NA	○	○	○	○	○	●	●	●	●	●	●	●
UTAH	●	●		●	●	●	●	NA	○	●	●	●		●	●	●	●	○	●	●
VIRGINIA	●		○	○	○	●	○	○	○	●	●		●	●	●	NA	●	●	●	●
WASHINGTON	●	●	○	○	●	●	●	NA	○	○	○	○	●	●	●	NA	●	●	●	●
WEST VIRGINIA	○		○	○	○		○		○	○				●	●	NA	●	●	○	
WYOMING	○	○	○	○	●	●	●	NA	○	●	○	●	○	●	●	●	●	●	●	

[a]Based on Office of Surface Mining's proposed permanent program regulations.

[b]Mining in Alaska and Arizona is on federal, state, or Native American land. Before PL 95-87, reclamation requirements were determined on a case-by-case basis; federal coal-leasing regulations applied, and local governments also exercised some control.

Source: Adapted from Skelly and Loy (1979a).

• to prohibit mining where reclamation as required under the act is not feasible;

• to ensure that reclamation occurs as contemporaneously as possible with mining;

• to balance protection of the environment and agricultural productivity with adequate coal production;

• to achieve reclamation of areas previously surface mined;

• to provide appropriate procedures for public participation in the development of regulations, standards, and programs; and

• to assist the states in developing, administering, and enforcing regulatory programs to achieve the purposes of the act.

Federal Surface Mining and Reclamation Regulations

The act established a federal Office of Surface Mining (OSM) to promulgate regulations under the act and administer and enforce, during an interim period, those regulations. As the various states establish regulations consistent with the OSM regulations and demonstrate an ability to administer and enforce those regulations, primary responsibility for regulation and enforcement passes to the states.

The OSM regulations to implement permanent regulatory programs under PL 95-87 were completed on March 13, 1979. These regulations placed heavy emphasis on design standards rather than performance standards. Whether compliance with design standards means that desired performance is uniformly achieved is a subject of dispute. Design standards were preferred, however, apparently because they would be easier to administer and enforce, since compliance with design standards is more easily monitored than compliance with performance standards. The requirements of the act and regulations promulgated by OSM can be summarized in several categories.

Permit application. Permit application is to be accompanied by topographic maps, geologic and other cross sections, aquifer maps, analysis of stratigraphic core samples, surface and underground water samples, seasonal flow data, a hydrologic impact assessment, and a reclamation plan, including a specific identification of post-mining land use. The maps and sample analyses are to be prepared by qualified professionals.

Areas unsuitable for mining. Certain areas, such as national parks, wildlife refuges, and wilderness areas, are deemed unsuitable for mining without exception. In other areas, such as those in the immediate proximity of public roads and occupied dwellings, mining is allowed only if special conditions are met. More generally, mining is not allowed if reclamation is not technologically feasible.

Permit fees. Permit application fees, designed to pay for the administrative costs of the permitting process, are required.

Performance bonds. A minimum performance bond of $10,000 must be posted for any mine. The actual level of the bond must be sufficiently high to ensure that, in case of default, the amount of the forfeited bond will cover the costs of reclamation by a third party. The performance bond will be returned after it has been determined that reclamation has been completed in compliance with the act.

Abandoned mine reclamation fund. A levy of 35 cents per ton of surface-mined coal and 10 cents per ton of deep-mined coal is collected, to establish a fund to pay for the cost of reclaiming abandoned mines.

Water-pollution control. Sediment-control measures are to be used to minimize both erosion and the contribution of surface mining to the sediment load of streams in the area. These measures may include: minimizing the area of land in a disturbed condition at any one time; stabilizing backfill material; retaining sediment in ponds within disturbed areas; diverting runoff away from disturbed areas; and the use of check dams, mulches, etc., to reduce overland flow velocity and runoff volume.

Backfilling. All toxic material must be covered by a minimum of 4 feet of nontoxic, noncombustible materials or treated adequately to eliminate the toxic effects. Backfilling and regrading should return the reclaimed land to its approximate original contour. In all cases the high wall is to be eliminated. Exceptions to the "approximate original contour" rule may be granted in the case of mountaintop-removal mining when it can be demonstrated that to do so would permit an economically preferred post-mining land use and on steep slopes when specifically requested by the surface owner and when watershed improvement will result.

Topsoil handling. A minimum of 6 inches of material must be removed and handled separately unless it can be shown that other material is more suitable. On prime farmland, separate removal of the entire *A* and *B* horizons, or appropriate substitutes, is required; if stockpiling is necessary the *A* and *B* horizons must be separately stockpiled; and the minimum depth of soil and soil material to be reconstructed is to be 48 inches or the typical depth of root penetration in the natural soil, whichever is less.

Replacement of soil horizons or other suitable soil materials must be done in a manner that avoids excessive compaction.

Disposal of excess spoil. Spoil not required to achieve the approximate original contour within the area where overburden has been removed must be placed in a specially designed spoil disposal area; all vegetation and topsoil material must be removed, segregated, and replaced in the spoil disposal area in the same manner as in other mining areas.

Revegetation. A diverse and permanent vegetative cover shall be established on all reclaimed areas. Seeding and planting of disturbed areas must be conducted during the first normal period of favorable planting conditions after final preparation. To control erosion, a temporary cover of small grains, grasses, or legumes may be used until a permanent cover is established. Mulching and other soil stabilization practices should be used to promote germination and to control erosion. In general, all disturbed areas must be restored in a timely manner to conditions capable of supporting the pre-mining land use or approved better uses. The period of liability for successful revegetation of nonprime farmland is 5 years after the last year of augmented seeding, fertilization, or irrigation if annual precipitation is greater than 26 inches and 10 years if it is less. On prime farmlands average annual crop yields should be equivalent to or higher than yields from unmined prime farmland in the vicinity, under equivalent levels of management, within a time period not to exceed 10 years after backfilling and grading.

These surface mining and reclamation design criteria are spelled out in considerable detail in PL 95-87, and the OSM permanent program regulations are probably the most detailed and complex regulations that have developed from a single environmental statute. It is therefore not surprising that the act and the regulations have been subject to considerable controversy and litigation. The coal industry has quite vehemently criticized the act and regulations as being too inflexible and costly. Many states have resented the intrusion of the federal government into the regulation of mining, particularly since the requirements of the permanent program, which are more stringent than any single state program, imply a failure to adequately regulate mining before the federal law was passed. Environmentalists, on the other hand, have criticized the OSM for being too lax in enforcing the act's interim regulations, which are less stringent than the permanent program regulations.

Since the regulations were published, more than one hundred specific parts of the regulations have been challenged in court. As of mid-1980, over

30 sections of the regulations were in the process of being modified. Some revisions were initiated by OSM after problems in the regulations were pointed out, and other revisions are being made at the direction of the U.S. district court in Washington, D.C., where specific challenges to the regulations were consolidated into a single case. In addition, there have been a number of broader constitutional challenges to the act. As of mid-1980 there had been several highly conflicting rulings handed down by federal district courts in Iowa, Indiana, Virginia, and Tennessee concerning the constitutionality of various provisions of the law.

It is still too early to fully evaluate the effectiveness of the act and regulations in meeting environmental protection goals, because the regulations have not been fully implemented. It can be anticipated, however, that problems currently perceived in the regulations may diminish as experience is gained in applying the regulations, and the regulations are fine-tuned through litigation and rule-making proceedings.

A very tight schedule was established for states to submit state programs to OSM for approval. All state programs are to be established by January 1981, at which time a federal program will be implemented in those states where an approved program is not in place. Two states, Washington and Georgia, have indicated that they will not develop a state program to control surface mining. Time pressures make it likely that most programs will closely follow the OSM permanent program regulations, even though there are allowances for variations from the regulations if local conditions justify a different approach. As states gain experience with implementing the act and regulations, greater differences among state programs will probably develop in response to local environmental conditions.

Other Legislative and Regulatory Requirements

Before coal production can begin at a new surface mine, permits required by federal, state, and county or local governmental agencies must be obtained. Since 1970 at least 21 federal acts affecting the coal industry have been enacted (see Table 3.4), and 5 pre-1970 federal acts are still in effect or have been replaced or amended by one of these acts. Only about a half dozen of the acts listed in Table 3.4 apply consistently to all mines. The number and kinds of permits that need to be filed and approved before mining can begin vary and depend on specific conditions at the proposed mining site. For example, an underground coal mine and preparation plant in West Virginia required 12 state permits and 5 federal permits from 6 different regulatory agencies (Antommaria 1979). In addition consultations with 5 other state and federal agencies were necessary. Counties and municipalities may also influence and regulate mining and reclamation

TABLE 3.4 Federal Legislation Affecting the Coal Industry

Antiquities Act of 1906
Archaeological and Historic Preservation Act of 1974
Bald Eagle Protection Act of 1904, amended 1969, 1979
Clean Air Act of 1955, amended 1970, 1973, 1974, 1977
Clean Water Act of 1972, amended 1973, 1974, 1975, 1976, 1977, 1978; replaced the Federal Water Pollution Control Act of 1948, amended 1952, 1956, 1959, 1960
Department of Energy Organization Act of 1977
Endangered Species Act of 1973, amended 1976, 1977, 1978
Energy Supply and Environmental Coordination Act of 1974, amended 1975, 1978, 1979
Federal Coal Leasing Amendments Act of 1976
Federal Land Policy and Management Act of 1976
Federal Mine Safety and Health Act of 1977, replaced the Federal Coal Mine Health and Safety Act of 1969
Fish and Wildlife Improvement Act of 1960, amended 1978
Migratory Bird Treaty Act of 1918, amended 1936, 1939, 1960, 1969, 1974
Mineral Leasing Act of 1920
Mining and Minerals Policy Act of 1970
Multiple-Use Sustained-Yield Act of 1960
National Environmental Policy Act of 1969
National Forest Management Act of 1976
National Historic Preservation Act of 1966, amended 1979
Powerplant Industrial Fuel Use Act of 1978
Resource Conservation and Recovery Act of 1976, amended 1978; replaced the Resource Recovery Act of 1970, amended 1973, 1975; replaced the Solid Waste Disposal Act of 1965
Rivers and Harbors Act of 1899
Safe Drinking Water Act of 1974, amended 1977, 1979
Soil and Water Resources Conservation Act of 1977
Surface Mining Control and Reclamation Act of 1977
Toxic Substance Control Act of 1976

through zoning laws (Curry and Fox 1978), and local taxes may be imposed on a mining company in addition to the fees and royalties assessed by the states. Section 513 of PL 95-87 recognizes the importance of involving local authorities in mine regulation; it instructs the regulatory authority to notify "various local governmental bodies, planning agencies, and sewage and water treatment authorities, or water companies in the locality in which the proposed surface mining will take place."

4 The Problems of Choice

The individual confronted with scarcity must make choices: one cannot have everything one wants. How is the individual to choose? There is a quite general answer. Assuming for the moment that information collection and decision making are costless, the individual identifies all of the feasible alternatives (the objects of choice) and their relative costs (what must be foregone if the object is chosen). The constraints on the individual's choice include a general constraint on the total amount of things that may be chosen and, most likely, a series of specific constraints defining certain (or certain categories) of the feasible alternatives as unacceptable for various reasons. Individual choice involves selection from among the alternatives of that package which provides the greatest personal satisfaction without violating any of the constraints. More realistically, the costs of information search and decision making require that the individual decide how much to invest in these processes, and that decision will influence the number of alternatives identified and the selections made.

General as this representation of the individual choice process is, it ignores the interrelations among individuals in a world where scarcity limits the choices—and hence the freedom—of all. How will scarcity in aggregate be brought to bear on the individual's choice problem? That is, how will aggregate scarcity be subdivided into a series of constraints on each individual's opportunities, and how will aggregate scarcity be reflected in the relative costs of the various choice objects? Finally, on whose authority and by what criteria shall certain choices be defined as *a priori* unacceptable?

Given the interdependence of individuals in society, some general rules must be made determining relative values of alternative choices and the way relative costs and constraints are to be imposed upon individuals. Who shall make such decisions affecting the well-being of members of society? And, however the decision makers are selected, by what criteria do they choose? What legitimizes the rule-making process? What constraints are there on the decision maker? That is, what protections are provided for the citizens? To what extent and upon what bases are conflicts among citizens adjudicated? What are the rights and duties of the individuals to one another and to the decision maker? Questions of value and questions of authority are thus inextricably interwoven.

All societies confront these questions, and to ensure a degree of stability and continuity, they must arrive at answers that are both intellectually acceptable to their members and able to be translated into a set of enforceable working rules. At different times, and in different places, societies have arrived at quite different solutions to these fundamental problems. In traditional conquest states, power alone was perhaps sufficient to determine who made decisions. Power without legitimacy is transitory, however, and the powerful sought means to establish their authority and ensure its continuity.

A legitimizing argument widely used in earlier times links the ruler and the deity(ies). The ruler's right to rule and to demand obedience is said to have been bestowed by whatever spirits or deities commanded the beliefs of the subjects. Under such a system, the rules defining which choices are *a priori* unacceptable and distributing scarce resources and opportunities among the population are determined by the sovereign acting as the representative of the deity. Value, in large measure, is what the sovereign says it is.

During the transition from feudal to modern times, when the authority of both established religion and sovereign rulers was breaking down, philosophers considered the legitimacy of power in terms of a social contract. Given that anarchy was intolerable, since it provided no assurance of protection for any individual, it was argued that rational persons would enter into a social contract in which they would voluntarily transfer some powers to the sovereign in exchange for the benefits of the order which the sovereign would impose upon relationships among individual subjects. The benefits of order, and the security it provided for the individual, were sufficient to justify the universal preference for a subject-sovereign relationship over the intolerable insecurity of anarchy.

Today there are two concepts of authority (and hence value and choice) prevalent in America. One is based on the individualistic philosophy that grew from the social contract theory of John Locke; it provides the logical basis for microeconomics and classic welfare economics as systems of thought and the justification for capitalism as a system of social organization. The other is the "public interest" theory of democratic government, which grew from Rousseau's version of social contract theory. It provides the philosophical basis for collective regulation through government of individual behavior for the common good.

INDIVIDUALISM AND CHOICE

In individualistic philosophy (and hence the most individualistic versions of economic theory), the individual is seen to be sovereign, and the legitimacy of governing authority is derived entirely from the consent of the subjects. This necessarily implies that each subject (citizen) has very substantial rights, which secure the individual's relationship with other citizens and with the government. The rights of the individual should be restricted only insofar as freedom of action must be constrained in order to protect the rights of other individuals, and a governing body must be established that has the power to protect individual rights and to raise revenues to finance its operations.

In the individualistic model, aggregate scarcity is to be brought to bear on the individual in inverse proportion to the individual's income and wealth. It is assumed that the individual's income is a direct reflection of the contribution that the resources commanded (including labor and capital wealth) make to total productivity, and that the individual's wealth is the result of saving by the individual and forebearers. The individual's opportunities should be bounded only by individual income and wealth, and particular choices should be identified by government as unacceptable only if government can demonstrate that such restrictions are necessary for the maintenance of order compatible with maximum individual freedom.

Choices are to be made by individuals based on their preferences and opportunities. The relative value of objects chosen is thus determined by the interaction of individual preferences, in an environment of scarcity, and with minimal restriction by established authority. The relative value of various choice objects is equal to their relative prices or, at least, the relative prices that would exist if markets functioned perfectly. This is the philosophical basis for the oft-stated economic argument that "value is price."

For markets to function perfectly, several conditions must be satisfied: a completely specified and effectively enforced system of exclusive and transferable property rights must be maintained; collective restrictions upon the use and transfer of resources, goods, and services, beyond those necessary to secure individual rights, must not be permitted to interfere with the process of trade; and the transactions of individual buyers and sellers must be very small relative to the total volume of goods and services in the market. These conditions establish an environment hospitable to unrestricted trade and ensure that trade will be competitive.

The essence of the system of value determination propounded by the individualistic economists is voluntarism. Since no individuals would willingly enter into a personally detrimental trade, the outcome of voluntary exchange must be beneficial to all individuals involved and, hence, to the broader society. The individual is the best judge of personal well-being, and what the individual wants is assumed to be good. The political variant of individualistic philosophy takes a similar approach. Collective action is clearly justified if it arises from unanimous agreement among all involved individuals. Collective action that cannot command unanimous consent (whether taken by an autocratic ruler or by a decisive coalition of individuals) is deemed coercive in that it imposes injury upon the dissenters. Coercive collective action requires overwhelming justification; the individualist philosophers would have little difficulty deciding that many of the taxation and regulatory policies of modern American governments are unjustified.

In this system, price serves multiple functions. Being the outcome of voluntary exchange, price is the only acceptable indicator of value. Since it determines the seller's rewards and the buyer's costs, price serves to ration scarce resources and commodities, and to provide the incentives that coordinate production and consumption and to distribute income and wealth among individuals.

The ideas that price is the appropriate indicator of value and that individual property rights are the foundations for a just and free society are quite recent philosophical notions, which would have been considered eccentric at other points in the history of ideas; indeed they are considered quite eccentric in other contemporary societies which are not heirs to the cultural history and philosophical traditions of our society. While these ideas are deeply imbedded in American society, the political events of the past century offer ample evidence that individualism alone does not provide an entirely satisfactory basis for social organization. Moreover, it is probably impossible for a truly individualistic economy to exist under conditions of majority voting.

Problems in an individualistic economy arise from three basic sources: (1) institutional conditions which do not ensure that all costs and benefits fall on the relevant parties; (2) incompatibility between natural conditions and the necessary conditions for efficiency in the individualistic economy; and (3) the fundamental failure of the individualistic economy to ensure equity, either intra- or intergenerationally. These problems are now briefly considered.

Externality. An externality is an effect—cost or benefit—borne by individuals other than those who produce it. These "external" costs (or benefits) are not brought to bear on the decision process of the acting party.

Deleterious externalities (called external diseconomies) that persist uncorrected represent not only an unwanted imposition on the affected parties but also a source of economic inefficiency. Theoretically, in the absence of an additional problem such as nonexclusiveness or indivisibility in consumption, uncorrected externality cannot persist (Coase 1960). And in fact, many of the "external" effects of surface mining (e.g., on air, water, landscape, social cohesion, and cultural symbols) are due to uncorrected externality in the presence of nonexclusiveness or indivisibility or both. The impacts of surface mining for coal on the natural and social environment are, in very large part, textbook examples of circumstances that lead the individualistic economy to fail to achieve efficient resource allocation.

Nonexclusiveness. The capacity of an individualistic economy to allocate resources and distribute the product efficiently depends upon a perfect system of markets, which, in turn, depends on the maintenance of a complete system of exclusive property rights. Nonexclusiveness makes trade impossible, since it makes little sense to pay for rights unless those who do not pay are excluded. By impeding trade, nonexclusiveness makes it impossible for the individualistic economy to achieve efficiency. Nonexclusiveness may be due to (1) a social decision that some things ought not be traded as commodities; (2) a time lag, which may occur when changing demands or technology make valuable a resource that was previously little valued and was therefore left nonexclusive; or (3) prohibitively high costs of exclusion (i.e., the gains from trade that would be facilitated by exclusion are insufficient to repay the costs of exclusion).

Important classes of natural resources and environmental amenities are nonexclusive. Ambient air, water in lakes and streams, and landscape amenities—all of which may be affected by surface mining—are substantially nonexclusive. Similarly, many of the intangible aspects of community, social cohesion, and the "quality of life" are nonexclusive. In an individualistic economy, markets provide no avenues by which conflicts arising from the impacts of surface mining on these nonexclusive but nevertheless important concerns may be resolved.

Temporal problems. The concept of ownership, and the crucial role it plays in individualistic economic theory, may be adequate for candy bars, items of clothing, and automobiles. But it remains an open question whether the concept of ownership, as it now exists, is adequate to resolve the immediate or long-range problems arising from land uses, such as surface mining, that drastically disturb the land.

Market rates of interest are supposed to play the role of reflecting, among other things, individuals' preferences between present and future consumption. In choosing between resource use today or 10 years hence, each dollar of benefits derived from the future resource use is given a value "today" of something much less than a dollar, while each dollar of current benefits is given its full dollar weight. But future generations (as well as today's children) are not participants in today's markets—they have no market "vote" in decisions affecting the allocation of resources over time. The question, then, is how distant future benefits would be weighted if recipients of such future benefits were to participate in assigning such discounts, (i.e., if they were participants in the markets wherein interest rates are determined).

Equity. In an economy where exclusive property rights serve as the foundation of the individual's capacity to make choices, ownership is the cornerstone of the system from which resource allocation, the distribution of rewards, and value emerge. Is ownership a conceptually fair basis for choice in the current time frame? Is it a conceptually fair basis for long-term choice when individual ownership necessarily means the "ownership" of potentially long-lived resources by the present generation of transitory individuals? And if it is considered conceptually fair for both of the above purposes, is the existing actual pattern of ownership fair?

COLLECTIVE CHOICE

The U.S. Constitution was written during the period when individualism was most influential; nevertheless it makes provision for such collective decisions as governmental appropriation of private property (with just compensation) for the public purpose; regulation of individual behavior for the protection of the public health, welfare, safety, and morals; taxation, subject to provisions of equal protection, to raise revenue to meet the expenses of government; and governmental expenditure for certain specified purposes and, by implication, all other purposes acceptable to the legislature and not inconsistent with the Constitution.

The philosophical roots of this development lie in the social contract theory of Rousseau, who argued that rational individuals will voluntarily relinquish some of their freedoms to government in order to enjoy the services and protections that only government will provide in the public interest. The list of activities subject to collective control through government has greatly expanded over the last two centuries. The list of "public purposes" and policies for "protection of the public welfare" has been continually expanded, largely in response to demands from various segments of the population seeking government protection.

The U.S. institutional structure can now be described as a substantial overlay of collective institutions and organizations on a base of individualistic institutions. The legislature now authorizes publicly owned economic enterprise, public financial backing for investor-owned enterprises, explicit income redistribution programs, and an array of regulatory programs. The judiciary, many have argued, has taken an increasingly activist role. And the executive has grown large and complex as the role of government has expanded.

The basic endowments of individuals operating in an individualist economy are income, wealth, property, technology, and managerial talent. The endowments useful in seeking one's own ends through collective organizations include not only these but also enthusiasm for and time to use the organizational skills, persuasion, legal maneuvering, and public relations techniques. Owing to the complexity of collective organizations and the roles individuals may play within them, it is not easy to analyze their workings or predict their outcomes.

Collective organizations are both a locus of authority and a device for reassigning authority. Their most significant roles are in reassigning rights, from individuals to "the public," from property owners to nonowners, and from some coalitions to other coalitions within "the public." They help determine the production mix of the economy, the relative values of particular resources, goods, and services, and the relative values of individual endowments.

CHOICE AND ECONOMIC VALUE

Market prices in this society are the outcome of the intricate workings of individualistic institutions and collective organizations under conditions of resource scarcity and changing technologies.

In an economy characterized by both individualist (market) and collective institutions, values and choices can interact in two ways (Bromley 1976). First, existing values—prices—can be used as data from which individual or collective choices are made. For example, prevailing land prices are often used by either individual or collective agents to determine the appropriate quantity or quality of land to be purchased for various purposes. Or in everyday life, when we shop around for the best "value," we let price determine our choice of what to purchase. Second, choices can determine values. When certain explicit actions are taken in the absence of monetary values out of individual or collective commitment to a certain course of action, implicit values (shadow prices) can be inferred. When wilderness areas are set aside over the protests of those who might otherwise make a living from exploiting the resources therein, a choice has determined a value—namely, that the area is worth *at least as much* in the condition of wilderness as it would be worth if left to those who would sell its trees and minerals.

While collective organizations can determine values by making choices, there can be problems. First, such organizations are constantly changing, and this may mean that at any given time they may provide imperfect indications of value. Second, it is not always reliable to infer values from complex actions taken by collective organizations.

The question of public control of surface mining and reclamation through the power of government brings the issues of authority and value into sharp focus. Although collective organizations have considerable influence in the market for coal, the market price provides at least some indication of its value. Similarly, the market price of rural land provides at least an indication of its value to the current generation of adults for farming, ranching, and outdoor recreation. The reliability of land markets in determining the value of land over many generations is questionable, however, and there is little direct role for market institutions in determining the value of scenic beauty, water-pollution control, and community stability, all of which are much influenced by surface mining and reclamation activities.

It is clear that individualistic market institutions, whatever their more general merits and failings, are inadequate to resolve mining and reclamation issues by themselves. The economic and political issues surrounding mining and reclamation illustrate the fundamental tension between individualistic and collective institutions.

MODELS AND CRITERIA FOR PUBLIC DECISIONS

The role and scope of both collective and individualistic institutions is continually redefined through the political process in response to new problems and new conflicts. In this kind of institutional environment, what choice models and choice criteria can be provided to assist public decision making?

In a purely individualistic society, outcomes emerge from the aggregate effect of individual decisions. At first glance it may seem that there is no distinct public role in such a process. That is by no means the case, however: the public role is sharply restricted but nevertheless vitally important. Public organizations define, assign, and enforce the property rights upon which the individualistic exchange economy rests. The chosen definitions and assignments of rights materially influence the aggregate outcomes of individual decisions—the prices; resource allocations; the mix of goods, services, and amenities produced; and the distributions of income and wealth that emerge.

Collective organizations are influenced directly by private citizens as voters, litigants, and presenters of testimony at public hearings, and indirectly as users of the information media. They are, however, maintained and operated for the most part by professionals. While private citizens and interest groups seeking to influence decisions find that information, broadly defined, may be useful, decision tools, decision models, and decision criteria are the province of the professionals. These tools, models, and criteria attempt to tell decision makers how to decide. Operations-research techniques, systematic budgeting devices, various multi-attribute ranking and weighting schemes, and benefit-cost analysis all seek to identify, for the benefit of professionals, the "best" of the available alternatives.

Private citizens, seeking to ensure that the managers of collective organizations make decisions in the "public interest," may take two rather different routes. They may place their faith in decision models and criteria and attempt to constrain the professionals to use these tools and abide by choices the tools suggest. Alternatively, they may seek direct access to collective organizations (including the executive and judiciary, which have traditionally offered the private citizen only limited direct access), in order to influence decisions.

The first approach—requiring that professionals and "managers" use decision tools and abide by their results—calls for improved decision tools and "more scientific" decision criteria. The second approach calls for the establishment of rules of access to collective organizations that ensure fair representation of interested parties in the process of conflict resolution. Such rules of access should address at least the following questions:

- Which decision mechanisms shall be used?
- What, if any, constraints shall be placed *a priori* on the decision process and its possible outcomes?
  —Who shall participate in the decision process?
  —What kinds of endowments will count?
  —What are to be the exchange rates among different kinds of endowments?
  —What behaviors are considered *a priori* illegitimate?
  —What outcomes are considered *a priori* unacceptable?

—What recourse does a dissatisfied party have (i.e., under what conditions can the question be reopened in the same, or a new, arena)?

- Which of the above questions may be renegotiated *during* the decision process?

Currently, both approaches are being pursued: decision tools are being sharpened and decision criteria proposed, while mechanisms for more effective citizen participation in institutional decision processes are being developed and implemented. (One of the objectives of PL 95-87 is to encourage more effective citizen participation.)

Benefit-Cost Analysis

Benefit-cost analysis is the most commonly accepted tool for analyzing projects of the nature and scope of surface-mined land reclamation. The premise of benefit-cost analysis—that an alternative should be selected if the present value of its benefits exceeds that of its costs, and its net present value exceeds that of all other alternatives—represents a combination of precepts derived from individualistic and collective institutions. From individualistic institutions, the benefit-cost analysis derives its concept of value. Market prices, where observable, are the value indicators. Where markets have been "distorted" and prices cannot be observed, the prices that presumably would be observed if perfect markets existed are used (Mishan 1976). From collective institutions, the benefit-cost analysis derives the criterion that proposals are acceptable if the benefits, to whomever they accrue, exceed the costs (Mishan 1976). The final decision is not required to command unanimous consent; individuals may be forced to acquiesce in collective decisions that leave them worse off.

In the framework for benefit-cost analysis of surface mining and reclamation alternatives, land and soil resources are seen as capital capable of producing over time a diverse stream of goods, services, and amenities (see Randall 1981). In its initial state, the land and soil resource is capable of serving a variety of purposes through time—e.g., agriculture and forestry, ecosystem support, moisture retention and drainage, aesthetic gratification, and sociocultural stability. The particular array of purposes served depends on the natural characteristics of the resource and on the way it is handled, both deliberately and inadvertently.

Any proposed alternative use of the resource—surface mining, for example, with a specified degree of reclamation—would change this array, by modifying the characteristics of the resource in significant ways and for a significant period of time. A benefit-cost analysis of a proposed mining project subtracts the present (discounted) value of the land and soil resource in its current use and the costs of the project from the present (discounted) value of the resource in its proposed use. A positive net present value indicates that the proposed use would increase the value of the resource; a negative present value indicates that the project will reduce the value of the resource.

The general framework proposed for benefit-cost analysis focuses on the relationships between "natural systems inputs," "controlled inputs," and resource attributes, and the relationship between resource attributes and the production of goods, services, and amenities. However, many of these relationships are at present unknown, and, with current scientific technology and current levels of investment in research, may remain that way for some time. Among the technical relationships that are currently unknown, or at best poorly understood, are the basic relationships affecting the production of environmental goods, services, and amenities associated with mining and reclamation; the effect of mining and reclamation on the complex interrelationships within watersheds and aquifer systems; the rate of formation of soil from parent materials under natural and altered conditions; the rate of recovery of soil characteristics following drastic disturbance; and the social, cultural, and political effects of large-scale surface mining in rural regions, and the kind of sociocultural-political equilibrium that will be achieved after the surface-mining phase has long been completed.

Many of the goods, services, and amenities produced by land and soil resources are not priced in markets. These include air and water quality, wildlife habitat, many kinds of recreational services, scenic beauty, and social, cultural, and political amenities. Yet, in a benefit-cost analysis of surface mining and reclamation, these may be among the important kinds of qualities affected.

Some progress has been made in finding ways to infer the value of unpriced amenities, and two kinds of techniques have emerged: inferential techniques and contingent valuation techniques.

Inferential techniques use observations from existing markets to infer the value of related but nonmarketed goods. For example, the value of air quality might be inferred from the difference in value of properties similar in all regards except the quality of the air at the two locations. Other examples are the travel-cost method of valuing recreation amenities; land-value methods of valuing air quality, water quality, scenic beauty, and beachfront amenities; and the use of labor-market observations to infer the economic value of increments or decrements in expected human health, safety, and longevity (Clawson and Knetsch 1965, Rosen 1974, Freeman 1979).

Contingent valuation techniques attempt to establish hypothetical or experimental markets in nonmarketed goods and amenities, in order to elicit marketlike prices for them (Water Resources Council 1979, Brookshire et al. 1980). A variety of such techniques have been used to estimate values for such benefits as recreational amenities, wildlife habitat, scenic beauty, and air and water quality. Randall and his colleagues (1978b) used these methods to estimate the economic value of landscape amenities damaged by surface mining and restored by reclamation in eastern Kentucky.

A considerable literature exists on each of these nonmarket valuation methods. While still imperfect and hardly ever validated, these methods should be used in any attempt at complete benefit-cost analysis of surface mining and reclamation. A decision not to use such methods would likely result in the omission of significant and substantial sources of value and therefore in biased results.

A more fundamental problem with benefit-cost analysis is that those who use the various services and those who feel the negative effects of a project are not always the same people, and individual calculations of benefit and cost by interested parties may therefore arrive at quite different conclusions. A complete and competent benefit-cost analysis, then, may serve to reduce but will seldom eliminate disagreement surrounding controversial proposals such as surface mining.

The Problem of Time

Land and soil resources are expected to exist and to be productive far into the future. After surface mining and reclamation in some environments, it may take a long-time for the land resource to revert to a condition indistinguishable from its pre-mining condition. Therefore, benefit-cost analysis of surface mining and reclamation must be concerned with long time horizons. This raises data problems and conceptual problems.

Data problems arise because the future is inherently uncertain. The benefit-cost analyst can only try to make the best of a difficult situation by: (1) using the best-available estimates of future conditions; and (2) using sensitivity analysis to determine the extent to which the final conclusions are sensitive to estimates of future parameter values.

The conceptual problems are perhaps more profound. Benefit-cost analysis uses price data derived from individualistic markets, including discount rate, which sets the price of future benefits and cost relative to current ones. Yet it is widely and reasonably argued that individualistic markets, reflecting the preferences of individuals whose time on earth is transitory, systematically undervalue future outcomes. The claims of future generations, who are unrepresented in the markets that determine prices, are necessarily discounted. But economists are currently expressing concern about the logic of discounting and are searching for better methods of handling trade-offs over time. Three somewhat different approaches to these problems are currently being taken.

One approach, perhaps most strongly identified with a group of natural-resource economists associated with the economics research organization Resources for the Future, attempts to perfect benefit-cost analytic procedures by searching for the "right" discount rate (Krutilla and Eckstein 1959). Shadow-pricing techniques incorporate the "real" values for natural resources and environmental amenities that are not adequately valued by existing price systems (Krutilla and Fisher 1975). The possibility that new and valuable uses for natural and environmental resources may grow over time and that individuals may be willing to sacrifice other kinds of consumption in order to preserve options for the future is explicitly introduced into the analysis via concepts such as option value, reservation value, and "the logic of conservation" (Fisher and Krutilla 1974). With these modifications, customary procedures of benefit-cost analysis are implemented.

The second approach, known as the "safe minimum standards" approach, is associated with the late S. V. Ciriacy-Wantrup and more recently Richard Bishop (1978, 1979). It is based on the notions underlying benefit-cost analysis but represents a relaxation of formalistic benefit-cost procedures. For natural and environmental resources in danger of depletion or extinction, the "safe minimum standard" (i.e., the minimum stock or population that will ensure survival of the resource or biological species into the future) is identified. The safe minimum standard is supposed to be maintained unless the costs of so doing are "unbearably great."

The third approach is concerned with intergenerational justice. It is associated with John Ferejohn and Talbot Page (1978), who attempt to apply the principles for the analysis of social choice and justice developed by Kenneth Arrow (1951), John Rawls (1971), and others to the problem of justice in intergenerational choice. Ferejohn and Page conclude:

> Our results suggest that the search for a "fair" rate of discount is a vain one. Instead of searching for the "right" number, "the" social rate of discount, we must look to broader principles of social choice to incorporate ideas of intertemporal equity. [p. 274]

This approach represents an interesting departure, but has not yet yielded principles to guide decisions about the long-run allocation of resources.

Because much of the data needed for thorough benefit-cost analysis of proposals for disturbance of complex environments is missing, a variety of other decision tools have been proposed. These tools are less inclusive than benefit-cost analysis but nevertheless enable alternative proposals to be ranked.

Cost-effectiveness analysis is a truncated version of benefit-cost analysis that bypasses economic estimation of the value of benefits. It ranks alternative programs in terms of cost to achieve a given objective, or cost per unit of benefit. This kind of analysis is most useful where a given result (e.g., satisfactory reclamation, however defined) is universally considered desirable, and the decision problem is simply to identify the least costly method of achieving that result.

Multi-attribute ranking schemes attempt to: (1) identify the pertinent attributes (e.g., scenic beauty, environmental uniqueness, ease of access, diversity of wildlife species); (2) provide an objective or subjective ranking, on an ordinal or quasi-cardinal scale, of each alternative program in terms of each attribute; (3) use some predetermined scheme for weighting and aggregating the attribute scores to determine an overall rating for each alternative; and (4) use the overall ratings to the rank alternatives in order of merit. The U.S. Forest Service uses a scheme of this kind to assist in land-use decisions, and the U.S. Fish and Wildlife Service has developed such a scheme for ranking wildlife habitats. Sinden and Worrell (1979) discuss several such ranking schemes.

These decision tools could be useful in identifying lands which should not be disturbed for surface mining and, assuming a more flexible regulatory environment, in relating the appropriate level of reclamation to the premining and desired postreclamation quality of the land resource.

Decision Tools: A Caveat

There can never be a purely scientific way to determine "truth" in politics and ethics—i.e., to determine what is right and good. No scientific decision tools could make right and good public decisions. Decision tools are merely devices for acquiring and arraying information. As such, they can be very helpful to private citizens and professionals, and they should be used wherever they can cast light on the issues at hand. But they are not substitutes for decision making itself—a complex process in which citizens interact through individualistic and collective institutions and organizations.

5 The Soil

The word *soil* in its most common usage means any natural medium for the growth of land plants. The science of soil as it has developed internationally for the past century, however, defines soil in a special way. It is a terrestrial resource that is life-supporting in function and is itself shaped by environmental factors and processes (Buol et al. 1980). To produce a more exact definition that describes structural components is a complex task, because it is often difficult to distinguish under all conditions the precise boundary between what is and what is not "soil."

Soil, as used in this report, refers to a dynamic three-dimensional piece of landscape, in places modified or even made by man of earthy materials, that has a unique combination of both internal and external characteristics with definable ranges of expression. These characteristics determine both the capacity of the soil to support plant and animal life and the way the soil functions as part of the hydrologic system.

Soil is an extensive blanket that covers all or significant portions of a landscape. Figure 5.1 shows a landscape that has almost complete soil coverage. Only the bedrock prominence and stream beds lack soil. The soil throughout the landscape exchanges, converts, stores, and transmits energy, water, and mobile materials, and these processes create geographic patterns of contrasting soils.

During periods of rainfall and snow melt, hillslope soils characteristically shed water more rapidly than do the nearly level upland soils. The wetland soils in the sink and the bottomland soils in the valley receive water both directly from precipitation and from surface and subsurface runoff. Vegetation (not shown in Figure 5.1) responds to variations in moisture and nutrient supplies from one part of the landscape to another and evolves in a manner that optimizes the trapping and retention of nutrient matter. Wetlands and bottomlands therefore typically have a thicker and richer layer of organic matter than do the well-drained uplands.

Over periods of many thousands of years, the dendritic network of streams will continue to dissect upland areas and will eventually breach the wall of the wetland sink. The valley walls will retreat, widening the valleys and diminishing the area of the upland. This landscape evolution is very slow. The valley wall might be expected to retreat at a rate of about 1 meter per 500 years in humid temperate regions (Frolking 1978).

The process of landscape evolution has been well described by Aldo Leopold (1949) in an essay on the land ethic:

> Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals. Food chains are the living channels which conduct energy upward; death and decay return it to the soil. The circuit is not closed; some energy is dissipated in decay, some is added by absorption from the air, some is stored in soils, peats, and long-lived forests; but it is a sustained circuit, like a slowly augmented revolving fund of life. There is always a net loss by downhill wash, but this is normally small and offset by the decay of rocks. It is deposited in the ocean and, in the course of geological time, raised to form new lands and new pyramids.

The first section of this chapter discusses soil genesis and how soils in coal regions in the United States reflect the interaction of the different factors and processes of soil formation. Next, various aspects of soil productivity are examined, with particular focus on its relation to soil properties and to soil erosion. Finally, we look at the role that the mosaic of soils on the landscape plays in the hydrologic balance and the equilibrium of watersheds.

SOIL FORMATION

Soil formation is an intricate process by which unconsolidated geologic material and organic matter are transformed into a unique resource. Over a period of time at a given site, the soil will reach an equilibrium state in which soil-forming processes do not result in large changes in the characteristics of the soil.

The major soil-forming processes are:

- additions to the soil through deposition of windblown material, ions in precipitation, and organic matter,
- transformation within the soil profile of organic matter to humus and

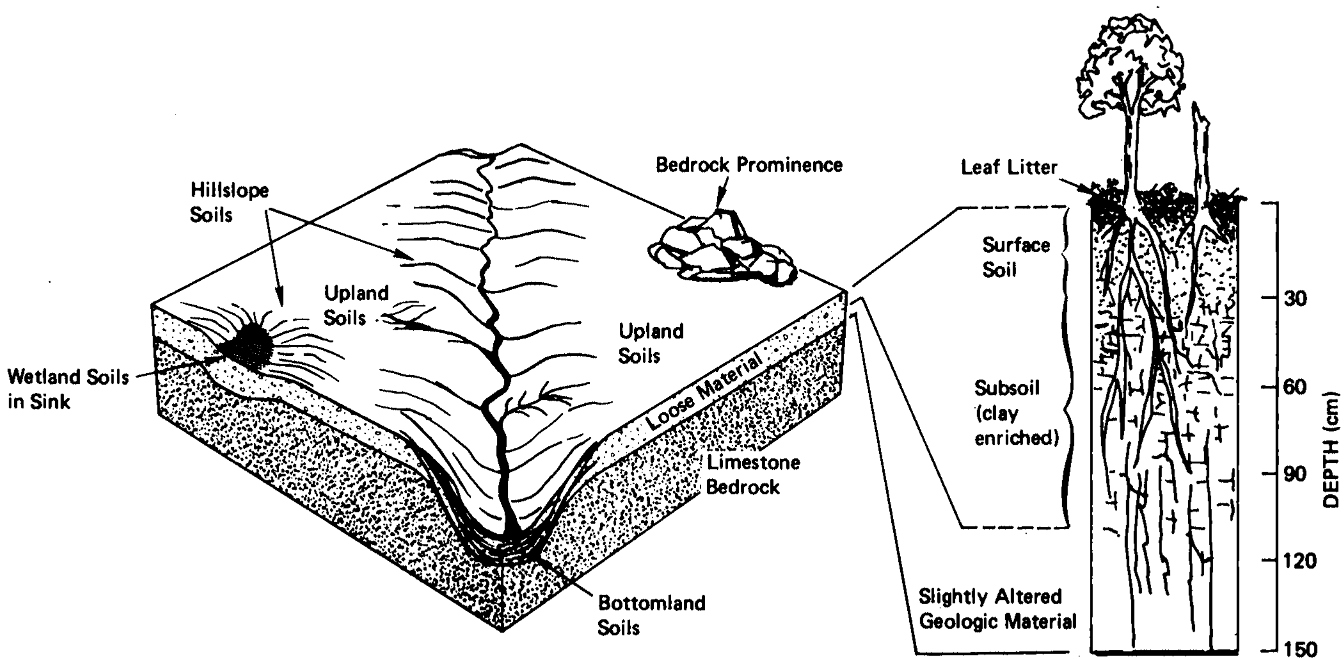


FIGURE 5.1 Generalized soil landscape in a humid temperate region. This sketch indicates the conventional boundaries of the volume of material called soil by soil scientists. Organic leaf litter and humus on the surface are considered part of the soil. Biomass above ground, such as dead wood in trees, is not considered part of the soil.

weathering of primary minerals to form clays and other weathering products,

- movement within the soil profile, such as the translocation of clay or the rising of soluble salts to the soil surface by capillary action, and
- removal of material from the soil either by erosion or leaching by water that percolates through the profile.

These processes are shown schematically in Figure 5.2.

Five basic factors control these processes: (1) climate, (2) time, (3) the nature of parent materials, (4) topography, and (5) living organisms. None of these factors can be considered independently of the others, and each has an intricate network of effects. The effects of climate, for example, will depend on the types of soil and plants on any particular site. The formation of new soils depends on such climatic factors as the frequency of freeze-thaw and wetting-drying cycles, and the length of the growing season (Gardner and Woolhiser 1978). The rate of accumulation of new topsoil on a site will also be affected by rates of soil erosion, which is in turn a function

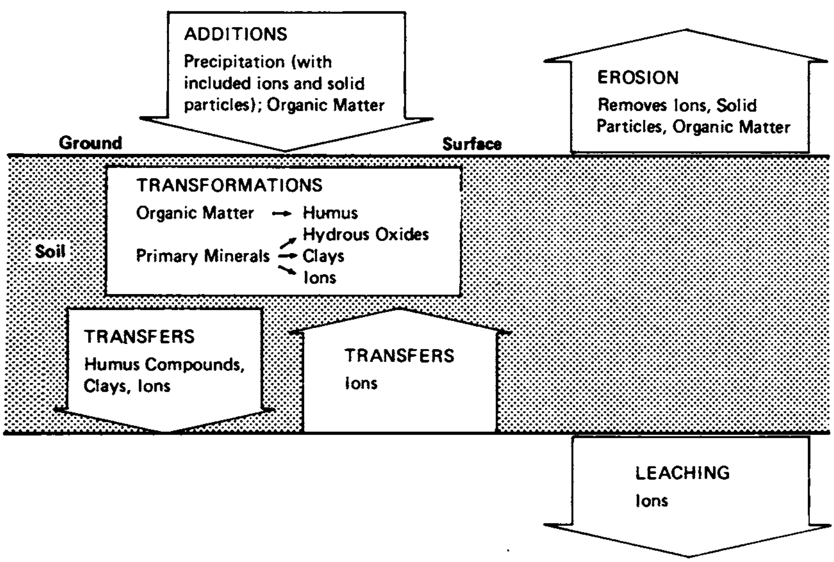


FIGURE 5.2 Flow of the major processes in soil development. *Source*: Adapted from Birkeland (1974).

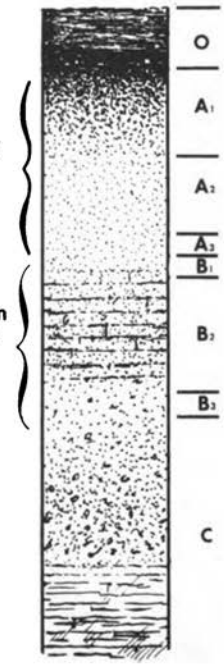


FIGURE 5.3 Idealized soil profile showing all the principal soil horizons. All horizons are not necessarily present in any particular soil.

of precipitation, rainfall energy, and seasonal variations in rainfall intensity (Wischmeier and Smith 1978). Soil formation and erosion are also influenced by vegetative cover. Climatic conditions affecting establishment of vegetation include precipitation, evaporation potential, length of the growing season, and the frequency and magnitude of fluctuations in temperature and precipitation.

Soil Horizons

During soil formation different zones, or soil horizons, are created. These horizons develop specific characteristics in accordance with properties of the parent soil material and in response to climatic, biologic, and topographic conditions at a locality. Generally, these horizons can be classified into 4 main groups, called the *O*, *A*, *B*, and *C* soil horizons (Figure 5.3). The *O* horizon is the organic leaf litter and humus. The *A* horizon contains considerable organic material, both living and dead, mixed with mineral particles. The *B* horizon is composed largely of mineral materials, including weathered materials translocated from the *A* horizon. The *C* horizon is the unaltered or slightly altered parent material.

The soil profile, although described in terms of these horizons and their subdivisions, should be thought of as a continuum rather than a sequence of discrete layers. The soil surface exposed to weathering, eluviation, leaching, and the accumulation of organic matter becomes an *A* horizon. Materials that are leached or washed downward into the soil profile by rainwater collect in what becomes the *B* horizon. Only by the relative importance of these processes can we differentiate the 4 main soil horizons and any of their recognizable subdivisions. In a forest soil, for example, there is an *Al* horizon containing more organic matter than an underlying *A2* horizon, while in grassland soil the *Al* horizon predominates and an *A2* horizon is usually absent.

It is the function, not the form, of soil horizons that is important. But since the form of soil horizons can easily be observed in the field or determined by laboratory methods, the horizons are used as indicators of soil properties. The identification and description of soil horizons in an individual soil allows evaluation of the productive potential of the soil in light of an understanding of the functions of soil properties for the plant-soil-water-air system.

Soil scientists sometimes use the terms *young* and *old* to describe the degree of soil development. A young soil is one whose properties are mostly inherited from its parent material, because modification of the parent material through soil development has been relatively minor (no matter how long the soil has been in existence). An old soil is one whose properties are mostly attributable to soil-developing processes, the features of the parent material having been greatly altered or obliterated. Moderately developed soils are commonly the most productive. Old soils are low in weatherable minerals, have been extensively leached (leaving them low in basic cations), and commonly have high clay content in their subsoils.

Some regions have only young soils or moderately developed soils, because of a particular combination of time and climatic factors. Other regions have soils ranging from old, in the most stable positions on the land surface, to young, in the most erosive positions. Soil development is retarded in the unstable positions by erosion of material from the surface, which exposes fresh parent material, or by sedimentation, which continually adds fresh material to the soil surface.

Figure 5.4 is a generalized diagram of the development of soil horizons in a humid climate over a period of about 100,000 years. Young soils typically increase in productive capacity over time, as the result of soil-forming processes that improve both the nutrient content and the water regime of the soil. The processes that probably are most important for enhancing soil pro-

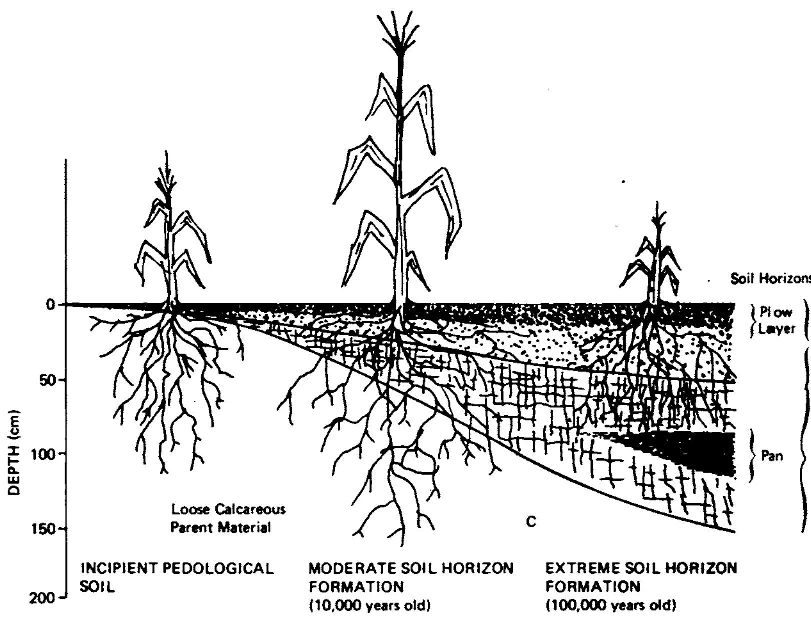


FIGURE 5.4 Formation of soil horizons over about 100,000 years in a humid climate. The development of soil horizons during soil formation usually improves the parent material as a medium for plant growth in early and intermediate stages. The later stages of the soil-formation process, however, may reduce the capacity of the soil to support plant growth. Soils of various ages exist today; the corn plants indicate the relative productivity of such soils.

ductivity are: (1) physical weathering of rock fragments into fine-earth-sized particles (less than 2 millimeters), (2) formation and accumulation of soil humus, (3) the release of nutrients by chemical weathering, and (4) formation of soil structure (aggregation of soil components to form granular or block conformations).

Microorganisms, plants, and soil fauna penetrate quickly into fresh, unconsolidated materials, such as recently established sand dunes, loess deposits, volcanic ash, and surface-mine spoils. However, the processes that create soil horizons in unweathered parent material tend to modify the properties of the material in ways that enhance the soil's ability to support plant growth. The buildup of organic matter in the *A* horizon enhances nutrient recycling and alters the structure of the parent material by improving aggregation, which in turn improves infiltration and retention of water for plant use. Thus, although the existence of horizons in the soil is not intrinsically harmful or beneficial to plant growth, the system of horizons is indicative of chemical and physical properties of the soil that do affect plant growth.

The productive capacity of soils under humid conditions reaches a peak and then slowly declines as nutrient depletion by leaching overbalances nutrient release. The time required to reach maximum productivity might be only a few hundred years, or it might be many thousands of years, depending on the parent material and the environment. In overdeveloped soils, an impervious claypan or fragipan (fragile pan) may form, which inhibits root growth, water movement, and aeration.

In arid and semiarid areas soil-forming processes operate much more slowly. In some places in the West, soils show little evidence of the effect of soil-forming processes. The productivity of such soils is determined more by the physical and chemical properties of the parent material than by changes created by soil-forming processes. However, changes in the parent material can still be significant in affecting a soil's productive potential in such areas. Where weathering of the parent material releases high concentrations of soluble salts and there is not enough precipitation to leach them from the soil, these salts will accumulate in toxic amounts. And although arid conditions do not permit the accumulation of much organic matter in the *A* horizon, the chemical and biological activity in the small amount of organic matter present does play an important role in nutrient cycles and other biogeochemical processes (Curry 1975).

Soil Formation in Coal Regions

Because climate, geology, topography, and vegetation differ in the major coal regions of the United States, the effects and relative importance of different soil-forming processes varies. Different coal regions therefore have distinctly different assemblages of soils (Figure 5.5). While there can be large variations in soil types within a relatively small area in each region, some generalizations can be made about regional differences in the factors and processes of soil formation. An understanding of these differences is useful in evaluating the effects of soil disturbance by mining and in developing strategies for restoring the productivity of mined soils. Table 5.1 summarizes the relative importance of the 5 factors of soil formation in the Appalachian, midwestern, Gulf Coast, and western coal regions of the United States.

Soil materials that are replaced after surface mining will be subjected to the same soil-forming processes as pre-mine soils, unless the pre-mine soils formed under a different climatic regime. Therefore, it is important to understand regional differences in the effects of soil-forming processes. Table 5.2 summarizes and contrasts the impacts of various soil-forming processes on soil materials in different regions.

SOIL AND PRODUCTIVITY

The livelihood of the human race depends to a large extent on the capability of the thin, fragile layer of soil that covers the earth's surface to support plant and animal life. Understanding what factors define a soil's productive potential and how to manage soils for maximum social benefit is important whether soils are disturbed by surface mining for coal or not.

The productive potential of a soil is defined by a matrix of physical and chemical properties that may or may not be amenable to modification by management. Omodt and his colleagues (1975) draw a distinction between soil properties and soil qualities as they relate to mined-land reclamation. Soil *properties* can be seen or measured in the field or laboratory. A soil *quality* is the result of the interactions of soil properties and soil management practices. Soil properties are relatively permanent within short time frames but may change over longer periods of time, owing to soil-forming processes. Soil qualities, such as productivity, fertility, and tilth, are qualities that are subject to change with improvements in knowledge and technology.

When the productive potential of a soil is being evaluated, it is necessary to measure the productivity under a variety of levels of management, because soils that differ in productive potential may differ in their response to different levels of management. Management practices can increase productivity, for example, by supplying water and nutrients that are limiting factors at the site or by changing unfavorable characteristics, as by installing drain tiles to prevent waterlogging. Thus, there may be little difference in yields between soil *X* and soil *Y* at a low level of management but a significant difference between these soils at a high level of management, because more of the limiting factors could be overcome for one soil than the other.

Measures of Soil Productivity

Soil productivity is the growth level of plant and animal life that a soil can support under a specified level of management or set of conditions. It refers to production levels averaged over a period of time rather than the production level achieved in a particular year. Soil productivity may be expressed and measured in several different ways, depending on the use of the soil.

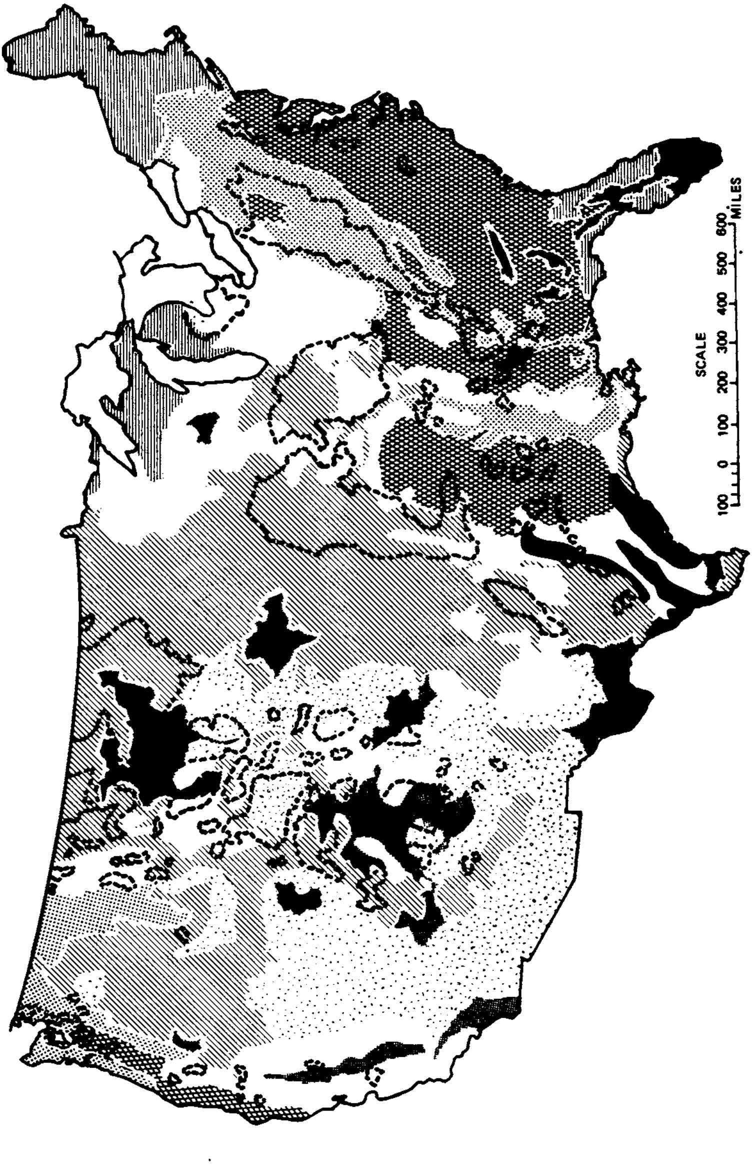
Crop Productivity

Crop production is usually measured in bushels per acre or metric tons per hectare harvested. Different crops or varieties of the same crop may have different soil or climatic requirements, so precise comparisons of the productivity of soils for cropland over a wide area are difficult. Some soils may produce good yields for a range of crops, while other soils may be well suited only for certain special crops. A crop variety, especially of corn, may be very specific to a narrow climatic zone and a distance of as little as 30 miles may permit another variety to do better. Productivity comparisons between soils must be based on an appropriate selection of crop type and variety.

Pasture and Rangeland Productivity

The ability of soil to support livestock, is commonly expressed in the number of hectares needed to support one animal unit (1 cow-calf unit, 1 horse, or 5 sheep) for a period of time (month or year), or in terms of metric tons of grass or alfalfa per hectare that a soil can produce. The yield of vegetation that is suitable for grazing on a sustained basis is an important factor in rangeland productivity and varies greatly according to soil type and ecosystem.

While sheer biomass production is an important factor in productivity for grazing, the ability of a soil to support a mix of species or varieties is a significant consideration. Prairie and grassland ecosystems have evolved to withstand periods of drought and the life cycles of different species are phased in such a way that palatable forage for livestock is available during different seasons of the year. Management to maintain the stability of these ecosystems is essential to allow grazing on a sustained basis. Productivity of


SCALE
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Boundaries of major coal fields in the United States (dashed lines) are superimposed on soil associations identified by the dominant order in the USDA soil taxonomy. Each soil association contains soils from other orders.

Map Symbol	Dominant soil order[a]
	ALFISOLS. Soils with well-developed *A* and *B* horizons formed under forest vegetation. The *A1* horizon, with high organic-matter content, is relatively thin. Soils generally have moderate to high inherent fertility.
	ARIDISOLS. Soils located in areas of arid climate, with low organic-matter content in the *A* horizon and salt or silica accumulations in the soil profile. May or may not have a well-developed *B* horizon.
	ENTISOLS. Incipient soils with only weakly developed surface horizons formed on steep, actively eroding slopes, or on flood plains that receive new deposits of alluvium at frequent intervals.
	INCEPTISOLS. Soils in humid regions that have a well-developed *A* horizon, but do not have a *B* horizon. Some alteration of the *C* horizon may be evident.
	MOLLISOLS. Soils formed under grasslands, with a thick well-developed *A* horizon. May have a well-developed *B* horizon, and in semiarid areas generally have accumulations of salts in the profile. Inherent fertility is generally high.
	SPODOSOLS. Soils formed in cool, humid areas, usually under coniferous forests. Have a thin *A1* horizon and a leached *A2* horizon, underlain by a spodic horizon containing accumulations of an amorphous mixture of organic matter and aluminum.
	ULTISOLS. Soils formed under forests with well-developed *A* and *B* horizons. The soils resemble Alfisols in most respects except profiles are more heavily leached of nutrients and consequently have a lower inherent fertility.
	VERTISOLS. Clayey soils that have deep wide cracks at some time of the year and have high bulk density between the cracks.

PEDOCAL-PEDALFER BOUNDARY. Separates soils in which soluble salts such as calcium carbonate have been or are being leached from the soil profile (pedalfer soils) from soils where soluble salts accumulate in the soil profile (pedocal soils). This is roughly also the line between the half of the continent where the potential evapotranspiration exceeds precipitation and the half where precipitation exceeds evapotranspiration.

[a] Areas of Histosols (organic soils, such as peat) in Minnesota have been omitted from this map.

FIGURE 5.5 General soil associations in coal fields of the United States. *Source*: Adapted from Soil Survey Staff (1975).

TABLE 5.1 Factors of Soil Formation in Coal Regions of the United States

Factor	Coal Region (Major Soil Orders in Parentheses): Appalachia (Inceptisols, Ultisols)	Midwest (Mollisols, Alfisols)	Gulf Coast (Ultisols, Alfisols)	West (Entisols, Aridisols, Mollisols)
Parent material	Bedrock lithology is a major factor in determining texture and mineralogy of soils in most of the region. Some glacial tills in northern Appalachia.	Glacial deposits (tills, outwash, lacustrine) are dominant parent material in north and central areas, weathered bedrock is predominant in southern and western areas. Texture of surface is usually silt loam due to mantle of windblown material (loess).	Main lignite-bearing rocks are mostly unconsolidated sands and muds; surface soils tend to be loamy or sandy.	Bedrock lithology (generally sandstone or shale) is a dominant factor, but texture of the surface horizons is sometimes strongly influenced by additions of windblown clays and silts. Glacial tills common in North Dakota and eastern Montana.
Topography	The existence of steep slopes in much of the region inhibits formation of well-developed soil profiles because of downslope movement of soil material through frost action and the force of gravity.	Gentle to moderately sloping topography is responsible for local variations in soils, but is not a major factor in inhibiting soil formation.		

Vegetation	Soils formed under forests (Alfisols and Ultisols) tend to have relatively thin Al horizons, into which nutrients are cycled from the living biomass. Forests are the dominant native vegetation in most of Appalachia, the southeastern parts of the Midwest, and from central Texas on east into the Gulf Coast region. Soils formed under grasslands tend to have thick, dark *A* horizons with a high content of nutrients and organic matter. Grasslands are the dominant native vegetation in the northern and western parts of the Midwest and in parts of south-central Texas.	Owing to the arid climate, vegetation is not a major factor in soil formation, except in scattered patches of shrubs and in the higher rainfall areas of the northern Plains where Mollisols have developed under prairie vegetation.
Climate	Humid climatic regime, with precipitation distributed fairly evenly through the year. Drought stress sometimes in late summer. Moisture and temperature conditions tend to promote good growth of vegetation, leaching of the soil profile, and formation of soil horizons. Semiarid conditions exist in parts of the south Texas lignite areas.	Semiarid climatic regimes limit soil development. In most coal fields precipitation is less than potential evapotranspiration, and the availability of moisture to the soil is reduced further because much of the precipitation occurs as snow or summer thunderstorms that result in runoff.

TABLE 5.1 *(Continued)*

	Coal Region (Major Soil Orders in Parentheses)			
Factor	Appalachia (Inceptisols, Ultisols)	Midwest (Mollisols, Alfisols)	Gulf Coast (Ultisols, Alfisols)	West (Entisols, Aridisols, Mollisols)
Time	The hundreds of thousands of years the landscape has been subject to weathering, in a humid climate, means that exchangeable bases such as Ca, Mg, and K have been leached from well-developed soil profiles. Steep slopes have prevented the formation of well-developed soil profiles in some areas.	There has not been sufficient time to leach nutrients from soils in glacial deposits of Wisconsin age (10,000 to 60,000 years old), and they therefore tend to be high in nutrients. Soils formed on pre-Wisconsin glacial surfaces and residuum (which often include a thin cap of Wisconsin-age loess) have been exposed to weathering and the effects of a humid climate for long periods of time and thus tend to have "old" soil profiles that are leached of nutrients and in some cases claypans or fragipans that restrict rooting depth.		Most landscapes have been exposed to weathering for periods of time exceeding hundreds of thousands of years, but because periods of active wind erosion and transport have occurred several times during the last 20,000 years, soils have been eroded and the profiles are not well developed. The present climate does not promote active soil formation; soils with well-developed profiles, found on stable surfaces, probably formed under previous, wetter climatic conditions.

rangelands can be significantly increased by management practices such as rotation grazing, irrigation, fertilization, surface manipulation to increase water infiltration, and seeding of forage species that produce more biomass.

Forest Productivity

Forest productivity is commonly measured by the site index, which is the average height of sample canopy trees at a selected index age, such as 50 years (Jones 1969). Productivity in different sites can be compared by determining differences in height for the same species and age of tree. Because the economic returns from forestry are generally less than from grazing and crop production, forest production is confined generally to marginal soils that are not suitable for grazing or crop production.

Ecosystem Productivity

Measurements of productivity described so far have been expressed in terms of biomass production of crops, livestock, and trees, and define the ability of a soil to provide food and fiber for human uses. The biomass production of the entire ecosystem can also be measured. But it is equally important to examine species composition and diversity and the nutrient cycles and processes that are at work in the soil.

Stability is an important aspect of ecosystem productivity. By *stable* we do not mean *static*. An ecosystem that is evolving through a succession of plant communities can be considered stable if each stage is a productive, self-sustaining community requiring minimal long-term management by humans.

After disturbance, ecosystems tend to have low diversity initially; over time diversity increases, as does the amount of energy that is used and stored in the system, until a "climax" is reached. In general, then, climax ecosystems are characterized by high levels of diversity and productivity. It is difficult, however, to delineate the specific nature of a climax community and the factors that permit the levels of productivity in such communities. Consequently, it is also difficult to define precisely the management practices needed to prevent irreversible reduction in productivity in climax communities (Harthill and McKell 1979).

A slightly narrower view of ecosystem productivity may be taken when protection or enhancement of the population of certain wildlife species is desired. In this case soil productivity may be defined in terms of the ability of soil to support plant species that provide suitable forage and habitat for the given species of wildlife. Physical characteristics of the soil or landscape

TABLE 5.2 Soil-Forming Processes in Coal Regions of the United States

Process	Appalachia, Midwest, and Gulf Coast	West
Addition of organic matter	Moisture and temperature conditions are generally favorable for growth of vegetation and additions of organic matter to the soil. Where forest vegetation dominates, organic matter is concentrated in a relatively thin *Al* horizon. Optimum conditions for buildup of organic matter in soils are found in areas of the Midwest where there was originally prairie vegetation. Organic matter decomposes more rapidly in the Gulf Coast region because of higher average temperatures.	Moisture and temperature conditions tend to inhibit formation of organic matter.
Addition of eolian material	Under present climatic conditions the addition of windblown material to soils plays a minor role in soil formation anywhere in the United States. The process is probably most active in the Midwest and West.	
Development of argillic *B* horizons	A significant increase in clay content of the *B* horizon due to movement of clays from the *A* horizon is generally found in soils in Appalachia, the Midwest, and Gulf Coast regions where slopes are not too steep and the soil has been exposed to weathering for a sufficient length of time. Well-developed *B* horizons require about 4000 years to develop in soils of temperate deciduous hardwood forest (Buol et al. 1980). Generally no *B* horizon in steep slope areas of Appalachia.	Found only on soils on stable surfaces, and where present probably developed during earlier, more humid climatic conditions. Excessive sodium causes flocculation of
Development of calcic and natric horizons	Calcium carbonate and sodium are not concentrated in sufficient quantities to affect the morphology of the soil profile, owing to the humid climate, except possibly in semiarid parts of south Texas.	Most soils have accumulations of $CaCO_3$ or sodium in the soil profile, but usually not in concentrations sufficient to be considered a calcic or natric horizon. Wherever potential evaporation exceeds precipitation and land surface has been stable for 30,000 or more years, however, such horizons are common.

Claypan and fragipan formation	Formation of impervious claypans and fragipans is common on gentle slopes in Appalachia, the Midwest, and Gulf Coast. Claypans require tens of thousands of years to develop; some fragipans are less than a thousand years old. Fragipans in the Midwest are usually found where pre-Wisconsin land surfaces are covered by a thin (less than 1 m) layer of Wisconsin-age loess.	Arid and semiarid climate inhibit formation of claypans and fragipans.
Erosion	Movement of soil material by water or wind is not a significant process where native vegetation exists, but use of soil for agriculture and cutting of forests can greatly increase erosion, causing major changes in the characteristics of the soil profile.	Soil erosion is active in many areas of the West under natural conditions, especially in desert areas, where vegetative cover is sparse.
Leaching	Removal of dissolved constituents in water percolating through the soil occurs wherever precipitation exceeds potential evaporation. The extent of leaching is a function of time. Wisconsin-age glacial drifts in northern Illinois are leached to a depth of 0.5 to 1.5 m, whereas Illinois-age glacial drifts are leached to as much as 2.5 to 3.5 m. Leaching of calcium carbonate is rapid enough to be an important consideration in the management of soils for agricultural uses.	Not generally significant, owing to climate.
Humus formation	Climatic conditions are favorable for the alteration of fresh organic matter into physically and chemically stable forms, but hundreds to thousands of years are needed to transform fresh organic matter into these states (see discussion of soil organic-matter formation in Chapter 6).	Not generally significant, owing to climate.
Weathering of primary minerals	Tens of thousands of years are needed to weather primary minerals such as pyroxene and hornblende into layer-lattice clays and sesquioxide under the humid climatic conditions that exist in Michigan and Central Europe (Birkeland 1974). Similar amounts of time are needed for the alteration of less stable clay minerals to more stable forms.	Hundreds of thousands of years or more are required for significant weathering of primary minerals in the arid West (Birkeland 1974).

must also be considered in determining suitability of habitat for some animals. For example, the local distribution of burrowing and digging mammals may be influenced more by the physical characteristics of the soil than by its chemical properties, whether or not the latter result in plant associations preferred by the mammals (Institute for Land Rehabilitation 1978).

Other Soil Potentials

Soils vary greatly in their engineering properties, which affect the suitability of a soil for such uses as absorption fields for septic-tank effluent, sewage lagoons, deep excavation and extraction of fill material, siting of dwellings, sanitary landfills, and roads. A knowledge of various physical properties of a soil makes it possible to evaluate the limitations the soil poses for such engineering uses (U.S. Soil Conservation Service 1972).

Soil Properties That Affect Productivity

Physical properties that affect soil productivity include soil texture, bulk density, infiltration capacity, permeability, rooting depth, organic-matter content, and water-holding capacity. Chemical properties that are important include cation-exchange capacity, soluble-salt content, exchangeable sodium (a major concern in the West), and available nutrients in the soil profile. Topographic characteristics of a soil, such as slope gradient and orientation, are also important factors in the productive potential of soil. These various properties affect productivity insofar as they assist or impede the availability of the nutrient elements and moisture essential for plant growth.

Table 5.3 classifies the 17 elements that are essential for plant growth according to sources. Ordinarily, 94 to 99.5 percent of fresh plant tissue consists of carbon, hydrogen, and oxygen. Carbon and oxygen are derived from the carbon dioxide in the air by photosynthesis; hydrogen comes either directly or indirectly from water in the soil. The remaining 0.5 to 6 percent of the plant tissue comes from soil solids (Brady 1974). The amount of plant growth that a soil supports can be no greater than that allowed by the most limiting of these elements essential to plant growth.

Tables 5.4 and 5.5 summarize the physical and chemical characteristics of soils in relation to plant growth and make it clear that many physical and chemical properties of soil are interrelated. For example, infiltration rates depend on organic-matter content, soil texture, and soil structure. A given quantity of micronutrients may be inadequate, may promote toxicity, or

TABLE 5.3 Essential Nutrient Elements and Their Sources

Essential Elements Used in Relatively Large Amounts		Essential Elements Used in Relatively Small Amounts[a]	
Mostly from Air and Water	From Soil Solids	From Soil Solids	
Carbon	Nitrogen	Iron	Copper
Hydrogen	Phosphorus	Manganese	Zinc
Oxygen	Potassium	Boron	Chlorine
	Calcium	Molybdenum	Cobalt
	Magnesium		
	Sulfur		

[a]Other minor elements, such as sodium, fluorine, iodine, silicon, strontium, and barium, do not seem to be universally essential, as are the 17 listed here, although the soluble compounds of some may increase crop growth.

Source: Brady (1974) (Copyright © 1974, Macmillan Publishing Co., Inc.)

may be toxic to plant growth depending on soil reaction. The effects of soil disturbance on the interaction of soil properties in relation to productivity are discussed in more detail in the next chapter.

Soil Organic Matter and Nutrient Depletion

Organic matter and microbial activity in soil are key factors influencing productivity, playing major roles in the physical, chemical, and biological aspects of soil. Physically, organic matter plays a major role in soil tilth, through its effects on aggregation, and in water-holding capacity (Allison 1973). Chemically, the organic fraction serves as a buffer, an ion exchanger, and a complexing/chelating agent. The last function is particularly important in influencing the behavior of minor nutrients such as the transition metals, copper and zinc (Stevenson and Ardakani 1972).

Microbial conversion of organic nitrogen and sulfur to inorganic chemical forms serves as a principal control on the availability of these elements to plants. In natural ecosystems most of the nitrogen and sulfur occur in organic forms. There is a serious lack of information on the relative amounts of organic and inorganic forms of phosphorus in soils; data available indicate that although inorganic forms generally predominate, the organic fraction is rarely less than 30 percent of the total (Brady 1974).

Early farming in this country was much like a mining process, in that it removed organic matter and essential elements from the soil. Plowing aerated the surface soils and caused the rapid oxidation and decomposition of the organic matter that had accumulated over hundreds and thousands of years. This released a flush of plant nutrients that initially supported good crop growth. Nutrients not taken up by crop plants were lost from the system by leaching and in runoff water. Some nutrients were hauled off with harvested crops, only part of which were returned in manure. Soil productivity decreased as the readily decomposable constituents of the soil organic matter were depleted.

The next era in soil management involved rotation of crops including forage legumes. Enough nitrogen was fixed by symbiotic bacteria associated with the legumes to supply the needs of the forage crop and to leave some residual nitrogen for subsequent crops. Good yield levels were sustained and the rate of decline in total soil nitrogen levels was reduced. Liming was practiced to establish and maintain a soil pH favorable to the forage legumes. Supplementary phosphorus and potassium were added as these elements became or were recognized as being limiting. The frequency with which row crops such as corn could be planted was limited by the need to include forage legumes in the rotation as a nitrogen source.

The current practice of continuous row cropping on the best farmland gained in popularity as nitrogen fertilizers were accepted as an alternative to rotation with legumes as a nitrogen source. Short-run economic considerations determine the amount of nitrogen, phosphorus, and potassium fertilizers used. Micronutrient deficiencies are rare in the Midwest, so there is usually no significant yield increase from micronutrient fertilizers. Liming must be practiced to maintain soil pH at a favorable level. This is particularly important because of the acidifying effects of some nitrogen fertilizers.

Soils that have been drained or developed for cropping undergo rapid decreases in organic matter during the first few years of cultivation. Most present cropland soils have already lost at least 40 percent of their original content of organic matter and soil nitrogen and have leveled off under present management with little current change in organic-matter and nitrogen levels over time (Stevenson 1965).

The total amount of crop residues returned to the soil under optimum fertilization in the Corn Belt is now nearly twice as great as it was under the rotation farming of the 1950s. Russell (1975) was not able to detect a feedback effect on soil nitrogen levels under continuous corn due to increased organic debris from higher yields. His data, however, were from plots that had not received fertilizer nitrogen.

Soil phosphorus and potassium levels were also steadily reduced under early agriculture. That trend has now been reversed. Fertilizing at economically optimum rates has resulted in a slow buildup in most soils, and these elements are present at higher than original levels in many fields.

Soil Erosion

Two kinds of soil loss are reducing agricultural, forest, and range production in the United States: (1) loss of soil by erosion; and (2) loss of land to other uses, such as urban development, transportation, water storage, industrial development, wildlife protection, and recreation. Our discussion here focuses on the first kind of loss.

Accelerated soil erosion has long been recognized as a serious problem with numerous detrimental effects. Erosion commonly removes the portions of the soil that are highest in organic matter and richest in plant nutrients (Barrows and Kilmer 1963). The quantities of plant nutrients lost through erosion each year generally exceed those returned by plant residue (Holt 1979). The finest and most fertile soil fractions are transported the farthest, along with agricultural chemicals (Frere et al. 1975).

In recent years, farmers have been compensating for depression of crop yields caused by soil erosion through various management practices, including fertilization (Fehrenbacher et al. 1978). These practices have masked the basic problem of soil loss and have postponed forthright dealing with the problem.

In this country about 1.1 billion metric tons of sediment leave 100 million hectares of cropland each year (Daniel et al. 1979). Soil erosion by water and wind proceeds at an average annual rate of about 22 metric tons per hectare (t/ha), which represents a loss of soil thickness on cropland of 15 centimeters every 100 years (Brink et al. 1977). In Iowa, for each bushel of corn produced about 2 bushels of soil are likely to be lost from a field (Brink et al. 1977). A recent appraisal of the status and conditions of soil resources in the United States, prepared pursuant to the Soil and Water Resource Conservation Act of 1977 (U.S. Department of Agriculture 1980) provides a detailed picture of the seriousness of soil erosion. Average annual sheet and rill erosion in 1977 from cultivated cropland was 12 t/ha, from native pasture (land on which the natural potential plant community is forest but which is used and managed primarily for the production of native grasses for forage), 9.2 t/ha; from rangelands, 7.6 t/ha; from grazed forest, 9.0 t/ha; and from ungrazed forest, 1.3 t/ha.

These averages mask a much wider range of figures due to differences in the susceptibility of soils to erosion. For example, average soil loss from cultivated croplands in Missouri and Tennessee exceeded 22.4 t/ha/yr in 1977. The Palouse prairies in west-central Idaho produce some of the

TABLE 5.4 Properties Affecting Soil Productivity

Property	Favorable Characteristics	Unfavorable Characteristics
Slope gradient	Nearly level and moderate slopes enhance infiltration of water and are less susceptible to erosion.	Flat slopes and depressions drain poorly and thus limit availability of oxygen to roots. Steep slopes allow less water to enter the soil and are more prone to erosion.
Slope aspect (most significant on steep slopes)	Northern slopes generally have better moisture retention than southern slopes, but orientations with optimum moisture retention vary considerably, depending on climatic and other factors.	
Slope position	Toeslopes and bottomlands retain most moisture.	Narrow ridgetops retain least moisture.
Organic matter	High levels improve aggregation and infiltration capacity and increase availability of nutrients.	Low levels inhibit aggregation, lower infiltration rates, and reduce availability of nutrients.
Infiltration	High infiltration increases moisture retention in soil, reduces erosion.	Low infiltration increases runoff and erosion, decreases moisture in soil.
Permeability	Moderate to high permeability increases soil moisture and decreases runoff under saturated conditions.	Very low permeability may mean less available water if associated with restricted rooting depth or high clay. Very high permeability may mean water is not retained in upper levels of the soil profile.

Soil texture	Mixture of silt, clay, and sand (silt loam or loam) has optimum moisture capacity. Clays are chemically active, promoting availability of nutrients.	Too much clay decreases water availability, because of high matric potential, and are difficult to work when wet. Too much sand produces low water-holding capacity and low availability of nutrients. Silts are easily eroded and crust easily.
Bulk density[a]	Low values generally indicate high organic matter, content, good granulation, high infiltration, and good aeration, making for good rooting medium.	High values generally indicate low aggregation, inhibited root penetration, and low infiltration and permeability rates.
Rooting depth	Unrestricted rooting depth allows plant to make maximum use of water and nutrients in the soil.	Restricted depth reduces water and nutrients available to plants.
Available water capacity	High capacity allows storage of water for plant growth during periods of low precipitation.	Low capacity means plant growth is reduced by moisture stress during periods of drought.
Soil structure	Granular structure improves infiltration, is resistant to the impact of rain drops. Blocky and prismatic structures improve permeability (except when part of a fragipan or claypan).	Platy and massive structures are less favorable for infiltration, permeability, and rooting. Crusting at surface may inhibit seedling emergence.

[a]In certain situations the relationships described here for bulk density do not hold true. For example, most sandy soils have much higher bulk densities than do soils high in sodium and montmorillonitic clay, yet the latter have poorer aeration and slower infiltration.

TABLE 5.5 Chemical Properties of Soils Affecting Productivity

Property	Favorable Characteristics	Unfavorable Characteristics
Macronutrients (N, P, K, Ca, Mg, S)	High availability is necessary for optimum plant growth.	Low availability restricts plant growth.
Micronutrients (Fe, Mn, Bo, Mo, Cu, Zn, Cl, Co)	Trace amounts are necessary for optimum plant growth.	Excessive quantities may inhibit plant growth or cause buildup of toxic concentrations in plant tissue.
Base saturation and cation-exchange capacity	High levels mean high availability of nutrients in humid climates.	Low levels indicate heavily leached soil profile and low availability of nutrients in humid climates.
Soil reaction (pH)	Slightly acid to slightly alkaline pH creates optimum availability of nutrients.	Very acid pH may create toxic effects due to excess soluble manganese and other metals. (On very alkaline pH, see discussion of soluble salts below.)
Soluble salts	In small amounts necessary for plant growth.	Excessive amounts retard plant uptake of water, remove water from plants by osmosis, limit the uptake and availability of certain nutrients, create toxic effects at certain concentrations.
Sodium	Not universally essential for plant growth, but soluble compounds in small quantities may increase plant growth.	Toxic to plants when the soil reaction is strongly alkaline. In the *B* horizon, impairs root penetration and air and water movement. At surface, disperses and seals pores, reducing infiltration. Crusting limits seedling emergence.

highest yields of dry-farmed wheat anywhere, but are also highly susceptible to erosion. When vegetation cover is inadequate on steep slopes, soil loss may be as much as 224 t/ha/yr.

Wind erosion on cropland is also a serious problem, particularly in the Great Plains states. Average annual wind erosion from cropland on highly susceptible soils may be more than 224 t/ha. Average soil losses from wind erosion for all cropland in the Great Plains states ranges from 4.5 to 9.0 t/ha/yr, but New Mexico and Texas average 25.8 and 33.4, respectively. Wind erosion from rangelands averages 4.0 t/ha/yr, but may run as high as 9.2. Of course, erosion rates may change over time; for example, erosion rates and sediment yields on arid and semiarid rangelands in the West were greatly accelerated in the last half of the nineteenth century, primarily because of overgrazing. This trend has been reversed in many parts of the West since 1942 by improved land-use practices (Hadley 1974).

Soil-erosion rates also vary greatly from one place to another within any sizeable tract of land. Most of the soil loss due to water erosion takes place on the least stable landscape positions, which are readily identifiable and commonly make up a relatively small portion of the total land area. Other areas in the same tract may receive sediment from the actively eroding areas. Shoulder slopes and sideslopes are most prone to sheet erosion. Footslopes, toeslopes, and grassed waterways in the same field are prone to sedimentation. Extensive areas in most fields will not be significantly affected by either net erosion or net sedimentation.

Most erosion-rate estimates refer to gross erosion, or the total amount of soil material moved. Much of that material is deposited as sediment before it reaches flowing streams or lakes; some of it moves only a few meters in a single transport event. The sediment-delivery ratio is the ratio of sediment delivered to a given point in a stream system to the gross erosion from all sources in the watershed upstream from that point. The delivery ratio varies considerably and depends on several watershed features (Onstad and Moldenhauer 1975, Roehl 1962). The delivery ratio can be adjusted by vegetation management or mechanical practices for erosion control. Hence it is possible to reduce sediment yields to streams and lakes both by reducing gross erosion and by reducing the delivery ratio. Sands, silts, and aggregated clays can be trapped most easily. Dispersed clays and fine organic-matter particles stay in suspension much longer and are most difficult to stop once they have started to move.

Damage caused by sediment washed from corn fields to land and water areas outside those fields has not traditionally been included in calculations of monetary loss resulting from soil erosion. It is useful to consider the on-site productivity loss damages separately from the off-site sediment damages, but off-site losses must not be ignored. Gunterman and his colleagues (1975) found the off-site damage to be considerably greater than the yield loss damages on six Illinois watersheds.

The loss of available nitrogen was probably the major factor in some of the early reports that soil erosion causes a substantial yield reduction; available nitrogen would be a much less significant factor today with the almost universal use of fertilizers. On the other hand, yield losses due to some other features of the eroded soils may be as significant today as they were in the 1930s and 1940s. New research to determine the effects of soil erosion on productivity under current technology is urgently needed.

Not all soils are alike. Productivity of a shallow soil over bedrock or a soil with a very unfavorable subsoil could be virtually destroyed by erosion. Many soils in the East have more clay in the subsoil than in the surface soil, and therefore erosion of the surface layer exposes a material that contains both more clay and less organic matter. The new plow layer has poor or unstable soil structure with reduced infiltration rates and poor tilth. If the clay content in the subsoil is high enough, severe erosion might make crop production impossible. At the other extreme, soils such as those formed in thick loess deposits, with subsoil and substratum materials that are nearly as good as the surface soil, might suffer little or no decline in productivity through the loss of the surface soils by erosion. Such differences in the character of soils must be taken into account when evaluating the effect of erosion on soil productivity.

The Illinois Environmental Protection Agency (1979) used available areal soil estimates (Runge et al. 1969) and productivity values from Fehrenbacher et al. (1978) to estimate that 2.2 percent of the potential productive capacity of Illinois soils has been lost to erosion since settlement about 100 years ago. This is equivalent to an annual loss of $110 million in production of Illinois crops at present values.

Future erosion will be most intense at the same points in the landscape that have been most intensely affected in the past. Severely eroded areas will grow somewhat in extent, and some soils will be further degraded. The relationship between soil loss and productivity is not linear for most soils. As erosion proceeds to the point of eliminating the *A* horizon, productivity falls substantially. This can be expected on substantial areas of the Midwest over the next 30 to 100 years under current management practices (Nelson and Seitz 1979). Once the *A* horizon has been removed and unfavorable subsoils are exposed, further erosion causes slower declines in productivity.

Little has been said so far about the effect of sediment deposition on productivity. Some sites are degraded by sedimentation because the sediment is inferior to the underlying soil. Considerably larger areas, however, are unaffected or are actually improved by sedimentation. The sediment is in many instances as fertile or more fertile than the underlying soils. Furthermore, some topographic improvement may result from sediment accumulating in low areas. Depressions that now collect water might be filled, or steepness of hill slopes might be reduced. There are instances in which control measures can be used to increase the positive effects and minimize the negative effects of sedimentation on cropland.

Rejuvenation of Soils by Erosion

Geologic erosion is effective in keeping some soils young. It is doubtful, however, that accelerated erosion induced by man should be considered a favorable process. As we saw earlier, accelerated erosion is most intense at the least stable positions on the land surface, where the soils are already least strongly developed because of natural geologic erosion. Rapid erosion would be more likely to degrade than to improve such sites. Furthermore, the effects of accelerated erosion on strongly developed soils in more stable landscape areas is likely to be unfavorable. Strongly developed soils are commonly underlain by unfavorable subsoils. Accelerated erosion will remove the surface soil more rapidly than a new *A* horizon can form and expose the undesirable subsoil.

Additional erosion should not be encouraged in order to remove undesirable subsoil from badly eroded soils even if there is a better substratum material, because too much time would be required to remove the subsoil, large volumes of poor-quality sediment would be produced, and the area of erosion could not be controlled adequately to prevent surface soil from being stripped upslope.

There are some soils, such as very deep loess-derived soils, that might be improved over a very long time by carefully managed erosion, but these are the exception, not the rule. Valley floors that receive sediment rich in plant nutrients from eroding agricultural fields can become sites of exceptionally productive soils in years of low flood incidence. It is clear, however, that far more soils are degraded than are improved by excessive soil loss.

Erosion-Control Practices

Erosion-control methods can be grouped into three categories:

- tillage, residue, and planting management;
- terraces and other mechanical control structures on the land; and
- limits on the intensity of use.

Selection of erosion-control strategies for a given site depends on whether the major concern is to prevent on-site productivity losses or off-site sediment damages. Some control measures that effectively reduce off-site sediment damage do not prevent soil from moving from one place to another on-site. Other control measures effectively reduce movement on-site as well as reducing off-site damages.

Some tillage, residue, and planting management practices that reduce erosion are generally good management from all perspectives. Such practices can be encouraged by educating farm managers and operators. On the other hand, some practices that reduce erosion might reduce current yields or increase costs of production, so it is important that alternative methods for erosion and sediment control be analyzed to determine the trade-offs involved.

Mechanical means such as terraces or water-retention structures involve a considerable capital investment at the time of construction. Projected yield benefits from such means, discounted at reasonable interest rates, are usually not great enough to provide an economic incentive for installation (Swanson 1979), and in some instances the economic effects to the individual land owner are strongly negative. As an incentive public funds have been used in the past to subsidize erosion-control construction on private properties.

Methods for reducing the intensity of land use include rotating small grain and meadow crops with corn and other clean-tilled crops and leaving filter strips of vegetation along the path of water flow to trap sediments. On gently sloping land, erosion can be adequately controlled by mechanical or tillage management practices, and thus reduced use intensity is only one of several ways erosion can be controlled. On more steeply sloping land erosion cannot be kept within currently accepted tolerances without some reduction in the frequency or extent of row-cropping.

For croplands, some erosion control can be accomplished with little increase and perhaps even a decrease in the cost of production. As erosion control objectives become more ambitious, however, progressively greater degrees of erosion control without losses in total production become more and more expensive (Heady and Vocke 1978). For rangelands, the erosive effects of grazing in excess of carrying capacity can only be mitigated by costly intensive management practices or by reducing livestock density.

SOIL AND THE HYDROLOGIC BALANCE

Soil is part of the hydrologic system and plays an important role in the distribution of precipitation among surface water, ground water, and soil water. Erosion of the soil surface affects water quality by contributing sediment to streams, and soluble salts in the soil may affect both surface-water and ground-water quality. The ability of the soil to support vegetation under any given climatic regime also affects the water balance in a watershed through evapotranspiration.

Soil hydrology can be viewed from two quite different perspectives. From the first, the primary concern is with the disposition of water in the soil profile in relation to its availability for plant growth. Soil-water-energy relationships and various physical characteristics of the soil are important (see Table 5.4), and the movement of water outside the soil profile is of concern only to the extent that the water is removing nutrients or soil material important to the productivity of the soil.

From the second, broader perspective, soil is viewed as a manifestation of the process of landscape evolution, and as a component of the hydrologic system that plays an important role in determining the relationship between precipitation and streamflow. Soil directs precipitation to surface streams as runoff, to aquifers by percolation, and to the atmosphere through evapotranspiration. This section examines soil hydrology from this broader perspective.

Hydrologically Important Soil Characteristics

Most streamflow comes from surface runoff, although during periods of little or no rainfall, ground water is the major contributor to the baseflow of perennial surface streams. Most recharge of ground water occurs by percolation of water through the soil and subsoil of the vadose zone. Infiltration capacity and permeability are two important soil characteristics that affect ground water and streamflow. If precipitation exceeds the capacity of a soil to receive and move water internally, the excess precipitation ends up as surface runoff. Generally speaking, the greater the infiltration capacity and permeability of a soil, the more precipitation ends up as ground water, and the lower the infiltration capacity, the more precipitation ends up as surface flow.

Infiltration capacity is a measure of the rate at which water can enter the soil from the surface, usually expressed in centimeters per hour. Soil permeability is that quality of a soil that enables it to transmit water and air, and it is also usually measured in centimeters of water that can move through a saturated soil in an hour. Although infiltration capacity and permeability are measured in the same units, they are distinctly different soil characteristics. Infiltration capacity is influenced by a number of factors, such as the type and extent of vegetative cover, the condition of the surface crust, temperature, rainfall intensity, physical properties of the soil, water quality, and the volume of storage available below the ground surface (Viessman et al. 1972). Infiltration rates will depend on the antecedent moisture content of the soil and other factors. Permeability, on the other hand, controls the rate at which water moves after it enters the soil.

Permeability sets an upper limit for infiltration capacity in a saturated soil, but the converse is not true. For example, inwash of fine material dislodged by raindrops striking the surface may seal the soil surface so that infiltration of water into the soil is low, even when the underlying soil is highly permeable. Heavily cultivated soils and soils that contain much sodium at the surface tend to form crusts at the soil surface, limiting movement of water into the soil to rates below those that the soil permeability could handle. Permeability and infiltration capacity are greatly enhanced by the presence of vegetation and organic matter in the surface horizon. Soil structure is also important in determining infiltration and water movement; channels through the profile between aggregations of soil particles will promote water movement.

Soil chemistry may also affect surface-water quality and, to a lesser extent, ground-water quality. Soil erosion contributes both sediment and dissolved solids to streams. Water percolating through the soil may leach nutrients and other soluble compounds into ground-water aquifers, but unless the water table is near the surface, ground-water quality is probably determined more by the chemistry of the water-bearing strata. Irrigation in the West may contribute significantly to the salt loading of ground and surface water, and heavy use of nitrogen fertilizers in the Midwest has resulted in nitrate contamination of ground water in some localities.

Soil and Watershed Equilibrium

The land surface and the stream channels that drain a watershed adjust over a period of time in such a way that although streamflow and sediment loading vary seasonally and yearly, the morphology of the stream channel remains relatively stable (unless a perturbation in climate or regional uplift or subsidence interrupts the adjustment). Various terms such as "equilibrium," "dynamic equilibrium," and "steady state" have been used by geomorphologists to describe streams where the channel remains stable in the face of variable streamflow and sediment loading (Morisawa 1968). Section 515(b)(10) of the Surface Mining Control and Reclamation Act of 1977 requires that mining minimize disturbance of the "hydrologic balance." This means essentially that mining and reclamation should not significantly alter the stability of watersheds that have attained a steady state, or, if a steady state has not been reached, they should reestablish the processes that are moving the watershed toward a steady state. Where a watershed is already extensively disturbed as a result of human intervention, the provision does not necessarily imply reestablishing the hydrologic conditions that exist when a mining operation is initiated, if reclamation can be done in a way that improves watershed stability.

Equilibrium states differ in humid areas in the East and arid areas in the West. The equilibrium state of a watershed cannot be precisely predicted or measured quantitatively, because of variability in climate, streamflow, and several complex interrelated geomorphic processes. These phenomena show an apparent randomness, and it would be difficult to develop deterministic models for them (Smart 1979).

There is some evidence that watersheds in a state of equilibrium will remain so until perturbations of system parameters exceed some threshold, at which point the watershed shifts relatively rapidly to a new equilibrium state (Schumm 1977). Perturbations induced by humans become significant when they exceed system thresholds. Surface mining for coal can alter parameters of the hydrologic system beyond the limits of the equilibrium threshold, but unfortunately our understanding of these thresholds is not good enough to define them with any precision.

Soil disturbance may create two major kinds of perturbations in the hydrologic system: (1) erosion and resulting sediment transport to surface streams may alter stream-channel morphology, and (2) changed infiltration/runoff relationships may alter streamflow response to precipitation events. The most detrimental effects on watershed equilibrium of mining, from a human standpoint, are the possibility of an increase in the intensity and frequency of flooding and damage to ground-water systems that are used as a source of water.

Changes in Streamflow

An alteration of infiltration/runoff relationships in a watershed by mining can have two very different effects. Reduced infiltration during periods of high precipitation increases the incidence, duration, and intensity of floods, and less water enters the ground-water reservoirs so that during periods of low precipitation there is not enough ground water to maintain the base flow of streams. Increased infiltration, conversely reduces flooding and increases base flow.

A common result of post-surface-mining practices in Appalachia has been an increase in flooding intensity, probably due to a combination of reduction of vegetation cover and a reduction of channel capacity by sediment. Increases in peak discharges from watersheds disturbed by mining as compared with undisturbed watersheds have been documented in Kentucky (Collier et al. 1970) and Tennessee (Minear and Tschantz 1974).

Some tributary drainage areas of Busseron Creek watershed in Indiana have had more than 30 percent of their area affected by surface mining.

Flood peaks have been significantly reduced, as a result of mining methods that left depressions between ungraded spoil piles that did not contribute surface runoff to the watershed (Harza Engineers 1975). Base flows in extensively mined areas increased 10 to 40 times compared to base flows before mining. This watershed is located on a nearly flat to gently sloping glacial till plain, and the hydrologic effects of mining are probably not generally the same as those in Appalachia and unglaciated parts of the Midwest (Murray 1978). Curtis (1972) measured peak flows in two small watersheds in Breathitt County, Kentucky, that were undergoing active mining or had recently been mined and found them significantly above those in an unmined watershed. After these watersheds were reclaimed, however, peak flows were lower than in the unmined watershed, evidently because the spoils had a higher water-holding capacity (Curtis 1979). In western states, where ephemeral streams recharge ground-water reservoirs seasonally, mining-induced changes often decrease base flows because more water is lost by surface flow in shorter periods of time, leaving less to recharge the ground water. Thus streams that carry water throughout most years in small quantities may dry up more frequently and flood more dramatically after establishment of a post-mining contour and soil mosaic.

Subsidence of the land surface over mined-out underground coal seams can significantly change surface and underground drainage patterns. Natural surface drainage networks can be altered, resulting in formation or occasionally destruction of swamps. Surface streams may be intercepted by subsided areas or rock fractures related to subsidence, resulting in flow into deep mines and loss of surface waters (Hill and Bates 1978). Ground water may also be intercepted and drained into underlying deep mines.

Off-Site Impacts of Erosion

Erosion is likely to occur whenever a soil is without the protective cover of vegetation. Since the mining operation necessitates removing vegetation to reach the coal and a certain period of time is needed to reestablish vegetation after mining is completed, erosion is an inevitable short-term effect of mining. Past reclamation practices often exacerbated this problem by failing to establish a good cover of vegetation after mining was completed or leaving unstable slopes that were subject to mass movement.

This problem has been especially severe in Appalachia, where a combination of steep slopes and high annual rainfall are conducive to erosion. Approximately 7700 kilometers of streams in Appalachia have been adversely affected by sedimentation caused by coal mining (Appalachian Regional Commission 1969). Sediment studies by Collier et al. (1970) in the Beaver Creek drainage basin in eastern Kentucky, which was mined in the 1950s, showed sediment discharge about 70 times that of comparable unmined watersheds (47 t/ha vs. 0.7 t/ha). Spoil banks in the eastern United States have been found to have 1000 times the sediment yield of unmined watersheds, and yield from haul roads can be 2000 times greater (Mills and Clar 1976).

Increased sediment discharge caused by mining may fill stream channels and reduce the volume of flow that streams can carry. The result is to increase the frequency of flooding. Again, this effect has been observed most often in Appalachia (Boccardy and Spaulding 1968).

Current mining practices in Appalachia often result in less sediment discharge downstream than did past mining practices. Sediment can be controlled by detaining and minimizing runoff on benches and terraces immediately adjacent to the mine area and by storage in sediment ponds. However, problems remain in the construction of effective sediment ponds in steep-slope areas of Appalachia. Erosion potential in the Midwest is similar to that in Appalachia, but slopes generally are not as steep.

In the West, until recent years, studies of erosion and sediment yield as influenced by land use have focused primarily on the effects of grazing and agricultural practices. In the northern Great Plains, erosion rates are greatest on cultivated uplands. The sparse vegetation in the arid Southwest, combined with the fact that precipitation often occurs as intense thunderstorms, albeit infrequently, results in some of the highest erosion rates in the United States. Sediments yields from cultivated lands with 6 percent slopes in the Bisti area, near Farmington, New Mexico, for example, are more than twice the yields from cultivated uplands on the slopes of the same gradient in the vicinity of Dunn Center, North Dakota (5.4 t/ha compared with 2.3 t/ha). On the other hand, sediment yield from an uncultivated 8 percent slope near Farmington is less than half those from the 6 percent slopes in North Dakota that were cultivated (0.99 t/ha compared to 2.3 t/ha) (Hadley et al. 1980).

These source-area sediment-yield rates cannot be extrapolated from the upland slopes where they were estimated to downsteam areas without consideration of the concept of a sediment-delivery factor (Roehl 1962). Data based on sedimentation surveys of small reservoirs in North Dakota indicate that sediment-yield rate decreases with increased drainage area. A 100-fold increase in drainage area in North Dakota may cut sediment yield in half. A similar relationship between basin-sediment yield and drainage area was found in New Mexico, although overall delivery rates are much higher. For example, basin sediment yield in the Bisti area drainage area is 6.7 t/ha for 50 km^2, compared to 0.7 t/ha for a watershed of approximately equal size in the vicinity of Dunn Center, North Dakota (Hadley et al. 1980).

Ringen and his colleagues (1979) compared sediment yield from two small headwater tributaries to the Tongue River in northern Wyoming, one surface mined for coal from 1949 to 1955 and abandoned without reclamation, and one in rangeland. Sediment yield from the mined basin was more than 11 times greater than that from the undisturbed basin, owing to the very erodible steep barren spoil piles and high walls. In the 25 years since mining ceased in the area, the annual sediment yield rate in the mined basin has been 2.6 t/ha, compared with only 0.2 t/ha in the undisturbed basin.

There are few actual data on soil erosion from mined land in the West. At Black Mesa, Arizona, measurements of suspended solids in the runoff from strip-mined areas in 1974 were 300 to 1300 percent greater than concentrations in runoff from undisturbed areas (Verma 1977). Farmer and Richardson (1976) computed annual soil loss from ungraded spoil piles at Decker, Montana, to range from 323 to 1543 t/ha depending on type and slope of overburden. Eroded sediments were of poorer quality than the original overburden (more finely textured, containing more total salts and more sodium, and having considerably higher pH). These erosion rates were not considered to be a serious environmental problem because through internal drainage, the sediments are either routed back into the pit, deposited between piles, or caught in a settling basin. Erosion simulation models have been developed that could be applied to mined land, but it is difficult to determine in advance all variables needed for hydraulic-based infiltration and erosion models (Smith and Woolhiser 1978).

6 Disturbance of Soil by Mining

Pre-mine soil and overburden characteristics and the particular mining methods chosen to deal with them influence the soil that results after reclamation is completed. In this chapter we will first look at some methods for evaluating the effects of soil disturbance. We then examine the effect of overburden characteristics on mining methods and the reclamation process, describe the various methods used to surface mine coal, and discuss the properties of disturbed soils that affect the productive potential of mined land—with a few words about the disturbance of soils by subsidence from underground mining. The chapter concludes with a discussion of soil-forming processes after mining, focusing on organic matter in disturbed soils.

EVALUATING THE EFFECTS OF SOIL DISTURBANCE

Evaluating the effects of soil disturbance by mining involves five major determinations:

- assessment of the productive potential of the natural soils before mining,
- identification of the physical and chemical characteristics of the overburden that will be disturbed by mining,
- estimation of the effect of mining on soil erosion and sediment loss,

- evaluation of the physical and chemical properties of reconstructed soils, and
- evaluation of the productivity of reconstructed soils.

One or more methods may be used in each of these categories.

SOIL SURVEY

A soil survey is an inventory of the soil resources of an area; it provides a data base for the evaluation of soil capabilities and limitations. The U.S. system of soil classification (Soil Survey Staff 1975) is based primarily on the physical and chemical characteristics of the soil profile, many of which are significant in determining the productive potential of the mosaic of soils in a landscape.

Soil surveys are also essential for planning the handling of topsoil for maximum benefit in reclamation. Some severely eroded soils with clayey *B* horizons may be totally lacking in topsoil. Sodic (sodium-containing) surface horizons in some areas are so toxic that they should be buried during mining. On the other hand, some soils in swales and small drainage ways have desirable properties and are so thick that they can serve as excellent material for spreading over the post-mine terrain. If a large tract of land proposed for mining is to be separated into several permit areas, soil maps may be useful in establishing permit area boundaries. Omodt and his colleagues (1975) suggest that reclamation of an entire tract might be improved if permit area boundaries were designed to combine soil areas having ample amounts of suitable plant-growth material with soil areas having limited amounts of suitable material. Schafer (1980) presents guidelines for identifying the best-available soil or overburden materials in a mine area. Atlantic Richfield Company has developed a computer program using data from a soil survey to assist in topsoil removal and replacement planning (Tate et al. 1979).

A soil survey in an area to be mined should be of sufficient detail to allow comparison of pre-mine and post-mine soils and identification of soil characteristics on which the mining and reclamation plan may be properly based. Soil maps of mine areas will generally need to show more detail than do conventional maps at the standard scale of 1:20,000 that are prepared by the Soil Conservation Service (SCS). Standard SCS soil-survey maps do not delineate units smaller than 2 acres. Consequently, an area designated as having one soil type on an SCS map may also contain a distinctively different soil over an area less than 2 acres, which will not appear on the map. More detailed mapping of soils allows delineation of small areas of differing soil types and recognition of soil properties necessary to meet the special requirements of mined-land reclamation (Patterson 1976).

For North Dakota, Omodt and his colleagues (1975) recommend a mapping scale of at least 1:4800 to show the kinds and classes of soil properties significant to reclamation. Schafer (1980) suggests a scale of 1:6000 for use in selecting topsoil and subsoil materials in the northern Great Plains, but notes that less detailed maps may be suitable if a qualified soil scientist is on site during stripping operations. The National Coal Policy Project recommended a scale of at least 1:7930 as a prerequisite for developing a reclamation plan (Murray 1978). A high level of detail is necessary where soil characteristics important to reclamation are highly variable or where the reclaimed land is to be used for intensive agriculture.

Mapping scales such as the 1:20,000 scale used by the SCS are probably acceptable where variability of soil properties is not critical for reclamation, as may be the case in forestry districts, in which topographic factors such as slope position, shape, and aspect have greater effect on forest productivity than do the characteristics shown in conventional soil maps. Problems with the use of standard SCS soil maps and soil survey information for the evaluation of forest productivity have been discussed by Jones (1969).

Something that might be valuable as part of a soil reconstruction plan is the preservation of sample patches of original soil landscapes near the areas disturbed by mining. The patches would serve as reference areas, not only during post-mining landscape reconstruction, but also during the period of monitoring the reconstructed landscape.

Overburden Characterization

Chemical and physical properties of the overburden must be evaluated before mining to identify potentially toxic material that should be buried and to identify strata that may be beneficial in soil reconstruction because of plant-nutrient or other values. Geologic studies in Appalachia have shown regional differences in the properties of coal seams and overburden that are good indicators of the acid-producing potential of the overburden (Carrucio et al. 1977). In the West, identification of the presence of sodic or alkaline strata is important for reclamation planning. At Colstrip, Montana, a sampling pattern of boreholes on a 30- to 60-meter grid has been found necessary to delineate unsuitable overburden material adequately to implement selective handling (Dollhopf 1979). Sobek and his colleagues (1978) describe field and laboratory methods that can be used to evaluate overburden, and Sandoval and Power (1977) have described sampling and laboratory methods that are recommended for chemical analysis of mined-land spoil and overburden in the western United States. Regional differences in overburden and the effects of overburden characteristics on mining methods are discussed in more detail later in this chapter.

Estimating Soil Loss

Predicting the effects of erosion caused by mining disturbance is important both for preventing adverse off-site impacts during and after mining and for protecting reclaimed soils. In most cases, the Universal Soil Loss Equation is the best tool available to plan erosion control in mined-land reclamation.

The Universal Soil Loss Equation was developed mainly from data collected from small runoff plots east of the Rocky Mountains. It is an empirical equation developed to estimate erosion losses from cropland:

$$A = R\ K\ S\ L\ C\ P$$

where

A is soil loss in tons per acre or metric tons per hectare;

R is the number of rainfall erosion index units, which are derived from measures of the energy and intensity of rainfall that occurs in an area on an average annual basis;

K is the soil erodibility factor and is the soil loss rate per erosion index unit for a specified soil;

L is the slope-length factor and is the ratio of soil loss from the field slope lengths to that of a standard reference slope length under identical conditions;

S is the slope-steepness factor and is the ratio of soil loss from the field slope gradient to that from a reference slope of 9 percent under otherwise identical conditions;

C is the cover and management factor and is the ratio of soil loss from an area with specified cover and management to that from an identical area of continuous fallow;

P is the supporting practice factor and is the ratio of soil loss with a support practice to that with straight row farming up and down the slope.

Complete instructions for determining each of the factors are given by Wischmeier and Smith (1978).

This equation is universal only in the sense that in any given situation the above six factors probably govern most of the erosion that occurs on a field. A number of refinements have been made in the equation in recent years to accommodate such factors as snow melt and cover conditions. A soil erodibility nomograph has been developed for determining *K* factors (Wischmeier et al. 1971). The simplicity and ease of use of the Universal Soil Loss Equation make it by far the most widely used estimator of gross erosion from cropland in the United States and probably in the world. Cautions on its use are carefully spelled out by Wischmeier (1976).

The Universal Soil Loss Equation can be used to estimate gross erosion from surface-mined areas (Gee et al. 1976, U.S. Soil Conservation Service 1977), but some modifications may be required. The Universal Soil Loss Equation was developed for cropland slopes, which are usually under 20 percent. This means that for surface-mined land it may be necessary to extrapolate the slope factor to much steeper slopes than those from which the original slope-factor equations were developed. The exponent for the slope-length factor may be different for 30-45 degree slopes than for usual cropland slopes. Published data are very scarce or nonexistent for erosion from slopes of this steepness. Some research is under way at Coshocton, Ohio, but no data are yet available.

Another potential problem is with the *K* or soil erodibility factor. Much of the material exposed in surface mining is very different from the *A* horizon of farmland. Roth and his colleagues (1974) worked with subsoils and developed a nomograph for these subsoils. But they based their results on only about 6 subsoil sites, and considerably more research is needed to develop *K* values for a greater variety of subsoil types.

Another problem is differential settling, which may make slopes quite uneven and soil loss difficult to predict. However, if slopes are steep enough and not protected by cover, the low areas will be filled by eroded material, and unevenness will be minimized.

Slope steepness affects many aspects of erosion control. Erosion-control practices such as mulches, terraces, or diversions may have quite different results on very steep slopes than they do on slopes of less than 20 percent. The overall gradient of a restored watershed together with the nature of the subsoil material may cause such practices as terracing and diversions to fail even under quite conservative spacings based on cropland criteria.

Steep slopes must also be protected from runoff from large areas of relatively level land above the slopes. Such runoff can invalidate estimates of the Universal Soil Loss Equation, especially if the surface material is susceptible to detachment by runoff. Surface mulches are not effective in protecting against excessive runoff from areas above the steeper slope.

Stones present on the surface will protect the underlying soil from erosion. A pebble or rock pavement can reduce soil loss to much below that predicted by the Universal Soil Loss Equation, and to compensate, the *C* factor should be adjusted. Details have not been worked out precisely, but recent work by James Box, USDA-SEA-AR at Watkinsville, Georgia, should be very helpful in determining the necessary adjustment.

Perhaps the most flagrant misuse of the equation has been in determining gross erosion on large areas without taking into account deposition of eroded material along the way to the principal drainageway. The Soil Conservation Service deals with this problem by using the Gross Erosion-Sediment Delivery Method. The equation is

$$y = E(DR)/W_S$$

where y is sediment yield per unit area, E is the gross erosion (estimated by the Universal Loss Equation), DR is the sediment-delivery ratio, and W is the area of the watershed above the point for which the sediment yield is being computed.

These factors are discussed further by Wischmeier and Smith (1978). Methods of estimating sediment yields from gullies, streambeds, and streambanks are given in the SCS *National Engineering Handbook* (U.S. Soil Conservation Service 1971). Guides for estimating sediment-delivery ratios are also given in the SCS engineering handbook and by Stewart and his colleagues (1975).

Even with the shortcomings mentioned above, it is possible to get an approximation of effective slope lengths for contouring, width for terrace spacing, level of residue cover, and width of grass or stubble strips, and the effectiveness of various cropping practices. Extrapolations of slope lengths to 1000 feet and slope gradients to 50 percent are possible. Average annual *R* values are available for most of the United States (Wischmeier and Smith 1978). *K* values can be estimated using soil erodibility nomographs. *C* and *P* values can be determined singly or in combinations that will keep soil loss within desired limits. The Universal Soil Loss Equation should be applied by people who have experience in the area and with the soil material used in restoring the surface-mined land. The equation should be used conservatively, and with diligent follow-up to see how effectively erosion was controlled. If this is done, "the Universal Soil Loss Equation can be quite useful for predicting the effectiveness of each feasible reclamation plan for mined areas" (Wischmeier and Smith 1978).

Characterization of Mine Spoils

After mining is completed, a new soil survey of the reclaimed area will identify the general characteristics of the reclaimed soils. Field methods similar to those used for mapping undisturbed soils can be used for such a survey, but modification of standard survey procedures is necessary to take into account the special characteristics of mine soils. Sobek and his colleagues (1978) have outlined methods for describing post-mine soils. Criteria for classifying mine soils in the context of the USDA soil taxonomy are at various stages of development in different coal regions.

Early spoil-classification systems emphasized a few major properties of mine spoils, such as acidity, slope, stoniness, and particle size (McKeever 1963, U.S. Soil Conservation Service 1973). Research in Appalachia has resulted in a fairly detailed classification system in the context of the USDA soil taxonomy, including 9 proposed new subgroups (Smith and Sobek 1978), and this system has been used sucessfully in the development of 7 distinct mapping units of mine spoils in a county soil survey in West Virginia (Delp 1978). The spoil classification system developed in Appalachia has been applied to a limited part of the Midwest (Ammons and Perry 1979). There has been less success in applying principles of soil taxonomy to mine spoils in the West. Schafer (1979), in studies of mine spoils in Montana, concluded that the USDA soil taxonomy was inadequate to identify many key properties of mine spoils affecting soil management.

Systematic regional characterization of mine spoils appears to be at too early a stage to develop a comprehensive scheme for classifying mine spoils in the context of the USDA soil taxonomy. In particular, much more work needs to be done in coal regions in the West, Gulf Coast, and Midwest. Furthermore, the need for mine-spoil classification may be changed by the requirements of the federal surface-mine law. Soil-reconstruction practices under the new law will probably create more uniform soil conditions through greater emphasis on selective handling of overburden and topsoil. If profiles are reconstructed to resemble the natural profile of the pre-mine soil, continuation of classification similar to that for pre-mined soils may be justified.

Early indicators of reclamation success could allow less emphasis on long-term monitoring of post-mine vegetation. Such indicators might be discovered by systematically conducting detailed surveys of mined sites in different regions. More intensive field and laboratory methods than are used currently for standard soil surveys would be needed. The resulting information on physical and chemical properties of the soil, along with careful monitoring of actual productivity after reclamation of the sites, would allow preliminary evaluation of how the beneficial and adverse effects of mining and reclamation have interacted.

Evaluating Post-Mine Productivity

Whenever the goal of reclamation is to restore or improve post mine productivity, procedures must be established for evaluating the productivity of reconstructed soil in relation to the pre-mine soils. It is important to evaluate the productivity of reconstructed soils properly even if the acceptable time period for restoration of post-mine productivity is longer than the period of responsibility of the coal operator to perform reclamation (i.e., if the longer-term natural soil-forming processes are relied upon to restore productivity). Near-term losses of productivity that are deemed acceptable on the basis of economic decisions must be quantified, and the expected long-term productivity levels must be projected.

There are two basic approaches to measuring revegetation success. The first is to specify levels of biomass production—amount of ground cover and kinds of plant species to be established—based on the capacity of soils to support vegetation or to grow crops. For example, an aggregate productivity index for the soils in an area can be determined on the basis of expected crop yields for individual soil series. The Soil Conservation Service has yield estimates for most established soil series, often including expected yields under different levels of management. A target yield for one or more crops could be selected as a goal for reclaimed lands from SCS estimates at a specified level of management, or perhaps target yields might be established using yield data from the county where the mine will be located, to reflect local growing conditions.

The second approach to evaluating productivity of reclaimed land is to set aside an undisturbed reference area near the reclaimed site, with a pattern of soils similar to that of the pre-mine soils. The productivity of the reclaimed area is then compared with the productivity of the reference area. The advantage of the first approach, setting target yields, is that once the target is set, it is a simple matter to determine whether the reclaimed soils have met the target. However, such targets do not take into account yearly variations in weather. The use of a reference area is more complicated than setting target yields but has the advantage of being more directly related to the conditions in the local area, reflecting more accurately variation in weather than does the setting of a target yield.

It is probably not necessary for reference areas to have exactly the same pattern of soils as the area to be mined, as long as the aggregate productivity index of the reference area is the same as that of the pre-mine soils.

Whether target yields or a reference area is used, the evaluation of yields from reclaimed land should be based on data collected over a period of several years.

The level of management chosen as a basis for comparison of pre- and post-mine productivity will depend on the post-mine land use. When restoration of a viable self-sustaining ecosystem is the goal, the comparison of productivity should begin after fertilization, seeding, and other short-term management practices to establish vegetation are complete. Where the reclaimed land is to be used for agricultural purposes, the comparison should also begin after short-term special management practices are complete, and the soil has had adequate time to respond. The comparison should be based on productivity of mined and unmined land under equivalent levels of management.

Probably the simplest way of comparing productivity under equivalent levels of management would be to use exactly the same cropping practices in a reference area and the reclaimed area (i.e., the same tillage practices, timing of operations, planting density, fertilization levels, and so on). A more complex method of comparison would be to produce equivalent returns from the reference area and the reclaimed area, but not necessarily through equivalent practices or even crops grown. Such an approach recognizes that reclaimed soils are not likely to duplicate exactly the characteristics of pre-mine soils but that the changes in characteristics may reduce some and increase other costs of production. If net returns from a reclaimed area and a reference area were the same, restoration of productivity could be assumed even if different management practices had been used. On the other hand, if equivalent yields were achieved but the costs of production on the reclaimed land were higher, this would mean that the productive potential of the soil had not been restored.

Restoration of productivity at one level of management may not ensure that the productivity at other levels of management will be the same. Bernard (1979) has speculated that the increased use of fertilizer may mask the importance of soil characteristics, such that yields could be equivalent at a high level of fertilization, but once the land were returned to a farmer who used a lower level of fertilizer, the yields would be lower than expected for an unmined soil. Conversely, the physical properties that affect soil productivity, such as water-holding capacity and rooting depth, may be more critical at high levels of fertilization than at low, and thus restoration of equivalent yields at a low level of fertilization might not hold up under a high level of fertilization. Thus croplands, at least, may require productivity comparisons based on more than one level of management.

So far, we have focused primarily on levels of management in relation to cropland, which generally requires fairly high inputs of energy through tillage and additions of fertilizer. Other land uses, such as for range and forest, require management as well to make best use of the productive potential of the soil. Management of rangelands and forests usually takes the form of regulating patterns of animal use or selective cutting to enhance growth of the most desirable trees, rather than tillage and fertilization.

The different management requirements for rangeland necessitate a different approach to evaluating post-mine productivity of reclaimed land. For example, crested wheatgrass pasture will not support season-long grazing as well as native pasture of mixed species, owing to the shorter period of active plant growth in this one-species community (Parton et al. 1979). Thus the establishment of monospecific stands of crested wheatgrass on mined land—even if the yield is the same as that for undisturbed soils—could not be considered reestablishment of the productive potential of the mined land, because the capacity to support cattle is lower than that of native range of mixed species, although establishment of crested wheatgrass stands might be acceptable if the amount and location of such pasture were planned with regard to the grazing needs of the integrated agricultural unit of which the mined land would be a part.

Cropland, rangeland, and forests all require different kinds and intensities of management. Furthermore, management practices for the same purpose may vary considerably from soil to soil and region to region. These disparities need to be recognized when deciding how to evaluate the productivity of mined land at a specific site.

OVERBURDEN AND THE MINING AND RECLAMATION PROCESS

The amount and character of overburden are major factors in determining which sites can be mined economically and which mining methods can be used. And, after the coal has been extracted, it is the overburden that remains and forms the basic material for the reclamation process.

Thickness and Stripping Ratio

Within all major regions in the United States (see Figure 2.2), the thickness of the coal deposit and the thickness of the overburden can vary considerably. Although some surface-mining methods being planned in West Germany will remove overburden to as much as 300 meters deep, most coal surface mines currently do not go deeper than 60 meters (Stefanko et al. 1973). The major factor limiting the depth of mining is the economic stripping ratio. In the United States stripping ratios have traditionally been expressed as cubic yards of overburden removed per ton of coal recovered.

The stripping ratio that can be handled at any mine is determined by both economic and technical factors. When the market value of coal is high relative to the unit cost of overburden handling, the break-even stripping ratio will be larger. The cost of handling overburden depends on its hardness and thickness, the topography of the site, the equipment being used, and the amount of special handling required for reclamation. Reclamation requirements such as the separate handling of topsoil and toxic material or requirements concerning post-mining land topography add to the cost of overburden handling and reduce the economic stripping ratio, unless the added costs can be passed through to the consumers of the coal.

Different types of mining equipment have different limits on the depths of cut they can economically make. Generally larger equipment can make deeper cuts more efficiently. The 1960s and 1970s saw a trend toward larger equipment in surface mines, but a point of diminishing returns appears to have been reached. Hard overburden requires preparation before it can be moved, and the more preparation required, the higher the costs. Steep topography may limit the adaptability of large equipment and thus reduce the economic overburden limits.

When a naturally dense material such as rock is broken up, it will have more voids between the solid particles than it had in its natural state, and its bulk density will change. In soil mechanics and earth-moving literature the resulting increase in bulk volume per unit weight of solids is called swell (Nummally 1977) and is usually expressed as a percentage of the natural in-place volume. Shovels, draglines, and wheel scrapers that dump spoil in loose piles produce spoil material with up to 25 percent swell. Trucks and scrapers that run over the spoil during placement generally recompact the material and produce less swell, commonly around 10 percent.

The coal volume removed may equal the swell volume of the overburden, but it is more likely that the coal volume will be less than or more than the swell volume. In Appalachia and the Midwest, where there is a high stripping ratio and naturally dense overburden, the volume of coal removed is generally less than the swell volume. In the northern Great Plains, where the coal seams tend to be quite thick, the volume of coal removed is generally greater than the swell volume of the overburden.

The general trend over the past decade has been toward higher coal prices and larger mining equipment, both of which contribute to an increase in the average stripping ratio is U.S. mines. Moreover, sites with low stripping ratios are generally mined first in a region, and thus the average stripping ratio will probably continue to rise as less favorable sites are developed, until the limits of economics and technology are reached.

Grim and Hill (1974) reported that, based on 1967 data, the average stripping ratio for active coal mines in the United States was 12.8, with most western mines being generally below the average and eastern and midwestern states average and above. In the Powder River Basin of northeastern Wyoming and southeastern Montana, where especially thick coal seams are mined, the stripping ratios generally average less than 3 (Kelly 1979). As a general rule, over the past decade coals with a stripping ratio greater than 30 have been marginally economical for surface mining, and stripping ratios greater than 40 have been uneconomical (U.S. Office of Technology Assessment 1979).

Slope of the Overburden and Coal Beds

Spoil placement during mining is severely limited on the steep slopes commonly found in the eastern mountains. Mining and reclamation must frequently be done in cramped quarters, resulting in inefficiencies of materials handling and accordingly higher costs. In addition, the problems of controlling drainage and erosion are more severe on these steep mountainsides than where slopes are more gentle.

Most bituminous coal in the East and Midwest lies in seams that are nearly horizontal. In the eastern mountains this generally means that only coal near the outcrop can be economically mined using surface methods. Auger mining has been used to recover additional coal from deeper in the hillside, and in some cases deep horizontal underground mines, called drift mines, are developed starting at the final cut of a surface mine. Because the width of pits on the steep slopes is severely limited, the trend is toward smaller, more mobile equipment such as front-end loaders and trucks to move the overburden along the cut in a haul-back procedure. This type of mining is generally less capital intensive but requires greater operating expenses than the large shovel or dragline.

The overburden in eastern mines contains a large percentage of hard rock, which swells when moved during mining. On most of the steep land the stripping ratios are relatively high, and an excess of spoil results. On the steep hillsides the options for disposal of excess spoil are limited. The excess material must be hauled to a suitable disposal area, generally the upper end of a mountainside hollow, and carefully placed to ensure stability.

In the Midwest, where overburden thickness is less variable within a given site and the topography is moderate, the use of large draglines—with their greater operating efficiency—is common. The more gentle slopes also allow more flexibility in spoil placement and sediment control.

In the northern Great Plains, most of the coal lies in thick, flat seams or multiple seams under flat to rolling topography. Many mines have very low stripping ratios and produce less spoil material than needed to refill the mine pit. It is sometimes necessary to grade material around these mine pits to make the final reclaimed site topography blend with the surrounding area.

Both in the East, where steep topography occurs over horizontal coal beds, and in some parts of the mountainous West, where topography and coal show marked slopes, the variations in overburden thickness require more extensive handling of material during reclamation. The overburden volume may vary widely from pit to pit, and direct placement of spoil in an adjacent, mined-out pit is frequently impractical. In these areas, highly mobile mining equipment is required to meet reclamation requirements.

Physical Nature of Overburden Material

The relative difficulty of removing and handling overburden material at a particular site will depend on the type of rock and soil, the hardness of the rock, and the amount of ground water present in the overburden.

In general, the eastern coal region tends to have thick deposits of hard rock with relatively thin layers of unconsolidated material and topsoil (Smith et al. 1976). Most of the coal beds lie high enough on the landscape to allow easy drainage of working pits. The midwestern coals tend to be associated with relatively thick layers of unconsolidated glacial material including thick layers of topsoil and relatively soft, fine-grained rock. Consolidated overburden in the Midwest and Appalachia may be very similar in places (Ammons and Perry 1979). In many areas of the Midwest the coal lies below the regional water table. Lignite deposits in the Gulf Coast region are generally associated with unconsolidated sands and muds (Kaiser 1974). The northern Great Plains are characterized by overburden with little or no topsoil and relatively soft rock (Persse et al. 1977). In the Rocky Mountain region coal is generally associated with overburden having little or no topsoil and relatively hard rock.

In general, overburden materials tend to grade from coarse in the East to fine in the Midwest (Smith et al. 1976). Coarse-grained materials have high infiltration but low moisture-holding characteristics. Vegetation growing on these soils experiences frequent stress from lack of available moisture. Such soils also exhibit very high erodibility when disturbed, and thus where these materials occur on moderate to steep slopes, the need for erosion control will be great.

Fine-grained materials have low infiltration but high moisture-holding characteristics. These materials form soils that tend to have high runoff and poor internal drainage (Foth 1978). Fine-grained materials have more tendency to compact when handled with heavy machinery. This compaction can cause severe problems in drainage and root penetration after regrading (Smith et al. 1976).

Chemical Nature of Overburden Material

The chemical makeup of the overburden will have an effect on the reclamation methods required to control environmental pollution and obtain biologically productive soils after mining. In the East and Midwest, where the average climate includes an excess of precipitation over evaportranspiration, the major problems are acid mine drainage and low fertility in highly leached soil profiles. Where leaching or erosion have produced soils with low fertility, other layers will frequently be more desirable for surface placement (Foth 1978).

The potential for acid mine drainage depends on the net acidity of the overburden, determined by comparison of the acid-producing potential of pyritic material to the acid-neutralizing potential of the calcareous material. In general, the acid-producing potential decreases from east to west; it is essentially absent in the western coal region. The acid-neutralizing potential of coal overburden generally increases from east to west. Therefore, the greatest acid-producing potential occurs in the East. Acid-producing potential also tends to decrease from north to south (Smith et al. 1976).

One way to control acid mine drainage is to reduce the contact between oxygen and the pyritic material in the overburden. This can be accomplished by burying the pyritic material under fine-grained, nontoxic overburden or below the prevailing regional water table. More fine-grained nontoxic overburden material is available in the Midwest than the East, and water tables tend to be higher in the Midwest (Smith et al. 1976).

Spoil materials in the northern Great Plains mining area are often extremely fine textured, moderately saline, and highly sodic. The severity of undesirable conditions generally increases with depth below the surface (Sandoval et al. 1973). Deficiencies in nutrients, especially nitrogen and phosphorus, are widespread in spoils of the arid and semiarid regions (Bauer et al. 1978) and also in the humid regions (Mays and Bengtson 1978). Concentrations of toxic chemical leachates from overburden strata may create adverse conditions for roots of vegetation growing in the spoils and may pollute seepage water passing through the spoils. Although soil profiles are generally not well developed in the western region, the surface soil is frequently the most fertile material in the overburden and is biologically active. Thus it is an important resource on the site. Selective placement of undesirable materials and topsoil are needed for satisfactory reclamation.

THE MINING PROCESS

As an industry, surface mining for coal in the United States began as early as 1866, using horsedrawn plows, scrapers, wheelbarrows, and carts (Ramani and Grim 1978). As earth-moving machinery became larger and more powerful, economic stripping ratios increased, until today in some areas up to 40 cubic yards of overburden are moved per ton of coal recovered (U.S. Office of Technology Assessment 1979). Most of the time and effort in a surface-mining operation now goes into the removal and handling of the overburden.

In 1940, about 9.4 percent of the coal mined in the United States was extracted from surface mines; by 1972 nearly half the coal mined in the United States came from surface mines (Grim and Hill 1974). It is estimated that less than 40 percent of the recoverable coal reserves of the United States are economically minable by surface-mining methods (U.S. Office of Technology Assessment 1979). Economic and safety advantages, however, will probably make surface mining the primary method in the near future.

It generally requires less capital, equipment, manpower, and lead time to open up a new mine on the surface than one underground. Morever, surface mines recover approximately 80 percent of the coal from a seam, as opposed to 50 percent in underground operations. Health and safety problems for miners are less serious in surface mines, and coal in areas with low stripping ratios are not technically minable using underground methods (Ramani and Grim 1978, U.S. Office of Technology Assessment 1979).

Mining Equipment

Power shovels were the first large pieces of equipment used in surface mines. These machines operate from the floor of the pit, scooping upward through the bank of overburden and casting the spoil to the side. The depth of the cut is limited by the height of the boom and different layers within the overburden are naturally mixed during this digging operation, making segregation for reclamation difficult. Shovels with bucket capacities up to 180 cubic meters and capable of mining to a depth of over 30 meters have been developed. However, power shovels are generally being replaced or used in conjunction with a dragline, except where overburden is extremely rocky.

Draglines operate from the ground surface, dragging a large toothed scoop across the overburden bank and casting the spoil to the side. Because the machine is located above the pit, depth is limited only by the height of the spoil pile. Draglines do require a level bench area ahead of the pit, which must be prepared by other support machinery in steeply sloping areas. However, they generally provide greater flexibility, allow deeper pits, and move more material per hour than shovels (Ramani and Grim 1978). Draglines also allow better segregation of overburden layers for reclamation than shovels.

Large bucket-wheel excavators are used extensively for overburden removal in Europe and have been used to a much more limited extent in the United States. While other machines are limited to a cyclic operation of load-transport-dump-return, bucket-wheel excavators are continuous excavating machines that dig the overburden, dump it onto a conveyor system, and transport it away from the digging face. Theoretically, these machines can move large quantities of material very efficiently. They are very complicated, however, with many moving parts, and they are limited only to handling soft, uniform materials.

Very few mine sites in the United States have this type of overburden. Random boulders in the overburden cause frequent breakdowns, making bucket-wheel excavators problematic. Bucket-wheel excavators have been used primarily in the Midwest, to remove a top layer of unconsolidated material while a second machine moves the harder unconsolidated materials. The unconsolidated nature of overburden associated with lignite deposits in the Gulf Coast region makes the bucket-wheel excavator an attractive possibility, but none are currently in use (Murray 1978).

In recent years, requirements for land reclamation have forced the introduction of additional mobile equipment into surface mining. Front-end loaders, bulldozers, trucks, and wheel scrapers are used frequently in mines today, as support equipment and occasionally as primary earth-moving equipment. Limits on the location of spoil piles in steep terrain and requirements for separate removal and replacement of specific spoil layers have made such mobile equipment necessary on most sites, particularly in the smaller mines of the East.

Mining Methods

The choice of mining method depends on the geology and topography of the mine site. Where the coal lies in relatively thin, nearly horizontal seams under high steep hills and mountains, contour mining is practiced. This situation is typical of the eastern coal region and some limited areas in the Midwest and West. Where the coal lies in relatively thin seams under flat or gently rolling land surfaces, area mining methods are used. These are the predominant methods used in the Midwest, Gulf Coast, and West, and a variation called mountaintop removal is used in some parts of Appalachia. Where the coal lies in thick seams under shallow overburden, open-pit mining is practiced. This method is used in some parts of the West (Ramani and Grim 1978).

Contour Mining

Contour mining begins at the coal outcrop on the side of a hill or mountain. The area is cleared of trees and surface debris. Topsoil and other unconsolidated material are removed from the area. The solid overburden is drilled, fractured using explosives, and removed. The exposed coal surface is cleaned, and the coal fractured, if necessary, with explosives or ripping machines. The coal is then loaded onto trucks and hauled from the pit. The pit is extended along the contour of the hillside, following the coal outcrop to the limits of the mine.

In the past, overburden was cast or pushed down the slope below the coal seam, creating unstable slopes that were prone to erosion and landslide. This procedure has been replaced by more environmentally acceptable haul-back procedures: newly excavated overburden material is hauled back along the cut to a point where coal has been removed and used to refill the cut area for reclamation. Topsoil or other suitable material is saved and respread over the surface of the replaced and graded spoil, and the area is revegetated (U.S. Office of Technology Assessment 1979).

Overburden in a typical surface mine will increase in total volume on the order of 10 to 25 percent when excavated. This requires an excess volume of spoil materials to be handled during backfill operations. Excess spoil is generally dealt with in contour-mine reclamation by filling in the heads of the narrow, steep-sided valleys adjacent to the mine pit according to well-engineered methods called head-of-hollow fill (Ramani and Grim 1978).

Area Mining

Area mining also begins with surface preparation. After removal of topsoil and subsoil, where required, an initial cut is made down to the coal, and the spoil is cast into a stockpile to one side away from the planned mine. This cut—referred to as the box cut—is extended across the property to the limits of planned mine and coal is removed as in a contour operation. Additional cuts are then made parallel to the first, with the spoil from each succeeding cut being placed in the previous mined-out pit (Figure 6.1). Each cut may be several hundreds or thousands of meters in length, and

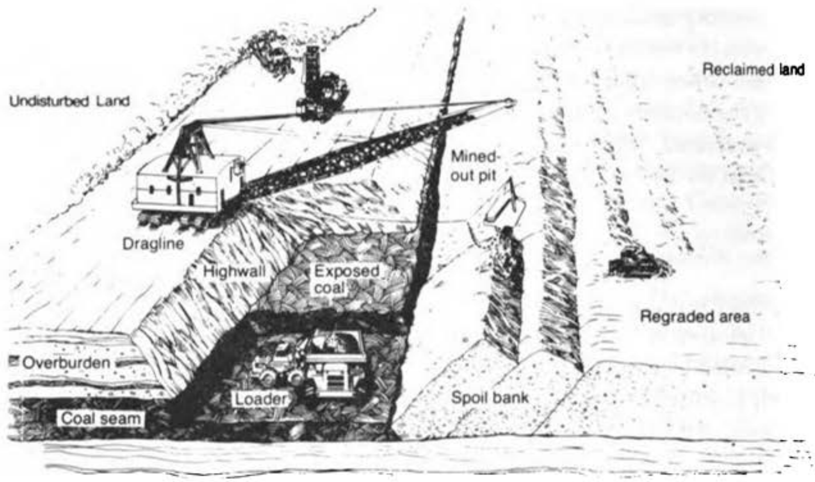

FIGURE 6.1 Area strip mining with concurrent reclamation. *Source*: Leathers (1980).

the final cut may be more than a kilometer from the intial cut. The former practice was to leave the spoil in a ridge and valley configuration, with an open final cut that frequently filled naturally with water, forming a long narrow lake. Today, reclamation requirements include smoothing the surface to conform to the surrounding topography, refilling the final cut, replacement of topsoil, and revegetation. These requirements have led at some mines to the introduction of wheel scrapers for topsoil handling and large bulldozers for regrading of spoil piles and topsoil.

Open-Pit Mining

Open-pit mining methods are practiced where thick coal seams lie under shallow overburden. Large mobile scrapers or shovels and trucks are used to remove the overburden from a relatively large area and stockpile it around the edges of the mine. The coal is then removed using large shovels and trucks (Figure 6.2). In the past, the open pit was abandoned after coal removal. Modern practice requires the backfilling of the pit with spoil material, regrading, replacement of topsoil, and revegetation. Frequently the volume of spoil material is smaller than the volume of the hole left by the removal of coal, and the pit cannot be refilled complely but will be regraded to fit in with the surrounding landscape. The large size of the pit makes concurrent reclamation difficult or impossible.

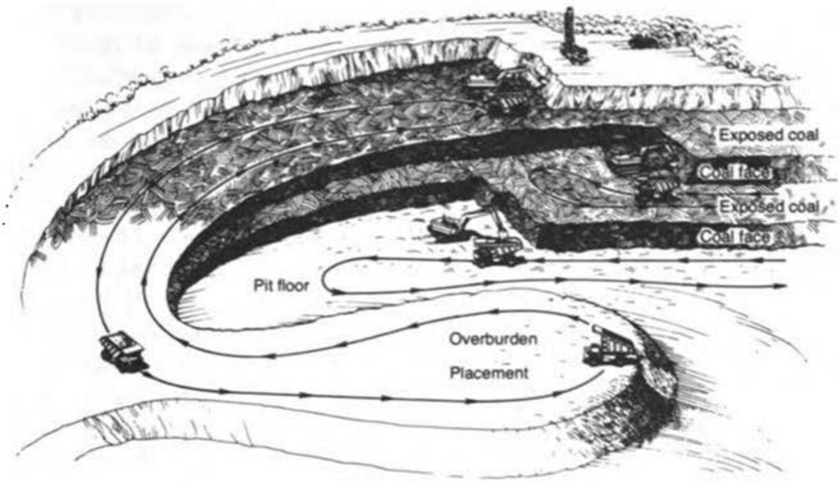

FIGURE 6.2 Open-pit coal mining. *Source*: Leathers (1980).

Remining

The increased price of coal and the development of larger earth-moving machines has increased the economic stripping ratio significantly during the past decade. In some instances, these economic incentives have resulted in the remining of old sites. In many of the contour mines in the East, the original mining company quit after one or two cuts along the contour, leaving behind coal deep under the hillside. Today miners are returning to these old sites to take additional cuts and in some instances to completely remove mountaintops using larger equipment and area mining techniques. In some states mine operators have been required to reclaim not only the newly disturbed areas but the earlier abandoned areas as well. Reclamation of these orphan mined lands as a result of remining activities has made a substantial contribution to the quality of the environment in many areas.

In some areas natural processes have stabilized orphan mined land and new, relatively stable environments have developed. In such areas remining opens old wounds in the landscape, which could again produce the sediment and acid mine drainage problems that have healed.

In area mines of the Midwest and West the increase in economic stripping ratios has made it worthwhile to mine deeper seams of coal, which were not taken during the first mining operation. This process requires the removal of all the overburden over the lower seam, including the overburden that was handled previously. The stripping ratio for the new, deeper seam is thus higher than the incremental increase of handling those materials between the upper and lower seams in one mining operation. On lands where the initial mining was done without saving and replacing topsoil, remining can mix spoil materials even more and complicate the reclamation procedure. The costs of rehandling old spoil and the added complications in reclamation make this type of remining less attractive than remining to follow the original seam as it dips deeper underground.

Data on the amount of remining currently being practiced or anticipated are scarce. An informal survey was conducted in the Midwest by the Panel on Mining and Reclamation of this Committee. State-agency personnel in Illinois estimate that approximately 40 hectares per year have been affected over the past 8 years and expect this trend to continue. In Kentucky approximately 10,000 hectares have been affected by remining. In Indiana estimates are that less than 10 percent of old mines have been reopened. In Missouri, Oklahoma, and Kansas very little remining has occurred or is anticipated.

THE EFFECTS OF MINING ON PRODUCTIVITY

Surface mining for coal may have beneficial or adverse effects on soil productivity, depending on the mining and reclamation methods used at a site and the extent to which these methods alter the physical and chemical characteristics of the soil. Many studies have documented the various changes in soil properties that can occur as a result of mining. If data from these studies are to be used to predict the nature and extent of possible changes at a particular site, care must be taken to determine what mining projects are comparable before conclusions drawn from one project are used in making decisions on others. The effects of different mining and reclamation methods should be considered even when the physical and chemical characteristics of the soil and overburden are comparable.

Beneficial Effects of Mining Disturbance

Beneficial modifications by mining and reclamation include improving the physical characteristics of the soil, increasing the availability of nutrients necessary to plant growth, and removing toxic elements that inhibit plant growth. Where rooting depth for plants is restricted by shallow bedrock, as is common in Appalachia, or by a claypan or fragipan, as is common in southern Illinois, southwestern Indiana, and western Kentucky, the breaking up of the impervious layers by mining can increase the depth to which plant roots can penetrate. Available-water capacity of a soil may be increased as a result of the increase in rooting depth or of a change in the texture of the surface material. Studies of shaly iron-mine spoils in West Virginia ranging from 70 to 130 years in age showed that the spoils had rooting depths greater than 72 inches, compared to 26-36 inches in undisturbed native soils (Smith et al. 1971). Water-holding capacity was also higher than in native soils. In the Texas lignite belt, where soils are naturally sandy, the mixing of soil and overburden by mining results in an increase in silt and clay that doubles the water-holding capacity of unmined soils (Hons et al. 1978). Coal-mine spoils in northwest Colorado may have a more favorable moisture regime for growth of deep-rooted plants than the moderately fine to fine-textured soils common in the area (Berg and Barrau 1972). Increased water-holding capacity is not likely, however, where spoils are rocky. Pederson and his colleagues (1980) found mine soils in Pennsylvania to have one quarter the water-holding capacity of native soils.

Mining may also modify soil chemistry in beneficial ways. We have mentioned the burial of unfavorable or even toxic natural topsoil under more suitable materials by selective handling of spoil during mining. Even when topsoil is not toxic, subsoil materials may contain higher levels of nutrients. In the West, toxic accumulation of micronutrients such as boron and selenium occurs locally in natural soils; in the East deficiency of micronutrients is the more common situation. Saline soils (which contain soluble salts in concentrations that interfere with plant growth) and sodic soils (with sufficient exchangable sodium to interfere with the growth of most plants) are found throughout the West and in some areas occupy a significant proportion of the landscape. Disturbance of saline-sodic soils by mining may improve productivity if there is sufficient suitable material to create more favorable soils.

Most soils formed on pre-Wisconsinan land surfaces in the Midwest and in the Gulf Coast are relatively infertile, owing to natural leaching of nutrients from strongly developed soil profiles. These soils may benefit from disturbance if the reconstructed soil includes material that has more available nutrients than the original soil profile. The iron-ore spoils in West Virginia mentioned earlier were found overall to have a higher cation-exchange capacity, higher levels of base nutrients (calcium, magnesium, and potassium), and more available phosphorus than native soils (Smith et al. 1971). In Perry County, Illinois, where original soils are formed in leached loess, unreclaimed spoils with a large percentage of limestone provide more productive pasture than adjacent unmined land, probably owing to the breakup of a claypan and higher levels of base nutrients (Murray 1978). Lignite spoils in Texas have been found to be higher in content of exchangeable bases (calcium, magnesium, and potassium) than native soils (Hons et al. 1978).

Adverse Effects of Mining Disturbance

Mining can, of course, adversely affect soil productivity. Soils with detrimental physical or chemical properties may be introduced to the surface and biological activity in the soil may be reduced or interrupted. This section describes adverse effects of soil disturbance that have been documented in various regions of the United States. Approaches to overcoming or mitigating adverse effects of soil disturbance by mining are described in the next chapter.

The old iron-mine spoils in West Virginia discussed earlier have a higher bulk density, lower infiltration rates, weaker aggregation of soil particles, lower nitrogen levels, and less organic matter than unmined soils (Smith et al. 1971). An increase in bulk density generally indicates a reduction in water-holding capacity for a given volume because of reduction in pore space between particles. Lower infiltration rates are detrimental, because less water enters the soil profile and erosion by surface runoff increases. Weaker aggregation of soil particles contributes to both reduced infiltration rates and reduced water-holding capacity. Low organic-matter and nitrogen content also indicate lower microbial populations and less favorable conditions for maintenance of soil nutrient status and formation of soil humus.

Such effects of soil disturbance are common in terrains that have been surface mined for coal, but their severity varies greatly with the way the spoil was moved and replaced. The effect of changes in infiltration rates, bulk density at the surface, and soil particle aggregation must be evaluated in context with the topography of the spoils. For example, if infiltration rates are reduced as a result of mining and reclamation, lower slopes might prevent the production of increased runoff.

Limstrom (1960) found infiltration rates up to 7 times greater on ungraded banks than on adjacent graded banks in Ohio. Compaction of spoils during regrading and increases in content of coarse fragments usually increase the bulk density at the surface of mine spoils compared to undisturbed soils. At depth, however, bulk density may be much lower than in native soils, owing to large cavities in the spoils (Pederson et al. 1980). Such decreases in bulk density reduce water-holding capacity by allowing water to drain rapidly through the spoils. Similar relationships between graded and ungraded spoils have been found in numerous other studies in the Midwest and Appalachia (Curtis 1973).

Grandt and Lang (1958) found infiltration rates of ungraded spoil ridges ranged from 2 to 40 times those of graded spoils and strike-off ridges in Illinois. Infiltration rates for vegetated ridges averaged 5 times that of bare ridges. Arnold and Dollhopf (1977) found bulk density of spoils in Montana to be 54 percent higher than in native range soils. Infiltration rates of the native soils were 60-86 percent higher than those of the spoils. These factors, combined with a saturated hydraulic conductivity in the native range that was 3.5 times greater than in the spoils, resulted in approximately 1.5 times more water moving through range soils than through mine soils.

Gilley and his colleagues (1976), using simulated rainfall events in North Dakota, found unrestricted water movement into undisturbed native rangeland but minimal movement of water into uncultivated spoil. Water flow into cultivated spoil material was restricted to less than 15 centimeters depth, and water storage on topsoiled sites was limited to the topsoil materials.

Increased bulk density and soil crusting has been found to inhibit oxygen diffusion and seedling emergence in Texas lignite spoils (Hons et al. 1978). The crusting of lignite spoils is aggravated by the lack of organic matter, which would normally serve as a binding agent for soil particles. The low content of organic matter also limits the growth of nitrifying bacteria, which carry on the biological oxidation of ammonium ions (NH_4^+) to nitrate ions (NO_3^-), a form more readily taken up by plants. Thus, the low organic matter in lignite spoils reduces the efficiency of ammonium nitrate fertilizers (Hons et al. 1978). On the other hand, if fertilizers containing only nitrate are used, several applications must be made throughout the growing season, because the very soluble nitrate that is not taken up immediately by plants is quickly lost in runoff and leaching.

Overburden materials generally contain little organic matter compared to topsoil, so soil disturbance by mining usually results in low levels of organic matter if topsoil is not saved and replaced. Coal fragments or black shales may elevate organic-matter content of surface spoils, but they do not contribute usable nutrients. In fact, such material may hamper the use of tests for organic matter as an indicator of fertility (Geyer and Rogers 1972). Such material may also have high acid-producing potential and other properties detrimental to plant growth (Byrnes et al. 1980).

Low availability of nutrients and organic matter in spoils creates an impoverished environment for soil microbiota. Jurgensen (1978), in a survey of the limited information available on microorganisms in unvegetated coal-mine spoils, found that microbial populations are generally much lower than normally found in undisturbed or agricultural soils nearby, the only exception being in some coal spoils in New Mexico, where bacterial populations were comparable to soil beneath adjacent sagebrush-juniper stands. Bacterial numbers generally increase in mine spoils as vegetation becomes established (Wilson 1965). Organic matter formation and evolution of soil microbiota are discussed in more detail later in this chapter.

Chemical properties of overburden that create problems for revegetation in Appalachia and the Midwest relate primarily to the potential acidity of mine spoils. Acid overburden is common in northern Appalachia and is a problem locally in southern Appalachia and the Midwest. The toxicity to plants of acid coal-mine spoils is caused primarily by excessive amounts of soluble manganese and other metals (Berg and Vogel 1973). Toxic levels of nickel, copper, and zinc have been found in acid spoils in eastern Kentucky (Massey and Barnhisel 1971), and concentrations of nickel may remain in the soil in toxic amounts even when the pH has been adjusted to a point level that would otherwise be satisfactory for plant growth (Massey 1972). Aluminum has been found to have toxic effects on tree-seedling growth on acid spoils in western Pennsylvania (Beyer and Hutnik 1969). Flood-plain soils in western Kentucky subject to contamination by acid drainage from coal mines have toxic concentrations of exchangeable aluminum (Blevins et al. 1970). This toxicity may be corrected by adjusting pH with lime and by proper fertilization.

Alkalinity of spoils is of more concern in the West than acidity, and toxicities from metals such as magnesium, boron, and molybdenum may be a problem (Bauer et al. 1978). For example, molybdenum concentrations and copper-to-molybdenum ratios found in sweetclover growing on coal-mine spoils at 5 out of 8 sites sampled in Montana and North Dakota are sufficiently high to cause molybdenosis, a nutritional disease affecting cattle and sheep (Erdman et al. 1978).

Salt-affected soils are characterized and classified according to their content of soluble salts, and the exchangeable sodium percentage. The main effect of salinity is to impede the uptake of water by plants through an increase in the osmotic pressure of the soil solution (Sandoval and Gould 1978). Sodic soils are a special category of saline soils, requiring special treatment. When excessive amounts of exchangeable sodium are present in a saline soil, soil particles lack structural stability, and water infiltration is restricted. Clayey sodic material in overburden is the reclamation problem most commonly identified by mining companies in the West. Half of the mines and 64 percent of the acreage were so affected in 1975 (Cook 1979).

Although in some geologic provinces the base status of spoils may be superior to that of natural soils (Ammons and Perry 1979), nutrient deficiencies are common in coal-mine spoils. Spoil banks in eastern Kentucky generally contain low levels of exchangeable calcium, an abundance of exchangeable magnesium, and amounts of available K and P that are low to adequate for plant growth (Cummins et al. 1965). In southern West Virginia a major problem in the establishment of vegetation on surface-mine spoils is deficiency of nitrogen and phosphorus (Plass and Vogel 1973).

Byrnes and his colleagues (1980) have identified a number of overburden properties that singly or in combination indicate a high probability of poor growth unless the condition is corrected:

Sulfur content > 1 percent total
Potential acidity > 15 meq/100 g
Exchangeable Al > 0.40 meq/100 g
Extractable Mn > 60 micrograms/g
pH in 1:1 H_2O < 4.5
Extractable B > 1.0 micrograms/g
Electrical conductivity > 1.0 millimhos/cm
Organic matter < 0.5 percent if used as topsoil
Available H_2O storage < 15 percent by volume
Bulk density > 1.4 g/cc after packing

The above criteria were developed based on background knowledge, literature reports, and experiments with various soil and overburden materials in Indiana.

Certain relief and microclimate characteristics may also have adverse effects on soil productivity. Surface-temperature measurements recorded on unvegetated strip-mine spoils in Pennsylvania indicated that heat injury to plants is a possibility on all commonly occurring bituminous spoil materials, and particularly on coal and black organic shales (Deely and Borden 1973). This effect is temporary, however, if adequate vegetative cover can be established on the spoils.

Average annual growth rates for black locust in surface-mined areas in West Virginia vary by a factor of almost 6 depending on slope, aspect, and elevation, with best growth rates on less steep northeast-facing slopes and worst rates on steep southwest-facing slopes (Brown 1973a). Average moisture content is higher and temperature is lower on northeast-facing surface-mined sites than on southwest-facing sites (Brown 1973b). Ungraded or partially graded spoil banks commonly have much more variable topography than pre-mine terrain, and a correspondingly high variability of vegetative cover. Best growth is in the ravines, and little or no growth takes place on slopes and ridges (Riley 1973, 1977).

Surface coal mining often reduces the stability of slopes. In Kentucky, before 1965, landslides occurred on about 12 percent of the acreage disturbed. Bench-width regulations reduced the incidence of landslides to 4.5 percent. But in spite of 63 percent decrease, total acres affected by landslides in 1971 exceeded prelaw levels because more acres were disturbed by mining (Mathematica 1974). Steepness of slope, excessive soil moisture, and reduction in the shearing resistance of the soil due to severe weathering and freeze-thaw cycles lead to instable coal-mine spoil banks (Hoffmann et al. 1964). Slides on revegetated spoils may disrupt vegetative cover, and settling of spoils may cause cracks that can be hazardous to grazing livestock and can damage building foundations and underground utility services (Drnevich et al. 1976). Seepage of water into spoils may exacerbate differential settling and attendant instability. Differential subsidence of the surface of graded spoils and piping (subsurface erosion caused by deep surface cracks along which sediment is carried by water) is a widespread problem in western North Dakota and adjacent areas (Groenewald and Bailey 1979). In 1975, 12 percent of the reclaimed acreage in the West developed sinkholes as a result of differential settling of spoils (Cook 1979).

Interaction of the Effects of Mining Disturbance

Interactions among the effects of mining disturbance are important. For example, a more favorable base status in mine spoils is not sufficient alone to make them superior to unmined soils. The status must be self-perpetuating: plant nutrients must be continually released by weathering of the strata, and the soils must also be free of unfavorable characteristics that might offset the benefits of the supply of nutrients.

The most common result of past mining practices has been a reduction in the productive potential of mined land. Under favorable conditions, however, the beneficial and adverse effects may cancel each other out and result in a soil with about the same productive potential or slightly improved productive potential. As we have seen, the beneficial effects of disturbance of iron-mine spoils in West Virginia (increased rooting depth, higher moisture-holding capacity, higher cation-exchange capacity, and higher availability of base nutrients and phosphorus) balanced the adverse factors (higher bulk density, lower infiltration rates, poorer aggregation of soil particles, and lower nitrogen and organic-matter content). The result is that tree growth on the mined land is very similar to that on unmined soils, and pasture productivity is superior (Smith et al. 1971). With special care in soil reconstruction, productivity of mined land in northern Appalachia has been raised above that of the native landscape (McCormack 1976).

Overdeveloped soils—located primarily in Appalachia, the Gulf Coast, and on pre-Wisconsinan land surfaces in the Midwest, may be rejuvenated by mining where high-quality substratum material is available and reclamation is carefully carried out. On the other hand, soils that are at their peak in productivity—primarily Wisconsinan-age glacial soils in the upper Midwest—cannot be improved by rejuvenation; it may be difficult even to equal pre-mine productivity in mined soils. Reclamation of soils in the arid and semiarid West presents similar difficulties, except possibly where sodium- or salt-affected soils could be replaced with more suitable post-mine soils.

Disturbance of Soils by Underground Mining

Although this report focuses on surface mining, some mention of underground mining is appropriate. Underground mining does not disrupt the soil and geologic overburden as radically as surface mining, but it can create significant disturbance of surface soils if subsidence occurs. Where room and pillar mining has been practiced, subsidence generally results in a pitted topography that is difficult to traverse with farm machinery, and the lack of integrated drainage may create waterlogged sinkholes. Longwall mining results in more uniform subsidence, but may disrupt drainage patterns. The economic impact of subsidence has been estimated for affected urban areas but not for farmland (see U.S. General Accounting Office 1979).

Subsidence in rural areas in southern Illinois has resulted in severe drainage problems and losses of tillable land (Murray 1978). The effects of subsidence on cropland are a particular concern in areas of nearly level prime farmlands in the Midwest, because relatively small changes in the land surface caused by subsidence may disrupt tile drainage systems or cause ponding at the surface, resulting in significant reduction in the productivity of the soils. Careful evaluation of the effects of subsidence on soil productivity needs to be included in underground-mine plans, especially because it is almost impossible to establish complete prevention of subsidence with absolute confidence (Hittman Associates 1976).

SOIL-FORMING PROCESSES AFTER MINING

Soil-forming processes may require time periods longer than are accommodated by the time frame of legal responsibility for satisfactory reclamation (5 years after successful establishment of vegetation in humid regions and 10 years in dry regions). To be sure, some natural soil-forming processes can effect measurable changes in fresh spoil or reconstructed soil profiles within relatively short periods of time, and an understanding of these processes can be valuable in reclamation planning. But if relatively long periods are acceptable (50 years or more), natural soil-forming processes may be relied upon to recover the full productive potential of mined lands.

Soil Organic-Matter Formation

Organic-matter deposition and decomposition occur primarily in the *A* horizon. In most ecosystems, the principal sources of organic matter are plant and animal residues, which are continuously deposited in surface horizons, normally to a depth no greater than the maximum depth of root penetration. Decomposition is primarily a microbial process, where in the presence of oxygen microorganisms metabolize the more readily degraded material to carbon dioxide or utilize it for their own structural matter. Most of the organic matter in soil thus exists in a dynamic state of turnover.

As noted in the preceding chapter, soil organic matter and the associated microbial activity are key factors influencing soil productivity. Organic matter in soil affects both the chemistry of the soil, by influencing the availability of essential elements for plant growth, and the physical quality of the soil, by increasing the water-holding capacity of soils and influencing the aggregation of soil particles in the development of soil structure.

When the *A* horizon of a soil profile is completely removed, either by erosion or disturbance by mining, a relatively long, complex process of organic-matter formation and accumulation begins as part of the development of a new *A* horizon. The first step is inoculation of the freshly exposed subsoil or mine soil with microbial species from surrounding soils. The lack of a ready source of organic carbon in subsoils limits microbial growth initially, but sparse growth of invertebrates, lichens, algae, and higher plants will follow microbial colonization. As these organisms die, their organic molecules are recycled or consumed as energy sources by the soil microflora. The end products of this metabolism are excreted into the soil to accumulate or to be further metabolized or chemically altered. Successive microbial populations develop in response to the increasing complexity of the biochemical substances in the soil. This intricate process ultimately leads to the presence of two classes of organic materials: (1) nonhumic substances, which are largely water soluble, of low molecular weight, and susceptible to microbial metabolism; and (2) humic substances, which are largely water insoluble, of high molecular weight and relatively resistant to further microbial degradation. Humic substances are derived over long time periods by complicated secondary synthesis and slow decomposition reactions (Hodgson 1963, Keeney and Wildung 1977).

Jenkinson and Rayner (1977) have identified three major groups of nonhumic organic materials in soils: decomposable plant material, woody plant material that is more resistant to decomposition, and the living biomass of the soil. These nonhumic materials form relatively rapidly but also decompose rapidly, having half-lives of 0.17, 2.3, and 1.7 years, respectively. Jenkinson and Rayner also separated humic substances into two groups—physically stabilized organic matter and chemically stabilized organic matter. Humic substances that are physically stabilized, perhaps by the protective actions of clays, have half-lives of about 50 years; those substances that are stabilized by virtue of their chemical structure have half-lives of about 2000 years.

It is the nonhumic substances that are most amenable to change by soil-management practices, and the quantity and composition of these materials will vary with soil, vegetation, and environmental conditions (Routson and Wildung 1969). For example, readily decomposable wastes such as sludge or manures added to soil under conditions appropriate for microbial growth may result in an immediate and marked increase in nonhumic organic substances. But although such nonhumic matter probably serves as precursors of the humic substances (Konova 1966, Wildung et al. 1970), formation of the more stable humic substances is still a slow, long-term process. It is the slow-forming humic materials that generally exhibit higher ion-exchange and water-holding capacities than the nonhumic materials.

Depending on the material entering soils and soil conditions, the decomposition of organic matter and the formation of soil humus may be initiated within hours and may go on for hundreds of years through many complex steps. Nonbiotic factors such as water, temperature, oxygen supply, pH, inorganic nutrients, and the presence of toxic substances (Alexander 1977) have complex interdependent effects on the rate of decomposition and the type of degradation products formed. Table 6.1 summarizes the conditions under which these factors promote decomposition.

The organic-matter content of soil can be increased in relatively short periods of time under proper management practices, with beneficial effects on soil productivity. In well-managed alfalfa-brome pastures on coal-mine spoils in western Illinois, organic matter has been observed to increase from 0.4 percent in raw spoils to 2.5 percent within 14 years (Caspall 1975). It must be realized, however, that such increases are almost entirely the result of unstable nonhumic components, which will decompose rapidly if intensive management is not continued.

Table 6.2 summarizes some of the available data on the development of organic matter in disturbed soils. Under normal conditions, the buildup of organic matter in disturbed soils to predisturbance levels is a process that takes 100 years or more. A 31-centimeter (12-inch) *A1* horizon has developed under prairie vegetation in 100-year-old spoil derived from loess in railroad cuts in Iowa (Hallberg et al. 1978). Organic-carbon content of the *A1* horizon reached a maximum of 2.6 percent, but the soil did not match the color of the surrounding, nearly black topsoil called the mollic epipedon. Organic-carbon content seemed to build up rapidly in the first 30 to 50 years of soil development and to increase at a slower, more steady rate thereafter. The 100-year-old iron-ore spoils in West Virginia under forest vegetation have not developed levels of organic matter comparable to those of unmined spoils (Smith et al. 1971).

Jenkinson and Rayner (1977) have developed a model of the process of organic-matter formation of soils based on the classical long-term field ex-

TABLE 6.1 Factors Affecting Decomposition of Organic Matter

Factor	Effect on Decomposition Rates	Comments
Temperature	Decomposition is generally optimum above 15°C. Soil organisms respond to changes in temperature at water contents as low as 1-2 percent (106-80 bar).	In arid and semiarid regions decomposition is generally limited by soil temperature in the fall, winter, and early spring and by soil water content in late spring and summer (Wildung et al. 1975, Sommers et al. 1980). In the more humid woodlands, moisture is seldom limiting and temperature plays the dominant role in controlling decomposition (Anderson 1973).
Water	Decomposition is generally maximum at intermediate water potentials (33-13 bar). Above 6°C increased water content results in increased decomposition.	
Oxygen	Decomposition is optimum in well-aerated soil; rates decrease with decreasing oxygen. Microbial populations change with decreasing oxygen from aerobic to anaerobic (Takai and Kamura 1966).	In waterlogged soils, aeration can be improved by drainage.
Nutrients	Decomposition is optimum with a carbon-to-nitrogen ratio from 8:1 to 12:1.	Incorporation of a residue with a high carbon-to-nitrogen ratio, such as straw, requires the use of other available nitrogen in the soil by microflora for its decomposition. As the available nitrogen is assimilated and incorporated into the microbial cell, decomposition rate slows until additional nitrogen is available again. Carbon-to-nitrogen ratio can be controlled by soil-management practices.
Soil reaction (pH)	Overall decomposition generally proceeds more readily in neutral and slightly alkaline soils than in strongly basic or acidic soils.	Can be modified by soil-management practices such as liming.
Particle size	Finely divided material decomposes most rapidly, particularly if uniformly incorporated in soil.	Can be affected by tillage practices.

periments on crop-residue persistence in soil at Rothamstead, England. Using the half-lives cited earlier for the various nonhumic and humic components of soil organic matter, they found that with continuous input of 1 tonne of carbon per hectare per year in the form of fresh plant residues, in 10,000 years 23.5 metric tons of carbon will have accumulated as physically and chemically stabilized humic sustances; 0.76 metric tons of the carbon as non-humic substances and the remaining thousands of metric tons would have been metabolized to carbon dioxide.

The broad diversity of organic substrates and soil conditions characteristic of pre-mine soils in the United States would appear to make impossible any accurate predictions of the distribution of organic matter in the post-mine landscape. However, the microbial activity and transformation rates of various classes of organic materials such as cellulose, hemicellulose, and lignins have been estimated under different temperature, moisture, and soil regimes. To some extent, then, it may be possible to estimate short-term (less than 2-year) decomposition rates of added organic materials from a proximate analysis of the material and knowledge of soil conditions. Selective subsequent monitoring of the type conducted at Rothamstead by Jenkinson and Rayner (1977) would be required to validate such estimates under different climatic regimes. Validations should take the form of definitions of the relationship between the overall composition of organic matter incorporated into soil and the formation of specific components of the soil organic fraction.

Development of Soil Structure and Translocation of Clay

Vegetation affects soil structure by increasing aggregation of soil particles. Wilson (1957) found that different vegetative ecosystems affected aggregation in mine spoils differently (nonvegetated < pine < locusts < forage grasses and legumes undisturbed). The development of soil structure in reclaimed surface-mine spoils is a relatively slow process. Soil structure is observable in the top 5 centimeters of 100-year-old iron ore spoils in West Virginia, but structure is very weak or unobservable below that (Smith et al. 1971).

There is also evidence that soil-forming processes have moved measurable, but relatively small quantities of clay out of the upper 5 centimeters of these spoils. Minor translocations of clay from the upper few centimeters of 22-year-old and 30-year-old coal-mine spoils in western Illinois have been measured (Caspall 1975). Such small translocations of clay are probably not significant in terms of improving a soil's productive potential. Some oil-shale spoils in Utah show evidence of possible downward migration of clays from the surface after a single winter under arid conditions (Institute for Land Rehabilitation 1979). Fifty-year-old mine spoils at

TABLE 6.2 Development of Organic Matter in Surface Layers of Disturbed Soils

Spoil Material	Time, Years After Disturbance	Organic Matter Accumulated	Comments	Source
Glacial till (western Illinois)	14	2.5 percent	Average of 4 sites. Well-managed alfalfa-brome pasture. Original organic matter content following disturbance was 0.4 percent. Nearby undisturbed soils contained 3.8 percent.	Caspall (1975)
	30	2.4 percent	Poorly managed bluegrass pasture.	Caspall (1975)
Loess (Germany)	40-50 (estimated)	2.5 percent	Cropped with grains. Original organic content following disturbance was 0.4 percent.	Heide (1973)
Loess (Iowa)	100	2.6 percent	Spoil in railroad cuts formed under prairie vegetation. Still less than native soils.	Hallberg et al. (1978)
Loess (Wisconsin)	400	Fully developed *A* horizon under native vegetation.		Van Rooyen (1973)
Shaley overburden (West Virginia)	120	Less than undisturbed soil.	Both iron-ore spoils and native soil under forest vegetation.	Smith et al. (1971)
Sedimentary rock (Kansas)	20	No measurable increase.	Initial level was 1.8 percent, but the high percentage appeared to be due to contamination by coal fragments.	Geyer and Rogers (1972)

Colstrip, Montana, may have weakly to moderately developed platy structure to a depth of 20 centimeters, whereas subangular blocky and prismatic structures are observed to a depth of about 100 centimeters in natural unmined soils (Schafer et al. 1977).

PHYSICAL AND CHEMICAL WEATHERING

Soil-forming processes such as freeze-thaw and wetting-drying cycles, which physically weather coal-mine spoils, and leaching by percolating water can bring about observable changes in the properties of mine spoils within relatively short periods of time. The rate of physical weathering depends largely on the characteristics of the overburden. Shales—particularly those composed of expanding-lattice clays—and siltstones will break down into smaller fragments relatively quickly, mainly by physical processes, while limestone generally breaks down chemically. Physical weathering of 20-year-old coal-mine spoils in Kansas has caused measureable increases (38.5 to 46.9 percent) in the percentage of soil-sized (less than 2 millimeters) particles (Geyer and Rogers 1972). Physical breakdown of some Colorado oil-shale spoils has been observed to break down physically (Institute for Land Rehabilitation 1979) and chemically (Garland et al. 1979) after one winter in arid conditions.

Mining, by breaking up overburden material, exposes to weathering a large surface area of fresh material. Consequently, chemical weathering processes are greatly speeded up by mining. Where the pre-mine soil profile has a low inherent fertility, this disturbance may increase the availability of nutrients for plant growth, but where amounts of toxic elements or soluble salts contained in the spoils are large, the result may be an inhibition of plant growth. In humid climates the effect of this disturbance is to increase the rate of movement of soluble salts through the soil profile (Struthers 1965).

Leaching of freshly exposed spoils composed of acid sandstone, silty shales, and clays in Ohio over a 14-year period has brought about significant changes in the chemistry of the spoil at the surface (Riley 1977). Over this period pH increased from 3.7 to 4.1; total soluble salts decreased by 90 percent; and concentrations of sulfur (as sulfate), iron, copper, zinc, and molybdenum decreased by 50 percent or more. Concentrations of manganese, chloride, aluminum, and boron increased over the same period.

The extent to which acid spoils and acid drainage develop in mine spoils depends upon the amount and form of pyrite in the spoils and the neutralizing potential of the remainder of the overburden. In acid-forming material most oxidation of pyrite occurs at or near the surface, although the active oxidation zone may extend to a depth of 5 feet in permeable soils (Caruccio 1973). Leaching experiments conducted by Grube and his colleagues (1971) showed oxidation of pyritic mine spoils that were buried by 90 centimeters of normal loamy soil. Sixteen-year-old coal-mine spoils in Missouri may have 90 percent of the pyrite in the top 60 centimeters oxidized (Von Demfange and Warner 1975). Oxidation of pyrite may occur relatively rapidly, and the resulting acidity in the spoils can be detrimental to vegetation for a long time. Some acid spoils in southwestern Indiana are still devoid of vegetation after 45 years of natural leaching (Byrnes and Miller 1973). Leaching of carbonates to depths of 10 to 12 centimeters has been observed in 20- to 30-year-old coal-mine spoils in western Illinois (Caspall 1975).

In the West, soil disturbance may foster upward migration of soluble salts to the soil surface rather than leaching, because there is insufficient precipitation to leach soluble salts from the soil. Concentrations of salts develop at the surface when water raised by capillary action evaporates. At a site in North Dakota, the sodium absorption ratio of 30 centimeters of topsoil covering sodic spoils increased 10-fold (from 2 to about 20) over a 3-year period (Agricultural Research Service 1977). On the other hand, studies of 1- to 45-year-old mine spoils in northwestern North Dakota have found that within 17 years, leaching of soluble salts from the upper soil zone reduced electrical conductivity to levels similar to unmined soils (Wali 1980). Significant increases in organic matter and related increases in concentrations of major plant nutrients (nitrogen, phosphorus, and potassium) were also observed as the age of the spoils increased. In the 45-year-old spoils, nitrogen levels were 40 percent and phosphorus levels were 70 percent of those in unmined soils in the area.

The long-term effect of upward migration of salts on the productivity of reclaimed land in the northern Plains is a major unresolved question. There has not been enough long-term experience with reclamation of sodic or saline spoils to determine what thickness of topsoil is necessary to cope with this problem (Power 1978). Dollhopf and his colleagues (1977) have measured unsaturated flow of deep stored water into the top 2 meters of reclaimed soils at several sites in Montana and North Dakota and have concluded that there is some potential of salinization of the surface soil, particularly at the North Dakota site where spoils contain high levels of salts.

7 Reclamation of Disturbed Lands

This chapter examines the goals and processes of reclaiming lands disturbed by mining. First, because climate is such an important factor in determining reclamation strategies and practices, we examine general aspects of climate in the different coal regions. We then discuss the basic goals of managed soil reconstruction and the specific approaches to reconstruction of soils and topography, reestablishment of the hydrologic characteristics of soil, and revegetation to accomplish reclamation goals. We review available information on the productivity of mined land to see what reclamation is able to accomplish. Finally, we review the economics of reclamation and problems involved in determining reclamation costs.

Before proceeding, we should say a few words about the term *reclamation*. An earlier National Academy of Sciences committee, concerned with surface mining on western coal lands, recognized the confusion created by the use of vague terminology in discussing landscape reconstruction and established distinctions between the terms *restoration*, *reclamation*, and *rehabilitation* (National Research Council 1974). Unfortunately, imprecision in the use of these terms has persisted, and two of the terms, *reclamation* and *rehabilitation*, have taken on similar connotations.

The Surface Mining Control and Reclamation Act of 1977 consistently uses the term *reclamation*, and while the law does not explicitly define the term, it does state in Section 515(b)(2) on Environmental Protection Performance Standards that a minimum general performance standard for mining and reclamation operations is to

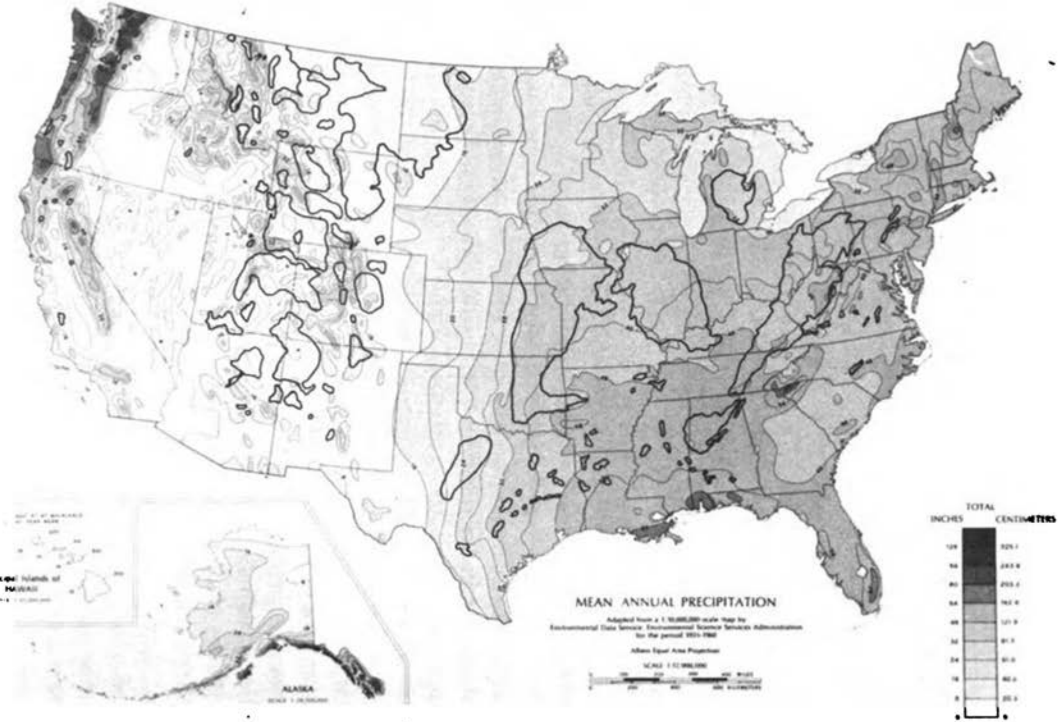

FIGURE 7.1 Mean annual precipitation (in inches) in relation to coal fields of the United States. *Source:* Adapted from U.S. Geological Survey (1970).

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 of which there is reasonable likelihood, so long as such use or uses do not present any actual or probable hazard to public health or safety or pose any actual or probable threat of water diminution or pollution, and the permit applicants' declared proposed land use following reclamation is not deemed to be impractical or unreasonable, inconsistent with applicable land use policies and plans, involves unreasonable delay in implementation, or is violative of Federal, State, or local law.

In this report we use the word *reclamation* in its broadest definition—the return of land to a form and level of productivity that will sustain the prior or future planned use or uses in an ecologically stable state, a state that will not contribute substantially to environmental deterioration and that is compatible with surrounding aesthetic values.

CLIMATE AND RECLAMATION

An understanding of how climate influences the interaction of physical, chemical, and biological processes over the land surface and in the soil is essential to the successful reclamation of mined lands. Reclamation practices must be selected and implemented taking into consideration both macro- and microclimatic conditions at a site.

Climatic Variables

Climatic conditions in a given region are governed by such factors as latitude, elevation, prevailing winds, moisture sources or the lack of them, and terrain (Baldwin 1973). The lower the elevation or latitudes, the higher the average temperature. The closer to the ocean or the higher the elevation, the higher the annual precipitation, particularly on the windward side of mountains. Large temperature fluctuations occur in relatively dry areas.

Precipitation data are readily available for nearly all parts of the country (e.g., National Oceanic and Atmospheric Administration 1974). Data on average annual precipitation (Figure 7.1) serve as a guide in estimating the adequacy of moisture supplies for the establishment and maintenance of vegetation at a site and also serve as an indicator of the soil-forming characteristics of a region. Precipitation occurring during the growing season generally is more beneficial to plant growth than that which occurs at other times of the year. The frequency and intensity of individual storms and the antecedent moisture in the surface soil affects the amount of surface runoff that occurs at a site and the potential for soil erosion.

Air temperature has an effect on the rate of plant growth, species adaptability, and the rate of soil formation. The extreme high and low air temperatures that occur at a site during a typical year, the frequency with which

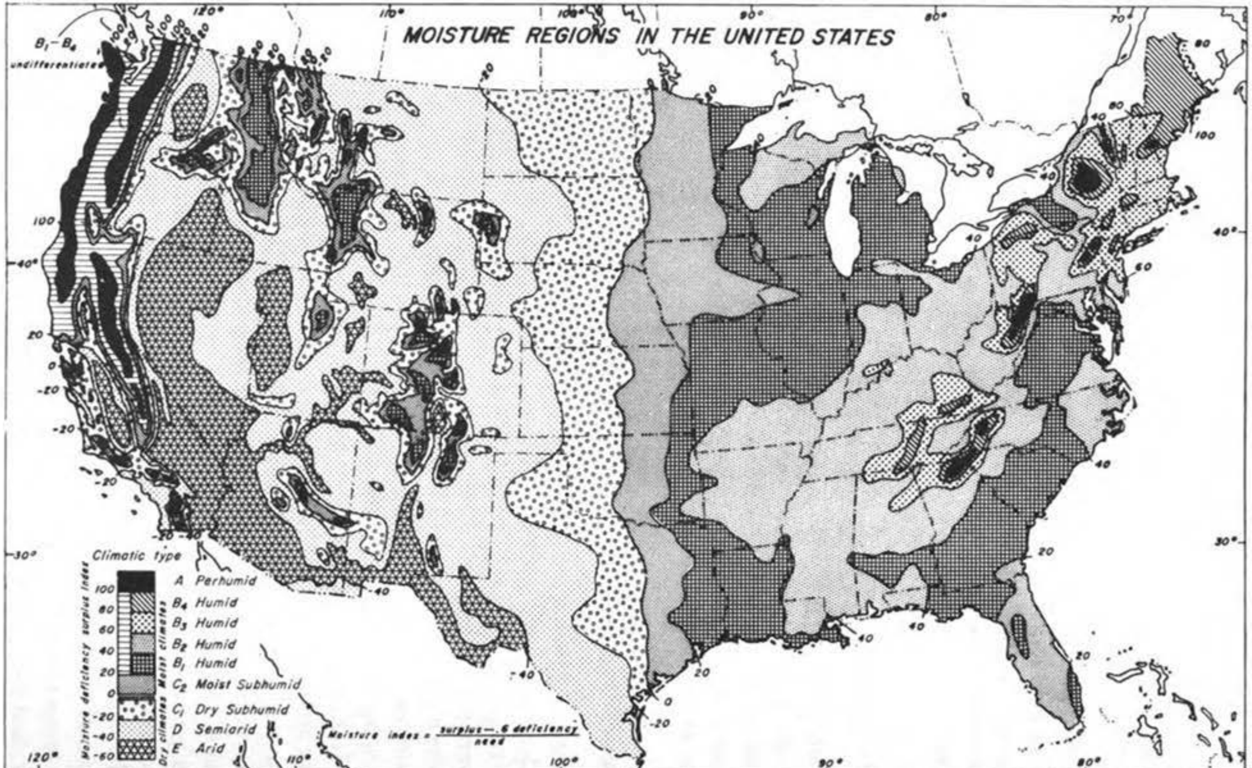

FIGURE 7.2 Moisture regions of the United States. *Source:* Wilsie (1962; adapted from Thornthwaite 1948).

those extremes are approached, and the duration of those temperatures will help determine the variety of plants able to thrive at that location (Wilsie 1962).

Length of growing season has a particularly important effect on soil formation and vegetation establishment. Long growing seasons promote rapid soil formation and faster, more diverse plant growth (Foth 1978). Revegetation of disturbed areas is much easier at sites with long growing seasons and adequate precipitation.

Year-to-year variability is another major factor in reclamation. In regions such as the northern Great Plains, seasonal precipitation and temperature show changes of 50 percent or more over decades in comparison to long-term mean values. For example, for the growing seasons of most of the last decade the precipitation in the northern Great Plains coal region has been well above the long-term normals (Murray 1978). This means that reclamation techniques developed over that period may not be appropriate for more "normal" conditions.

The interaction of various climatic factors and the soil-plant system must also be considered when evaluating reclamation alternatives in a region. One such interaction is between available moisture and potential evaporation. Available moisture is the sum of effective precipitation and soil-moisture storage and therefore depends on both precipitation and the moisture-holding capacity of soils. Thornthwaite (1948) developed a climatic classification based on these factors integrated in a moisture index (Figure 7.2). This index includes monthly values of precipitation, potential evaporation, and soil moisture-storage levels to define a moisture surplus or deficit. Areas with a negative moisture index have more periods of moisture deficiency than they do of moisture surplus. Since soil-moisture storage is included in the index, the soil characteristics of a particular site will affect the index for that site.

Another climate-soil interaction is between the annual precipitation and the mean annual erosion rate. On natural watersheds the mean annual erosion rate is highest where the mean annual precipitation is between 250 and 400 millimeters. Areas with higher annual precipitation generally have natural vegetation that protects the soil from the erosive forces of rainfall and runoff, and areas with lower annual precipitation experience few storms capable of causing severe erosion (Langbein and Schumm 1958). Reclamation in areas where the mean annual precipitation falls within the middle range will most likely be difficult. When frequent extreme temperatures hamper vegetation establishment at a site, the problems of soil erosion are likely to be compounded.

Microclimate (the climate at and near the soil surface, in which plants grow) has an important effect on the reclamation process. The temperatures near the surface will be influenced by the color of the surface, the aspect of the surface relative to the sun, the soil moisture content, and the shading provided by the existing plant community. During the summer, relatively dark, dry, bare, newly reclaimed soils with a southern exposure will experience extremely high midday temperatures, which can kill young seedlings on a revegetated area, even when the air temperature above the surface is within a normal range. In arid and semiarid areas there will be less evapotranspiration on a northern slope than on a southern slope and the northern slope will thus support more vegetation on the same amount of available moisture (Hadley 1961).

General Aspects of Climate in the United States

The continental United States lies entirely in a region dominated by prevailing winds from the west. These prevailing westerlies are modified by air-mass movements from the south during warm seasons and from the north during cold seasons. Air masses originating over oceans provide most of the moisture; warm southern air masses contain more moisture than cool northern air masses. Clashes between warm, moist and cool, dry air masses create frontal storms, which are frequently violent with high winds and intense rainfall.

When warm, moist air masses pass up over mountains they tend to drop most of their moisture on high windward slopes, becoming warm and dry as they descend down the lee side. The three major mountain systems in the United States (the Sierra Nevada-Cascade range, the Rockies, and the Appalachians) all lie in a general north-south direction. The prevailing westerly winds thus create arid regions in the intermountain valleys and the plains east of the Rockies. The climate east of the Rockies is dominated by two air-mass systems: warm, moist air masses from the Gulf of Mexico move up across the interior plains and frequently clash with cool, dry Canadian air masses. Both are pushed by the prevailing westerlies across the Midwest and East before they pass on out into the Atlantic Ocean. Precipitation generally decreases to the north and west. The effects of the eastern mountains, though not as dramatic as those of the higher mountains of the West, modify this general trend. Table 7.1 summarizes climatic variables important to reclamation in selected coal-mining areas.

Eastern Climate

The climate of the Appalachian coal region is temperate and moderate. Average annual precipitation tends to increase from north to south, with orographic effects modifying this general trend, inducing higher precipitation at higher elevations. Precipitation is moderate to high, ranging from just over 800 millimeters in the valleys of central Pennsylvania to near 2000 millimeters near the tops of the Great Smoky Mountains in Tennessee. It is nearly uniformly distributed throughout the year, with a slight increase during the summer months (National Oceanic and Atmospheric Administration 1974). Although the annual precipitation totals are relatively high, seasonal distribution results in moderate-to-low growing-season precipitation, as low as 300 millimeters in some of the northern valleys. Precipitation during the summer months occurs mostly in thunderstorms of high intensity, which result in high surface runoff. Short periods without rainfall during the growing season can result in drought conditions.

Temperatures are generally moderate. Summers are warm in the north and hot in the south; winters are generally mild. Generally humid conditions prevent frequent large temperature fluctuations. Temperatures as low as −40°C have been recorded at higher elevations in Pennsylvania, but such extremes are rare. Growing seasons in almost all localities exceed 110 days and range up to 260 days in the south. Potential evaporation ranges from less than 700 millimeters per year in central Pennsylvania to over 1000 millimeters per year in northern Alabama. Everywhere the mean annual precipitation exceeds the mean annual potential evaporation.

The high annual precipitation that occurs in the eastern region and the predominantly rolling to steep topography make erosion and sediment control problematic. Establishing vegetation to help control erosion can be difficult because many eastern soils are low in fertility, as a result of continuous leaching by precipitation, which also removes the natural compounds capable of buffering the acid potential of coal overburden.

The natural soils are generally thin and coarse and thus have low moisture-storage capacities. Therefore, although annual precipitation exceeds potential evaporation, the moisture index in many areas is relatively low. This makes for frequent droughty periods during the summer, which can frustrate reclamation effects.

Climate in the Midwest and Gulf Coast

The midwestern area from eastern Kansas to Ohio and from central Texas to the Great Lakes has a climate controlled by latitude, general air-mass movements, and distance from moisture sources (Baldwin 1973). Except in the Gulf Coast region, the climate is predominantly continental. Most of the area has cool, wet spring seasons with frequent violent storms; hot, humid summers, with temperatures frequently approaching 40°C and precipitation occurring mostly in short-duration, high-intensity thunderstorms; mild, dry autumns; and cold winters, with temperatures frequently

TABLE 7.1 Climatic Variables Important to Reclamation in Representative Coal-Mining Regions

Location	Mean Annual Precipitation, mm	Average Warm Season Precipitation, mm	Average Annual Rainfall Erosion Factor[a]	Average Annual Air Temperature, °C	Average Annual Maximum Air Temperature, °C	Average Annual Minimum Air Temperature, °C	Average Length of Growing Season, days	Moisture Region (Moisture Index)[b]	Normal Annual Runoff, mm
Central Pennsylvania	1020	510	130	10	33	−23	150	B_3 humid (70)	510
West Virginia	1100	640	140	13	32	−18	150	B_2 humid (50)	510
Northern Alabama	1320	640	350	17	38	−12	220	B_2 humid (50)	510
Southern Illinois	1100	560	240	13	38	−21	200	B_2 humid (40)	380

Central Iowa	860	560	180	9	38	−26	170	C_2 moist subhumid (10)	150
South-central Texas	760	460	300	20	41	−7	260	C_1 dry subhumid (−10)	80
Northeast Wyoming	360	250	35	6	38	−32	120	D semiarid (−30)	6
Northwest New Mexico	150	130	20	10	38	−23	150	D-E semiarid to arid (−40)	10

[a] This is the *R* factor in the Universal Soil Loss Equation; see discussion in Chapter 6.

[b] Refer to Figure 7.3 for definition of these terms.

Source: Data from National Oceanic and Atmospheric Administration (1974).

approaching −20°C. The Gulf Coast has milder temperatures and higher precipitation.

Mean annual air temperatures range from below 10°C in the North to over 20°C in the South. Maximum temperatures exceed 38°C at least once during an average year in nearly all areas. Minimum temperatures go below −30°C occasionally in the North and −20°C in the South, limiting the vegetation to frost-tolerant plant species. The growing season ranges from approximately 150 days in the north to 260 days in the South.

Mean annual total precipitation ranges from 800 millimeters in the Northwest to 1200 millimeters in the Southeast. The precipitation is uniformly distributed through the year in the South and East, but in the North and West there is a decided increase in monthly precipitation during the growing season.

Annual potential evaporation decreases with latitude and, slightly, with increases in atmospheric humidity. It ranges from a high of more than 1500 millimeters in the Southwest to a low of 800 millimeters in the Northeast. Potential evaporation generally exceeds annual precipitation in the western parts of the area from Iowa to Texas, the largest moisture deficits occurring in the southern portion of this area.

The soils of the Midwest are generally deep and fine grained, with high natural water-holding capacity. These qualities tend to mitigate the moisture deficits, and grasses will fluorish without irrigation under natural conditions. The same qualities, however, cause these soils to be compacted severely when they are handled during mining and regrading. Compaction inhibits infiltration and natural drainage and prevents root systems from developing normally. The water-holding capacity of the soil is decreased, and thus the wet and dry periods of a typical year become periods of excess and deficit soil moisture, decreasing agricultural productivity. Reclaimed soils are generally less erosion-resistant than natural soils and when compacted are more likely to produce runoff. On these soils there is a fine and poorly defined line between slopes that allow adequate surface drainage and those that produce excessive erosion.

Periods of drought are a frequent problem in the southern part of the region, particularly Kansas, Oklahoma, and Texas, where shallow, coarse soils are common. Irrigation is generally necessary for crop production, and drought stress may occur in reclaimed areas, hampering the establishment of vegetation and the formation of soil.

Western Climate

Climatic patterns in the western United States are characterized by temperature extremes, intense winds, meager precipitation, short growing seasons, and short, often intense storms. A consistent feature of climates in the western coal region is the erratic nature of most weather (U.S. Department of Agriculture 1941, National Oceanic and Atmospheric Administration 1974).

On the plains of Wyoming and Montana, temperature can range from over 38°C in the summer to well below freezing in winter. Only the most hardy perennials can withstand the temperature extremes at sites where high temperatures result in rapid drying of the soil surface and high transpiration loss of water from vegetation, and the frost heaving in certain soil types in cold winters makes it difficult to establish plants.

Precipitation in the western states is generally low, ranging from 100 millimeters or less in desert areas to 500 millimeters or more in mountainous areas. Much of the precipitation occurs from May through September, when high temperatures mean that a high proportion of the moisture is lost to evaporation. Further, much of the summer precipitation occurs in high-intensity thunderstorms, which create serious problems of soil erosion and offer little help to deep-rooted vegetation except on soils with a high infiltration capacity. Most winter precipitation occurs as snow, when plants are dormant. In the colder regions this snow blows away or evaporates without contributing to soil moisture.

Air masses from the west and northwest move rapidly over the region, often creating high wind velocities as they encounter mountains, valleys, and plains, and storm fronts are common. Winds are a hazard to revegetation and mining operations because of wind erosion and the drying effect on spoils.

Growing seasons are generally short in most western states except for Arizona and New Mexico. Some examples from coal fields are: Black Mesa, Kayenta, Arizona, 167 days; Navajo Mine, Shiprock, New Mexico, 163 days; Williston Basin, Dickenson, North Dakota, 111 days; Powder River Basin, Gillette, Wyoming, 129 days; Kemmerer field, Kemmerer, Wyoming, 60 days; Yampa field, Steamboat Springs, Colorado, 28 days. The short growing seasons of the north and the prolonged exposure to high temperatures in the south pose serious problems for plant establishment and survival.

Drought is an ever-present threat, both from periods of dry, hot summer days and from seasons of below-normal precipitation. Use of native plants for rehabilitation is a logical requirement because of the adaptation of native plants to climatic conditions of the area in question. Under drought conditions, however, both native and introduced plant species are difficult to establish unless soil moisture is enhanced through irrigation or other practices.

A succession of favorable events is necessary for establishing vegetation. Costly false starts are common in western reclamation: a short period of favorable weather conditions initiates seed germination and plant growth, but subsequent unfavorable conditions kill or damage the plants, requiring that some portions of the reclamation program be repeated.

Intense, brief storms may be highly erosive of arid, sparsely vegetated soils. These storms are common over the arid and semiarid West (although their frequency or actual timing are not easily predicted), and projects must be planned to accommodate them. But not all surface-mine sites are subject to the same intensity of storms, nor are the soil or spoil characteristics identical in their infiltration capacity. Thus, site-specific climatic data must be used in managing soil and surface hydrology. Long-term climatic fluctuations make recommendations based on short-term data unreliable.

SOIL RECONSTRUCTION AND LANDSCAPE MANAGEMENT

The practices that are used for soil reconstruction will depend to a large extent on the decisions that are made concerning post-mining land use and level of management. There are three broad categories of reconstruction: (1) establishment of ecosystems that do not depend on continued intensive inputs to maintain a geomorphically and hydrologically stable landscape; (2) establishment of soils and landscapes amenable to agricultural production on a sustained basis; and (3) construction of landscapes suitable for and committed to such uses as housing, industry, or commerce. Pre-mine or post-mine landscapes may have immutable characteristics, such as steep slopes, that preclude one or more of these options, but the basic goal of soil and landscape reconstruction should be to ensure that society has not lost important land-use opportunities available prior to disturbance and that the soil will function as part of a balanced hydrologic system. In the absence of well-defined land-use decisions, the establishment of an ecologically stable, desirable, and productive self-sustaining plant community leaves the widest range of options for future land use.

Reclamation should not create soils that depend on continued intensive management to maintain stable landscapes unless it is clear that such management will be continued after reclamation is completed. Landscape reconstruction solely for intensive post-mining land uses such as housing or commercial development limits future land use, and consequently the short-term benefits of restricting land-use options in this way should be weighed against the possible long-term costs of pre-empting other future land uses. A relatively small percentage of mined land is likely to be suitable for or needed for such uses.

Time Requirements

The discussions of basic concepts of soil genesis and soil-forming processes after mining in Chapters 5 and 6 indicate that natural soil-forming processes require relatively long periods of time to change unweathered materials into soils of optimum productive potential. Actual time requirements for reestablishing soil productivity vary considerably depending on climate and the characteristics of the reconstructed soil. Congress recognized in PL 95-87 that climate was an important factor in time requirements for reclamation and set different periods of responsibility for successful revegetation in semiarid and humid regions. In the East, responsibility extends for 5 full years after the last year of augmented seeding, fertilizing, irrigation, or other work carried out. In the West, responsibility extends for 10 years. The dividing line is the 26-inch (660 millimeter) annual-precipitation isohyet, west of which evaporation generally exceeds precipitation.

Congress defined successful revegetation in section 515(b)(18) of PL 95-87 as a "diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area." The periods of responsibility for reclamation represent a compromise between times long enough to meet what is a quite stringent standard for revegetation and times that are not excessively burdensome to mine operators. Thus these specified periods of responsibility may not be long enough to ensure the vegetation standard of the act is met, particularly in the arid and semiarid West. In moisture-deficient areas, vegetation on reclaimed land must be tested by the stresses of drought before its effectiveness, permanence, and self-regenerating capacities can be determined. In the northern Great Plains, drought cycles have periodicities ranging from 15 to 20 years (Murray 1978). In the Southwest, however, because conditions are always very arid, continued viability can probably be expected if vegetation can survive well enough to meet the vegetation standard in the act for 10 years after the last augmented seeding, fertilization, and irrigation.

Natural successional processes may take tens to hundreds of years to reach climax conditions, so if the "species diversity" demanded by the act refers to native climax vegetation, time periods of 5 or 10 years are likely to be too short. An alternative approach to evaluating species diversity and self-regenerating capacity might be to look at intermediate successional stages. If ecosystems on the reclaimed land are moving toward climax communities in successional stages and at similar rates and levels of productivity as the pre-mined soil would during natural revegetation, then the 10-year time period may be sufficient to evaluate revegetation success on mined land. It would take considerable experimentation and research to develop methods for evaluating productivity based on successional processes. But if reliable methods could be developed, success in revegetation might possibly be determined in time periods shorter than those specified in PL 95-87.

Good reclamation practices can certainly speed up natural soil-forming processes and vegetational succession. Caspall (1975) concluded that reinstatement of the *A* horizon—with its organic-matter and microorganism content—would shorten the time required for soil redevelopment on surface-mined land in the Midwest by 30 to 50 years. In the West, using containerized seedlings has proved more successful than direct seeding in establishing shrubs and trees (Institute for Land Rehabilitation 1978), and this procedure could be considered a speeding up of the natural successional process.

In some circumstances the period of responsibility for reclamation under the federal surface-mine law may extend beyond 5 or 10 years after the completion of revegetation practices. If the vegetation standard is not met within the specified time, or if the operator decides that augmented seeding, fertilization, or irrigation is necessary after the beginning of the prescribed period, the time clock is reset at zero. For example, if an operator in the West has to perform augmented seeding and fertilization in the tenth year after completion of revegetation because the standard has not been achieved, he then becomes responsible for another 10-year period. The possibility that the period of responsibility could extend on 20 or more years makes the development of successional criteria for assessing soil productivity all the more attractive.

Strategies for Soil Reconstruction and Landscape Management

As discussed in detail in the previous chapter, there are 5 basic steps necessary in the process of soil and landscape reconstruction related to mining for coal: (1) predisturbance inventory of soils and land productive potential, (2) a decision on post-mining land use, (3) preparation of a reclamation plan based on the results of the inventory to accomplish the chosen goal, (4) reconstruction of the soil and landscape after mining is completed in accordance with the reclamation plan, and (5) management of the resulting soil and monitoring to determine success of reclamation.

Mining and reclamation practices necessary to achieve selected post-mining land uses need to be determined on a site-by-site basis. It is possible, however, to formulate some general principles for use in site-specific planning. A reconstruction plan that focuses on reestablishing a soil's productive potential and its functions as part of the hydrologic system should be based on two general considerations: (1) an understanding of the beneficial and adverse effects that disturbance of soil and overburden by mining may have on the characteristics of the reclaimed soils and (2) an understanding of soil-forming processes operating within the time frame of the mining plan that may help or hinder restoration of productivity.

In general the effects of soil disturbance are more adverse than beneficial because many beneficial soil characteristics have been attained by soil-forming processes that require hundreds to tens of thousands of years to reach a steady state. Therefore, special care must be taken in the attempt to minimize the adverse effects of soil disturbance on these characteristics and to create beneficial changes that offset unavoidable adverse changes. For some old soils, disturbance may provide an opportunity to rejuvenate the soil profile by substituting or blending in more favorable materials.

Topographic Reconstruction

The relief of the terrain affects the potential productivity of a soil by its influence on soil moisture and potential for erosion. Requirements in the federal strip-mine law for restoration of approximate original contours place constraints on the large-scale manipulation of topography, but some deviations from original contours may compensate for other, adverse effects of mining disturbance.

An almost unavoidable result of any grading of soil is a reduction in infiltration capacity resulting from compaction and breakdown of the soil structure. The result is increased runoff, greater soil erosion, and reduced water availability in the soil profile. One way to mitigate the adverse effects of restricted infiltration is to make new slopes less steep than those before mining, so that water runs less quickly over the surface. In the Rhine brown-coal region in Germany, loess soils to be reclaimed for crop production are regraded to a maximum slope of 1.5 percent (Heide 1973). On mined lands in Iowa, where pre-mine slopes were too steep to support continuous row crops, bench terracing in reclamation created a topography more amenable to row crops (Henning and Colvin 1977). Topographic and soil reconstruction in Germany is often planned so that areas of intermediate gradients are replaced after mining with small level areas, in which favorable topsoil is concentrated, and larger steeply sloped areas, which are planted with forest.

Contour terracing, furrowing, ditching, and diking can be used in any region to shorten slopes of reclaimed land and thereby lessen erosion potential and increase infiltration (Verma and Thames 1978, Glover et al. 1978). Microtopographic manipulations such as gouging and dozer basins can be effective in the very short term but may fill rapidly with sediment. Dollhopf and his colleagues (1977) found that the life of such depressions at several sites in Montana and North Dakota was generally less than 2 years. A surface layer of topsoil in several instances increased the effective life of depressions to over 5 years, but all treatments at one site filled in less than a year.

In areas where reconstructed slopes can be expected to experience a certain amount of uncontrollable erosion, a thicker blanket of topsoil and favorable subsoil material may be placed on the upper parts of slopes than on the lower parts. In this way soil erosion that cannot be controlled during the early stages of reclamation would be relied upon to redistribute topsoil fairly evenly. This method has never been tried, and experimentation would be necessary to see if it is practical.

In some situations, grading of spoils to make south-facing slopes less steep and north-facing slopes more steep than pre-mine slopes might increase soil moisture. In the northern Great Plains, where natural cliff-forming strata near the surface can minimize potential for erosion, infiltration rates might be ameliorated by creating steeper slopes than is generally the practice at highwalls and flatter slopes on the remainder of the reclaimed area (Murray 1978).

In western states where much of the topographic diversity is provided by rimrocks, buttes, and badlands, broken topography is an important feature of the wildlife habitat, providing diversity of microclimates for vegetation and escape cover. In areas where rock outcrops, rimrocks, or badlands are present, excess rock can be spread out horizontally in places to recreate nesting/denning sites for small birds and mammals. Although not currently allowed by the federal strip-mine law, some highwalls in the West and Midwest could be a good source of wildlife habitat for raptors, hole-nesting birds, and small mammals (Harju 1980).

Soil Reconstruction and Management

Reconstruction of suitable soil profiles after mining involves placement of soil and overburden material in such a way as to establish physical and chemical characteristics at, and just below, the surface of the landscape that ensure restoration or even improvement of the productive potential of the mined land.

The benefits of saving topsoil and replacing it during reclamation have been extensively documented (Schuman and Power 1980). Pennsylvania and West Virginia, which before the federal surface-mine law had two of the oldest and most stringent reclamation laws in the United States, required this practice, even though *A*-horizons in these states tend to be thin, and the directors of reclamation for these states attributed a large part of the success of their reclamation programs to that requirement (Grim and Hill 1974).

It should be kept in mind that the term *topsoil* is not necessarily restricted to the *A* horizon of the soil profile. The U.S. Department of Agriculture has defined it as "presumed fertile soil material . . . used as a top-dressing" (Soil Survey Staff 1951). In a discussion of topsoiling for reclamation Smith (1973) distinguishes between three kinds of topsoil: (1) synthetic topsoil, such as flyash, sawdust, and manure; (2) weathered topsoil, or the *A* horizon of soil profiles; and (3) geologic topsoil, which is natural top-dressing material occurring in the overburden below the zone of intense weathering.

It is the properties of the topsoil that are important, not the *A* horizon per se, and if other soil material or the *A* horizon combined with other material is superior to the original topsoil, this would be the preferred top-dressing. Situations where material other than the original topsoil may be preferable include areas where excessive erosion has exposed subsoil at the surface; areas in the West where the *A* horizons are sodic or saline; and areas where organic-rich lacustrine sediments are available as a topsoil substitute or additive.

Lacustrine sediments are found in limited areas of the Indiana coal region. These sediments have levels of organic matter comparable to or higher than levels in *A* horizons, and are thus superior topsoil material. A study of the potential of various soil horizons and overburden materials in Indiana for plant growth found lacustrine sediments (material deposited in large glacial lakes) and *A*-horizon material to be clearly superior as media for plant growth compared to *B* horizons and various overburden materials (Byrnes et al. 1980). The general ranking of suitability of materials was as follows: lacustrine sediment ≥ *A* horizons, > *B* horizons = glacial tills = loess ≥ brown shale > sandstone > gray shale > black fissile shales. Surface soil replacement is particularly important when there are physical or chemical problems (Power 1978).

A study using various thicknesses of topsoil to cover mine spoils near Stanton, North Dakota, demonstrated that vegetation yields increased in direct proportion to the thickness of the topsoil layer up to a thickness of 60-75 centimeters. Increments above 75 centimeters did not result in significantly greater yields (Power 1978). Mixing *A*-horizon soil with subsoil overburden material merely diluted the beneficial effects of increasing the thickness of surface material. Caspall (1975) reported similar dilution effects on corn yields from reclaimed land in western Illinois, where the *A* horizon soil and subsoil are mixed. In the northern Great Plains, mixing alkaline, carbonate-rich lower soil horizons from depths of 15 to 40 centimeters with the organic rich neutral to slightly acid surface horizons was found to cause reactions in stockpiled or redistributed materials that kill off soil microorganisms and limit soil productivity (Curry 1975).

Salinity concentration in surface soils can be a problem if the soil or spoils release salts that are conducted by capillary rise to the surface and deposited there when evaporation occurs. Special practices may be necessary to reduce capillary rise, leach surface salts, modify the soil/spoil

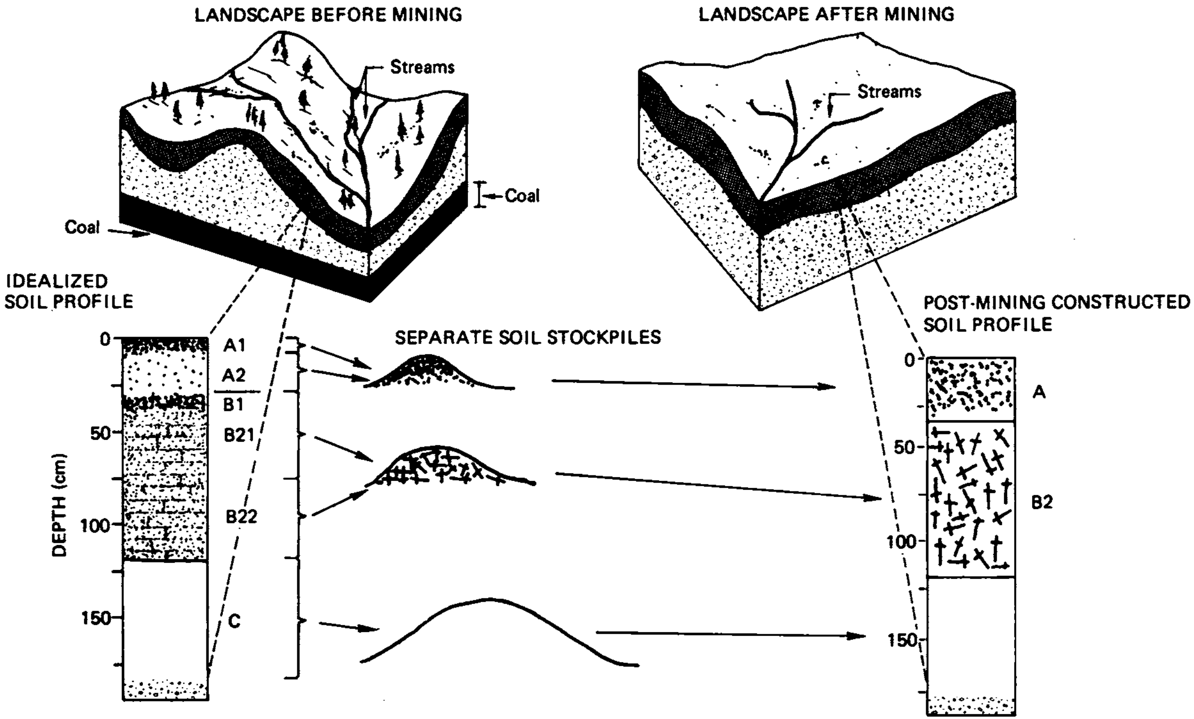

FIGURE 7.3 Idealized soil-reconstruction scheme. The stockpiling of soil horizons and the emplacement in reconstructed soil of mixed horizons can be managed so as to enhance plant growth. The two *A* horizons are mixed to form the top layer of the new soil. The two *B* horizons are mixed to provide new subsoil that has better overall qualities than did either of the original subdivisions of the *B* horizon.

surface, or utilize salt tolerant plant species. Saline-sodic spoils can best be reclaimed by burying the undesirable material with overburden of better quality or covering the graded spoils with suitable soil materials (Sandoval and Gould 1978). Similarly, acid-forming spoils are best placed below the zone of oxidation (generally 120-150 centimeters).

Although the *A* horizon is generally the most suitable surface material, it is not invariably so. We noted in Chapter 5 that the original surface material may be toxic, and its burial may therefore be warranted. Nevertheless, the benefits of the *A* horizon in terms of fertility, promotion of aggregation of the surface horizon, and superior infiltration characteristics are in most instances sufficient to justify selectively removing and replacing the surface soil.

Furthermore, in many cases it is worthwhile to retain the *B* and *C* horizons as well. The *A* horizon is commonly too shallow (15 to 25 centimeters thick) for adequate rooting of plants, and the *B* horizon, except where there is a high clay content or "pan" layers, usually provides better rooting conditions than the *C* horizon. Of course, some *B* horizons have such low fertility or unfavorable textures that it may be profitable to place the *C* horizon over them in reconstructing the soil. Once again, the importance of site-specific decisions is clear. McCormack (1974) suggests that soil reconstruction be planned to a depth of at least 150 centimeters (about 5 feet) using a sequence of horizons chosen from available soils and geologic strata that will provide the most favorable medium for plant growth.

Figure 7.3 shows how a complex set of conditions based on a site in Ohio (McCormack 1976) might be managed. The *A1* and *A2* horizons are mixed and stockpiled, and replaced together because the *A1* horizon is too thin to be handled separately. The upper *B2* horizon (*B21*) is excessively acid and moderately clayey; the lower *B2* horizon (*B22*) is excessively clayey but only slightly acid or even alkaline. A blend of these two layers will be an improvement over the original profile, and thus the entire *B* horizon is stockpiled and replaced as a unit. Attempting to keep each layer distinct would in this case be counterproductive.

If subsoils are placed on the surface, the formation of soil humus can be aided by addition of plant residues such as straw, fresh plant material (green manuring), or organic wastes to soil. The process of humification can be physically accelerated by exposure of larger areas of organic matter to decomposition through alteration of the particle size of organic residuals (e.g., cutting, disking) and then incorporating the finely divided organic material into the soil. If economical and commensurate with other objectives, land surfaces might be constructed to achieve slope and aspect that take maximum advantage of temperature effects (in humid regions) or moisture effects (in arid regions) on microbial decomposition processes.

Since decomposition is principally an aerobic process, it is markedly accelerated by tillage.

High salt contents and extreme pH levels retard decomposition as well as plant growth. Therefore, leaching of salts through irrigation or alteration of physical properties of the soil to improve rainfall infiltration may be necessary. Addition of acidic supplements (e.g., elemental sulfur) may be required in alkaline (usually arid) soils; liming may be necessary in acidic (usually humid) soils.

Stockpiling of topsoil is problematic in itself, disrupting both favorable soil properties and the microbial regime. Stockpiled topsoil at a site in North Dakota was found to have increased bulk density and both decreased water-holding capacity and smaller amounts of organic matter than undisturbed topsoil (Miller and Cameron 1976). Storage of topsoil for 4 months at an oil-shale site in Colorado resulted in a decrease in organic matter near the surface of the pile (Klein et al. 1979). Soil-moisture levels increased with depth, suggesting that aerobic conditions and perhaps wetting and drying of the surface of the storage pile stimulated oxidation of soil organic matter.

The best method of topsoil handling is thus to avoid stockpiling by immediately reapplying topsoil in an area contemporaneously under reclamation. If topsoil must be stockpiled, saturation with water or construction of storage piles deep enough to limit diffusion of oxygen to their lower reaches could effectively limit decomposition, but soil microbial populations would also be dramatically altered (Parr and Papendick 1971). Resulting anaerobic conditions might result in loss of nitrate-nitrogen and increased levels of organic acids and trace elements in forms (e.g., manganous ions) that may be somewhat toxic to plants. Thus, although organic matter would be stabilized in deep piles, ancillary reactions might nullify the advantage, particularly since the important humate and fulvate fractions would be quite stable even under aerobic conditions. There is a need to develop information on the extent of these effects, the results of pile depth under different soil and climatic conditions, and the rates of recovery that could be expected after renewal of aeration following placement and cultivation.

In relation to farmland reconstruction, Sendlein (1979) has suggested that it might be possible to identify a combination of optimum values or ranges of values for specific soil properties such as density, texture, permeability, pH, and exchange capacity. These values might serve as a standard by which to determine a soil's productive potential.

Restoring Hydrologic Characteristics

Reclaimed landforms should be designed to mesh hydrologically with local natural landforms. Because current reclamation practices generally include grading and often require repeated handling of soil and spoil material to meet broader reclamation objectives of landscape restoration, the infiltration capacity of mined soils is likely to be lower than that of pre-mined soils. Reestablishing landscapes after mining so that infiltration/runoff relationships for reclaimed soils are similar to those for pre-mine soils is perhaps one of the greatest challenges for reclamation.

Separate removal and replacement of the surface soil horizon has been found to boost infiltration rates significantly and consequently to reduce erosion under a variety of site conditions in the northern Great Plains (Dollhopf et al. 1977). And, as discussed earlier, reduced infiltration capacity can be somewhat offset by reducing the slope of the reclaimed surface, or shortening the slope length. Requirements for restoration of approximate original contour, however, limit the extent to which slopes can be reduced. Ripping or scarification of the surface may help, but the effect is generally only temporary. Surface scarification of graded raw spoils in Kentucky had no measurable effect on moisture status or bulk density (Curtis 1973), and in North Dakota tillage of surface-mine spoils with a high sodium absorption ratio did not increase water flow into spoils (Gilley et al. 1977).

Any altered drainage and infiltration characteristics of the reclaimed landscape should be taken into account when planning the spacing and relative length of the drainage channels (Murray 1978). Until a stable vegetative cover is achieved on reconstructed soils, conservation practices and sediment ponds should be used to minimize erosion and sediment discharge to off-site surface streams. Toxic overburden should be kept below the rooting depth of plants and isolated from subsurface water flows to prevent contamination of ground water.

Revegetation

Revegetation of reclaimed soils can serve a variety of purposes, and selection of species for revegetation and timing of planting depend on the purpose under consideration. The short-term goal of rapid establishment of vegetative cover to prevent erosion and, in some situations, to be used as green manure may require different species than does the long-term goal of establishment of a level of productivity similar to that of pre-mine soils. Much research on revegetation of mined land has focused on the short-term goal, identifying species that grow well on less favorable spoils and provide a quick ground cover. Techniques are reasonably well established for the short-term stabilization of reclaimed soils in all coal regions, but transition to the longer-term goal of a "diverse, effective, and permanent" ground cover within the times required by the federal surface mine law may be difficult to achieve. The U.S. Fish and Wildlife Service is now making available information on various vegetation types that may be useful in reclamation in Colorado, Wyoming, and Montana through the Plant Information Network (Vories and Sims 1977). However, only sketchy information is available on establishing native plant species adapted to the poor soils and harsh climatic conditions of the coal fields in the Southwest (McKell et al. 1979).

Herbaceous ground cover is best for rapid stabilization of the soil surface, but it can create difficulties when reforestation or reestablishment of rangeland vegetation is the longer-term goal. Planted together, herbaceous vegetation and tree seedlings will compete for moisture, nutrients, and light, and there is evidence that certain grasses and legumes create a biochemical environment in the soil that is detrimental to tree growth. On mined land in the northern Great Plains, vegetation has been established that provides short-term stability (of 3 to 5 years), but systematic experimentation with and restoration of self-sustaining vegetative ecosystems have not gone on long enough to evaluate success through the stress of extended periods of drought (Murray 1978, Wiener 1980).

Annual grasses and forbs have proven easier to establish by seeding than perennial grasses and shrubs. Handling of topsoil to maintain the viability of seeds already in it greatly enhances establishment of perennial grasses. Experiments at the Decker Mine in Montana showed that immediate spreading of topsoil over spoil resulted in a cover of perennial grasses over 53.6 percent of the surface, compared to a cover of 14.8 percent on topsoil that had been stockpiled (Kleinman and Layton 1979). In the arid West it is generally necessary to plant drought- and salt-tolerant species or ecotypes (Institute for Land Rehabilitation 1978). Where mined land is reclaimed for growing row crops, it is important to use cover crops such as alfalfa for several years to improve soil tilth before planting crops (Grandt 1978).

Where the purpose of reclamation is to reestablish ecosystems that do not require continual intensive management, soil supplements should be used only to establish initial vegetative cover, which should gradually be replaced through a natural succession of species and communities. It may take longer to establish a climax community through natural succession than through direct, intensively managed installation of climax or subclimax species, but the longer process should allow the evolution of a soil-vegetation combination that has much greater resiliency to stresses in the environment once stewardship ceases (Murray 1978).

Aesthetics

Reclamation that establishes self-sustaining or agricultural ecosystems generally results in a landscape that is aesthetically acceptable to a majority of local citizens. When the post-mining land use is for recreational or more intensive uses such as housing or commercial development, however, particular attention must be paid to aesthetic considerations. Aesthetically pleasing results have been achieved by applying principles of landscape design—regarding spatial characteristics, landforms, type and arrangement of vegetation, and location of walks and overlooks—to reclaimed mined lands in Moraine State Park in Pennsylvania (Fenton 1973). Successful landscape planning has an ecological basis, as has been demonstrated on a large scale in the Rhine brown-coal district in Germany (Olschowy 1973).

PRODUCTIVITY OF SURFACE-MINED LANDS

Until recently, reclamation of lands mined for coal has been oriented toward restoring mined land to productive *uses* but not necessarily toward reestablishing pre-mine productive *potential*. Consequently, there are few systematic comparisons of the productivity of pre-mine soils in an area with the productivity of reclaimed land after mining. Future reclamation efforts will need to document more carefully the characteristics of pre-mine soils for more rigorous evaluation of the changes that occur through mining.

LAND RECLAIMED FOR CROPS

In steep-slope areas of Appalachia, mining practices may create extensive nearly level areas where none existed before, producing new potential for growing row crops. However, the stoniness of soils that were originally shallow to bedrock can create difficulties in the use of farm implements (U.S. Soil Conservation Service 1973).

In parts of Ohio and Pennsylvania, coal mining and construction of a new landscape may take farms out of production for only 2 years. In some places the post-mining terrain that is created is better adapted to farming than the original landscape was, and the reconstructed soil is more uniform in depth. With the help of forage crops, soil conditions permitting crop production can be established within a year or two, with yields as good as or better than before mining (McCormack 1976). The improvement in some of these areas can probably be attributed to the low inherent fertility of pre-mine soils and increased rooting depth and available-water capacity due to breaking up of a claypan.

Studies at the University of Illinois in the late 1940s showed that corn yields as high as 60.5 bushels per acre (approximately 619 kg/ha) could be achieved without topsoil at a high level of management (Grandt 1978). In the 1950s and early 1960s, research conducted by Peabody Coal showed that by using various fertilizer treatments and crop rotations over a 10-year period, an average field-crop harvest of 87.5 bushels per acre could be achieved (Grandt 1978). Yields from these experiments varied from a low of 25 bushels per acre to a high of 105 bushels per acre during the 10-year period; the crops were found to be more susceptible to drought damage than those on average corn-producing land (Higgins 1973).

Between 1974 and 1978, research plots in Knox County, Illinois, on 20-year-old spoils covered with a fresh 38 centimeters (15-inch) layer of topsoil yielded an average of 116 bushels per acre of corn. This yield was 83 percent of the yield that would have been expected from unmined soils in the area under an intensive level of management, but higher than yields from unmined soils under a basic level of management (Grandt 1979). Yields on graded spoils without topsoil average 76 bushels per acre. Corn yields on reclaimed land in Randolph County in southern Illinois, planted the same year as soil reconstruction, 1977, averaged 68.7 bushels per acre (Grandt 1979). This was 76 percent of the yield from pre-mine soils under intensive management (which are "overmature" soils on pre-Wisconsinan land surfaces) but was again higher than the yield under a basic level of management.

The National Coal Policy Project (Murray 1978) concluded that there was a good possibility of restoring or improving agricultural productivity of overmature soils through reclamation in areas of the Midwest. The project also concluded that current reclamation practices were unlikely to restore the high productivity of the soils formed in Wisconsin glacial tills within a reasonable period of time (10 years or less) and recommended that mining in these areas be allowed only on an experimental basis.

In the Gulf Coast lignite belt, extensive mining and reclamation is relatively recent, so there are not many published data on crop yields from reclaimed land. Hons and his colleagues (1978) considered the yield potential for grain sorghum on mined soils to be excellent.

The dry-land wheat-farming areas of North Dakota and eastern Montana are the only areas that are suitable for cultivation of crops without irrigation in the coal-bearing regions in the West. Research in North Dakota indicates that about 76 centimeters of good topsoil over sodic spoils gives yields that are comparable with those obtained on unmined land (Power et al. 1978). However, some questions remain as to whether this thickness of topsoil is sufficient to maintain long-term productivity, which may be curtailed by salt migration upward from spoil into the replaced soil and by surface erosion losses.

The only place where long-term data have been compiled on crop production on reclaimed mined land is from the Rhine brown-coal district in Germany. Yields for summer barley and winter wheat from reclaimed loess soils 1 to 4 years in age were 81.7 percent and 89.7 percent, respectively, of yields from natural loess soils (Heide 1973). Yields from reclaimed soils that are 13 to 20 years old were 89.0 percent, for summer barley, and 95.8 percent, for winter wheat, of yields from natural soils.

Land Reclaimed for Pasture and Rangeland

Where overburden conditions are favorable, productivity of pasture on mined land can be equal to or better than that on unmined soils in the Midwest and Appalachia. The nutritive quality, species diversity and composition, and biomass production from pastures on 100-year-old iron-mine spoils in West Virginia have been found to be superior to those on unmined soils (Smith et al. 1971); neither spoils nor unmined soils had been fertilized.

Before recent requirements to reestablish row-crop potential on mined lands, most reclaimed areas devoted to agriculture were devoted to producing beef feeder calves (Higgins 1973). Grandt and Lang (1958) found no statistically significant difference between average daily weight gains of beef cattle grazed on strip-mined pasture and pasture on unmined land in western Illinois over the 3-year period from 1948 to 1950. They did report slightly lower weight gains on strip-mine pasture than on improved grass-legume pasture on unmined land in Southern Illinois. In the Gulf Coast region, forage production on 3-year-old mined land in Freestone County, Texas, is comparable to or greater than yields reported on unmined soils at similar rates of nitrogen fertilization (Hons et al. 1979).

In the northern Great Plains, use of introduced species, fertilization, and management can induce biomass production on mined land greater than that on undisturbed soils. Total herbage production on a reclaimed area at the Decker Mine in Montana was twice that of native soils in 1977, and 30 percent higher than that of native soils in 1978 (Kleinman and Layton 1979). Both native soils and reclaimed soils were fertilized, but at different rates, and thus the herbage production of the reclaimed soil is not strictly comparable to that of the native soil. In 1978 the reclaimed land had a surface cover of perennial grasses, annual grasses, and forbs similar to those on native soils, but had less shrub cover. Green (1977) notes that, because of unfavorable soil and climate conditions in coal fields of the Southwest, species seeded on reclaimed spoils will probably require more careful management than species growing naturally on more favorable undisturbed sites.

Barker and his colleagues (1977) found higher initial establishments and production of grasses on strip-mine spoils in North Dakota than on undisturbed soils, but over a period of 3 years plant density and production declined rapidly on mine spoils and increased on undisturbed soils. Warm-season grass species were very difficult to establish on spoils; moreover, once established on spoil material, their survival was low. These findings are from such a short time period, however, that the only conclusions we can confidently draw are that large changes can be expected in the establishment and production of range species over relatively short periods of time, and that longer time periods will be necessary to evaluate the productivity of reclaimed rangelands. Data collected over a 3-year period near Center, North Dakota (where the spoil consists of good plant-growth material, unlike many other mined sites in the state), show that cool-season introduced species on reclaimed land provided cattle weight gains equal to or greater than those on unmined pastures with similar introduced species or those on native pasture during early season grazing (Hoffman and Ries 1980). Such pasture could be used in a complementary grazing system, provided sufficient native pasture was associated with the reclaimed land.

In areas of the Midwest, Appalachia, and Gulf Coast where favorable overburden conditions prevail, restoration or improvement of the productivity of mined land for grazing is apparently not difficult. Nonetheless, restoration or even improvement of a mined soil for grazing is not necessarily the same thing as restoration of the overall productive potential of the soil, particularly if the soil has potential for crop production as well. Overall yields of alfalfa from reclaimed loess soils in the Rhine brown-coal district of West Germany are 104.5 percent that of undisturbed soils within the first few years of reclamation and may increase to more than 140 percent that of undisturbed soils within 20 years. Yet yields for summer barley and winter wheat do not equal those of undisturbed soils during the same time period (Heide 1973). Reclaimed soils in Pike County in southwestern Indiana produce good forage, but attempts to grow grains have not been successful, and consequently mining might shift the pattern of agriculture from cash-grain and concentrated livestock production to grassland cattle farming (Armstrong 1978).

Land Reclaimed for Forests

There are relatively few data on timber growth on reclaimed lands compared to pre-mine silvicultural productivity, even though the earliest reclamation efforts in this country usually involved tree planting, and much research has been done on reforestation in Appalachia and the Midwest. Most timber stands on reclaimed land have not been consistently managed or monitored (Ashby et al. 1978).

Growth rates and site quality of 20-year-old red pine plantations on mine spoils in Clarion County, Pennsylvania, were significantly lower than on plantations the same age on an adjacent old-field site (Aharrah and Hartman 1973). Smith and his colleagues (1971), on the other hand, found no significant difference between forest site quality on 100-year-old iron-mine spoils in West Virginia and on undisturbed soils. Many stands of hardwood planted on coal-mine spoils in Indiana are equal to or better than other hardwood plantations in the state (Callahan and Callahan 1971). Lyle et al. (1976) found timber volumes on naturally revegetated abandoned mine spoils in Alabama to compare favorably with volumes on unmanaged unmined land, but the value of the timber was reduced because ridges were too steep for easy logging or other operations that require access by vehicles. Geyer (1973), in an evaluation of 22 years of tree growth on ungraded strip-mine spoils in Kansas, found most species present to show growth rates comparable to those on moderately productive undisturbed soils. Walnut trees grew much more poorly on spoils than in native stands and oaks a little more poorly. Chapman (1967), reporting on the results of 20-year-old experimental plots in Ohio, Illinois, Missouri, and Kansas, found that rates of tree growth and survival were almost always higher on ungraded spoils than on graded spoils but did not compare stand quality with that of undisturbed soils.

Reforestation experiments in the West have been under way for a much shorter period of time than in the East. Certain shrubs and tree species have proved difficult if not impossible to establish on mined land in Montana by direct seeding (Cull and DePuit 1979). Planting of container-grown seedlings of trees and shrubs has been somewhat successful in disturbed sites in various locations in the West (Institute for Land Rehabilitation 1978). Heavy irrigation at a mined site in North Dakota has resulted in good survival rates after one year for juniper, green ash, and plum, with no significant difference between survival of potted stock versus bare-root stock (Williamson and Wangerud 1980). The Energy Fuels Corporation has had good success in transplanting trees and shrubs in northwestern Colorado without the use of supplemental irrigation (Wiener 1980).

Equal or higher productivity for forestry again does not necessarily mean restoration of the overall productive potential of a mined soil. In Indiana the forests that are growing on "pre-law" ungraded spoils may be more productive than those on pre-mine soils, possibly owing to the breakup of a fragipan, but many of these sites had good row crop potential before mining, so the overall productive potential of the mined land must be considered reduced.

Land Reclaimed for Wildlife

Where mined land in Appalachia and the Midwest is not reclaimed for crops or grazing, diverse and populous biologic communities can be developed. The edges of mined areas become ecotones between biotic communities and are able to support a mixture of animals and plants characteristic of the two communities (Holland 1973). The diversity and numbers of animal species depend largely on the planting or natural invasion of suitable plant species for food and cover (Brenner 1978). Studies of small mammal populations in reclaimed lignite spoils in Freestone County, Texas, found species diversity slightly higher in grasslands on reclaimed land than on unmined land, but species diversity was reduced overall because woodland habitat was reduced after mining (Van Waggoner 1978).

Scientific information concerning wildlife in relation to large-scale disturbance of vegetation by surface mining for coal in the West is limited (Institute for Land Rehabilitation 1978). A major concern is the restoration of forage plants necessary to provide winter range for large wildlife species such as antelope and mule deer. In Wyoming, antelope feed on a different mix of vegetation than cattle, about 75 percent of the antelope diet coming from shrubs. Current reclamation efforts in the Northern Plains have been more successful in establishing forbs and grasses than shrubs, and reclamation has not yet established vegetation that provides good year-round forage for antelope (Murray 1978).

THE ECONOMICS OF RECLAMATION

There are a number of conceptual problems to be surmounted if reclamation costs associated with surface mining are to be properly calculated and interpreted. But we must first consider whether such measurement is even necessary. Surface mining on a significant scale takes place in both the United Kingdom and in West Germany, for instance, with little or no attempt to measure "reclamation costs" as such. In each of these nations, for a variety of institutional, historical, and economic reasons, restoration is considered an integral part of the mining process. In the United States, however, reclamation has only recently been considered important, and hence the tendency is to consider it as an add-on expense. Moreover, we have become accustomed in many facets of our life to think in benefit-cost terms. Attempts to measure environmental and other externalities associated with resource utilization mean that there must be corresponding efforts to measure the costs associated with the mitigation of externalities. If for no other reason, consistency with the analytical procedures followed for other fuel cycles requires that we examine reclamation costs.

One problem with benefit-cost analysis of reclamation is that while costs are relatively easy to think of in monetary terms—they are costs imposed on coal operators and consumers of coal—the costs of not reclaiming mine sites—that is, the benefits of reclamation—are often difficult (if not impossible) to measure in monetary terms, and, more critically, many of them will not occur for some time. This disparity tends to distort the analysis, and it gives reclamation an appearance of being uneconomical. In spite of such difficulties, there *are* instances where such costs have been estimated. For example:

- The estimated costs imposed upon industrial users, municipal water supplies, navigation, and public facilities by acid mine drainage in Appalachia have been estimated to total $3.5 million annually. Capital expenditures for cleaning up acid mine drainage exceed $6.6 billion (Appalachian Regional Commission 1969).
- Property damage resulting from improper blasting practices in coal surface mining in Appalachia and the Midwest is estimated to have exceeded $200 million in 1975 (Darcey et al. 1977).
- Flood control, the primary function of dams built with public funds have been impaired by excessive sedimentation from surface mining (U.S. General Accounting Office 1973). The administrative costs and disbursement by government relief agencies for a single flood in April 1977 in Harlan County, Kentucky, exceeded $2.2 million. The severity of this flood has been attributed to sediment in stream channels resulting from coal surface mining in the watershed (Hardt 1978).
- Cherokee and Crawford Counties in Kansas have lost $1.6 million in assessed valuation owing to abandoned mined land, resulting in a tax loss of approximately $80,000/year (Camin et al. 1971).

Costs in each of these examples are the result of an individual set of circumstances and therefore it is not valid to extrapolate these figures to other sites. And there are many other types of damages for which monetary estimates are not possible—in particular, aesthetic damages. If these are not included in an analysis, the weighing of reclamation costs against reclamation benefits (damages avoided) will be seriously biased.

Another conceptual problem is reflected in consumers' resentment over coal being made more expensive by reclamation efforts. In the absence of reclamation, however, important social costs are not included in the market price of coal. Decisions on energy use should reflect these costs, and they are quite properly passed along to consumers of coal and coal-using products. With this pass-through, coal will become slightly more expensive and other energy sources will become less expensive relative to coal. When the adjustment in relative prices has worked through the economy, consumers will be making a more appropriate use of the various energy sources.

It is perhaps an interpretive rather than a conceptual problem that over the last couple of years, economic difficulties in the coal industry have been blamed on the environmental statutes in the federal surface-mine law. But these difficulties appear to be the result of a surplus of production capacity rather than of federal regulation. During 1979, the coal industry expanded production capacity significantly in response to an anticipated market demand for coal that did not fully materialize. About a hundred million tons of excess capacity, and thus a soft market for coal, resulted.

Finally, some lament the fact that per-acre reclamation costs can be higher than the market price of the land. This is beside the point in the broader social context. The current market price for land merely reflects what the current generation of possible users is willing to bid for that land at this time. Its normative significance as a guide for public policy should not be overstated. Current and future individuals should not be made to bear unreasonable costs in terms of destroyed landscape for the sake of current consumers of coal.

Limitations of Studies of Reclamation Costs

Beyond the conceptual problems, there are further problems with the estimation process itself.

Mining and reclamation are carried out by private firms, which are not usually required and seldom volunteer to open their books to the general public or even to the research investigator. Some data have been collected in publicly financed experimental projects, but the trial-and-error approach involved in some of these activities coupled with cost-plus contracting—contracts with payment based on costs plus a profit margin—makes these studies useful but not definitive, because incentives to achieve minimum costs do not exist. Many of the data available are based on hypothetical information from engineering studies. Studies made under these limitations must be taken as indicative rather than definitive.

Cost analyses in many sectors of the economy—particularly in manufacturing—can proceed on the basis that the underlying conditions encountered in one location are likely to be similar to those at other locations. In mining, however, this is far from the case. Contour mining in Appalachia takes place on land of widely varying slopes. The earth-moving costs associated with reclamation can vary by a factor of 3 or 4, depending on the slope and thus the overburden ratio (Bohm et al. 1975). Since earth-moving costs may be around 90 percent of reclamation costs, such variation significantly affects the total. In the West, too, the depth of overburden significantly affects reclamation costs. Under the conditions of the typical North Dakota mine (a 450-acre [182 ha] mine area, a 12-foot [3.7-meter] coal seam, 5 feet [1.5 meters] of topsoil, and the use of draglines for overburden stripping), Gronhovd and Scott estimate that reclamation costs increase from about $7000 per acre with 60 feet (18.3 meters) of overburden to about $10,000 with 100 feet (30.5 meters) (Gronhovd and Scott 1979).

Coal-seam thickness has only a small effect on per-acre reclamation costs per unit area. In Appalachia, when the seam is thick there is less overburden to move and recontour in the initial spoil-bank area and the reclamation is cheaper. But the favorable stripping ratio of a thicker coal seam will encourage mining deeper into the slope and increase the cost of recontouring the final highwall. The interaction of the changes in these two costs causes per-acre reclamation costs to decrease up to a seam thickness of 12 feet (3.7 meters) and increase thereafter. In the West, over a range of seam thicknesses of 5 to 30 feet (1.5 to 9.2 meters), reclamation costs change less than $100 per acre ($247 per ha) (Gronhovd and Scott 1979). But since reclamation costs per acre are not substantially affected by coal-seam thickness, reclamation costs per ton of coal mined clearly are.

Increasing mine size allows for economies of scale in mine planning but at a certain point leads to increased haul distances for topsoil stockpiling. Thus, under North Dakota conditions, per-acre reclamation costs are estimated to decrease from $7600 per acre ($18,772 per ha) for a 100-acre (40.5-ha) mine to about $6800 per acre ($16,796 per ha) for a 400-acre (162-ha) mine and then to increase gradually to about $7300 per acre ($18,031 per ha) for a 1500-acre (607.5-ha) mine (Gronhovd and Scott 1979).

Cost will also be affected by the planned post-mining land use. The costs of returning Appalachian land to forest, midwestern land to cropland, and Gulf Coast or western land to pasture or rangeland are likely to result in regional differences in revegetation costs, but there will also be intraregional variations associated with different land uses as well as with site and climatic conditions and the types of plant materials native to different areas.

A number of other site-specific circumstances need to be considered as well.

- Total costs will vary widely with the terrain and the locations of off-site stockpiling of overburden and topsoil.
- Costs will be affected by distance from roads and other aspects of the infrastructure. In Pennsylvania, for example, many contour operations are undertaken in close proximity to public roadways; in much of central and southern Appalachia the mines are many miles from existing roads and the added costs of developing access must be considered.
- How much rock must be blasted? Can the overburden be easily segregated? Is there toxic material to be isolated and buried? The answers are all site specific.

• The severity of water-control problems will depend on a number of circumstances including slope, ground-water levels, the characteristics of the overburden, whether or not a watercourse is intersected by the mining process, the amount and distribution of rainfall, etc.

• Costs may be affected by whether or not the area has been previously mined. If an unreclaimed, abandoned mine site is remined, the earth-moving costs may be somewhat reduced, but if the area has previously been augered or if the activity intersects old deep mine workings, costs may be higher.

• Mining operations vary considerably in size as measured in annual tonnage of output. The smaller operations tend, of course, to be more labor intensive, while the larger operations tend to be capital intensive.

Reclamation standards have changed substantially over the years. In the 1950s and early 1960s many states had no reclamation requirements. Not until 1965 did the Tennessee Valley Authority—the nation's largest buyer of coal—write minimum reclamation requirements into its coal-buying contracts. Clearly, historical information on reclamation costs reflects the widely different and rapidly changing standards in effect at the times of measurement—standards that also differ significantly from state to state. Moreover, some small operators tend to move into and out of the market in response to changes in spot market prices, making it all the more difficult to trace expenditures.

A further complication introduced by time is inflation. Even if the end-points of reclamation had not changed during the last couple of decades, the costs of producing a given level of reclamation have changed substantially and unevenly.

Another complication in the measurement problem is cost allocation. For example, permitting costs and bonding costs could be considered as either *mining* or *reclamation* costs.

Until more experience is gained with the new reclamation provisions, the precision of cost estimates will remain uncertain. There are reasons to suppose that current estimates are higher than costs will probably be in the long run. The operating experience upon which estimates are based is almost always experience accrued in relatively small-scale, first-time trial or demonstration efforts. Larger reclamation operations will enjoy some economies of scale. Through trial and error, more efficient procedures will be identified and implemented. Given the substantial cost of reclamation, incentives exist for the development of cost-saving technologies. Operating costs are thus likely to decrease over time.

Unfortunately, if the surface-mining industry's reports of reclamation expenses err, current incentives make it likely that they will err on the high side, because the industry is engaged in extensive lobbying and litigation based on the argument that the 1977 federal law and the proposed regulations impose unreasonably high costs. In addition, most long-term contracts for the purchase of coal include provisions for the pass-through of reclamation and other expenses imposed by governmental regulations. Again, this provides little incentive for low estimation of reclamation expenses, although new contracts will add such incentives.

In light of all of these measurement problems outlined above, it would be irresponsible to claim too much accuracy for cost estimates. With regard to measurement issues, Mishan (1976) has said, "In view of the existing quantomania one may be forgiven for asserting that there is more to be said for rough estimates of the precise concept than precise estimates of economically irrelevant concepts. . . . " Unfortunately, we are dealing with a situation in which we must settle for rough estimates of a somewhat rough concept. With these qualifying remarks, we now turn to a discussion of the costs of reclamation in the various coal-producing regions.

APPALACHIA

Before PL 95-87

The U.S. Bureau of Mines in 1975 reported on some 20 cases in Appalachia and the Midwest (Evans and Bitler 1975). We will analyze the 6 cases that represent the Appalachian experience on steep slopes (>20°) with partial backfilling (approximately 20 feet of highwall exposed) or (in 2 cases) complete backfilling.

The costs for 1975 are given in Table 7.2. They show that backfilling costs dominate all other reclamation costs and that all costs vary widely from site to site. On the whole, the costs for southern Appalachia are considerably higher than for central and northern Appalachia. For Appalachia as a whole, the range of costs is from $2.70 to $5.99 (midpoint $4.35) per ton and from $4239 to $12,481 (midpoint $8360) per acre. The Evans and Bitler figures are comparable to those of two other studies made in this region. It should be noted that in the 20 cases studied the seam thickness varied from 2.5 feet to 4.0 feet, but the "thin-seam" case did not represent the highest cost per ton.

In 1974 the Appalachian Resources Project (ARP) at the University of Tennessee made estimates of earth-moving (backfilling) and revegetation costs in the context of a benefit-cost study of Appalachian contour surface mining (Bohm et al. 1975). For earth-moving costs, a computer program was developed in which seam thickness, highwall, slope, and costs of moving a cubic yard of earth were independent variables. The ARP case that

TABLE 7.2 Reclamation Costs on Slopes Greater Than 20° in Appalachia at 1974 Prices

	Pre-mining		Backfilling		Revegetation		Total	
	$/Ton	$/Acre	$/Ton	$/Acre	$/Ton	$/Acre	$/Ton	$/Acre
Southern Appalachia	0.08-0.36	167-721	3.34-5.76	3723-11,994[a]	0.15-0.33	320-355	3.88-5.99	4239-12,481
Central and northern Appalachia	0.08-0.10	200-205	2.47-3.75	6163-7510[b]	0.15-0.17	335-370	2.70-4.02	6733-8050
Midpoint of the range for both regions	0.22	444	4.12	7859	0.24	345	4.35	8360

[a]Partial backfilling.

[b]Complete backfilling.

Source: Data derived from Evans and Bitler (1975).

most resembles Bureau of Mines observations involves a 25° slope and a bench width of roughly 110 feet. If we adjust the ARP figures to 1975 levels and remove the costs associated with pre-mining activities (e.g., surveying and permits) from the Bureau of Mines figures (since no estimate of these costs was made by ARP), the ARP estimate of $3.63 per ton falls within all the Bureau of Mines ranges—but toward the bottom of the range for southern Appalachia, which includes the Tennessee area for which the ARP estimate was prepared.

In 1976, the Oak Ridge National Laboratory (ORNL) published results of a study of reclamation costs under various reclamation standards (Nephew and Spore 1976). The levels of reclamation defined in that study are:

No reclamation (grade 0). Coal surface mining without any subsequent relamation is considered for reference purposes. Mining activities are wholly production oriented, with special water control measure and spoil placement procedures undertaken only to the extent necessary to facilitate coal production. The coal outcrop barrier is mined; no backfilling, grading, or planting operations are performed.
Basic reclamation (grade 1). Basic reclamation represents the minimally acceptable level of mined land rehabilitation and principally requires stabilization of the spoil material to prevent the occurrence of offsite damages from erosion, landslides, and water runoff. The stabilization requirement is largely satisfied by limited backfilling to bury toxic or acid-forming materials and by grading, ditching, and revegetation to control erosion. No priority is accorded to the aesthetic rehabilitation of the disturbed area or to enhancing productive post-mining land uses.
Intermediate reclamation (grade 2). Intermediate reclamation encompasses the objectives of basic reclamation and, additionally, requires that the land be restored to a state of useful productivity. This requirement is met by increased backfilling to provide graded terraces of various shapes suitable for crop production, grazing, or other uses, and, to enhance the establishment of permanent vegetation, the original topsoil is saved and replaced after mining.
Full reclamation (grade 3). Full reclamation also includes stabilization of the mined area but further encompasses the attempt to restore the disturbed land to its original state. High priority is accorded the preservation and enhancement of landscape aesthetics. Thus, substantial backfilling and grading are required to restore the approximate original contour of the land. Topsoil replacement and the establishment of a plant cover consistent with surrounding land uses are required.

If we assume that the level of reclamation involved in Bureau of Mines sites was "grade 2" and adjust the 1973 ORNL figures to 1975 levels, the ORNL estimates for 25° slopes are $3.71 per ton (60 feet highwall) and $4.85 per ton (90 feet highwall). These figures are reasonably consistent with the Bureau of Mines figures or the ARP estimates.

Considering the wide variation among factors influencing reclamation costs, there does seem to be some general agreement among several studies of Appalachian reclamation costs prior to passage of the 1977 Surface Mine Act. In general terms, these studies were concerned with what ORNL termed "grade 2" reclamation. The midpoint, estimated at 1975 prices (with about 60 feet highwall), was $3.71 per ton for ORNL, $3.81 per ton for ARP, and $4.26 per ton for the Bureau of Mines. To be sure, considerable variation from site to site is common.

Selection of the appropriate cost index is a matter of some concern, since it cannot be assumed that mining costs move in tandem with other indicators. To check how closely the Gross Domestic Product (GDP) deflator tracks an estimated index of mining costs, such an index was constructed for Appalachia. The mining-cost index was weighted by major cost elements such as fuel, labor, explosives, and machinery. The differences between the two indices turn out to be relatively small, and therefore the GDP deflator was used in this report to adjust figures for various years to comparable levels. The figures are shown in Table 7.3.

TABLE 7.3 Estimated Reclamation Cost Index for Eastern Surface Mining

Year	Estimated Reclamation Cost Index[a]	Gross Domestic Product Deflator[b]
1967	100.0	100.0
1968	103.0	104.6
1969	107.8	109.9
1970	113.4	115.7
1971	118.8	121.5
1972	123.9	126.6
1973	131.4	133.8
1974	152.7	146.3
1975	174.3	160.5
1976	184.7	168.7
1977	197.3	178.6
1978	212.9	191.8

[a]Computed from cost breakdown reported in Skelly and Loy (1979b) based on 9 case studies reported (see pp. 202–322). Price data used in the calculation from U.S. Office of the President (1979). For miscellaneous expenditures the gross domestic product deflator was used. Other indices used were fuels and related products and power, chemicals and allied products, and machinery and equipment. Changes in wage costs were estimated based on changes in average hourly earnings of production workers in the bituminous coal industry (Department of Labor 1975 and June issues of Department of Labor, *Employment and Earnings*, for 1975–1978).

[b]U.S. Office of the President (1979), p. 187.

After PL 95-87

The costs of reclamation prior to 1977 are difficult to determine precisely, and anticipating the additional costs of compliance with the 1977 law is even more difficult. It may be helpful, however, to review some of the studies in this area.

Between 1973 and 1976, the Tennessee Valley Authority undertook an experimental back-to-contour mining project on Massengale Mountain in northeast Tennessee. The purpose of the project was to gain insights into the cost of compliance with possibly more stringent future reclamation standards. Costs were compared with those associated with earlier mining on the same mountain, where reclamation probably met ORNL grade 2 standards. In 1973 dollars, the midpoint of the range of costs calculated (with no vertical outslope) was an additional or incremental cost of $2.67 per ton (Bohm and Schlottmann 1973), a figure almost identical to the incremental cost of $2.66 per ton calculated for this site by use of the ORNL model.

Skelly and Loy (1979a) have undertaken a study of compliance with the 1977 law and associated OSM regulations. They report:

> the major cost increases will range from $4.61 to $22.51 per ton in the steep slopes of Appalachia. The provisions resulting in the highest costs in this region are valley fill construction standards, topsoil handling, sedimentation ponds, backfilling and regrading, and road construction.

In addition, however, the report develops a mining and reclamation scenario for a 57,000 ton/year mine on a slope in excess of 20°. The result is an *incremental* cost per ton of $3.94 if we assume a 4-foot seam of coal and about $5.24 if we assume a 3-foot seam.

Consolidation Coal Company (Consol) has estimated the cost of compliance with the Office of Surface Mining (OSM) Permanent Regulatory Program design standards as compared to the utilization of "good engineering practice" to meet the performance standards set forth in PL 95-87. According to Consol, good engineering practice would result in costs of $8.47 per ton, whereas *maximum* cost of compliance with OSM is estimated at $17.77 (Consol 1979). The $9.30/ton difference is due to differences in: (1) spoil-disposal methods; (2) use of sedimentation ponds; (3) topsoil use; (4) dust-control procedures; and (5) blasting practices. Consol assumed none of the OSM regulations would be exercised with the flexibility provided for, and there is some dispute over the "good engineering practices" employed.

Despite the difficulty of determining the precise impact of PL 95-87 on surface-mining costs in Appalachia, some inferences can be drawn. In constant dollars, and remembering that there will be significant variations from

TABLE 7.4 Calculated Mining Costs Before and Under PL 95-87 in Appalachia

	Annual Costs[a]	
	Before PL 95-87	Under PL 95-87
Equipment utilization[b]		
Runoff diversions and ditches	$ 1,560	$ 6,890
Sedimentation pond	630	2,380
Access road	500	1,790
Highwall haul road	—	2,120
Mine area clearing	2,000	4,950
Blasting	69,070	69,070
Mine area topsoil removal	—	4,720
Overburden removal	233,050	319,020
Coal removal	7,260	7,260
Topsoil storage area	—	560
Valley fill construction	—	12,180
Mine area regrading and reclamation	25,750	40,400
Maintenance[c] (9% of operating costs)	30,600	42,550
Supervision	71,000	71,000
Additional operating supplies (explosives)	67,000	67,000
Miscellaneous costs[d]	14,300	18,000
Auxiliary costs		
Royalty	85,500	85,500
Power	2,000	2,000
Communications	1,000	1,000
Union welfare	85,000	85,000
Payroll overhead (35% of labor and supervision)	51,900	61,800
Health and safety	4,500	4,500
Contract coal haulage	99,800	99,800
Reclamation fee ($0.35/ton)	—	19,500
Indirect costs (15% of labor, supervision, maintenance, and supplies	57,040	71,580
Fixed costs (taxes and insurance, 2% of mine cost)	38,060	42,800
Depreciated costs (5 year)		
Fees	8,400	8,400
Permit and mine plan preparation[e]	1,000	5,000
Engineering	1,000	2,000
Field indirect costs[f]	5,000	7,000
Overhead and administration	14,830	29,650[g]
Contingency	33,920	38,160
Interest during construction	19,030	20,990
Site facilities and buildings	2,600	2,600
Annual operating cost	$1,033,320	$1,257,290
Annual production (ton)	57,000	57,000
Cost/ton	18.12	22.06

site to site, additional costs associated with OSM compliance will probably be at least equal to the cost of reclamation practice typical of the mid-1970s. Table 7.4 shows (in 1978 dollars) the estimated cost of grade 2 reclamation and the incremental costs of reaching the type of reclamation required under the federal law and regulations. The per/ton incremental cost under PL 95-87 is approximately $4.00 more than before PL 95-87. This $4.00 represents about 20 percent of the price of coal.

The Midwest

Before PL 95-87

Variation in reclamation costs may be greater in the Midwest than in other areas owing to greater variation in possible post-mining land use. The figures in Table 7.5 show ranges of cost on a tonnage and acreage basis for "typical" midwestern conditions. Costs are estimated for a hypothetical state in the Midwest where minimal backfilling, grading, and revegetation are required—conditions that existed in Missouri or Oklahoma in 1975 and in Illinois in 1970. Estimates in Table 7.5 are in 1978 dollars and have, where necessary, been adjusted by use of the Gross Domestic Product deflator.

A second set of pre-PL 95-87 estimates is also shown in Table 7.5, based on return to row-crop production without topsoiling and with revegetation efforts for 1 or 2 years only. The midpoint of the range of minimum reclamation costs is $0.55 per ton ($3500/acre); the midpoint of costs for a return to row-crop production is $2.07 per ton ($8500/acre). As in the Appalachian area, earth-moving costs tend to dominate the total costs, running in the 60-85 percent range.

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[a] Minimum costs assuming ideal site and mining conditions.

[b] Assumes 85 percent job efficiency and availability.

[c] Includes road grading, water trucks, and general maintenance.

[d] Idle time.

[e] Assumes minimum information acceptable by Regulatory Authority on initial submittal.

[f] Culverts and miscellaneous field supplies.

[g] Assumes 1 additional full-time salaried person at $12,000 per year for blasting records, blast surveys, advertisements, and required paperwork.

Source: Skelly and Loy (1979a).

TABLE 7.5 Estimated Reclamation Costs in the Midwest Under State Regulations Before PL 95-87 (1978 Dollars)

	Minimal regulatory constraint[a]		Rowcrop[b]	
	$/Ton	$/Acre	$/Ton	$/Acre
Backfilling and grading	0.10-0.45	1000-3000	1.30-2.50	6000-8000
Other	0.20-0.35	1000-2000	0.10-0.23	1000-2000
Total	0.30-0.80	2000-5000	1.40-2.73	7000-10,000
Midpoint of range	0.55	3500	2.07	8500

[a]Reclamation to prevent off-site damages; includes planning, minimal backfilling and grading without topsoiling, establishment of vegetative cover, minimal sediment control, and removal of roads.

[b]Assumes no topsoiling and minimal to intensive revegetation efforts for 1 or 2 years only.

Source: Data from Carter et al. (1974), Consol. (1979), Evans and Bitler (1975), Grim and Hill (1974), Persse et al. (1977), Skelly and Loy (1979a), U.S. Department of the Interior (1972).

After PL 95-87

Reclamation costs in the Midwest will fluctuate as a result of changes in:

- the stringency of certain portions of the law, such as bonding requirements, back-to-contour regulations, and topsoil segregation rules.
- types of equipment used and efficiency of use. Conveyor belt systems, bucket wheel excavators, equipment with lower tire pressure (to reduce soil compaction), and cropping sequences designed to improve soil may become more important components of the reclamation industry in attempts to comply with overburden replacement and compaction regulations.
- research efforts as companies attempt to reduce reclamation costs over the long run.

Table 7.6 shows the most likely range of costs where backfilling, grading, and topsoiling are major components of reclamation. Certain mines in lignite regions of Texas currently have reclamation costs that are much lower; in some Illinois mines in prime farmland regions, reclamation costs are much higher.

Under PL 95-87 earth-moving costs—topsoiling and grading plus backfilling—are expected to become somewhat more important in some cases and somewhat less important in others. Overall, earth-moving costs are projected to be 70-80 percent of the reclamation cost. Topsoiling costs

TABLE 7.6 Probable Ranges of Costs of Reclamation in the Midwest (1978 Dollars)

	$/Ton	$/Acre
Pre-mining planning	0.01-0.07	200-500
Backfilling and grading	1.30-2.50	6000-8500
Topsoiling	0.40-1.85	2000-8000
Sediment control	0.08-0.17	400-1300
Mulching	0.02-0.03	100-200
Revegetation		
General	0.10-0.31	100-700
Pasture	—	100-1000
Recreation	—	100-1400
Trees	—	100-800
Fish and wildlife; minimum cover	0.01	50-100
Prime farmlands	0.16-0.42	1000-2000
Hazard prevention and overhead	0.10	400
Fees	0.35	800-1500
Range of total cost	2.40-5.50	11,000-21,000
Midpoint of range	3.95	16,000

Source: Consol. (1979), Evans and Bitler (1975), Faerber (1979), Gronhovd and Scott (1979), Mine Regulation and Productivity Report (1978), Skelly and Loy (1979a). Computations for topsoiling prime farmland and sediment ponds were developed from *Caterpillar Handbook* (1978), Nielson (1977), R. M. Smith et al. (1976), *Cooperative Extension Service* (1978).

will vary greatly, mainly according to topsoil depth, which ranges from zero to 56 inches (142 centimeters) in the Midwest. In some areas, underlying strata are composed of loess or other unconsolidated material, which may be segregated and replaced as well, increasing costs. Revegetation costs, even for prime farmland restoration over the minimum period until bond release, appear to be relatively small in comparison to topsoiling and backfilling costs. In addition, costs for sediment contol and mulching appear to be relatively small.

Skelly and Loy (1979a) have also estimated costs of compliance with PL 95-87. According to their estimates for the Midwest, based on government and industry reports, the incremental costs per ton range from $0.62 to $8.43. For a model mine producing 500,000 tons per year from a 3-foot seam on a less than 10° slope, the costs with and without PL 95-87 are shown in Table 7.7. The incremental cost in this case amounts to $1.80 per ton or $7500/acre (based on 120 acres disturbed per year), 11 percent over pre-PL 95-87 costs. Reclamation is based on row-crop production. Consol (1979) estimates incremental cost for maximum compliance with OSM

TABLE 7.7 Calculated Mining Costs Before and Under PL 95-87 in the Midwest

	Annual Costs[a]	
	Before PL 95-87	Under PL 95-87
Equipment utilization[b]		
Topsoil handling	$ 125,860	$ 337,020
Road construction	169,460	202,040
Runoff and stream diversion	770	6,940
Sedimentation pond	18,810	37,660
Blasting	504,650	504,650
Elimination of highwalls	—	64,320
Overburden handling	2,607,900	2,809,700
Mine area revegetation	37,300	37,300
Maintenance (15% of operations cost)[c]	519,710	599,940
Supervision	214,000	214,000
Additional operations supplies (explosives)	647,000	647,000
Miscellaneous equipment[d] cost	59,000	59,000
Auxiliary costs		
Royalty	500,000	500,000
Power	5,000	5,000
Communications	10,000	10,000
Union welfare	500,000	500,000
Payroll overhead (35% of labor and supervision)	325,880	355,380
Health and safety	11,000	11,000
Contract coal haulage	15,000	15,000
Reclamation fee ($0.35/ton)	—	175,000
Indirect costs (15% of labor, supervision, and operating supplies)	454,600	500,120
Fixed costs (taxes and insurances)	425,620	427,190
Depreciated costs (10 years)		
Fees	41,730	41,880
Permit and mine plan preparation[e]	2,000	5,000
	5,000	2,000
Field indirect cost[f]	36,200	40,200
Overhead and administration	46,560	74,770[g]
Contingency	189,670	190,370
Interest during construction	106,400	106,800
Exploration and site facilities	2,500	2,300
Annual mine cost	$7,581,620	$8,481,580
Annual production (ton)	500,000	500,000
Cost/ton	15.16	16.96

[a]Minimum costs assuming ideal site and mining conditions.

[b]Assumes 85 percent job efficiency and availability.

regulations in the Midwest at $1.67 per ton above the cost of what they define as good engineering practice, which they claim would meet regulatory goals at $3.07 per ton.

The West

Before PL 95-87

The long-term consequences of surface mining in the West are not yet fully known, because only a small percentage of the strip-mined lands have been successfully reclaimed. A recent study by Leathers (1980) provides estimates of reclamation costs in 8 western states under 1976 conditions but in 1977 dollars (Table 7.8). Reclamation costs differ substantially among the states, ranging from a high of $4700 per mined acre in Montana to a low of $2600 per acre in Colorado. High reclamation costs in Montana and North Dakota resulted primarily from high costs for earth moving. The major component of earth-moving cost in both of these states was for topsoiling. When costs are expressed per ton of coal mined, they range from a high of $0.25 in North Dakota to a low of $0.03 in Wyoming. As a percentage of the value of the coal, reclamation costs range from 0.3 percent in Wyoming to 5 percent in North Dakota. Thus, while costs per acre are substantial, the thick coal seams in most western mines lead to very low reclamation costs per ton.

Several key assumptions of this study should be kept in mind. First, in order to simplify the analysis, the author assumed that all mines in the region used draglines for overburden removal (Leathers 1980). The costs for recontouring, then, may not be good approximations for those mines which use other overburden removal techniques (e.g., truck and shovel). Second, the author simplified the analysis by developing standardized cost functions for recontouring and topsoiling, and these functions were applied uniformly to all mines. Cost differences arising from local topographic, geologic, and

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[c]Includes road grading, water trucks, and general maintenance.

[d]Idle time.

[e]Assumes minimum information acceptable by Regulatory Authority on initial submittal.

[f]Culverts and miscellaneous field supplies.

[g]Assumes 1 additional full-time salaried person at $12,000 per year for blasting records, blast surveys, advertisements, and required paperwork.

Source: Skelly and Loy (1979a).

TABLE 7.8 Estimated Total Costs, in Dollars, of Mined-Land Reclamation by Type of Activity, Western States, 1977

Activity	Montana	North Dakota	Wyoming	Colorado	New Mexico	Arizona	Washington	Alaska
Recontouring	1711	795	1872	890	1008	979	1469	2465
Topsoiling subtotal,	2460	2952	733	1230	738	738	738	492
earth-moving	4171	3747	2610	2120	1746	1717	2207	2957
Revegetation	183	158	243	153	391	400	100	250
Overhead	380	318	486	305	785	800	400	500
Total cost per acre	4700	4200	3300	2600	2900	2900	2700	3700
Cost per ton of coal mined	0.08	0.25	0.03	0.18	0.09	0.07	0.05	0.11
Coal price (f.o.b. mine)	6.00	5.00	9.00	13.00	12.00	11.00	7.00	9.00
Reclamation cost as a percentage of price	1.3	5.0	0.3	1.4	0.8	0.6	0.7	1.2

Source: Adapted from Leathers (1980).

climatic factors are not reflected in the estimates. Finally, the cost estimates reflect only the costs of complying with the reclamation law in effect in each state of 1976.

A second study that provides estimates of reclamation costs in the western region was conducted by Persse et al. (1977). This study reflects reclamation requirements in effect in late 1974 and early 1975 and equipment, labor, and other costs from the first quarter of 1976. At the time the data for the study were collected, 5 of the 9 states examined did not require replacement of topsoil, and thus the estimated reclamation costs do not include the costs of topsoiling in all cases. Likewise, the enviromental protection costs associated with mining and mine planning have increased in most western states since the study.

Reclamation costs at 6 sites in the Rocky Mountain and northern Great Plains states are summarized in Table 7.9. Variables that affect reclamation costs include terrain, soil, vegetation, type and thickness of overburden, thickness of the coal seam, ground- and surface-water conditions, climate, type and size of equipment used, method of mining, reclamation laws and regulations, and the individual operator's method of reclaiming the land (Persse et al. 1977).

A third recent study that provides useful insights concerning current reclamation costs was conducted by Gronhovd and Scott (1979). This study provides cost estimates only for mines in North Dakota. It is of interest, however, both because it is based on mining conditions and costs prevailing in 1978 and because it includes an analysis of the effects of various site characteristics and reclamation requirements on reclamation costs. Cost estimates were developed in this study for a hypothetical typical mine and for 3 operating mines in North Dakota (Table 7.10).

Topsoiling was by far the most costly reclamation activity (under the regulations in effect in North Dakota in 1978). North Dakota reclamation requirements typically require 5 feet of "suitable plant growth material" to be salvaged and respread on the recontoured overburden materials (Gronhovd and Scott 1979). The suitable plant growth material is removed in 2 lifts, which are based on the color change of the soil. Table 7.10 demonstrates the sensitivity of reclamation cost per ton of coal mined to variations in the quantity of coal recovered per acre. For example, cost per ton is only $0.17 at the Gascoyne Mine, where the coal yield is 34,722 tons per acre (from a 23-foot seam), but rises to $0.54 per ton at the Larson Mine, where 10,417 tons are recovered per acre (from a 7-foot seam).

After PL 95-87

Two recently completed studies provide estimates of the additional costs that would be incurred by surface mines operating in the West as a result of

TABLE 7.9 Estimated Total Costs, in Dollars, per Acre of Mined-Land Reclamation by Type of Activity, Western States, 1976

	Region				
	Rocky Mountain		Northern Great Plains		
Activity	Sites 1 and 2	Site 3	Site 1	Site 2	Site 3
Design, engineering, and overhead					
Average	775	685	410	570	230
Range	480-1070	625-750	350-730	350-650	200-400
Bond and permit fees					
Average	25	35	60	30	70
Range	0-80	25-45	50-70	20-40	60-100
Backfilling and grading					
Average	1680	1430	4410	2410	2050
Range	1250-3420	990-1970	3700-6200	2200-5500	1800-2900
Revegetation					
Average	350	35	170	120	150
Range	110-470	30-45	100-200	100-150	140-200
Total reclamation cost					
Average per acre	2830	2185	5050	3140	2500
Range per acre	1840-5040	1670-2810	4200-7200	2670-6340	2200-3600
Average per ton	0.15	0.22	0.15	0.34	0.07

Source: Persse et al. (1977).

TABLE 7.10 Estimated Total Costs, in Dollars, per Acre of Mined-Land Reclamation by Type of Activity, North Dakota, 1977

Activity	Typical Mine	Larson Mine	Gascoyne Mine	Glenharold Mine
Preparation and planning	198	208	197	210
Recontouring	2076	1652	2324	1538
Topsoiling	4511	3682	3376	4567
Revegetation	41	41	40	41
Total	6825	5583	5936	6350
Tons of coal mined per acre	15,000	10,417	34,722	15,277
Cost per ton	0.45	0.54	0.17	0.42

Source: Gronhovd and Scott (1979).

compliance with the provisions of PL 95-87. The first was performed by Skelly and Loy (1979a), who used two approaches in estimating the cost of compliance with the provisions of the law and the regulations issued by OSM. In the first approach, a nationwide survey of coal-mining companies was conducted. Estimates of increased costs were obtained for 65 individual mines in 16 states. For the West, estimates of incremental costs for existing mines to comply with OSM regulations ranged from $0.78 to $1.25 per ton. Cost increases were expected to result primarily from road-construction standards and standards for treatment of prime farmland.

In the second approach, Skelly and Loy developed estimates of the cost of compliance for typical new coal mines in each of 4 regions. What they called "scenario mines" were supposed to be typical of new mining operations in each region, reflecting typical environmental conditions of the region. For the western region, the typical mine was assumed to produce 7 million tons of coal per year from a 45-foot-thick seam with an average of 70 feet of overburden. Precipitation averages 15 inches annually, and topsoil thickness averages 12 inches. Draglines are used for overburden removal. Ten percent of the permit area is located at the boundaries of an area designated as an alluvial valley floor, which is currently supporting farming activities. It is assumed that current OSM regulations would prevent mining of the alluvial valley floor.

The estimated additional mining and reclamation costs associated with compliance with PL 97-87 are summarized in Table 7.11. The total is $0.57 per ton of coal mined, including the reclamation fee (toward the abandoned-mine fund) of $0.35 per ton. Of the remaining costs, the largest is the coal loss associated with the alluvial valley-floor mining restriction; this component is estimated to amount to $0.15 per ton. Thus compliance

TABLE 7.11 Calculated Mining Costs Before and Under PL 95-87 in the West

	Annual Costs[a]	
	Before PL 95–87	Under PL 95-87
Equipment utilization[b]		
Topsoil handling	$ 62,600	$ 125,200
Road construction	8,560	10,160
Runoff diversions	1,200	2,120
Sedimentation pond	1,570	13,150
Blasting	1,209,400	1,209,400
Elimination of highwalls	—	20,420
Overburden handling and coal removal	5,299,600	5,459,100
Revegetation of mine area	26,700	26,700
Maintenance (13% of operations cost)[c]	859,250	1,030,150
Alluvial valley floor mining loss	—	1,058,000
Supervision	736,000	736,000
Additional operations supplies (explosives)	740,000	744,500
Miscellaneous equipment cost[d]	51,000	53,800
Auxiliary costs		
Royalty	7,000,000	7,000,000
Power	279,000	279,000
Communications	70,000	70,000
Union welfare	7,000,000	7,000,000
Payroll overhead	1,044,640	1,059,090
Health and safety	350,000	350,000
Reclamation fee ($0.35/ton)	—	2,450,000
Indirect costs (15% of labor, supervision, and operating supplies)	1,010,170	1,031,920
Fixed costs (taxes and insurance, 2% of mine cost)	627,370	630,510
Depreciated costs (20 years)		
Fees	$ 30,750	$ 30,900
Permit and mine plan preparation and engineering[e]	40,000	45,000
Field indirect cost[f]	25,200	30,200
Overhead and administration	74,620	99,600[g]
Contingency	139,790	145,490
Interest during construction	78,420	78,820
Exploration	25,000	26,000
Site facilities and building	174,000	174,000
Preparation plant	225,000	225,000
Unit train loading facilities	175,000	175,000
Annual operating cost	$27,364,840	$31,389,230
Annual production (ton)	7,000,000	7,000,000
Cost/ton	3.91	4.48

with PL 95-87 is estimated to increase total mining and reclamation costs of the typical western mine from $3.91 to $4.48 per ton, an increase of $0.57 per ton, or 15 percent. If the cost of coal loss due to alluvial floor restrictions are left out, on the basis that it is not a true cost per ton of mined coal, the increase is $0.42 per ton.

The Consol study referred to above drew heavily on estimates by engineers at the company's mines in different regions of the country. For the western region, the differences between cost of compliance with OSM regulations and cost of "good engineering practices" was estimated to be $1.23 per ton (Consol 1979). The major cost differences were in backfilling and grading ($0.68 per ton), road construction ($0.23 per ton), fugitive dust control ($0.10 per ton), reconstruction of preexisting structures ($0.08 per ton), and hydrologic performance standards ($0.07 per ton).

SUMMARY

A general pattern of reclamation costs measured in 1978 prices emerges in Table 7.12, which summarizes the data reported above for the 3 regions (adjusted, when necessary, to 1978 price levels). We have not attempted to estimate costs under PL 95-87 on a acreage basis since the area disturbed will probably differ little from the area disturbed under previous laws. Thus the increase in costs per acre basis will tend to be roughly proportional to the increase in costs per ton.

Reclamation costs per ton fall substantially moving from east to west. Furthermore, if the reclamation fee of $0.35 per ton is subtracted from the incremental costs shown for the West, the incremental mining costs are approximately equal to the pre-law reclamation costs shown. In other words, PL 95-87 is estimated to double reclamation costs (with the $0.35 fee then added to the total). Nevertheless, total mining costs per ton are only slightly affected.

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[a] Minimum costs assuming ideal site and mining conditions.

[b] Assumes 85 percent job efficiency.

[c] Includes road grading, water trucks, and general maintenance.

[d] Idle time.

[e] Assumes minimum information acceptable by Regulatory Authority on initial submittal.

[f] Culverts and miscellaneous field supplies.

[g] Assumes 2 additional office staff personnel at $12,000/year for additional records, advertisements, and other required paperwork.

Source: Skelly and Loy (1979a).

TABLE 7.12 Summary of "Typical" Reclamation Cost Estimates (1978 Dollars)

	$/Ton		$/Acre	
	Range	Midpoint	Range	Midpoint
1. Pre-PL 95-87				
a. Appalachia	3.23-7.16	5.19	2,676-$14,915	9,460
b. Midwest (rowcrop)	1.40-2.73	2.07	7,000- 10,000	8,500
c. West	0.08-0.39	0.24	1,899- 8,186	5,043
2. Incremental cost with PL 95-87				
a. Appalachia	—	5.24	—	—
b. Midwest (rowcrop)	—	1.80	—	—
c. West	—	0.57	—	—
3. Estimated total reclamation costs with PL 95-87 (1 + 2)				
a. Appalachia	—	10.33	—	—
b. Midwest (rowcrop)	—	3.87	—	—
c. West	—	0.81	—	—

Source: (1a) Table 7.2, adjusted for inflation.
(1b) Table 7.5.
(1c) Table 7.9, adjusted for inflation.
(2a) Table 7.4.
(2b) Table 7.7.
(2c) Table 7.11.

Reclamation costs are clearly smallest in the West, both per acre and per ton. If costs are measured in terms of heating value, the West's advantage is smaller but remains substantial, although transportation distance to major eastern and midwestern markets may partially or completely offset this cost advantage.

8 Conclusions, Alternatives, and Research Needs

It has been estimated that the total consumption of coal in the United States in the year 2000 could be approximately 2 billion tons (with, in addition, an export of 150 million tons) and that coal could provide almost 35 percent of total U.S. energy needs. The coal resource base is considered adequate to meet foreseeable needs for the next 50 years. But enthusiasm for coal is more a result of its sheer abundance within our borders than its own attractiveness as a fuel. The underground mining of coal involves significant health and safety hazards and leads to subsidence problems. Surface mining of coal disturbs the landscape, and burning of coal releases large quantities of pollutants into the atmosphere. Thus, coal should probably be seen as a transitional source of energy, to be used while better sources are being developed, and it will be essential to invest considerable resources in the control and mitigation of the adverse effects of mining and burning coal.

Since surface mining is a drastic disturbance of soil and land systems, it has the capacity to disrupt the complex system of interactions between land and human society. Land and soil are the basis for food and fiber production and for the maintenance of natural ecosystems. These resources also physically support man and his artifacts, including buildings and terrestrial transportation and communication arteries. They provide a spatial basis for the organization of human interactions. And they serve as a source of spiritual meaning and cultural identification for humankind and human societies.

As of 1977 there were approximately 413 million acres of cropland in the United States, 987 million acres of grassland pasture and range, and 662 million acres of forest. Through 1971, approximately 2.3 million acres of land had been disturbed by coal mining. By way of comparison, an estimated 5 million acres of cropland were converted to urban uses between 1967 and 1975. At the national level, then, the disturbance of land for coal mining is not a major factor in the withdrawal of land from agricultural production.

At the local level, however, the picture is different. In some rural counties essentially the entire area is underlain with strippable coal. Obviously, surface mining for coal could have tremendous impacts, both physical and social, in such areas. Not only will land use be radically changed, at least temporarily, but the sudden influx of outsiders is likely to have boom-town effects on local communities.

Moreover, mining is only one of the many uses chipping away at the land resource base. The accumulation of many such small conversions over the years will indeed reduce the productive potential significantly, and only by dealing with the individual conversions can we address the overall problem.

The length of time a parcel of land is diverted from other uses by mining depends on the level and effectiveness of reclamation efforts. As little as 5 to 15 years may be required before productivity in its prior uses is substantially restored. Under less effective reclamation efforts, land productivity may be irretrievably lost. The effectiveness of reclamation will be a major determinant of whether the cumulative effect of surface mining for coal on land productivity will eventually be viewed as major and unacceptable or minor and tolerable.

Reclamation activities reduce off-site damages, mitigate aesthetic damage on disturbed land, and reconstruct topography, hydrological patterns, and soil profiles to permit a wide range of options for future land use. These benefits are real and valuable, but usually not easily measured in monetary terms. Reclamation costs, on the other hand, are for the most part quantifiable using ordinary cost accounting methods.

Are the benefits of reclamation worth the often large costs per hectare of disturbed land? Where reclamation costs exceed the going market price of undisturbed land by several multiples, doubts may arise. The prices of land for agricultural pursuits, however, are established in myopic markets and massively underestimate reclamation benefits at most mine sites.

When government acts to influence the way in which the private sector conducts its business—by requiring reclamation, for example—parts of the private sector often complain that the free market is not being allowed to work. The relationship between the private and the public sectors has always been one of mutual support and mutual suspicion; it is doubtful that it could have been otherwise. But there is no such thing as a "free market," nor has there ever been. Markets and private enterprise cannot exist without government sanction and protection.

The issue of reclamation of coal-mined land demonstrates the ineluctable necessity of choice on the part of government. Government cannot simply avoid the issue, for to do nothing is to choose a course of action. If government insists upon reclamation, it sides with those who are disturbed by the scars of mining. If government is silent on reclamation, it sides with those who prefer no reclamation. There is no way to avoid the fact that there are gainers and losers regardless of the action taken.

The development of productive capacity in soils is governed by climate, parent material, topography, and biota. Thus there are fundamental differences in soil processes among the major coal-producing regions, and there are important variations among sites within a region. In humid climates, soils reach a peak of productivity after which they slowly decline as nutrients are leached out and clay layers form, impeding water movement and root growth. In arid conditions, the buildup of salts at the soil surface is more likely to limit productivity. Reclamation goals and techniques should be adapted to specific regional and local conditions.

RECLAMATION

The basic goal of reclamation should be to ensure that society does not lose important land use opportunities that were available before soil disturbance or that can be generated in the mining/reclamation process. This can best be accomplished by creating the physical, chemical, and biological properties of reclaimed soils that are important for productivity—e.g., water-holding capacity, low potential for erosion, adequate rooting depth, and fertility—and restoring the hydrologic balance. In addition, regardless of the end use planned for the site or the reclamation techniques used, off-site damages should be controlled and the project should be conducted in an aesthetically acceptable manner; these considerations were major elements leading to passage of state and federal laws.

Beneficial vs. adverse impacts. Depending upon the properties of the soil and climate and the mining and reclamation methods used at a site, mining reclamation can have beneficial or adverse effects on soil properties that determine productivity. Soil reconstruction cannot be expected to preserve or recreate every individual property of the pre-mine soil but should attempt to restore or improve plant rooting depth and the availability of water and nutrients. In most cases reconstruction of soil by replacing soil horizons produces the most productive soil after mining, but there are cases where it is possible to utilize subsurface soils entirely or in combination with surface soils to provide the most productive soil resource.

Some old soils with well-established soil horizons have begun to decline in productivity because of leaching of nutrients, development of claypans, or accumulation of salts. Overdeveloped soils—located primarily in Appalachia, the Gulf Coast, and on pre-Wisconsinan land surfaces in the Midwest—and a saline or sodic soil may be rejuvinated by mining. Under favorable conditions, where high-quality substratum is available, and with time and proper reclamation the productive potential of the landscape can be equalled or improved.

Soils at their peak in productivity, such as high-quality Corn Belt soils, cannot be improved by the mining and reclamation process, and even equaling the pre-mine conditions would be extremely difficult and expensive. If acid or sodic soils are placed on the surface of the reclaimed land, the productive potential of the soil may be drastically reduced for a very long period under natural conditions. Soils that are at present highly productive and soils with toxic lower layers, then, require especially careful reclamation.

Soil and hydrologic balance. Soil plays an important role in the equilibrium of watersheds, because the infiltration capacity of the soil is the major factor in determining what part of local precipitation ends up as surface flow and whether soil moisture is adequate to support vegetation, which stabilizes the land surface. Surface mining may change both infiltration/runoff relationships and stream-channel morphology as a result of sedimentation and erosion. When the infiltration capacity of mined soils cannot be restored to its original level, it is sometimes possible to reestablish infiltration/runoff relationships and soil-water regimes through compensating modifications of topography and drainage patterns. While irrigation may play a significant role in the early stages of a reclamation effort, it is not reasonable to develop ecosystems that are dependent upon continued applications of large quantities of scarce water resources.

Short-term and long-term goals. The thousands of years required for natural soil-forming processes to establish equilibrium conditions obviously make it impossible to duplicate pre-mine conditions within any reasonable time frame for reclamation. There are natural soil-forming processes, however, that can create dramatic changes in mine spoils in periods of time that are short compared to geologic time but relatively long compared to the 5- and 10-year limits set by PL 95-87. We may want to perform reclamation in stages, initially stabilizing the landscape, perhaps through high levels of management, and then making use of these natural processes.

But short- and long-term goals in the reclamation process should be carefully distinguished. To quickly stabilize the land surface against erosion, for example, it may be useful to introduce kinds of vegetation that are not desirable as permanent cover. Likewise, initial cover crops can serve as mulch or green manure. There is nothing wrong with using nonnative species for such purposes, as long as these purposes do not replace long-term goals.

Equally important, the time table for long-term goals should not be confused with short-term requirements. The most effective means of reestablishing a climax community may be to initiate a process of plant succession, although the successional process may take a long time. Good management can improve soil productivity fairly quickly in the humid East; in the arid West, improvements are likely to come more slowly. In both cases, achieving a stable equilibrium system is a longer-term goal. Attempting to produce a stable ecosystem immediately may be technically difficult and prohibitively expensive.

Back to contour. Restoration of pre-mining land contours is one of the most controversial issues in the reclamation area. Because the issue has significantly different implications in the three major coal-mining regions, each region must be considered separately. In general, however, we conclude that land should be reclaimed to the contour most advantageous for its final use, regardless of whether this contour is the original contour. Most land uses—including crop production, grazing, and forestry; construction, siting, landfill, and waste disposal siting; and even many recreational uses—are best served by relatively level and well-drained sites.

In the East, the vast majority of mine sites should be returned to approximate original contours. On a very small proportion of the acreage disturbed, bench terraces or flat mountaintop removal sites may have commercial uses and should be maintained—but most citizens usually prefer that mined lands be returned to the original contour, and most mining areas are inaccessible for commercial uses. Another exception to the back-to-contour rule, which might have wider application, is the retention of limited access roads in areas to be used as timberland. But on the whole, in the steeply sloped eastern mining regions, prevention of off-site damages must be a major reclamation objective, regardless of the site-by-site resolution of the back-to-contour question.

In the Midwest, where area mining disturbs agricultural land, grading to original contour is reasonable only where a more level grading would not improve the productivity of the soil by reducing erosion problems or improving infiltration. Care must be taken, however, to ensure that the original or other acceptable surface and subsurface drainage patterns are restored.

In the West, appropriate post-mine contours will probably be determined primarily on the basis of management of the limited water resource, whether the land is to be used as cropland, rangeland, or wildlife habitat. Where the objective is to provide improved wildlife habitat, it may be appropriate to leave an occasional exposed highwall in order to provide habitat diversity. Especially in the arid West, it would generally be an asset to allow water bodies created in the mining process to remain, if the water is of high quality.

Evaluation of reclamation. Scientific procedures for evaluating the productivity of the reclaimed land need to be agreed upon. Where the land is being reclaimed to a prior use or to a use that is common in the area of the mine site, the productivity and ecological stability of the mined land could be compared with those of reference areas. The level of management at the time of evaluation must be equivalent to the level of management that will continue to be used after the reclamation effort has been terminated.

Where the original surface materials are not replaced or the original contour is changed, resulting levels of productivity are liable to be different from those of surrounding areas, and productivity may increase only gradually over a long period of time. Soils created from productive parent materials, for example, will weather and accumulate humus, becoming a productive resource only after a number of years that may significantly exceed the 10-year limit for completing reclamation generally set under existing law. In these cases, it may be appropriate to have independent technical experts evaluate reclamation success on the basis of the conditions created in the reclamation process and expectations for future productivity, taking into account such variables as weather conditions in the year of measurement.

In fact, periods of 5 to 10 years may be too short under many circumstances to achieve the "species diversity" required by law, if "species diversity" is defined in terms of native climax vegetation. In this time frame, the appropriate criteria for successful reclamation may be ecosystems in intermediate successional stages that are dependably moving toward local climax communities.

Reclamation planning. Creating chemical and physical properties in reclaimed soil that enhance productivity requires pre-mine planning, including a careful and detailed survey and characterization of the surface soil and overburden to determine what materials can be used on the surface or need to be buried and what the general slope characteristics of the site should be to minimize erosion and promote an acceptable hydrologic system. In planning for the control of erosion on a mined site, the Universal Soil Loss Equation is the best tool available, although its application is limited by the fact that the equation was developed for use on undisturbed soil, and thus some of the conditions on a reclaimed site may not fit the assumptions underlying the equation.

In developing, executing, and reviewing plans, the ultimate objectives of reclamation law should always be the central concern. Industry planners should not attempt to circumvent the purposes of the law while meeting specific requirements; likewise, government authorities should be flexible in their administration of the law in light of the variety of conditions under which mining is conducted. It is appropriate that departures from specific requirements of the existing law be allowed or even encouraged when a "better" reclamation product will result. "Better" in this case is defined as producing higher yields, supporting a more diverse ecosystem, leading to less off-site damage, generating a more aesthetically pleasing landscape, resulting in more rapid recovery of the productivity of an area, or generating an equivalent reclamation result at a lower cost. To foster site-specific planning, procedures could be improved to remove the stigma and delay associated with the process of seeking a variance. Because of the negative connotations of variances, mining firms sometimes do not seek approval for reclamation plans that exceed legal requirements. Some experimentation with alternative practices is needed, and laws should be administered with enough flexibility to permit improved methods to be developed.

Reclamation costs and coal prices. The fluid situation with respect to the reclamation requirements associated with the passage of a new law and the development of new procedures make it impossible to determine costs with precision. The actual cost at each site will be revealed only with experience in operating under the provisions of the new regulations. There are reasons to believe, however, that current estimates are on the high side. To the extent that current estimates are based on actual operations, they are skewed by the fact that many of these operations are at small sites and are "first-time" or demonstration efforts. Undoubtedly, experience will help to reduce costs as operators learn by doing; and economies of scale can be realized on larger sites. Moreover, most long-term coal contracts include provisions for the pass-through of the increased costs of reclamation. Under this institutional arrangement little incentive exists for companies to search for ways to reduce reclamation costs; competition for new contracts, however, will create pressure to achieve efficiency in reclamation.

The price of coal in the absence of any reclamation requirement is artificially low, for the simple reason that important social costs are not included. In a market economy, the prices of all goods and services should accurately reflect the full social cost of their manufacture and use. Reclamation is expensive. In the East these costs may be high enough to influence whether an area is mined. In the West, where the coal seams are quite thick, the high per-acre costs of reclamation will translate into low costs per ton.

It is not in the best interests of the nation to attempt to make reclamation equally difficult and expensive in all areas regardless of local conditions. Standards required to protect uniquely valuable and fragile lands in one region should not be required in all regions simply for the purpose of maintaining equity. Mining in areas in which reclamation is relatively easy and inexpensive will, and should, be encouraged.

It is *not* undesirable that coal companies pass along to consumers a considerable portion of the increased costs of coal made necessary by reclamation. With users paying the real, slightly higher price for coal, alternatives to coal become a bit more attractive. The new constellation of relative prices more accurately reflects total costs and benefits than did the prereclamation law set of relative prices. As technological developments make renewable energy resources available, coal may eventually be priced out of the fuel mix when its price incudes the social costs of mining and combustion. That, in fact, should be a long-run objective of national energy policy.

Surface mining and reclamation clearly present a major challenge to the existing regulatory environment. The complexity of the interactions among geological, hydrological, ecological, and social systems seem to guarantee that even the best practicable set of design standards, nationally imposed, will occasionally have unreasonable or even absurd results in particular localities. Important situations calling for variations include the following, some of which are allowed under current law.

- The original *A* and *B* horizons are not invariably the most desirable topsoil material. They may have been naturally or artificially degraded, in the sense that important or natural qualities necessary for good production are no longer present. For example, plant nutrients may have leached out, salts may have accumulated, or claypan may have formed. In the West, the surface soil horizons are often quite thin and lack the characteristics of a mature soil. In these situations replacing or mixing the *A* and *B* horizons with components of the overburden other than topsoil can lead to an improvement in the chemical, physical, or biological characteristics of the root zone and thus a more productive resource.
- Alternatives to the present sediment- and water-control methods that would accomplish the intent of the law more cheaply and that would be more consistent with overall water-use policy are being investigated. Also, in some western areas, the present regulations result in the use of scarce water resources for initial irrigation on reclamation projects.
- Reintroduction of climax native species may not always be the best means of initially achieving stable conditions, and considerable latitude should be present in the selection of species to be used in the reclamation

process. After stability has been achieved, the site can be converted, by natural succession or replanting, to species consistent with long-term conditions.

- In the West, where multiple use of rangelands for grazing, watershed, wildlife habitat, recreation, and other purposes is the accepted policy, stability and diversity are just as important criteria for determining the adequacy of reclamation as productivity. There are situations where these goals may be best achieved by allowing grading to contours other than originally present, allowing water bodies created in the mining process to remain, and even occasionally retaining a highwall to enhance habitat diversity.
- Where noncropland environments or habitats are in short supply and declining significantly, it may be appropriate to consider a more diverse use pattern. While the primary land use in the Midwest will be cropland, allotting some portion of the land to wildlife habitat may be desirable from ecological, aesthetic, and recreational perspectives.
- The time allowed for the completion of the reclamation project might be considered one of the variable inputs to the reclamation process. Increasing the time allocated for reclamation may reduce the cost of reclamation and improve the eventual outcome, however, in some cases a return to original productivity in a short period of time may be the most desirable.

ALTERNATIVE APPROACHES TO RECLAMATION

It is widely argued that federal regulations in general, and in the particular case of surface mining and reclamation, tend to be insufficiently responsive to the often substantial variations among the different regions and localities affected. There are several reasons for this tendency. (1) For reasons embedded in the constitution and the political history of the United States, "police power" regulation seems to be the preferred method by which government directs the allocation of natural and economic resources. While economists generally prefer that governments direct the allocation of resources through the modification of prices (i.e., through the power to tax), this route is seldom taken. (2) It is sometimes easier to use overbroad rules, which are not responsive to contingencies. Often it is simpler to determine whether required practices have been followed than whether required performance has been achieved, especially in areas such as surface-mine reclamation. These considerations lead to a political preference for regulation by design standards rather than performance standards. (3) Since the federal government does not directly possess the police power, it must achieve its regulatory goals by bringing pressure to bear on state or local governments. Administratively it is convenient to treat all the states alike, even if this occasionally results in the inequity of treating unlike cases alike.

Such a regulatory climate makes it difficult for legislatures and regulators to provide an adequately flexible response to variations in local conditions. Furthermore, interested parties seldom agree on whether legislation is overregulated or provides "adequate flexibility." Existing institutions provide little incentive for or means of forging a consensus. Instead, incentives tend to encourage particular local interests to appeal directly to the state or federal government for relief from provisions they find onerous. In the most extreme cases, this is tantamount to an appeal by one interest group for federal complicity in preventing another interest group from achieving its objective.

There are, then, a number of dimensions to the reclamation process that may be more effectively handled by something other than the approach currently in use. In the following material we consider a number of possible changes that could be adopted. These alternatives fall into three categories: regulatory approaches, economic incentives, and forms of property to facilitate conflict resolution.

Regulatory Approaches

Design standards could be more closely tailored to local conditions. For example, the number of inches of topsoil to be segregated and replaced could be specified regionally. The number of years allowed for full recovery of productivity could be similarly diversified, in accordance with variations both in local conditions and in the final use to which the land will be put. Specific provisions could be developed for regrading to contours other than the approximate original in the East, Midwest, and West. The list of changes could go on and on, and probably will if the design standards remain the basis for regulation.

Procedures for establishing design standards could be modified. To allow variation in reclamation plans on a site-by-site basis, a committee of experts could be established to review site-specific proposals for achieving the general goals of PL 95-87. Appeal boards could hear complaints from citizens believing that a reclamation plan was inadequate or from a coal company believing that denial of a plan was unreasonable. England and Germany have successfully used committees composed of specialists and representatives of concerned local groups to judge mining and reclamation plans.

Control over design standards could be decentralized. Rather than centrally creating policies and regulations for each region, each region could be permitted to develop its own regulations. A further step toward responding to varying conditions and situations would be to place the control of the reclamation process at the local level. This approach holds the potential for most effectively dealing with conditions peculiar to given regions and sites and accomplishing acceptable programs of reclamation consistent with local objectives and values. The danger, of course, is that national objectives would not be met.

The current delegation of administration of the design standards to the states under PL 95-87 is a middle course. To the extent that states, either initially or over time, are given the authority to respond to local conditions, flexibility will be achieved. If the flexibility is allowed, the extent to which the states achieve the general objectives of the law, and thus desired performance, will determine whether it will continue.

Performance standards could replace design standards. Performance standards have considerable appeal, because they fix objectives while allowing the operator freedom to choose the combination of inputs and methods to be used in achieving those objectives. Performance standards thus encourage the development of improved technologies and the efficient combination of inputs to achieve the specified performance. Such standards, if realistic, could provide the desired flexibility.

Performance, however, is difficult to monitor and enforce, especially in cases when performance measures have not been adequately defined. And while regulated industries typically complain about the inflexibilities inherent in regulation by design standards, they generally prefer design standards to performance standards. The cost of determining how to meet performance standards may be higher for the mine operator than the cost of developing ways of meeting design standards. But more importantly, performance is probabilistic: even with the best intentions, significant failures leading to major damages may occur, thereby exposing the operator to considerable penalties and civil litigation. Compliance with design standards, however, may absolve the operator from further liabilities even if the final outcome is not as good as desired.

Economic Incentives

Environmental economists have long but rather unsuccessfully argued that economic incentives should be used to direct the allocation of environmental resources, through such means as effluent charges. A comparable program would be difficult to institute for surface mining because there are many kinds of environmental damage, some of which are not easily measured; and continuous monitoring of damages would be expensive, if not technically unfeasible. The concept could be adapted, however, in the form of a bonding system. A mining company would pay a bond equal to the estimated dollar value of environmental damages expected if mining were performed without any consideration for reclamation goals. The bond would be returned on a schedule based on the degree of achievement of the specified performance objectives. Such a plan would provide economic incentives to: (1) conduct surface mining at those sites in which estimated environmental damages were relatively low; (2) encourage an efficient level of reclamation effort; and (3) provide the general public with monetary compensation—the unreturned part of the bond—for residual environmental damage once the operator has ceased mining and reclamation.

Another possibility would be to develop a system under which firms would be subsidized on a predetermined schedule for levels of reclamation performed. It might be possible to support such subsidies through a tax on coal mined, but this alternative is probably politically unfeasible.

New Forms of Property

With the increasing reliance on large-scale projects to provide for the nation's energy needs, conflicts between those national needs and the needs of the local communities affected are attracting more attention. The institutions currently used for resolving such conflicts (police power regulation, the environmental impact assessment provisions of National Environmental Protection Act, and various licensing and permitting procedures) are time consuming and not especially effective. Decisions may be made in spite of considerable opposition without a serious attempt to reach consensus. There is very little evidence that the established procedures have actually changed major project-location decisions in significant ways; such evidence is, of course, by its very nature difficult to come by.

O'Hare (1977) has proposed that the siting of facilities be determined by a compensation auction. Communities would be given the property right to determine whether they would accept a given facility or activity. In a sealed-bid auction, the community asking for the least compensation would be selected as the site for the project. The idea has some advantages: (1) locally disruptive projects would tend to be sited where they would do the least damage; (2) local opposition to the project could be largely eliminated, since compensation would be made for negative impacts; and (3) the compensation auction would provide a mechanism for rational decisions concerning the abandonment of some planned projects.

The fact that sentiment within most communities is by no means monolithic raises problems for this scheme. Some members of the community would remain opposed even if their community received compensation. The procedures by which decisions would be made within the community and the received compensation would be distributed among community members need to be elaborated.

Safeguards

Alternatives permitting increased flexibility in the regulations must be accompanied by safeguards to prevent the pitfalls of flexibility. Flexibility must not be used to subvert the intent of environmental protection requirements. If more local and regional discretion is allowed, we must ensure that enough technical expertise is available to the communities that they can deal with industry on an equal footing. And if time requirements are changed, we must be sure we do not relinquish all assurance that standards will be met, especially when information and experience are inadequate to provide a basis for judging long-term results.

RESEARCH NEEDS

The development of appropriate reclamation policies and practices in the diverse environments of the several coal regions of the United States depends upon adequate technical information and an efficient and effective institutional setting under which to make choices. Unfortunately, the technical information available for developing the most appropriate procedures for the reclamation of surface-mined lands is limited. At present, research results from studies of conventional or undisturbed soils are often used, and where studies on mine-reclamation sites have been undertaken, the study duration has been relatively short in relation to questions being asked. These limitations and the unique characteristics of specific sites make it difficult to set national standards.

The following discussion of research needs does not include specific research topics but rather suggests general areas of work. We have not set priorities within the list, nor have we reconciled it with specific current research activities.

Physical and Technical Problems

We must understand the physical, chemical, and biological processes governing the formation and development of soils, in order to carry out efficient and effective reclamation. The intense pre-mining studies of overburden currently being conducted at each potential mine site attempt to determine the chemical and physical properties of the primary geological strata and the most likely reclamation alternatives. Other, more general studies are also needed, in such areas as:

• Whether topsoil should be returned to the surface, mixed with subsurface material, or replaced entirely with subsurface material expected to be most productive.

• The weathering of mine spoils and the movement of soluble nutrients. Spoil that is acid or that has been influenced by acid-forming minerals can create an almost sterile soil. In conjunction with high rainfall and temperature, it can also generate serious off-site damages. On the other hand, weathering processes, particularly in areas with high rainfall, can rapidly increase the productivity of mine soils. Thus, these processes have long-term implications for sustained productivity and require evaluation in the early stages of the reclamation so that only the desired changes occur.

• Alterations of hydrologic properties—such as permeability and infiltration—of mine spoils, disruption of natural aquifers, and changes in surface- and ground-water quality as a result of surface mining in various geologic materials.

• The relations between slope gradients and such objectives as erosion control, crop production, water management, rangeland production, and habitat diversity.

• The relationship between sustained plant performance, soil properties, and compaction; development of material-handling methods that cause less compaction; methods of reducing compaction that has occurred, and methods of controlling differential settling and piping. Excessive compaction of soil inhibits root system development and causes poor air-water relationships in the soil. The result is slow water infiltration, increased susceptibility to drought, and poor crop performance even in favorable seasons. At present there is a trade-off between additional material handling to generate more desirable soil horizons and the increased compaction that results.

• Means of protecting land from erosion through grading, facilitating accelerated infiltration, and especially vegetative cover processes. As these questions are addressed, it will be possible to reassess the allowable erosion levels and associated standards for suspended solids in water. Research is also needed to develop better empirical factors for use of the Universal Soil Loss Equation on mined land or to develop an alternative to predict erosion on these lands.

• Methods of promoting post-mining soil stability through revegetation and the transition to a permanent post-mine land use under the diverse climatic conditions of surface-mining areas. Different revegetation programs are appropriate for achieving climax ecosystems, croplands, rangelands, and forests.

• The rate at which nutrients are recycled and organic matter accumulates in replaced overburden as the result of biological activity.

- The effects of stockpiling topsoil on organic-matter decomposition and the survival and reestablishment of microbiota, under different climatic conditions.
- The appropriate use of nonsoil additions such as green manures, organic sludges, and nitrogen fertilizers. In the arid West, the use of water is also a major question. It is important to determine the long-term stability or viability of plant ecosystems generated with the aid of heavy additions of water or fertilizers.
- The appropriate levels of productivity to which land should be returned—not only for croplands but also for wetlands, rangelands, wildlife habitats, and forests.

In addition to these general reclamation problems, unique problems will arise in certain geological and social situations that will require special consideration in planning for both mining procedures and post-mine uses.

Societal Problems

The nation's energy, environmental, food, economic, and social policies are intertwined, and choices made with respect to surface mining and reclamation determine at least in part our policy in each of these areas. These interrelationships are not well understood. It is therefore important to conduct research on these interrelationships and on the implications of choices among alternative mining and reclamation policies.

Reclamation of surface-mined land raises important questions concerning the appropriate relationships among private industry and the several levels of government. The present decision structure responds to a particular set of property rights and responsibilities. How might these property rights be modified to allow the private enterprise system to more accurately achieve national policy objectives with minimal regulatory influence? What are the most appropriate roles of local leaders, state and national political groups, environmental groups, economic interest groups, and regulatory agencies? How should federal legislation and administrative procedures respond to local concerns?

The challenge is to develop a federal program with both national equity and the ability to recognize local circumstances in the choice of mining sites and subsequent reclamation practices. New institutional arrangements that allow variation among and within regions may be appropriate in several aspects of the surface-mining and reclamation process. Reclamation law attempts to prevent offsite damages, but it will never be completely successful. An interesting research challenge is to develop a way to provide suitable compensation to individuals who have suffered damages. Research is needed on the social impacts of mining and other energy projects, so that citizens can be compensated for or protected from the social as well as physical disruptions. Specific items of interest include the way in which social structure is modified by new residents, how these changes initiate new social tensions and conflict patterns, modifications associated with changes in occupation and distribution of wealth, and the ways individuals cope with these changes. Researchers should examine different types of local communities, including small towns, rural neighborhoods, and Native American reservations.

A particularly difficult issue is the long-term economic implications of surface mining. Our use of coal, a nonrenewable resource, deprives our heirs of a similar opportunity or increases the cost to them of a less bountiful supply. Furthermore, the environmental costs of our current use may be borne, for the most part, by future generations. We can be fair to the future now by exploring alternative sources of energy—primarily renewable resources—so that along with the depleted coal, we leave a technology that is not dependent on coal or other nonrenewable resources. We can also be fair to the future by ensuring that agricultural productivity and aesthetics have not been sacrificed in our quest for coal. We must recognize that our use of finite resources diminishes the options of future generations and creates a responsibility to attempt to offset this loss by expanding options in other ways.

Appendix

Panels of the Committee on Soil in Relation to Surface Mining for Coal

Three committee panels gathered and evaluated information at an early stage of this study. The Committee invited outside contributors to participate in this research; their assistance is greatly appreciated. Neither these contributors nor the consultants are responsible for the contents of the report.

PANEL ON MINING AND RECLAMATION

Ralph P. Carter, *Chairman*
Carl Anderson
Alten F. Grandt
Sterling Grogan
Lloyd R. Hossner
Willard D. Klimstra
Cyrus McKell
Jerry Barker, *Consultant*
John R. D'Antuono, *Consultant*
Doris J. Price, *Consultant*

CONTRIBUTORS

F. Larry Leistritz, North Dakota State University
Wendell Long, Long P.T. Mining Company, Knoxville
Joe B. Maddox, Tennessee Valley Authority
(now with the U.S. Office of Surface Mining, Knoxville)
John R. Moore, University of Tennessee

PANEL ON SOIL GENESIS AND SOIL LOSS

Robert R. Curry, *Chairman*
William C. Moldenhauer
Raymond E. Wildung
Thomas Bateridge, *Consultant*

CONTRIBUTORS

Richard F. Hadley, U.S. Geological Survey, Colo.
Francis D. Hole, University of Wisconsin
Ivan J. Jansen, University of Illinois

PANEL ON SOIL VALUES

Alan Randall, *Chairman*
John W. Bennett
Daniel W. Bromley
Marion Clawson
John R. Stoll, *Consultant*

CONTRIBUTORS

Richard C. Bishop, University of Wisconsin
Ronald G. Cummings, University of New Mexico
Joseph L. Jorgenson, University of California, Irvine
Maurice M. Kelso, University of Arizona
Talbot R. Page, California Institute of Technology

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