Surface Coal Mining Effects on Ground Water Recharge

Committee on Ground Water Recharge in
Surface-Mined Areas
Water Science and Technology Board
Commission on Engineering and Technical Systems
National Research Council

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Preface

The availability of coal as a source of energy is important to our modern style of living and to the U.S. economy. The production of coal is a complex, heavy industry that can have many impacts on the environment, including the hydrologic functions of the areas in which mining occurs, such as water quality and rainfall-runoff-ground water recharge relationships. Currently, approximately 60 percent of the coal production in the United States is by surface mining.

In order to consider and minimize the potential negative impacts of surface mining, Congress passed the Surface Mining Control and Reclamation Act of 1977 (SMCRA; P.L. 95-87), which contains requirements relative to the hydrologic character of mined areas. Among these is a requirement that, in the restoration of the landscape, mining operators restore the "recharge capacity" of mined areas to approximate pre-mining conditions. Interpretation and the means for implementation of this requirement are not well understood by the Office of Surface Mining Reclamation and Enforcement (OSM) of the U.S. Department of the Interior, which in 1988 asked the National Research Council's Water Science and Technology Board for assistance in evaluating existing hydrologic technology for its usefulness in helping parties/mining operators to comply with this requirement.

In response to the request from the OSM, in March 1989 the Water Science and Technology Board formed a committee of specialists in hydrology, soil science, water quality, and law to undertake an assessment of technologies currently used to evaluate ground water recharge. The scope of the work for this committee included the following items:

1. definition of the term "recharge capacity" technically and in the context of SMCRA and with regard to the matter of overall local water budget;
2. identification of methods for estimating ground water recharge in mining areas;
3. a critique of the strengths and weaknesses of existing approaches with respect to their hydrologic validity;
4. recommendations for preserving ground water recharge in comparable terms for pre-mining "natural" and post-mining "restored" conditions;
5. identification of considerations, such as data requirements, design standards, mining methods, landscape, water quality effects, precipitation, and vegetation factors, that are relevant to analysis of hydrologic functions of mined locales;
6. identification of any research required to strengthen the recommended approach; and
7. recommendations for policy change, if warranted.

To accomplish its tasks, the committee met four times to observe mining operations, to examine the existing state of hydrologic applications in the mining sector, to review regulatory requirements, and to write this report. The committee first met for briefings and to plan its activities in Pittsburgh, Pennsylvania, on April 6-7, 1989. Subsequent meetings and field trips were in

Lexington and Hazard, Kentucky, on June 19-21, 1989; and in Billings and Decker, Montana, on September 7-9, 1989. The final meeting was held in Washington, D.C., on November 20-21, 1989, to complete this report.

The committee's assignment was difficult owing to a number of factors, not the least of which is the paucity of accurate historical data on hydrologic functions (e.g., precipitation, evapotranspiration, runoff, ground water recharge) in the often remote areas in which surface mining occurs. The committee's focus of attention, "ground water recharge capacity," also presented the difficulty of not having an established scientific definition. Further, there is the aspect that the impact of mining might be less than the magnitude of uncertainty associated with the ability to quantify recharge. Nonetheless, in this report, the committee makes recommendations that should allow relevant parties to comply with the spirit of the SMCRA, i.e., to assure minimum negative disturbances to the hydrologic system in surface-mined areas.

This report includes chapters on regulatory aspects of the issue, the hydrology of ground water recharge, pre-mining conditions in U.S. coal mining regions, methods and impacts of mining, and techniques for quantifying ground water recharge rates. Although not the major charge of this committee's report, a discussion of the relevant water quality issues is included (Chapter 5). Chapter 7 presents the committee's conclusions and recommendations. A glossary and technical appendixes supplement the main text, which was intentionally kept brief and focused.

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1

Introduction

Surface mining of coal affects large areas in the United States (3 million hectares so far). Currently, this figure is increasing by about 150,000 hectares per year and could eventually reach about 7 million hectares. Since 1977, when Congress passed the Surface Mining Control and Reclamation Act (SMCRA; P.L. 95-87), there have been strict federal rules for restoring the land to "approximately its original contours" and for minimizing degradation of the quality of surface and ground water (e.g., by controlling sediment content and acid or alkaline drainage).

Although Congress's general goal in passing SMCRA may appear fairly clear for the water-related provisions, problems arise with some of the specifics that Congress mandated. The general goal is that in areas where there are usable surface water and/or ground water resources, those resources should be qualitatively and quantitatively suitable for post-mining land use. One of the specific provisions is the focus of this report. Congress mandated that the "recharge capacity" of the surface-mined lands be restored to approximately pre-mining conditions. Congress provided no definition of recharge capacity, nor does one exist in either the legal or scientific literature. Yet several things are clear about the recharge capacity requirement: (1) Congress was thinking about ground water and not surface water; (2) this requirement was viewed as quantity and not quality related; and (3) it was conceived to prevent a lessened recharge capacity without indicating any concern for an increased recharge capacity.

Intuitively, recharge capacity could be interpreted as the maximum capability of the land surface and underlying materials (vadose zone or unsaturated zone) to recharge ground water at some maximum rate as if, for example, the land were continuously flooded with water. The actual recharge, however, is primarily controlled by the climate (precipitation, evaporation from soil, transpiration from vegetation) and by rainfall-runoff relationships that may not be adversely affected by the mining operation if the land is properly restored and the vadose zones are sufficiently permeable to transmit the water to underlying aquifers.

Desert alluvial fans in the southwestern United States have a high recharge capacity but very little actual ground water recharge because of the very low rainfall and high evaporation in those areas. On the contrary, soils and geologic profiles in more humid areas may be less permeable and have less recharge capacity, but ground water recharge rates are higher because of higher rainfall and lower evaporation. Thus recharge capacity, as such, is not a true indicator of actual ground water recharge rates. As a matter of fact, surface mining and restoration of the land conceivably could reduce recharge capacity but increase recharge of ground water, and vice versa! A better term than "recharge capacity," therefore, would simply be "ground water recharge." In the context of SMCRA, this would mean that restoration of surface-mined land must also restore long-term average ground water recharge rates to at least pre-mining levels (assuming, of course, that the climate does not change).

Ground water recharge rates typically are expressed in centimeters or inches of water per year. Rates vary from year to year as annual rainfall (amount and distribution) and temperatures vary. Rates also vary from location to location as conditions governing recharge vary. Quantification of ground water recharge from atmospheric precipitation is difficult. Thus there is a paucity of good data. Studies in various parts of the world have shown that ground water recharge may range from 50 percent of precipitation or more in humid, temperate climates to 1 percent of precipitation or less in dry, warm climates. Regional ground water recharge rates can sometimes be estimated from a simple analysis of rainfall, evapotranspiration, and surface runoff data. Such an estimate shows, for example, that the relatively dry, coal mining area of Gillette, Wyoming, may get less than 5 cm/year recharge out of 40 cm/year precipitation, or less than 12 percent. For the warm, humid area of Oak Ridge in eastern Tennessee, evapotranspiration is 73 cm/year, leaving a total recharge and runoff of 64 cm/year out of 137 cm/year precipitation, or 47 percent.

Ground water recharge rates are very difficult to measure, and quantification may even be impractical for operational purposes, such as restoring ground water recharge rates to original levels after surface mining of coal. A more practical approach would be to require that surface-mined areas be restored in such a manner that the factors controlling ground water recharge are returned to a condition that produces ground water recharge at rates that are not lower than those that existed before mining.

Water quality considerations also are very important. Depending on the particular geologic materials and geochemistry, water percolating through "reconstituted" vadose zones will leach more chemicals than it did when it moved through natural formations. In the eastern United States, acid drainage and leaching of trace elements can be a problem. In the western United States, salts, alkalinity, and leaching of trace elements are of concern. Restoring ground water recharge becomes meaningless if the quality of the resulting ground water is so poor that it becomes useless or degrades the quality of existing aquifers or streams. Thus protection of ground water quality in mined areas may actually require reduction of post-mining recharge for specified subareas.

Aquifers differ in different coal mining regions. In eastern Kentucky, "aquifers" may be consolidated rock formations that trap and convey water in vertical stress-relief fractures so that it may be pumped from small, mostly shallow, domestic wells. When these fractures are replaced by disturbed material due to surface mining and restoration of the land, the original "aquifer" system is also destroyed in the mine area. After reclamation, aquifers will then form in unconsolidated fill material. If local fracture systems are drained, deeper aquifers may have to be tapped if they are available. If coarser fill materials are placed on the mine floor and the finer ones on top, and if the fill is bowl-shaped or has a controlled outlet so that water can be stored in the coarse material, an "engineered" aquifer can be created. This is being done, for example, at the Starfire Mine in eastern Kentucky, where the engineered aquifer also is connected to the land surface with specially constructed rock shafts to enhance ground water recharge. In large coal fields of the West, the Coal seams themselves may be the major aquifers. Removing the coal seams, then, also removes the aquifers and replaces them with mine spoil. If the lower layers of this spoil become saturated, the spoils become the new aquifers.

Apparently because of uncertainties about the definition of recharge capacity and the method for ascertaining or measuring its restoration, the regulatory authorities responsible for the implementation of SMCRA have generally not stressed its implementation. Or at least it was perceived by some that this aspect of SMCRA was among provisions not being implemented in Kentucky, the top coal-producing state in the United States.

The supervisory agency for SMCRA is the Office of Surface Mining Reclamation and Enforcement (OSM) of the U.S. Department of the Interior. Basically OSM has three roles to perform: (1) promulgation of procedural and substantive regulations to carry out the provisions in SMCRA; (2) oversight of state administration of SMCRA and the regulations adopted under SMCRA by those states that have assumed primacy; and (3) administration of SMCRA and the regulations adopted under SMCRA to coal mining operations in those states that have not assumed primacy.

It was alleged that the ground water recharge capacity provisions of SMCRA were not being addressed adequately in Kentucky. Because Kentucky had been granted primacy, it was sued for this alleged failure of administration and enforcement. The OSM, in turn, was sued for a failure in oversight. Eventually the suit against OSM was dismissed when the Kentucky suit was settled and OSM joined as a party to the settlement. That settlement, known as the Kentucky Settlement Agreement, included a requirement for hydrologic balance among other items. A steering committee was to be selected to advise OSM on a study of hydrologic balance, and specifically, that study was to undertake to "identify ... cost-effective approaches to determination of the pre-mining recharge capacity for both eastern and western Kentucky coal field regimes." Thus at OSM's request the Committee on Ground Water Recharge in Surface-Mined Areas was established to clarify issues associated with the requirement of restoring "recharge capacity."

Therefore, as a result of the Kentucky Settlement Agreement, this report was prepared to resolve a scientific uncertainty, namely how to measure in an efficient, cost-effective way whether the "recharge capacity" restoration requirement has been implemented. Before the scientific question can be addressed, it must be determined what "recharge capacity" means. Thus a somewhat detailed examination of the SMCRA language, its legislative history, and prior interpretation of the recharge capacity restoration provision follows in Chapter 2.

2

Legal and Regulatory Framework

THE FEDERAL SURFACE MINING CONTROL AND RECLAMATION ACT OF 1977 AND "RECHARGE CAPACITY"

Introduction

The Federal Surface Mining Control and Reclamation Act of 1977 (SMCRA; 30 USC 1201-1328) is comprehensive, covering over 85 pages of printed text. The specific language that this committee was concerned with is a subpart of one of 25 listed environmental protection performance standards that are to guide surface mining. Because the context in which the language appears is helpful in understanding the scope and meaning of the language, the full context is set out, with the language of concern to this committee highlighted:

> (b) General performance standards shall be applicable to all surface coal mining and reclamation operations and shall require the operation as a minimum to—
>
> (10) minimize the disturbances to the prevailing hydrologic balance at the mine site and in associated offsite areas and to the quality and quantity of water in surface and ground water systems both during and after surface coal mining

operations and during reclamation by—

(A) avoiding acid or other toxic mine drainage by such measures as, but not limited to—

(i) preventing or removing water from contact with toxic producing deposits;

(ii) treating drainage to reduce toxic content which adversely affects downstream water upon being released to water courses;

(iii) casing, sealing, or otherwise managing boreholes, shafts, and wells and keep acid or other toxic drainage from entering ground and surface waters;

(B) (i) conducting surface coal mining operations so as to prevent, to the extent possible using the best technology currently available, additional contributions of suspended solids to streamflow, or runoff outside the permit area, but in no event shall contributions be in excess of requirements set by applicable state or federal law;

(ii) constructing any siltation structures pursuant to subparagraph (B) (i) of this subsection prior to commencement of surface coal mining operations, such structures to be certified by a qualified registered engineer to be constructed as designed and as approved in the reclamation plan;

(C) cleaning out and removing temporary or large settling ponds or other siltation structures from drainways after disturbed areas are revegetated and stabilized; and depositing the silt and debris at a site and in a manner approved by the regulatory authority;

(D) **restoring recharge capacity of the mined area to approximate pre-mining conditions**;

(E) avoiding channel deepening or enlargement in operations requiring the discharge of water from mines;

(F) preserving throughout the mining and reclamation process the essential hydrologic functions of alluvial valley floors in the arid and semiarid areas of the country; and

(G) such other actions as the regulatory authority may prescribe . . .

In the language to be interpreted, "restoring recharge capacity of the mined area to approximate pre-mining conditions," there are three key phrases whose meaning must be delineated: (1) "recharge capacity," (2) "the mined area," and (3) "restoring . . . to approximate pre-mining conditions." None of these words, terms, or phrases, is defined in SMCRA.

A common dictionary contains meanings for all of the listed words. For example, "recharge" is "to charge again" (Webster's New Collegiate Dictionary, 1953, p. 706, and "capacity" is either "power of receiving" or "extent of room or space" p. 122). However, a listing of even only two definitions for "capacity" requires that selections be made. "Approximate" is "nearly resembling" p. 44); "restore" is "to put back into the former or original state" p. 722).

Although standard dictionary definitions and common usage may be sufficient for words such as "restore" and "approximate," the definitions are not sufficient for other words such as "recharge" and "capacity." These words are used in SMCRA in a specialized context in a specific combination. Dictionary definitions do not reflect this context and combination. Even in the specialized contexts of water science and water law, the combination "recharge capacity" does not have a clear and universally understood meaning.

History* and Context

Surface Mining Control and Reclamation Act of 1974

The recharge capacity provision was added to a Senate bill (S. 425) on October 9, 1973, through amendment on the Senate floor. This bill was to

* For an overview of the legislative history available on SMCRA, see Appendix B.

become the Surface Mining Control and Reclamation Act of 1974. The specific proposal read as follows:

> At the appropriate place in Section 213 [Criteria for surface mining and reclamation operations], add a new paragraph (E) as follows: by restoring recharge capacity of the aquifer at the mine site and protecting alluvial valley floors.

(119 Cong. Rec. 33321 (1973)). For the entire context, including two other amendments, in which Senator Moss presented the proposal, see Appendix B. All of the amendments were agreed to by legislators acting as a bloc without a roll call (119 Cong. Rec. 33322 (1973)).

This earliest language varies in two respects from the language in SMCRA of 1977. It focuses on the recharge capacity of the "aquifer at the mine site" and includes the concept of protecting "alluvial valley floors." These focal points are explained in Senator Mosses comments. He referred to the problem that both surface and underground mining could cause as "intersecting aquifers and discharging this ground water into surface drainage systems" (119 Cong. Rec. 33322 (1973)). He noted that while such action might have little impact in the eastern states, it could have substantial impacts on land use and the economy in the arid and semiarid states. He then stated:

> In order to assure that both the short-and long-term disruptive impacts of mining on ground water supplies are minimized, it is necessary that reclamation be conducted in such a way so as to maximize the recharge capacity of the mine sites. The design of spoil handling, placement, and grading operations should be done to enhance recharge potential at the site.
>
> For those mining operations, singularly or in combination, which cut across or destroy large aquifers, mining should be predicated on the

> ability to replace the aquifer storage and recharge capability by selective spoil material segregation and handling.
> Similarly, the alluvial valley floors and stream channels at the mine site must be preserved . . . .

(119 Cong. Rec. 33322 (1973)).

The House bill (H.R. 11500) that passed and was to be reconciled with S. 425 already contained the provisions added by the Moss amendment to S. 425 when it was reported by committee to the House in May 1974. Because none of the 15 House bills that were introduced and considered in the public hearings in 1973 contained the recharge capacity language, it must have been added by committee action. H.R. 11500 divided the recharge capacity and alluvial valley provisions and omitted reference to aquifers:

> (D) restoring recharge capacity of the mine sites to approximate pre-mining conditions;
> (E) preserving throughout the mining and reclamation process the hydrologic integrity of alluvial valley floors in the arid and semiarid areas of the country . . .

(120 Cong. Rec. 23702, 23703, 23705 (1974)).

Since the House Committee first reported the recharge capacity provision in 1974, the House did not change its explanation of the provision. That explanation is as follows:

> In order to assure that both the short and long term disruptive impacts of mining and ground water supplies are minimized, it is necessary that reclamation be conducted in such a way so as to maximize the recharge capacity of the mine site upon completion. Recharge capacity refers to the ability of an area to replenish its ground water content from precipitation and infiltration from surrounding lands. Restoring recharge capacity does not mean restoring the aquifer, but

> rather that the capability of an area to recharge an aquifer be restored. Spoil handling and placement and grading operations should be designed to enhance the recharge potential of the site. It is anticipated that in those mining operations which singularly or in combination would mine or seriously affect large aquifers, mining should be predicated on the ability of the operator to replace to the extent possible the ground water storage and recharge capability of the site by selective spoil material segregation and handling.

(H.R. Rept. No. 93-1072, 93d Cong., 2d Sess. 100 (1974); H.R. Rept. No. 94-45, 94th Cong., 1st Sess. 106 (1975); H.R. Rept. No. 94-896, 94th Cong., 2d Sess. 63 (1976); H.R. Rept. No. 95-218, 95th Cong., 1st Sess. 116 (1977)).

Several comments made on the House floor reflect on the meaning of the recharge provision. Congressman Roncalio of Wyoming commented: "What is the difference [contrasting permitted river bed mining] if the coal seam is an aquifer and the ground has porosity and is not adversely affected? That can be done under this very reasonable bill, providing there is no damage to the hydrologic balance of the mined area" (120 Cong. Rec. 23666 (1974)). The following exchange occurred between Congressman Hechler and Congressman Regula:

> [Hechler:] What would the gentleman propose in those areas where the coal seam is actually the aquifer? It seems to me in the vast areas in the West which are very short in the supply of rainfall, under 15 or 16 inches, and where the coal seam constitutes the aquifer, that it would make sense to prevent surface mining where we could destroy the water supply in those areas. [Regula:] What we have to weigh is the best use of our land resources, including the mineral that is contained therein in terms of our nation's needs. There may be some instances where the total use of our coal resource is just as we have

> done in the bauxite mines, just as we have in cement mines, gravel mines, and many other types of mining, where we actually are in effect mining the aquifer as the mineral resource. I do not see any difference in some of the western areas with approaching coal mining in the same way we handle other types of mineral mining.

(120 Cong. Rec. 23671 (1974)).

In the discussions of surface mining bills, members of Congress frequently referred to a 1974 National Research Council study (NRC, 1974); particularly Chapter 4, "Water Resources in Relation to Surface Mining", which was also cited in the discussions on recharge capacity and alluvial floors. The following excerpts from that NRC study were noted in a statement by Congressman Hechler: "Groundwater supplies upslope and downslope from the cut may be depleted either temporarily or permanently . . . . It is not known to what extent the aquifer characteristics of the stratum formerly occupied by the coal seam might be restored" (120 Cong. Rec. 24100 (1974)). Congressman Evans also referred to a statement from the 1974 NRC study: "In planning of any proposed mining and rehabilitation it is essential to stipulate the alluvial floors be preserved" (120 Cong. Rec. 25011 (1974)).

Mr. Roncalio in discussing alluvial valley floors and aquifer protection noted:

> The Evans' amendment to protect these alluvial valley floors should not be confused with mining of coal seams that are aquifers. The committee bill and the Evans' amendment would allow the mining of aquifers so long as the hydrologic impact of the mining operation is 'minimized'—section 211. This would mean that a coal company could remove a coal seam that was serving as an aquifer.

(120 Cong. Rec. 25011 (1974))

The other two bills actively being considered by the House at the same time as H.R. 11500 contained differing versions of Subsection (D). H.R. 12898 provided: "(E) restoring to the maximum extent practicable recharge capacity of the aquifer at the mine site to pre-mining conditions" (120 Cong. Rec. 23694 (1974) (emphasis added)). H.R. 15000 provided: "(E) restoring recharge capacity of the aquifer at the mine sites to approximate pre-mining conditions" (120 Cong. Rec. 23703 (1974)).

Although, as originally introduced in the Senate, the recharge provision included the dual protection of aquifers and alluvial floors, they were separated by the House and remained permanently separated thereafter.

The Conference Report draft, adopted in both the Senate and the House and sent to the president, contained the House's separation of the recharge capacity and alluvial floor provisions but more nearly the Senate's language on recharge capacity: "(D) restoring recharge capacity of the aquifer at the mine site to approximate pre-mining conditions" (H.R. Rept. No. 93-1522, 93d Cong., 2d Sess. 37 (1974)). The Conference Report did not state any reason for adopting the Senate's language. SMCRA of 1974 was vetoed.

Surface Mining Control and Reclamation Act of 1975

As passed in the Senate, S. 7 included the language: "(D) restoring recharge capacity of the mined area to approximate pre-mining conditions" (121 Cong. Rec. 12943 (1975)). The House version, H.R. 25, contained different language: "(D) restoring recharge capacity of the aquifer at the mine site to approximate pre-mining conditions" (121 Cong. Rec. 6824 (1975)). The House language had thus become identical to the language that the Conference Report had adopted in SMCRA of 1974 and to what had been originally the Senate language. However, the new language in the Senate version was similar to the House language in SMCRA of 1974 prior to the Conference Report. The draft of S. 7 reported to the Senate by the Senate Committee contained interlineations showing that the committee had changed the draft language from "aquifer" restoration to "mined area" restoration (S. Rept. No. 28, 94th Cong., 1st Sess. 84 (1975)). However, the Senate Committee did not explain in the report why it had changed the language.

Congressman Melcher of Montana moved on the House floor to substitute the Senate language into the House bill (121 Cong. Rec. 6830 (1975)). This meant two changes. First, "of the aquifer" would be deleted. Second, "mined area" would be substituted for "mine site." Congressman Melcher explained the reasons for the two changes as follows:

> [T]his amendment comes to me after virtually the identical language was adopted by the Senate in their version of the bill and at the recommendation of Montana Power Co. who through Western Energy is engaged in strip mining at Colstrip, Montana.
>
> . . . (D) refers to restoring the capacity of the 'mined area' to approximate pre-mining conditions. As we have the bill before us we are talking about the 'recharge capacity of the aquifer at the mine site.' There are other points to consider. One is when coal is the aquifer and we remove it, it is pretty difficult to come up with an equal aquifer, but what we are really intending in the bill is to restore the recharge capacity, the amount of water that was there before.
>
> That is what is important. Then rather than saying 'mine site,' the amendment says 'mined area.' Rather than just restrict the requirement to the very narrow area being mined, my amendment protects the water capacity of the area around the mine site. Farmers and ranchers around the perimeter of the mined area, may find themselves having their water diminished or damaged. At

> times they are seriously damaged. We want to prevent that. The first part of my amendment would give them protection.

(121 Cong. Rec. 6830-31 (1975)). This amendment was approved without a roll call. As thus changed, the language appeared in SMCRA of 1975, which, however, was vetoed.

Surface Mining Control and Reclamation Act of 1977

Both the House and Senate bills reported by committee in 1977, and which were to become SMCRA of 1977, contained identical recharge capacity provisions: "(D) restoring recharge capacity of the mined area to approximate pre-mining conditions" (123 Cong. Rec. 12668 (1977) (House); S. Rept. No. 95-128, 95th Cong., 1st Sess. 25 (1977) (Senate)). Furthermore, this is the identical language that had passed in SMCRA of 1975. Neither the House nor the Senate discussed the 1977 provisions on the floor.

Because Congress contemplated that some aquifers might be mined, it is essential to ask what would determine which would be mined and which would not. Two answers are reflected in SMCRA of 1977. First, aquifers could not be mined if they were in areas that had been declared unsuitable for mining. Congress specifically provided in SMCRA that "a surface area may be designated unsuitable for certain types of surface coal mining operations if such operations will . . . affect renewable resource lands in which such operations could result in a substantial loss or reduction of long-range productivity of water supply or of food or fiber products, and such lands to include aquifers and aquifer recharge areas" (30 USC 1272(a)(3)(c)). Second, if not already included in areas designated unsuitable for mining, aquifers could be mined if the mine operation had been designed to prevent material damage to areas outside the mine permit area. One circumstance that would lead to material damage would be an inability to restore the "recharge capacity" of the mined area to approximate pre-mining conditions. The regulatory authority determines in the permitting process whether restoration can be accomplished. Detailed information relevant to determining hydrologic balance in the context of recharge capacity and in other contexts has to be submitted in the application. These information requirements are specified in SMCRA sections that are direct successors to the other provisions introduced with the recharge capacity provision by Senator Moss as amendments to S. 425, noted above in the discussion titled "Surface Mining Control and Reclamation Act of 1974" and set forth fully in Appendix B. These sections as they appear in SMCRA of 1977 are set forth in Appendix B. If the recharge capacity cannot be restored, the permit is denied. However, if either temporary or permanent interference with a water supply should occur, Congress protects preexisting state law water rights (30 USC 1307(a)) and requires the operator to provide for a substitute water supply under some circumstances (30 USC 1307(b)).

Although the phrase "approximate pre-mining conditions" is not defined in SMCRA or by OSM regulations, SMCRA uses the word "approximate" in a different context in which SMCRA provides a definition. After mining, the land is to be restored to its "approximate original contour" (30 USC 1265(b)(3)). In defining "approximate original contour," Congress indicated that the land after reclamation was to "closely resemble the general surface configuration of the land prior to mining" (30 USC 1291(2)).

Interpretation and Action Subsequent to Passage of SMCRA

Since March 13, 1979, when the original permanent program regulations were promulgated, OSM has defined "recharge capacity" as "the ability of the soils and underlying materials to allow precipitation and runoff to infiltrate and reach the zone of saturation" (44 Fed. Reg. 15320 (1979); 30 CFR 701.5 (1988)).

In addition to repeating the statutory requirements, the regulations promulgated in 1979 also required that the reclamation plan include "a plan for the restoration of the approximate recharge capacity of the mine plan area in accordance with 30 CFR 816.51 . . . "(44 Fed. Reg. 15359 (1979). In 30 CFR 816.51, the 1979 OSM regulations provided that

> Surface mining activities shall be conducted in a manner that facilitates reclamation which will restore approximate pre-mining recharge capacity, through restoration of the capability of the reclaimed areas as a whole, excluding coal processing waste and underground development waste disposal areas and fills, to transmit water to the ground water system. The recharge capacity shall be restored to a condition which—
> (a) Supports the approved post-mining land use;
> (b) Minimizes disturbances to the prevailing hydrologic balance in the mine plan area and in adjacent areas; and
> (c) Provides a rate of recharge that approximates the pre-mining recharge rate.

(44 Fed. Reg. 15402 (1979); 30 CFR 816.51 (1979)). This provision was removed from the regulations in 1983 (48 Fed. Reg. 43958-89, 43992 (1983)). The regulations adopted in 1983 rely instead on the hydrologic reclamation plan and the following:

> (1) Ground water quality shall be protected by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to ground water systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the ground water; and

> (2) Ground water quantity shall be protected by handling earth materials and runoff in a manner that will restore the approximate pre-mining recharge capacity of the reclaimed area as a whole, excluding coal mine waste disposal areas and [excess spoil] fills, so as to allow the movement of water to the ground water system."

(48 Fed. Reg. 43990 (1983); 30 CFR 816.41(b) (1988)). The complete hydrologic information regulations are set forth in Appendix B.

The primary court challenge on recharge capacity has been to the OSM regulations that required restoration of recharge capacity in underground mined areas. These regulations were promulgated in 1979 and continued in the 1983 revisions (30 CFR 784.14(g), 817.41(b)(2)). However, during the course of the litigation that challenged a substantial number of the 1983 regulations, including the recharge capacity regulation for underground mining (In Re Permanent Surface Mining Regulations Litigation, 620 F. Supp. 1519, 1525 (D.D.C. 1985)), OSM voluntarily suspended the underground recharge capacity regulations (50 Fed. Reg. 7278 (1985). OSM deleted the regulations after reconsideration (52 Fed. Reg. 45920 (1987)). Although the underground mining provisions of SMCRA contained a hydrologic balance requirement and listed some of the same factors that were listed for surface mining, the underground provision never specified a recharge capacity requirement.

Consequences of the Provision

The recharge capacity provision is a mandatory minimum environmental protection standard. Two consequences flow from this. At the stage of permit-application-approval, the regulatory authority must determine that the operator can meet the standard before the regulatory authority can issue the permit. If it concludes that the operator cannot meet the standard, it must deny the permit application: "No permit . . . shall be approved unless . . . the regulatory authority finds . . . that— . . . (2). . . reclamation. . . can be accomplished . . . (3) the assessment of the probable cumulative impact of all anticipated mining in the area on the hydrologic balanc. . . has been made . . . and the proposed operation thereof has been designed to prevent material damage to hydrologic balance outside permit area" (30 USC 1260b)(2)(3)). Subsequently, at the stage of mining and reclamation, the regulatory authority must enforce the standard.

KENTUCKY AND OSM ROLES

As noted in the discussion in Chapter 1, states are allowed to assume primacy in the administration of SMCRA and the regulations promulgated pursuant to SMCRA with the approval of the Secretary of the Interior and thus to become the regulatory authority. Kentucky has assumed primacy with federal consent (30 CFR pt. 917 (1988)). However, OSM retains oversight duties when a state assumes primacy. Thus the role and action of each, in their respective capacities, will be set forth.

The Kentucky Surface Coal Mining Law (Ky. Rev. Stat. Ann. 350.420(5) (1983)) contains the same provision on recharge capacity that is in SMCRA. The Kentucky regulations (405 Ky. Admin. Reg. 16:060, 5 (1989); 405 Ky. Admin. Reg. 8:030, 32(1)(2) (1989)) copy the new federal regulations set forth above.

Neither the federal regulations nor the Kentucky regulations provide specifically that the applicant must provide information on the amount and rate of recharge in the area prior to mining and after reclamation. However, the Kentucky permit application form contains numerous ground water provisions. They are set forth in Appendix B.

Surface Mining Control and Reclamation Act of 1977 provides that when a state assumes primacy, the state's jurisdiction in administering SMCRA and its regulations is exclusive except as provided in Sections 1271 and 1273 of SMCRA (30 USC 1253). Furthermore, SMCRA makes it clear that if any part of a state program is not being enforced by the state, OSM can enforce that part under Section 1271 (30 USC 1254). Section 1271(a)(1) provides that when the federal government learns of a possible lack of enforcement, it is to notify the state, and if the state fails to act or to explain its inaction within ten days, the federal government is to inspect and proceed as specified (30 USC 1271(a)(1)). Section 1271(a)(2) provides for direct federal intervention in case of an "imminent danger" (30 USC 1271(2)). Section 1271(b) provides for full assumption of the state program by the federal government (30 USC 1271(b)). The Section 1271(a)(1) role, the most likely to apply in the recharge capacity situation, is delineated clearly in a recent federal court opinion arising in Kentucky, Annaco, Inc. v. U.S. Department of the Interior (675 F. Supp. 1052 (E.D. Ky. 1987)).

In addition to performing this direct oversight function, OSM is permitted to promulgate regulations that will facilitate its primacy approval and oversight roles (In Re Permanent Surface Mining Regulation Litigation, 653 F.2d 514 (D.C. Cir. 1981) (in banc)).

In 1986 the National Wildlife Federation and others sued the Kentucky Natural Resources and Environmental Protection Cabinet et al., claiming that Kentucky had not properly administered and enforced the SMCRA requirements since assuming primacy. Among the claims was one that Kentucky had not enforced the hydrologic protection requirements of SMCRA. The case was settled, and one of the specific items included in the settlement agreement dealt with a hydrologic study. OSM had been sued separately but became involved in the suit against Kentucky and when OSM became a party to the settlement with Kentucky, the separate suit against OSM was dismissed. A steering committee was to be selected to advise OSM on a study of the hydrology of Kentucky, and specifically, that study was to undertake to "identify . . . cost-effective approaches to determination of the pre-mining recharge capacity for both eastern and western Kentucky coal field regimes." As previously stated, the steering committee requested assistance from the National Research Council regarding the issue of recharge capacity, and hence this committee was formed.

CHAPTER CONCLUSIONS

1. The recharge capacity provision of SMCRA does not prohibit mining aquifers or otherwise disturbing the ground water if after mining and reclamation the hydrologic balance of the mined area is not damaged materially when compared to the premining situation.
2. The hydrologic balance is damaged materially if the mine operator cannot restore the recharge capacity of the mined area to approximate pre-mining conditions.
3. "Recharge capacity" means recharge capability. Although there is language in the legislative history suggesting that at least some members of Congress expected any mined aquifer to be restored, this language gives way to the change in the language of the recharge capacity provision since first introduced and to clear statements such as those in the House Reports cited above. (Technically, however, "ground water recharge rate" is the preferred term.)
4. The definition contained in the Code of Federal Regulations since 1979, "the ability of the soils and underlying materials to allow precipitation and runoff to infiltrate and reach the zone of saturation," represents a correct interpretation of the law (30 CFR 701.5 (1988)).
5. Although substantial relevant data are required, neither the OSM nor Kentucky regulations specify a data requirement on measuring pre-mining or post-mining recharge capacity. Although the hydrologic data that are required may provide

relevant parameters indirectly, the regulators, OSM and Kentucky, should mandate specifically the relevant parameters.

6. In summary, to implement the recharge capacity restoration provision of SMCRA, the regulatory authority must first determine whether there is a useable ground water supply in the area to be mined or an offsite supply affected by the area to be mined.

If there is not a useable ground water supply, the recharge capacity need not be restored because the provision has meaning only in the context of restoring something (a useable ground water supply) of value. Congress was not concerned in the recharge capacity provision with water in the root zone, whereas it was concerned with that aspect in the alluvial valley floor provision.

If there is a useable ground water supply, the "recharge capacity" must be restored to approximate pre-mining conditions. "Approximate" means closely resembling. The legislative history and the regulations indicate that this is to be done through materials handling and placement. Although not specifically stated in SMCRA, the assumption would be that this restoration should be complete before bond release. However, because the requirement is only that the capability to recharge ground water supplies in the area be restored, there is no need that actual recharge to any pre-existing level has occurred. Furthermore, how much recharge will take place is also a function of how much precipitation occurs and where.

The major problem, then, for the regulatory authority is that it must be able to either (1) calculate in a scientifically acceptable yet economical way how much recharge could take place before mining and how much can take place after mining or (2) determine that no matter how much recharge capability existed before mining, the conditions are such that recharge capability could not be less after mining because the factors controlling recharge have not been adversely affected.

3

Hydrology of Ground Water Recharge

HYDROLOGIC CYCLE

This chapter deals with those parts of the hydrologic cycle associated with the occurrence of ground water in surface-mined areas. This water may move rapidly through the part of the hydrologic cycle of interest, going from precipitation to percolation into a rock fracture where it may quickly flow to a spring or stream and out of the system. Other water may infiltrate and percolate into slowly permeable formations and aquifers. It may then take many years, decades, or even longer before the water emerges and reenters the more active parts of the hydrologic cycle through surface water flow, ground water pumping, or evapotranspiration (Figure 3.1).

Surface mining activities may alter many hydrologic processes, including infiltration, overland flow, surface runoff, surface storage and detention, interception, evapotranspiration, percolation, vadose zone storage, ground water storage, ground water flow, streamflow, and water quality. In fact, about the only part of the cycle not generally considered to be influenced potentially is precipitation.

The flow and storage processes shown in Figure 3.1 are unsteady—that is, the flow rates and

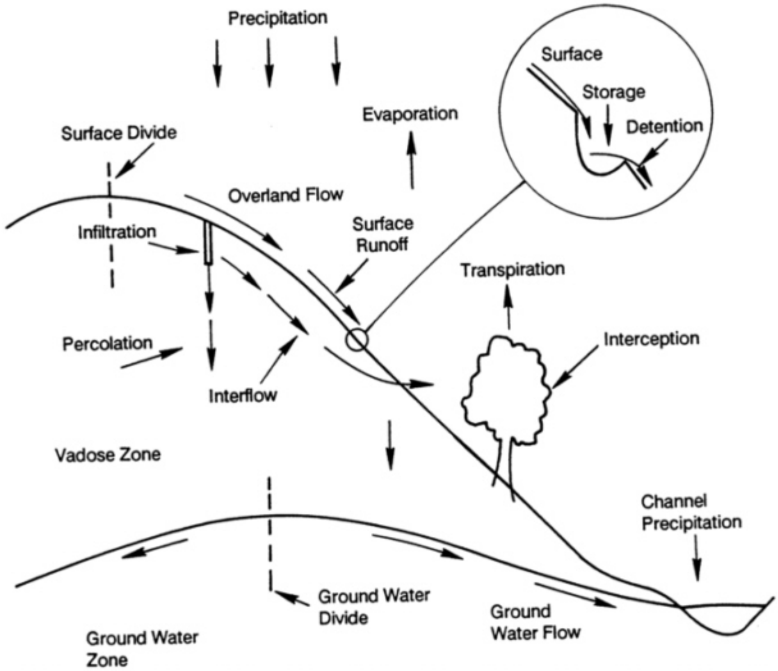

Figure 3.1 Schematic of hydrologic cycle.
Source: Barfield et al., 1981.

volumes of water in any particular form of storage are constantly changing with time. The time rate of change of some processes such as precipitation and surface runoff may be rapid, measured in minutes and hours, while the rate of change of ground water storage and discharge may be very slow, measured in days, weeks, and months.

The principle of conservation of mass relates the flow and storage processes. Over a selected time interval and area, the difference in the volume of water entering and leaving a control element must equal the change in the volume of water stored in the element. In other words, inflow volume less the outflow volume equals the change in storage.

Over short intervals of time (up to a few years), the change in inflow, outflow, or the volume of water stored in the control element may be substantial. In an undisturbed control element, for long time intervals (several years), the change in the average value of these quantities is relatively small and the inflow and outflow volumes are nearly equal. Under these conditions, a state of dynamic equilibrium exists. The relationship between the inflow, outflow, and change in storage for any control element refers to the hydrologic budget of the element. Any factors that alter inflows, outflows, or storage characteristics potentially alter the hydrologic budget.

Ground water is generally considered to be water contained in underground formations in a saturated or near-saturated condition at a pressure greater than atmospheric. Water in the unsaturated (vadose) zone is at a pressure less than atmospheric. Permeable formations that contain and transmit ground water in useable quantities are known as aquifers. Aquifers are classified as unconfined, confined, and perched (Figure 3.2). An unconfined aquifer, also known as a water table aquifer, has as its upper boundary the ground water table. A capillary fringe exists immediately above the water table. A confined aquifer has a relatively impervious layer as its upper boundary. The pressure potential of the water in contact with

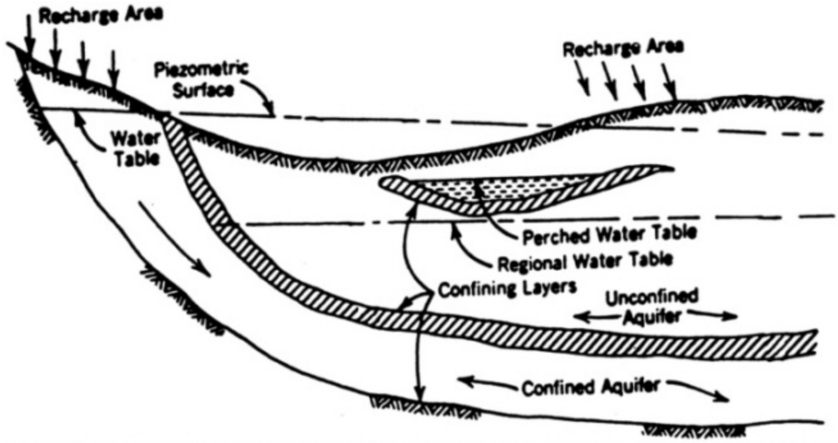

Figure 3.2 Idealized aquifer settings.

this confining layer is greater than atmospheric. The confining layer may be an aquitard or an aquiclude. Confined aquifers are also known as artesian aquifers. A perched aquifer is an unconfined aquifer of limited areal extent that retains water because of an underlying restricting layer, which in turn is above an unsaturated zone. Perched aquifers may be seasonal or permanent.

For a given section or finite element of an aquifer, inflow or water accretion may consist of downward-moving water from the vadose zone, flow through semiconfining layers, or lateral flow from upgradient portions of the aquifer. Outflow of water, also called depletion, may consist of pumping from wells, flow from seeps and springs, evaporation, leakage through semiconfining layers, and lateral flow to downgradient portions of the aquifer.

Water in the vadose zone and .ground water zone is governed by the same basic chemical and physical relationships. For unconfined aquifers, water may transfer freely between the zones. A zone occupied by ground water may become a part of the vadose zone as the water table is lowered. At a later time, as the water table rises, the zone may again become a part of the ground water zone. Virtually the same water may be ground water at some time, vadose water at a later time, and ground water once again at still a later time. The chemical and physical properties of the material that water comes in contact with and the rate of movement of underground water both have an affect on the quality of that water.

Ground water becomes surface water when it emerges as a spring or seep. These can be located on the land surface or below the water level of a stream, pond, or lake. Ground water discharge to streams, springs, and seeps generally forms the base flow for streams between major runoff-producing events. The pathways taken by water, as it infiltrates and percolates to become ground water and then emerges as baseflow to become surface water, have a major impact on the quality of that water.

The interchange between ground water, vadose water, and surface water points to the need to consider the entire hydrologic system in assessing the impact of alterations within a catchment on any aspect of the hydrology of that catchment.

OCCURRENCE AND MOVEMENT OF GROUND WATER

The material that constitutes the earth's outer mantle is composed of solid material and void spaces. The solid material may be in the form of individual particles or more massive rock formations. The void spaces occur between the particles and as cracks, fractures, or solution channels in the rock. They are occupied by gases or liquids, most commonly air and water. In the ground water zone, the voids are filled with water (some entrapped air may be present), and a condition of saturation or near saturation exists. In the vadose zone, there is more air in the void spaces.

Water-bearing formations may be either consolidated (rock) or unconsolidated (clay, sand, gravel). Except for rock outcroppings, the earth's surface is covered by a layer of unconsolidated material that may range in thickness from a few centimeters to several thousand meters. Consolidated material always underlies the unconsolidated material. Alternating strata of consolidated and unconsolidated material may exist above the basement consolidated rock.

Unconsolidated material consists of individual particles derived from the breakdown of consolidated rock. Individual particles may range from clay-sized particles measuring two micrometers or less to rocks and boulders measuring several meters across.

Consolidated material consists of mineral particles that have been fused together by heat and pressure or by chemical reactions to form solid masses. They generally consist of sedimentary, metamorphic, and igneous rocks. Consolidated rocks of importance relative to ground water are limestone, dolomite, shale, siltstone, sandstone, conglomerate, granite, and basalt. These rocks can only become aquifers if they are fractured or, in the case of limestone, have solution openings (Figure 3.3).

Porosity is defined as the percentage of the volume of a material that is occupied by voids. Materials with high porosity contain considerable water when saturated, typically from 15 to 30 percent for coarse materials and 50 percent for clays on a volume basis (Table 3.1). All of the water contained in a formation will not drain solely due to gravity. The amount of water that will drain from a saturated material due to gravity is referred to as the specific yield, while the amount of water retained is known as the specific retention. For saturated material, the sum of the specific yield and the specific retention is the porosity (Table 3.1).

Darcy's equation (see, for example, Bouwer, 1978) indicates that the rate of water movement in a porous medium is proportional to the hydraulic gradient. The proportionality factor is known as the hydraulic conductivity. For saturated systems, hydraulic conductivity depends, among other things, on the size, shape, and connectedness of pores and fractures and varies over a wide range (Figure 3.4). For unsaturated systems, the hydraulic conductivity is additionally dependent on the water content, which is in turn a hysteretic function of the matric water potential. For a given material the hydraulic conductivity may vary by several orders of magnitude as the water content ranges from very dry to saturation.

Flow in fractured systems is dependent on the extent of fracturing, the interconnectedness of the fractures, and the mechanisms available for water to enter the fracture systems. All of these factors are highly variable and site specific. Highly fractured rock may have quite high hydraulic conductivities and thus be able to rapidly transmit water.

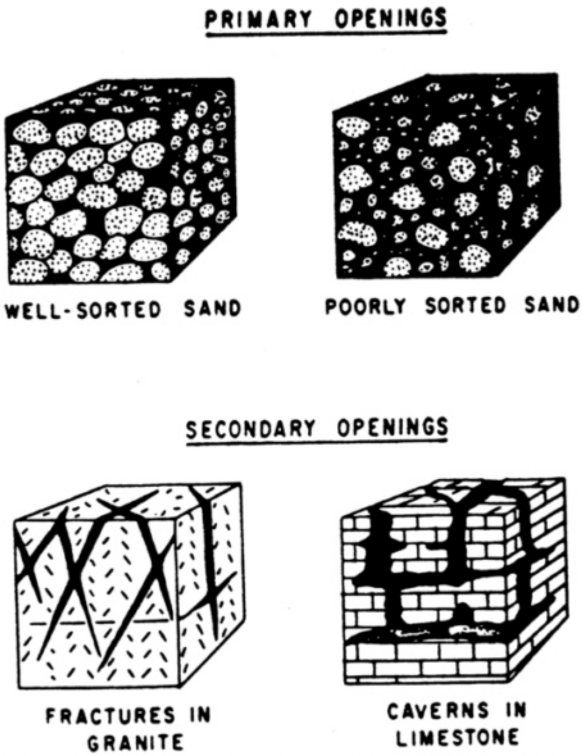

Figure 3.3 Examples of primary and secondary porosity.
Source: Adapted from Heath, 1982.

TABLE 3.1 Typical Values (Percent by Volume) for Porosity, Specific Yield, and Specific Retention

Material	Porosity	Specific Yield	Specific Retention
Soil	55	40	15
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone (semiconsolidated)	11	6	5
Granite	0.1	0.09	0.01
Basalt (young)	11	8	3

SOURCE: Heath, 1982.

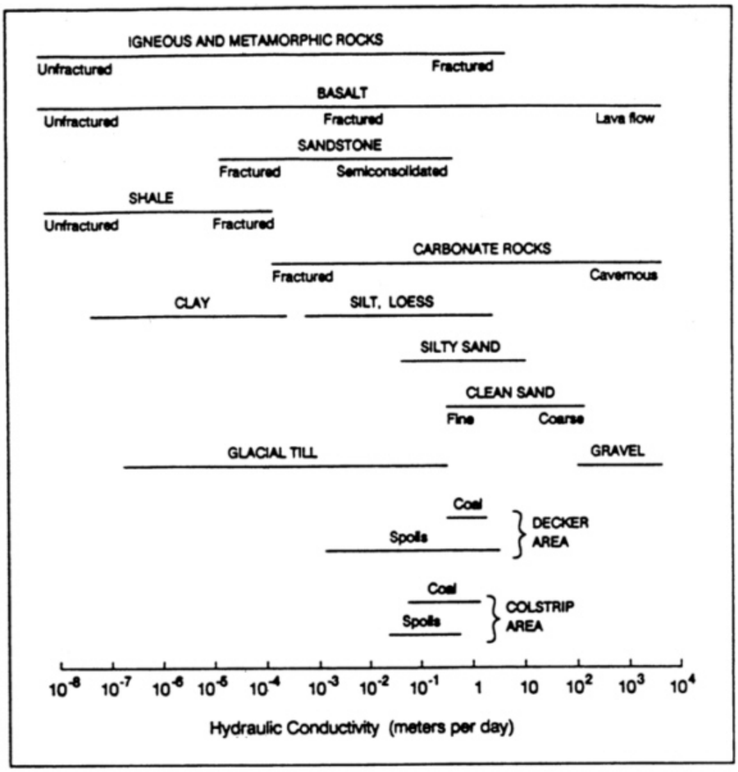

Figure 3.4 Typical values for hydraulic conductivity of selected rocks.
Source: Adapted from Heath, 1982, and Van Voast and Reiten, 1988.

Spatial variability in hydraulic properties of both the vadose and ground water zones makes quantification of underground flow processes difficult. Measurements at many points are required, with the number of measurements depending on the variability present and the desired degree of accuracy. Rehm et al. (1982) found that ground water recharge varied by more than a factor of 10 in a limited area due to spatial variability in hydraulic properties of the material overlying an aquifer (Figure 3.5).

GROUND WATER RECHARGE

Ground water recharge is the addition of surface or precipitation water to the ground water reservoir, and is expressed as volume per unit time or depth of water per unit time. Natural recharge occurs as a result of the natural movement of water through the vadose zone. Artificial recharge occurs when water is added to the ground water reservoir that would not have reached the reservoir naturally. Artificial recharge can result from recharge basins, water spreading, artificial impoundments, recharge wells, applying water to the land surface through irrigation, waste disposal, and other means. Recharge enhancement refers to activities that increase the rate of natural recharge. Such activities as land treatment to increase infiltration or vegetation management to reduce evapotranspiration could constitute recharge enhancement.

The combinations of hydrologic and geologic settings that contribute to natural ground water recharge are many and varied. Some of the major settings include general infiltration of precipitation water and percolation over large areas, percolation from bodies of surface water, and rapid movement of water from the surface through fractures, solution channels, and other highly pervious areas.

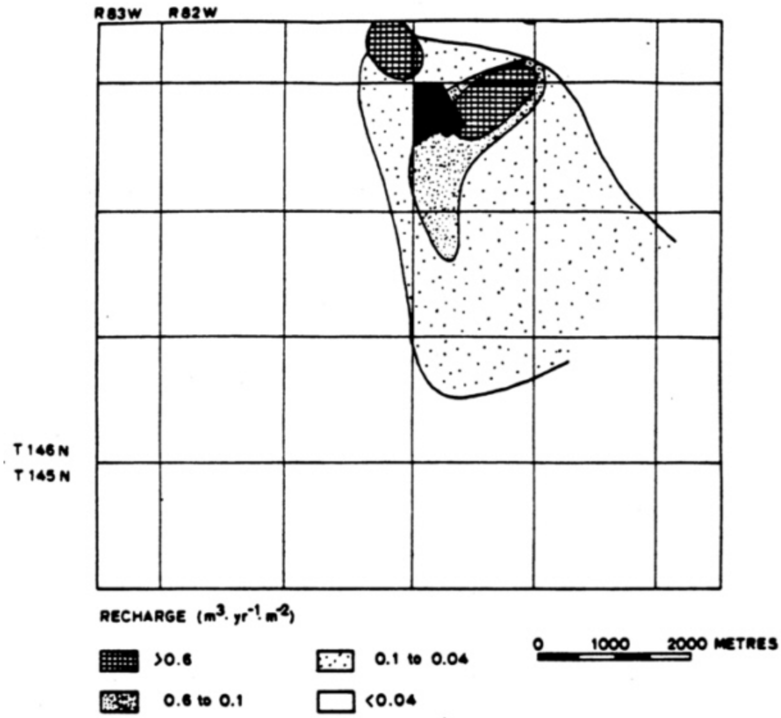

Figure 3.5 Spatial distribution of ground water recharge rates based on field data for pre-mining conditions.
Source: Rehm et al., 1982.

Recharge depends on the availability of water for recharge, the physical characteristics of soil and rock material the water must pass through, and the ability of the ground water reservoir to accept the recharge water. Any one of these three major factors may be limiting and thus define the actual recharge. The actual recharge rate cannot exceed the rate at which water is available to supply the recharge process.

Deep percolation of infiltrated precipitation is a common and widespread means of natural recharge. Hydrologic processes at the surface and in the vadose zone largely determine the quantity of water that becomes deep percolation. Rainfall amounts, timing, and intensities are influential. Large quantities of rainfall occurring at low intensities during periods when surface conditions are such that high rates of infiltration can be sustained will maximize the water available for recharge via percolation. Surface runoff prevents precipitation water from infiltrating where it landed. The finer the soil texture (including crusting), the sparser the vegetation, the steeper the slope, the higher the rainfall intensity, and the smoother the surface, the more water will flow off laterally as surface runoff. Evapotranspiration also removes a large fraction of the infiltrated water before it can become deep percolation. Climatic, plant, and soil factors govern evapotranspiration rates. In arid and semiarid regions evapotranspiration is nearly equal to precipitation. There only large, normally infrequent precipitation events may then contribute to deep percolation. In humid regions, annual deep percolation can be a significant part of the hydrologic budget, accounting for about half of the annual precipitation.

Thus recharge via deep percolation is governed to a large extent by the hydrologic processes that take place in the near-surface zone. This zone generally constitutes the root zone of any actively growing vegetation. The character of the vegetation can significantly affect the amount of recharge. In evaluating evapotranspiration, type of vegetation, density of vegetation, leaf-area index, root density, root depth, and growing season must be considered. Factors that reduce evapotranspiration would tend to increase recharge if all other factors remained the same.

The permeability of the material in the vadose zone is often an important determinant of the recharge rate. Highly permeable materials that allow rapid infiltration and movement of water vertically are primary contributors to recharge. If the aquifer is overlain by a layered system, very slowly permeable layers may restrict the recharge rate. Perched ground water may then form.

Fracture zones and solution channels through rock material may increase recharge if they reach the surface or are otherwise located so that they come in contact with water at atmospheric pressure or greater. In such cases they may act as localized sinks and rapidly transmit water to the ground water reservoir. Most fractures tend to terminate at depths of about 30 m (Bouwer, 1978). Thus the lower parts of the fractures often are filled with water, and the rock becomes, in a sense, an aquifer.

Localized areas overlying an aquifer may contribute much of the recharge to an aquifer. Such areas may have more favorable conditions for allowing the relatively rapid movement of water from the ground surface to the ground water. These conditions may be the result of very permeable soils, solution channels or highly fractured rock, and adequate precipitation. Such areas are often termed recharge areas even though recharge may also be occurring at slower rates over other parts of the aquifer. Disturbances of these recharge areas have a great potential for having an impact on the actual recharge rate of an aquifer.

Streams, lakes, and ponds may be sources of recharge for some aquifers. In humid regions, the water table often slopes downward toward surface water bodies. In such instances the surface water is being augmented by subsurface or ground water flow. Under semiarid and arid conditions, the slope of the ground water surface is often away from the surface body of water, indicating that the surface water is a recharge source for the ground water. Streams that contribute water to ground water are known as losing streams, while streams that receive water from ground water are known as gaining streams. Any particular stream may be a gaining stream over a part of its length and a losing stream over another part of its length. A stream may be a gaining stream part of the time at a particular location and a losing stream at the same location at another time. The factor determining whether a surface water body is gaining or losing is the relative elevation of the surface water and the ground water.

Aquifer characteristics may limit water recharge in instances where the potential recharge rate exceeds the rate at which the water is transmitted away from the recharge area, resulting in the buildup of a ground water mound. This mound would continue to build until the hydraulic gradients in the aquifer were sufficient to cause lateral flows in the aquifer equal to the recharge rate or until the mound limited the recharge rate itself. Sometimes recharge rates are controlled by perched mounds on restricting layers in the vadose zone.

FRACTURED ROCK HYDROLOGY

Flow systems in fracture zones are very difficult to quantify. The controlling factors are the extent, size, distribution, and degree of interconnection of the fractures. A highly fractured material may allow rapid transmission of water and thus promote recharge of ground water. If fractures are not interconnected, they cannot serve as conduits for water movement. Slightly fractured systems are thus not likely to allow significant movement of water, whereas highly fractured systems may serve as major conduits.

Fracturing of rock is brought about by stresses applied to and released from rock formations.

Stress-relief fractures are common in the Appalachian area where overlying soil material has gradually eroded away, removing part of the lateral compression load on the exposed rock walls. As this load is relieved, the rocks tend to expand and fracture vertically. Fracture zones in the Appalachian region may be up to 25 m thick and can provide pathways for significant movement of water.

After water enters a near-surface fracture system, it tends to continue its downward movement. Fracture flow may result in ground water recharge, hillside seepage, or seepage into tributary streams. For water to enter any but the smallest fractures, it must be at or above atmospheric pressure. Water from saturated materials can move readily into fracture systems if the water is at atmospheric pressure or above.

In a conceptualization of flow in eastern Kentucky, the fracture flow is limited to the near surface (top 15 to 25 m) of the hillside (Figure 3.6). Water makes its way downslope relatively rapidly through the system. For this system major recharge to the hillside aquifer occurs when precipitation soaks through the soil and colluvium covering the ridges and hillsides or when runoff is directly intercepted by open fissures in rocks exposed at the surface. Water percolates down through the fractured sandstones until it ends above a confining bed. The perched water then flows laterally out toward the hillsides along bedding planes until it can move vertically downward where fractures penetrate the confining bed. Wet-weather springs form on the hillside where the confining bed is relatively unfractured, and ground water is forced out to the surface. This results in a stair-step pattern of ground water movement from the ridgetops to the valley bottom (Kipp and Dinger, 1988).

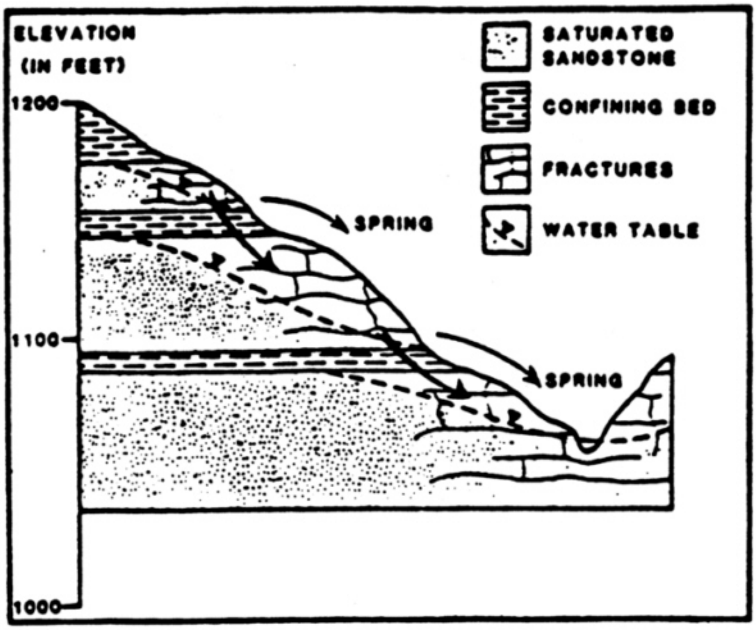

Figure 3.6 Conceptual model of fracture flow in a ground water system.
Source: Kipp and Dinger, 1988.

4

Pre-Mining Conditions in Coal Mining Regions of the United States

The conterminous United States has been divided into 28 coal regions that are grouped into six larger coal provinces (Figure 4.1). Most coal regions are coincident with regions containing fractured carboniferous formations and associated consolidated rock aquifers (Figure 4.2). Mining of coal affects the hydrogeology of a site and to varying degrees the surrounding area. The magnitude of change depends on the initial geologic and hydrologic conditions, including the natural recharge areas, recharge mechanisms and rates, and the methods of mining and reclamation. This chapter describes the general hydrogeology of the nation's coal regions prior to disturbance by mining. It briefly describes the coal resource and the climate; the occurrence, recharge, and discharge of ground water systems associated with coal resource areas; and the soils. A more detailed discussion of each province (but not of the soils) is presented in Coal Mining and Ground-Water Resources in the United States (NRC, 1981a).

EASTERN COAL PROVINCE

The Rhode Island, Pennsylvania, Atlantic Coast, and Appalachian regions are included in the Eastern

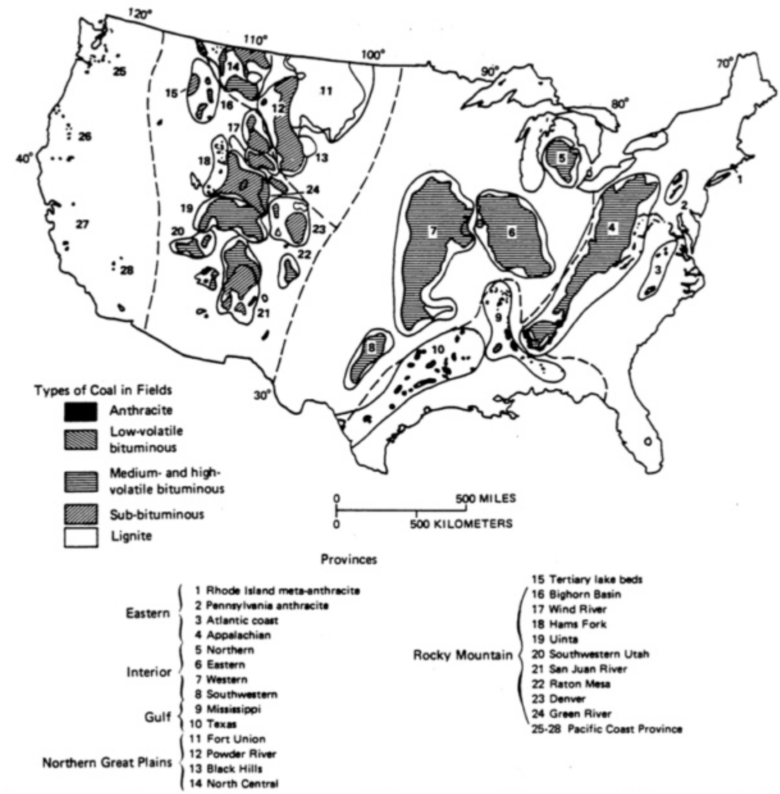

Figure 4.1 Coal fields of the conterminous United States.
Source: NRC, 1981a.

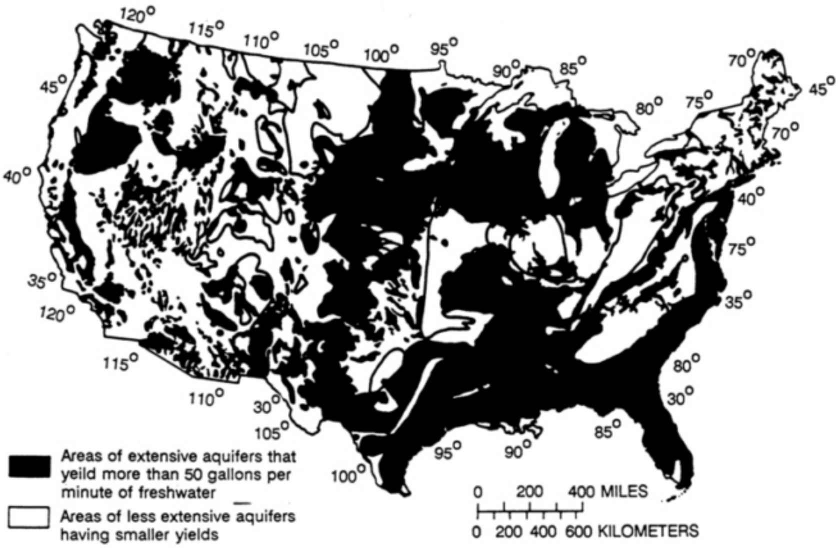

Figure 4.2 Ground water resources in relation to the coal fields of the conterminous United States.
Source: NRC, 1981a.

Coal Province (Figure 4.1). Eastern Kentucky, Ohio, Pennsylvania, and West Virginia contain the majority of the coal in this province. Coal is mined by underground and surface techniques from Pennsylvanian-age (280 million to 325 million years ago) deposits except where it occurs in the Triassic (190 million to 225 million years ago) deposits of the Atlantic Coast basins.

The climate of the Eastern Coal Province is generally humid. Precipitation ranges from about 75 cm to over 125 cm annually depending on the latitude and topography. Yearly potential evaporation is approximately 65 to 75 cm in the northern regions and 85 to 110 cm in the southern area (NRC, 1981a). Ground water occurs in the soils and within the underlying fractured sandstones, shales, coals, and limestones. Ground water discharge from water table aquifers and deeper confined systems creates stream baseflow. Ground water is recharged by direct precipitation on the soils that have accumulated on bedrock. Yields from wells are typically less than 200 liters/minute.

Most of the soils in this province (Figure 4.3) are acid and have low inherent fertility. They vary in depth from shallow (<<50 cm) on some uplands to very deep (>150 cm) on some footslopes. Soils on uplands are generally well drained to moderately well drained, but may be somewhat poorly to poorly drained in footslope positions. Although most soils have moderate permeability, some soil horizons have moderately slow to slow permeability.

The eastern Kentucky coal field is an intensely dissected upland with sharp ridges, V-shaped valleys, and a local relief of up to 250 m.

Surface mining by contour stripping, augering, and mountaintop removal produces about 50 percent of the region's coal. Principal coal seams are found interbedded with sandstone, shale, and siltstone and crop out in valley walls and underlie small stream valleys.

Eastern Kentucky receives about 114 cm of precipitation annually. Streams forming the

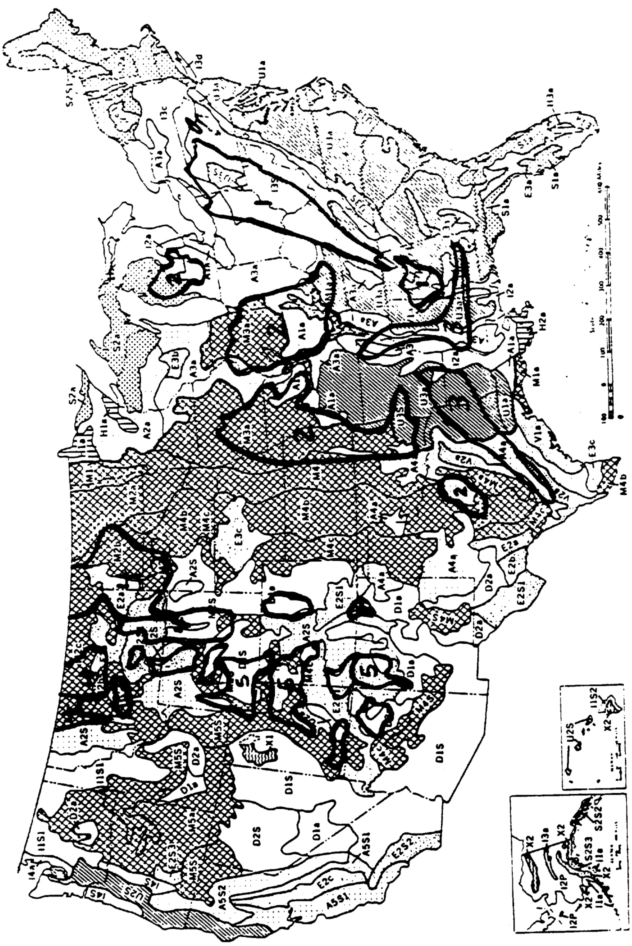

Figure 4.3 Generalized soil map of the United States, showing coal fields (outlined areas).
Source: Soil Survey Staff, 1975.

Figure 4.3 Map Legend

Alfisols

Aqualfs

A1a—Aqualfs with Udalfs, Haplaquepts, Udolls; gently sloping.

Boralfs

A2S—Cryoboralfs with Borolls, Cryochrepts, Cryorthods, and rock outcrops; steep.

Udalfs

A3a—Udalfs with Aqualfs, Aquolls, Rendolls, Udolls, and Udults; gently or moderately sloping.

Ustalfs

A4a—Ustalfs with Ustochrepts, Ustolls, Usterts, Ustipsamments, and Ustorthents; gently or moderately sloping.

Aridisols

Argids

D1a—Argids with Orthids, Orthents, Psamments, and Ustolls; gently or moderately sloping.

D1S—Argids with Orthids, gently sloping; and Torriothents, gently sloping to steep.

Orthids

D2a—Orthids with Argids, Orthents, and Xerolls; gently or moderately sloping.

Entisols

Ortbents

E2a—Torriorthents, steep, with borollic subgroups of Aridisols; Usterts and aridic and vertic subgroups of Borolls; gently or moderately sloping.

E2S1—Torriorthents, steep; and Argids, Torrifluvents, Ustolls, and Borolls, gently sloping.

Inceptisols

Aquepts

I2a—Haplaquepts with Aqualfs, Aquolls, Udalfs, and Fluvaquents; gently sloping.

Ochrepts

I3b—Eutochrepts with Uderts; gently sloping.

I3c—Fragiochrepts with Fragiaquepts, gently or moderately sloping; and Dystrochrepts, steep.

I3S—Dystrochrepts, steep, with Udalfs and Udults; gently or moderately sloping.

Mollisols

Aquolls

Mla—Aquolls with Udalfs, Fluvents, Udipsamments, Ustipsamments, Aquepts, Eutrochrepts, and Borolls; gently sloping.

Borolls

M2b—Typic subgroups of Borolls with Ustipsamments, Ustorthents, and Boralfs; gently sloping.

M2c—Aridic subgroups of Borolls with Borollic subgroups of Argids and Orthids, and Torriorthents; gently sloping.

M2S—Borolls with Boralfs, Argids, Torriorthents, and Ustolls; moderately sloping or steep.

Udolls

M3a—Udolls, with Aquolls, Udalfs, Aqualfs, Fluvents, Psamments, Ustorthents, Aquepts, and Albolls; gently or moderately sloping.

Ustolls

M4b—Typic subgroups of Ustolls with Ustalfs, Ustipsamments, Ustorthents, Ustochrepts, Aquolls, and Usterts; gently or moderately sloping.

M4c—Aridic subgroups of Ustolls with Ustalfs, Orthids, Ustipsamments, Ustorthents, Ustochrepts, Torriorthents, Borolls, Ustolls, and Usterts; gently or moderately sloping.

Xerolls

M5S—Xerolls with Cryoboralfs, Xeralfs, Xerorthents, and Xererts; moderately sloping or steep.

Spodosols

Orthods

S2a—Orthods with Boralfs, Aquents, Orthents, Psamments, Histosols, Aquepts, Fragiochrepts, and Dystrochrepts; gently or moderately sloping.

Ultisols

Udults

U3a—Udults with Udalfs, Fluvents, Aquents, Quartzipsamments, Aquepts, Dystrochrepts, and Aquults; gently or moderately sloping.

U3S—Udults with Dystrochrepts; moderately sloping or steep.

Verti***sols***

Uderts

Vla—Uderts with Aqualfs, Eutrochrepts, Aquolls, and Ustolls; gently sloping.

Slope Classes

Gently sloping—Slopes mainly less than 10 percent, including nearly level.

Moderately sloping—Slopes mainly between 10 and 25 percent.

Steep—Slopes mainly steeper than 25 percent.

headwaters of the ridge and hollow areas are perennial to intermittent with flows of less than 1.5 m^3/s and more typically less than 0.3 m^3/s most of the year. Soils develop from weathering of the parent rock. Steep slopes and layered strata cause variation in soil depth, with flat benches containing the thickest soil cover.

Kipp and Dinger (1988) instrumented a 75-hectare surface water basin prior to mining with a number of wells and developed a conceptual model of the ground water flow system operating in their study area and most likely in many similar valleys in eastern Kentucky (see Figure 3.6). They found that ground water occurred in sandstones, which are commonly overlain and underlain by lower-permeability claystone or argillaceous siltstone. Near-surface fracturing of the rocks appears to create a hydrogeologically connected zone immediately underlying the soil zone. Water levels in wells finished in this zone with fracture permeability generally respond to recharge from precipitation. Perching of ground water occurs in some basins at contacts between sandstones and underlying units located on valley walls and bottoms. This perching causes springs. Water level responses to precipitation were not apparent in wells finished below the near-surface pressure-relief-fractured zone. Thus the hydrologically active zone in the eastern Kentucky coal field is generally associated with the secondarily fractured units.

Pre-mining ground water quality ranges from good to poor in the Eastern Coal Province. The presence of highly acidic materials in coal overburden contributes to possible acidity and to high sulfate levels.

INTERIOR COAL PROVINCE

The northern, eastern, western, and southwestern interior coal regions are found within the Interior Coal Province (see Figure 4.1). The coal resources are found principally in Pennsylvanian-age deposits, with 95 percent of the production from regions in Indiana, Illinois, and western Kentucky. Both underground and surface mining techniques are used to extract the coal.

The climate is generally subhumid. Precipitation ranges from about 75 to 115 cm annually over much of the area, with lower annual rates in the westernmost portions. Yearly potential evaporation ranges from 60 to 80 cm in northern and eastern areas and up to 150 cm in the western areas (NRC, 1981a). Ground water occurs in the northern glacial drift, in alluvium and fractured sandstones, and in shales, coal, and limestone. Precipitation recharges drift, alluvium, soils, and bedrock outcrops directly. Noncropping bedrock is recharged by saturated overlying unconsolidated materials.

In this province most soils are deep and very deep mollisols and alfisols (Figure 4.3). Soils of these two orders occupy 95 percent of the land area of Illinois (Fehrenbacher et al., 1984). Mollisols are dark-colored soils generally formed under grass with base saturation of more than 50 percent in the A and B horizons. These soils vary widely in texture, permeability, and degree of subsoil development. Alfisols have light-colored surface horizons with B horizons of clay accumulation that have a base saturation of more than 35 percent at a depth of 125 cm below the top of the B horizon. Clay contents in B horizons of some of these soils may exceed 60 percent, but most have less than 35 percent clay. Many of these soils are moderately well to well drained, but some are somewhat poorly to poorly drained.

The dominant soils in upper Michigan are generally sandy textured, moderately well to well drained, and moderately to rapidly permeable. They have low base saturation.

In western Kentucky coal is extracted by slope and/or shaft mining and surface mining. Principal coal seams are found interbedded with the sandstone, shale, and limestone of the Upper, Middle, and Lower Pennsylvanian-aged formations.

The region receives 112 to 117 cm of precipitation annually. Streams are found in poorly drained, broad flat valleys.

Most of the soils in the mining regions of western Kentucky formed in loess or loess over a residuum of sandstone, siltstone, and shale (Cox, 1974, 1980; Fehr et al., 1977). Some of the soils developed in residuum with little or no loess cover. Because of the loess, soil textures are predominantly silt loam in the surface horizons and silty clay loam in the subsurface horizons. Clay loam, silty clay, or clay textures may be represented in subsurface horizons developed in residuum.

Soils are moderately deep to deep and moderately well to well drained. Most soils have moderate permeability, but some have slow permeability. When unlimed, these soils are generally medium to strongly acidic.

Pre-mining ground water quality is generally good in the Interior Province. There is some mineralization in shallow aquifers. Overburden is predisposed to increasing alkalinity.

GULF COAL PROVINCE

The Mississippi and Texas coal regions are included in the Gulf Coal Province (see Figure 4.1). The coal is a shallow lignite found interlayered with silts, clays, and coarser beds of Tertiary age (2.5 million to 6.5 million years ago). Coal is mined by surface techniques.

The climate is humid. Annual precipitation ranges from 112 to 150 cm. Yearly potential evaporation ranges from 76 to 112 cm over much of the area. Surface runoff is estimated to range from 45 to 65 cm annually. Recharge occurs by direct precipitation on soils. Unconfined flow is to discharge areas, and confined flow is assumed to be down stratigraphic dip. Aquifer yields in the coal regions can exceed 4000 liters/minute.

Soils in this province developed from loamy, clayey, and sandy coastal plain sediments, loess, and fluvial materials (Pettry and Furst, 1985). Many of the soils are siliceous, acidic, and highly leached and have low organic matter contents. Generally, they tend to be infertile until limed and fertilized. Texture is usually coarser in the surface horizons than in the subsoils, which commonly contain horizons with illuvial clay.

Some of the soils have fragipans, which restrict root penetration and movement of water. Some of the soils are very deep and clayey, and other soils are clayey with high shrink-swell characteristics.

Pre-mining ground water quality in the Gulf Coal Province is good to excellent.

NORTHERN GREAT PLAINS COAL PROVINCE

The Fort Union, Powder River, Black Hills, and North Central coal regions are included in the Northern Great Plains Coal Province (see Figure 4.1). Coal deposits occur in sequences of sandstone and shale of the Tertiary Paleocene age (54 million to 65 million years ago) formations. Seams are also associated with clinker deposits described below. Coal is extracted by surface mines and underground mining.

The climate is semiarid. Precipitation ranges from 20 to 50 cm annually. Yearly potential evaporation is 71 cm in eastern Montana. The landscape is rolling plains, with areas of greater local relief associated with major stream drainages. Recharge occurs from direct precipitation and snowmelt on alluvial, clinker, and bedrock outcrop areas. Larger streams are major receptors of ground water discharge. Numerous ephemeral drainages concentrate surface water runoff and contribute to local recharge. Sandstone, coal, and clinker deposits form principal aquifers. Well yields are typically 40 to 200 liters/minute.

Although most soils are deep to very deep, in some areas soil thickness is less than 50 cm over bedrock (WRSSWG, 1964). Most soils have well-developed profiles with A, B, and C horizons. Some subsurface horizons are calcareous, some have clay accumulation, and others may be saline. Base saturation of most soils is 80 percent or higher.

Properties affecting use of soils for reclamation are soluble salts, exchangeable sodium percentage, texture, and structure (Omodt et al., 1975). Soluble salts are normally present within 2 m of the surface in soils formed from medium-to fine-textured sedimentary beds, but are normally lacking in soils formed from glacial till, soft sandstone, loess, or local alluvium on concave slopes. Exchangeable sodium percentages greater than 5 percent are common in all soils except in those formed from moderately coarse-textured materials and from local alluvium. Soils formed from glacial till commonly have less than 12 percent exchangeable sodium while those formed from medium-to fine-textured parent materials generally exceed 12 percent within 150 cm and frequently exceed this level within 90 cm. Exchangeable sodium percentages as low as 5 percent will cause dispersion and crusting or sealing if material with this level of sodium is placed on the surface of mined land. Some sodium soils have dense, dispersed B-horizon claypans.

Decker Mine, Montana

The Decker mine in Montana is an example of mines in the Northern Great Plains, and most of the following information was summarized from the final environmental impact statement developed for that mine (U.S. Geological Survey and Montana Department of State Lands, no date).

The Decker mine lies near the northwest margin of the Powder River Basin, a large structural depression in the earth's surface that has been filled with sedimentary formations ranging in age from Holocene (the last 10,000 years) to Cambrian (500 million to 570 million years ago). The uppermost bedrock unit is the Wasatch Formation of Eocene age (38 million to 54 million years ago), a sequence of interbedded claystone, shale, siltstone, sandstones, and thin coal beds that crop out in the southeastern part of the area. Underlying the Wasatch Formation is the Fort Union Formation of Paleocene age (54 million to 65 million years ago), a sequence of interbedded sandstone, siltstone, shale, and coal beds that forms the bedrock throughout most of the Decker area.

In general, where coal beds are unburned, they are overlain by sandy shale interbedded with varying amounts of clayey siltstone and sandstone. A prominent rock type in areas of burned overburden is clinker (also called scoria, red shale, burned shale, lava rock, porcelainite, nonvolcanic glass, or red dog) which occurs in shades of red, brown, yellow, and gray. Clinker is formed by the natural burning of coal beds, the heat from which either bakes or fuses the overlying strata, depending on the thickness of the coal and the rate of burning. The baked rock has a hard bricklike appearance and generally is characterized by extreme fracturing and consequent moderate to high permeability. The fused rock often resembles porous lava and is highly permeable. The transition from baked to fused clinker is often abrupt, and in outcrop the fused rock appears to represent local vent areas where burning was accelerated by circulation of air through collapse fissures. Both baked and fused clinker are resistant rock types that cap many of the hills and ridges in the area and are easily recognized by the hummocky terrain and characteristic reddish color.

Alluvial deposits of unconsolidated silt, sand, and gravel are found in the bottoms of all the larger stream valleys in the Decker area. These deposits have a maximum thickness of about 30 m in the Tongue River valley, about 12 m in the Deer Creek valley, and less than 12 m in other stream valleys in the area. In addition, a few terrace deposits (ancient deposits of the Tongue River consisting of sand, pebbles, and cobbles) underlie the surface of several terrace remnants that lie adjacent to the Tongue River and 12 to 67 m above the present river bed.

Rock strata in the Decker area are locally warped into several small flexures or folds of very low amplitude. For the most part, however, beds appear to be essentially flat-lying with a regional southeastward dip of less than 1º. Several northeast-trending normal faults have been mapped in this area.

The principal sources of ground water that have been developed in the Decker area include the aquifers formed by beds of coal and associated lenses of sandstone and by saturated zones at the base of the clinker and alluvium. The aquifers formed by the coal beds are the most predictable sources of ground water owing to their continuity over broad areas. Although coal does not have appreciable primary porosity or permeability, beds of coal in their natural state are rendered more permeable by fractures that provide minute openings for the storage and transmission of ground water. In most locations the coal beds are sufficiently permeable to yield adequate amounts of water for domestic and stock use.

Sandstone aquifers occur as permeable discontinuous lenses in the otherwise less-permeable material that forms the overburden and interburden above and between the coal beds. They appear to be isolated bodies with very limited degrees of hydraulic connection. Withdrawal of ground water from one of these aquifers would probably have little immediate effect on one nearby.

Clinker ranks as among the most permeable of the aquifer materials in the Decker area. It contains two kinds of rock openings. The baked rock is extremely fractured, while the fused rock is prone to contain tubular or pipelike openings. These two types of openings are intermixed to the extent that in any given area the entire rock mass has a very high porosity and permeability. Water from precipitation or from surface runoff enters the clinker and accumulates to form a zone of saturation in the lower part of the porous material. Where the base of the clinker is exposed at the land surface, springs are likely to occur. Where the clinker underlies low areas, however, the top of the zone of saturation rises until it reaches a spillover level. Clinker materials adjacent to the Tongue River Reservoir tend to be recharged by inflow from the reservoir during high stage and subsequently discharge to the reservoir during low stage.

The pattern of ground water movement in the Decker area is strongly influenced by local topography. In general, movement follows the slope of the land surface, away from the topographically high interstream areas toward the Tongue River valley, where most of the shallow ground water is discharged.

The influence of topography appears to be most pronounced on the movement of ground water in the alluvium and clinker. It appears to be least pronounced on the movement of ground water in the coal aquifers. This is attributed to the fact that water in the clinker is unconfined, whereas water in the coal is confined by overlying and underlying beds of shale, mudstone, or siltstone.

Other features that seem to influence ground water movement in the Decker area are the orientation of faults and fracture systems that traverse the area. The displacement of rock units along fault planes constitutes abrupt interruptions in the physical, and thus the hydraulic, continuity of aquifers. As a result, movement of ground water across a fault plane tends to be impeded. Where fault planes are oriented parallel to the prevailing hydraulic gradient, the resistance offered to ground water movement is not evident. Where the fault planes are oriented perpendicular to the gradient, however, the hydraulic effect of a fault can be appreciable.

Soils in the Decker area are formed in residuum, alluvium, or a combination of these materials. Residual soils generally occur on upland areas such as hillslopes and ridges that are source areas of sediment. As a rule, they are less than 50 cm thick, have poorly developed A and B horizons, and closely reflect the character of the underlying parent materials in color, texture, mineral composition, and salinity. For example, light-colored sandstone generally weathers to form light-colored, nonsaline to moderately saline sandy loams that are commonly nonsodic. In contrast, siltstone and shale generally weather to form silty or clayey soils of comparable color that commonly are moderately to highly saline and contain sodium as the dominant cation. In areas where the parent rocks have been altered to clinker, soils generally are less saline than most other soils in the area.

Clays in bedrock formation and in soils derived from these rocks are typically of the expanding-lattice or swelling type. Because sodium salts are generally more soluble than those of calcium and magnesium, soils in the Decker area are often leached to the extent that they contain comparatively little sodium. The existing soils, therefore, generally contain low-swell clays in which calcium and magnesium ions occupy most of the exchange sites. Sodic soils may be found in the West Decker area, where the source of sodium apparently is the predominantly fine-grained sequence of shale, siltstone, and sandstone beds exposed in escarpments.

Alluvial soils are best developed in the broad valley bottoms and adjacent slopes where sediment derived from erosion of the upland has accumulated to form flood plains, terrace deposits, alluvial fans, and alluvial slopes. These soils are composed of a heterogeneous mixture that reflects both the variety of the source areas and the depositional environment. Textures range from sandy loam to silty clay. Color ranges widely depending on parent materials and organic matter. Soils formed on alluvial deposits generally are more permeable and less saline than are residual soils, and they are nonsodic. Although the soils are generally greater than 125 cm thick, the A and B horizons are only 15 to 50 cm thick. Horizon development apparently has been retarded by the semiarid climate.

Pre-mining ground water quality in the Northern Great Plains is poor to good. Water in the coal and overburden sometimes has high salinity but is more desirable than other water in the area.

ROCKY MOUNTAIN COAL PROVINCE

The Tertiary lake beds, Bighorn Basin, Wind River, Hams Fork, Uinta, Southwestern Utah, San Juan River, Raton Mesa, Denver, and Green River coal regions are included in the Rocky Mountain Coal Province (see Figure 4.1). Coal occurs in the Cretaceous (65 million to 136 million years ago) and Tertiary sediments of the mountains, intermontane basins, and dissected plateaus. Both underground and surface mining techniques are used to extract the coal.

The climate ranges from subhumid in the mountains to arid in the adjacent plateaus. Annual precipitation varies from less than 25 cm in the arid plateaus to over 125 cm in the mountains. Yearly potential evaporation ranges from 75 to 200 cm. Ground water occurs in the alluvium associated with perennial streams and in the fractured sandstone, shale, and coal. Precipitation and snowmelt directly recharge bedrock outcrops exposed at topographic highs, and soils and alluvium. Ground water discharge occurs as contact spring flow, perennial stream baseflow, and by phreatophytes. Wells completed in alluvial aquifers typically yield over 400 liters/minute, however.

Soil properties in this province are quite variable because of the variability in elevation, precipitation, temperature, vegetation, and parent materials (WRSSWG, 1964). Soils vary from those with weakly developed soil profiles with coarse textures to those with strongly developed B horizons with clay accumulation (Figure 4.3). Organic matter accumulation varies from low to high. Some soils in the arid and semiarid regions are calcareous throughout the profile, while soils in the subhumid and humid forested regions may be very strongly acidic.

Pre-mining ground water quality in the Rocky Mountain Province is poor to good. In areas with poor water quality, salinity is the problem.

PACIFIC COAST COAL PROVINCE

The Pacific Coast Coal Province groups small valley deposits of coal in the physiographic provinces of the Cascade-Sierra Mountains, Pacific Border, and portions of the Columbia Plateau and Basin and Range (see Figure 4.1). Coal occurs in complexly faulted and folded Tertiary age sediment. Washington State holds the largest deposits and is the focus of the following description.

The climate is humid, with mountain precipitation ranging from 100 to over 500 cm annually. Soils are thin on steep slopes and thicker in the valley bottoms. Ground water occurs in the valley alluvium and fractured coal, siltstone, and sandstone. These deposits are recharged at outcrops by direct precipitation and snowmelt that originates from the surrounding higher topography, and by downward flow from overlying saturated surface deposits. Discharge is to springs and streams in the valleys. Wells finished in deposits associated with the coal usually yield adequate water for domestic use.

5

Mining: Methods and Impacts

OVERVIEW OF SURFACE MINING, SPOIL HANDLING, AND RECLAMATION

There are three major types of surface mining procedures, which in the context of the whole mining and reclamation process have common features as well as significant differences. The three mining types, contour, mountaintop removal, and area mining, differ in their size of operation, equipment use, spoil handling, and final landscaping. The mechanics of the mining process involve several steps, including:

1. planning and permit approval (for the complete operation);
2. site preparation (topsoil storage, sediment pond construction);
3. mining (blasting, spoil dumping, coal extraction);
4. reclamation (landscape stabilization and revegetation); and
5. bond release (operator no longer responsible for the site).

Two reports from the National Research Council (1981a,b) provide comprehensive summaries of surface mining methods, impacts, and land restoration. One of these reports, prepared by the Committee on Ground-Water Resources in Relation to Coal Mining, provides a full description of each of the main surface mining methods (NRC, 1981a). A brief summary is provided here as a framework for addressing the recharge focus of this report.

Contour Mining

The overburden above the approximately horizontal coal beds in the mountainous areas (Figure 5.1) of the Appalachian Coal Basin is removed in a stepwise procedure that includes topsoil removal and overburden blasting and removal to expose the coal seam. The spoil from the first cut in a contour operation may be stored for replacement in the reclamation of the last cut (generally not favored due to double handling), reclamation of an adjacent abandoned surface mine (encouraged), or by head-of-hollow fill (most frequent). Contour mining is often accompanied by lateral augering to extract the unexposed coal seam. Horizontal holes up to 60 m long at spacings from 15 to 60 cm can become subsurface reservoirs influencing the occurrence and movement of ground water in the reclaimed site. In general the landscape is returned to approximate original contour unless a variance has been granted in the mine plan. Previously stored topsoil or a substitute material is placed over the spoil and is stabilized by mechanical compaction on sloping terrain, and the area is revegetated with herbaceous, shrub, and/or tree species. The main features of this mining method that influence recharge include initial vegetation removal, compaction of the reclaimed soil profile and the mine floor (e.g., clay material underlying the coal seam), spoil generation with an increase in porous material volume, and change in vegetation type.

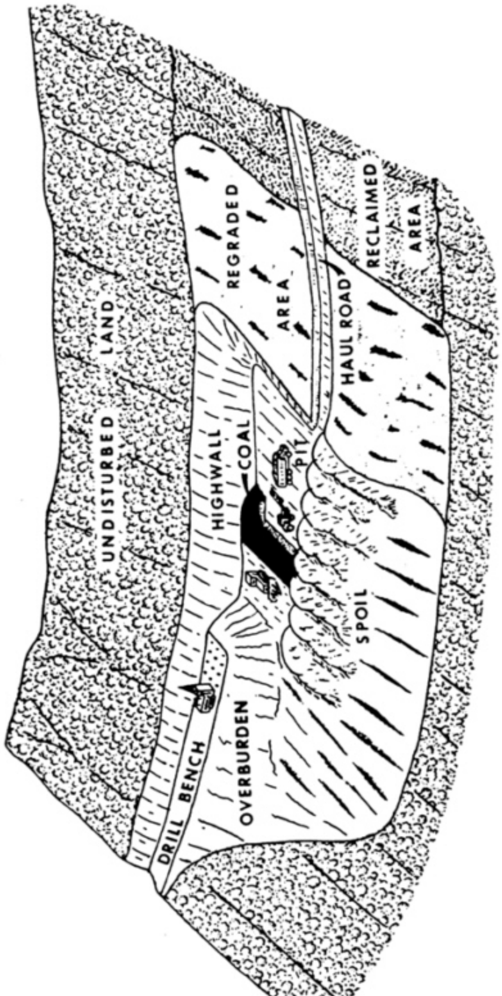

Figure 5.1 Typical contour strip method.

Mountaintop Removal

In this procedure complete extraction of upper coal seams in a mountain (Figure 5.2) is achieved by sequential removal of all overburden above the seam (s). Spoil material is placed and graded to favor surface runoff toward the center of the mountain in the restructuring of the landscape. The volume increase in spoil due to the porosity being greater than that in the original overburden rock is usually handled by deposition in a head-of-hollow fill. The main features of this mining method that influence recharge are similar to those described for the contour method. However, the greater size of the operation and the longer duration of the mining process may result in greater impacts on recharge in the vicinity of the mine site.

Area Mining

This method uses the largest equipment. It is well established in the western United States (e.g., the Northern Great Plains Region), southern Illinois, Indiana, and in western Kentucky, and is also being practiced in mountain areas of Appalachia where several mountaintop removal operations are combined. These operations have common features with the other mining methods in terms of vegetation removal, topsoil storage, blasting, overburden removal, coal extraction, landscape restructuring, and revegetation. Sequential mining of the area is usually practiced whereby current overburden is used to fill the previous extraction pit (Figure 5.3). Sometimes the last pit is landscaped as a water body, thus eliminating the cost of hauling large amounts of stored overburden. Recharge and ground water systems can be subject to the greatest disturbance when the area mining method is used, due to the large mine size, heavy equipment use, and long duration of the mining operations.

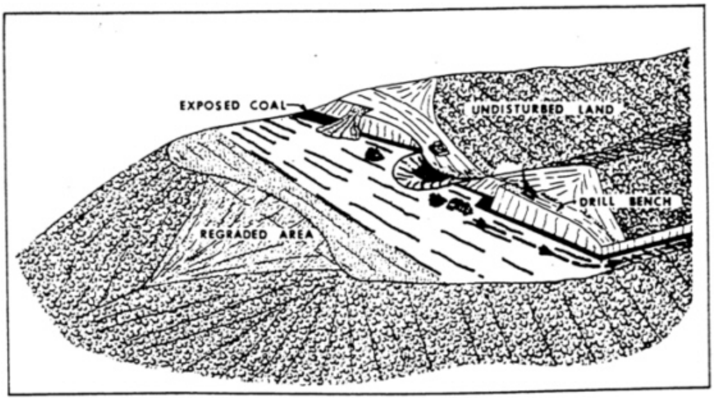

Figure 5.2 Surface mining mountaintop removal and valley fill method.

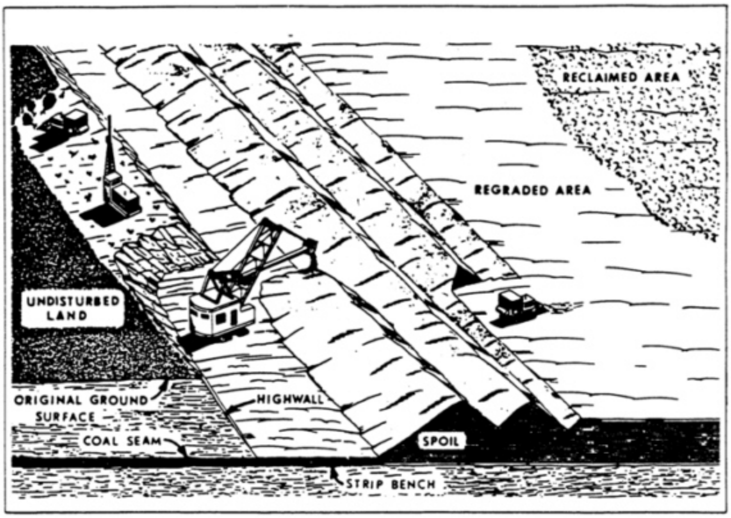

Figure 5.3 Typical area mining method with stripping shovel.

Common Features of Three Mining Methods

The common features of these three mining methods that can influence recharge of ground water in the reclaimed landscapes are

1. initial vegetation removal (eliminates transpiration);
2. blasting (increases volume of overburden, fracturing of adjacent and underlying bed rock);
3. mine floor compaction (reduces recharge to lower aquifers);
4. disruption of aquifer(s) (dewatering, destruction of storage zone);
5. water storage in spoil (greater porosity, extra fill areas);
6. surface compaction (greater surface runoff);
7. unfavorable reclaimed soil (poor water storage in root zone); and
8. change in vegetation type (change in rooting depth and growing season).

MINESOIL PROPERTIES

Surface coal mining and other land disturbances often significantly change soil properties. Minesoils, which are the materials on the restored land after mining, have properties that reflect the character of the coal overburden that becomes the parent material of the soil. Proper placement of soils and overburden after mining produces minesoils suitable for plant growth, but haphazard placement of these earth materials may result in minesoils that are difficult to vegetate even with lime and fertilizer amendments. Haphazard placement of overburden materials generally results in extreme variability of minesoil properties. Some minesoil properties change rapidly over time, especially for the first few years after revegetation. These changes are caused by the weathering of fresh, unweathered, or partially weathered overburden materials, a process that may be accelerated or decelerated by applying amendments such as lime, fertilizer, or sewage sludge to the minesoil.

Most minesoil textures are loamy, but some are clayey or sandy. Rock-fragment content varies, but most minesoils in areas without an original loess cover of 60 cm or more have greater than 35 percent by volume rock fragments in subsoil horizons (some as high as 80 to 90 percent) and fewer than 35 percent fragments in the surface horizons (Ciolkosz et al., 1985; Thurman et al., 1985). Minesoils, in general, have more rock fragments than do contiguous native soils (Bussler et al., 1984; Pedersen et al., 1978; Thurman and Sencindiver, 1986).

Soil structure develops very quickly in some minesoils, but it is generally more strongly developed in older minesoils. New minesoils constructed with scrapers tend to have massive, compacted layers, but minesoils constructed with a mining wheel excavator in combination with belt transportation tend to have a fritted structure, which is a porous structure with rounded aggregates loosely compressed together (McSweeney and Jansen, 1984).

Surface horizons of minesoils generally have higher bulk density, lower porosity, and lower water-holding capacity than do those of contiguous native soils (Bussler et al., 1984; Potter et al., 1988; Smith et al., 1971; Thomas, 1987; Thurman and Sencindiver, 1986; Younos and Shanholtz, 1980). As minesoils age, however, these properties become more like those of the native soils. The subsoil horizons of minesoils also may have properties that differ from those of the subsoil horizons of native soils.

Infiltration rates and saturated hydraulic conductivity of minesoils are highly variable and may be lower or higher than are those of contiguous native soils (Hnottavange, 1987; Pedersen et al., 1978). Large macropores in some minesoils cause water to move rapidly through the profile, but compaction of clayey-textured material may cause water to move very slowly through the soil.

Other factors affecting physical and hydraulic properties of minesoils are the presence or absence of topsoil and land use. Topsoil layers on minesoils typically have higher water-holding capacities than do the surface layers of non-topsoiled minesoils, because topsoil generally has fewer rock fragments (Thurman et al., 1985). However, water may infiltrate more rapidly and move through the profile more quickly in non-topsoiled minesoils than in minesoils with topsoil layers (Rogowski and Jacoby, 1979). Grazing of minesoils by livestock may significantly lower the infiltration rate (Hnottavange, 1987).

ACTIVE SURFACE MINING EFFECTS ON RECHARGE

In the site-preparation phase of mining, vegetation is removed, topsoil is scraped off and stored, and overburden is blasted and excavated to expose the coal. Significant changes in the landscapers water-budget components (evapotranspiration, drainage, storage) result from these activities; however, the effect on recharge depends on the season of the year and the coal field's location. Differences in mining effects on water-budget components for an eastern and a western coal region are given as examples.

Appalachian Coal Basin

Summer Operations

Site preparation that is initiated in May, followed by mining, site reconstruction, and completion of revegetation by September may have a small impact on long-term recharge. Recharge is usually negligible during the summer. Removal of vegetation eliminates transpiration at the site, and summer rainfall can result in increased recharge if infiltration is not restricted. However, surface compaction usually limits infiltration and causes surface runoff to dominate the hydrologic processes during mining. In undisturbed forest, surface runoff is essentially nonexistent due to the high infiltration rates of forest soils. Ephemeral stream flow (apparent surface runoff) is generated by storm events from subsurface water exfiltrating to the surface by convergent flow induced by topography. Surface water diversion into sedimentation ponds and pond discharge into stream waters are the dominant impacts of summertime mining operations, replacing the normal evapotranspiration water-loss component of the water budget.

Winter Mining

Most recharge in eastern coal basins occurs during the winter and the spring into a natural fracture system within the outer rock zones of mountains. These recharge zones have formed as a result of stress-relief fracturing during landscape erosion (Wyrick and Borchers, 1981). Mining operations destroy some of the natural fracture system, and during the winter period mining can significantly reduce recharge through surface compaction effects caused by mining equipment. Reduced infiltration leads to enhanced surface runoff, which is routed to sedimentation ponds if the mine operation is conducted according to approved procedures. Overflow from the ponds is channeled into local stream waters. The net effect is a bypassing of the natural ground water recharge-discharge process by overland routing to streamflow.

Summer and winter mining represent two extremes of direct mining effects on recharge, with patterns of impact expected to be intermediate for operations conducted during the spring or autumn.

Western Coal Basins

The large mining operations of western coal basins have a long period of coal extraction often lasting for a decade or more, and they occupy large areas relative to most eastern mines. The aquifer systems in western coal basins can be extensive, and several different aquifers, with differing recharge areas, may exist at a mine site. Mine operations often require dewatering of the intended mining area since the coal seams are usually a significant component of the aquifer system. Ground water pumping causes a drawdown of the aquifer, forming a cone of depression in the water table (Figure 5.4). The extent of drawdown may be small in relation to the whole aquifer, but the local effect is necessarily large (Woessner et al., 1979). Van Voast and Reiten (1988) estimated that the aquifer drawdown at the Decker mine in southeastern Montana extended over several kilometers (Figure 5.5). The surficial and deep aspects of recharge are noted for the western coal basins.

Surficial Recharge Processes

There is a definite seasonality to recharge in the western coal basins. The occurrence of frozen soil and the dynamics of snowmelt result in runoff to nearby alluvial depressions and valleys during spring. Snowmelt can be a very dramatic pulse event resulting in water accumulation in the lower landscape positions. Recharge to the upper aquifers in the landscape takes place largely during the snowmelt period. Rainfall during winter and early spring can also be effective in recharging the upper aquifers in the landscape. The operations at a mine site disrupt recharge within the mine area. However, this local effect may be offset to some extent by the collection and discharge of mine site precipitation through

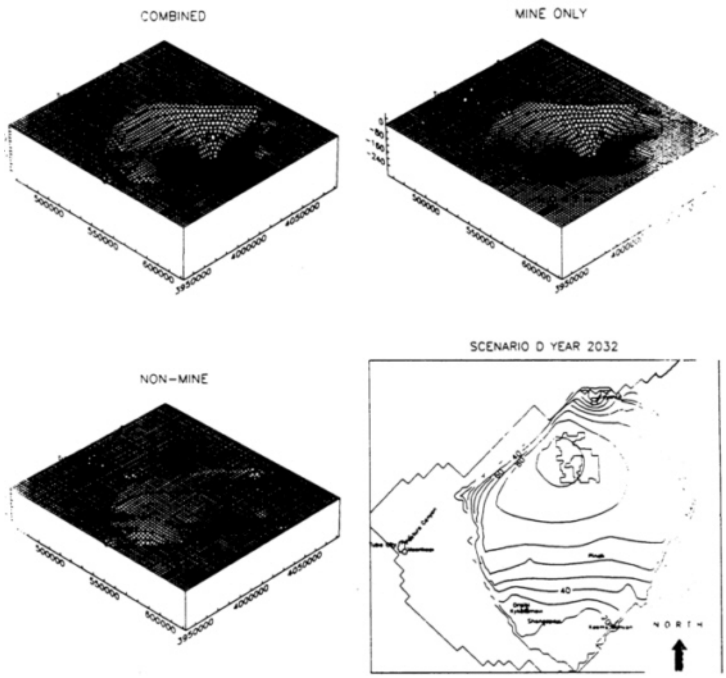

Figure 5.4 Three-dimensional representation of drawdown and percent of that drawdown resulting from mining for Scenario D in 2032.
Source: Office of Surface Mining Reclamation and Enforcement, 1988.

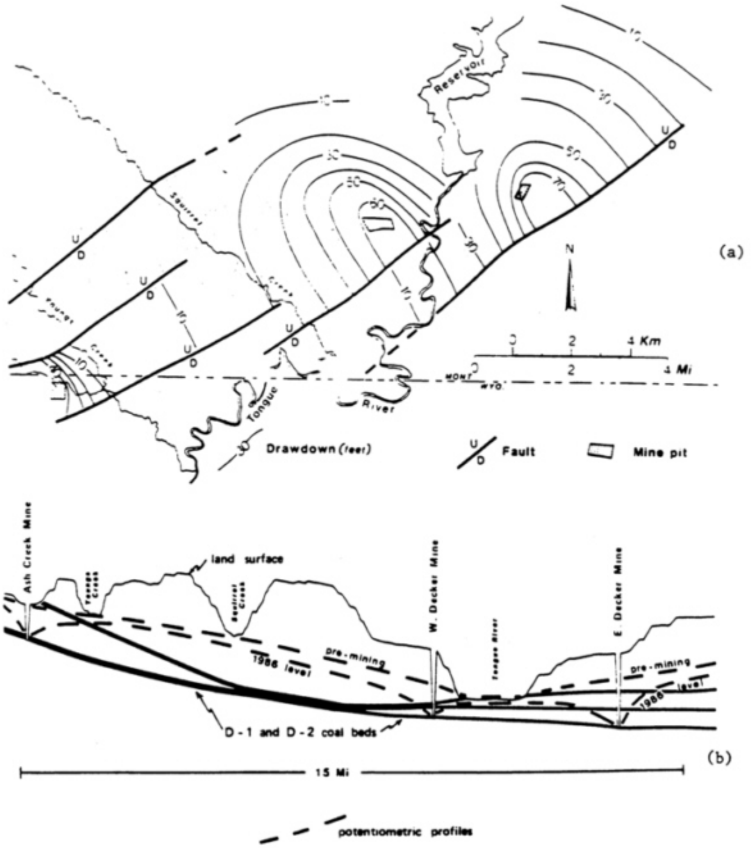

Figure 5.5 Aquifer drawdown at the Decker mine in southeastern Montana. (a) An area of potentiometric decline more than 15 miles long and 5 miles wide has developed for the D-2 coal bed; (b) lowered potentiometric levels pass unaffected beneath valley bottoms and perennial streams.
Source: Van Voast and Reiten, 1988.

sedimentation ponds to surface waters, which may contribute to recharge of surficial aquifers outside the area of active mining.

Deep Recharge Processes

Mine site operations may have little effect on the recharge of deep aquifers since in many cases the recharge occurs in permeable upland areas remote from the mine site. These permeable areas are formed in the approximate location of an outcrop of a former coal seam. Coal at or near the surface usually had been ignited by natural causes in earlier geological times, and the heat from the combustion had fractured the surrounding rock, forming the highly permeable material called clinker or scoria. Part of the precipitation received on clinker percolates through this material into adjoining coal seams, recharging deep aquifer systems. Recharge to such deep aquifers proceeds unimpaired during mining operations.

RECLAMATION EFFECTS ON RECHARGE AND ON WATER QUALITY

Water Quantity

Restoration of the mine site to approximately the pre-mining landscape by spoil placement, surface application of topsoil or other approved material, and revegetation can lead to an increase or decrease of recharge to aquifer systems relative to that of the original landscape.

The factors contributing to an increase in post-mining recharge are

- Poor vegetation establishment. Reduced evapotranspiration increases soil water drainage.
- Revegetation with species having more shallow root systems. Smaller available soil water storage favors reduced transpiration.

- Reduced soil water storage in root zone—leads to increased drainage below the root zone and to lower transpiration.
- Increased porosity of the vadose zone—provides greater water storage for potential recharge to aquifers.
- Increased permeability of the vadose zone—allows more rapid movement of water to the aquifer.
- Increased fracture porosity in the aquifer (from blasting)—results in greater aquifer water storage to receive and transmit recharge.
- Water impoundments. Mine plans allowing lakes and ponds may increase recharge through reduced runoff and increased seepage from the impoundments into aquifers.
- Enhanced zones of stress-relief fracturing in the rocks above buried head walls, especially in sites that received extensive augering.

Post-mining recharge may be decreased by:

- Reduced infiltration of the reclaimed surface. Greater surface runoff bypasses aquifer recharge.
- Slope instability and erosion—expected to increase surface runoff in channel flow bypassing recharge to the aquifer.
- Enhanced evapotranspiration. Prolific vegetation may have greater canopy interception and transpiration than did the original vegetation.
- Reduced effective porosity in the aquifer (from blasting)—less storage to receive and transmit recharge.
- Reduced permeability in vadose zone due to compaction during spoil placement and reshaping.
- Mine floor compaction—limits recharge to deeper aquifers.
- Elimination of surficial scoria or other high-recharge areas from within the mine site boundaries.

One of the dominant effects of the mining operations on recharge is the conversion of rock to rubble. In the pre-mining landscape, deep percolation may often be restricted by layers with low hydraulic conductivity, leading to perched water table development and lateral outflow as seeps or springs. In the post-mining landscape, deep percolation is often enhanced by the high hydraulic conductivity and high porosity of the spoil material.

One critical zone in the restoration of recharge occurs at the surface. Restoration of the infiltration rate of the reclaimed site is a prerequisite for restoration of recharge. Reduction in infiltration rates below pre-mining rates can be caused by compaction by earth-moving equipment during the landscape reconstruction. Compaction is deliberately used on sloping terrain to stabilize the spoil material and minimize erosion during revegetation. Some spoil materials from eastern Kentucky can withstand compaction without lowering infiltration to unfavorable levels (Wells et al., 1982). Not all spoil materials exhibit favorable infiltration properties. In particular, spoils from a western Kentucky surface mine were shown to have extremely low infiltration rates that were associated with high bulk density and a well-graded particle size (Wells et al., 1982). Deep ripping of the restored profile prior to revegetation can have a helpful influence on infiltration in some cases. Materials that form surface seals during wetting and crusts during drying will also reduce recharge by enhancing surface runoff rather than infiltration. Vegetative cover is one of the better means of overcoming surface sealing and crusting problems. Several non-mining changes in land use due to natural and human-induced causes can alter landscape water budgets, and these provide some comparisons with the effects of surface mining on recharge. A discussion of these other land use effects on recharge is given in Appendix C.

In low-rainfall areas, recharge may not be limited by recharge capability, and restoration of recharge capability could be viewed as an excessive requirement. In high-rainfall areas such as the coal provinces east of 100º W longitude, recharge capability can limit recharge rates, as evidenced by lateral subsurface flow and wet weather seeps. Such seeps have been observed, for example, in vertical faces of rock formations with vertical fractures that terminate on horizontal strata of low hydraulic conductivity. Seeps then occur above the outcrops of the less-permeable strata.

Restoration of recharge capability to pre-mining conditions at a surface mine permit area requires two main component steps: (1) the infiltration characteristics of the reclaimed site need to favor/produce recharge rates that equal or exceed the pre-mining rates, or exceed the highest rainfall intensity of the area, whichever is smaller, and (2) the hydraulic-conductivity values of the root zone and the vadose zone need to equal or exceed the equivalent pre-mining values. Also, revegetation should be carried out in such a way that the evapotranspiration rates after mining are not greater than those that occurred before mining. Due to soil and subsurface heterogeneity, it is not practical to undertake major field hydraulic-conductivity measurements (Klute, 1986), and indirect methods of evaluation should be used. In most cases, the hydraulic-conductivity characteristics of the restored vadose zone are much higher than the corresponding pre-mining values due to the greater porosity of the reclaimed spoil materials relative to the original rocks and other geologic deposits and due to the breakup of layers of low hydraulic conductivity.

Restoration of infiltration rates is needed to initiate the recharge process. Compaction of spoils is the major factor that may inhibit the recharge capability at a mine site, and such effects can usually be identified by the occurrence of surface erosion and poor establishment of vegetation. The reclaimed permit area should not have any visible signs of particle erosion rates exceeding pre-mining values. This requirement provides evidence that the surface hydrologic regime has been restored and that surface runoff is not exceeding pre-mining levels. Additionally, the requirements for revegetation specified in SMCRA favor the restoration of recharge capability by maintaining the integrity of the soil surface for infiltration as well as the permeability of the root zone for soil water drainage. Special attention needs to be given to evaluating compaction in reclaimed spoils as part of the post-mining assessment of recharge capability, particularly in areas with loess deposits, such as in western Kentucky.

Water Quality

From the standpoint of water quality, coal surface mining has its greatest impact on the shallower aquifers. The most notable effect is increased total dissolved solids and increased sulfate, calcium, and magnesium concentrations. In some cases there have been increases in the concentration of trace metals, including lead, manganese, nickel, chromium, cadmium, zinc, arsenic, and selenium (NRC, 1981a; Appendix D of this report).

Increased selenium content in ground water is a particularly onerous problem. The selenium content of some coals is 10 to 200 times the crustal abundance of this element (Lakin, 1973). Selenium is mobilized as selenate (SeO_4^{2-}) in alkaline coal spoils and is readily transported by ground water. Selenate is the form most available for accumulation by plants (Presser and Barnes, 1984). Some species of Astragalus accumulate up to several thousand ppm selenium (Walter et al., 1972), and selenium is concentrated by animals. Fish in the selenium-contaminated waters of the Kesterson National Wildlife Refuge were found to have selenium concentrations 100 times that of fish found in selenium-free waters (Presser and Barnes, 1984). Above levels required for good health (0.04 to 0.1 mg/liter) selenium is toxic, causing mutations in waterfowl hatchlings (Presser and Barnes, 1984) and acute selenosis in other animals (Fishbein, 1977).

Ground water quality data that have been collected to date are obtained from samples collected on or very near coal surface mine sites. Data are collected from probable hydrologic consequence (PHC) reports and compiled by the regulatory authority into cumulative hydrologic impact assessments (CHIAs) to evaluate cumulative effects of multiple coal surface mines in a given area. Although no long-term consistent trend (i.e., several decades to centuries) has been confirmed through evaluation of analytical data, (Groenewold et al., 1983; Van Voast and Reiten, 1988), it is anticipated that there may be long-term water quality impacts.

CONTROL OF ADVERSE EFFECTS OF COAL SURFACE MINING ON GROUND WATER QUALITY

All three phases of coal surface mining—pre-mining exploration, active mining, and post-mining reclamation—can potentially have negative impacts on ground water quality.

Exploration boreholes, drilled to determine the extent and quality of the coal seams, are, after data collection, now plugged as mandated by the Federal Surface Mining Control and Reclamation Act of 1977. This action is an important step in preventing contamination of deeper aquifers that often have better water quality than do shallower aquifers. Many coal companies now have a routine program of sealing all exploration drillholes that they find even though they may have existed from exploration periods predating the 1977 Surface Mining Control and Reclamation Act (W. A. Van Voast, Montana Bureau of Mines and Geology, personal communication, 1989).

During mining, blasting can create vertical fractures or widen existing fractures, allowing percolation of contaminated water into deeper aquifers of higher quality. Little can be done during the actual mining phase to prevent this from occurring other than continual dewatering to minimize the amount of water flowing to or from the deeper aquifer.

During post-mining reclamation, considerable effort is devoted to minimizing the short-and long-term impacts of coal surface mining on ground water quality. Blending of spoils and selective placement of spoils are techniques now being developed further, and in some cases practiced, to minimize the deterioration of water percolating through the backfill of reclaimed coal surface mines (Phelps and Saperstein, 1982; Groenewold et al., 1983; Caruccio and Geidel, 1989). One example of spoil blending is the mixing of acid-producing spoils with alkaline spoils to "neutralize" acid produced by iron sulfide oxidation.

Selective placement of weathered overburden may play an important role in controlling ground water quality in the western United States. The uppermost zone of the alkaline overburden of the West is highly weathered, and soluble salts have migrated only a few meters into the underlying zone over geologic time, because of low precipitation. It is this zone of very soluble salts that has often been placed on the mine floor as a result of overburden handling. Lateral and vertical ground water recharge into the spoils forms a new aquifer with the mine floor as the aquitard. Material high in water-soluble salts is readily leached by the new mine floor aquifer, resulting in serious deterioration of the new aquifer (Pagenkopf et al., 1977; Woessner et al., 1979; W. A. Van Voast, Montana Bureau of Mines and Geology, personal communication, 1989). To avoid increasing the salinity of the new aquifer, it has been proposed (Pagenkopf et al., 1977) that the zone containing the water-soluble salts be perched below the root zone and above the mine floor aquifer by selective spoils handling.

Toxic and acid-producing spoils, identified during the pre-mining evaluation of the overburden, are often isolated with clay barrier materials and placed well below the root zone and above the mine floor aquifer. This technique establishes differential permeabilities, reducing percolation through the undesirable spoils, which could lead to ground water deterioration. However, this technique may only provide a temporary solution, since clay barriers may eventually leak.

The reduction of recharge by decreasing permeability may at first blush appear inconsistent with the mandate of the SMCRA to restore ground water recharge capacity. However, if local reduction of recharge preserves water quality, then isolation of toxic and acid-producing spoils should be implemented. Because such isolation practices are localized and percolation is diverted, not prevented, the overall recharge may be preserved. Should recharge, however, be substantially reduced over a given area because of isolation practices, then artificial recharge through zones, engineered to assure good water quality, should be implemented. If isolation practices are required to protect water quality and the isolation technique reduces recharge and this reduction in recharge cannot be overcome by engineered recharge zones, then the area should be evaluated under the "unsuitable-for-mining" provision of SMCRA (Sect. 522).

6

Quantifying Ground Water Recharge

This chapter describes the basic techniques for quantifying ground water recharge used by soil scientists, engineers, hydrologists, and hydrogeologists. The standard methods available to quantify ground water recharge are discussed, and their applications to ground water recharge of surface mining sites are assessed.

TECHNIQUES FOR ESTIMATING GROUND WATER RECHARGE

Ground water recharge at a mine site can be estimated, in principle, by a variety of techniques. Tracing water that enters the surface soils as it percolates through the soils and underlying material (vadose zone) to the water table is one example of a direct measurement technique. Other indirect techniques involve such approaches as evaluation of water budgets of root zones and/or aquifers, analysis of surface-water-discharge hydrographs, and interpretation of soil water and ground water chemistry.

Attempts at determining recharge in small research plots typically require measurement of many climatic, geologic, soil, and ground water parameters (Table 6.1). For mine scale

TABLE 6.1 Experimental Measurements Required to Determine Ground Water Recharge

Measurement	Instrument or Technique
Onsite data—atmospheric	
Precipitation	Tipping-bucket rain gauge
Atmospheric pressure	Barometric-pressure transducer
Air temperature	Thermistor probe
Relative humidity	Relative-humidity probe
Wind speed	Anemometer
Net radiation	Fritschen-type net radiometer
Onsite data—subsurface	
Hydraulic head	Piezometer and duplicate tensiometer nests
Water table	Water-table well
Water content of soil	Neutron probe, gravimetric method, and gypsum blocks
Bulk density	Gamma probe and core method
Soil temperature	Thermocouples
Water characteristic	Tensiometers and neutron probe
Hydraulic conductivity	Determined from changes in water content and tension of a bounded soil volume during drainage and/or evaporation.
Laboratory data	
Soil texture	Hydrometer method
Particle density	Pycnometer method

Measurement	Instrument or Technique
Bulk density	Clod method
Water characteristic	Hanging column, pressure plate, pressure membrane
Hydraulic conductivity	Constant-head permeameter, water-characteristic-based methods

SOURCE: Adapted from Sophocleous and Perry, 1985.

evaluations, spatial and temporal variability in recharge and differences between pre-and post-mining site hydrology are important considerations in the selection of measurement techniques (Allison, 1988).

Interpretation of recharge data collected under ideal conditions requires an appreciation of possible sources of measurement error and uncertainty. Measurement error can usually be estimated or controlled, but uncertainty is more difficult to quantify. For instance, uncertainty is introduced when short-term hydrologic conditions are assumed to be a valid representation of the long-term site data base, which in fact may be quite different (Court, 1960; McKay, 1965). Uncertainty is also introduced when recharge is measured for a small area and then extrapolated to a larger area. The sources of these uncertainties are temporal and spatial variability. Comparative studies have shown that different methods can give different estimates of recharge even when the study site and time period are the same (Johansson, 1987; Uma and Egboka, 1988).

Direct measurement and observation of the migration of water from the land surface to the water table require installation of instruments to detect variations in the water content of soil with depth, from the land surface to the water table, over an extended period of time. Generally, these methods require banks of instrumentation and a large data-measurement program (Sophocleaus and Perry, 1985). Interpretation of the fluctuation of a water table can also be direct evidence of net recharge.

Hydrologic-budget calculations are based on the continuity equation, which states that all water entering and leaving a system must be accounted for (i.e., inflow minus outflow equals change in storage). This concept is applied over a selected area (i.e., a mine site or basin) for a specific time interval. A budget equation written in terms of ground water recharge from the vadose zone is

$$P = ET + RO + GW_R + \Delta Soil\ Storage,$$

where
P = precipitation;
ET = evapotranspiration;
RO = surface runoff and lateral vadose interflow;
GW_R = ground water recharge; and
ΔSoil Storage = change in soils water storage.

An equation written in terms of ground water recharge for the saturated zone is

$$GW_{in} + GW_R = GW_{out} \pm \Delta GW\ Storage$$

where
GW_{in} = ground water inflow rate;
GW_R = ground water recharge;
GW_{out} = ground water outflow rate; and
ΔGW Storage = change in ground water storage.

(The units of all above terms are length/time.) Use of the above equations assumes that other system inputs and outputs are negligible.

Accurately quantifying ground water recharge by water-budget calculation is more difficult than it may appear because it requires measurement of all the terms in the equation except ground water recharge. Most hydrology and hydrogeology text books—including Kirkby (1978), USDI (1977a, b), and Fetter (1988)—address the method for calculating the water budget. Knott and Olimpio (1986) compiled water-budget estimates of the average annual recharge rate for Nantucket, Massachusetts, and also made estimates from water table fluctuation and isotope data (Table 6.2). Their recharge rate calculations have a standard deviation of 39 percent.

Typically, the parameter most difficult to estimate in water-budget calculations is evapotranspiration (ET) (Bouwer, 1989). Lysimeters have been used to document the seasonal changes of ET and the resulting downward flux of water that escapes ET (Bouwer, 1989; USDI, 1977a, b; Williams and Hammond, 1988). However, given the relatively shallow placement of most lysimeters, the assumption that all the draining water would make it to the water table should be carefully considered.

Another method for estimating ground water recharge involves the measurement of water flow through the vadose zone. The flux of water through the vadose zone is a function of the ability of the medium to transmit water, its unsaturated hydraulic conductivity, and the driving force, the hydraulic gradient. In order to use this method the unsaturated hydraulic conductivity and total head distribution must first be quantified in three dimensions and through time. The hydraulic conductivity may be measured using field or laboratory techniques. Hydraulic gradients are estimated from measurements of total head in a series of vertical profiles (Wilson, 1979). These techniques require sophisticated instrumentation and the expertise of trained personnel, and therefore these techniques are most commonly applied to small research plots and are not typically employed in large basin studies.

Some studies have used infiltration rates to infer the occurrence of ground water recharge. These infiltration rates have been found to be helpful in assessing rainfall-runoff relationships (Wells et al., 1982). However, field measurement techniques may not provide values representative of natural rates (Bouwer, 1989). Infiltration values alone will not allow calculation of recharge without

TABLE 6.2 Comparison of Recharge Rates (Centimeters Per Year) Derived from Tritium, Water Table Fluctuation, and Water-Budget (Thornthwaite) Methods for Southeastern Massachusetts

		Method		
Study	Location	Tritium	Water Table	Water Budget
This study	Site 1	66.3	—	—
[Knot and	Site 2	≥42.4	—	—
Olimpio, 1986]	Site 3	—	52.1	—
Guswa and LeBlanc (1985)	Cape Cod	—	—	45.7
LeBlanc (1984)	Falmouth, Cape Cod	—	—	53.3
Olimpio and de Lima (1984)	Mattapoisett	—	—	40.4
G. J. Larson (1982)[1a]	Truro, Cape Cod	27.9-40.6	—	—
Walker (1980)	Nantucket	—	—	46.0
Delaney (1980)	Martha's Vineyard	—	—	58.4
Williams and Tasker (1974)	Mattapoisett	—	—	45.7
Delaney and Cotton (1972)	Truro, Cape Cod	—	—	46.2-49.3[b]
				43.9-46.7[b]
Magnusen and Strahler (1972)	Truro, Cape Cod	—	30.5	—
Strahler (1972)	Cape Cod	—	—	44.4

[a] Michigan State University, written communication, 1982.

[b] Ranges based on values of the water-holding capacity of the root zone between 5 and 10 cm, respectively.

SOURCE: Knot and Olimpio, 1986.

corresponding measurement of ET, changes in soil water storage, and rates of vertical movement through the vadose zone.

Measurement of a change in the position of a water table in response to precipitation events or snowmelt is evidence of ground water recharge, but other possible influences on water table elevations must first be eliminated (Table 6.3) (Freeze and Cherry, 1979; Todd, 1980). To estimate the total annual or storm-event recharge from water table hydrographs, both the quantity of water added to storage during the period of rise and that quantity of water flowing away from the water table during the event must be determined (Johansson, 1987). Rasmussen and anderson (1959) developed a method to estimate seasonal recharge using an estimated recession level from which to calculate the water table rise and the ground water recharge (Figure 6.1). To compute recharge from such plots, the estimated total change in the water table, Ah, is multiplied by the specific yield and the surface area over which the change is estimated to occur.

Analysis of stream baseflow recession curves has also been utilized to estimate basin ground water recharge (Fetter, 1988; Figure 6.2). This method requires streamflow hydrographs for two or more consecutive years and assumes that all recharge is reflected in the stream hydrographs. The method should not be used for cases where the stream recharges the ground water system (losing streams).

Ground water recharge rates have also been inferred from geochemical studies of water in the unsaturated and saturated zones (Stone, 1985; Bouwer, 1989; Knott and Olimpio, 1986; Colville, 1984; see Table 6.2). Measurement of thermonuclear tritium, chlorine-36, and chloride mass balance in vadose zone water profiles have been used to infer recharge.

Numerical modeling of ground water systems can also be used to estimate areal recharge rates. The inverse method is used to determine a recharge necessary to calibrate the model to measured fluctuations in ground water level (Wang and

TABLE 6.3 Summary of Mechanisms That Lead to Fluctuations in Ground Water Levels

	Unconfined	Confined	Natural	Human-induced	Short-lived	Diurnal	Seasonal	Long-term	Climatic influence
Ground water recharge (infiltration to the water table)	X		X				X		X
Air entrapment during ground water recharge	X		X		X				X
Evapotranspiration and phreatophytic consumption	X		X			X			X
Bank-storage effects near streams	X		X				X		X
Tidal effects near oceans	X	X	X			X			
Atmospheric pressure effects	X	X	X			X			X
External loading of confined aquifers		X		X	X				
Earthquakes		X	X		X				
Ground water pumpage	X	X		X				X	
Deep-well injection		X		X				X	
Artificial recharge; leakage from ponds, lagoons, and landfills	X			X				X	
Agricultural irrigation and drainage	X			X				X	X
Geotechnical drainage of open pit mines, slopes, tunnels	X			X				X	

SOURCE: Freeze and Cherry, 1979.

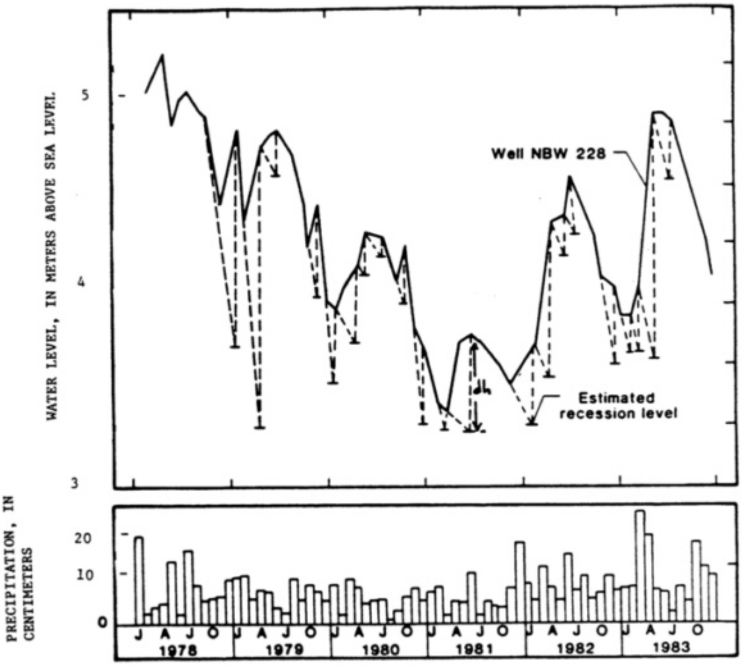

Figure 6.1 Hydrograph of monthly ground water levels and bar graph of monthly precipitation.
Source: Knot and Olimpio, 1986.

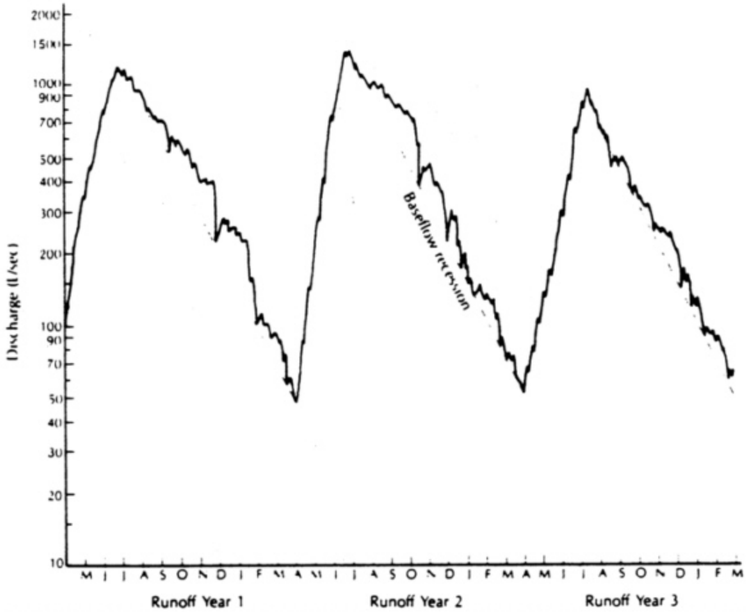

Figure 6.2 Semilogarithmic stream hydrographs showing base flow recessions. Source: Fetter, 1988.

anderson, 1982). Such ground water modeling requires input of aquifer geometry, boundary conditions, initial conditions, aquifer parameters, and other inflows and outflows at each model node. Water level data spanning the time period of interest are required for calibration.

APPLICATION OF TECHNIQUES TO SURFACE MINING SITES

Attempting to quantify ground water recharge at mine sites requires an appreciation for the strengths and limits of monitoring techniques, the impact of the selected mining technique on the hydrologic system, and the constraints of the climatic and geologic setting. Successful evaluation of recharge in western settings, such as those found in the Northern Plains Coal Province, requires an assessment of recharge parameters associated with thick coal seams covering thousands of hectares, semiarid climates (observations likely to be highly variable over short distances), seasonally frozen ground, thin soils overlying bedrock, coal aquifers, and clinker outcroppings in potential recharge areas. In contrast, recharge evaluations in the Appalachian Coal Province usually encompass sites of a few hundred hectares, steep wooded terrains, small perennial streams, temperate climates, thin soils overlying fractured bedrock, and small recharge areas. Mining in either of these coal provinces produces a different topography, soil profile, and stratigraphy than existed prior to mining. The mining process also disrupts the local ground water system, which can make identifying post-mining ground water recharge trends difficult (Western Water Consultants, Inc., 1985). It also has been demonstrated that ground water recharge varies spatially and temporally in both pre-mining and post-mining areas (see Figure 3.5) (Rehm et al., 1982; Van Voast and Reiten, 1988; Kipp et al., 1983). The choice and success of a particular method or combination of techniques to estimate recharge will depend on site conditions and the desired post-mining hydrology, and on the desired degree of resolution—criteria that have not yet been set.

Water-Budget Methods

The water-budget techniques for both unsaturated and saturated zones are generally applicable in principle to pre-and post-mining conditions. The equations appear to be simple, with the requisite number of input parameters limited. In practice, however, accurately quantifying these few parameters, such as soil water storage and ground water flow rates (input and output), poses a formidable task. The uncertainty associated with estimating recharge using water-budget techniques can be quite significant and must be assessed on a site-by-site basis. Further, if included, water-budget measurements for the vadose zone are data intensive and have been predominantly applied in research situations only.

Vadose Zone Flux Measurements

Most mine sites in the United States exist in areas of thin unconsolidated soils that overlie coal, sandstone, shale, and limestone. Such sites do not lend themselves to detailed vadose zone monitoring, principally because unsaturated consolidated formations and secondary fracture porosity and permeability make standard instrumentation unuseable or unreliable. While there may be special situations where the technique would be valuable (e.g., monitoring the effectiveness of spoil-segregation techniques), mine-scale problems generally are not amenable to the use of this type of instrumentation and analysis.

Water Table Fluctuation Measurements

Water table recession analysis requires monitoring recessions and quantifying specific yield. Analysis is complicated by several factors. The specific yield and the points of system recharge (natural and post-mining) and discharge are spatially variable and are influenced by mining. Post-mining analysis is further hampered by the time delay in the ground water system recovery period, which may mask recharge events. Implementation requires measurement of the level of the water table, which may be quite difficult to obtain in zones of secondary fractures.

Stream Hydrograph Separation

Stream hydrograph separation may have the widest applicability in the eastern United States. This method is only appropriately applied to areas large enough to support perennial streams draining mined watersheds. The data-collection techniques use well-established methods. Data analysis is complicated by climatic trends and variability, so meaningful analysis demands either a prolonged data-acquisition phase or comparisons limited to similar climatic conditions. Stream hydrographs are sensitive to both the size and type of mining disturbance. Increases in the post-mining baseflow component of the hydrograph can be attributed to enhanced water storage in reclaimed spoils accompanied by slow release (Minear and Tschantz, 1976).

Geochemical Techniques

Geochemical techniques have some applicability to pre-mining conditions, particularly in arid regions, because they reflect long-term averages (Bouwer, 1989; Stone, 1985; Knott and Olympio, 1986). Because of the long-term averaging aspect of this technique, it is generally not applicable to post-mining evaluations. Also, leaching of chemicals from the mine spoils may interfere with the chemistry of ground water recharge.

Numerical Modeling

Numerical methods can be used for comparison or optimization of proposed techniques. Because of the typically data-intensive nature of ground water models, they are usually employed only in conjunction with other techniques. In the absence of an extensive data-collection program, numerical methods to infer recharge are not particularly useful.

CONCLUSION

In conclusion, recharge estimation is frought with difficulty and uncertainty. Recharge cannot be measured directly. Uncertainty in the measurement of relevant parameters results in an uncertainty in recharge estimates that likely exceeds changes in long-term recharge due to mining if proper reclamation practices are followed.

Also, it must be recognized that at some mine sites that are small or are located in dry climates, reliable recharge quantification may be outside the realm of current technology. As an example, consider Van Voast and Reiten's (1988) comment that at some wells associated with mine sites in the Montana coal fields" ... no local recharge has been observed over 15 years of (water level) record; at others, recharge has been evident only during occasional periods of unusually high snow melt or springtime precipitation."

7

Conclusions and Recommendations

The committee's mission was basically to assist the Office of Surface Mining Reclamation and Enforcement (OSM) concerning interpretation of the term "ground water recharge capacity" in the context of the Surface Mining Control and Reclamation Act of 1977 and to advise OSM in regard to its estimation or assessment before and after mining. The committee expresses the results of its deliberations in terms of the following several sets of conclusions and recommendations that correspond generally to the items of its charge, outlined in the Preface. These conclusions and recommendations are of three general types: (1) those that should clarify the meaning of the term "ground water recharge capacity"; (2) those that should provide operational guidance to the OSM and their constituents; and (3) those concerning research and development that may produce more long-term and general benefits to the evaluation of the hydrologic functions of surface-mined areas in the future.

GROUND WATER RECHARGE CAPACITY INTERPRETED

CONCLUSION:

"Ground water recharge capacity" has no clear scientific meaning. This committee's legal interpretation is that the term means ground water recharge capability, as concluded in Chapter 2. Again, this term has no scientific definition but is an indicator of the "ability of soils and underlying materials to allow precipitation and runoff to infiltrate and reach the zone of saturation." Notwithstanding the issue of definition, for reasons stated in Chapter 1 both terms ("capacity" and "capability") are nebulous and are poor indicators of actual ground water recharge.

RECOMMENDATION:

For the above reasons, the term "ground water recharge capacity" should be interpreted to mean ground water recharge, which is the movement of surface water to ground water or the addition of precipitation or surface water to ground water, the real issue of concern. The rates of this movement are controlled by precipitation, infiltration, surface and subsurface runoff, evapotranspiration, and site stratigraphy and structure. All of these parameters exhibit spatial and temporal variabilities, making accurate measurement of pre- and post-mining recharge rates for mine-scale areas difficult.

HYDROLOGIC EVALUATIONS

CONCLUSION:

The several parameters relevant to ground water recharge can, in principle, be measured for a given point. However, spatial and temporal variabilities would require intensive instrumentation at high costs, and these variabilities and the uncertainty in measurement techniques would generally preclude accurate extrapolation to mine-scale areas. Nonpoint methods for estimating ground water recharge, made by hydrograph separation, tracer techniques, and regional water budgets, are also not exact. The errors in resulting estimates of ground water recharge may exceed the change in recharge due to mining.

RECOMMENDATION:

No single technique or set of techniques for assessing recharge at surface coal mines should be required as part of the "recharge capacity" provision of SMCRA.

CONCLUSION:

Although accurate determination of differences between pre-and post-mining recharge rates is not practical, the committee concluded that enforcement of existing OSM regulations concerning mine reclamation will, in the vast majority of situations, result in post-mining recharge rates that equal or exceed pre-mining rates. This conclusion is based on the following currently required conditions:

1. The land surface is recontoured and stabilized to the approximate pre-mining topography;
2. The site is typically revegetated with plants using less or approximately the same quantity of water as the pre-mining species;
3. Compaction of surface soils and vadose zone materials is avoided; and
4. Restricting layers in the original vadose zone are broken up and dispersed in the reconstituted vadose zone by the mining and reclamation process.

RECOMMENDATION:

No additional instrumentation and measurement, over and above that already required by other sections of the SMCRA and justified solely on the grounds of establishing whether or not differences exist in pre-and post-mining recharge, should be required as part of the permitting process for surface coal mining, because such measurement cannot be justified rationally given the present state of recharge measurement technology.

CONCLUSION:

Isolation practices can be implemented to preserve water quality in surface mine restoration projects. These practices can have an impact on the process of ground water recharge.

RECOMMENDATION:

When practices implemented to preserve water quality substantially reduce recharge over a given area, recharge should be restored through other areas that are especially engineered to assure good quality and quantity of water. But if isolation practices substantially reduce mine-site recharge and this recharge cannot be restored by engineered zones, the area should be reconsidered in respect to its suitability for mining. There is an "unsuitable-for-mining" provision of SMCRA (Sect. 522).

CONCLUSION:

The impacts of mining on the hydrology of a region with many mining operations may be substantial but are currently not well known, because cumulative hydrologic impact studies currently are difficult to conduct in a meaningful manner due to the lack of a central digitized data base.

RECOMMENDATION:

Each state regulatory authority should be encouraged to produce and maintain a Geographic Information Systems data base of all mined areas. Such data bases should be uniform across states.

RESEARCH AND DEVELOPMENT

CONCLUSION:

The long-term cumulative consequences of large surface coal mining projects on the ground and surface water parameters are unknown.

RECOMMENDATION:

A long-term research program of hydrologic monitoring should be provided for such sites. This monitoring may have to continue well beyond the current bond-release dates.

CONCLUSION:

No single current technique or combination of current techniques can provide a sufficiently accurate characterization of ground water recharge at mine scale. Improvement in our ability to determine site recharge rates is needed to allow for better quantification of pre-and post-mining hydrologic systems so as to improve our ability to predict the effects of mining and reclamation on the surface and ground water resources of an area.

RECOMMENDATION:

Research should be undertaken in eastern and western coal provinces to help improve our understanding of the recharge process, its spatial and temporal variability, and the accuracy of individual measurement techniques.

CONCLUSION:

Issues of hydrologic balance, recharge, and pre-and post-mining monitoring need to be addressed in a more coherent hydrologic framework.

RECOMMENDATION:

In conjunction with research to improve hydrologic methods and information, annual water budgets should be developed based on available monthly records representative of the pre-mining landscapes in the permitting areas. Several water budgets may be needed because the rates and timing of recharge can differ between and within the coal mining areas of each state. As part of each permit application, the applicant should qualitatively describe the anticipated changes in water-budget components (evapotranspiration, runoff, infiltration, soil water storage, drainage, and recharge) during mining operations and the reclamation period. (A written review of the reclamation project could take place at the time of bond release.) All the above data should be incorporated into the above mentioned Geographic Information System data base for use in subsequent cumulative hydrologic impact studies.

CONCLUSION:

Soil compaction can be a major factor affecting the restoration of the recharge process in a reclaimed landscape.

RECOMMENDATION:

Innovative methods should be developed for overcoming compaction problems in reclaimed spoil materials and minesoils, particularly in surface-mined areas with identified compaction problems.

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Appendix A

Glossary

alluvial Pertaining to processes or materials associated with transportation or deposition by running water.

aquiclude A formation that may contain ground water but is incapable of transmitting it in significant quantities. Aquicludes often form confining layers for aquifers.

aquifer A sufficiently permeable formation storing, transmitting, and yielding ground water in useable quantities.

aquitard A layer of low permeability that may contain and transmit water from one aquifer to another but cannot itself serve as an aquifer. An aquitard is a leaky, semiconfining layer.

argillaceous Containing appreciable clay.

artesian aquifer See **confined aquifer**.

bulk density The weight of a dry porous medium per unit volume of the material in its natural conditions (including pores and voids).

calcareous Containing sufficient free carbonate to effervesce visibly when treated with cold 0.1 M HCl.

carbonaceous Pertaining to, or rich in, carbon.

clastic Consisting of fragments of rocks or of organic structures that have been moved individually from their places of origin.

coastal plain Any plain that has its margin on the shore of a large body of water, particularly the sea.

colluvium A general term applied to deposits on a slope or at the foot of a slope or cliff that were moved there chiefly by gravity.

confined aquifer An aquifer with an upper boundary that is a confining layer and having a pressure potential at this boundary in excess of atmospheric. The potentiometric surface of a confined aquifer is above the top of the aquifer. Also known as an artesian aquifer.

confining layer A layer of material having a permeability lower than that of the associated aquifer. If the permeability is essentially zero, the confining layer is impermeable and may be an aquifuge or an aquiclude. If the permeability is small relative to that of the adjoining aquifer, the layer is said to be leaky and is called an aquitard.

Darcy's equation A formula stating that the flow rate of water through a porous medium is proportional to the hydraulic gradient. The factor of proportionality is the hydraulic conductivity.

fluvial of, or pertaining to, rivers; produced by river action.

fracture A crack in a rock formation usually formed by stresses imposed on or released from the formation. Fractures may be interconnected or isolated.

fragipan A natural subsurface soil horizon with high bulk density and/or high mechanical strength relative to the soil horizons above, seemingly cemented when dry, but when moist showing a moderate to weak brittleness.

ground water Subsurface water under a pressure greater than atmospheric.

hysteretic function The difference between water content and water pressure relations in unsaturated porous media due to antecedent conditions, i.e., wetting or drying.

hydraulic conductivity	The factor of proportionality in Darcy's equation relating flow velocity to hydraulic gradient having units of length per unit of time. A property of the porous medium and the water content of the medium.
hydraulic head	The energy per unit weight of water made up of the sum of the pressure potential (head), velocity potential (head), and elevation potential (head). The velocity head is often negligible and taken as zero for subsurface flow. Also called water potential.
illuvial (clay)	Clay that has moved into a soil horizon from the soil horizons above.
intrinsic permeability	A quantitative measure of water-transmitting ability of a porous medium that is related to the size and interconnectedness of the void openings.
lenticular	Shaped approximately like a double convex lens.
lithology	The physical character of a rock, generally as determined megascopically or with the aid of a low-power magnifier.
loess	A sediment, commonly nonstratified and commonly unconsolidated, composed dominantly of silt-size particles, ordinarily with accessory clay and sand, deposited primarily by the wind.
perched aquifer	A localized unconfined aquifer formed above a relatively impermeable layer. May be seasonal due to recharge patterns and leakage through and flow around the restricting layer.
permeability	A description of the ease with which a fluid may move through a porous medium; abbreviation of intrinsic permeability.
phreatic surface	Same as water table.
piezometric surface	The surface defined by a pressure potential and position. For an unconfined aquifer it is equal to the elevation of the water table. For a confined aquifer it is equal to the elevation to which water would rise in a well penetrating and open to the aquifer.
porosity	A measure of the total void space present in a volume of formation. The percentage of any volume of material occupied by voids.

Voids may be filled with water or air. If all of the voids are filled with water, saturation exists. Porosity consists of primary and secondary porosity.

potential gradient or hydraulic gradient	The change in hydraulic head per unit distance.
primary porosity	Porosity composed of voids between individual particles such as grains of sand and gravel or clay or silt particles.
residuum	Unconsolidated and partly weathered mineral materials accumulated by disintegration of consolidated rock in place.
saline (soil)	A soil containing sufficient soluble salt to adversely affect the growth of most crop plants.
saturation	The condition that exists when all voids are filled with water.
secondary porosity	Porosity due to fractures, solution channels, root channels, and animal burrows.
sodic (soil)	A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most soil and plant type conditions.
solution channels	Channels formed within soluble rocks (such as limestone) by the action of water and chemicals in dissolving rock material.
specific capacity	The yield of a well per unit drop of the water level in the well (volume per unit time per unit length).
specific retention	The volume of water retained per unit volume of material when the material is allowed to drain due to gravity. Similar to field capacity in an agricultural setting. Specific retention plus specific yield equals porosity.
specific yield	The volume of water drained per unit volume of material when the material is allowed to drain due to gravity. · Specific yield and the storage coefficient are the same for an unconfined aquifer. Specific yield plus specific retention equals porosity.

storage coefficient The volume of water released per unit area of aquifer and per unit drop in head.

till (glacial) Nonsorted, nonstratified sediment carried or deposited by a glacier.

unconfined aquifer An aquifer with a water table as an upper surface. Also known as a water table aquifer.

vadose zone The zone between the surface and the aquifer containing water at pressures less than atmospheric. It includes the capillary fringe.

water table The surface defining the location where the pressure potential is atmospheric for an unconfined aquifer. Equivalent to the phreatic surface. The water table is the top of an unconfined aquifer.

Appendix B

Legal Background

B1. The Legislative History of SMCRA

Three distinct categories of legislative history assist in the process of interpreting language in SMCRA of 1977 (P. L. 95-87): (1) other surface mining bills, (2) committee hearings and reports, and (3) floor discussions in the Senate and House of Representatives.

1. Other surface mining bills. Although surface mining bills were introduced into the Congress as early as the 1940s, the first significant step in the process that led to SMCRA was the inclusion of a section in the Appalachian Regional Development Act of 1965 that required the secretary of the interior to "make a survey and study of strip and surface mining operations and their effects in the United States." In 1966 before the interior secretary's final report was issued but after an interim report came out, Senator Lausche of Ohio introduced a bill (S. 3882) to control surface mining. Time ran out before the bill could be considered, and the process began again in the 90th Congress (1967-1968). The interior secretary's final report came out in 1967. Senator Lausche introduced a new bill (S. 217) in 1967; the

Administration introduced its bill in 1968 through Senator Jackson (S. 3132); Senator Nelson introduced a third bill (S. 3126). Over the period from 1966 to 1977 and the passage of SMCRA, the number of bills introduced was substantial. For example, at least 18 bills were introduced in the House of Representatives alone in the 93rd Congress (1973-1974). In this interim two bills, S. 425 in 1973-1974 and H.R. 25 in 1975, passed both the House and Senate but were vetoed by the president.

2. Committee hearings and reports. Although congressional hearings on surface mining go back at least to the 1940s, the first hearing on surface mining after the Department of Interior Report came out was held during the 90th Congress (1967-1968) on April 30th, May 1st and May 2nd, 1968. This hearing was on S. 3132, S. 3126, and S. 217, three bills referred to above in the discussion of other surface mining bills. In addition, Congress held hearings on proposed surface mining legislation in 1971, 1972, 1973, and 1977. House of Representatives and-Senate committee reports accompany bills that are recommended for passage by the respective committees. When the

House and Senate pass different versions of a bill, a conference committee is named to resolve the differences. Conference reports set forth and justify the major changes agreed to by the conferees. From the earliest report on a surface mining bill (S. Rept. No. 92-1162, 92nd Cong., 2nd Sess. (1972)), dated September 18, 1972, to the Conference Report on SMCRA (H. Rept. No. 95-493, 95th Cong., 1st Sess. (1977)), inclusive, Congress issued 13 reports.

3. Floor discussions in the Senate and House of Representatives. The first floor discussion dealing with a bill proposing surface mining regulation after the Department of Interior Report came out occurred in the House of Representatives

in the 92d Congress (1971-1972). This discussion, on October 11, 1972, was on H.R. 6482 and ended with the House passing H.R. 6482 on a 265 to 75 vote. Thereafter there were 12 significant floor discussions in Congress before SMCRA was passed in 1977.

For additional discussions of legislative history related to surface mining control, see Dunlap (1975) and Waters (1980).

B2. Context of Recharge Capacity Provision As Introduced In 1973

[Senator Moss:] At the appropriate place in Section 208 [permit application requirements] add the following:

(14) a determination of the hydrologic consequences of the mining and reclamation operations, both on and off the mine site, with respect to the hydrologic regime, quantity and quality of water in surface and ground water systems and the collection of sufficient data for the mine site and surrounding area so that an assessment can be made of the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability. For those mining and reclamation operations which remove or disturb strata that serve as aquifers which significantly insure the hydrologic balance of water use either on or off the mining site, the regulatory authority shall specify:

(A) monitoring sites to record the quantity and quality of surface drainage above and below the mine site as well as in the potential zone of influence;

(B) monitoring sites to record level, amount, and samples of ground water aquifers potentially affected by the mining and also directly below the lower most (deepest) coal seam to be mined;

(C) the maintenance of records of well logs and boreholes; and

(D) monitoring sites to record precipitation.

The monitoring, data collection and analysis required by this section shall be conducted according to standards and procedures set forth by the regulatory authority in order to assure their reliability and validity.

At the appropriate place in Section 213 [Criteria for surface mining and reclamation operations], add the following:

(11) a detailed description of the measures to be taken during the mining and reclamation process to assure the protection of (A) the quantity and quality of surface and ground water systems, both on-and off-site, from adverse effects of the mining and reclamation process, and (B) the rights of present users to such water.

At the appropriate place in Section 213 [Criteria for surface mining and reclamation operations], add a new paragraph (E) as follows: by restoring recharge capacity of the aquifer at the mine site and protecting alluvial valley floors."

(119 Cong. Rec. 33,321 (1973))

B3. SMCRA of 1977 Versions of Sections in Appendix B2

(b) The permit application shall be submitted in a manner satisfactory to the regulatory authority and shall contain, among other things—

. . .

(11) a determination of the probable hydrologic consequences of the mining and reclamation operations, both on and off the mine site, with respect to the hydrologic regime, quantity and quality of water in surface and ground water systems including the dissolved and suspended solids under seasonal flow conditions and the collection of sufficient data for the mine site and surrounding areas so that an assessment can be made by the regulatory authority of the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability. Provided, however, that this determination shall not be required until such time as hydrologic information on the general area prior to mining is made available from an appropriate Federal or State agency: Provided further, that the permit shall not be approved until such information is available and is incorporated into the application." (30 U.S.C. § 1257(b)(11))

[F]or those surface coal mining and reclamation operations which remove or disturb strata that serve as aquifers which significantly insure the hydrologic balance of water use either on or off the mining site, the regulatory authority shall specify:

(A) monitoring sites to record the quantity and quality of surface drainage above and below the mine site as well as in the potential zone of influence;

(B) monitoring sites to record level, amount, and samples of ground water and aquifers potentially affected by the mining and also directly below the lowermost (deepest) coal seam to be mined;

(C) records of well logs and borehole data to be maintained; and

(D) monitoring sites to record precipitation. The monitoring, data collection and analysis required by this section shall be conducted according to standards and procedures set forth by the regulatory authority in order to assure their reliability and validity.

(30 U.S.C. § 1267(b)(2))

[In addition, the applicant for a mining permit must submit a reclamation plan that includes:]

. . .

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

(30 U.S.C. § 1258(a)(13))

B4. OSM Hydrologic Information and Balance Regulations

30 C.F.R. § 780.21 Hydrologic information.

(a) Sampling and analysis methodology. All water-quality analyses performed to meet the requirements of this section shall be conducted according to the methodology in the 15th edition of "Standard Methods for the Examination of Water and Wastewater," which is incorporated by reference, or the methodology in 40 CFR Parts 136 and 434. Water quality sampling performed to meet the requirements of this section shall be conducted according to either methodology listed above when feasible. "Standard Methods for the Examination of Water and Wastewater" is a joint publication of the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation and is available from the American Public Health Association, 1015 15th Street, NW, Washington, DC 20036. This document is also available for inspection at the Office of the Federal Register Information Center, Room 8301, 1100 L Street, NW, Washington, DC; at the Office of the OSM Administrative Record, U.S. Department of the Interior, Room 5315, 1100 L Street, NW, Washington, DC; at the OSM Eastern Technical Service Center, U.S. Department of the Interior, Building 10, Parkway Center, Pittsburgh, Pa.; and at the OSM Western Technical Service Center, U.S. Department of the Interior, Brooks Tower, 1020 15th Street, Denver, Colo. This incorporation by reference was approved by the Director of the Federal Register on October 26, 1983. This document is incorporated as it exists on the date of the approval, and a notice of any change in it will be published in the Federal Register.

(b) Baseline information. The application shall include the following baseline hydrologic information, and any additional information required by the regulatory authority.

(1) Ground-water information. The location and ownership for the permit and adjacent areas of existing wells, springs, and other ground-water resources, seasonal quality and quantity of ground water, and usage. Water quality descriptions shall include, at a minimum, total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese. Ground-water quantity descriptions shall include, at a minimum, approximate rates of discharge or usage and depth to the water in the coal seam, and each water-bearing stratum above and potentially impacted stratum below the coal seam.

(2) Surface-water information. The name, location, ownership, and description of all surface-water bodies such as streams, lakes, and impoundments, the location of any discharge into any surface-water body in the proposed permit and adjacent areas, and information on surface-water quality and quantity sufficient to demonstrate seasonal variation and water usage. Water quality descriptions shall include, at a minimum, baseline information on total suspended solids, total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese. Baseline acidity and alkalinity information shall be provided if there is a potential for acid drainage from the proposed mining operation. Water quantity descriptions shall include, at a minimum, baseline information on seasonal flow rates.

(3) Supplemental information. If the determination of the probable hydrologic consequences (PHC) required by paragraph (f) of this section indicates that adverse impacts on or

off the proposed permit area may occur to the hydrologic balance, or that acid-forming or toxic-forming material is present that may result in the contamination of ground-water or surface-water supplies, then information supplemental to that required under paragraphs (b) (1) and (2) of this section shall be provided to evaluate such probable hydrologic consequences and to plan remedial and reclamation activities. Such supplemental information may be based upon drilling, aquifer tests, hydrogeologic analysis of the water-bearing strata, flood flows, or analysis of other water quality or quantity characteristics.

(c) Baseline cumulative impact area information. (1) Hydrologic and geologic information for the cumulative impact area necessary to assess the probable cumulative hydrologic impacts of the proposed operation and all anticipated mining on surface-and ground-water systems as required by paragraph (g) of this section shall be provided to the regulatory authority if available from appropriate Federal or State agencies.

(2) If the information is not available from such agencies, then the applicant may gather and submit this information to the regulatory authority as part of the permit application.

(3) The permit shall not be approved until the necessary hydrologic and geologic information is available to the regulatory authority.

(d) Modeling. The use of modeling techniques, interpolation or statistical techniques may be included as part of the permit application, but actual surface and ground-water information may be required by the regulatory authority for each site even when such techniques are used.

(e) Alternative water source information. If the PHC determination required by paragraph (f) of this section indicates that the proposed mining operation may proximately result in contamination, diminution, or interruption of an underground or surface source of water within the proposed permit or adjacent areas which is used for domestic, agricultural, industrial, or other legitimate purpose, then the application shall contain information on water availability and alternative water sources, including the suitability of alternative water sources for existing permining (sic) uses and approved post-mining land uses.

(f) Probable hydrologic consequences determination. (1) The application shall contain a determination of the probable hydrologic consequences (PHC) of the proposed operation upon the quality and quantity of surface and ground water under seasonal flow conditions for the proposed permit and adjacent areas.

(2) The PHC determination shall be based on baseline hydrologic, geologic and other information collected for the permit application and may include data statistically representative of the site.

(3) The PHC determination shall include findings on:

(i) Whether adverse impacts may occur to the hydrologic balance;

(ii) Whether acid-forming or toxic-forming materials are present that could result in the contamination of surface or ground-water supplies;

(iii) Whether the proposed operation may proximately result in contamination, diminution or interruption of an underground or surface source of water within the proposed permit or adjacent areas which is used for domestic, agricultural, industrial, or other legitimate purpose; and

(iv) What impact the proposed operation will have on:

(A) Sediment yield from the disturbed area; (B) acidity, total suspended and dissolved solids, and other important water quality parameters of local impact; (c) flooding or streamflow alteration; (D) ground-water and surface-water availability, and (E) other characteristics as required by the regulatory authority.

(4) An application for a permit revision shall be reviewed by the regulatory authority to determine whether a new or updated PHC determination shall be required.

(g) Cumulative hydrologic impact assessment. (1) The regulatory authority shall provide an assessment of the probable cumulative hydrologic impacts (CHIA) of the proposed operation and all anticipated mining upon surface-and ground-water systems in the cumulative impact area. The CHIA shall be sufficient to determine, for purposes of permit approval, whether the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area. The regulatory authority may allow the applicant to submit data and analyses relevant to the CHIA with the permit application.

(2) An application for a permit revision shall be reviewed by the regulatory authority to determine whether a new or updated CHIA shall be required.

(h) Hydrologic reclamation plan. The application shall include a plan, with maps and descriptions, indicating how the relevant requirements of Part 816, including §§ 816.41 to 816.43, will be met. The plan shall be specific to the local hydrologic conditions. It shall contain the steps to be taken during mining and reclamation through bond release to minimize disturbances to the hydrologic balance within the permit and adjacent areas; to prevent material damage outside the permit area; to meet applicable Federal and State water quality laws and regulations; and to protect the rights of present water users. The plan shall include the measures to be taken to: avoid acid or toxic drainage; prevent, to the extent possible, using the best technology currently available, additional contributions of suspended solids to streamflow; provide water-treatment facilities when needed; control drainage; restore approximate premining recharge capacity and protect or replace rights of present water users. The plan shall specifically address and (sic) potential adverse hydrologic consequences identified in the PHC determination prepared under paragraph (f) of this section and shall include preventive and remedial measures.

(i) Ground-water monitoring plan. (1) The application shall include a ground-water monitoring plan based upon the PHC determination required under paragraph (f) of this section and the analysis of all baseline hydrologic, geologic and other information in the permit application. The plan shall provide for the monitoring of parameters that relate to the suitability of the ground water for current and approved postmining land uses and to the objectives for protection of the hydrologic balance set forth in paragraph (h) of this section. It shall identify the quantity and quality parameters to be monitored, sampling frequency, and site locations. It shall describe how the data may be used to determine the impacts of the operation upon the hydrologic balance. At a minimum, total dissolved solids or specific conductance corrected to 25ºC, pH, total iron, total manganese, and water levels shall be monitored and data submitted to the regulatory authority at least every 3 months for each monitoring location. The regulatory authority may require additional monitoring.

(2) If an applicant can demonstrate by the use of the PHC determination and other available information that a particular water-bearing stratum in the proposed permit and adjacent areas is not one which serves as an aquifer which significantly ensures the hydrologic balance within the cumulative impact area, then monitoring of that stratum may be waived by the regulatory authority.

(j) Surface-water monitoring plan. (1) The application shall include a surface-water monitoring plan based upon the PHC determination required under paragraph (f) of this section and the analysis of all baseline hydrologic, geologic, and other information in the permit application. The plan shall provide for the monitoring of parameters that relate to the suitability of the surface water for current and approved postmined land uses and to the objectives for protection of the hydrologic balance as set forth in paragraph (h) of this section as well as the limitations found at 40 CFR Part 434.

(2) The plan shall identify the surface-water quantity and quality parameters to be monitored, sampling frequency and site locations. It shall describe how the data may be used to determine the impacts of the operation upon the hydrologic balance.

(i) At all monitoring locations in the surface-water bodies such as streams, lakes, and impoundments, that are potentially impacted or into which water will be discharged and at upstream monitoring locations the total dissolved solids or specific conductance corrected to 25ºC, total suspended solids, pH, total iron, total manganese, and flow shall be monitored.

(ii) For point-source discharges, monitoring shall be conducted in accordance with 40 CFR Parts 122, 123 and 434 and as required by the National Pollutant Discharge Elimination System permitting authority.

(3) The monitoring reports shall be submitted to the regulatory authority every 3 months. The regulatory authority may require additional monitoring.

§ 816.41 Hydrologic-balance protection.

(a) General. All surface mining and reclamation activities Shall be conducted to minimize disturbance of the hydrologic balance within the permit and adjacent areas, to prevent material damage to the hydrologic balance outside the permit area, to assure the protection or replacement of water rights, and to support approved post-mining land uses in accordance with the terms and conditions of the approved permit and the performance standards of this part. The regulatory authority may require additional preventative, remedial, or monitoring measures to assure that material damage to the hydrologic balance outside the permit area is prevented. Mining and reclamation practices that minimize water pollution and changes in flow shall be used in preference to water treatment.

(b) Ground-water protection. In order to protect the hydrologic balance, surface mining activities shall be conducted according to the plan approved under § 780.21(h) of this chapter and the following:

(1) Ground-water quality shall be protected by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to ground-water systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the ground water.

(2) Ground-water quantity shall be protected by handling earth materials and runoff in a manner that will restore the approximate premining recharge capacity of the reclaimed area as a whole, excluding coal mine waste disposal areas and fills, so as to allow the movement of water to the ground-water system.

(c) Ground-water monitoring. (1) Ground-water monitoring shall be conducted according to the ground-water monitoring plan approved under § 780.21(i) of this chapter. The regulatory authority may require additional monitoring when necessary.

(2) Ground-water monitoring data shall be submitted every 3 months to the regulatory authority or more frequently as prescribed by the regulatory authority. Monitoring reports shall include analytical results from each sample taken during the reporting period. When the analysis of any ground-water sample indicates noncompliance with the permit conditions, then the operator shall promptly notify the regulatory authority and immediately take the actions provided for in §§ 773.17(e) and 780.21(h) of this chapter.

(3) Ground-water monitoring shall proceed through mining and continue during reclamation until bond release. Consistent with the procedures of § 774.13 of this chapter, the regulatory authority may modify the monitoring requirements, including the parameters covered and the sampling frequency, if the operator demonstrates, using the monitoring data obtained under this paragraph, that—

(i) The operation has minimized disturbance to the hydrologic balance in the permit and adjacent areas and prevented material damage to the hydrologic balance outside the permit area; water quantity and quality are suitable to support approved postmining land uses; and the water rights of other users have been protected or replaced; or

(ii) Monitoring. is no longer necessary to achieve the purposes set forth in the monitoring plan approved under § 780.21(i) of this chapter.

(4) Equipment, structures, and other devices used in conjunction with monitoring the quality and quantity of ground water onsite and offsite shall be properly installed, maintained, and operated and shall be removed by the operator when no longer needed.

B5. Ground Water Provisions in Kentucky Application Form

14.5 Do aquifers exist within the proposed permit area below the lowest coal seam to be mined, which may be adversely affected by the mining operation? If yes, describe the structural geology, lithology and thickness of each stratum from the lowest coal seam to be mined to such aquifers. Submit description and related information as 'Attachment 14.5.A.' 14.6 Describe all aquifers within and adjacent to the proposed permit area which the mining operation may adversely impact. Identify the description as 'Attachment 14.6.A.' At a minimum, the description must include, for each aquifer, the following information:

Aquifers within the permit area	Aquifers adjacent to the permit area
(a) aquifer identification	(a) approximate areal extent
(b) top elevation	
(c) lithology	(b) approximate thickness
(d) thickness	
(e) areal extent	(c) aquifer identification
(f) number of users	
(g) structural geology	(d) number of users

15.1 Provide the results of the ground water inventory conducted for the proposed permit and adjacent areas. The inventory must identify wells, springs, underground mines or other similar ground water supply facilities which are currently being used, have been used in the past, or have a potential to be used. For each supply source, describe the location, ownership, type of use and where possible other relevant information such as the depths and diameters of wells, approximate rate of usage, pumpage or discharge. Provide results as 'Attachment 15.1.A.'

15.2 Describe the pre-mining ground water monitoring program used to determine the seasonal variations in ground water quality and quantity for all aquifers and water transmitting zones. At a minimum, six months of data must be collected. The description must identify the location and construction specifications of each monitoring point used, parameters tested, and laboratory methods used. Submit the description as 'Attachment 15.2.A.'

15.3 On approved cabinet forms submit the results of the pre-mining ground water monitoring program. Original or notarized copies of all laboratory analyses must be provided. Submit this information as 'Attachment 15.3.A.'

17.1 Provide as 'Attachment 17.1.A,' a determination of the probable hydrologic consequences (phc) which the proposed mining operation will have on both surface water and ground water systems within the proposed permit and adjacent areas. The contents of the determination must conform to the requirements of 405 KAR 8:030, Section 32 (surface mine) or 405 KAR 8:040, Section 32 (underground mine).

17.2 Provide as 'Attachment 17.2.A,' a detailed description of the protective measures to be taken as part of the mining and reclamation operations to ensure compliance with 405 KAR 16:060, Sections 1, 2, 3, 4, 5, 6, 8, 9, 12, and 405 KAR 16:080 (surface mine) or 405 KAR 18:060, Sections 1, 2, 3, 4, 5, 7, and 405 KAR 18:080 (underground mine). Detailed designs of protective measures must be presented in other pertinent sections of this application.

29.1 Provide as 'Attachment 29.1.A,' a detailed description of the in-stream surface water quality and quantity monitoring program to be used during the mining and reclamation operations. The location, frequency, and method of collection must be described along with a list of parameters tested and the reporting procedure.

Appendix C

Other Land Use Change Effects on Recharge

Several changes in land use due to natural and human-induced causes other than mining alter the landscape water budget and change recharge. Removal of forest vegetation leads to an increase in Streamflow, as documented by Douglass and Swank (1972) for four watershed study sites in the Appalachian Highlands. The greater the proportion of forest removal, the greater the increase in streamflow during the first year after clearing (Figure C.1). This increase in streamflow occurred mainly during the late summer and autumn at the Coweeta site in North Carolina (Figure C.2) and was attributed to the reduction in transpiration that increased both stormflow (Hewlett and Helvey, 1970) and baseflow. The increase in baseflow is a good indication of greater recharge. Similar results occurred in a watershed in West Virginia where deforestation of half of the watershed changed the stream from intermittent to perennial flow (Patric and Reinhart, 1971).

Surface disturbance by logging operations can reduce infiltration and increase runoff (Lull and Reinhart, 1972) and can lead to large increases in stream turbidity (Packer, 1967). Stoeckeler (1959) demonstrated that infiltration rates of forest soil declined by 10 to 20 times with woodland grazing. Such grazing has been shown to increase overland

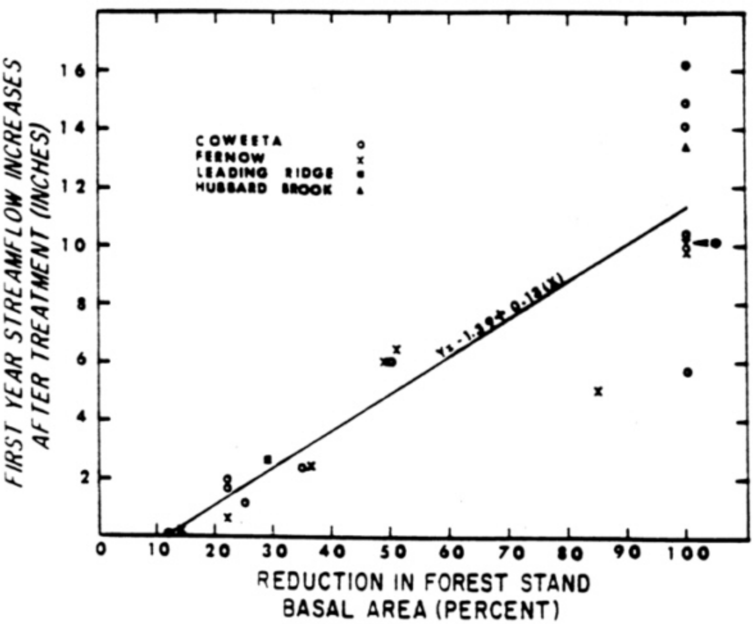

Figure C.1 Relationship between streamflow increase the year after forest removal and the percentage reduction in forest stand.
Source: Douglass and Swank (1972).

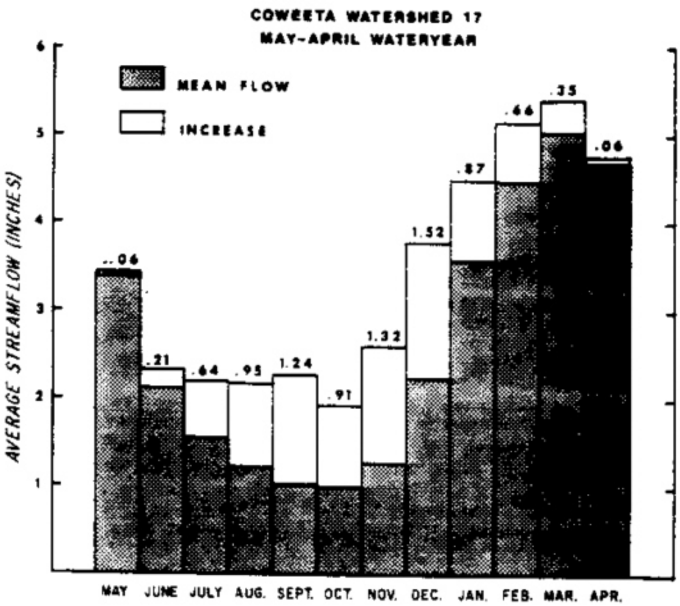

Figure C.2 Timing of mean flow before treatment and the average increase in flow produced by a Coweeta watershed which was clearcut and recut annually for 7 years.
Source: Douglass and Swank (1972).

flow, and the frequency and magnitude of peak streamflow (Johnson, 1952). These studies have relevance to land use during and after reclamation of surface mining. Compaction caused by grazing of surface-mined areas reclaimed as pastureland may reduce recharge by causing less infiltration and more surface runoff.

Conversion of forest land to crop or pasture land use usually leads to less evapotranspiration, and recharge would be expected to increase. Short vegetation often has less interception and a more shallow root system than does forest. These effects could lead to greater soil water drainage and enhanced ground water recharge. However, infiltration can be less in croplands favoring greater overland flow than in forests (Hobbs, 1946).

Appendix D

Water Quality Issues Associated with Surface Coal Mining

Comprehensive studies confirm that water quality can be adversely affected by pre-mining, mining, and post-mining activities associated with surface coal mining (NRC, 1981a; Western Water Consultants, Inc., 1985). During the pre-mining period exploration boreholes may intersect aquifers allowing communication of ground water, which could result in deterioration of deeper, more pristine waters. Blasting activities during mining fragment rock materials, thus expose fresh mineralized surfaces. In the post-mining period, ground water recharge, in the form of atmospheric precipitation, surface water, and lateral or vertical ground water flows, may wet loosely consolidated overburden. This process initiates chemical reactions with exposed minerals, which could ultimately result in serious deterioration of ground water quality. Affected ground water quality parameters can include pH, specific conductance, acidity, alkalinity, physical appearance, total dissolved solids, ionic composition, and trace metal burden.

This appendix reviews criteria used to evaluate ground water quality; describes factors affecting the chemical composition of waters infiltrating unconsolidated overburden; surveys the methods for assessing and monitoring water quality; and investigates issues concerning water quality protection in surface coal mined areas.

GROUND WATER QUALITY: EFFECTS OF COAL SURFACE MINING

Water Quality Criteria

Several criteria are used to determine which chemical constituents must be analyzed when assessing the impact of surface coal mining on water quality (Turk et al., 1986):

1. Constituents specifically required by the Permanent Regulatory Program (Office of Surface Mining Reclamation and Enforcement);
2. Constituents required at the discretion of the regulatory authority;
3. State and federal drinking water standards;
4. Irrigation criteria; 5. Aquatic life criteria;
6. Minimum groups of constituents necessary to perform routine quality control checks; and
7. Minimum groups of constituents necessary to evaluate possible geochemical controls on the hydrologic system.

Constituents that may be analyzed by these criteria include a number of chemical and physical constituents as well as biological aspects (Table D.1). Water quality standards are established by the U.S. Environmental Protection Agency; the Office of Surface Mining Reclamation and Enforcement is responsible for enforcing these standards relative to coal surface mining activity.

Factors Affecting the Quality of Ground Water

Geochemical and biogeochemical processes that affect water quality as a result of coal surface mining are oxidation of mineral and organic matter, the reaction of carbon dioxide and water to form carbonic acid, precipitation and dissolution of

TABLE D.1 Chemical, Physical, and Biological Constituents and Parameters That May Be Measured As Required by Several Criteria

Measured Onsite	Measured in Laboratory
Temperature	Total dissolved solids (TDSs)
pH (in standard units)	Carbonate and bicarbonate
	Trace metals:
Specific conductance (in micromhos/cm)	Iron
	Manganese
	Arsenic
Acidity	Mercury
Alkalinity	Boron
	Lead
	Zinc
	Silver
	Copper
	Chromium
	Calcium
	Magnesium
	Sodium
	Potassium
	Chloride
	Aluminum
	Selenium
	Fluoride
	Radium-226
	Nitrogen species:
	Nitrate
	Ammonia
	Organic nitrogen
	Total suspended solids (TSSs) (surface water only)
	Microbiology

SOURCE: Turk et al., 1986.

calcite and dolomite, precipitation and dissolution of gypsum, cation exchange and adsorption, and transport of solutes (Forstner and Wittmann, 1979; Groenewold et al., 1983; Western Water Consultants, Inc., 1985).

Important Oxidation Reactions

The most significant reaction contributing to ground water degradation in the post-mining environment is sulfide mineral oxidation. Common sulfide minerals associated with coal surface mining overburden are pyrite and marcasite.[1] In the presence of oxygen introduced into the overburden during the mining process, these minerals will slowly oxidize:

$$FeS_2 + 7/2\ O_2 + H_2O \xrightarrow{\text{(chemical)}} Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad [1]$$

However, in the presence of the aerobic, acidophilic[2] bacterium Thiobacillus ferrooxidans, this oxidation rate is increased by 500,000 times:

$$2\ FeS_2 + 15/2\ O_2 + H_2O \xrightarrow{\text{(bacteria)}} 2\ Fe^{3+} + 4\ SO_4^{2-} + 2\ H^+ \qquad [2]$$

Thiobacillus are ubiquitous and proliferate rapidly in sulfide-containing coal spoils. Under acid conditions (pH << 3) the Thiobacilli directly attack the sulfide minerals and also oxide the ferrous ion:

[1] pyrite and marcasite are both designated by the formula FeS_2.

[2] Acidophilic (acid-loving) bacteria grow at pH values between 1 and 3.

$$2\ Fe^{2+} + 3\ SO_4{}^{2-} + 2\ H^+ + 1/2\ O_2 \ \underline{(bacteria)} > 2\ Fe^{3+} + 3\ SO_4{}^{2-} + H_2O \qquad [3]$$

Ferric iron is a strong oxidizing agent, chemically. attacking sulfide minerals:

$$FeS_2 + 14\ Fe^{3+} + 21\ SO_4{}^{2-} + 8\ H_2O \ \underline{(chemical)} > 15\ Fe^{2+} + 23\ SO_4{}^{2-} + 16\ H^+ \qquad [4]$$

Hence, the reactions become cyclic, creating conditions that further enhance the production of acid and cause bacterial proliferation (Hutchins et al., 1986). Reactions [1] through [4] are responsible for the creation of acid mine drainage (AMD), a familiar problem in the Appalachian region of the United States; however, these reactions also play a major role in the salinity problem associated with western coal surface mining. If unabated by deliberate control or by natural buffering reactions, the acid can become concentrated enough to solubilize deleterious trace metals, such as aluminum, arsenic, zinc, copper, and selenium.

Organic matter associated with coal spoils is oxidized by a complex biota existing in coal spoils (Millar, 1973; Harrison, 1978). The resulting products—organic acids and carbon dioxide—undoubtedly alter the chemistry of interstitial waters of the coal spoil, but this aspect has had limited study.

Buffering Reactions, Salinity Production, and Sulfate Precipitation

Backfill systems of coal surface mines are chemically complex with a series of acid-generating and acid-consuming reactions occurring. Ferric ion hydrolysis is an acid generating process which also precipitates jarosite[3]:

[3] jarosite is a basic ferric sulfate mineral.

$$Fe^{3+} + 7/3\ H_2O + 2/3\ SO_4^{2-} \text{------>} 5/3\ H^+ + 1/3\ Fe_3(SO_4)_2(OH)_5 . 2\ H_2O \quad [5]$$

The most important acid-consuming reaction, which buffers the coal spoil system and contributes calcium and magnesium to waters percolating through overburden spoil, is the dissolution of the carbonate minerals, calcite and dolomite[4]:

$$CaCO_3 + 2\ H^+ + SO_4^{2-} + H_2O \text{----->} CaSO_4 + 2\ H_2O + CO_2 \quad [6]$$

Carbonate minerals are also soluble in the presence of carbon dioxide:

$$CaCO_3 + H_2O + CO_2 \text{<=====>} Ca^{2+} + 2\ (HCO_3)^- \quad [7]$$

Reaction [6] is very important in understanding the chemistry of overburden materials, because this reaction decreases sulfate concentration in solution through the precipitation of gypsum. The solubility of gypsum in water controls sulfate concentration in interstitial waters in the mine-waste overburden.

Cation Exchange and Adsorption

Clay minerals, precipitated iron hydroxides, amorphous silicic acids, and organic matter are all capable of sorbing cations from solution and releasing equivalent amounts of other cations into solution. The mechanism of cation exchange is based on the metal-binding properties of negatively charged hydroxyl groups on clays, metal precipitates, and organic substances. Cation

[4] Dolomite is a carbonate mineral containing both calcium and magensium.

adsorption, which is also an important chemical phenomenon in backfill materials, occurs when fine-grained materials having a large surface area accumulate metals in the solid-liquid interface as a result of intermolecular forces, such as electrostatic attraction, hydrogen bonding, or Van der Waals forces. In backfill materials cation exchange and adsorption increase the concentration of dissolved salts, particularly sodium, in the infiltrating waters.

Transport of Solutes

When water and solutes move together through vadose zones or aquifers, chemicals that are adsorbed to the soil materials (trace elements, metals, and certain organic compounds, for example) move more slowly than the water. This is of great importance in ground water quality monitoring, especially, for example, to assess offsite effects of surface mining. As contaminated ground water moves laterally through an aquifer, an offsite monitoring well will first show the arrival of sulfate, chloride, and other nonsorbing chemicals. Metals can arrive much later. Thus, to get the full effect of mining on offsite ground water quality, long-term monitoring programs (lasting decades and perhaps even centuries) are required. Preferential channeling flow processes, however, can result in rapid breakthrough of strongly adsorbing solutes.

Biogeochemical Reactions

Other than the important role of Thiobacillus, and the possible contribution of several recently characterized thermophilic bacteria that also oxidize sulfide minerals on a geologic scale, little is known about the overall contribution of biogeochemistry to the fate and transport of deleterious ions in coal mine waste overburden.

Biological sulfate reduction has been implicated in anoxic coal overburden environments to account for sulfide production in spoils that have a sparsity of sulfide minerals (Olson et al., 1981). Because these spoils have a high salinity due principally to sodium, it is believed that sulfide oxidation must occur to initiate the sequence of reactions necessary for salinity to occur (Groenewold et al., 1983). This would be expected if the water infiltrating the spoils is of ground water origin and is anoxic (Olson et al., 1981).

Nitrate concentrations sometimes increase in coal surface mine spoils. This increase is believed to be due, in part, to the solubilization of nitrate from nondetonated blasting compounds at the mine site. A variety of microorganisms are active in nitrogen cycling: conversion of organic nitrogen to ammonium; oxidation of ammonium to nitrate; nitrate reduction to free nitrogen and ammonium; and free nitrogen fixation to organic nitrogen. Biogeochemical processing of nitrogen species in coal spoils has been demonstrated (Williams, 1975).

Onsite Disposal of Wastes

Fly ash, scrubber sludges, wastes from coal cleaning, spent machine oils, municipal waste, and industrial waste have been buried in the backfill of surface coal mines (NRC, 1981a). Such burial requires a solid-waste permit. Burial of waste is accompanied by isolation practices, whereby the wastes are encapsulated in clay materials that are designed to minimize leakage or leaching of toxic materials. Care is taken to avoid placement of wastes in areas where a high contamination potential exists. However, little is known about the long-term effects of such burial practices on the quality of recharge to ground water.

Monitoring and Assessing Ground Water Quality Impacts

Monitoring Ground Water Quality

Surface and ground water samples are collected during pre-mining, mining, and post-mining phases of surface coal mining and analyzed for various constituents among those listed in Table D.1. Monitoring wells for ground water sampling are constructed in aquifers within the pre-mining overburden and coal seam(s) to be mined as well as in the aquifer(s) that are below the eventual mine floor. Pre-mining water samples are evaluated to obtain baseline data for mine permits. Samples collected during and after mining are used to evaluate water quality as a result of mining activities. Monitoring wells often disappear during mining, and new wells are constructed in the backfill. Post-mining monitoring continues until the property is released for post-mining use.

There are essentially no regulatory requirements or guidelines mandating (1) correct procedures for collecting ground water samples, (2) proper handling and storage procedures of collected samples, (3) selection and execution of analytical techniques (Western Water Consultants, Inc., 1985), and (4) the reporting of a cation-anion balance. Failure to perform a cation-anion balance often results in reporting erroneous water quality data (A. E. Whitehouse, Office of Surface Mining Reclamation and Enforcement, personal communication, 1989). Approved methods include those published by the American Public Health Association et al. (1985) and the U.S. Environmental Protection Agency (1986).

Pre-Mining Overburden Assessment to Evaluate Impacts

During the pre-mining phase of coal surface mining, overburden is assessed, when the need is evident or mining is to occur in a new area, in an attempt to predict mine drainage and ground water quality. Assessments are assigned to two test categories—static and dynamic. Static tests entail whole-rock analyses for total sulfur and neutralization potential, and from these analytical data an acid and base accounting is made. Dynamic tests involve simulated weathering of the overburden material. This is accomplished by placing crushed rock materials in a humidified atmosphere and leaching periodically by adding water to the rock material. Chemical analysis of the effluents from these tests determines leachability of the material. As with analytical techniques, there are no prescribed standards for evaluating surface coal mine overburden materials by testing category. Several different methods for overburden assessment have been employed (Table D.2). There are advantages and disadvantages of each method. In addition to those methods listed in Table D.2, several techniques, including the American Society for Testing and Materials (ASTM) method "B" and the U.S. Environmental Protection Agency's extraction procedure (EP), have been evaluated (Schuller et al., 1981). The ASTM-B and EP tests, which use acetic acid as an extractant, were not predictive of field conditions (Schuller et al., 1981). The comparative evaluations of static and dynamic tests tabulated in Table D.2 indicate that, in fact, none of the test results predicts observed field conditions, because of the complex geochemical and hydrologic system that exists at each mine site. Column leach tests, however, were found to more closely approximate field conditions, and data generated from such tests are useful in identifying potentially toxic strata and formulating overburden-handling plans to dispose of problem spoils (Perry, 1985; Caruccio and Geidel, 1986).

Although still limited in use, computer models are gaining popularity as a method to simulate ground water quality as a result of coal surface mining (Western Water Consultants, Inc., 1985;

TABLE D. 2 Overburden Assessment Methods

Test	Procedure	Advantages	Disadvantages	References
Static tests				
Acid/base accounting	Perform whole rock analysis and relate acid potential to sulfur content; relate neutralization potential to hot HCl digestion.	Quick and easy test with low cost. OK for qualitative prediction.	Does not provide rate data; assumes parallel release of acidity and alkalinity, giving arroneous results.	Sobek et al., 1978; Sturey et al., 1982; Perry, 1985; Caruccio and Geidel, 1986; Hedin and Erickson, 1988
B.C. research test	Perform whole rock analysis; relate acid potential to total sulfur content; relate neutralization capacity to sulfuric acid titration.	Quick and easy test with low cost. OK for qualitative prediction.	Does not provide rate data; assumes parallel release of acidity and alkalinity, giving erroneous results.	Bruynesteyn and Duncan, 1979; Caruccio and Geidel, 1986
Dynamic test				
Soxhlet reactor	Pulverize sample and leach in Soxhlet extractor; dry sample and releach in extractor.	Quick and easy test, reportedly providing rate data.	Apparatus is expensive; leaching is aggressive and not related to natural weathering processes.	Renton et al., 1973; Caruccio and Geidel, 1986; Renton et al., 1988

Test	Procedure	Advantages	Disadvantages	References
Humidity chamber	Place crushed rock in humidity chamber; leach periodically with water; relate leachate character to acidity, alkalinity, and rock weight.	Yields rate data and mimics weathering.	Long turn-around time required and large data base generated.	Caruccio, 1968; Perry, 1985; Caruccio and Geidel, 1986
Beaker leach test	Place pulverized sample in beaker with water end monitor chemistry over time.	Simulates submerged conditions; provides some rate data.	Oxygen transfer is limited, end therefore rate data may not be representative.	Sobek et el., 1978; Schuller et al., 1981; Caruccio and Geidel, 1986
B.C. research test with bacteria	Place pulverized sample in beaker with water end bacteria end agitate to incorporate oxygen; monitor pH and analyze leachate.	Similar to beaker leach test; oxygen i s not limited and text incorporates bacteria.	To date data from this test have not been correlated to any other test data.	Bruynesteyn and Duncan, 1979; Caruccio and Geidel, 1986
Column leach test	Place samples in columns and leach periodically with water; bacteria can be added. Analyze leachate and correlate data with rock weight.	Results approximate field conditions.	Lord turn-around time required and large data base generated. Solutions can channel, giving erroneous data.	Hood end Oerter, 1984; Sturey et al., 1982; Perry, 1985; Caruccio and Geidel, 1986.

SOURCE: Perry, 1985; Caruccio and Geidel, 1986.

Perry, 1985; Rymer II et al., 1988; Renton et al., 1988). Computer models consist of algorithms to simulate pyrite weathering and ground water flow. Modeling techniques require a considerable amount of input of site-specific hydrogeochemical information, including static or dynamic overburden assessment test data and detailed geologic and hydrologic data. Computer simulations are tools for evaluating the short-and long-term ground water quality impacts of geochemical and biogeochemical factors operating in backfill material. Software programs to evaluate the hydrologic impacts, including ground water quality of coal surface mining are available (Whitehouse et al., 1989; Rymer II et al., 1988). Computer modeling is expected to assist in providing information on a topic of considerable concern: What are the cumulative effects of multiple coal surface mines on the ground water quality of a region, and how long is this impact expected to last?

CONTROLLING WATER QUALITY

Controlling Acid Mine Drainage

Acid mine drainage (AMD) is usually thought of as a surface water phenomenon; however, ground water can also become acidified as a result of an influx of contaminated water emanating from pyrite-and marcasite-containing spoils.

AMD is usually treated by the conventional technique of neutralization of the acidic water with caustic, lime, limestone, or soda ash or mixing of these materials with acidic spoils. To terminate the geochemical and biogeochemical processes of iron oxidation and its concomitant production of acid, attempts have also been made to diminish oxygen availability through selective spoils handling. Several new alternative technologies have been introduced for both treatment of AMD as well as prevention:

1. Wetlands—In this approach artificial wetlands are constructed with the typical components of limestone, compost, and cattail (Typha) plants. As the wetlands mature a complex ecosystem is established in which higher plants, algae, and microorganisms are inhabitants. AMD is directed through the wetlands where geochemical and biogeochemical processes neutralize the acid and remove dissolved metals through plant uptake, microbial accumulation and immobilization, or both (Kolbash and Romanoski, 1989; Hammack and Hedin, 1989; Wenerick et al., 1989). A variation of the wetlands approach is the use of a microecosystem employing a collection of encapsulated microorganisms (immobilized microbial pollution purification systems, IMPPS) (Davidson, 1989).
2. Phosphatic clay abatement—AMD is limited at its source with the addition of phosphatic clay from the Florida phosphate mining operations. The phosphatic clay reduces AMD by (a) forming a low-permeability clay layer around spoils and (b) precipitating soluble iron that is formed by pyrite and marcasite oxidation (Bowders et al., 1989).
3. Bactericides—Surfactants can be added to acidic spoils to minimize microbial growth.

Re-Mining to Control Water Quality

Much of the current ground and surface water pollution in the Appalachian region is associated with abandoned coal mines. Re-mining of abandoned coal mines, which contain substantial mineable coal reserves, is a viable means of minimizing a significant water quality problem. Strict regulations and modern technology can reclaim these lands after re-mining to diminish further contamination of ground water (Giovannitti and Merritt, 1989).

DISCUSSION

Communication of water between aquifers during exploration and mining and interaction by drainage water and lateral inflow with chemically reactive backfill material contribute to contamination of ground water. What is difficult to predict is the overall extent of water quality deterioration over both time and space. How extensive will ground water quality deterioration be due to cumulative mining efforts—i.e., multiple mines in an area? How long will the deterioration last? Decades? Centuries? The presumption among many experts and the coal industry is that time and dilution will diminish the impacts of coal surface mining on water quality. Part of the problem in predicting short-and long-term impacts is inadequate standards for pre-mining sampling, assessing, and analytically evaluating overburden samples to generate data that can be used to predict effects.

As a result of pre-mining overburden assessment, there is some selective materials handling, blending of spoils, encapsulation of toxic and reactive spoils, special contouring, and controlled revegetation to minimize ground water contamination. These techniques at this time are "more art than science."

Selective materials handling, blending, and isolation have been particularly practiced with sulfidic overburden, but greater consideration should be given to selective materials handling to avoid dissolution of soluble salts in western coal surface mining operations. In reclamation one objective is to restore ground water recharge. This restoration can sometimes compromise ground water quality. There should be serious attention given to controlling recharge through spoils handling in those areas where water quality is at risk.

More emphasis needs to be placed on collecting and making available relevant data that can be applied to predict short-and long-term impacts on ground water quality as well as estimate the effects of cumulative mining on regional ground water quality. Further research and development are needed to enhance the science of spoils handling.

Appendix E

Biographical Sketches of Committee Members

HERMAN BOUWER (Chairman) received his Ph.D. in agricultural engineering (soil and water management) in 1955 from Cornell University. He is currently the director of the USDA Water Conservation Laboratory and an adjunct professor, Arizona State University and University of Arizona (teaching semester courses in ground water hydrology, supervising graduate dissertation projects, giving lectures and seminars). As laboratory director, he directs a research program consisting of development of efficient irrigation systems, water measurement, irrigation scheduling, remote sensing of crop stress and evapotranspiration, ground water recharge, ground water quality protection, and other projects on conserving water and its quality.

ROBERT E. BECK is a professor of law at Southern Illinois University, Carbondale. He received his LL.B. from the University of Minnesota in 1960 and his LL.M. from New York University in 1966. His expertise is natural resource law and he specializes in oil and gas, coal mining, and water resources. Dr. Beck has received several honors and awards, including the Chester Fritz Distinguished Professorship in 1975 and the Order of the Coif in 1960.

CORALE L. BRIERLEY obtained her Ph.D. from the University of Texas, Dallas in 1981. She is presently a consultant at VistaTech in Salt Lake City, Utah. Her research interests include biogenic extractive metallurgy, biological treatment methods for inorganic wastes, thermophilic chemautotrophic microorganisms, and reclamation of solid mine waste. Dr. Brierley is a member of the Society for Mining, Metallurgy and Exploration, and the Society for Industrial Microbiology.

C. THOMAS HAAN acquired his Ph.D. (1967) from Iowa State University in agricultural engineering. Dr. Haan is a Regents Professor and Sarkeys Distinguished Professor of agricultural engineering at Oklahoma State University. His research is in the areas of mathematical, statistical, and empirical models of various phases of the hydrologic cycle; and hydrology of agricultural, surface-mined, and forest lands. Dr. Haan is a Registered Professional Engineer, a fellow of the American Society of Agricultural Engineer, and a member of the American Institute of Hydrology.

GEORGE M. HORNBERGER obtained his Ph.D. from Stanford University (hydrology) in 1970. He also holds a bachelors (1965) and masters (1967) in civil engineering from Drexel University. As a professor at the University of Virginia, his current research interests include modeling of environmental systems with uncertainty, the hydrogeochemical response of small catchments, water quality modeling, and ground water and lake interaction. Dr. Hornberger is a member of the American Geophysical Union, the American Geological Institute, and Sigma Xi. He is also a member of the WSTB Committee on USGS Water Resources Research and other NRC committees.

ROBERT J. LUXMOORE has been at Oak Ridge National Laboratory since 1973 as a soil and plant scientist. He obtained his Ph.D. in soil physics (1969) from the University of California, Riverside. He specializes in areas of experimental and computer modeling research on relationships between environmental variables and whole-plant physiological processes, including disruptions induced by pollutant stress and soil variability effects on hydrologic transport. Dr. Luxmoore is a member of the American Geophysical Union and a fellow of the Soil Science Society of America.

JOHN C. SENCINDIVER received his Ph.D. in agronomy and soil science in 1977 from West Virginia University. He is currently a professor of soil science at West Virginia University. His research interests lie in soil genesis and classification, overburden and minesoil properties, surface mine reclamation, and the impacts of surface mining on ground water recharge and quality. Dr. Sencindiver is a member of the American Society for Surface Mining and Reclamation, of the Soil Science Society of America, and of various other organizations.

JAMES R. WALLIS received his B.S. in forestry from the University of New Brunswick in 1950, an M.S. from Oregon State University in 1954, and a Ph.D. in soil morphology from the University of California, Berkeley in 1965. Currently he is a research staff member at the IBM Thomas J. Watson Research Center, where he has been since 1967. His principal interests are in mathematical models applied to hydrology, soils, forestry, and land management. Dr. Wallis is a member of the Water Science and Technology Board.

WILLIAM W. WOESSNER is an associate professor of hydrogeology at the University of Montana, Missoula. He holds a Ph.D. in geology (hydrogeology), minor in civil and environmental engineering, from the University of Wisconsin, Madison. He teaches and conducts research on basic and applied hydrogeology topics. He has assessed coal hydrology and mining impacts in Montana and was a member of the NRC's Committee on Coal Mining and Ground Water Resources in the United States.