OCCURRENCE OF GROUND WATER IN MINE SPOIL, A RENEWABLE RESOURCE: STAR FIRE TRACT, EASTERN KENTUCKY[1,2]

by

James S. Dinger, David R. Wunsch, and John E. Kemp[3]

Abstract. The Star Fire site is a large surface mining operation in eastern Kentucky owned and operated by Cyprus-Southern Realty. Approximately 10,000 acres of reclaimed, usable land will result from the ongoing mining operation by the year 2010. Ultimately, development on the tract will depend on the availability of an adequate water supply utilizing both surface and ground waters. The water resources of the first 1,000-acre tract of mine spoil have been investigated. Areas of ground-water recharge and discharge have been identified at the site. Major recharge enters the spoil by way of disappearing streams, ground-water flow from bedrock that is in contact with the mine spoil, and specially designed infiltration basins. Ground water discharges predominantly from springs and seeps along the western outslope of the spoil. Monitoring wells drilled into the spoil indicate a saturated zone ranges from 8 to 25 feet in thickness. Data from water-level measurements, dye-tracing, and geochemical analyses of water samples indicate that a compacted haul road acts as a low-permeability barrier to ground-water movement.

Water samples from surface and ground water taken from the site show that all waters are a Ca-Mg-sulfate type, differing only in the total concentration of these constituents. Specific conductance measurements of samples collected at the site ranged from 257 microsiemens in surface runoff to 3,725 microsiemens in a monitoring well situated in the interior of the spoil. The pH ranged between 6.23 and 6.66 for ground water sampled at the site, and between 7.67 and 8.28 for surface water.

Additional Key Words: water supply, ground water, spoil aquifer, infiltration basin, base flow, surface water, ground-water quality

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Introduction

In 1988 Kentucky produced 161 million tons of coal, ranking number two in the nation. However, the work force generating this production has been reduced approximately 30 percent since 1980, and unemployment among the general work force is estimated to be in the 10 to 20 percent range. A principal cause for this high unemployment rate is the lack of economic diversification. Two of the major factors that hamper economic diversification are the lack of water supplies and rugged topography, particularly in the Eastern Kentucky Coal Field, where local relief ranges from 300 to 2,500 feet. Water supplies sufficient to support economic development are restricted to the larger streams, and even these supplies must be enhanced by construction of expensive reservoirs. Rugged terrain also makes it difficult to pipe water from the source of treatment to outlying areas.

Many coal companies operating in eastern Kentucky have no real interest in these limiting factors because they generally own only the mineral rights to the properties they mine, not the land surface. Cyprus Mountain Coals, a subsidiary of Cyprus Minerals, Inc., is unique in that they own, fee simple, the 17,000 acres at the Star Fire surface mine and therefore have considerable interest in post-mine development of the property. It is estimated that 10,000 acres of gently rolling land will be created by the year 2010 through the mining of coal by mountaintop removal techniques, thus providing a site for new land uses and future economic development.

This paper discusses the concepts of developing a water supply for the site. It documents the initial planning and construction phases of building and recharging an aquifer in the spoil material generated during mining, and it reviews initial ground-water quantity and quality data measured at the site between March and September 1989.

Hydrogeologic Setting

The Star Fire Mine encompasses portions of Breathitt, Perry, and Knott Counties and is located approximately 5 miles northeast of Hazard, Kentucky, near the Daniel Boone Parkway (KY-80) (Fig. 1). Regional geology of the site is mapped on the Noble (Hinrichs, 1978) and Vest (Danilchik and Waldrop, 1978) 7.5-minute geologic quadrangle maps. The coal zones being mined are the Hazard Nos. 7, 8, 9, and 10 beds (Fig. 2), all of which are included in the Breathitt Formation of Pennsylvanian age. These beds range in thickness from 3 to 7 feet, and several of the zones contain rider coals that are also mined. Overall, these coals can be characterized as high-grade, low-sulfur, bituminous. The overburden at the site consists of calcareous sandstones and shales. Mine permit data indicate that the potential for acid-mine drainage is low because of the high net neutralization potential of the overburden lithologies at the site.

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[2] Publication in these proceedings does not preclude authors from publishing their manuscripts, whole or in part, in other publication outlets.

[3] James S. Dinger, Ph.D., Head of Water Resources Section, and David R. Wunsch, hydrogeologist with the Kentucky Geological Survey; John E. Kemp, graduate student at the Department of Geological Sciences, University of Kentucky, Lexington, Kentucky 40506-0107, (606) 257-5500.

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Figure 3 is a map showing the major drainages and the sequence of mining through the years 1989, 1995, 2002, and 2007 for Jobs 5 and 7 within the Star Fire Mine. The years indicate the completion date for that section of the mine; each job represents approximately 5,000 acres. The computer model Sediment, Erosion, Discharge by Computer Aided Design (SEDCAD+) (Schwab, 1987; Schwab and Warner, 1987) was used by Dinger and others (1987) to estimate annual total runoff for the site in 1995 and 2007 (these dates represent the completion of mining for major sections at both job sites). The model estimated an upper limit of 2,770 and 2,960 acre-feet of annual runoff would be generated in those years, respectively.

Mountaintop removal mining methods are being used at each job site, with primary emphasis presently being placed at Job 5. At Job 5, truck-and-shovel techniques are recovering the No. 9 and No. 10 coals, and a 64-yard^3 bucket dragline is employed to mine the No. 7 and No. 8 seams. In the process of mining, a 200- to 300-foot-thick spoil backfill is being created.

Three major watersheds drain the 17,000-acre site: Buckhorn Creek (8,019 acres), Long Fork (5,129 acres), and Lick Branch (2,049 acres) (Fig. 3). Field observations indicate that these streams are flashy and have low flows during the summer months. These characteristics do not lend themselves to a reliable long-term water supply upon which significant economic development can depend.

Ground-Water Considerations

Introduction

In order to substantially increase the amount and seasonal reliability of available water at the site, ground water from within the spoil material is being investigated. If a substantial aquifer can be developed within the spoil material, it may serve two purposes: (1) provide a unique ground-water supply, and (2) provide base flow to the major drainage basins and subsequent surface reservoirs during drought conditions, which generally prevail in eastern Kentucky between May and October.

Several elements of the spoil have been studied at Job 5 since August 1987, in the section of the mine completed between 1981 and June 1989 (Fig. 3). These elements are: (1) creation of coarse-rock zones within the spoil for the recharge and movement of ground water (i.e., the creation of an aquifer framework), (2) design and construction of infiltration basins to enhance recharge to the ground-water reservoir, and (3) characterization of ground-water quality and quantity in the spoil material. Consideration of these elements comprises the remainder of this paper.

Figure 1. Location of the Star Fire Mine.

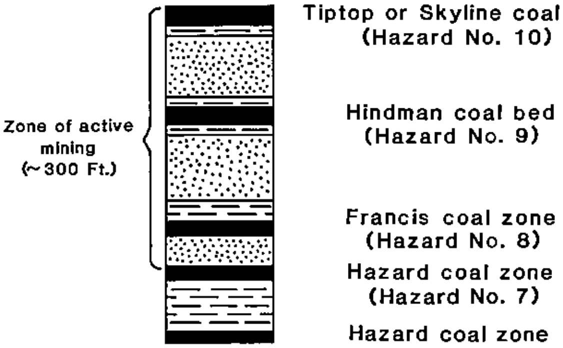

Figure 2. Schematic geologic column of site.

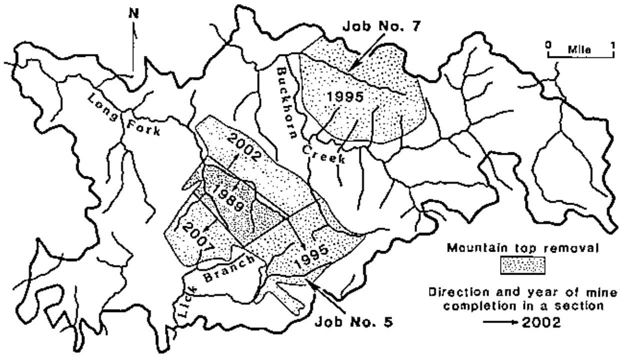

Figure 3. Map of the drainage basins and sequence for mining Job 5.

Spoil Aquifer Framework

Dinger and others (1988) provided a detailed description of the spoil material and its potential as aquifer material. Coarse rubble zones (Fig. 4, features A, B, C, and F; Fig. 5) provide avenues for ground-water movement. The finer sized or compacted material between the coarse rubble (Fig. 4, features C, D, E, and G) may provide for ground-water storage once saturated or may even act to significantly retard the movement of ground water within the spoil.

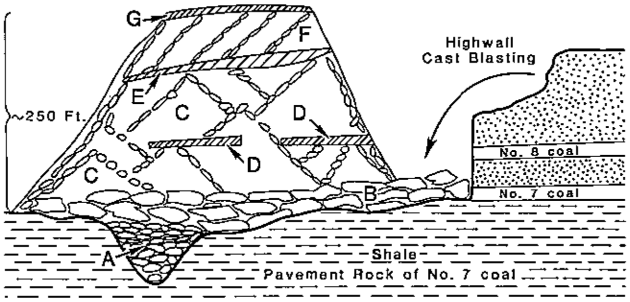

Figure 4. Schematic cross section showing components of spoil significant to the development of an aquifer framework: A=hollow fill, B=cast-blasted rubble, C=dragline spoil, D=dragline pad, E=temporary haul road, F=end-dumped spoil, and G=final graded land surface.

Infiltration Basins

The final graded land surface is a compacted continuous surface (Fig. 4, feature G) that has been observed to prohibit surface water from infiltrating into the spoil material. In addition, future development of the site might include construction of impervious structures such as paved roads, parking lots, and buildings that would substantially hinder recharge to the ground-water system. With these conditions in mind, infiltration basins constructed in the spoil may be the best way to facilitate ground-water recharge. Therefore, special spoil-handling techniques are being pursued to capture surface runoff from the land surface for recharge to the ground-water system within the spoil material.

Two alternative infiltration basin designs were proposed for the Star Fire Project (Dinger and others, 1988). The two designs differ only in the depth of the rock chimney, one being shallow (approximately 70 feet deep) and the other deep (approximately 250 feet deep). The selection of the shallow alternative was made based upon existing mining operating procedures that leave an open space approximately 70 feet deep between spoil cones (Fig. 5). A selectively filled rock chimney to this depth may be sufficient to bypass the potential near-surface confining layer within the spoil (Fig. 4, features E and G). This alternative may prove to be as effective in recharging the spoil as the deeper option, but more economical to construct.

Selection of the deep option was based on the premise that such an infiltration basin will function as a direct connection to the rubble zone resting on top of the No. 7 coal underburden (Fig. 6). This rubble zone is created by blast casting the interburden rock from the highwall into the pit from which the No. 7 coal bed has been removed. The extensive rock chimney constructed to this zone bypasses all intermediate compacted zones within the spoil that might tend to perch percolating ground water. To date, only this deep basin has been installed, but the final surface grading has not been completed. Therefore, the basin is receiving only limited recharge from surface runoff.

Evaluation of these designs will provide data to evaluate a tradeoff between recharge capability and construction costs. Over the next several years this research should reveal many interactions among infiltration basin design, ground-water recharge rate and quality, required contributing watershed area, number and location of infiltration basins, and cost of installation.

Water-Monitoring Methods

In order to characterize the hydrogeology of the spoil aquifer, several research methods were utilized. These included: (1) precipitation measurement, (2) discharge measurement on streams and springs, (3) installation of monitoring wells in spoil, (4) dye tracing in spoil, and (5) water-quality analysis.

Precipitation Measurement

Daily precipitation data from the Robinson Forest Camp Gage was provided by the University of Kentucky, Department of Forestry. The camp gage is a standard 8-inch, non-recording gage located 3.5 miles from the study area (Fig. 3).

Discharge Measurement

Instantaneous discharge measurements were made at three springs (S#1, S#2, and S#3) discharging from the spoil, and where Chestnut Gap Branch flows into the base of the spoil (swallet) in a manner similar to that of a disappearing stream in karst areas (Fig. 7). These springs were monitored to characterize the variability of discharge in relation to recharge events, determine the sources of recharge to the spoil, and determine the nature of ground-water flow through the spoil. Chestnut Gap Branch was monitored to determine the amount of recharge it contributes to the spoil aquifer.

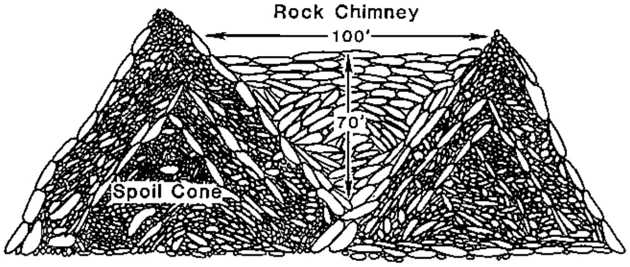

Figure 5. Schematic cross section of 70-foot-deep, V-shaped rock chimney for infiltration basin.

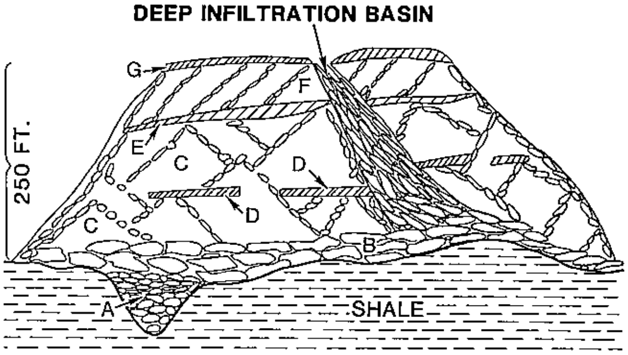

Figure 6. Schematic cross section showing components of spoil significant to the development of an aquifer framework: A = hollow fill, B = cast-blasted rubble, C = dragline spoil, D = dragline pad, E = temporary haul road, F = end-dumped spoil, and G = final graded land surface.

Monitoring Well Measurements

Three monitoring wells (MW#1, MW#2, and MW#3) have been installed in the spoil to study the development and fluctuations of the water table in the spoil, characterize the ground-water quality, determine the effectiveness of the deep infiltration basin, and determine the hydraulic properties of the spoil (Fig. 7).

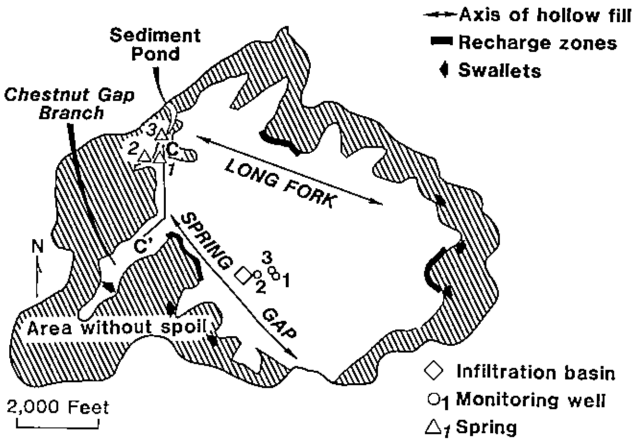

Figure 7. Map showing locations of ground water related to features.

Dye Tracing

Dye traces using Rhodamine WT were conducted in an attempt to define flow paths through the spoil, and to determine travel times along these flow paths. Rhodamine WT has been widely employed in the study of karstic carbonate aquifers, and to a lesser extent in granular aquifers (Aulenbach and others, 1978). It exhibits many properties favorable for ground-water tracing, including detectability at very low concentrations, low toxicity, a distinct peak-emission wavelength, chemical stability over a wide range of pH values, photochemical and biological stability, and a low rate of adsorption (Smart and Laidlaw, 1977). For this study, the most critical of these factors is thought to be adsorption, because the dye is assumed to flow through an aquifer matrix rich in clays, organic shales, and ferric hydroxide. Ferric hydroxide was found to adsorb significant quantities of Rhodamine WT in an experiment designed to test fluorescent dyes for use in ground-water tracing in underground coal mines (Aldous and Smart, 1987).

Two dye traces were conducted; one trace was initiated at the Chestnut Gap Branch swallet and the other at MW#1 (Fig. 7). The three springs served as monitoring points using charcoal detectors. An additional detector was placed in Chestnut Gap Branch upstream from the dye introduction point in order to test for interference from organics. The elutriant from the detectors was analyzed with a Turner Model 10 filter fluorometer.

Water-Quality Sampling and Analysis

Water samples from the three spoil springs, three monitoring wells, Chestnut Gap Branch swallet, and the deep infiltration basin were collected to establish water-quality characteristics and determine changes in water quality that occur between recharge and discharge points. Samples have been collected on a monthly basis since May 1989 for the springs and sporadically from well water as the monitoring wells were completed through the summer of 1989. Some samples were taken from springs and wells to study recharge events. Variables determined in most samples were temperature, specific electrical conductance, pH, sulfate, bicarbonate, calcium, magnesium, sodium, potassium, manganese, and iron. In some cases chloride and nitrate were measured.

Results and Discussion

Recharge

Field reconnaissance of the study area revealed numerous places where streams and storm runoff recharge the spoil aquifer (Fig. 7). Several streams were observed to flow directly into swallets at the toe of spoil slopes. The largest of these streams is Chestnut Gap Branch, a first-order stream with a watershed area of 0.32 mile^2.

A number of recharge zones (specific points in some cases) were observed on the spoil during storm runoff events. These zones occur at places where the spoil adjoins highwalls or natural bedrock slopes, or in places where spoil handling resulted in boulder zones being locally exposed at the surface. The largest of this type of recharge zone is located in the northeastern part of the spoil, where a depression approximately 150 feet deep has been left open since 1982 (Fig. 7, point A). Storm runoff was observed to flow into this pit and then rapidly disappear into the spoil. Likewise, the deep infiltration basin has been partially functional in this regard, although its present watershed is limited at this time.

Recharge also occurs when precipitation falls directly on ungraded dragline-cast spoil cones. The size of this area varies depending on the amount of grading that has occurred, but an extensive area, often 2 million feet^2 or larger, is always present.

In addition to these major points of recharge, numerous small cracks and fissures in the spoil surface were observed to capture lesser amounts of storm runoff. Another source of recharge to the spoil aquifer is the contribution from the bedrock aquifer in places where it is in contact with spoil.

Infiltration through the spoil surface is not thought to account for a significant amount of recharge because of the compacted nature of the graded spoil. Drilling and excavation have shown that the spoil is dry within a few inches of the surface, and storms have been observed to quickly form a thin sheet of mud on the surface, which indicates that rainfall does not easily infiltrate the spoil. This situation may change as vegetation re-establishes itself and aids in the development of soil profiles, resulting in a more porous surface structure.

Ground-Water Movement

Knowledge of ground-water movement has been gained by examining discharge hydrographs and dye tracing to the springs, through water-level measurements in the spoil monitoring wells, and through ground-water quality determinations made at both the springs and wells.

Spring Discharge. The most significant area of observed discharge is a group of three springs located at the northern toe of the Spring Gap Branch hollow fill (Figs. 7-8). This area has remained swampy throughout the time of field investigation. Spring No. 1 (S#1) is the largest of the three springs, and discharges at an approximate elevation of 1,040 feet. The discharge point is located at the toe of a 130-foot-thick lift of end-dumped sandstone spoil from the recent mining operation (1981-1989). This spoil joins and partially overlaps a much lower permeability hollow-fill material from previous mining (1950-1960's) and a 45-foot-thick lift of end-dumped shale (1982), which is considered to have a lower permeability than the sandstone spoil (Fig. 8). During times of extremely high discharge, a number of small springs have been observed to crop out along the toe of this lift at an elevation equivalent to S#1. Spring No. 2 (S#2) boils up from a small hole located directly in the middle of the 45-foot lift, about 200 feet from S#1 (Fig. 7), at an approximate elevation of 1,030 feet. Spring No. 3 (S#3) discharges from a boulder zone along the outslope of the 45-foot lift at an approximate elevation of 1,010 feet (Fig. 8).

In contrast to the Spring Gap hollow fill, discharge was not observed from the toe of the Long Fork hollow fill. It is believed that ground water is flowing through this hollow fill, but is discharging directly into the sediment pond at a point below the water level of the pond (Fig. 8).

Ground water has also been observed to discharge from the spoil into the active dragline pit when the pit is at the level of the No. 7 coal bed. During the past 6 years, ground water has been discharging from the spoil into the active pit at a rate high enough to require pumping on a daily basis. On occasion, pumping rates have reached an estimated 0.56 cfs (360,000 gallons per day). Discharge measurements range from 1.10 to 6.05 cfs for S#1, 0.13 to 0.41 cfs for S#2, and 0.58 to 1.37 cfs for S#3 (approximately 1 to 5 million gallons per day) (Fig. 9). Spring No. 1 is by far the largest of the three springs.

Flow at S#3 seems to correspond to S#1, whereas S#2 generally flows at a steady rate, independent of recharge events. The rapid response of S#1 and S#3 to precipitation and their location at the base of the mine spoil are good indicators that these springs are discharge points for ground water moving through permeable spoil. Because of its location close to the bedrock valley wall and its steady flow, it can be inferred that S#2 is ground water coming primarily from the bedrock through the low-permeability shale spoil that was dumped in this general location in 1982 (Fig. 8).

The difference in discharge between S#1 and S#3 also provides evidence for the effectiveness of the low-permeability shale fill in reducing ground-water discharge from S#3. Spring No. 3 is at a lower elevation than S#1, but has a lower rate of discharge. If a flow barrier did not exist, the majority of discharge would be expected to occur at S#3 instead of S#1.

Spring No. 1 was observed to respond within an hour after the 1.37-inch storm event started, and after only 5 hours its discharge was measured at 70 percent of peak flow (Fig. 10). The peak dis-

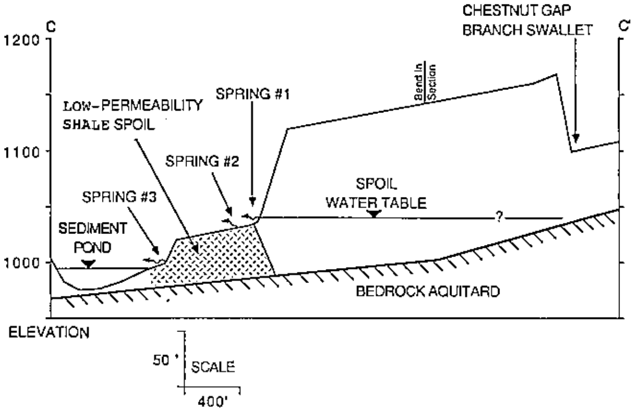

Figure 8. Cross section C-C' showing the configuration of the springs, spoil, and bedrock along the axis of the Spring Gap Branch hollow fill.

charge occurred between 29 and 50 hours after the storm began. This indicates that the spring responds quickly to recharge from a storm event. Such rapid flow through the aquifer suggests that the storm pulse moves along discrete high-porosity conduits composed of loose boulders similar to those described by Carrucio and Geidel (1984).

Figure 10 also indicates that the discharge recession for this storm event is slow and extended, in contrast to the rapid rise and peak in discharge. Measurements recorded on June 11, 4 days after the peak discharge, show that S#1 was discharging at a rate equal to 80 percent of the peak. The fact that the spring does not recede as fast as it rises indicates that the spoil has the ability to store a significant amount of ground water and release it over an extended period of time. A similar hydrograph response was observed at S#1 after a 3-day storm event that began on June 13 (Fig. 9).

The source of recharge to the spoil aquifer can be analyzed by studying the relationship between S#1 and Chestnut Gap Branch, the largest stream recharging the aquifer. Figure 11 shows that two storms in June produced similar hydrographs at both gaging locations, reflecting the close relationship between recharge from surface runoff and peaks in spring discharge. However, the volume of water discharged from S#1 consistently exceeds the input from Chestnut Gap Branch, indicating that this stream is not the sole source of recharge to the spring.

Through the process of hydrograph separation and developing recharge:area ratios from the spring hydrographs, it was determined that 90 percent of the flow at S#1 can be accounted for by ground-water recharge from Chestnut Gap and Spring Gap Branch basins. This indicates that the large area of mine spoil to the east is not contributing significantly to the spring's discharge.

Monitoring Well Measurements. In an effort to study the ground water in the large mine spoil area to the east of the springs, a field of monitoring wells has been proposed. Presently, three wells have been drilled (Fig. 12). Water levels in the wells verify that a water table does exist within a

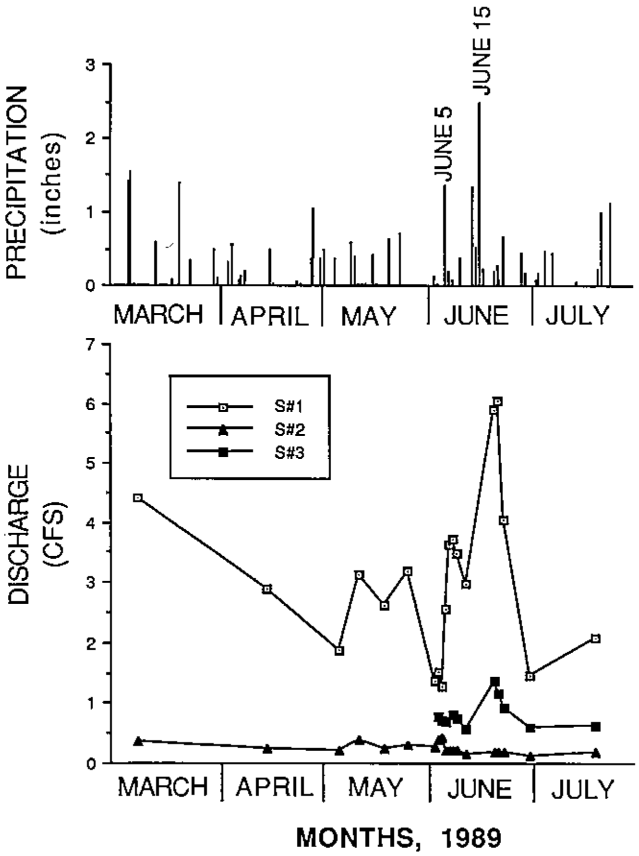

Figure 9. Precipitation and discharge hydrographs for Springs #1, #2, and #3 (March 1-July 25, 1989).

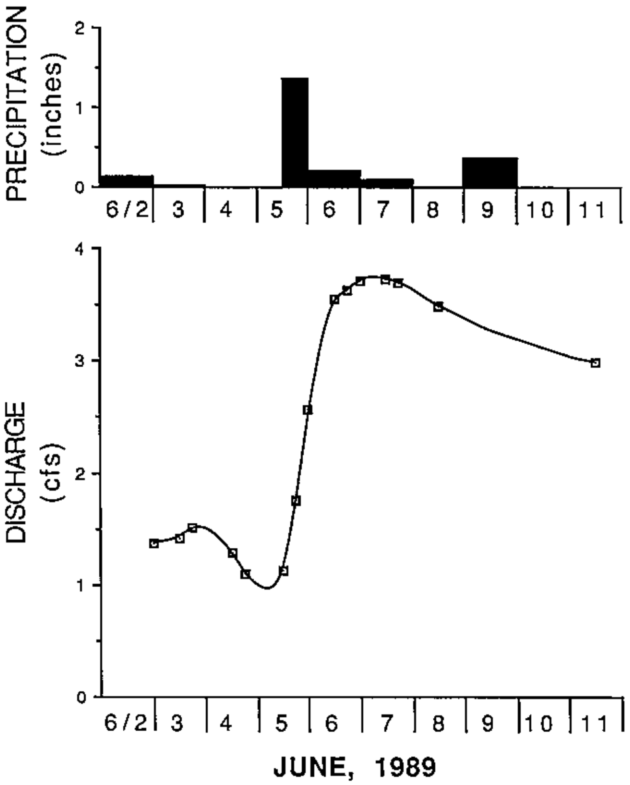

Figure 10. Precipitation and discharge hydrograph for Spring #1 (June 2-11, 1989).

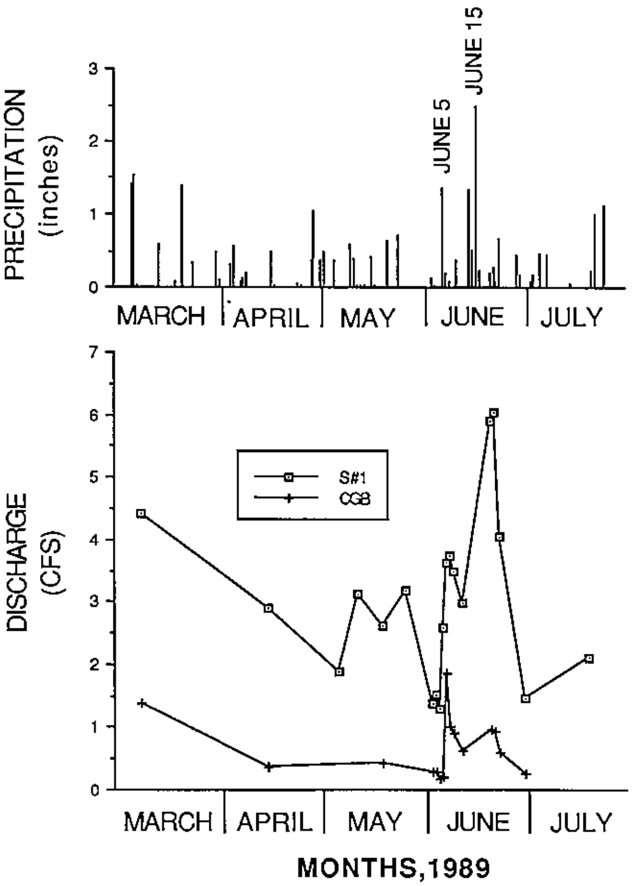

Figure 11. Precipitation and discharge hydrograph for Spring #1 and Chestnut Gap Branch (March 1-July 25, 1989).

portion of the area containing blast-cast and dragline-cast spoil. The water-level elevations in all three wells average nearly 1,130 feet, which is approximately 90 feet above S#1. The thickness of the saturated zone in the spoil is a function of the elevation of the bedrock aquitard below the spoil: the higher the bedrock elevation, the thinner the saturated zone (Fig. 13). The saturated thickness varies from 25 feet at MW#2, to 16 feet at MW#1, to only 8 feet at MW#3, based on measurements recorded on July 18, 1989.

The existence of a water table within this area of the spoil indicates that a significant body of ground water has accumulated. Assuming a constant saturated thickness of 15 feet and an estimated porosity of 20 percent, there would be approximately 3,000 acre-feet (980 million gallons) of water stored within this 1,000 acres of spoil.

Hydrographs for the monitoring wells reveal some important behaviors of the ground-water system (Fig. 14). Response of water level to a 4.55-inch storm event was measured at MW#1 and MW#2 between June 13 and June 17. Water levels in the wells rose approximately 1 foot, peaking within 10 days of the storm's end, whereas the recession to equilibrium levels took an additional 21 days. This behavior is similar to the response measured in the springs and reinforces the concept that the spoil has the ability to store recharged water and release it over an extended period of time.

Monitoring well No. 2 is located on the periphery of the deep infiltration basin (Fig. 12). The water level in MW#2 responds more rapidly to recharge compared to the other two monitoring wells (Fig. 14). One idea is that the deep infiltration basin, although not completely functional, is allowing significant recharge to the spoil, which is raising the water level in MW#2. Based on limited data, the water level in MW#2 averages a consistently higher level (approximately 1.5 feet) compared to the water levels recorded in MW#1 and MW#3.

One explanation for this elevated water level is that a barrier to flow exists west of this well, preventing the movement of ground water toward the spoil outslope and toward the springs previously discussed. Additional supporting evidence for the presence of a ground-water flow barrier is that 90 percent of the spring discharge can be accounted for by drainage from the Spring Gap and Chestnut Gap Branch watersheds, which are located on the opposite side of this barrier.

Field observations indicate that the coal haul road constructed and maintained along the western outslope of the sandstone spoil created by mining between 1981 and 1989, which was continuously compacted by heavy equipment, acts as a low-permeability barrier to ground-water flow (Fig. 13). The effectiveness of this barrier was observed during the active mining of the east-west-oriented pit. Sumps were created against the eastern edge of the haul road at the bottom level of the mine to collect and pump out ground water discharging from the spoil into the pit (Fig. 12).

Dye Tracing. Two dye traces have been conducted at the site: trace No. 1 consisted of introducing dye at the Chestnut Gap Branch swallet and trace No. 2 was conducted by introducing the dye into MW#1. In both traces the springs were monitored for dye discharge. Visual confirmation of dye discharge was overshadowed in the elutriant by a tea-colored interference fluid. Similar coloration has been reported in the literature, and is attributed to the presence of organic matter (Quinlan, 1986). Although visual inspection was unsuccessful, subsequent analyses of the elutriant with a fluorometer produced positive readings. These analyses were reviewed with the knowledge that the intensity could be affected by the interference fluid, which fluoresces at a wavelength close to Rhodamine WT (Smart and Laidlaw 1977). Dye concentrations at S#1 indicate that dye definitely arrived at the springs 49 to 93 hours after injection (Table 1).

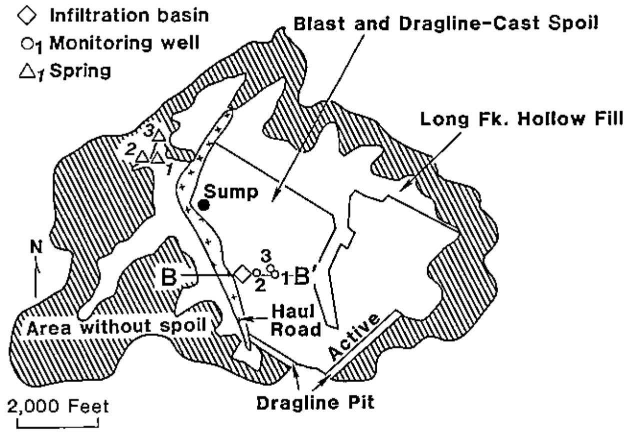

Figure 12. Map showing hydrologic features associated with the monitoring wells.

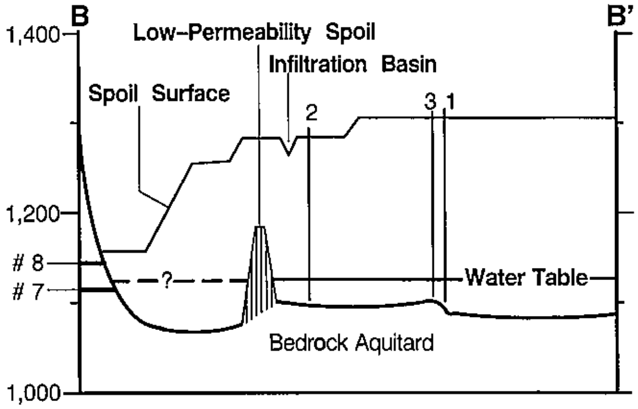

Figure 13. Schematic showing relationship between water table, base of spoil, and thickness of saturated zone. Cross section B-B' located on Figure 12.

Table 1: Trace No. 1 Dye Concentrations

Date	Hours after Start	Dye Concentration (µg/L) S#1	S#2	S#3
2/22 to 2/27	-118-0	0.00	0.00	0.00
2/27 to 3/1	0-49	0.35	0.00	0.00
3/1 to 3/2	49-74	29.00	0.55	1.75
3/2 to 3/3	74-93	40.00	2.80	3.20
3/3 to 3/13	93-33	2.10	0.45	1.30
3/13 to 3/16	334-411	1.80	0.20	0.30
5/11 to 5/18	1749-1917	0.00	0.00	-

Breakthrough time for trace No. 1 was used to calculate an apparent velocity ranging from 0.014 to 0.009 feet/second based on a straight-line travel distance of 2,400 feet and a travel time between 49 and 73 hours. This range is close to the flow velocity of 0.002 feet/second reported by Ladwig and Campion (1985), who used an unidentified tracer in spoil at a mountaintop removal operation in Pennsylvania.

Dye injected at MW#1 for trace No. 2 was not recovered at any of the springs. Three months after dye injection, water samples from MW#1 showed high concentration of Rhodamine WT, indicating that ground water in the vicinity of the well flows slowly through saturated, porous media. This result is in contrast to the rapid flow through boulder zones in the hollow fill characteristic of Chestnut Gap Branch, as demonstrated by dye trace No. 1. This slower movement of ground water in this part of the mine spoil and the lack of dye emerging from the springs also suggest that a low-permeability barrier exists between this area and the lower elevation hollow fill in Spring and Chestnut Gap Branches.

Hydrogeochemistry

The range of values and arithmetic means calculated for a limited set of data for both the surface water and ground water are listed in Table 2. Figure 15 is a tri-linear diagram showing the water types and the relative amounts of dissolved solids found in water samples taken from S#1, MW#1, MW#2, Chestnut Gap Branch (CGB), and surface runoff that was flowing into the deep infiltration basin (IB). All five of

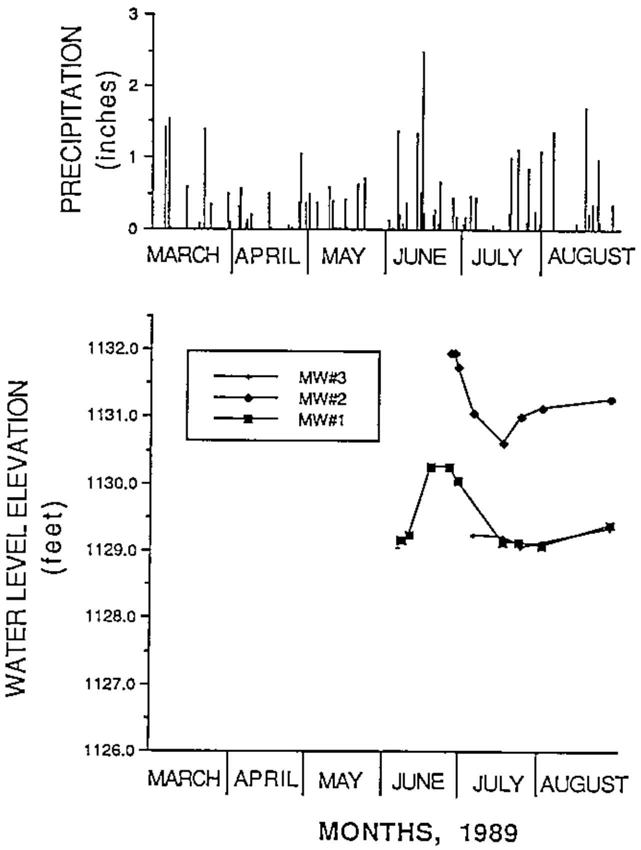

Figure 14. Precipitation and hydrograph for Monitoring Wells #1, #2, and #3 (March 1-August 29, 1989).

the samples plot on Figure 15 as a calcium-magnesium-sulfate type water, the only major difference being in the quantity of total dissolved solids. As used here, the area of the circles plotted on the diagram is proportional to the total dissolved solids of the samples.

The samples with the least amount of dissolved solids are the two surface-water samples, IB and CGB. S#1 shows a dramatic increase in dissolved constituents compared to the surface waters that are recharging the spoil, but considerably less than the samples derived from the monitoring wells at the site. MW#2 consistently has lesser amounts of dissolved solids compared to MW#3. MW#2 is located on the periphery of the infiltration basin; thus, its chemical signature is most likely a result of dilution by surface water as it moves down into the spoil by way of the infiltration basin. This observation is substantiated by the water-level data discussed previously, which indicate that the water level in MW#2 is consistently higher than the level in MW#3 (Fig. 14), and that the water level will exhibit a greater response in MW#2 after a recharge event.

Based on limited data, the total dissolved solids in the water recharging spoil at CGB is significantly lower (as estimated from measurements of specific conductance) than that of the water emerging from the springs at the discharge zone. Discharging ground water has a total dissolved solids content nearly three times the content of the water entering the spoil at Chesnut Gap Branch swallet.

This dramatic increase in mineralization of waters discharging from the springs may result from several scenarios. Two worthy of discussion, are: (1) the recharging water, although only in contact with the spoil material for a very short time (as evidenced by travel times determined by dye-tracing), is reacting with the spoil material, resulting in an increase in dissolved solids; or (2) the relatively fresh water from the stream flowing into and recharging the spoil is mixing with the more mineralized water from stagnant or isolated areas of the spoil (as evidenced by the high conductance values obtained from MW#1 located in the interior section of the spoil), resulting in discharging ground water that is a function of the mixture of the more dilute water entering the spoil at Chestnut Gap Branch swallet and the more mineralized water flowing from within the spoil. Based on preliminary chemical data, dye-trace data, and the fact that the majority of the total discharge measured from the springs can be accounted for by the estimated recharge from the Spring Gap Branch and Chestnut Gap Branch watersheds, it appears that the reaction of water and spoil materials encountered along the ground-water flow path is the most important factor affecting water quality observed at S#1.

Conductivity measurements taken from MW#3 are nearly twice as high as the conductance values of the water discharging from S#1. Increased mineralization is most likely the result of the longer contact time between the ground water and spoil. The monitoring wells are located near the interior of the spoil, somewhat isolated from the majority of fresh water recharge that is thought to be entering near the boundaries of the spoil. Slower ground-water movement is thought to be occurring in the interior section of the spoil, as evidenced by dye-trace data from the monitoring wells. Even if the hydraulic conductivity of the spoil near the monitoring well field is assumed to be the same as that of the Chestnut Gap Branch hollow fill, ground water recharging the spoil at the eastern edge of the spoil (Fig. 12) would have a much longer flow path, resulting in increased contact time and mineralization.

In general, the pH of all the surface and ground water at the site is favorable. The range of pH values for the surface water at the site is 7.62 to 8.28. The pH's of ground water sampled at the site were slightly acidic, but consistently ranged above 6.0 (Table 2). The high quality of the coal, non-acidic overburden, and high neutralization potential of the spoil provide for favorable conditions and minimal occurrence of acid mine drainage. This aspect of the site is integral for the construction and maintenance of an aquifer that may someday provide a usable and beneficial water supply.

Only one sample of water has been taken from the storm water that flowed into the infiltration basin. This sample had a relatively low value of conductance (257 microsiemens) and a pH of 7.67. Future plans include installation of an automatic sampler at the inlet to the infiltration basin to collect water samples for measurement of temporal variation in the runoff quality during recharge events.

Summary and Conclusions

Major recharge to the spoil appears to be limited to swallets in the border of the spoil, where spoil adjoins higher bedrock outcrops at highwalls and natural slopes, and areas where the spoil has not been graded and compacted. Local recharge can occur where isolated boulders crop out in the graded spoil. Future land use may result in the creation of many structures, including roads and buildings, which could hamper ground-water recharge. Therefore, a deep infiltration basin has been constructed into the spoil. This basin, although not entirely operational at this time, may be responsible for raising the water table approximately 1.5 feet in its vicinity.

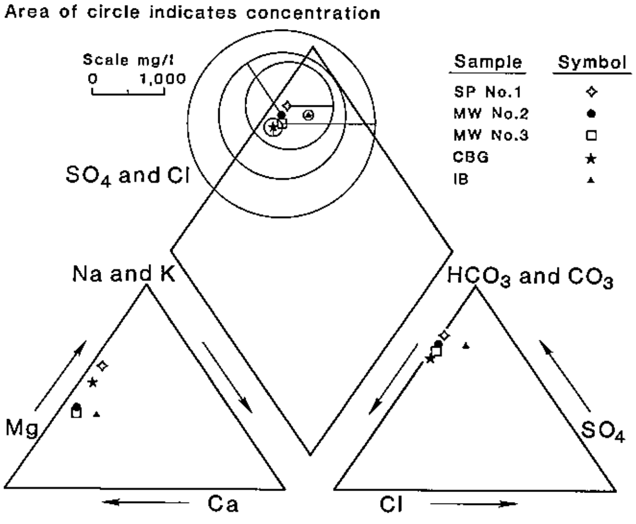

Figure 15. Tri-linear diagram showing the water types and relative amounts of dissolved solids from samples SP#1, MW#1, MW#2, CBG, and IB.

Table 2. Geochemical Data of Samples from Selected Sampling Sites

		Sample Location				
		I.B. (n=1)	CGB (n=3)	S#1 (n=3)	MW#2 (n=3)	MW#3 (n=3)
pH	range	7.67	7.96-8.28	6.37-6.39	6.23-6.41	6.42-6.66
	mean	–	–	–	–	–
Ca	range	31.4	44.2–54.6	201-256	291-339	490-520
	mean	–	50.8	237	312	501
Mg	range	13.6	35.8–42.0	111–134	124–149	213–231
	mean	–	39.9	126	136	222
Na	range	10.1	7.9–13.1	32.0–46.0	31.3–44.5	46.9–54.2
	mean	–	11.9	39.6	37.1	51.0
K	range	0.72	3.04–4.02	7.62–10.5	8.7–10.3	18.8–20.7
	mean	–	3.51	9.03	9.5	19.8
Cl	range	<10	<10	5.6-7.0	5.3-7.0	9.2–11.0
	mean	–	–	6.2	6.1	10.4
SO_4	range	85.0	145–240	717–894	884–994	1520–1650
	mean	–	180	827	939	1600
HCO_3	range	27	110–146	286–411	492–539	695–805
	mean	–	123	338	524	732
Cond.	range	257	590–720	1686–2048	1927–2434	3061–3635
	mean	–	610	1911	2133	3310
TDS*		180	427	1337	1493	2317

*TDS estimated by conductance value multiplied by 0.7

Dissolved solids date in mg/L; Cond. = conductivity in microsiemens; I.B. = infiltration basin; CGB = Chestnut Gap Branch, n = number of samples.

Observed ground-water discharge is taking place at the spoil outslope as springs that have emerged only in the past year. Discharge has varied from approximately 1 to 5 million gallons per day, and measurements indicate that the springs react quickly to precipitation events. The rapid rise in discharge within a few hours of the beginning of rainfall indicates that coarse rubble zones are behaving as conduits, whereas the extended recession curve of spring hydrographs indicates that the finer sized spoil material is releasing ground water over a period of days. Recharge:area runoff estimates and dye tracing indicate that the springs are being fed primarily through the older hollow fills in Spring Gap and Chestnut Gap Branches. The extensive spoil created by the present mining, which began in 1981, does not appear to be contributing significant ground water to the springs.

Data from three monitoring wells and water levels measured in the active pit indicate that this more recent spoil (approximately 200 feet thick) has a water table approximately 90 feet above the springs and a saturated thickness ranging from 8 to 25 feet, depending on the structural contour of the underburden of the lowest coal bed that is being mined. The large difference in elevation between the water table and the springs, dye tracing and chemical data from a swallet and monitoring wells, and the discharge:area runoff ratios indicate that the extensively used (heavily compacted) haul road along the western edge of the present mine site retards the flow of ground water from the active mine site to the springs. Changes in spoil compaction or overburden type affecting ground-water movement is also observed in the hollow fills from which the springs emerge. In this location shaly spoil placed into the hollow has forced the ground water to the land surface. The effects of compaction and spoil lithology on ground-water movement is an important observation when developing the concept of building aquifers in spoil to meet water-resources needs. There is also a need to coordinate mining with reclamation plans in order to develop the most advantageous water supplies for post-mining development.

Ground-water quality for both the springs emerging from the hollow fill and the monitoring wells in the upper spoil can be classified as a calcium-magnesium-sulfate type. Spring water has a specific electrical conductance mean of 1,911 microsiemens, whereas that of the monitoring well away from the infiltration basin averages over 3,300 microsiemens. This higher value reflects the longer travel time and concomitant mineralization of ground water flowing through the areally extensive upper spoil. The monitoring well near the infiltration basin has a reduced conductance value of 2,133 microsiemens when compared to the other two wells, which indicates that better quality surface water is infiltrating to the ground water and improving its quality. The pH of all springs and wells fell into a favorable range of 6 to 7, whereas sulfate was high, ranging from 717 to 1,652 mg/L.

Based on the initial water-quality and -quantity data measured at the Star Fire Mine, it is apparent that the mining techniques can provide the physical framework to construct an aquifer in the extensive mine spoil. Development of a useful water supply within the spoil will be a key factor in future land use and economic diversity of the site.

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